



HOW TO WORK  
WITH  
THE MICROSCOPE.

#### TO THE READER.

THIS work may be "read" by carefully studying the figures, and then referring to the text. A description of every drawing is placed beneath it, and, in most instances, a reference is given to the very page upon which the subject of the drawing is considered. A teaching experience, extending over more than five-and-twenty years, has convinced the author that, although the student will certainly obtain more correct views upon the microscopic characters of objects by attentively examining accurate representations, than by reading over and over again the most minute and elaborate descriptions of them, the information thus gained will be of little real use unless the student himself prepares and examines actual specimens, and makes careful drawings of what he sees.

On p. 429, *for* 1-1,000,000th, *read* 1-100,000th.

No 1120

# HOW TO WORK

WITH THE

# MICROSCOPE.

BY

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PRESIDENT OF THE ROYAL MICROSCOPICAL SOCIETY.

FIFTH EDITION,

REVISED THROUGHOUT AND MUCH ENLARGED, WITH ONE HUNDRED PLATES, COMPRISING MORE THAN SIX HUNDRED ENGRAVINGS, SOME PRINTED IN COLOURS, AND MOST OF WHICH HAVE BEEN DRAWN ON WOOD BY THE AUTHOR.

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## P R E F A C E.

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THE present edition has been revised throughout. More than one hundred pages of new matter, and upwards of one hundred and fifty new engravings, have been introduced.

For valuable assistance in preparing and improving several of the articles which would otherwise have been defective, the author is greatly indebted to the kindness of many friends. Professor Gulliver, F.R.S., made the accurate drawings of plant crystals in Plates XLVII and XLVIII, and very kindly furnished the author with an abstract of his well-known researches.

Conscious of the advantage to be derived from further experiments connected with the construction of object-glasses, the author has obtained the permission of Mr. Wenham to print, in this edition, some of his valuable practical memoirs upon this subject. Any one who possesses some mechanical dexterity, and is desirous of entering upon practical optical work, is almost sure to succeed in acquiring sufficient technical knowledge and skill if he patiently and with due care follows the directions given in Part VII.

Mr. H. C. Sorby, F.R.S., wrote the article on spectro-microscopy, as well as some of the sections on the examination of minerals, and on the cavities in crystals. The directions for the microscopic examination of

minerals, rocks, and fossils, introduced in this edition for the first time, as well as the figures in Plates LV, LVIII, and LIX, were contributed by Mr. Frank Rutley, of the Geological Survey.

Dr. Maddox is the author of the greater portion of Part V, on photography. This has been extended and carefully revised by Dr. Clifford Mercer, who has also introduced several of the recent improvements adopted by Mr. Deecke, and has further added to the value of this book by compiling a very complete list of memoirs on the application of photography to the microscope, which is exceedingly accurate, as most of the titles and dates have been verified by reference to the memoirs themselves.

The author also desires to acknowledge his indebtedness to Professor Brown, of the Veterinary Department of the Privy Council, Dr. Lockhart Clarke, F.R.S., Mr. Glaisher, F.R.S., Dr. Pritchard, Dr. Hudson, Dr. Child, the late Dr. Bowerbank, Mr. Wenham, Dr. Edmunds, Dr. Matthews, Mr. Robertson of Oxford, Mr. J. W. Stephenson, Mr. John Browning, Mr. Swift, and others, whose names are mentioned in the text.

The new drawings added to this edition have been engraved by Miss Powell. Those in Plates XLII to XLV, page 170, deserve attentive study as examples of excellent work. They have been copied from the very careful lithographic drawings of the veteran Lens Aldous, and so accurately have the details been rendered that it would be difficult to distinguish some of these wood engravings from the original lithographs.

## ORIGINAL PREFACE.

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AN earnest desire to assist in diffusing a love for microscopical enquiry, not less for the pleasure it affords to the student, than from a conviction of its real utility and increasing practical value in promoting advancement in various branches of art, science, and manufacture,—a wish to simplify, as far as possible, the processes for preparing microscopical specimens, and the methods for demonstrating the anatomy of different textures,—and the belief that many who possess microscopes are deterred from attempting any branch of original investigation solely by the great difficulty they experience in surmounting elementary detail and mere mechanical operations,—are my chief reasons for publishing this elementary course of lectures, which was delivered during the winter of 1856–7.

It has been thought desirable to append the tables which I have been accustomed to use in my course of practical demonstrations, in order that everyone may be enabled to practise by himself the most useful branches of manipulation. Each table will occupy the student about two hours.

L. S. B.



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# HOW TO WORK

WITH

# THE MICROSCOPE.



## INTRODUCTION.

**1. Importance of Skilful Manipulation in Observation and Experiment.**—Manual dexterity, although subordinate to many higher mental qualifications, is as essential for the successful prosecution of microscopic observation as it is for that of every kind of experimental science. It assists us in the discovery of new means of enquiry, and in devising methods by which difficulties may be surmounted. Without skilful manipulation we can neither teach by demonstration facts which have been already discovered, nor hope to extend the limits of observation and experimental knowledge. It is not, therefore, surprising that many of the most important facts which have been recently added to microscopical science, have been discovered by men who had previously well trained themselves in experiment—particularly in practical chemistry and minute anatomical dissection. Improvements in the practical details of manipulation almost necessarily precede an advance in natural knowledge, and invariably promote and expedite true scientific progress.

The main object of this work is to instruct learners in microscopical manipulation, and in the performance of those operations which are essential to the successful demonstration of form, structure, colour, and movement under the microscope. To manipulate well requires mental application and power, as well as practice. An indisposition to master practical elementary details before proceeding to perform experiments and make observations is almost universal among students. And yet it is only by being thoroughly grounded in first principles, and well practised in mechanical operations, that any one can hope to achieve real success in the higher branches of scientific enquiry, or to detect the fallacy of certain so-called observations and experiments, by which those skilled in conjecture seek to bolster up their arbitrary

dogmas and false statements, and thus deceive and humbug those whom they pretend to teach. Not a few unconsciously minister to the propagation of error by seeming to despise manipulatory details and mechanical skill, and by ridiculing those whose finger-tips are eminently sensitive, and who are unusually clever in the use of their digital muscles. Nor have these false notions been condemned by teachers with the decision and firmness with which they ought to have been met.

In the particular branch of enquiry I am considering, the importance of such operations as the dissection and demonstration of the nerves of an insect, of injecting the vessels of a mouse or a frog, preparing minute specimens, and other such practical work, has been very much overlooked and underrated. It is, however, by practical work of this kind that the student learns, as it were, the very grammar of the subject, which ought to be mastered, and mastered thoroughly, and not only by those who intend to work, but by those who desire to be able to appreciate and form a judgment concerning the reliability and value of the work of others. Every student should be taught to dissect small animals, and those who have succeeded in displaying the nerves of a frog may practise on smaller animals, such as caterpillars and beetles, and some will succeed in dissecting with the aid of a lens the nervous system of a bluebottle.

The number of original observers emanating from our schools will vary as practical work is favoured or discouraged. It is certain that they who are most fully conversant with elementary detail and most clever at demonstration, will be the most successful in the consideration of the higher and more abstruse problems, and will feel a real love for their work, which no mere superficial enquirer will experience.

To endeavour to discover new methods of investigation is one of the most important duties of every observer. To communicate these to his pupils must be the anxious desire of every earnest teacher of any branch of natural science.

Many little matters to which I shall have to refer are sure to be reproachfully stigmatized as mechanical. Some may be considered to belong to the province of the chemist rather than to that of the microscopical observer; and not a few will perhaps seem to many readers unimportant and hardly worthy of attention; but those who understand the real use of actual work will not find fault with me for trying to teach others how to work, and it is to those who love work that this book appeals. No man ever performed real work before he had himself mastered many minute and apparently unimportant practical details. Every one who has experienced the happiness of prosecuting original research naturally desires to encourage others in the same course; and now can this be better done than by showing as clearly and precisely as is possible *how* work is to be conducted?

For want of a little practical experience in connection with microscopic observation, most ridiculous mistakes have been made ; and it is probable that many of the wild fancies which have lately been recklessly hazarded, accepted, and spread would never have disgraced science if their authors had in the first instance been able to demonstrate, for then they might have determined whether the things they talked about had actual existence, and could be seen with their own eyes and rendered evident to others, or were but the creations of their own imaginations. No one who had seen and properly studied the lower forms of life would have jauntily suggested the possibility of their ride through space from their birthplace on a fragment broken off from a remote world. The man who had often pondered over the movements of the transparent matter of an amœba would surely have hesitated before suggesting to the public the presence of machinery, and would never have compared them with the movements of an automaton. Even a very superficial acquaintance with the actual structure and mode of growth of any tissue in nature would have interfered with the affirmation of many of the silly dogmas, of which "man is a machine" is by no means the only or the most significant example. Moreover, it is quite certain that a very moderate amount of practical information upon matters microscopic would have prevented the public from falling headlong into many philosophical traps which have been laid to catch the ignorant who desire to be thought learned, and the unwary who wish to appear knowing. Not one of those who have devoted themselves to the study of living matter, and have seen with their own eyes and contemplated with their own understandings the phenomena of living matter, has been able to discern those promises and potencies which Dr. Tyndall boastfully declares have been discerned by him in matter, nor has one single observer been able to see "molecular" or other machinery in the living matter of any living being. For these and other absurd and mischievous statements received by the materialist faithful experienced observers who are familiar with the use of the microscope are not responsible.

By describing the results of the investigations of others, a teacher may spread knowledge. By prosecuting original enquiries himself, he may contribute his mite to the gradually increasing stock of information ; but by demonstrating to his pupils the successive steps by which conclusions in scientific enquiries have been at length arrived at, and by describing minutely the methods which have been actually employed in investigation, the teacher not only encourages his pupils to become original *observers*, and to investigate for themselves, but he may succeed in placing them in a position to commence their researches at the point where an enquiry has been abandoned by preceding observers.

The opinion that it is only necessary to place an object in the field of the microscope in order to make out its structure, seems far too pre-

valent. Much of the disappointment suffered by many who are provided with microscopes, may be traced to this erroneous idea. Too many look upon the microscope as a mere toy, and microscopical observation as an amusement, by the help of which time may be made to pass away pleasantly. Few are aware of the real interest derived from intelligent investigation, and the instruction afforded, and the facts for contemplation and thought easily to be obtained if only the observer will acquire the necessary dexterity and elementary knowledge to enable him to study with success. Many who have become interested in what was at first but rough and superficial investigation have persevered, and have at length become excellent observers, who have added new facts to our knowledge, or have rendered more accurate, information which was already possessed.

Microscopical investigation may be undertaken by persons in almost any position, and, it need scarcely be said, by both sexes; indeed, this is a department in which ladies are likely to excel. It should also be borne in mind that money is to be earned in various departments of microscopical work. By making specimens and preserving and mounting them, by drawing, by making enlarged diagrams from the microscope, and, lastly, by engraving on copper, steel, stone, or wood the appearances of various microscopical specimens, fair remuneration may be obtained by any one who has acquired the requisite skill. The numerous cheap and excellent microscopes which have lately been made by many English makers have largely contributed to diffuse a knowledge of the minute structure of various natural objects. The annually increasing sale of instruments of all classes shows how popular this branch of enquiry is becoming; yet it must be confessed that the additions to scientific knowledge are by no means so great as a consideration of these circumstances would have led us to expect. Although there are many instruments, I fear it must be confessed that the real *observers* are comparatively few. At the same time it is quite certain that some persons set themselves up as original investigators whose range of observation has been very limited. Although by working at one special department of enquiry a man may undoubtedly discover new facts, he will be liable to make grave errors, and will almost certainly arrive at wrong conclusions if he attempts to generalize. Before attempting original investigation, however, every student should obtain instruction or instruct himself in different departments of microscopic enquiry, and should examine the same object in many different ways. The experience thus gained will be of the greatest service to him in special investigations, and his eye and mind will have been subjected to careful training, by which alone success is rendered possible, and the most unfortunate mistakes avoided. For teachers of natural science a practical knowledge of microscopical investigation is becoming daily more important. It is more than ever

needful we should teach as much as possible by the eye. In teaching every branch of natural science *demonstration* ought to be combined with *oral* description. The student should *see* what is described; and where it is not possible for the teacher to exhibit illustrative specimens, good models, drawings, and explanatory diagrams should be supplied. It is the duty of every teacher to study how to communicate knowledge *most easily* and *most clearly*, and to save the student as much time as possible, for it is not likely that the amount of work required of him will be reduced, nor indeed is it desirable that it should be. But it is certainly the duty of all teachers to facilitate the acquisition of knowledge in every possible way. A lecturer on any branch of microscopic enquiry should show his pupils the structure he describes, and teach them how they may demonstrate for themselves the facts observed in his specimens, and depicted in his drawings. With the aid of the little microscopes referred to on page 17, twelve microscopical specimens can be passed round a class consisting of more than a hundred students in the course of an hour's lecture, and without the lecture itself being in any way interrupted. It is desirable to encourage the students to make rough diagrams of what they are able to observe in a cursory glance at the specimens.

Some years ago, when Professor of Physiology, I exhibited and described at each of my lectures at King's College, three or four specimens, so that in the course of a session each pupil had an opportunity of examining more than three hundred preparations of the tissues and organs of the body. The microscopes referred to (see § 19, p. 17) are well adapted for every kind of class demonstration. With low powers these instruments may be employed in village schools with great advantage. Not only may parts of insects, the hairs and other parts of animals, crystals of different substances, stones, minerals, and various objects of general interest be shown, but the internal structure of the petals of flowers, the hairs and leaves of various plants, and other organs, may be displayed and clearly demonstrated.

As a teacher first of general anatomy and physiology, then of morbid anatomy, and lastly of medicine in a large medical school and hospital, I have naturally been led to direct my attention chiefly to the special branches of microscopical investigation which belong more particularly to those departments, and which bear more or less directly upon the investigation and treatment of disease, and which are treated of in "The Microscope in Medicine" (fourth edition, 1878). But from the present work I shall exclude every thing of a strictly medical character. Only those processes applicable to general microscopical research, and to the investigation of animal and vegetable tissues, organic and inorganic, fluids and solids, minerals and fossils, will be discussed in the following pages.

## PART I.

THE MICROSCOPE AND GENERAL MICROSCOPICAL APPARATUS—OF ILLUMINATING OBJECTS—OF DRAWING, ENGRAVING, AND MEASURING—INSTRUMENTS, GLASS CELLS, CEMENTS, PRESERVATIVE FLUIDS, AND OTHER THINGS REQUIRED IN ORDINARY MICROSCOPICAL WORK.

**1. The Microscope.**—It is not desirable in a practical work like the present to enter into minute details, concerning either the mechanical or optical arrangements of the microscope, especially as there are many excellent books published in this country, in America, and on the Continent, in which these points are fully discussed. I shall therefore allude only in general terms, and as briefly as possible, to the various parts of which the instrument is composed.

**2. The Simple Microscope,** fig. 2, pl. I, is of use chiefly in the examination and dissection of comparatively large objects. It consists of a firm support, on which the stage or rest for the object is placed, the mirror being beneath, and the magnifying lens above. In this arrangement the magnified image of the object passes at once to the eye of the observer. A very good substitute for a simple microscope is a watchmaker's loup or lens, the frame of which can be grasped by the muscles around the eye.

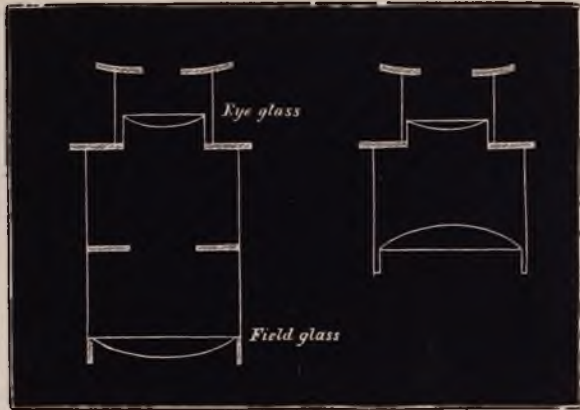
**3. The Compound Microscope** is the only instrument now used for minute research. Until those great improvements in the mode of combining the glasses, now universally adopted, had been introduced by the successful labours of Mr. Lister, Mr. Ross, Mr. Powell, and others, the compound microscope was a very imperfect instrument, and even up to the present century the simple microscope, as employed by Leeuwenhoek, and improved by Wollaston and others, possessed some advantages over its more complex but imperfect rival. In the *compound microscope*, fig. 1, pl. I, the *object-glass*, c, is placed at one end of a brass tube and the eye-piece at the other. The greater the distance between the two the higher will be the amplification of an object. The total length of the tube with its eye-piece and object-glass varies in different instruments, but upon the whole it will be found that from six to twelve inches will be sufficient, as the tube can be easily lengthened if desired.

Fig. 1.



Diagram of compound microscope. p. 3

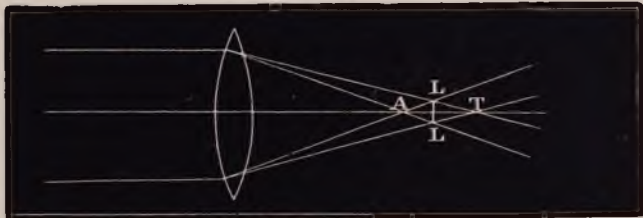
Fig. 3.



Negative or Huyghenian eye-piece. p. 7.

Positive eye piece, invented by Ramsden. p. 7.

Fig. 5.



To illustrate 'chromatic aberration' The violet and blue rays being most refrangible are brought to a focus, A, nearer the lens than the red rays, T, which are the least refrangible of the rays of the spectrum; any object placed at LL would exhibit coloured fringes. p. 9

Fig. 2.

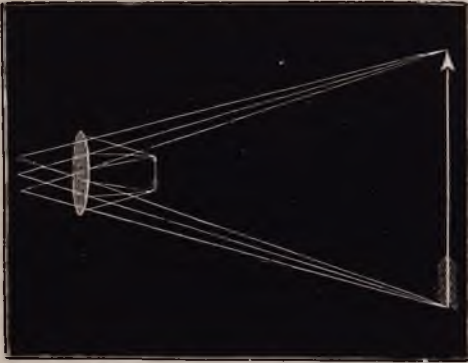
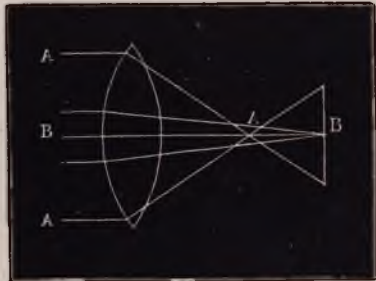


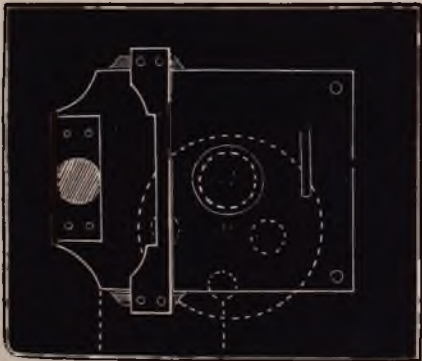
Diagram of simple microscope. p. 6.

Fig. 6.



To illustrate 'spherical aberration' The rays AA being more refracted than those near the centre, B, are brought to a focus nearer the lens. p. 9

Fig. 9.



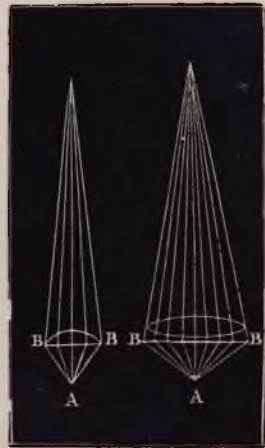
Stage of student's microscope, showing diaphragm placed beneath. From a to b should not be less than two inches. p. 12.

Fig. 7.



Compound glasses of an achromatic object glass. p. 8.

Fig. 8.



a, objective with low angle of aperture, BAB. b, another with high angle of aperture, BAB. p. 10.





The magnifying power of the compound microscope may be augmented :—1, by increasing the power of the *object-glass* ; 2, that of the *eye-piece* ; or, 3, by increasing the distance between the object-glass and the eye-piece by means of a draw-tube provided in the instrument, or by adding a tube. I have had several such tubes made, of different lengths, which may be interposed as desired.

It must be borne in mind, however, that in the two last cases any imperfections which may exist in the object-glass are greatly augmented. Hence, as a general rule, we should not work with deep eye-pieces, but when we wish to magnify an object more, we should adapt to the instrument an objective of higher magnifying power. In some observations, however, it is a matter of importance to be able to work with a lens which permits some space between its lower glass and the preparation, and the increased length of the tube becomes the most satisfactory way of obtaining the necessary degree of amplification. In studying the circulation of the blood in the smaller vessels of the frog's foot I found great advantage result from the adoption of this method. Information upon employing very high powers will be found near the end of the work.

### *Optical Portion of the Microscope.*

The *optical portion* of the ordinary microscope includes the *eye-piece*, *object-glass*, and the *mirror* from which the light is reflected so as to pass through the object.

The image in the compound microscope is inverted, but this inconvenience may be obviated by causing it before it reaches the eye to pass through another set of lenses inserted in the tube of the microscope, and termed the *erector*. This instrument consists of a tube, at one end of which is a plano-convex lens, and at the other a meniscus, a diaphragm being placed about midway. This is inserted in the tube of the microscope above the object-glass, and, like the similar arrangement in the telescope, reverses the image.

**4. Negative Eye-piece.**—The *eye-piece* in ordinary use is the *negative* or *Hughenian* eye-piece, fig. 3, pl. I. It consists of two plano-convex glasses, the flat surfaces of each being directed upwards. The one nearest the eye of the observer is the *eye-glass*, and the other at the greater distance the *field-glass*. The large microscopes are usually supplied with two or three eye-pieces, so that the amplification of an object may be doubled or trebled.

*Kelner's eye-piece* is made like the above, but the eye-glass is an achromatic combination. At the suggestion of Mr. Brooke I have lately used this eye-piece as a condenser with the best results.

**5. The Positive Eye-piece**, of Ramsden, is only used in those cases

in which it is necessary to see distinctly some object in the eye-piece, as, for instance, an instrument for measuring, at the same time that the object is in focus. In this eye-piece the convex surfaces of each of the two glasses are directed towards one another as seen in fig. 4, pl. I.

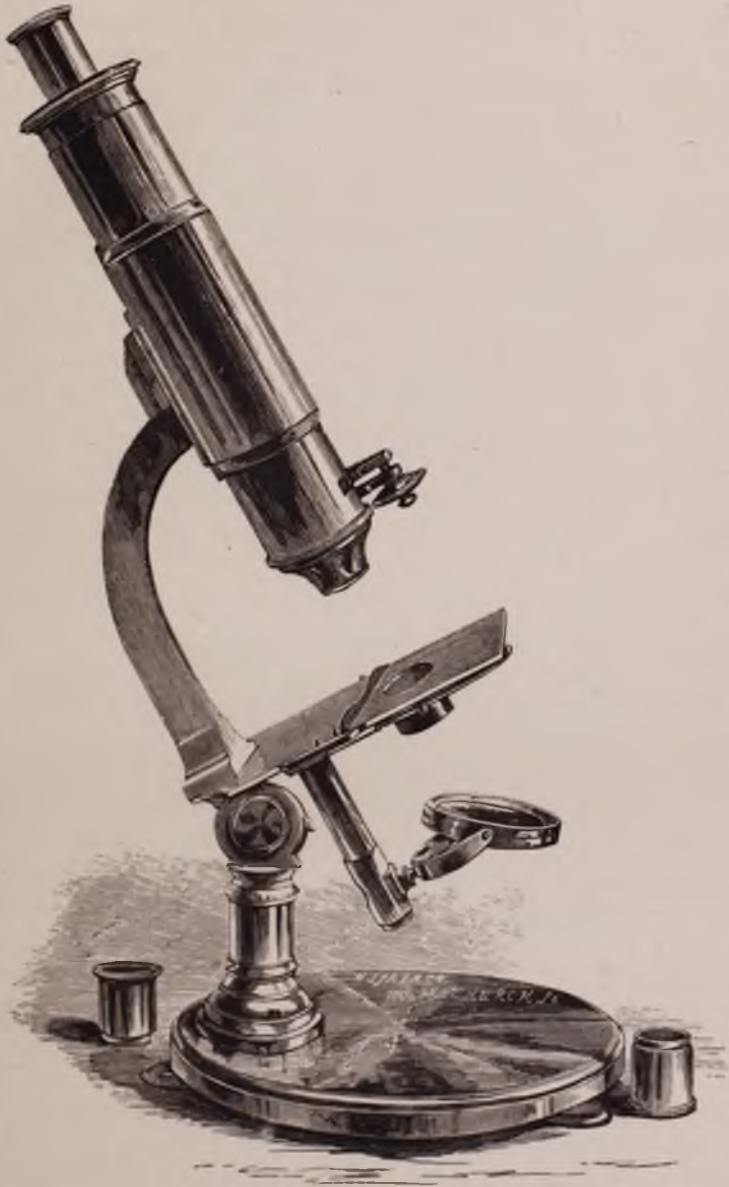
**6. Object-glasses.**—The *object-glasses*, fig. 7, pl. I, used in the best instruments, are of English manufacture, but many really good object-glasses are now furnished with the cheap microscopes, some of which are made on the Continent, and are produced at a very cheap rate.

The two most useful object-glasses for a student are the *quarter of an inch* which, with the No. 1 eye-piece, should magnify from 200 to 220 diameters, and the *inch* which should magnify from 30 to 40 diameters. The definition of these glasses should be good, and they should transmit plenty of light. Any lines in a structure examined by them should appear sharp and distinct. The field should be flat, every part of it in focus at the same time, not too small, and there should be no coloured rings round any object subjected to examination. The achromatic object-glasses consist of three sets of lenses, each of which is in itself compound. Mr. Wenham, however, made some excellent high powers with a *single* front lens, and this plan has since been adopted by some of the makers. An important improvement in the making of object-glasses has been made by Mr. Wales, of Fort Lee, New Jersey, who at the suggestion of Prof. H. L. Smith, of Kenyon College, U.S., has added a second posterior combination, which may be substituted for the ordinary one when objects are to be examined with very oblique light. The arrangement also possesses some advantages for photographic purposes.

Many of the new French and German objectives have excellent defining power, and are produced at very small cost. Of late Mr. Swift and other English makers have succeeded in making objectives quite equal to them, at the same price. By employing a glass of great refractive power Messrs. Parkes and Son, of Birmingham, have made some high power lenses, which have excellent defining power, at a very low price. The one-sixth cost 1*l.* 15*s.*, and the one-seventh, of 105° aperture, 2*l.* The working distance of these objectives from the thin glass covering the object is greater than in the case of most objectives of the same degree of magnifying power.

Object-glasses of high power are now generally made so that the object must be viewed through a thin stratum of distilled water placed between and touching the surfaces of the front lens of the objective and the covering glass (*à immersion*). The image has a peculiar brightness, and as Mr. Brooke has observed, the object is more highly illuminated, because more oblique rays are admitted than would otherwise pass into the lens; the working distance of the objective is somewhat increased, while the price of glasses of the same magnifying power is less. Immersion object-glasses were first made by M. Hartnack, of Paris, the

ORIGINAL CHEAP STUDENT'S MICROSCOPE, 1853.



One of the first cheap student's microscopes made for the author by Mr. Salmon in the year 1853 p. 13.



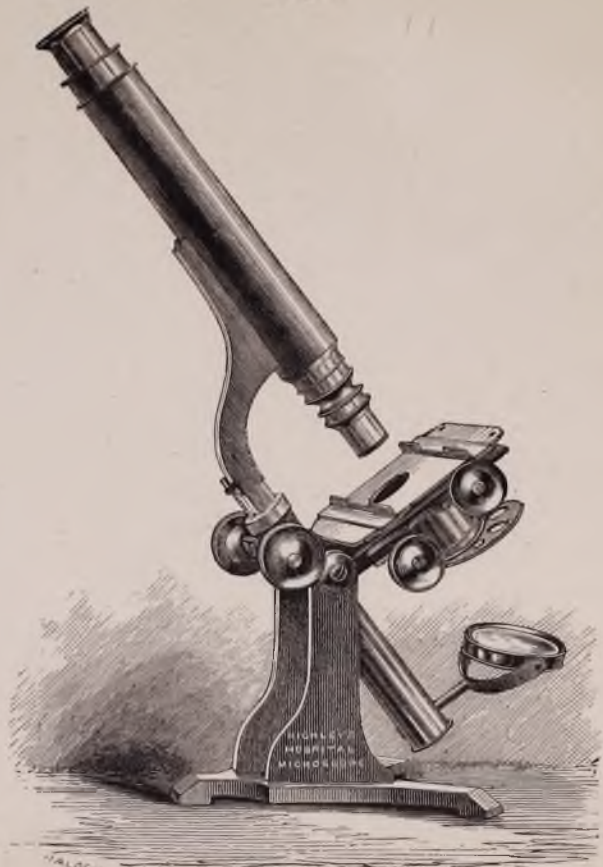
STUDENT'S MICROSCOPES.

Fig. 1.

Fig. 2.



Complete microscope, designed by Mr. Highley, p 13



Mr. Highley's complete student's microscope p 13



Fig. 1.



The same instrument as Fig. 4, inclined. p. 13.

Fig. 2.



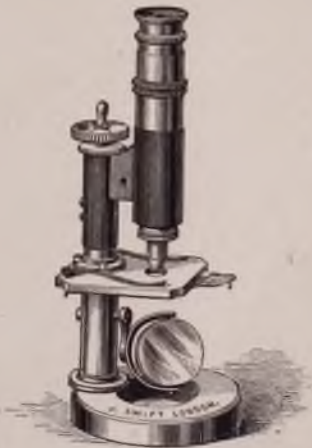
New histological microscope, arranged by Mr. Collins. The fine adjustment is according to a new plan, and is very simple and efficient. pp. 11, 13.

Fig. 3.



Cheap student's microscope. New model recently made by Mr. Swift. p. 13.

Fig. 4.



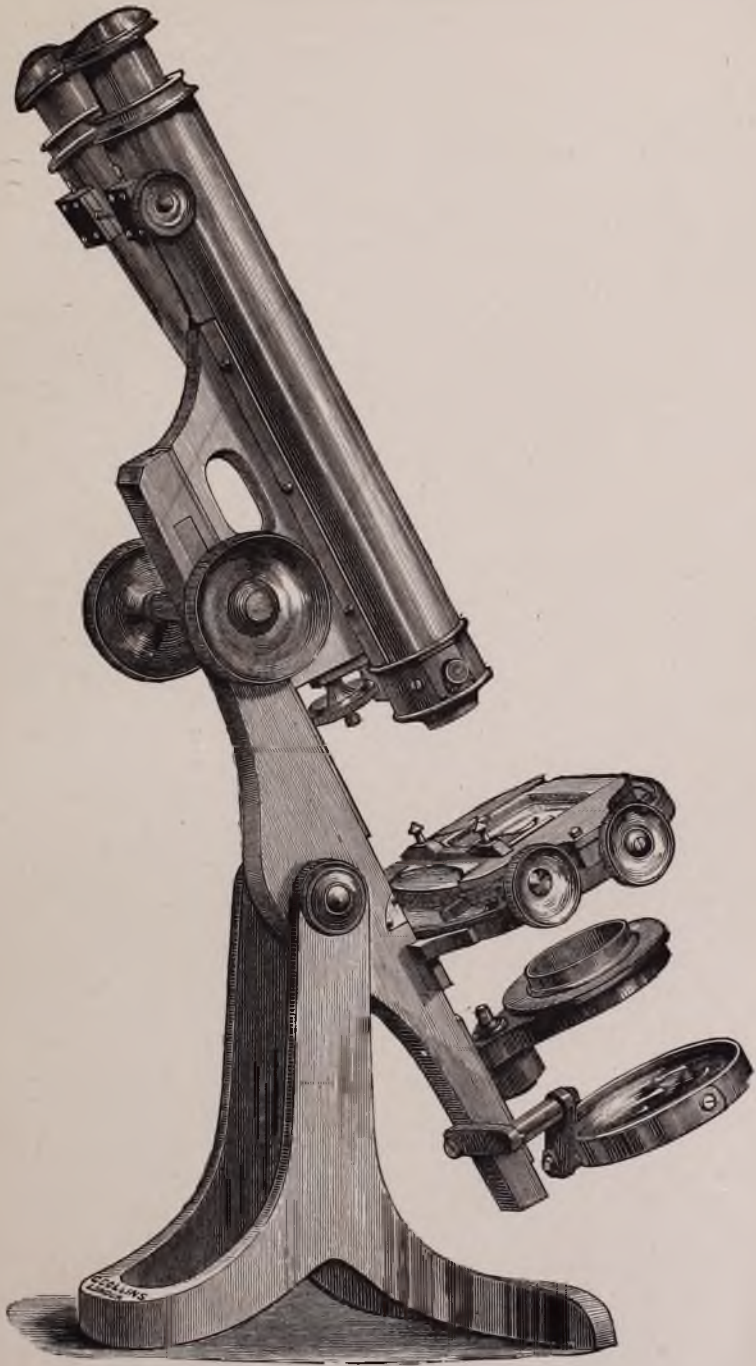
After Gundlach's model. Made by Mr. Swift. p. 13.

[To follow Plate III.]





BINOCULAR MICROSCOPE.



"Harley" binocular microscope, made by Mr Collins p 13.

[To follow Plate IV.



successor of Oberhäuser, but they are now produced by all the best makers. Mr. Stephenson uses oil instead of water, and thus gains great advantages in resolving P. Angulatum, and such objects. Zeiss has lately made some improved immersion lenses, for use with oil of cedar-wood.

For the use of objectives of very high magnifying power, *see* part VI.

*Mr. Brooke's double nose-piece* is useful and saves much time. A revolving frame is arranged for carrying two or more objectives, which can be easily brought into position at the end of the body one after the other.

*Mr. Swift's centring nose-piece.*—Mr. Swift has designed a very ingenious nose-piece, by the aid of which the object-glass can be perfectly centred after it is screwed on to the body of the microscope. The arrangement is similar in principle to that employed for centring the condenser. It will be understood by reference to fig. 11, pl. VIII, p. 18.

**7. Spherical and Chromatic Aberration.**—Unless the objective is properly corrected for spherical and chromatic aberration, pl. I, figs. 5 & 6, it is valueless to the observer. *Spherical aberration* may be known by the want of sharpness when a fine line or small spot, or body with a well-defined circular outline, is examined. The lines seem to be blurred and foggy, and when there are several lines or spots near to one another, they appear to run together, producing a general shadow, instead of each one being distinctly defined and separated from its neighbours. If the glass has not been properly corrected for *chromatic aberration*, lines and dots are seen with coloured fringes, *blue* if the lens is *under-corrected*, reddish if *over-corrected*.

**8. Flatness of Field** can be tested by moving an object from one part of the field to another without altering its distance from the object-glass. If the field is flat, the object will appear equally well-defined in all parts, but if the glass is defective in this particular, an object accurately focussed in the centre will be found to be blurred and out of focus when it is moved to the circumference. Or a stage micrometer, § 60, ruled to hundredths and thousandths of an inch, may be brought into focus. If the lines are sharp and clear, and perfectly parallel to one another in every part of the field, the glass is a good one; but if some appear curved and thicker at the circumference of the field than at its centre, the glass is defective.

It is not to be supposed that, even if the most minute directions were given, the student just commencing work would be able to test the object-glasses he was about to purchase, in all necessary particulars. Generally he must trust the maker, but if he desires to ascertain if his object-glass is good, perhaps the simplest plan is to compare the images produced by the same object first placed under his own power and then under a glass magnifying in the same degree, but of known excellence.

**9. Angle of Aperture.**—For ordinary work it will be found inconvenient if the object-glass, when in focus, comes too close to the object. This is a defect in glasses having a high *angle of aperture*. The angle of aperture is the angle made by two lines from opposite sides of the aperture of the object-glass with the point of focus of the lens. The angle B A B in fig. 8, pl. I, is the angle of aperture. Glasses with a high angle of aperture admit much light, and define many structures of an exceedingly delicate nature, which look confused when examined by ordinary powers. For general microscopical work, however, glasses of medium angular aperture are to be recommended.

Glasses having an angle of 150 degrees and upwards are valuable for investigations upon many very delicate and thin structures, such as the diatomaceæ; but such powers are not well adapted for ordinary work. The importance of arranging the object very carefully and the necessity of paying great attention to the adjustment and illumination, render these glasses inconvenient for general observation. The *penetrating power* of glasses with a low angle is greater than in those of a high angle of aperture, and exact adjustment of all the lenses is of the utmost importance. If then the object to be examined is of considerable thickness, an objective of moderate angle is to be preferred, but this view can only be acted upon within certain moderate limits, for if the angle is reduced too much there is great loss of definition, as I have learnt to my cost in the case of a quarter which I had made and which was almost useless, except for examining objects by reflected light.

The refraction produced by the passage of the light through the thin glass covering the object varies according to its thickness, and it has been found necessary to render the higher objectives capable of being adapted to this varying refraction. An arrangement for "correction" is especially necessary in the case of glasses of high angle of aperture, and usually consists of a screw collar, by turning which the distance between the front and second pair of glasses may be increased or reduced. An engraved line shows the point to which the lens should be set for *uncovered objects*. Its adjustment for *covered* objects is to be effected in the following manner:—arrange the objective as if for an *uncovered* object; then any object covered with thin glass is brought into focus by moving the body of the microscope; next the milled adjustment ring adapted to the object-glass is turned round until any particles of dust upon the upper surface of the thin glass covering the object are brought into focus. The lens is thus "*corrected*" for the thickness of the cover, and it only remains to re-focus the object.

The mechanical arrangement usually employed in this country for "correcting" is not quite satisfactory, especially in the case of the very high objectives. The screw works too hard, and the thread is too coarse. Mr. Wenham has introduced a great improvement, which

entirely overcomes these objections, and enables the observer to "correct" from time to time while he is examining the object. The middle and posterior lenses are made to alter their position instead of the front lens. This is a very valuable improvement. Other modifications have since been made, among the most simple and advantageous of which may be mentioned the very ingenious movement recently introduced by Mr. Swift. The screw should work so easily that the observer may turn it first in one direction and then in the opposite while the object is being examined. In this way he will be able to ascertain the exact point at which a particular object is seen in the greatest perfection. In using the highest magnifying powers different objects in the very same preparation will vary in clearness according to the depth at which they lie in the preservative medium, and the lens will accordingly require varying adjustment.

**10. The Mirror**, pl. VI, fig. 6, p. 14, should slide upon a perpendicular bar or tube beneath the stage, so that it may be arranged near to, or at a distance from, the object, and it should be capable of being inclined at any angle, so that rays of light may be reflected from it and made to pass directly through the object, or thrown upon it very obliquely. The mirror should be of at least two inches in diameter, one surface quite plane and the other concave, so that a strong light may be condensed upon the object, if desired. The achromatic condenser and other pieces of apparatus of advantage for examining objects by transmitted and reflected light are described further on. See p. 29.

#### *Mechanical Portion of the Microscope.*

In directing attention to the mechanical portion of the microscope, I must say a few words upon the arrangements for altering the focus, the body of the instrument, the diaphragm, and the stage.

**11. Adjustments for altering the Focus.**—The ordinary movement is obtained by the rack and pinion. In some microscopes the body is moved by the fingers alone, and is arranged to slide in a tube (which may be lined with cloth) like a telescope. In the instruments of Mr. Ladd the requisite motion is obtained by the ordinary milled head, which operates upon a chain instead of the rack and pinion which is commonly employed. Besides coarse adjustment, however, every microscope should be provided with a more delicate movement for altering the focus when high powers are employed. The details of the arrangement of the *fine adjustment* are different in various instruments. The movement of Mr. Ladd's chain is so regular and delicate as to supersede the necessity of a fine adjustment. Mr. Collins has recently introduced a very ingenious modification of the arrangement for fine adjustment, which works excellently, and is not likely to get out of order. This will be understood by reference to pl. IV, fig. 2.

**12. The Body of the Microscope.**—The instrument should be perfectly steady, whether the body be inclined or arranged in a vertical position ; and not the slightest lateral movement or vibration should be communicated to the body of the microscope when the focus is altered by turning either of the adjustment screws. The base or foot should be sufficiently heavy to give steadiness, and should touch the ground in three places only, or the body should be fixed upon three feet. The foot or base may be made of cast iron, or even of zinc, or some other cheap metal.

The body ought to be provided with a joint, so that it may be inclined or placed in a horizontal position, as is requisite when drawings are made with the camera, or when objects are measured by the aid of that instrument or the steel disc or neutral tint glass reflector. Another advantage gained by this moveable joint is that the muscles of the observer's neck do not become so tired when the body of the microscope is inclined as when the head has to be bent, for several hours at a time, over an instrument standing upright. The larger the microscope may be, the more necessary is this joint for the comfort of the observer ; and as it in no way impairs the steadiness of the instrument, and only adds a few shillings to the expense, I recommend every one, in choosing a microscope, to select an instrument the body of which may be placed in a vertical, inclined, and horizontal position.

**13. The Stage** should be at least three inches in length by two and a half in width, and there should be a distance of at least an inch and a half from the centre of the opening in the stage over which the slide is placed, to the upright pillar—*a*, fig. 9, pl. I. The stages of the microscopes of Nacet, Oberhäuser, and indeed those of most of the foreign makers are too contracted for convenience. A good large stage is a great advantage, and it should be so arranged that a small saucer can be placed upon it and moved freely in various directions. A piece of thin plate-glass, of a required size, may be made to fit on the stage, and thus a small stage is easily converted into a large one.

**14. Diaphragm.**—Beneath the stage a circular diaphragm plate with holes in it of several different sizes, should be so arranged that it can be made to revolve without difficulty and any hole brought under the object ; a catch is of great advantage, as it tells the observer when each particular opening reaches the centre of the field, pl. I, fig. 9. Various arrangements have been adopted for altering the size of the aperture in the diaphragm instead of having a revolving plate with several holes of different sizes. One of the most ingenious is that devised by Mr. B. Kincaid (" Mic. Journal," July, 1866, p. 75). This is made of a short piece of thin India-rubber tube, the two ends of which, fixed to brass rings, are made to revolve in opposite directions, so that the central part becomes contracted. An aperture of any size may be obtained, and the

opening must be always perfectly central. The graduating diaphragm of Mr. Collins is, however, the most useful diaphragm yet made, pl. XVII, fig. 3.

## DIFFERENT FORMS OF MICROSCOPES.

**15. Students' Microscopes.**—Mr. Salmon (1853), Mr. Highley, *see* pl. III, and Mr. Matthews were, as far as I know, the first makers in London who brought out really good, practical instruments, furnished with good object-glasses, at very low prices. Mr. Salmon's original student's microscope is represented in pl. II. This was a good working instrument and cost five pounds. The sale for cheap instruments has much increased and is now enormous. Although many teachers strongly recommend foreign microscopes in preference to those made in their own country, it is difficult to understand why,—seeing that instruments as good and as cheap are made here. It is probable that many more cheap microscopes are made in England than elsewhere, and there can be no doubt that any instrument could be made here as well as, and at a lower price than, abroad, if only a large number could be put in hand. Of late years the improvements in cheap microscopes have been very great, and nearly all the makers now furnish student's microscopes, which are really good and useful, for from 3*l.* to 5*l.* I would strongly recommend all who are about to purchase a cheap instrument to examine the student's microscope made by Messrs. Smith and Beck, Mr. Collins, Mr. Crouch, Mr. Baker, and the microscopes recently introduced by Mr. Swift (Plates IV, X), and those made by Mr. Parkes, of Birmingham.

**16. Large Microscopes.**—The large expensive microscopes are provided with every instrument which modern science has placed at the disposal of the observer. For delicate investigations many of these are invaluable, but for ordinary work they are not necessary, and their expense is so great as to place them beyond the reach of the majority of students. Very expensive and delicate instruments are seldom necessary for ordinary work, and on those few occasions when a very perfect instrument is required, the student may appeal to some friend, who possesses a large microscope, for permission to examine his objects by it. The members of the Microscopical Society have the advantage of using, under certain regulations, most beautiful instruments provided with very high powers. A complete one has been liberally presented to the Society by Mr. Ross. These microscopes are now arranged ready for work at the Royal Microscopical Society's rooms, at King's College, from 6 to 8 o'clock on each evening the Society meets. In the Radcliffe Library at Oxford is placed one of Powell and Lealand's large microscopes complete, including a  $\frac{1}{36}$ , which may be used for examination under certain restrictions.

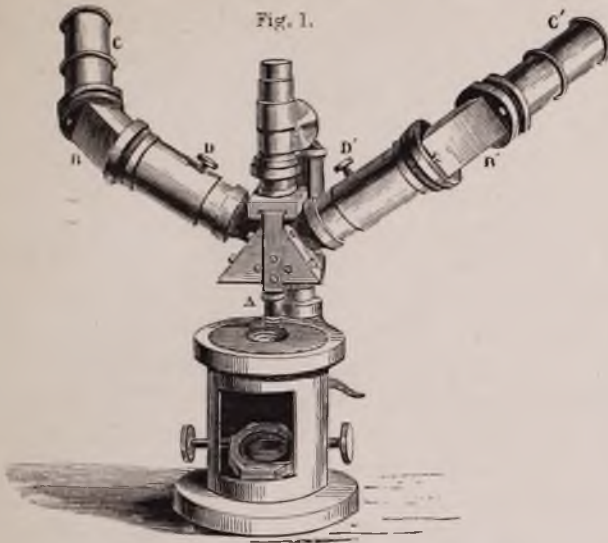


I should advise those who wish for a microscope as perfect as can be made in the present day, to examine the beautiful microscopes of Messrs. Powell and Lealand. In alluding specially to these instruments, I wish it to be distinctly understood that I do not in any way disparage the work of other makers; but as I have very great experience in the use of these instruments, I feel it right to say that I have always found their working powers excellent. Messrs. Powell and Lealand have done much to perfect the compound microscope, and they have produced the highest and most perfect object-glasses yet made. The folding microscope is a valuable and highly convenient form for traveling, and occupies a very small space. It is represented in pl. VII, p. 16.

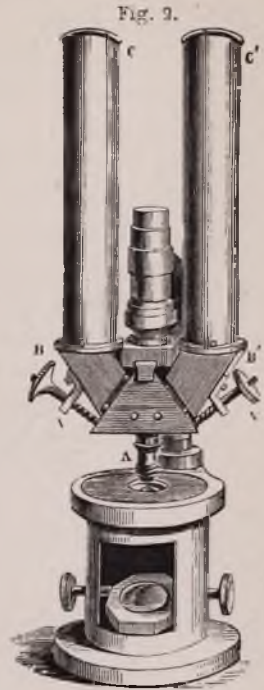
**17. Binocular Microscopes.**—The binocular is applicable to almost every kind of microscopical research, but it is not necessary for the student, and I do not recommend those who are beginning to work at microscopical investigation generally to provide themselves with one. The instrument is, however, very desirable for special work, and by its use a more correct idea of many objects may be obtained; but for the ordinary microscopic work undertaken by beginners, and for the examination of vegetable and animal tissues, the usual instrument is to be much preferred. The binocular should be a separate microscope altogether, or it should be possible to remove the binocular tube from the body of the microscope, and substitute for it an ordinary single tube. Excellent and cheap binocular microscopes are made by Messrs. Crouch, Messrs. Murray and Heath, Mr. Collins, pl. V, Mr. Swift, and other makers. (*See the list of makers at the end of the volume.*) Binocular microscopes may now be obtained of the above makers at prices ranging from 12*l.* to 20*l.*

M. Nacet's instrument, fig. 2, and Mr. Wenham's perfected binocular, fig. 3, are represented in pl. VI. Mr. Wenham has succeeded in producing two or three binocular arrangements. The first plan he adopted will be understood by reference to pl. XIII, fig. 2; but the new method last suggested by him, and now adopted by all microscope makers in this country, is shown in pl. VI, fig. 3.

*Binocular for the highest magnifying powers.*—Messrs. Powell and Lealand have recently succeeded in devising a plan by which a binocular arrangement can be adapted to the highest powers; the binocular in ordinary use being suitable only for the examination of objects by powers magnifying less than 200 diameters. This new plan is adapted only for high powers, and may be used with the  $\frac{1}{30}$ . The prisms employed are represented in pl. VI, fig. 5. They are placed above the object-glass. Of the total number of rays which have passed through the object-glass, the greater part are transmitted through the prism B and the straight tube of the microscope, but some suffer reflection from its lower surface, and are received upon the reflecting surface E of the

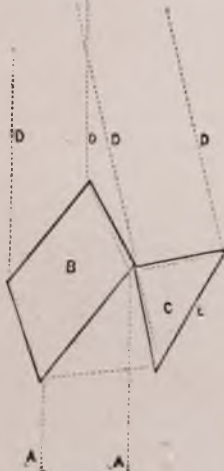


M. Nacet's microscope, to enable two observers to examine an object at the same time.



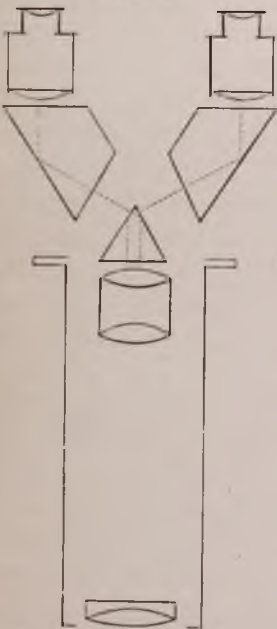
Nacet's binocular microscope. p. 14  
See also Fig. 4. Plate XIII. p. 22.

Fig. 5.



Prisms in Powell & Lealand's binocular arrangement for the highest powers. AA rays of light proceeding from object. B parallel piece of glass. C, triangular prism. DDDD emergent rays. p. 14.

Fig. 4.



The arrangement of the prisms and lenses in Tollee's binocular eyepiece, made by Iadd. p. 15.

Fig. 6.



Mirror. p. 11

Fig. 3.



Binocular microscope as recently arranged by Mr. Wenham, and now generally adopted. p. 14.

[To face page 14.]



prism C in an oblique direction, as shown by the dotted lines, and after emerging from the surface, enter the diagonal tube of the microscope. The last of the two images is less intense than the first, but still it is light enough to be clearly seen. The two images thus formed are exactly similar, and the two pictures blend and appear to the observer as one, and in relief. There is, however, no true *stereoscopic* image, for the one picture seems to be in every respect, save in intensity of illumination, the counterpart of the other. I have examined many objects by the arrangement of Messrs. Powell and Lealand, and find that it works exceedingly well in practice, and is less fatiguing than the monocular instrument. It is to be recommended to those who work with very high powers.

Modifications of the principle adopted by Messrs. Powell and Lealand in their binocular for high powers have been suggested by Mr. Wenham, with the view of utilising some of the light lost in their system, but I have not had an opportunity of carefully comparing the working of the new prisms with those of Powell and Lealand. From Mr. Wenham's description there appears to be some difficulty in obtaining perfectly satisfactory results. "The two prisms need not be pressed into contact—if so, Newton's rings are formed; they may be set a visible distance asunder, but great care is needed in adjusting the small prism so as to get both reflections combined, otherwise a blurred image will be seen in the slanting body." Mr. Wenham, however, assures me that the results are highly satisfactory if the instrument is properly made according to the directions he has given.

Mr. Tolles, of Canastota, New York, adapted a binocular eye-piece to the ordinary single body. This gives a large field well illuminated, and seems to perform well with low and medium magnifying powers. Professor H. L. Smith, in a note to Dr. Maddox, to whom I am indebted for the following observations, says he has even used it with the  $\frac{1}{12}$  and  $\frac{1}{16}$  objectives. It is constructed thus:—An adjustable shallow achromatic erector or eye-piece slides in a setting that fits the tube of the single-body microscope. By this an image is formed at the eye-glass end. This image then passes through the flat surface of an equilateral prism placed over the eye-lens, and by it is bisected, one half being refracted towards the right, the other half to the left. After these rays emerge from the prism, they pass into prisms of the form used by M. Nacet in his binocular microscope (suggested for use here by Professor Smith, as the rectangular prisms first employed by Mr. Tolles did not give satisfactory results), and escape from their outer surfaces at the angle of total internal reflection. The rays are lastly transmitted through two deep eye-pieces or oculars superposed over the two prisms last described. See pl. VI, fig. 4.

By a small pinion the prisms are adjusted for the variable distance between the eyes of different observers, and Mr. Ladd has much

improved and simplified that adjustment by the use of a circular disc with two eccentric slots, which entirely supersedes the rack and pinion. The shallow eye-piece, or erector, is made to slide in the eye-piece tube for the purpose of varying the distance between the eye-lens and the prism placed over it, according to the power of the objective in use.

In this new binocular we have a modification of the plan first adopted by M. Nacet, but which promises to be more successful. Mr. Ladd has undertaken the manufacture of this form of binocular apparatus in England.

**18. Travelling Microscopes.**—*Mr. Warington's Arrangement.*—For travelling, and especially for sea-side work, it will be convenient to be provided with a microscope which can be packed in a small compass with the instruments and apparatus required. Mr. Warington, some time since, designed a very simple microscope for travelling purposes. The stand consists of two flat pieces of oak, fitted at right angles to each other by means of pegs. The stage is inserted into the longer one, to the top of which the body of the microscope is adapted by means of a clamp. The horizontal bar carrying the body can be moved backwards and forwards through a tube arranged to receive it. This instrument can be placed in an upright or inclined position, and by means of the clamp the body can be attached to a table, so that living objects in upright glasses can be subjected to examination. Several improved forms of microscope arranged according to the same principle have been suggested.

Among the most perfect instruments for travelling, is the microscope made by Messrs. Powell and Lealand, represented in plate VII. This has all the advantages of one of the larger instruments of the same makers, and is most convenient. It does not get out of order, and, as will be seen by reference to the description below the figure, this microscope can be packed in a very small box.

*Travelling, Dissecting, and Aquarium Microscope.*—A simple form of travelling microscope is described by me in the fourth volume of the "Transactions of the Microscopical Society," page 13. This instrument was made entirely of tubes. It could be used as a microscope for dissecting, for looking at objects in an aquarium, and for all ordinary purposes. Focussing was effected very rapidly by means of a knee lever, which was kindly made for me by Mr. Becker, instead of a screw. The arrangement was, however, somewhat expensive to make, and cheaper instruments are now produced.

Mr. Highley suggested a very cheap form of travelling microscope which is also strong and useful. This is described in the "Microscopical Journal," vol. iv, page 278. An ingenious little microscope, which packs in a small leather case, has more recently been introduced by Mr. Baker, of Holborn. The body of the last two instruments can be readily

TRAVELLING MICROSCOPE.



Folding microscope of Messrs. Towell and Lealand, adapted for all purposes. This instrument may be used for the highest powers. It is perfectly steady, and is packed with all the required apparatus and instruments in a case 12 inches long, 7 inches wide and 3 inches deep. p. 10.



adapted to the tube carrying the stage of the microscope next to be described. Mr. King, naturalist, of the Portland Road, has devised a most convenient microscope for examining living objects in aquaria. It is fixed to the glass of the aquarium by means of a vulcanized India-rubber pneumatic arrangement. This instrument is made by Mr. Collins, of 157, Great Portland Street. A very good form of cheap pocket and seaside microscope is made by Messrs. Murray and Heath, 69, Jermyn Street, London.

**19. Clinical, Pocket, Travelling, and Class Microscope.**—Under this head I propose to describe an instrument devised by me some years since which I have found very useful for ordinary observation, in the field, and at the seaside, and also for medical work. It has been employed with great advantage for class demonstration. Its construction is very simple, and it can be made for a very small sum.

*The Microscope.*—Like some other instruments which have from time to time been proposed, this microscope is composed of drawtubes, like a telescope; but the arrangement of the stage, and the plan adopted for moving the slide when different parts of the object are submitted to examination, differ entirely, as far as I am aware, from those hitherto proposed. The instrument consists of three tubes *a*, *b*, *c*, fig. 1, pl. VIII; *a* carries the eye-piece, is four and a half inches long, and slides in *b*, which is of the same length, but only slides up to its centre in the outer tube *c*. Tube *b* carries the object-glass. The tube *c* can be fixed by aid of a screw-ring, *d*, at any position, according to the focal length of the object-glass. This arrangement prevents the object-glass from being forced through the preparation by careless focussing. At the lower part of the body is an aperture for throwing the light on opaque objects. The preparation is kept in contact with the flat surface below by a spring, which allows the requisite movements to be made with the hand, figs. 2, 3. That part of the object which it is desired to examine can be easily placed in position opposite the object-glass if the instrument is inverted. The proper focus is obtained by a screwing movement of the tube *b*; and if it be desired to examine any other parts of the object, the slide may be moved by one hand, while the instrument is firmly grasped by the other. Delicate focussing is effected by drawing the tube *a* up and down. By this movement the distance between the eye-piece and object-glass is altered.

Any object-glass may be used with this instrument. I have adapted various powers, from a *three-inch*, magnifying *fifteen diameters*, to a *twelfth*, magnifying *seven hundred diameters*, and I feel sure that even higher powers may be used, if, as in one of my instruments a fine-threaded screw be adapted to the lower part of the tube which carries the object-glass, for careful focussing.

In the examination of *transparent objects*, p. 29, ordinary daylight or



the *direct* light of a lamp may be used, or the light may be reflected from a small mirror inclined at the proper angle; or, if low objectives only are required, the light may be reflected from a sheet of white paper. In examining objects *by reflected light*, p. 26, sufficient illumination is obtained from an ordinary wax candle placed at a short distance from the aperture, just above the object. But the most beautiful effects result from the use of the Lieberkuhn, § 30, with direct light. The best paraffine lamp for microscope work generally, is the small lamp I have described in page 25.

The slide, as has been stated, is kept in contact with the lower part of the instrument, which I have called the stage, by a spring which is therefore made to press on the *back of the slide*. On the other side of the stage a little screw and clamp are placed so that the specimen may be fixed in any position that may be desired, figs. 1, 3, 7.

In using this microscope, the slide with the object to be examined is placed upon the stage, the thin glass being upwards towards the object-glass, while the spring is made to press upon the *under* surface of the slide. The little screw is removed. The slide may be moved in any position, and any particular object to be examined can readily be placed exactly under the object-glass. Tube *a* is withdrawn about two-thirds of its length. The tube *c* being held firmly with the left hand, *b* is grasped with the right, and with a screwing motion the object-glass is brought to its proper focus. The specimen having been found, the slide may, if desired, be firmly fixed by screwing down the little clamp, and the tube retained in its position and prevented from slipping by screwing down the ring fitted on tube *a*. The instrument and preparation may then be passed round a class without any danger of derangement. In removing the slide, it must be rotated on the stage, until it slips from under the spring. In applying it the slide is placed in the same position and rotated until it slips under the spring. If this precaution be observed, slides may be very quickly removed, and replaced without any danger of damaging the thin glass and the preparation. This microscope is well suited for field-work and especially for botanical purposes. It is not heavy, and, including the powers and an animalcule cage, will easily pack into a tube or case six and a half inches long and two inches in diameter. It may be made about one-third smaller without disadvantage, and without requiring special objectives. It is very useful in clinical teaching. This simple microscope is admirably adapted for demonstrating general specimens to classes, and may be used in village schools for displaying vegetable, animal, or mineral specimens to the children.

*The Stand.*—The above tube microscope may be adapted to many forms of stands. The arrangement I have employed for class demonstration will be at once understood by reference to figs. 9, 10, pl. VIII. The structure of the lamp is represented in fig. 6, but the chimney should



DEMONSTRATING CLASS MICROSCOPES.

Fig. 1.



Pocket or clinical microscope.  
Half the real size p. 18.

Fig. 2.



The slide. Side view, showing  
the position of the spring.  
p. 18

Fig. 3.



Under surface of the body or stage  
of the pocket microscope. p. 18.

Fig. 4.



Mirror employed for examining  
objects by transmitted light.

Fig. 5.



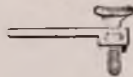
Mirror to fit  
into slide.

Fig. 6.



Lamp. Sectional  
view

Fig. 7.



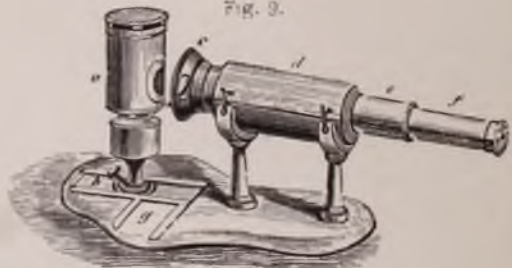
Screw, with an arm, for fixing  
the specimens. e, Fig 1.  
p. 18.

Fig. 8.



Sectional view of cell for examining  
deposits in fluid infusoria &c

Fig. 9.



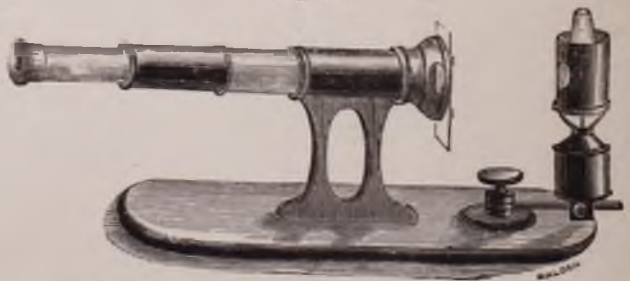
Clinical microscope for class demonstration p. 19.

Fig. 11.



New centring nose-piece,  
designed by Mr. Swift.  
p. 9.

Fig. 10.



Clinical microscope for class demonstration,  
with improved stand  
and lamp. p. 19.

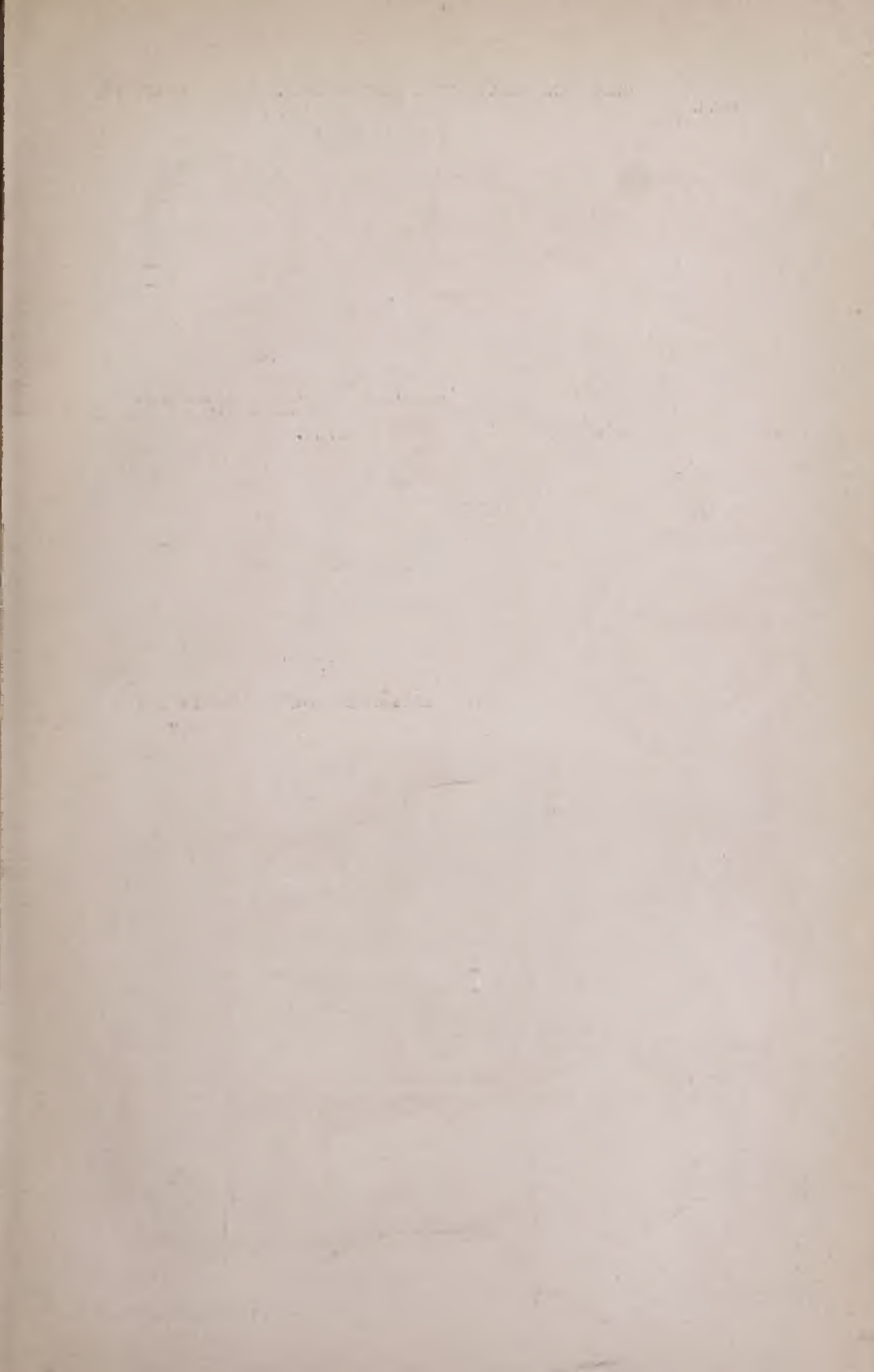
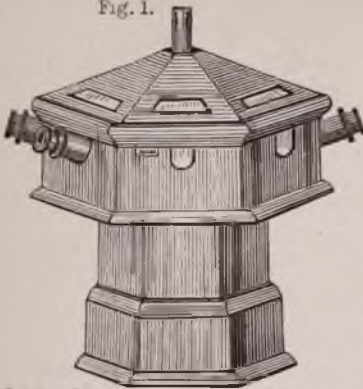
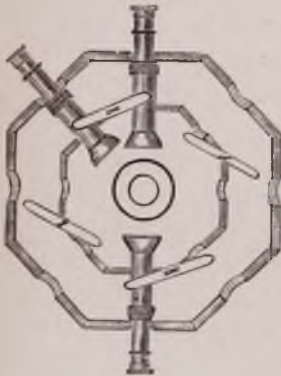


Fig. 1.



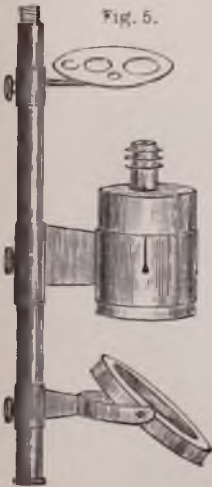
Octagonal box for holding eight microscopes illuminated by one lamp in the centre. p. 19.

Fig. 2.



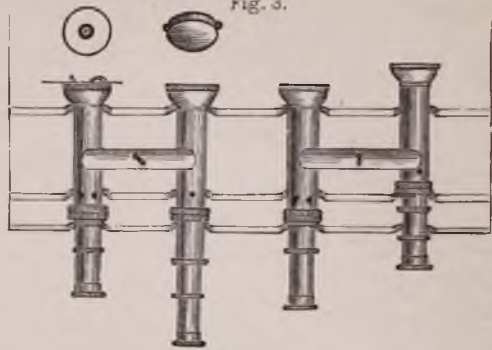
Section of Fig. 1, showing relative positions of microscope and lamp, mode of fixing, &c. p. 19.

Fig. 5.



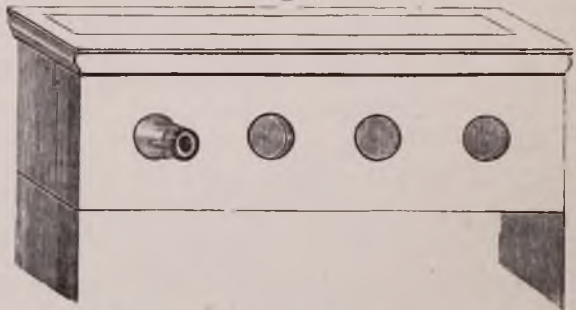
The arrangement by which diaphragm, mirror, and condenser may be adapted to the pocket microscope. p. 19.

Fig. 3.



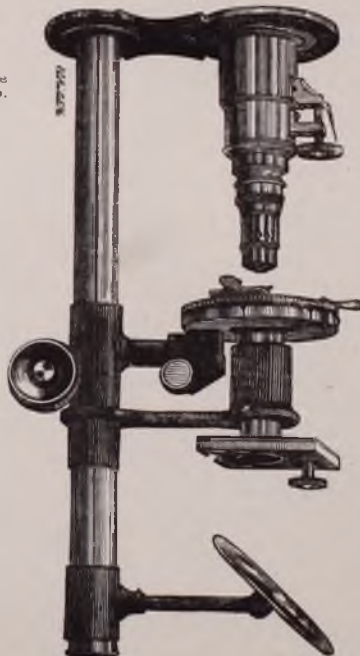
Another arrangement for mounting four of the pocket microscopes. p. 19

Fig. 4.



Front view of the arrangement represented in Fig. 3. p. 19

Fig. 6.



Simple arrangement for adapting stage and mirror to body for photographic work. After Mr. Hignley.

Fig. 7.



Waistcoat pocket microscope, only 4 inches long. Made by Mr. Hignley. p. 20.

[To follow Plate VIII.]

be conical, or a small conical lamp-glass placed over the diaphragm of the cylindrical chimney, as shown in the drawing, fig. 10, pl. VIII. It is a simple paraffine lamp with a conical copper chimney, and a diaphragm, just level with the wick, in order to cause a powerful current of air round the flame. By this means all flickering is prevented, and the instrument may be moved about without fear of the light being blown out. The diaphragm is made of a plate of mica, and the same substance is placed over the aperture in the chimney, *h*. The lamp is made to slide in the grooves marked *b*, *g*, fig. 9, pl. VIII, and it is fixed at a proper distance from the object by the screw *l*, fig. 6. At first I used oil, but for some time past I have burnt paraffine which is much cheaper and gives a far better light. When required for reflected light, the lamp is placed in the groove marked *g*, fig. 9. In the last arrangement the lamp, as suggested by Mr. Highley, was made to slide on a horizontal bar which turns on a pivot, so that the position for reflected light is easily secured, pl. VIII, fig. 10. A mirror is employed by day, and slides in the same groove, or upon the same rod, as the lamp. The mirror, achromatic condenser, polariscope, and drawing apparatus can all be readily adapted to this instrument, and it will be found convenient for photographic purposes. The microscope, without powers, can be purchased for twenty-five shillings, and with the stand it costs about three pounds, but if a number could be made at once the price would be still less.

By this plan I have been able to show more than twelve preparations magnified from 15 to 500 diameters, to a class of upwards of a hundred during an hour's lecture. In about two minutes the specimen may be changed and another placed in its stead. The condenser, mirror, diaphragm, polariscope, &c., may also be made to slide upon a rod fixed to the lower part of the stage as shown in fig. 10, pl. VIII. I have had an arrangement, already referred to, adapted to this microscope, which enables me to use it for demonstrating structures with high powers. In the instruments used at my lectures given at the College of Physicians in 1861, I was able to use successfully all powers up to the twelfth of an inch objective (700 diameters) and I feel quite satisfied that the plan will succeed equally with the highest. An instrument has been made to take the  $\frac{1}{6}$ .

The hand microscopes can also be readily arranged in a box fitted to contain several in a line, pl. IX, figs. 3, 4, or in a six or eight-sided frame, figs. 1, 2, in the centre of which the light, to illuminate all the objects at once, may be placed. One advantage of these arrangements for demonstrating to a class is that while every one can alter the focus to suit his vision, the microscopical preparation and light are quite out of reach, so that they cannot be disarranged.

The hand microscope has been recently modified and improved

upon by many different makers. A very convenient form has been introduced by Mr. Baker and Mr. Moginie, and another by Mr. Hawksley. Still more recently, a new form, arranged by Mr. Swift, is used as a clinical and seaside microscope. With a low power only this instrument may be obtained for about thirty shillings.

*Dr. Guy's Arrangement.*—My colleague, Dr. Guy, devised an ingenious form of hand microscope, which was brought out by Mr. How, of Foster Lane, and is known as the "Illuminator Hand Microscope." This is well adapted for examination with low powers, and for showing popular objects in schools and to classes, but it is not adapted for the real work of the medical practitioner or student of physiology. My friend, in praising the merits of the class microscope he has constructed, has, I think, been unduly hard upon the complexities of other instruments, while he has scarcely given due weight to the fact that any microscope, to be of real service to the student and practitioner, ought to work well with a magnifying power of at least 200 diameters. In his paper he does not even mention the highest amplifying power that can be adapted to the hand microscope he describes. ("Journal of the Quekett Club," No. 20, October, 1872, page 65.)

**20. Smallest Pocket Microscope.**—The simple tube microscopes have been modified in many ways by various makers, and some have been made so small that they may be carried in the waistcoat-pocket. An instrument of this kind was made some years ago by Mr. Highley. It was four inches long and only three-quarters of an inch in diameter, and was sold for a guinea. Not being provided with the stage and spring, only one spot in the field could be brought under the object-glass, but it was intended for low magnifying powers only, which give a large field, pl. IX, fig. 7. A microscope upon the same plan had been made many years previously by Messrs. Powell and Lealand.

Professor Brown, of the Veterinary Department of the Privy Council, has lately introduced a very valuable modification of the clinical pocket microscope which occupies far less space than the one above described. This beautiful little instrument can be used for examining objects under the highest powers, and can be carried in the waistcoat-pocket. It is figured in pl. X, figs. 1, 2, 3, of the actual size. It is four inches long by one inch in diameter in its widest part. The general arrangement of the instrument will be understood by the figures, but it has been fully described by Professor Brown in the "Veterinarian" for November, 1870, and it is made by Mr. Swift, University Street, Tottenham Court Road. The instrument, with a quarter, costs about three guineas. I believe this microscope will be of great use to naturalists, to members of the medical profession, and to all who desire to have a very portable microscope, adapted for examining objects with high powers. A very little practice will enable any one to use it without difficulty. Professor Brown employs

Fig. 1.

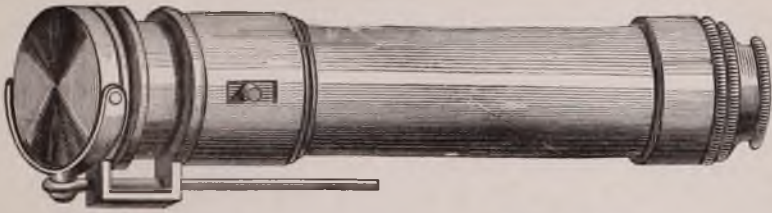


Fig. 2.

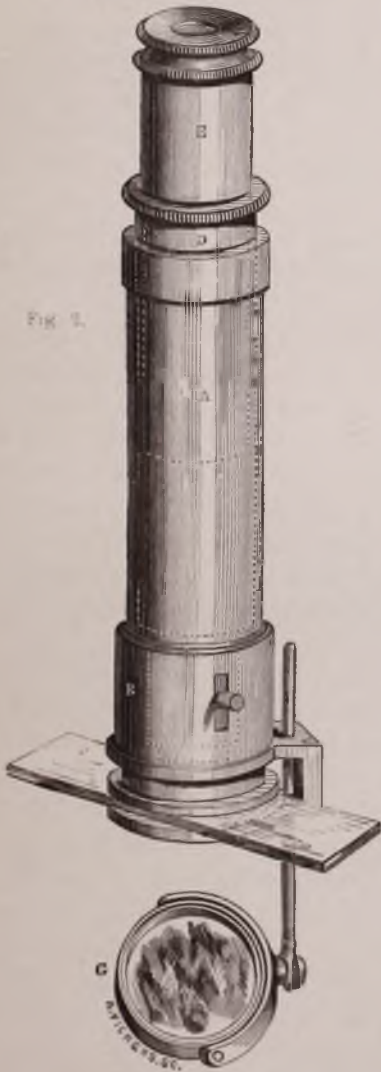


Fig. 3.

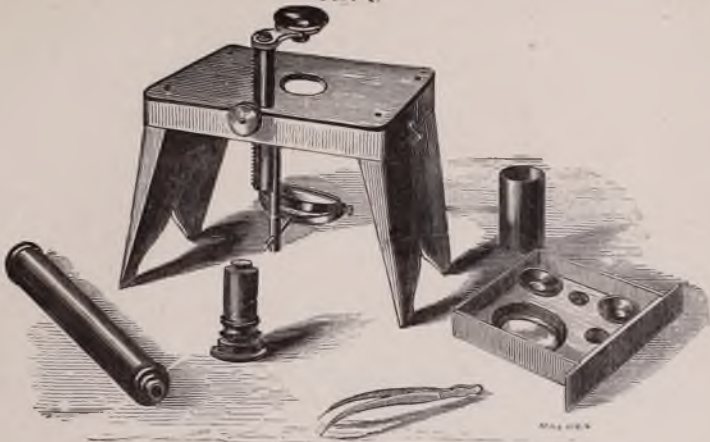


Waistcoat pocket microscope, designed by Prof. Brown. The figures are the exact size of the instrument. Fig. 1. The microscope folded up. Fig. 2. The instrument arranged for use. Fig. 3. Engraved clamp for holding microscope with spike which may be temporarily fixed in any piece of wood as a gate post.



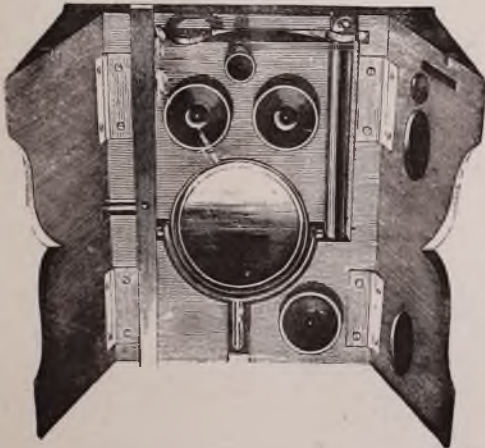


Fig. 1.



Professor Quekett's dissecting microscope, with apparatus p. 21.

Fig. 2.



Professor Quekett's dissecting microscope. Mode of packing the different pieces of apparatus. p. 21.

Fig. 3.



Professor Quekett's dissecting microscope. The instrument folded up for travelling p. 21

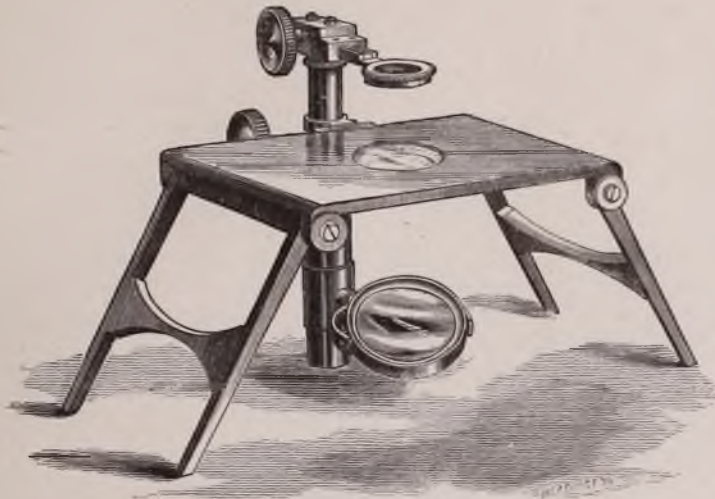
Fig. 4.



Dr. Lawson's binocular dissecting microscope, made by Collins. On the left, the instrument is shown folded up. p. 21.



Fig. 1.



Dissecting microscope, as recently improved by Mr. Swift. This may be packed up in a very small space. p. 21.

Fig. 2.



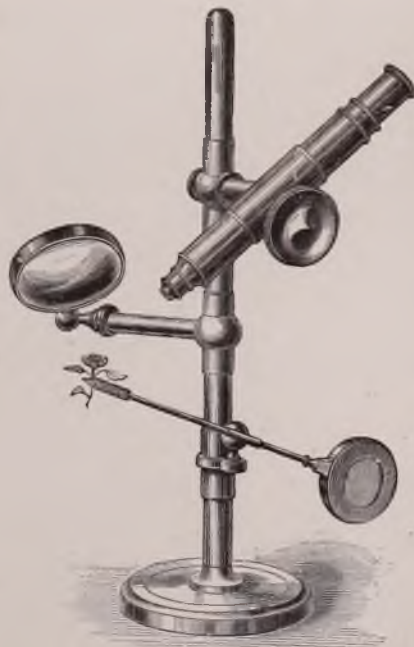
Beck's parabolic reflector, with Mr. Sorby's modification. p. 26.

Fig. 3.



Round-tipped lamp, with shoe. Showing position when used for examining objects with direct light. p. 25.

Fig. 4.



Microscope with low power, with bull's eye and forcers, for examining general specimens and for dissecting. The body of any microscope may be reclined and used as shown in the drawing. Made by Mr. Swift. p. 21.

[To follow Plate XI]



it in veterinary work. He can use it in the open air, and can examine secretions of the blood of animals in the sheds in which they stand, and under powers magnifying one thousand diameters.

The eye-pieces and objectives of this instrument have their aberrations accurately corrected to the short length of the body. Pl. X, fig. 2, represents the instrument when in use. The slide is held in its position by a spring box, marked B, and can be freely moved about when under examination. The coarse adjustment is obtained by sliding the tube L in its fitting, to which the object-glass is attached; the fine adjustment is effected by moving the tube E, which enables the object to be accurately focussed with the greatest ease.

Eye-pieces of different power, condensers, polarising apparatus, and other appliances can be added to the instrument without difficulty, if required. The glass slides, thin glass covers, pipettes, needles, &c., can be packed in the same little case with the microscope. The instrument Mr. Swift made for me is packed, with its stand, in a small strong box, which measures in inches  $3\frac{3}{4} \times 1\frac{3}{4} \times 1\frac{1}{2}$ , and is provided with an inch, a quarter, and a one-sixteenth of an inch objective, with slides and thin glass.

**21. Dissecting Microscopes** are very useful in many microscopical enquiries and have been long in use. Quekett's original dissecting microscope is seen in figs. 1, 2, 3, pl. XI. Figs. 2, 3, show the internal arrangement and the manner in which the mirror, lenses, and lens-holders are packed away. The instrument is furnished with three lenses, and is to be purchased at a moderate price.

*Lawson's Dissecting Binocular Microscope*, as made by Collins, pl. XI, fig. 4, though only constructed for slight magnifying power, is exceedingly compact, and enables the observer to use both eyes. It is furnished with two sets of stereoscopic lenticular prisms, dissecting instruments, &c. It costs two guineas. This instrument has been further modified and improved. An excellent form is made by Mr. Swift, and is figured in plate XII, fig. 1.

*Compound Dissecting Microscope*.—An excellent compound microscope, of low power, was arranged for dissecting purposes, by Messrs. Powell and Lealand. The body was attached to an arm, which could be moved up and down by a rack and pinion. The instrument was kept ready for use in a case. Modifications have been suggested by others. A cheap useful instrument for dissection, for rough examination, or for examining living objects in an aquarium, has been made by Mr. Swift. This is represented in fig. 4, pl. XII.

#### *Apparatus for Students' Microscope.*

**22. Apparatus necessary for the Student.**—Every student's micro-

scope should be provided with a *neutral tint glass reflector for drawing and measuring objects*, a *diaphragm*, to the under part of which is fitted a tube to receive an *achromatic condenser* or *polarising apparatus*, a *bull's eye condenser*, one *shallow eye-piece*, and two powers—a *low one, magnifying from 20 to 40 diameters*, and a *quarter, or a four-tenths of an inch which magnifies 180 diameters*, a *stage micrometer* (§ 60), a *Maltwood's finder on the plan adopted by Mr. Baker* (§ 68), and an *animalcule cage* (§ 134).

These accessory instruments should be conveniently packed in the case with the microscope. The polarizing apparatus and the achromatic condenser are not absolutely necessary for a beginner, and can be purchased afterwards. The cost of the microscope without these last, but including the other pieces of apparatus mentioned, in a well-made case, need not be more than six pounds; and if the microscope be mounted on a cast-iron foot instead of a brass one, it may be obtained for about a pound less, without its practical utility being in any way impaired.

The great number of different microscopes and the excellent workmanship employed in their construction render it a difficult as well as a delicate task for a teacher to recommend any special one to his pupils. Many of the instruments which I have used, and which I have recommended, are exceedingly good, but I have no doubt that there are others, which I have never had the opportunity of testing, which are as good in every respect. The names and addresses of the principal English and foreign microscope makers will be found at the end of this volume.

#### ON ILLUMINATING OBJECTS.

**23. Reflected Light, Transmitted Light, and Polarised Light.**—If the internal structure as well as the external surface of the same object be studied in the microscope, the observer will form an idea of its nature very different from that which he would have arrived at if he had regarded the characters ascertained by one mode of examination only. By employing polarised light peculiarities in the structure of an object may sometimes be discovered, of which no indication is afforded when it is examined by ordinary light.

The student's attention must, therefore, be directed to the three following methods of throwing the light upon and through objects to be submitted to microscopical examination. The directions for arranging the microscope for observation are given on pp. 29, 81, to which the student is referred for further information.

1. *Reflected light*—In the examination of an object by reflected light, ordinary diffused daylight may be allowed to fall upon it, or light

Fig. 1

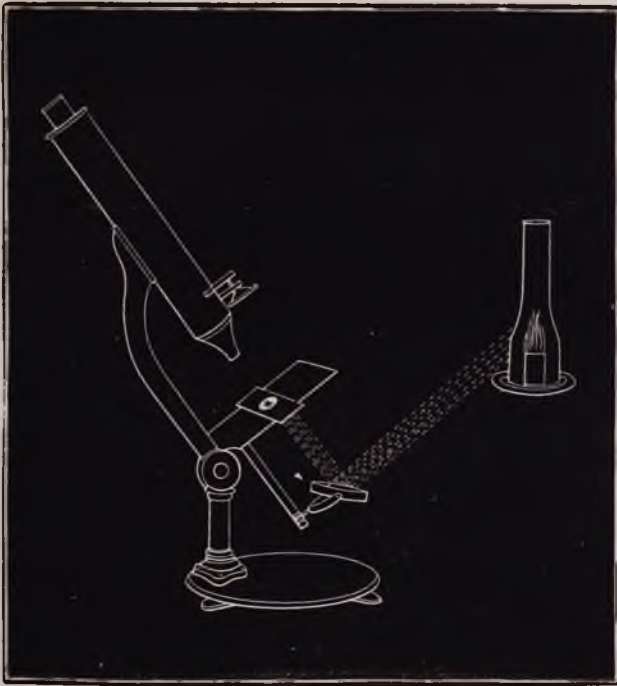
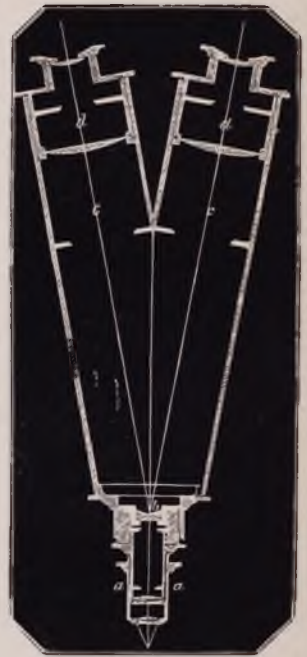


Diagram to show the arrangement for examining objects by transmitted light. pp. 23, 82.

Fig. 2.



Mr. Wenham's original arrangement of the binocular microscope p. 14.

Fig. 3.

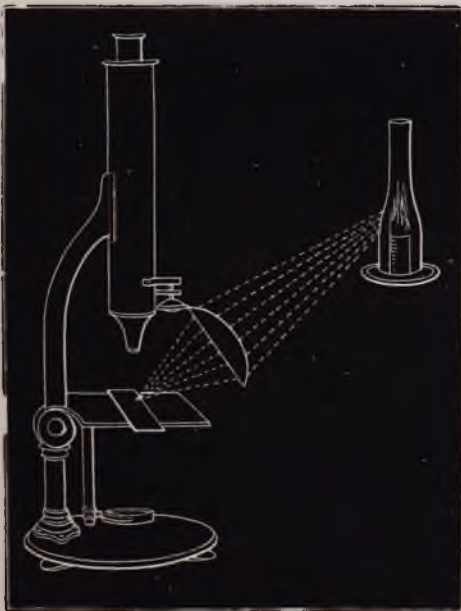
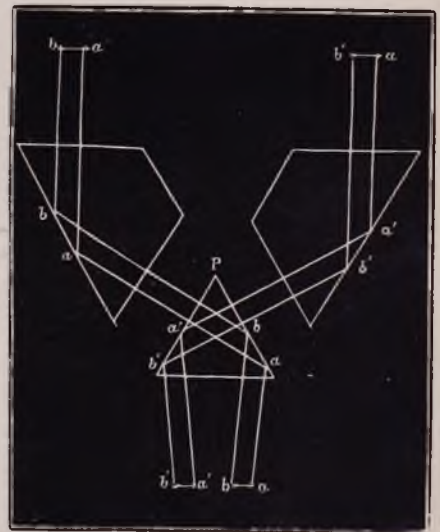


Diagram to illustrate the arrangement for examination by reflected light. pp. 23, 82.

Fig. 4.



Arrangement of prisms in Nache's binocular microscope. p. 14.





may be received upon a metallic reflector, or be refracted through a prism placed at the proper angle and thus made to impinge upon the surface of the object. The intensity of the illumination may be much increased by employing a concave mirror or a bull's-eye condenser, § 27. By the examination of objects by *reflected light* we gain information concerning the peculiarities of the surface only, just as in looking at objects under ordinary circumstances. The surface of any object, be it transparent or opaque, may be examined by reflected light, §§ 30, 32.

2. *Transmitted light* passes through the object under examination, which must, therefore, be *transparent* or capable of being rendered so by some special method of preparation, § 140. By this method of examination any peculiarities of internal structure are rendered evident. Transmitted light may be made to pass from the source of illumination direct through the object, or the rays of light may first be received by a mirror or prism and then reflected or transmitted in a straight or oblique direction through the preparation. The position of the microscope will be seen if plates III, IV, VII, and XIII, be referred to.

*Oblique illumination* is of great assistance in some forms of enquiry. Many delicate lines, in highly transparent structures, although invisible when the specimen is examined by ordinary transmitted light, are clearly discerned when a ray of light is made to traverse the specimen obliquely. In order to obtain this result the mirror is moved to the side of the stage so as to throw the light obliquely on the under surface of the object. The diaphragm is often provided with eccentric openings and slits, varying in form and position, so that pencils of light, of different shapes and degrees of obliquity, may be readily obtained.

3. *Polarised light*.—The light is polarised for the examination of microscopical objects by being made to traverse certain crystalline substances which are known to have the property, before it is transmitted through the object. A crystal of that form of carbonate of lime, known as Iceland or rhomboidal spar, tourmaline, or iodo-quinine, is the most advantageous for this purpose. The first is generally used under the name of Nicol's prism, which is made by dividing a crystal of Iceland spar obliquely, and then carefully cementing the two portions together with Canada balsam. By this method one of the two images produced by this double refracting crystal is refracted out of the field of vision while the polarising property is not in any way affected. Dr. Herapath gave me two large and beautiful crystals of the iodo-quinine or herapathite which he discovered some years ago, and prepared for examining objects in the microscope by polarised light. The crystals are mounted between two pieces of thin glass and work very satisfactorily. One of the crystals above referred to is fitted beneath the stage of the microscope. This is called the *polariser*. Another termed the *analyser* is

inserted in the tube of the microscope or is placed above the eye-piece, pl. XVII, p. 34, figs. 1 and 2. Either the *analyser* or the *polariser* should be so arranged that it may be made to rotate.

By polarised light the internal structure of various transparent objects can be rendered evident in a very beautiful manner, but for ordinary microscopical work, upon the tissues of vegetables and animals, this method of observation is seldom required. The advantage of polarized light in general microscopical enquiries has perhaps been over-rated, though the appearances produced are interesting, and many of them very beautiful. In examining objects by polarised light wonderful effects may be obtained by interposing between the polariser and the object thin plates of certain crystalline substances, which should be so arranged as to be capable of revolving. The play of colours which may be produced in this way, by the aid of selenite, is in the case of many objects very beautiful. Plates of different degrees of thickness, each giving a different colour, may be obtained of the opticians. Mr. Swift has arranged such plates in his condenser, and in slides of a convenient form, pl. XVI, p. 28, fig. 5.

#### *Sources of Illumination.*

Ordinary daylight or sunlight reflected from a white cloud affords the best illumination, but the light of gas, of a candle, or good lamp answers exceedingly well for every department of microscopical enquiry, if certain precautions be taken. Daylight is usually reflected from the mirror. In the examination of transparent objects the microscope is arranged as in pl. XIII, fig. 1, and the light is usually reflected by the mirror. Sunlight is only employed under very special circumstances, as for examining objects by coloured media, when an intense light is required, or for the purpose of taking photographs of microscopic objects. *See Part V on Photography.*

It has been said with truth that microscopical work should be undertaken only by day, since the most perfect artificial light which can be obtained is far inferior to daylight for delicate observation, while it strains the eyes very much more. But unfortunately it happens that in this country, and especially in the lower parts of houses in our large cities, during a great part of the year, the only daylight obtainable is not very suitable for microscopical investigation. However, many of us, in consequence of being occupied in duties of perhaps a very different kind by day, are compelled to work principally or entirely by night. It is therefore a matter of the greatest importance that we should be provided with satisfactory artificial illumination.

From time to time various special lamps for microscope work have been introduced. The small *camphine lamp*, brought out many years

Fig. 1.



Lamp of Messrs. Smith and Beck for camphire or belmontine. p. 24.

Fig. 2.



Simple paraffine lamp, with round wick. p. 25.

Fig. 3.



Pocket lamp, made by Collins, with round wick. p. 25.

Fig. 4.



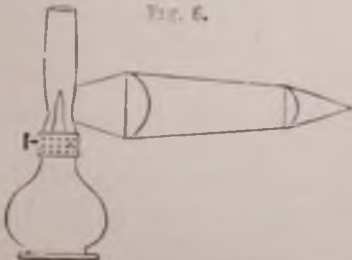
Gas microscope lamp, with water bath, &c arranged by Mr. Highley. p. 25.

Fig. 5.



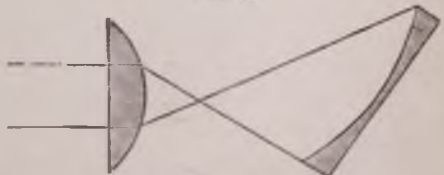
New lamp for paraffine with china chimney and shade. Made by Mr. Swift. p. 25.

Fig. 6.



Lamp with arrangement of plano-convex lenses, mounted in a tube like an eye-piece, for condensing light. p. 26.

Fig. 7.



Reflection of light from a concave mirror, showing rays becoming parallel after having passed through a plano-convex lens. p. 26.



ago by Messrs. Smith and Beck, and since modified for paraffine, which is represented in pl. XIV, fig. 1, will be found to give a white light, and it possesses the advantage of producing very little heat.

**24. Oil Lamps.**—Of *oil lamps* there are several which serve for microscopical examination. The *German Argand lamp*, lately imported into this country by Mr. Pillischer, is a good microscope lamp, and so also is the ordinary *French moderator*, especially if provided with a blue or neutral tint glass chimney, and a shade. But these lamps, and indeed gas itself, yield to paraffine and belmontine, which give an exceedingly steady and white light, with very little heat.

**25. Paraffine Lamps.**—For some years past I have been in the habit of using one of the common little paraffine lamps, termed night lamps, with a small *round* wick, which may be bought for 1s. 6d., pl. XIV, fig. 2. This gives a very white light, and is most convenient, as well as economical. A pale blue glass chimney improves the quality of the light, and a shade protects the eyes from the general glare. I use this lamp with the fiftieth, and find that it works admirably. Such lamps may be made to occupy very little space if constructed of brass tube, and I have had chimneys of sheet copper made for them, with an aperture three-quarters of an inch in diameter, over which a piece of mica is fixed with a screw collar. By whitening, with a paste of chalk or plaster of Paris, the chimney behind the wick, the light is improved. I have now for years used one of these small round-wicked paraffine lamps without any mirror for illuminating objects magnified with very high powers. The arrangement is shown in pl. XII, fig. 3. A lamp of the same kind was adapted to a self-illuminating ophthalmoscope I devised some years ago, and which is made by Mr. Hawksley, 300, Oxford Street.

Mr. Collins sells an excellent paraffine lamp, under the name of the "Bockett lamp," which is provided with an adjustable silvered reflector, a bull's-eye condenser, and a blue glass chimney. One of these has been fitted up with a round wick, like the little lamp above referred to, fig. 3, pl. XIV.

Mr. Swift has recently perfected some excellent microscope lamps, fig. 5, pl. XIV. One is a modification of the small round-wicked lamp which I use for the demonstrating microscope (page 19), and is supported upon a telescope foot, so that it can be arranged at any required height.

**26. Gas Lamps.**—For those who prefer gas I can recommend the Argand gas lamp of Mr. Highley, which is provided with a flat brass plate and a water bath, instruments of great use in microscopical investigation, pl. XIV, fig. 4. The light is made to pass through an opening in a moveable diaphragm, so that the eyes are quite protected from the diffused light. A very pleasant light is produced, as in other lamps, by causing the rays to be transmitted through a blue chimney glass and a

flat piece of neutral tint glass. A bull's-eye is also adapted. The objection to this lamp is its great heating power.

Whatever method of illumination be adopted the eye not observing should always be kept open, but protected from the direct glare of the microscope lamp. For this purpose Mr. Brooke long ago suggested a shade made of black paper, which was fitted to the body of the microscope, at a convenient distance below the eye-piece.

*Of Instruments for examining the Surface of Objects by Reflected Light.*

Ordinary diffused daylight or lamplight may be used, but is not of sufficient intensity to give very satisfactory results. Unless sunlight or some other very powerful light is employed, it is necessary to concentrate the rays upon the surface of the object placed in the focus of the object-glass by the aid of one of the following instruments.

**27. Bull's-Eye Condenser.**—This instrument is provided with all microscopes, and needs no description. Different modes of mounting the plano-convex lens are represented in figs. 2 and 4, pl. XVI, and the position of the microscope, condenser, and light in figs. 2, 4, pl. XVI, p. 28.

Any ordinary bi-convex lens may be used as a condenser. It may be mounted in a gutta-percha rim and attached to a piece of copper or lead wire. In examining many objects with an ordinary lens, great advantage is gained by condensing the light of the sun or of a lamp upon the precise point of the surface which it is desired to study. By condensing the light of a lamp by two plano-convex lenses mounted in a tube, as shown in fig. 6, pl. XIV, a very satisfactory pencil of bright light may be obtained.

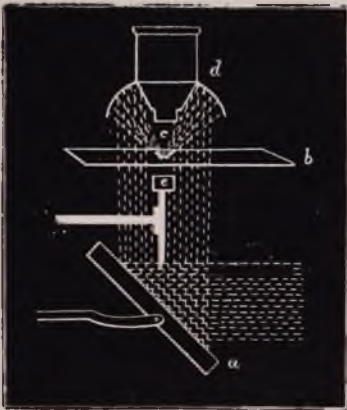
**28. Metallic Reflector.**—A concave metallic reflector may also be used to bring the rays of light from a lamp to a focus on the object. This instrument is fitted to the side of the microscope. I do not, however, think it possesses any advantages over the bull's-eye condenser.

**29. Beck's Parabolic Reflector,** pl. XII, fig. 2, p. 20.—This instrument is made to fit on and rotate round the object-glass; it answers admirably for condensing the light on the surface of objects, and by throwing the rays in any particular direction across the surface enables the observer, by the assistance also of the shadows, to determine the nature of irregularities upon some objects in a very satisfactory manner.

By the adaptation of a little reflector, arranged as represented in fig. 2, pl. XII, Mr. Sorby gained some great advantages in the examination of the fractured surfaces of iron and steel. See "Microscopical Journal," Oct. 1865, p. 117.

**30. Lieberkuhn.**—The rays of the light reflected from the mirror and passing round the *circumference of the object* placed in the field, impinge upon a *concave annular reflector* or *Lieberkuhn* adapted to the

Fig. 1.



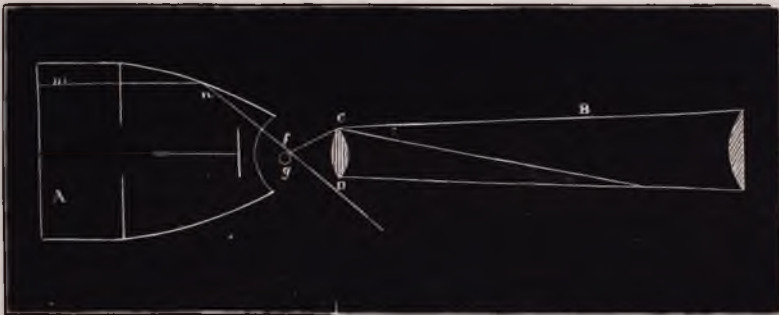
To illustrate the mode of examining an object by reflected light with the Lieberkuhn. The light reflected from the mirror *d*, passes through the glass slide *b*, around the object, and impinges on the concave annular mirror, *d*, by which the rays are brought to a focus and condensed upon the object placed at *c* p. 27.

Fig. 2.



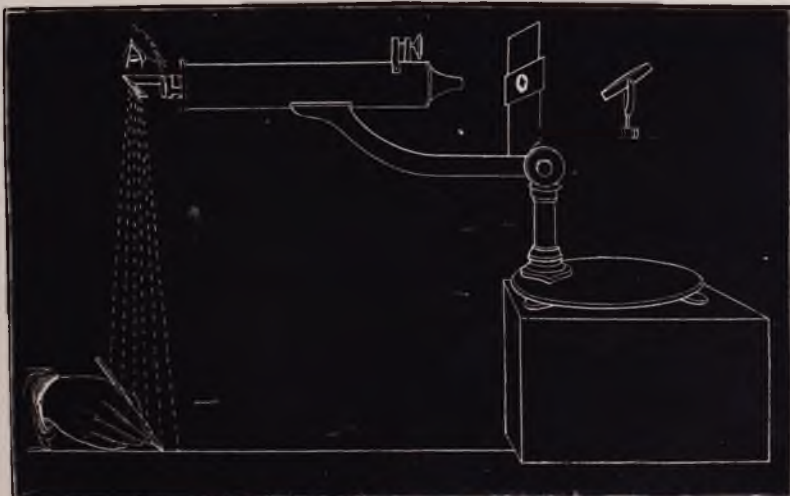
Achromatic condenser mounted with a lever handle. p. 30.

Fig. 3.



Parabolic illuminator, showing course of a ray of light, *m, n, f*, when an uncovered object, *g*, is placed in focus. p. 28.

Fig. 4.



Arrangement of microscope for drawing and measuring objects. pp. 31, 43.

[To face page 26.





object-glass, from which the rays are reflected downwards, and are brought to a focus upon the surface of the object itself, pl. XV, fig. 1.

If a transparent object is to be examined by a *reflected light*, a piece of dull, not glazed, black paper, rather larger than the aperture of the object-glass, should be placed behind it to prevent the passage of light through it, or one of the stops, fig. 1, *e*, supplied with some instruments may be inserted in its place beneath the stage. The stops, however, are not generally furnished with students' microscopes.

**31. Arrangements for examining Opaque Objects with very high Powers.**—Prof. H. Lawrence Smith, of Kenyon College, Gambia, Ohio, U. S., has introduced a plan by which the object-glass is made its own illuminator. The rays of light admitted at the side of the lower part of the tube of the body are received upon a small silvered mirror, set at the proper angle and having a small opening in the centre, and by it thrown down through the objective to the object, and return through the same object-glass and aperture in the centre of the mirror to the eye-piece.

Messrs. Powell and Lealand substituted for the silver mirror a piece of thin plate glass ( $\frac{1}{16}$ th of an inch thick) placed at an angle of 45 degs. In this way loss of light was avoided, as the magnified image was seen *through* the glass. The late Mr. R. Beck, about the same time, adopted a similar plan, using a circular piece of ordinary thin covering glass, which was arranged so that the angle of inclination could be altered if required. I learn from Dr. Maddox that Prof. Smith still gives the preference to his own arrangement. Mr. Dancer has proposed another modification of the above plan. A little speculum, only one-sixth of an inch in diameter, is introduced through a lateral aperture two inches and a half above the top of the object-glass, and placed at a proper angle to reflect the rays downwards ("Popular Science Review," April, 1866, p. 249).

These new methods of illumination, which are improvements upon that devised five years since by Mr. Hewitt, but on the same principle, are valuable for observations upon the diatomaceæ. For a full description the reader is referred to Prof. Smith's paper in "Silliman's Journal" for September, 1865; Mr. R. Beck's paper in the "Microscopical Journal" for April, 1866; and the remarks made by Mr. Wenham, Mr. Slack, Mr. Lobb, and others, in the same number.

**32. Dark-ground Illumination.**—In this place I must allude briefly to a mode of illumination which has been much in repute of late years, and which is very advantageous for demonstrating some structures. I refer to *dark-ground illumination*, in which the object appears to the observer in relief upon a black ground. In this mode of illumination, which is particularly applicable to investigations upon some very minute organisms, such as the diatomaceæ, the direct light rays are prevented

from penetrating the specimen, and passing through the object-glass, but the preparation is highly illuminated upon all sides by light made to impinge upon any point of circumference in a very oblique direction. Thus the object is thoroughly illuminated upon every part of its surface, but the ground on which it lies appears perfectly dark.

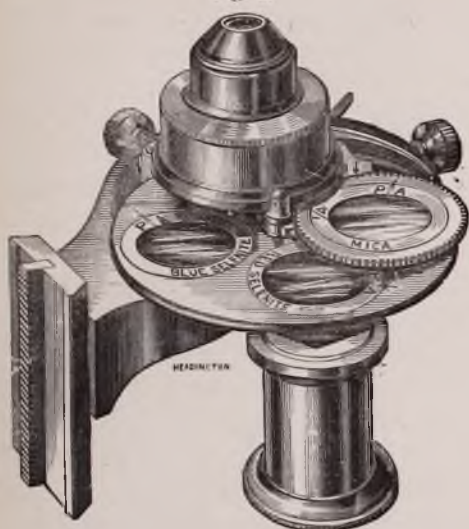
There are several methods by which the result above referred to may be obtained. One very simple little instrument is termed a *spot-glass*, and consists of a plano-convex lens, the convexity being so great that rays passing through it converge with a great degree of obliquity, and are brought to a focus at a short distance above the flat surface of the lens, in the centre of which is placed a small circular piece of black paper in order that the passage of direct rays of light may be prevented. The lens is fixed in a brass tube made to slide up and down, so that it may be adjusted at the proper distance below the object. The spot-glass may be purchased of the instrument makers for about 7s. 6d.

**33. Paraboloid Illumination.**—*The parabolic reflector* or Mr. Wenham's, Mr. Shadbolt's *annular condenser*, and the *parabolic illuminator* of Messrs. Smith and Beck are beautiful instruments for producing dark ground illumination in a very efficient manner, pl. XV, fig. 3.

Another excellent plan, upon a somewhat different principle, has lately been devised by Mr. Wenham, the simplicity of which recommends it strongly to our attention. A small triangular prism is placed beneath the object, so that one of its plane surfaces is in contact with the under surface of the slide carrying the object. The light is refracted so highly that none passes directly through the object, but, being thrown at the proper angle upon the under surface of the thin glass which covers it, is entirely reflected from thence upon the object itself, which is thus highly illuminated. Professor Abbé has recently devised an immersion illuminator with a balsam angle of  $138^{\circ}$ .

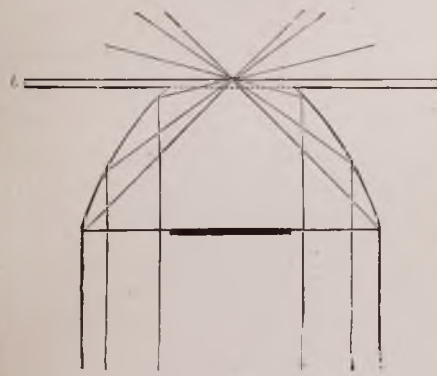
*The Immersion Paraboloid Illuminator*, designed by Dr. James Edmunds, is described in the "Monthly Microscopical Journal" for August, 1877, and in the "Quekett Society's Journal" for May, 1878. This paraboloid is constructed by Messrs. Powell and Lealand, at about the same cost as the Wenham paraboloid, and it is mounted and used in the same way, fig. 3, pl. XVI. Its top is, however, plane, and has to be made *optically continuous with the under surface of the slide by means of a drop of pure glycerine or other medium of high refractive index*. The paraboloid is made of hard white crown glass, and the area of the plane top is stopped out beneath the base, so that no light passes directly through. Its formula is such that all the parallel rays of light entering the base are made to converge, by total internal reflection, upon the object placed on the slide, and the plane top is at such point below the focus of the object-glass as to allow exactly for the thickness of the slide and connecting film of glycerine. With the usual sub-stage movements, the

Fig. 1.



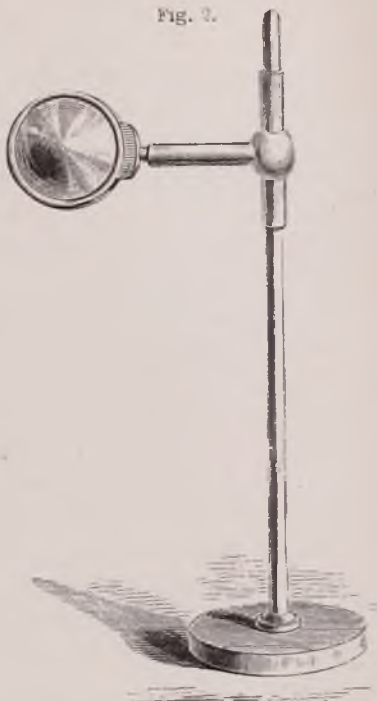
New condenser, arranged by Mr. Swift, containing spot lens, polarizing apparatus, contracting diaphragm, &c. pp. 24, 26

Fig. 3.



Dr. Edmunds' paraboloid illuminator. Over *a* is the stop; *b* is the glass slide upon which the object is placed. The under surface of the slide is connected with the summit of the illuminator by a little strong glycerine. Made by Messrs. Powell and Lealand. p. 18

Fig. 2.



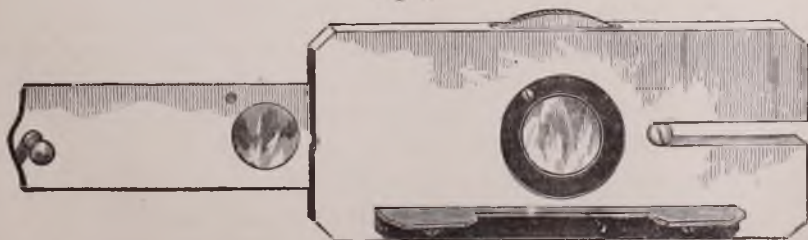
Bull's-eye condenser, on upright stand p. 26

Fig. 4.



Bull's-eye condenser for student's microscope' p. 26

Fig. 5.



Blankley's compound revolving mica-selenite stage, giving twelve or more different tints of colour. pp. 24, 80



focussing or centring of this paraboloid can be varied as readily as that of the objective. All the light, except that entering the object, is thrown back from the upper surface of the slide, so that, with immersion lenses of the largest aperture, the object is seen upon a black field. An object may easily be lighted up so intensely as to appear incandescent, and a luminous image of structural details, difficult to demonstrate by ordinary illumination, is shown upon a soft black background. The markings upon the Podura-scale are resolved into distinct featherlets, which seem to project from a hyaline-beaded membrane and the lines of *Amphipleura Pellucida*, which with their interspaces number 200,000 to the inch, are displayed as green and black bands. Saliva, blood, &c., under a good dry quarter-inch, appear almost as new objects when thus illuminated, but nothing in the field is visible except the objects which are in optical contact with the slide, and thin films only should be worked upon.

*Of Instruments for examining the Internal Structure of Objects.*

**34. Transmitted Light.**—The microscope in pl. XIII, fig. 1, is arranged in the ordinary position for examining transparent objects. The light may be received upon the plane or concave mirror, according as a moderate or brilliant light is required; but, as a general rule, the intensity of light should not be greater than necessary to make out distinctly the structure of the object. The converging rays from the concave mirror may be rendered parallel by being passed through a plano-convex lens, according to the arrangement given in fig. 7, pl. XIV, p. 24. Direct sunlight is not to be employed, and a very strong light of any kind is hurtful to the eyes. The best light during the day is to be obtained from a white cloud upon which the sun is shining. In some investigations it is well to cause the light to pass through ground glass, or very thin tissue-paper oiled or varnished, before it impinges on the object. The light is thus much softened.

**35. Monochromatic Illumination.**—Professor Amici seems to have been the first to have tried experiments with monochromatic light in the examination of objects in the microscope. He employed the rays of the solar spectrum, but I am not aware that any great advantages have been gained or new facts discovered by this process. Yet it seems probable, now that we are enabled to examine objects so much more minutely than heretofore, that something may be obtained by enquiries in this direction. Any ray from an ordinary prism may be caused to pass through the object or condensed upon it with the aid of the condenser. Count Castracane has since used monochromatic light for microscopical observation and for taking microscopical photographs ("Microscopical Journal," October, 1865, p. 250), and a similar plan has also been adopted in America by Mr. L. W. Rutherford. Count Castra-

cane used one of Dubosq's heliostats, a rather expensive instrument, by which the whole field could be illuminated by any single ray desired, and by the movement of the prism, effected by clockwork, this particular ray was prevented from passing out of the field.

**36. The Diaphragm** has been already described in § 14. The definition of the structure of a transparent object is often found to be very much clearer when only the more direct and central rays of light from the concave mirror are allowed to pass through it. An excellent contrivance for altering the size of the aperture in the diaphragm has been recently devised by Mr. Collins, fig. 3, pl. XVII. See also § 39. Apertures of various sizes and in different positions are made in the diaphragm, so that pencils of light of different forms, and of different degrees of obliquity, may be made to impinge upon the object.

**37. Achromatic Condenser.**—The illumination of some objects examined with high powers is much improved by causing the light to pass through an achromatic condenser, which may consist of an ordinary achromatic objective of half or a quarter of an inch focus, arranged in a sliding tube immediately beneath the stage. One of these instruments can be fitted to the student's microscope. Mr. Quekett has adapted a simple lever handle, by means of which the right focus is readily obtained, pl. XV, fig. 2, p. 26. The instrument is not an expensive one, if it be made of a French combination. I have often obtained very good illumination suitable for the examination of most tissues without using an achromatic condenser. In working with high powers, however, it is absolutely necessary.

**38. Kerner's Eye-piece,** as already stated, makes a most valuable achromatic condenser, and has been of the most material assistance to me in many of my recent investigations. The observer will find that by stopping off the greater part of the light passing through the condenser, by placing over the upper lens a thin plate with a very small central hole, great advantage results in working with high powers. The hole may be made in a flat piece of thin brass, which is kept in its place by a very slight rim, projecting about the twentieth of an inch or less above the top of the condenser. In this way apertures of different sizes may be tried without trouble. My friend Mr. B. Wills Richardson uses stops over the condenser, in which slits and holes are made of peculiar shape, and varying much in position, some allowing only a very small pencil of light to pass at the side. ("Microscopical Journal," January, 1866, p. 10.)

**39. Gillett's Condenser.**—Mr. Gillett has adapted a diaphragm plate and stops to the achromatic condenser, and a beautiful instrument of this kind has been made by Mr. Ross. Messrs. Powell and Lealand have, however, improved upon it, and brought out a much smaller and more compact condenser, which is attached to their microscope. The Rev. J. B. Reade, to whom we are indebted for many improvements in

this direction, has contrived a valuable hemispherical condenser for examining objects marked with very fine lines by oblique light. "Trans. Mic. Soc.," 1861, p. 59. The same observer has recently modified his instrument by the addition of another lens, by which arrangement he is able to obtain a ray of greater obliquity than is possible by ordinary methods of proceeding. ("Microscopical Journal," January, 1867, p. 3.)

**40. New Webster Condenser.**—Lately a form of achromatic condenser, which passes by the name of "Webster's," and like the eye-piece used for a condenser, lets a flood of light upon the object, has been much improved by Mr. Highley, Mr. Collins, and other makers. Mr. Collins' ingenious arrangement for altering the size of the aperture of the diaphragm, instead of using the plate with holes in it, will be understood by reference to fig. 3, pl. XVII, p. 34. It seems to me likely that this will supersede other plans entirely. This condenser is well adapted for working with the binocular. Mr. Collins is endeavouring to increase the angular aperture by the addition of a third lens, and render it really achromatic like Kelner's eye-piece above referred to.

Many improvements have been recently made in the achromatic condenser during the past few years, most of which have been adopted in the achromatic condenser recently introduced by Mr. Swift, which combines several valuable pieces of sub-stage apparatus. It contains centring apparatus, contracting diaphragm, polarising apparatus, spot-lens, fig. 1, pl. XVI, p. 28.

Although it seemed to me desirable to refer to the above different methods of modifying the illumination of objects, it must not be supposed that the delicate instruments which have been described are essential for beginners engaged in ordinary observation. The student may even pursue some branches of original investigation in which high powers are not required, without employing one of them. In special enquiries, however, great advantage has resulted from the use of some of these instruments, and no one ought to attempt to undertake certain researches, as for instance, upon the nature of markings on diatoms or other delicate structures, until he had made himself familiar with the different effects resulting from their use, and he would probably soon find that by modifying the plan which gave the most favourable results still better definition was to be obtained, or new facts were to be demonstrated.

#### OF DRAWING AND ENGRAVING OBJECTS.

**41. Of Drawing Objects.**—The student cannot too soon try to delineate what he demonstrates. He will teach himself to observe the more accurately and the more quickly if he records the results of his work in pencil sketches. Any one can teach himself to draw without



difficulty, and by a little practice the student will be able in a very short time to make a drawing of what he observes in the microscope. It may be truly said that no real advance in our knowledge of the minute structure of animal or vegetable tissues can be communicated to others unless accurate drawings are made, for it is almost hopeless for an observer to attempt to describe what he sees in words, and such descriptions, however careful they may be, scarcely admit of comparison with those of other persons. On the other hand, a truthful drawing of what a man has seen recently may be compared with drawings which may be made a hundred years hence, and although the means of observation will be far more perfect than they are at present, such comparisons may be useful in many ways, and especially in preventing erroneous conclusions from becoming popular. By description ingenious persons who take the pains to do so may so express themselves as to render it very doubtful what their opinion really is, but if they can be persuaded to make a drawing, the ambiguity which pertains to language does not add to the difficulties of ascertaining the exact nature of the view entertained when the observations were made. It is doubtful whether an honest enquirer, skilled in observation, can be of greater use in his time than by making good drawings of what he has seen. We may reasonably hope that those who follow us will look at our drawings, if we are careful to make honest copies of nature, but we can hardly expect that much of what is now written will be read some years hence, when the whole aspect of the department of science we love to develop shall be completely changed.

In delineating an object magnified by the microscope it is important to copy it accurately, both as regards the relative position of the several parts to one another, and also with respect to size. To copy the size of many objects exactly will be found extremely difficult if we rely upon the eye alone, but there are several ways of proceeding by which accuracy may be ensured.

The simplest method of copying an object magnified in the microscope is the following: arrange the paper on a piece of stiff cardboard, so that it may be upon the same level as the stage upon which the object is situated, on the left side, if the right eye is the one used for observation. If we now look steadily at the object with the right eye, it will be found that the object appears to be thrown, as it were, upon the paper, and it may be clearly seen by the left eye, and its outline be very readily traced, the movements of the pencil being executed by the right hand, if the observer is not able to use the left. By far the best course, however, is for the observer to acquire the habit of observing with the left eye, in which case the paper can be placed on the right hand of the stage, and the right hand used for drawing. With a little practice the relative position and correct size of objects may be insured in this

manner. But it is somewhat troublesome and difficult to keep the image of the object perfectly still.

**42. Camera Lucida.**—The camera lucida has long been employed for making microscopical drawings. The object appears to be thrown down upon the paper, and with a little practice the observer may trace the lines with a fine-pointed pencil with exceeding accuracy. If there should be any blueness round the edge of the field, the distance between the prism and the eye-glass should be increased.

**43. Steel Disk.**—If a little steel disk be placed at an angle of 45 degs. with the eye-glass, it will receive the magnified image of the object and reflect it upwards upon the retina of the observer. The disk being smaller than the aperture of the pupil, the pencil can at the same time be well seen, while the image apparently thrown down upon the paper beneath is carefully traced. The steel disk is represented in pl. XVII, fig. 5, p. 34.

**44. Neutral Tint Glass Reflector.**—The simplest and cheapest reflector for microscopical drawing consists of a small piece of plate-glass, slightly coloured, but not so dark as to prevent an object being seen through it perfectly. This is also arranged at an angle of 5 degs. with the eye-glass; by it the draughtsman can very easily follow the outlines with his pencil upon the paper. This instrument is represented in pl. XVII, fig. 4. It may be mounted in various ways so as to conveniently fit on the end of the eye-piece.

In order to use either of the above instruments, the microscope is arranged horizontally, and the paper placed on the table, as shown in pl. XV, fig. 4.

**45. Arranging Light for Drawing.**—It is important, however, in using these instruments that the light should be carefully arranged. The image should not be illuminated too intensely, and the paper upon which the drawing is made should not be too much in the shade, or the point of the pencil will not be distinctly seen. Experiment can alone decide the relative intensity of the light upon the object and upon the paper, but with a little practice the proper degree of illumination will be discovered. The object appears to be thrown upon the paper, and its outline can be very readily traced. If a small representation is desired, it is only necessary to place the paper upon a stand a few inches nearer to the reflector. If, on the other hand, a large *diagram* is required, the distance between the reflector and the paper must be increased. By placing the diagram paper upon the floor, the object can be readily traced with a long pencil. In this manner many of my diagrams have been made. Such are of course accurate copies of the objects themselves, and are therefore more truthful than diagrams copied from drawings can be. In making microscopical drawings it is usual to fix the paper at some arbitrary distance, as 10 inches, from the eye-piece. If

the distance be always the same, the drawings so obtained may be compared with each other, and scales of measurement may be appended to them by proceeding in the manner described in § 62.

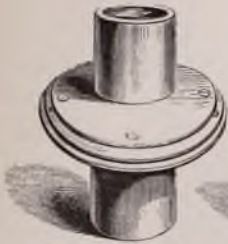
Mr. Conrad W. Cooke, in 1865, designed a new instrument for drawing, which he terms a "micrographic camera." By this instrument an image can be thrown on a sheet of paper placed in a horizontal or slanting position, so that any one may trace on the paper the outlines and even details of structure with accuracy. It is useful also for purposes of demonstration, for two or more persons may at the same time conveniently examine the image of the object reflected upon the paper. The head of the observer is isolated from external light by means of a curtain which falls over the back of his chair. Measurement of the objects shown in this camera may be very easily made, and boxwood scales corresponding to the magnifying powers of the different objectives are furnished. All the necessary adjustments can be effected from the inside, so that the inconvenience to the observer of continually altering his position is avoided. The use of this instrument is not entirely confined to the examination of transparent objects, for an image of many of the opaque preparations may be satisfactorily thrown on the paper. The effects of dark ground illumination (with the paraboloid and other instruments) and those of the polariscope may also be shown without loss of definition. The accessory instruments, as well as the objectives used, are the same as those of a microscope of the ordinary construction. The whole apparatus is made to fold up so as to occupy little space for the sake of portability. The apparatus was furnished by Messrs. Ross and Co.

**46. Of making Drawings which it is intended should be Engraved.**

—With a little practice the student may acquire the power of drawing on wood, and the engraver will often be able to produce a more faithful representation of the object than he could do if he himself copied on the wood the drawings of the microscopical observer. The drawing should first be made roughly on paper, in order to obtain the size and general characters of the object. A piece of retransfer paper is then placed upon the prepared wood block, and the prominent lines of the drawing transferred to the wood by going over the lines with some firm, blunt-pointed instrument. A needle, the point of which has been made slightly blunt by filing it, answers very well. By using moderate pressure, the colour of the retransfer paper is impressed upon the wood block, the lines exactly corresponding to those of the drawing. These lines are afterwards reproduced by lead pencil, corrected, if necessary, and the delicate parts of the drawing filled in by carefully copying from the object itself.

If the engraving is to be a fac-simile of the drawing with the different parts on corresponding sides, it is necessary, in the first place, to copy

Fig. 1.



Polarizer, placed beneath the object p. 24

Fig. 2.



Analyser, placed above the object p. 24

Fig. 3.



Collins' graduating diaphragm pp 13, 31.

Fig. 4.



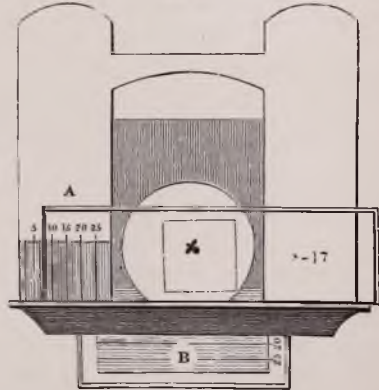
Neutral-tint glass reflector for drawing p. 33

Fig. 5.



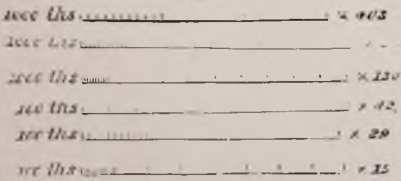
Steel disk p. 33

Fig. 6.



Simple finder, designed by Mr Wright. p. 48

Fig. 7.



Scales, hundredths and thousandths, magnified in different degrees p. 44.

Fig. 8.



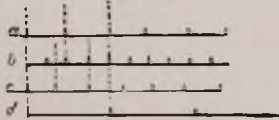
Lines separated by 1/1000 of an inch magnified 215 diameters with objects magnified in the same degree. p. 43.

Fig. 9.

11	12	13	14	15
24	24	24	24	24
11	12	13	14	15
25	25	25	25	25
11	12	13	14	15
26	26	26	26	26
11	12	13	14	15
27	27	27	27	27

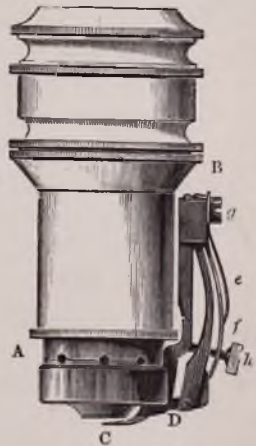
A portion of Maltwood's finder, as seen in the microscope. p. 49.

Fig. 10.



Mode of ascertaining the magnifying power of an object glass *a* 1000ths of an inch x 200, *b*, inch scale divided into tenths as seen by the unaided eye, *c* 1000ths of an inch x 130, *d*, 100ths of an inch x 40. Each magnified 1000th of an inch covers two tenths, or one fifth of an inch, therefore the glass magnifies 60 times for  $\frac{1}{1000} \times 200 = \frac{2}{10}$  or  $\frac{1}{5}$  of an inch. Each 100th of an inch covers four tenths of an inch, therefore the glass magnifies 40 times, for  $\frac{1}{100} \times 40 = \frac{4}{10}$ . p. 4.

Fig. 11.



Instrument for scratching a circular line on the thin glass, to mark the exact position of a particular object. p. 48.



the picture with ordinary tracing paper, and *invert* the tracing upon the retransfer paper on the wood-block, as the impressions are of course always reversed ; or a reverse may be obtained by copying the image of the drawing reflected from a looking-glass. Many specimens of wood engraving, the drawings of which were placed on the block as I have described, will be found in the plates in this volume.

**47. Pencils.**—Excellent lead pencils are now made and are very cheap. Those known as Faber's, 1s. 9d. a-dozen, are among the best. HH's or HHH's are sufficiently hard for ordinary drawing on paper, but for drawing on wood a four or five H is to be preferred. Drawings of microscopic objects may also be made with Indian ink or sepia, a fine brush or pen being used. If the observer draws on wood, he will save time by representing the shading as a *tint*, and different kinds of shading may be indicated by different colours applied with a camel's hair brush in the usual way.

**48. Tracing Paper** is a very transparent paper, obtained by soaking tissue-paper in some oily material, and allowing it to dry. Retracing paper consists of tracing paper, upon one side of which a fine red, blue, or black powder has been rubbed, which adheres to the paper pretty firmly, but which at the same time, may be readily transferred to another surface if firm pressure be applied.

**49. Wood Blocks** are *prepared* by rubbing a little dry carbonate of lead and brick dust moistened with water upon the surface, a very little being allowed to dry on. In this way a smooth white surface is obtained, admirably adapted for receiving the most delicate drawing. It is well to moisten the white lead with a little very weak gum water, which makes it adhere firmly to the surface and gives a very smooth face. If the face of the block is not smooth, it may be rubbed with the hand or a piece of hard paper or wash-leather. Every observer should learn to draw on the wood block himself. There is no great difficulty, and a little practice will enable him to draw as well on wood as on card-board.

**50. Of obtaining Lithographs of Microscopical Drawings.**—I think it desirable to give a few directions for drawing on stone, as I believe there are many observers who would willingly give up the necessary time required to place their own work on the stone, who could not afford to employ a lithographic artist. I made many drawings in this manner some years ago to illustrate some of my books, and with the help of a boy, who could at first draw but little, was able to execute numerous drawings, which are very accurate copies of the objects, although in execution they will not bear comparison with artists' work.

**51. Drawing on Transfer Paper.**—If the drawing does not contain much very minute work, it may be faintly drawn on properly *prepared lithographic transfer paper*, with lead pencil, direct from the microscope.

The lines must then be traced with a pen with lithographic ink. The shading is effected by drawing delicate lines made with the pen or with lithographic chalk. The latter plan, however, is not well adapted for making transfer drawings. The drawing is then to be sent to the lithographic printers, where it is damped, placed downwards on a dry stone, and after being subjected to firm pressure, the paper is peeled off, and the preparation, with the drawing, left on the stone. The latter is removed with water, the drawing properly set, and the printing ink applied with the roller. The whole process, including the printing, may be conducted at home if the observer likes. Small lithographic presses are now made at a cheap rate, but the results will not be equal to those obtained by an experienced lithographic printer.

**52. Transfer Paper for Lithographic Drawing** is prepared for the purpose. Some which was made of India paper, and was supplied to me by Messrs. Harrison and Sons, of St. Martin's Lane, answered exceedingly well.

**53. Drawing on the Stone.**—There are two plans of drawing on the stone itself, which afford better results than the preceding method, but much practice is required if satisfactory results are to be obtained. When the drawing is much shaded and extreme delicacy of outline is unnecessary, the outline is first sketched on paper, and the drawing retraced on the stone in the manner described in § 46; the outline may then be followed on the stone with ink—a pen, or very fine sable hair brush, being used for the purpose. The shading may be given with the lithographic chalk. The chalk is to be very finely pointed by cutting downwards, the point being uppermost (as in pointing an ordinary chalk crayon), and held in a handle made out of a common quill. The lines are to be made very gently, repeating the strokes frequently with a light hand, when depth of colour is required, rather than by leaning heavily so as to remove a considerable quantity of chalk at once, and deposit it upon the stone. When chalk shading is employed, a finely *grained* stone is required. The stones can be provided and prepared by most of the lithographic printers, or they may be purchased of various firms who supply the instruments and apparatus required by lithographers.

**54. Of Engraving on Stone.**—If the work is very delicate, as is the case with most subjects of which the microscopical observer will desire to obtain representations, engraving on stone is to be preferred. The process is very simple, but he who intends to obtain good results, must be content to spend some time in practice. The stone for an engraving must be finely polished, and it is well to have it tinted with a little infusion of logwood, or to cover it with a thin layer of lamp black, which enables the draughtsman to see his fine strokes very distinctly. The outline of the drawing is traced in the manner already described, and then

the lines are to be scratched upon the stone with a very fine point. A needle point previously hardened by being heated red hot and suddenly dipped in cold water, inserted into a strong handle, may be used. I generally used an etching needle; the point of which was sharpened from time to time upon a hone. A properly pointed diamond is, however, far better than a needle. The dark parts are shaded by lines placed very close together, or cross-shading may be adopted, or the tint may be given by dots, as in copper-plate engraving. Generally, it is better to try to obtain the appearance of texture by copying, as nearly as possible, the character of the tints of the object itself. The thickness of the line in the impression will depend upon its *width* upon the stone, and not upon the *depth* to which it may extend into it. When a thick line is required, it is desirable to make two or three narrow lines near to each other, instead of one wide one. After all the lines have been scratched in, the stone is sent to the lithographic printer, who will obtain a proof of the engraving. The oily material which is applied adheres to the rough scratches only, and subsequently when the stone is wetted, the ink only attaches itself to the oily parts.

**55. Lithographic Ink, Lithographic Stones.**—The ink may be obtained in the fluid state, but it is better to use the solid ink, a little of which is rubbed up with water when required. Lithographic chalk may be procured of different degrees of hardness,—it can always be made much harder by melting it and rolling it into sticks. The stones are sold by the pound. It is desirable to obtain stones large enough to hold four octavo pages of drawings, as the expense of working a stone of this size is but little more than one large enough to contain only a single plate.

The apparatus, ink, chalk, &c., alluded to, can be obtained of Messrs. Waterlow, Messrs. Hughes and Kimber, Red Lion Court, Fleet Street, and most lithographers. It is due to Messrs. Harrison, of St. Martin's Lane, that I should thank them for the kindness they have always displayed in assisting me in carrying out this and many other plans of producing drawings. Without the important help they and their workmen have afforded, on all occasions, my efforts would probably have failed, as I had no knowledge of practical lithography.

**56. Of representing Peculiarities of Texture.**—Success in drawing microscopical specimens, depends mainly upon a careful study of the different methods of shading, by which the idea of texture may be given, as well as mere differences of light and shade. It is most difficult to give general directions on this matter, and much depends upon the method of illustration determined upon. Various tints and textures would be produced in a different manner according as the drawings were engraved on copper, stone, or wood. I have no doubt that the most perfect results can be obtained on steel, or copper, or by engraving upon stone, but the expense of these methods is a serious



objection, and for some years past I have abandoned them in favour of wood engraving. This process possesses many advantages, and where a great number of illustrations is required is by far the least expensive, if a large number of copies can be printed. The illustrations in the present work are all wood engravings. The blocks are not themselves used for printing, but electrotype facsimiles are prepared, which scarcely deteriorate at all by wear. These are built up by the printer and the necessary descriptions placed below them, eight pages being worked at a time. In this way the large number of illustrations required can be produced at far less cost than lithographs could be procured, and alterations can be introduced in successive editions without difficulty.

Differences of texture may be well rendered on wood if the engraver is encouraged to execute the work with care and delicacy. The observer must of course learn to draw on the block, and either copy the particular shading he requires from other engravings, or, with the assistance of the engraver, may introduce various plans of his own. By drawing on the wood himself, not only does he save one third of the cost, but he will obtain far more faithful representations of natural structures. In many of the plates of this volume illustrations of different kinds of work will be found. By attentive examination the reader will see how each different appearance is produced. None of the different kinds of shading represented are very expensive, and it will be observed that cross shading with dark lines, which is most expensive in wood engraving, has been almost entirely avoided. An example of the cross shading work referred to will be found in the plate illustrating a transverse section of the spinal cord, which is beautifully executed, and if the observer will take a magnifying glass, and bear in mind that every one of the little white spaces has been cut out by the engraver and the black lines left, he may form some idea of the labour and care required to engrave such a block. The wood engraver is obliged, unless expense is no object, to shade as much as possible with parallel lines, which system entirely fails to produce the appearances required by the microscopist. However, by simply breaking these lines at short intervals by running the graver across them and keeping them a little irregular, a variety of truthful characters may be produced and at comparatively little cost.

There can be no doubt that much more perfect results would be obtained in wood engraving, if the observer not only drew upon the block but engraved the drawings himself, and I see no reason why many might not do this. The art of wood engraving may be learnt in a few months, and although the process is tedious and occupies much time, I am sure that the greater perfection of the results would more than compensate. It may be possible in certain cases for some members of the family to engrave the work under the eye of the ob-

server, and in this way the engraving will be almost as good as if the latter had performed the whole work. Wood engraving is a delightful occupation for ladies who have the time to devote to it, and any really good wood engraver may earn two pounds a week or more if he only works a few hours a day. The only instruction required may be obtained from Mr. Thomas Gilk's little book "The Art of Wood Engraving," published for 1s., by Winsor and Newton, 38, Rathbone Place. The apparatus and the few tools required may be obtained of Mr. Buck and other tool-makers, of Messrs. Winsor and Newton, and some artists' colourmen.

**57. On the Importance of Observers delineating their own Work.—**

It will, I know, be said that the processes of drawing on stone and wood engraving are of a nature which a skilful draughtsman can perform, and the labour which a microscopical observer, who wishes to carry them out, must be content to bestow, may be better employed. Objections of other kinds might be urged, but I feel that if in my early days I had not been able to have lithographs and drawings executed at home, very few of the illustrations in my works would have been published. Remembering how much I needed at one time the little information given here, and the difficulty I experienced in gaining it, I think it well to mention the most important points in case some of my readers may be desirous of trying to illustrate their own observations. Natural history and microscopical societies may by the methods I have described record some of the most important observations of their members, and at very small expense, if the work is carried out by themselves.

The student must not, however, suppose that the task of microscopic drawing and engraving is an easy one. It is quite as impossible to obtain a good representation of any microscopic object without long and careful study, as it is to produce a correct copy of any other object in nature; and surely it is hard to expect a draughtsman, who is engaged in copying various subjects to spend hours in looking at specimens in a microscope, observing things which he neither knows nor probably cares to know anything about. Neither is it possible that any one man can make himself fully conversant with all the beautiful minutiae in every branch of microscopic enquiry. It is true that Mr. Tuffen West, and one or two other gentlemen, have taken up this kind of drawing and engraving, and have produced most beautiful results. I believe Mr. West's success as an engraver of microscopic objects to be due to the interest he takes in the subject, and to his being himself a very skilful microscopical observer. There are many drawings of microscopic objects which ought to be published, and although these may be of little interest to persons generally, they are necessary to those who are working at special subjects. However well

skilled artists may be, unless they have devoted very great attention to the microscope, they will not be able to delineate objects so truthfully as the observer himself. Few artists have time or inclination for microscope study. There cannot be the same difficulty as regards our own time, for is not that which is worth observing worth recording, and worth an expenditure of time? Anything that has been correctly observed is worth delineating if it has not been accurately copied before.

Very much yet remains to be done in representing various microscopic textures faithfully. Photography has advanced wonderfully, and will doubtless assist us more, but there are many structures the colour of which alone renders it quite impossible to obtain photographs of them, and there must always be many appearances which can only be rendered by accurately copying by hand. I cannot, therefore, too strongly urge on all those who wish to work at the microscope, to practise drawing as much as possible; and from the very first. All advances in our knowledge of structure, as well as of the minute changes incessantly going on in living organisms, depends I think, in great measure, upon accurate copies being made of the objects. By drawings only is it likely that the microscopic work of the present generation will be useful to that which will succeed it.

It is beyond the power of language to describe the characters of many structures in such a way that their peculiarities could be reproduced in the mind of another, and even if this could be done, so wonderfully delicate and minute are the observed differences in many cases, that any attempt to classify and arrange our observations, without drawings, would be hopeless, and will become more impossible in proportion as observations multiply; while the different meaning attached by persons to the same words and phrases, introduces another difficulty in our attempt to collate and deduce inferences from the observations which have been made.

Now surely, at this present time, our knowledge would have been much more extensive as well as more accurate, if instead of long descriptions we had been furnished with accurate drawings of the minute structure. It is true that all persons cannot draw well, but a very little patience will enable any one to copy a microscopical specimen. An accurate copy, although it be very roughly executed, has an aspect of truth about it which is unmistakeable, while a drawing which is the offspring of the imagination instead of a simple copy of nature, bears the mark of untruth in every line, however elaborate and unexceptionable its execution may be. Errors of observation are much more easily detected in a drawing than in verbal description. A mistake or misinterpretation expressed in a drawing can, and at length must be, corrected by subsequent observation, while ill-observed or misinterpreted facts, cloaked in obscure language, may be propagated for years, and

no matter how false they are, it may be very difficult to refute them. I would, therefore, urge upon every one the importance of making drawings at whatever cost of time and labour. It is worth any sacrifice to do really good work, and if every observer could but record a few accurate delineations of structure during his life, the results of the united labour of those now working would be very valuable.

I would also strongly urge upon observers the importance of at once agreeing upon some general plan of delineating microscopic objects, so that our observations may be useful to all, while the task of those who will hereafter have to arrange and deduce conclusions from our work will be much facilitated. The value of many beautiful drawings would be greatly increased if a scale of 100ths or 1000ths of an inch was appended to each of them, and the magnifying power of the object-glass stated. This would not have added five minutes to the time required for the task, while it would have rendered each drawing comparable with others. In many published drawings, the magnifying power is not even mentioned, and in others there is reason to believe it has been wrongly computed. Every one who copies an object should state the magnifying power of the combination of lenses he employed, and should append a scale magnified by the same combinations. *See* § 64, p. 45.

I venture to hope that the desire for seeing our work useful to one another and to our successors, will be received as a sufficient apology for the above remarks. The reader must not conclude that I am insensible to my own shortcomings in these and many other matters, or that I am not aware that every drawing I have published might have been, and ought to have been better than it is.

#### ON MEASURING OBJECTS AND ON ASCERTAINING THE MAGNIFYING POWER OF OBJECT-GLASSES.

Most of the larger and complete microscopes are furnished with special micrometers, but the simple method of measuring objects, presently to be described, to a great extent supersedes more expensive arrangements. In the first place it is necessary to refer to some of the different forms of micrometers in use.

**58. The Cobweb Micrometer**, originally applied to telescopes by Ramsden, its inventor, can be fitted to the upper part of the body of the microscope. A fixed cobweb crosses the field of view, and parallel to this is another cobweb thread which may be brought near to, or separated from the first, by turning a milled head, to which is attached a graduated circle. The value of each degree on the circle is ascertained by placing an object of known dimensions, as the *stage micrometer* graduated to thousandths, under the object-glass, and ascertaining the number of degrees on the screw which corresponds to the 1-1000th of an

inch. From these data a simple table may be constructed, and the diameter of any object can be readily ascertained by bringing one side of it up to the fixed line, and causing the moveable line to touch the opposite side. If we ascertain the value of the degrees as marked upon the circle when the lines are separated at the proper distance, we may estimate directly the diameter of the object. The older observers used to measure objects by means of very delicate wires, separated from one another by certain known distances, placed in the focus of the eye-piece, or by employing points, one of which could be moved from, or towards, the other by means of a screw.

**59. Jackson's Eye-piece Micrometers.**—Mr. Jackson arranged a micrometer slide in the eye-piece so that it could be brought over the magnified image of the object by means of a screw.

**60. Stage Micrometers.**—Within the last few years, lines, separated from each other by certain known but very minute intervals, have been ruled upon slips of glass by means of a diamond attached to a beautiful instrument, provided with a most delicate arrangement for moving it the required distance from the last line engraved. A second line is then ruled, then a third, and so on. Excellent stage micrometers of this kind have been ruled by the late Mr. Jackson. After his death Mr. Jackson's micrometer engine was purchased by Mr. Ackland, of the firm of Horne and Thornthwaite, Strand, who, I believe, now rules most of the stage micrometers, and from whom the slides may be obtained.

**61. Test Objects.**—To such wonderful perfection has this process of ruling lines upon glass been carried, that M. Nobert of Griefswald, in Prussia, has engraved lines upon glass so close together that more than 100,000 would go in the space of an English inch. Several bands, each containing many lines equidistant from one another, were engraved upon one slip of glass, but the lines in each different band were separated by gradually diminishing intervals, constituting a series which could be readily submitted to examination one after another. By aid of these the *defining power of any object-glass could be estimated*. As test objects, they are equal to, and even rival, many natural objects which have hitherto been employed for this purpose. The delicate lines on some of the diatomaceæ are separated from one another by the 1-50,000th of an inch, while the finest lines engraved by M. Nobert are less than the 1-100,000th of an inch apart.

The podura scale is a most excellent "test object." It is very remarkable that notwithstanding all the efforts of a large number of highly skilled observers, having the advantages of excellent apparatus, the precise nature of the markings upon this wonderful scale are not yet conclusively determined. Great differences in appearances result according to the method of examination pursued. If, for instance, the same scale be examined as a transparent object and under dark ground illumina-

tion, the difference is so great that most would conclude that they had seen two distinct objects. With the aid of Dr. Edmunds' parabolic illuminator (page 28) the markings appear as little spatulate bodies projecting from the surface of the scale.

According to Prof. Bailey of the United States, *Grammatophora subtilissima* and *Hyalodiscus subtilis* are the most delicate tests. ("Smithsonian Contributions," vols. II and VII; also a paper by Mr. Hendry, "Quart. Journ. Mic. Science," vol. I, p. 179, 1861; one by Messrs. Sullivant and Wormley, "Silliman's American Journal," Jan. 1861.)

For testing the penetrating power of an object-glass, very fine nerve fibres lying on different planes, as, for example, those distributed to vessels, particularly the small arteries of the frog and newt, or the capillary vessels of the palate of the same animals, or very delicate fibres of striated muscle, mounted in glycerine, may be employed. It should be borne in mind that the object-glasses with a very high angle, although very valuable for researches upon the diatomaceæ, and other delicate objects of extreme tenuity, do not answer so well for investigations upon the structure of animal and vegetable tissues, as glasses of a moderate or low angle. This question is fully discussed in the remarks on "Test Objects," by Dr. Carpenter, "The Microscope and its Revelations," pp. 141, et seq.

In order to measure the diameter of an object the glass slide upon which the lines have been engraved (1-1000th or 1-100th of an inch apart according to the magnifying power) may be placed beneath the object upon the stage. This arrangement, however, is only suitable for low powers, since the object and lines cannot be in focus at the same moment, and it is, therefore, impossible to obtain a very correct measurement.

**62. Simple Method of Measuring Objects.**—The most simple and efficacious method of measuring objects is with the aid of the camera lucida or neutral tint-glass reflector referred to before, § 44. We proceed as follows: the microscope is arranged as already described for drawing, fig. 4, pl. XV, p. 26. In the field of the microscope is placed an ordinary glass micrometer, the lines of which are separated by thousandths of an inch. Care being taken that the microscope is arranged at the proper distance from the paper, the lines magnified by a quarter of an inch object glass are carefully traced with a hard pencil. The micrometer is removed and replaced by the object whose diameter is to be ascertained. In pl. XVII, fig. 8, both micrometer lines and objects are shown magnified by the same power. The object is traced over the lines, or upon another piece of paper, and compared with the scale by the aid of compasses. The lines may be engraved upon a slate, or upon pieces of ivory or cardboard, and their value affixed, so that any object may be at

once measured. We require of course a different scale for each power.

Scales may be made on pieces of gummed paper, and one of them may be affixed to every microscopical drawing. Fig. 7, pl. XVII shows several such scales magnified by different powers. Thus the size of every object delineated may be at once ascertained, and the trouble of making individual measurements saved, while at the same time the inconvenience of a long description of the dimensions of various objects is avoided, than which nothing can be more tedious or less profitable to the reader.

In comparing the representations in books of the same object delineated by different observers, it will be found that great confusion has resulted in consequence of the magnifying power of the object-glass not having been accurately ascertained, and an object said to be magnified the same number of times by two authorities is not unfrequently represented twice as large by one as it is by the other. This discrepancy in most cases arises from the magnifying power of the glasses not having been accurately ascertained in the first instance. I cannot, therefore, too strongly recommend all microscopic observers to ascertain for themselves the *magnifying power of every object-glass* and, to prepare, in the manner presently to be described, *a scale of measurement by which the dimensions of every object can be at once ascertained*. The plan of appending to every microscopical drawing a scale magnified in the same degree as the object represented, supersedes the necessity of giving measurements in the text, while it is free from any of the objections above referred to.

### 63. On Ascertaining the Magnifying Power of Object-glasses.—

Although the several object-glasses are termed one inch, one quarter of an inch, one-eighth, &c., the magnifying power of each is not fixed and definite, for the quarters of some makers magnify with the same eye-piece many times more than those of others. It is important, therefore, that every observer should be able to ascertain for himself the magnifying power of his different glasses. Suppose I wish to know how much a French quarter magnifies. The one-thousandth of an inch micrometer is placed in the field, and the magnified image is thrown by means of the neutral-tint glass reflector upon a scale, divided into inches and tenths of inches, placed ten inches below the eye-piece. If the magnified one-thousandth of an inch covers about two-tenths of an inch, the glass magnifies 200 diameters; if it covered one inch, the thousandth of an inch must have been magnified 1,000 times, but in this case it only corresponds to the one-fifth of an inch, and therefore the one-thousandth is magnified 200 times. For lower powers the one-hundredth of an inch scale may be employed. The manner of ascertaining the magnifying power is therefore exceedingly simple; but it is very important for the observer to know the magnifying power of every lens with each

different eye-piece, and he should ascertain this before he commences to make any observations. This simple process will be readily understood if fig. 10, in pl. XVII, be carefully studied. To carry out this plan, it is only necessary to be provided with a glass *stage micrometer*, divided to rooths and 1,000ths of an inch, which can be purchased for 5s. *od.*, and an inch scale divided into tenths.

**64. To Ascertain the Diameter of an Object.**—If an object be substituted for the micrometer, and its outline carefully traced upon paper, its dimensions may of course be easily ascertained by comparison with the micrometer lines, the magnifying power used being the same in both cases.

In order to apply this plan to microscopical drawings generally, the following seems to be the simplest mode of proceeding, and it undoubtedly saves much trouble. Scales are carefully drawn upon gummed paper, the magnifying power and the micrometer employed being stated, as represented in pl. XVII, fig. 7. If a number are drawn together, one of the rows can be cut off and appended to the paper, upon which the drawing, magnified in the same degree, has been made. The observer may save himself the trouble of drawing these scales upon paper, by having them engraved on wood or stone, and several copies struck off. This is the plan I have followed in the drawings which illustrate my observations, and the scales have been copied in the plates in all my published works.

**65. Standards of Measurement.**—In this country we usually employ the English inch, but on the continent the Paris line =  $\cdot 0888$ , or about  $\frac{1}{11}$ th of an English inch, and the millimetre =  $\cdot 03937$  English inch, are very generally used. The sign "'' is used to signify "of a line," while "'' signifies "of an inch."

**66. Conversion of Foreign Standards of Measurements.**—In order to compare the researches of different authors, it is often necessary to convert one expression of measurement into another. The accompanying table of Dr. Robertson's ("Edin. Month. Jour. of Science," Jan., 1852) will be found of use in making these calculations. See Table, p. 46.

Deputy Inspector-General Lawson gives the following rules for converting different standards of measurement in a paper communicated to my "Archives" (vol. II, page 292). A unit is required that will admit of microscopic measurements being expressed in the smallest number of figures, and permit of foreign measures being easily converted into English, and *vice versa*, and the decimal notation should be adopted to facilitate comparisons between the measurements.

Most microscopic measurements are greater than the one hundred-thousandth of an inch, for an object of this diameter can only be measured with accuracy when magnified by the  $\frac{1}{25}$  or  $\frac{1}{50}$ . See part VI. The require-



TABLE FOR MUTUAL CONVERSION OF BRITISH AND FOREIGN LINEAL MEASUREMENTS.

To convert—	1	2	3	4	5	6	7	8	9	
1. British Inches into Mil- linimetres .....	25'39954	50'79908	76'19862	101'5982	126'9977	152'3972	177'7968	203'1963	228'5959	Millimetres.
2. Do. Old Paris Lines.....	11'25936	22'51872	33'77808	45'03774	56'29680	67'55616	78'81552	90'07488	101'33424	Paris Lines.
3. { Rhineland or } { Prussian Lines }	11'65275	23'30550	34'95824	46'61099	58'26384	69'91649	81'56923	93'22198	104'87473	Prussian Lines.
4. Millimetres into British Inches .....	0'3937079	0'7874158	1'1811237	1'5748316	1'9685396	2'3622474	2'7558553	3'1496632	3'5433711	British Inches.
5. Do. Old Paris Lines.....	0'44329	0'88658	1'32987	1'77316	2'21645	2'65974	3'10303	3'54632	3'98261	Paris Lines.
6. { Rhineland or } { Prussian Lines }	0'45878	0'91756	1'37635	1'83511	2'29389	2'75267	3'21145	3'67022	4'12900	Prussian Lines.
7. Old Paris Lines into } British Inches ... }	0'88815	1'77630	2'66445	3'55260	4'44075	5'32890	6'21705	7'10520	7'99335	British Inches.
8. Do. Millimetres.....	2'25586	4'51172	6'76758	9'02344	11'27930	13'53516	15'79102	18'04688	20'30274	Millimetres.
9. { Rhineland or } { Prussian Lines }	1'03494	2'00988	3'10482	4'13976	5'17469	6'20963	7'24457	8'27951	9'31445	Prussian Lines.
10. Rhineland or Prussian } Lines into British } Inches .....	0'85817	1'71633	2'5745	3'43267	4'29083	5'1490	6'00717	6'86532	7'7235	British Inches.
11. Do. Millimetres .....	2'179704	4'359408	6'539112	8'718816	10'89852	13'07822	15'25793	17'43763	19'61734	Millimetres.
12. Old Paris Lines .....	1'9662407	1'9324814	2'898722	3'8649628	4'8312034	5'7974414	6'7636848	7'729255	8'6961662	Paris Lines.

## I.—EXAMPLE.

Given 245,9003 Paris Lines. Required the value in  
British Inches.

By line seven of Table—  
Old Paris Lines.

		British Inches.
200	=	17'7630
+	40	= 3'55260
+	5	= 444075
=	'9	= 0799335
=	'0003	= 0000266445

21'8396351445 British Inches.

Data from which the Table has been calculated, extracted from Mr. Woodhouse's 'Table in the "Encyc. Metropolitane,"—British foot = 1. Metre = 3'2808992.

## Illustrations of Use of the above Table.

## II.—EXAMPLE.

Given '00215 Millimetres. Required the value in British  
Inches.

By line four of Table—

		British Inches.
Millimetres.	=	
'002	=	0000787415
+	'0001	= 000003937079
+	'00005	= 0000019685395

0000846471985 British Inches.

## III.—EXAMPLE.

Where extreme exactitude is not required, only one or  
two decimal places need be used. Thus—

Given 21'8386 British inches. Required the value in  
Paris Lines.

By line two of Table—

		British Inches.	Paris Lines.
20	=		225'19
+	1	=	11'26
+	'8	=	9'01
+	'04	=	'45

245'91 Paris Lines *very nearly*.

Old Paris foot = 0'06578. Rhineland or Prussian foot = 1'0298.

ments of the case therefore may be stated in decimals of an English inch by  $\cdot 00101$ , and if the two ciphers next the decimal point be struck out, and the first number be considered the unit, it may be written  $1^{\cdot}01$ , in which a thousandth of an inch is the unit. This method will embrace nearly every microscopic magnitude in three consecutive figures.

A millimetre contains  $\cdot 03937$  English inch or  $39^{\cdot}37$ ; according to the method proposed, the length to be converted will seldom amount to one-fourth of this. To convert millimetres into thousandths, shift the decimal point one place to the right and multiply by 4; if greater accuracy be required, subtract  $1^{\frac{1}{2}}$  from the second place of decimals for each of the nearest numbers of units of the product. Thus  $0^{\text{mm}}\cdot 250$  becomes  $2^{\cdot}50$ , which  $\times 4 = 10^{\cdot}00$ , from which subtract  $\cdot 15$ ; and  $9^{\cdot}35$  is obtained as the value in thousandths of an English inch, while  $0^{\text{mm}}\cdot 25$  is equal to  $9^{\cdot}84$ , which differs from the former by a quantity too small to measure.

To convert thousandths of English inches into millimetres, add  $1^{\frac{1}{2}}$  in the second place of decimals for the nearest number of units in the sum, divide by 4, and shift the decimal point one place to the left, thus—to  $9^{\cdot}84$  add  $\cdot 15$  and the sum  $6^{\cdot}99 \div 4 = 2^{\cdot}498$ , and shifting the decimal point  $^{\text{mm}}\cdot 2498$ , which does not differ sensibly from  $^{\text{mm}}\cdot 25$ , the correct quantity.

A French line contains  $\cdot 0888$  English inches. The *French* and *Prussian lines* are so nearly equal that the same rule will serve for the conversion of both. To convert lines into thousandths of an inch, shift the decimal point one place to the right, and multiply by 9; if greater accuracy be required, subtract  $1^{\frac{1}{3}}$  from the second place of decimals for each of the nearest number of units in the product. Thus  $0^{\text{''}}\cdot 125$  becomes  $1^{\cdot}25$ , which  $\times 9 = 11^{\cdot}25$ , from which subtract  $\cdot 14$ , and the value in thousandths is found to be  $11^{\cdot}10$ , which is correct.

To convert thousandths into lines add  $1^{\frac{1}{3}}$  in the second place of decimals for each of the nearest number of units in the sum, divide by 9, and shift the decimal point one place to the left, thus—to  $11^{\cdot}10$  add  $\cdot 14$ , the sum  $11^{\cdot}25$  divided by 9, and the decimal point shifted one place to the left, gives  $0^{\text{''}}\cdot 125$ , as before.

In most cases it will be unnecessary to apply the corrections noticed above, but by remembering the short rules given, any one on reading a foreign work may correct the measurements as he reads, and insert them in the margin without delay or interfering with his progress.

*Method of finding the same Spot in a Specimen.*

**67. Of marking the Position of an Object.**—Various plans have been proposed from time to time for marking the exact position of a minute object in a specimen, so that it can be found with certainty and

placed in the field of the microscope whenever required. A fine line of varnish or Brunswick black may be drawn round it, or a small and very thin metal tube (about the tenth of an inch in diameter), may be moistened with the varnish and pressed upon the glass cover, so as to encircle the particular object with the line.

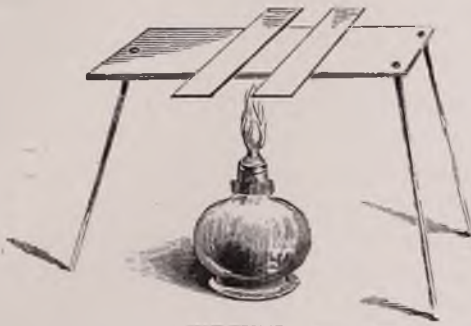
Mr. Bridgman, of Norwich, has designed an instrument for drawing a circle upon the thin glass with a diamond point ("Micro. Journ.," vol. III, p. 237). This instrument is represented in pl. XVII, fig. 11, p. 34. A is a brass cap fitting upon the end of the object-glass, which it entirely covers up and protects from injury; B, a stem soldered to the side of the cap with the upper end having two projecting sides to steady the ends of C, *e*, and *f*, which are firmly secured to it; C, an elastic arm of hammered brass, which carries at its lower end D, a lever of thin brass plate, having a fragment of diamond inserted in its thinner end, and directly under the centre of the cap A; *e* and *f* are two springs, pressing upon the shorter end of the lever D, the longer one, *f*, has a hole to allow the screw *h* to pass without touching it; *g*, a screw holding the two springs and the elastic arm to the arm of the cap; *h*, a milled screw to adjust the elastic arm, C, so as to bring the diamond point away from the centre, according to the size of the ring required. When the object has been found, the cap carrying the diamond is placed on the object-glass and carefully adjusted, so that the diamond point is brought into contact with the surface of the glass, then it is turned round, and thus a line is drawn round any object, so that it can be readily found at any future time.

This same end has been gained in another manner. Graduated scales have been affixed to the stage of the microscope, so as to measure the exact amount of movement in the vertical and horizontal direction; the slide being placed in position against a stop at the side. The number on the two scales is noted when the object is seen in the field, and, by placing the stage opposite the same numbers, at any future time the object must appear in the same position. Many such ingenious "finders" have been proposed. A very simple and efficient one is represented in pl. XVII, fig. 6, in which the scales are ruled on paper (Mr. Wright, "Microscopical Journal," vol. I, p. 302, 1853), which is afterwards fixed upon the stage. It is better to have the lines ruled on the brass itself.

*Bailey's Universal Indicator.*—Mr. J. W. Bailey, of the United States, has described an instrument for registering the positions of various objects upon a slide, in vol. IV of the "Quarterly Journal of Microscopical Science." This indicator is to be firmly fixed to the stage of the microscope, care being taken that the centre of the indicator corresponds to the centre of the object-glass. The mode of using the indicator is obvious.

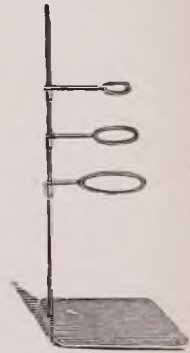
All such devices have, however, been superseded in cases where the

Fig. 1.



Place plate to distribute an uniform heat as in mounting objects in Canada balsam, and for heating glass slides for other purposes. p. 50.

Fig. 2.



Small retort stand to support watch-glasses &c. p. 49.

Fig. 3.



Spirit lamp, with wire stand attached for supporting watch-glasses &c. p. 49.

Fig. 4.



Tripod wire stand for supporting platinum foil, or basin. p. 50.

Fig. 5.



Porcelain basin arranged for a water bath. p. 50.

Fig. 6.



Small copper bath for warming or drying objects, with ring (a) to diminish aperture. p. 50.

Fig. 7.



Fig. 8.



Double-edged scalpel for cutting thin sections. p. 50.

Fig. 9.



New form of section knife. p. 51.

Fig. 10.



Section of Fig. 9, through a-b. p. 51.



microscope is provided with a travelling stage, by the two following very clever arrangements, the first suggested by Mr. Maltwood ("Trans. Microscopical Society," vol. VI, p. 59, 1858), the second by Mr. Bridgman, of Norwich. In order to use Maltwood's finder, a little stop is placed upon one side of the stage, in contact with which one end of the finder, and afterwards the glass slide containing the object, can be placed. The finder consists of a plate of glass upon which numbers are arranged in minute squares. These run in two directions, vertically and horizontally, so that in each square there are two different numbers, except in the case of the central square, which of course contains two 25's. Any object having been found, its exact position may be registered by removing the slide and placing on the stage the finder. The numbers seen in the field are then marked on the slide itself, and the same spot can always be found by looking for these numbers on the finder, moving the stage till they come in the centre, and then substituting the slide for the finder. The numbers and lines are photographed on the finder which is made by Messrs. Smith and Beck, and costs 7s. 6d. A few of the squares of a Maltwood's finder are represented in pl. XVII, fig. 9, p. 34.

**68. Mr. Bridgman's Finder**, which is sold by Mr. Baker, of Holborn, consists of a curved bar fixed to the stand of the microscope and capable of being moved upwards and downwards upon a hinge joint. The bar terminates with a fine point, and when pressed down this point comes upon a piece of paper gummed to one end of the slide, and makes a slight prick, or it may be tipped with ink if preferred. When the observer sees an object which he desires to find again, a mark is made with the point. In order to find this same spot at any future time, it is of course only necessary to place the slide in such a position that the original mark exactly corresponds with the point of the finder, and the part of the specimen must then be again in the centre of the field. This plan is so simple and efficacious, that it will probably supersede the various finders which have from time to time been invented.

#### APPARATUS AND INSTRUMENTS REQUIRED IN GENERAL MICROSCOPICAL RESEARCH.

**69. Spirit Lamp.**—The spirit lamp may be made of brass, tin, or glass fitted with a ground glass cap. It may be provided with a stand for holding watch-glasses, pl. XVIII, fig. 3. Brass lamps, to which a small retort-stand is adapted, may also be purchased of the instrument makers.

**70. Wire Retort Stands.**—Simple wire stands, made like retort-stands, which are fixed to a heavy leaden foot, will be found exceedingly useful little instruments to the microscopical observer. The rings can be readily raised or lowered at pleasure, and are well adapted to support

light objects, such as glass slides over a lamp, test-tubes, flasks, and watch-glasses, pl. XVIII, fig. 2.

**71.** Tripods are made of thick iron wire, and are useful for supporting several pieces of apparatus used in microscopical research, pl. XVIII, figs. 4, 5.

**72. Brass Plate.**—The brass plate should be about six inches long by two broad, and about the thickness of thin millboard. It should be supported on three legs, of a convenient height for the spirit or other lamp to be placed underneath, or the brass plate may be supported on one of the rings adapted to Mr. Highley's gas lamp, pl. XIV, fig. 4, p. 24. It is used for heating glass slides in order to fix on the glass cells with the aid of marine glue, for mounting objects in Canada balsam, and for other purposes, where a uniform degree of heat is required to be applied to glass, which is very liable to crack if exposed suddenly to the naked flame. These different pieces of apparatus have been figured in pl. XVIII, fig. 1.

**73. The Water Bath** is of great use for drying objects previous to mounting them in Canada balsam. The object may be placed in a small porcelain basin, or large watch-glass, or it may be simply laid upon a flat plate. The basin or plate is then placed over the vessel containing water, to which heat may be applied, fig. 6, pl. XVIII. In order that vessels of different sizes may be heated upon the bath, it is convenient to have a few pieces of thin copper plate, with holes of different sizes cut in them, adapted for watch-glasses and small vessels, fig. 7, *a*. The advantage of drying by a steam heat consists in there being no danger of destroying the texture of the object by the application of too high a temperature. A water-bath may be very readily extemporised by placing two porcelain basins one above the other, water being poured into the lower one. These may be supported upon a tripod or upon one of the rings over the spirit-lamp, fig. 3.

*For Cutting thin Sections of Tissues and Dissection.*

**74. Scalpels.**—The observer will find it convenient to have three or four ordinary dissecting knives or scalpels for general use. One should be strong for the purpose of cutting hard substances.

**75. Double-edged Scalpels.**—For cutting thin sections, a knife of the form of a lancet, but much narrower, will be found useful, and where only sections of small dimensions are required, this will answer all the purposes of Valentin's knife. In cases, however, where a section is wanted of considerable size, the latter instrument must be used. The double-edged scalpel should be very thin, pl. XVIII, p. 8. Beautiful scalpels of this form have been made for me by Messrs. Weiss, of the Strand, and also by Mr. Hawksley, 300, Oxford Street. In making a section, after cutting a clean surface, the point is made to perforate the

surface, and carried along at a proper depth, so as to cut its way out. The width of the section may then be increased by carrying the knife from side to side.

**76. Section Knife of a New Form.**—A new section knife has been devised by Deputy Inspector-General Lawson, for cutting very thin sections of soft tissues. The general form of the knife is represented in pl. XVIII, figs. 9 and 10. It is fully described in my "Archives," vol. III, p. 286.

**77. Double-bladed or Valentin's Knife.**—This instrument is of the greatest value in making thin sections of soft tissues, but care is required to keep it in good order. It is soon made blunt if used for cutting fibrous or cartilaginous textures. By its aid very beautiful sections of the kidney, liver, and other soft glandular organs may be obtained with the greatest facility. The blades should always be dipped in water or glycerine just before use, for if wet the operation of cutting is facilitated, and the section more easily removed from between the blades. Immediately after use the blades should be washed in water and dried with a soft cloth or piece of wash-leather. If a drop of water gets into the upper part of the knife where the blades meet, the screw must be taken out, and each blade cleaned separately. With care in cleaning it, the knife may be kept in use a long time.

There are two forms of Valentin's knife; in one the blades are sharp on both edges and of a lancet-shape, and in the other, which I much prefer, they are sharp at the point and wide at the base, so that the cutting edge slants downwards from the point, and they only cut on one side, plate XIX, fig. 2. The best form of Valentin's knife, however, is that which has been made by Mr. Matthews, fig. 1. The blades of this knife can be completely separated from one another and easily cleaned. The distance between the blades is regulated by a little screw, which is a most convenient arrangement. This knife has been further improved by Mr. Matthews, by the addition of two screws, so that the perfect parallelism of the blades is secured.

**78. Razors.**—A strong knife made like a razor is very valuable for making thin sections of many tissues, pl. XIX, fig. 4, p. 52.

**79. Scissors** are useful instruments for cutting small thin sections of different tissues. The most convenient form for this purpose is one in which the blades are curved, as in pl. XIX, fig. 6. When only very small portions of a tissue are required for examination, they will be more readily removed with the scissors than with any other instrument. Several pairs of scissors are required for microscopical purposes. Besides the ordinary form used for dissection, a small pair, with curved blades, a pair of very delicate scissors with blunt points, fig. 5, such as are employed for the dissection of insects, will be found of use. Some time since, I devised a new form of spring scissors, somewhat resembling



the microtome. These are particularly well adapted for dissecting the nervous systems of insects, for following out the delicate ramifications of nerves and other minute dissections, pl. XIX, p. 52, fig. 7. I strongly recommend all students to practise the dissection of the nervous system of insects and of other small animals. See method of dissection under water, § 144, p. 91.

**80. Needles** of various sizes are very useful instruments to the microscopist. They are required for making minute dissections; for tearing or unravelling various tissues, in order to display their elementary structure, and for separating any minute object from refuse or extraneous matter, previous to its being examined and mounted. Very thin needles are useful for separating substances in the field of the microscope while under observation. Needles which have been flattened at the points, and subsequently hardened, tempered, and sharpened on the two edges, make capital knives for very delicate work, or the pins used by the surgeons, and termed *harelip pins*, may be sharpened on a hone and used with advantage. They may be inserted in a small wooden stick, pl. XIX, p. 52, fig. 3, or held in the handle of a crochet needle. Mr. Matthews has lately made some needles with cutting edges, which are very useful for making minute dissections.

**81. Forceps.**—A pair of thin brass forceps will be found convenient for applying the thin glass cover after the preparation has been placed upon a slide or in a cell. A pair of dissecting forceps is also required by the microscopist. One pair should be strong with straight limbs, the other pair should be small, with thin curved blades, terminated with somewhat circular ends, and flattened at the points, the surfaces slightly roughened. These forceps are represented in pl. XIX, fig. 8.

Forceps for holding minute objects under the microscope are made to fix upon the stage, or fit on to the body of the instrument, pl. XIX, fig. 9.

Leaves and feathers and other flat objects can be examined by being placed flat on a glass slide, covered or not covered, or they may be taken up and placed in position with the stage forceps. Mr. James Smith has invented a leaf-holder, which may be useful to those who desire to prosecute particular researches in this direction with low powers. The instrument in question is described in the "Microscopical Journal" for July, 1866, p. 100.

**82. Wooden Forceps** made of box-wood, with broad ends, are convenient for holding the glass slides when hot, as when cells are to be fixed on with marine glue, for if held with cold metal forceps, the glass often cracks. The same object may be gained more simply by fastening to the limbs of an ordinary pair of forceps pieces cut from a common cork. Modifications of the simple spring-clips described in p. 58, may also be used for the same purpose.

Fig. 1.



New form of Valen's knife, as improved by Mr Matthews p. 51.

Fig. 2.



Valentin's knife p. 51

Fig. 3.



Ordinary sewing needles, mounted in cedar handles, for dissecting p. 52

Fig. 4.



Fine strong knife, for cutting thin sections pp. 92, 93.

Fig. 5.



Fine straight scissors, for dissecting, p. 51

Fig. 6.



Curved scissors for cutting thin sections of tissues. pp. 51, 91.

Fig. 7.



Spring scissors, for making minute dissections. pp. 52, 91.

Fig. 8.



Curved forceps, with flattened points, for minute dissections p. 52.

Fig. 9.



Forceps which can be attached to the stage of the microscope for holding objects during examination, with low powers p. 52



The different instruments above referred to may be obtained packed in a case, of Mr. Collins and of Mr. Swift.

*Glass Slides, thin Glass, Watch-glasses, Glass Shades.*

**83. Plate Glass Slides**, the edges of which have been properly ground and polished, may be obtained ready for use, at six shillings per gross, or they may be easily cut out with the diamond, and the edges ground on the grinding slab. The slides now in common use in this country are three inches in length and one in breadth, and I cannot too strongly recommend the observer to employ slides whether of metal, wood, or glass of this size only for microscopical purposes. The glass slides should always be made of thin plate-glass, and pieces as clear as possible should be selected.

**84. Thin Glass.**—An object placed for examination upon a glass slide should be always protected with a piece of thin glass before it is placed upon the stage of the microscope for examination. Thin glass now used for microscopical purposes is called cylinder glass, and I believe all or nearly all that is used is manufactured by Messrs. Chance, of Birmingham. It may be obtained of different degrees of thickness. Thin glass in sheets should be kept in fine sawdust. As it is imperfectly annealed it is very readily broken. When cut up in small pieces, it should be kept in a little box, with a little powdered starch, which prevents the pieces being broken, but great care must be taken to remove the starch from the surface, or the observer will be continually discovering starch in specimens in which he would little expect to find it. For cutting the thin glass an instrument termed a *writing diamond* is employed, and this is also used by some observers for writing the name of the preparation upon the glass slide, pl. XX, fig. 8, p. 54. As a general rule, however, I think it better to write the name of the specimen upon a small label which can be gummed to the glass.

OF CLEANING THIN GLASS.

The thin glass is easily cleaned with the aid of an old cambric handkerchief. If the glass is excessively thin it should be placed upon a pad of clean writing paper. The thin glass being firmly kept in contact with the paper by pressing firmly with the finger of one hand, it is carefully wiped with the handkerchief, a fold of which is twisted round the index finger of the other. The piece of glass is next turned round and the other side wiped in the same manner. It is then taken up in the forceps, breathed upon and placed over the specimen.

*Glass Cells* are described in §§ 124 to 135. Ordinary thin glass of various degrees of thickness, and already cut into squares and circles, may be obtained of Messrs. Claudet and Houghton, High Holborn. For the very high powers the thinnest pieces must be selected from a

considerable quantity. Messrs. Powell and Lealand supply the thin glass for use with their twenty-fifth. *See* Part VI.

Brass cells and tin cells are referred to in § 118.

**85. Watch Glasses** of various sizes should be kept by every observer, as they are convenient for many purposes. They cost about a shilling per dozen, and may be obtained of the watch-makers. The lunette glasses are useful for examining substances in fluids with low powers, as in these we are enabled to obtain a considerable extent of fluid of nearly uniform depth.

The little porcelain moulds in which moist colours are kept, and the little circular and oval shallow dishes, used by the artist's colourmen, will be found very useful for receiving microscopical specimens while soaking in various solutions prior to examination or mounting. They may be covered by circular pieces of glass.

**86. Glass Shades.**—Every microscopist should be provided with from six to twelve small glass shades from two to four or five inches in diameter, to protect objects from the dust which are being mounted. The cheap slightly green propagating glasses, now commonly sold at all the glass shade shops, are most convenient for this purpose. They cost from *2d.* to *5s.* These shades are figured in pl. XX, fig. 1.

Glass slides, thin glass and watch-glasses are included in some of the cases of instruments and apparatus sold by many of the microscope makers.

#### VARNISHES, CEMENTS, AND MARINE GLUE.

The chief cements employed in microscopical work, are *Gold size*, *Sealing-wax varnish*, *Solution of shell-lac*, *Solution of asphalt*, *Marine glue*, *Canada balsam*, *Gum Damar in Benzol*, *Gum*, and a *French cement* composed of lime and India-rubber. These cements are used for attaching the glass cell to the glass slide, for fixing the cover upon the preparation after it has been properly placed in the cell, and for other purposes. The liquid cements should be kept in wide-mouthed bottles, or in capped bottles, fig. 2, pl. XX, p. 54, or in pots with tin or brass covers, pl. XXIV, fig. 1, p. 88.

**87. Gold Size** is prepared by melting together gum animi, boiled linseed oil, red lead, litharge, sulphate of zinc, and turpentine. Gold size adapted for microscopical purposes may be also prepared as follows:—25 parts of linseed oil are to be boiled with one part of red lead, and a third part as much umber, for three hours. The clear fluid is to be poured off and mixed with equal parts of white lead and yellow ochre, which have been previously well pounded. This is to be added in small successive portions, and well mixed; the whole is then again to be well boiled, and the clear fluid poured off for use. In this country gold size may be obtained of any varnish maker.

Fig. 1.



Glass shades for protecting objects from dust while being mounted p. 54.

Fig. 2.



Vessel for containing Canada balsam, gum, cements, &c. p. 54.

Fig. 3.



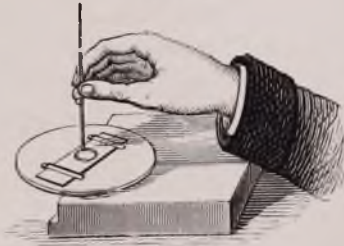
Dr Maddox's spring clip p. 58.

Fig. 4.



Modified spring clip p. 59.

Fig. 5.



Mr. Shadbol's apparatus for making round cells of Brunswick black. p. 60.

Fig. 6.



Fig. 7.



Large bradawl, for scraping away superfluous marine glue in making cells. p. 62.

Fig. 8.



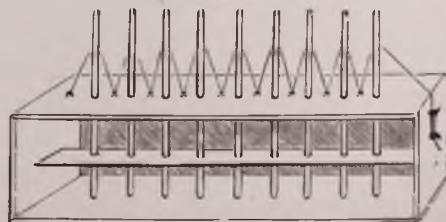
Writing diamond, for cutting thin glass. pp. 63, 70.

Fig. 9.



Flat brass rings, for cutting circles of thin glass. p. 71.

Fig. 10.



Arrangement for exerting continued pressure upon the glass covers of nine specimens while the cement is drying. p. 68.

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**88. Sealing-wax varnish** is easily made by dissolving the best sealing-wax of any colour, in tolerably strong alcohol. This cement is, however, apt to dry rather brittle, and should not, therefore, be used in cases where it is of the greatest importance to keep the cell perfectly air-tight. It forms, however, a good varnish for the last coat. Various colours may be kept according to taste.

**89. Solution of Shell-lac** is a very good cement for fixing down the thin glass cover. It is made by dissolving shell-lac in spirits of wine. The shell-lac should be broken in small pieces, placed in a bottle with the spirit, and frequently shaken, until a thick solution is obtained.

*Bell's Cement.*—A good cement for specimens immersed in glycerine is sold by Messrs. Bell, chemists, Oxford-street. This, I believe, was originally suggested by Mr. Tomes, but I do not know its exact composition. It appears to contain shell-lac and gold size.

**90. Damar Cement.**—This is made by dissolving gum Damar in Benzol, and is applied with a brush. It is one of the best cements, especially when glycerine is used as the preservative fluid.

**91. Brunswick Black.**—Solution of asphalt in turpentine commonly known by the name of Brunswick black, may be obtained at any oil-shop, and forms a most useful cement, both for making very thin cells, (§ 116), and also for fixing on the thin glass covers. If a little solution of India-rubber in mineral naphtha be added to it, there is no danger of the cement cracking when dry. For this hint I have to thank my friend, Mr. Brooke. I have many preparations which have been cemented with Brunswick black which have kept well for upwards of twenty years. It is always desirable, however, to paint on a new layer from time to time, perhaps once in twelve months.

Common Brunswick black is made by melting one pound of asphaltum, and then adding half a pound of linseed oil, and a quart of oil of turpentine. The best Brunswick black is prepared by boiling together a quarter of a pound of foreign asphaltum, and four and a quarter ounces of linseed oil, which has been previously boiled with half an ounce of litharge until quite stringy; the mass is then mixed with half a pint of oil of turpentine, or as much as may be required to make it of a proper consistence. It is often improved by being thickened with lamp black. It must be remembered that this cement is soluble in oil of turpentine. Dr. Eulenstein, of Stuttgart, finds that equal parts of Brunswick black and gold size with a very little Canada balsam forms a good lasting cement, which does not crack or contract.

**92. Marine Glue.**—This substance was, I believe, first used for microscopical purposes by Dr. Goadby, of Philadelphia. It is prepared by dissolving, separately, equal parts of shell-lac and India-rubber, in coal or mineral naphtha, and afterwards mixing the solutions thoroughly with the application of heat. It may be rendered thinner



by the addition of more naphtha. Marine glue is dissolved by naphtha, ether, and solution of potash. It is preserved well in a tin box. The manner of using marine glue and the different cements I have alluded to is described in §§ 116, 122.

**93. Cement for attaching Gutta Percha or India-rubber to the Glass Slides.**—A cement for attaching cells of gutta percha or India-rubber to the glass slide may be made as follows:—According to Harting, gutta percha is to be cut into very small pieces and stirred, at a gentle heat, with fifteen parts of oil of turpentine; the gritty, insoluble matter, which the gutta percha always contains, is to be separated by straining through linen cloth, and then one part of shell-lac is to be added to the solution, kept at a gentle heat, and occasionally stirred. The mixture is to be kept hot until a drop, when allowed to fall upon a cool surface, becomes tolerably hard. When required for use, the mixture is to be heated, and a small quantity placed upon the slide upon which the cell is to be fixed; the slide itself is then to be heated.

**94. Canada Balsam,** a thick viscid oleo-resin, which becomes softer on the application of a gentle heat, is much employed by microscopical observers: formerly it was used for cementing cells together, but this is now effected more readily by the aid of marine glue. If it be exposed to too high a temperature, the volatile oil is expelled, and a hard brittle resin remains behind. It is chiefly employed for mounting hard dense textures; and, in consequence of its great power of penetrating, and its highly refracting properties, the structure of many substances, which cannot be made out by the ordinary mode of examination, is rendered manifest by this medium. Canada balsam should be preserved in a tin box, fig. 1, pl. XXIV, p. 88, care being taken to exclude the dust; or in a bottle having a cap to it. The balsam should be kept very clean, otherwise preparations mounted in it will be spoilt by the accidental introduction of foreign bodies. It has been frequently recommended that the oldest specimens of balsam should alone be employed for microscopical preparations. By exposure to the air, the balsam becomes very thick, and unfit for use: it may, however, be thinned by the addition of turpentine, ether, or chloroform. Turpentine is apt to render the balsam liable to become streaky some time after the preparation has been mounted, and bubbles are not unfrequently formed in it.

*Vessels for Keeping Canada Balsam in.*—The tubes, made of thick tin-foil, used for artists' colours, with a small cap that screws on to the top, as suggested by Mr. Suffolk, are very convenient receptacles for the preservation of Canada balsam. As they contain no space for air, the balsam does not become hard and unmanageable, as is too often the case when it is kept in bottles or tin pots. There is no necessity for using a glass or metal rod, as the quantity of balsam required can

always be forced out without the slightest difficulty. Other cements and varnishes can be kept in the tin tubes also for any length of time. It is as well, however, to keep them in an upright position, to prevent the cement from running into the thread of the screw, and so fixing the top too tightly.

**95. Solutions of Canada Balsam.**—Canada balsam is soluble in ether, but the best solvent for it is chloroform. Many very delicate structures may be mounted in Canada balsam, by immersing them in a chloroform solution. Sufficient chloroform is added to make a solution that will run freely. As the chloroform evaporates the balsam becomes more viscid and gradually gets hard. Solutions of Canada balsam in chloroform are now much used for mounting different parts of insects, various tissues, geological and mineralogical specimens, and many objects of general interest. Mr. Hepworth, of Croft's Bank, was among the first to use a solution of Canada balsam in chloroform for mounting objects. Mr. W. H. Heys ("Trans. Mic. Soc.," Jan., 1865, p. 19) prepares the solution as follows. Old balsam is mixed with sufficient chloroform to make it quite fluid so that it will drop easily from the lip of the vessel containing it. The prepared balsam is then poured into long thin half-ounce phials, corked up, and set aside for at least a month. The balsam thus prepared is clearer and sets much more quickly than if mixed with the chloroform at the time it is required for use. A solution of balsam in Benzol is referred to on p. 90.

**96. Arrangements for pressing down the Thin Glass Cover while the Balsam or Cement is becoming hard.**—Some specimens which are more or less elastic, immersed in Canada balsam, gelatin, and other media require firm pressure to be maintained upon the thin glass until the balsam or the cement by which it is attached to the slide shall have hardened. Many specimens immersed in fluids require to be made thinner and more transparent by being subjected to moderate, but sustained pressure, while the cement in which they are embodied or that by which the thin glass cover is fixed down gradually becomes dry and hard. Other specimens require very firm pressure while the process of drying goes on. Several methods have been devised for producing pressure and for maintaining it in uniformity. A very simple plan is to place a small piece of wood, about an inch in height, upon the cover. This may be fixed in its place by passing a piece of thread over it, and tying it at the back of the slide; or the wood may be kept in its place by a vulcanized India-rubber ring. Ordinary weights may also be used, or springs arranged as in the ingenious apparatus devised by Mr. Gorham. My friend, Mr. White, has also suggested a very simple and effective apparatus for the same purpose. It consists of a bent lever, which, by acting upon a screw, can be forced down upon the thin glass with the amount of pressure required. Another form

of instrument, with a graduated spring, was designed by the Rev. G. Isbell, pl. XXIV, fig. 2, p. 88. The compressorium may also be employed for the same purpose, if a small piece of cork be inserted between the thin glass to which the pressure is to be applied, and the glass of the compressorium itself.

Mr. Hoblyn, of Bath ("Archives of Medicine," vol. III, p. 140), has devised an ingenious apparatus for the same purpose. In this instrument, a number of slides may be placed at the same time, and a graduated pressure exerted upon each of them, pl. XX, fig. 10, p. 54.

The above pieces of apparatus have however been superseded by the use of the simple spring clip devised by Dr. Maddox ("Trans. Mic. Soc.," July, 1865, p. 84). This is made by bending a piece of brass wire in the form represented in pl. XX, fig. 3. The end which is to press upon the thin glass must be filed perfectly flat, or a piece of flat cork may be fixed to it. Or, in cases where the glass cover is very thin, a smaller piece of thicker glass may be placed upon it and the spring allowed to press upon the latter. This clip has been modified by Mr. Webb, as represented in pl. XX, p. 54, fig. 4. These clips may be obtained at 1s. 6d. and 2s. per dozen of Mr. Baker, Holborn, and of Mr. Swift, University Street.

Another very simple and efficient spring clip was suggested by Dr. T. F. Allen, of New York. This was made of a piece of ordinary watch spring, bent in a spirit lamp in the form of a hoop, so that a small portion of one end would press gently on the cover, the other on the under surface of the glass slide. A number of such springs may be made out of any old watch spring.

**97. Gum.**—Thick gum-water will be found very useful for attaching labels to preparations, and also for fixing on the thin glass cover when preparations are mounted in the dry way. It is prepared by placing common gum-arabic in cold water, and keeping the bottle in a warm place until the solution has become sufficiently thick. It should always be strained before it is placed in the bottle for use.

Gum-water, thickened with powdered starch or whiting, is a very useful cement for attaching the glass cover in the case of preparations mounted dry. When dry it forms a hard white coating. The addition of a little arsenious acid will prevent the growth of mildew. Another very convenient solution is made by dissolving powdered gum in a weak solution of acetic acid.

**98. French Cement composed of Lime and India-rubber.**—The French cement composed of lime and India-rubber is very valuable for mounting all large microscopical preparations. The principal advantages are, that it never becomes perfectly hard, and it therefore permits considerable alteration to take place, under the influence of varying temperature, in the fluid contained in the cell without the entrance

of air. It also adheres very intimately to glass, even though it be perfectly smooth and unground.

If a glass cover is to be attached to a large cell containing fluid, we may proceed as follows:—A small piece of the cement is to be taken between the finger and thumb and carefully rolled round until it can be drawn out into a thread about the eighth or tenth of an inch in thickness. This is applied to the top of the cell, before any of the fluid is introduced. The cement is to be slightly pressed down with the finger previously moistened. It will adhere intimately. The preservative fluid with the preparation are now introduced and the cell filled with fluid which indeed is allowed to rise up slightly above its walls. The glass cover, cut rather smaller than the external dimensions of the cell, and slightly roughened at the edges, is to be gently breathed upon. One edge is then to be applied to the cement, so that it may be allowed to fall gradually upon the surface of the liquid which is now seen to wet each part of the cover successively, until it completely covers the cell, and a certain quantity of the superfluous fluid is pressed out. By the aid of any pointed instrument a very little cement is removed from one part, so that more fluid may escape as the cover is pressed down gently into the cement. The pressure must be removed very gradually, or air, of course, will enter through the hole. A bubble of air entering in this manner may often be expelled again by pressure, or it may be driven out by forcing in more fluid through a very fine syringe at another part of the cell; but it is far better to prevent the entrance of air in the first instance. The edge of the glass cover being thoroughly embedded in the cement, the small hole is to be carefully plugged up with a small piece of cement, and the cell allowed to stand perfectly still for a short time, when it may be very gently wiped with a soft cloth. The edges of the cement may be smoothed by the application of a warm iron wire, and any superabundance removed with a sharp knife. A little Brunswick black or other liquid cement may be applied to the edges, for the purpose of giving the whole a neater appearance.

The cement is made as follows:—A certain quantity of India-rubber scraps is carefully melted over a slow fire, in a covered iron pot. The mass must not be permitted to catch light. When it is quite fluid, lime, in a perfectly fine powder, having been slaked by exposure to the air, is to be added by small quantities at a time, the mixture being well stirred. When moderately thick, it is removed from the fire and well beaten in a mortar and moulded in the hands until of the consistence of putty. It may be coloured by the addition of vermilion or other colouring matter. I have several preparations which have been placed in the creosote and naphtha solution in large cells, and they are now perfectly air-tight, although upwards of twenty years have elapsed since they were first put up. The lime and India-rubber cement answers well

for fixing on the glass tops of large preparation jars, and looks very neat; but, if moderately strong spirit be used, a little air must be permitted to remain in the jar.

As cements are required in different investigations for making apparatus of various kinds, and for other purposes, I venture to republish the following receipts, which have been taken from "The Journal of Applied Chemistry," though few may be required by microscopists.

**98\*.** **Other Cements.**—A good rubber cement may be prepared by dissolving one part India-rubber in two parts linseed oil, and adding to the solution a sufficient quantity of bole, say, about three parts.

For amber and tortoiseshell, a cement was made by mixing together equal parts of mastic and linseed oil, and warming gently. This cement should be used warm.

To unite wood to wood, a thick solution of shell-lac in alcohol may be used. It is well to put a piece of fine gauze or crape between the broken surfaces of wood, and then press them tightly together until the cement becomes perfectly firm. Another good, durable cement for woodwork is made by fusing together shell-lac, mastic, and common turpentine, and adding some broken isinglass.

For attaching small objects to anything turned, a mixture of colophonium, turpentine, and yellow wax, with the addition of a little pulverized sealing-wax, answers nicely. The cement sets quickly and holds well.

To fasten knives and forks in silver handles, a mixture of two parts of melted black pitch and one part of fine brick-dust may be used. It must be used warm.

A varnish or cement to protect wood from the action of mineral acids, alkalies and corrosive gases, like chlorine, is made from six parts of colophonium and three parts of wood tar by heating together in an iron kettle on a furnace in the open air, and then stirring in four parts of fine brick-dust. The varnish is applied with a brush while warm.

An excellent cement for glass is made by dissolving one part India-rubber in sixty parts of chloroform, then adding thirty-four of mastic, and letting it digest for a week at a gentle heat. This cement is also applied with a brush, and is especially distinguished by its transparency.

Another cement for glass and porcelain is made by digesting small pieces of isinglass in sixteen times their weight of water for twenty-four hours. The solution is evaporated to one-half, strained, and, while still hot, eight parts of alcohol added, and at the same time a solution of one part mastic in six parts warm alcohol. One half-part of finely-powdered gum ammoniac is triturated in the warm solution until the whole mass is homogeneous. When used, both the cement and the

object to be mended are warmed. This cement is highly recommended for its adhesive qualities.

*Glue and Gum Cements.*—These are very tenacious and well adapted for mending ornaments. They resist the action of water and the atmosphere. There are various kinds of these cements for bone, ivory, whalebone, mother-of-pearl and precious stones.

One of them is made by dissolving two parts isinglass and four parts colourless glue in sixty parts water, evaporated to half its volume, then adding  $\frac{1}{15}$ th part mastic dissolved in one part alcohol, and stirring in two parts zinc white. The surfaces are warmed when the cement is applied to them. This cement holds well, dries easily, and may be kept a long time in tightly-corked bottles.

For bone, ivory, whalebone, mother-of-pearl, &c., a cement with a beautiful gloss may be prepared as follows:—Soak common cabinet-maker's glue in hot water, warm the jelly formed, add enough pulverulent slacked lime to give it consistency. Warm the object to be cemented, clean the surfaces carefully, apply the cement and tie the parts firmly together. In a few days it gets very hard. Even common glue, with pulverized chalk stirred in, makes an excellent cement for wood and metals.

For fastening leather to metal, the metal should be coated with a hot solution of glue, and the leather with a hot extract of nut galls. Allow them to dry quietly, and they adhere well.

For porcelain, the well-known white-of-egg cement is best. To prepare this it is only necessary to stir the white of eggs into quite a stiff solution of glue, and then apply to the fracture.

A cement of gum for porcelain is made by pulverizing four parts of oyster shells and mixing intimately with two parts pulverized gum arabic. The powder is kept in a well-stoppered bottle, and when needed for use is rubbed up with white of egg, or warm water, to a thick dough, applied to the object and dried by a gentle heat. Another cement for glass and porcelain is made from eight parts well-burnt pulverized alabaster gypsum and two parts fine gum arabic, mixed with water to a thick paste, and forty to fifty drops of oil of turpentine added to an ounce of the cement.

*Cements containing Casein.*—For glass, porcelain, stone, and wood, the very best cement is made of a suitable quantity of old cheese, rubbed fine and mixed with water to a thick magma, and a fourth part of pulverized lime added.

A still stronger cement for the same purpose is made by slaking one pound of quicklime in water, and mixing with three-quarters of a pound of finely powdered lime or sandstone and one pound pulverized cheese. Before using, it is well to moisten the fracture or edges with warm water.

A so-called casein water-glass is made as follows:—The casein

of skimmed milk is separated from it by the addition of acetic acid, filtered, and the acid washed out with water. The pure casein thus obtained is mixed with six times its volume of concentrated solution of casein in water. This cement is thoroughly commendable, and well repays the trouble taken to make it.

An excellent cement for artificial meerschaum, and one that may be used to give consistency to silk goods or to coat artificial flowers and court plaster, to give more adhesiveness and firmness, is made by rubbing two to four parts of the above casein with cold borax solution till a thick liquid is obtained that becomes clear on standing. This also renders goods waterproof.

*Water-glass Cements.*—For glass, earthenware, porcelain, and all kinds of stoneware, these cements are excellent. A cement for glass and marble is prepared by rubbing together one part of fine pulverized glass and two parts of pulverized fluorspar, and then adding enough water-glass solution to give it the consistency necessary in a cement.

Water-glass mixed with hydraulic cement to a thick dough makes a good cement for the edges and joints of stone and marble slabs. It is well to mix but little at a time, as it hardens very quickly.

*Lime, Gypsum, Clay, and Cement, mixed with Water, Oil or Blood.*—For cementing stone and for filling crevices in buildings, before they are painted, the masons use a cement made of fresh blood, slaked lime, brick-dust, broken up coal ashes, hammerslag, and sand, in all proportions. This excellent cement hardens quickly, and offers great resistance to the action of the weather.

A lime cement for connecting water pipes, bathing tubs, &c., a mixture of two-thirds fine brick-dust, two-thirds unslaked lime, and two-thirds hammerslag, is made and stirred up with lye or hot oil to a stiff dough.

Another cement, intended to render Hessian clay retorts impenetrable, is obtained by rubbing freshly slaked lime into a concentrated solution of borax. The solution is applied with a stiff brush and allowed to dry, after which it is heated until the glazing begins to fuse.

Clay mixed with water and fresh warm blood, containing some unslaked lime, is used in Germany to close joints in stoves. The cement is applied while the stove is hot. Wood ashes, fire clay, and salt, mixed with water, is used for the same purpose. Fat and burnt clay, in equal proportions, moulded with water into a dough, is also used.

Plaster of Paris, mixed with water and a cold solution of alum, is an excellent cement for stoneware. It sets slowly, but becomes hard as stone.

*Oil Cements.*—An excellent oil cement for porcelain and for luting of retorts, flasks, and porcelain evaporating dishes, is obtained when ordinary brick-dust is powdered, sifted, and mixed with an equal quantity of red lead, and then rubbed, under great pressure, with old

boiled linseed oil to a thick paste, which is mixed with coarse sand to the stiffness of cement. When a dish is to be covered with it, paste is applied before the sand is put in, and the sand then strewn upon it. The dish is afterwards exposed to a steady heat for a long time.

For large vessels take six parts litharge, four parts fresh-burnt pulverized lime, and two parts white bole, and mix with cold linseed oil.

To fasten metallic letters to a smooth surface a cement is made as follows:—Thirty parts copal varnish, ten parts linseed oil varnish, six parts crude oil of turpentine, ten parts glue dissolved in a little warm water, and twenty parts pulverulent slaked lime. It is very pliant and soon hardens.

To unite copper and sandstone take three and a half parts white lead, three parts litharge, three parts bole, and two parts broken glass, and rub up with two parts linseed oil varnish.

As a polish for rough stones, basins, &c., a paint is made of nine parts of finely sifted and burnt brick-clay and one part litharge, mixed with a sufficient quantity of linseed oil.

For connecting cast-iron water pipes, twelve parts Roman cement, four parts white lead, one part litharge, and a half part colophonium are pulverized and mixed; from two and a half to three pounds of the mixture is triturated with old linseed oil, in which is boiled two ounces of colophonium.

Another, for the same purpose, is made of equal parts of burnt lime, Roman cement, potters' clay; and clay, separately well dried, finely ground, sifted, well mixed and triturated with linseed oil. Common lead lute, for stopping openings in apparatus, is best made from litharge and red lead mixed with old boiled oil. In all cases the surfaces must be clean. These cements stand well under water.

As lead lutings are somewhat expensive, the following is recommended:—Take two parts red lead, five parts white lead, and five parts of the finest clay, and mix with boiled linseed oil.

A good oil cement for wood, especially for antique carvings, is made of one part pulverized slaked lime, and two of rye flour, mixed with linseed oil varnish. It takes any desired colour and polish.

To make water holders tight, we may use pulverized slaked lime and cod-liver oil.

A cement to make chemical apparatus tight can be prepared from oil cake or pressed almond cake rubbed with water.

*Miscellaneous Cements, &c.*—Furniture polish:—Moisten 120 parts bees-wax with oil of turpentine, and add 7·5 parts finely pulverized resin, and enough aniline red to give the desired mahogany colour.

Oil cement:—100 parts red lead, 250 parts white lead, 200 parts pipe-clay: mixed with boiled oil.

Water cement:—100 parts slaked lime, 190 parts brick-dust, 160



parts sand, 50 parts blacksmiths' dross, 50 parts powdered lime ; mix with water.

Another :—600 parts iron filings, 100 parts ignited sand, 100 parts powdered slacked lime ; mix with water.

Iron and blood cement :—100 parts pulverized lime, triturated with bullock's blood, 290 parts cement, and from five to ten parts iron filings.

#### PRESERVATIVE FLUIDS.

In all cases it must be borne in mind that an object to be mounted in a preservative fluid should be soaked in a considerable quantity of it for at least a day before it is mounted permanently, and if the specimen is large, it should be soaked for many days previous to being finally placed in the cell.

**99. Spirit and Water.**—Spirit and water constitute a well-known and valuable medium for preserving anatomical preparations. In diluting spirit, distilled water only should be employed ; for, if common water be mixed with spirit, a precipitation of some of the salts dissolved in it not unfrequently takes place, which renders the mixture turbid and unfit for use. The mixture of water and spirit should be made several days before it is required, or a number of air bubbles will adhere to the specimen. Proof spirit will be strong enough for all general purposes, except for hardening portions of the brain or nervous system, when stronger spirit must be used. Two parts of rectified spirit, about sp. gr. '837, mixed with one part pure water, make a mixture of sp. gr. '913-'920, which contains about 49 per cent. of real alcohol, and will, therefore, be about the strength of proof spirit. One part of alcohol, sixty over proof, to five parts of water, forms a mixture of sufficient strength for the preservation of many substances, and not a few microscopical specimens may be preserved in a solution more diluted than this.

For many years past, the Government has permitted the use of methylated alcohol for various purposes in the arts. This pays no duty, and answers well for preserving anatomical preparations, and is a great boon to all engaged in putting up large anatomical specimens. It may be obtained at the price of 5s. 6d. a gallon, sixty degrees over proof, of varnish makers and most of the chemists.

**100. Glycerine.**—This is one of the most valuable fluids ever employed for microscopical purposes. I believe Mr. Warrington, of Apothecaries' Hall, was the first observer who used glycerine as a preservative medium for microscopical preparations.

A solution of glycerine adapted for preserving many structures is prepared by mixing equal parts of glycerine and camphor water. The latter prevents the development of mildew. Glycerine may also be mixed with naphtha and water, or with the creosote solution described in § 101. The degree of dilution of the glycerine will depend upon the

nature of specimen. If the substance be at all opaque it will be necessary to employ strong glycerine. I have many preparations which have been preserved in glycerine for nearly thirty years. Of the importance of strong glycerine as a preservative medium, I shall have to speak more fully in part VI. Glycerine may be mixed with various chemical tests and preservative substances, for special enquiries. Analyses may be conducted by the test compounds being dissolved in the menstruum instead of in water. For preserving medusæ and other delicate marine animals Dr. Carpenter recommends a solution composed of *sea water* with one-tenth of *alcohol*, and the same quantity of glycerine. Dr. Maddox tells me that, for some years past, he has been in the habit of using equal parts of sweet spirits of nitre (Sp. Eth. Nit. of the Pharmacopœia) and glycerine, especially in preparing delicate tissues of insects. He finds that many objects are rendered very transparent if soaked in this mixture before they are preserved in glycerine.

The best glycerine is distilled by a patent process, and is perfectly colourless, free from all impurities, and of great density. The specific gravity of Price's patent glycerine is 1,240, while the common is only 1196.6. The strongest glycerine obtainable is crystallized, but it is very expensive. The purest glycerine costs 3s. or 4s. a pound, but good glycerine may now be obtained for 1s. 6d. per pound.

For more than twenty years I have used glycerine for preserving almost every structure. I shall give the results of my most recent experience concerning this substance, from the use of which I have learned very much, in part VI.

**101. Thwaites' Fluid.**—This fluid has been much employed by Mr. Thwaites for preserving recent specimens of desmidiæ, but it is also applicable to the preservation of a vast number of other vegetable and of animal organisms.

It is made as follows :—

Water	. . . . .	16 ounces.
Spirits of wine	. . . . .	1 ounce.
Creosote,	sufficient to saturate the spirit.	
Chalk,	as much as may be necessary.	

Mix the creosote and spirit, stir in the chalk with the aid of a pestle and mortar, and let the water be gradually added. Next add an equal proportion of water saturated with camphor. Allow the mixture to stand for a few days, and filter. In attempting to preserve large preparations in this fluid, I found that it always became turbid, and therefore was led to try several modifications of it. The solution next to be described was found to answer very well.

Water may also be impregnated with creosote by distillation. It should be remarked that M. Strausdurkheim has succeeded in preserving animal preparations in camphor water only.

**102. Solution of Naphtha and Creosote:**—Creosote, 3 drachms; wood naphtha, 6 ounces; distilled water, 64 ounces; chalk, as much as may be necessary. Mix first the naphtha and creosote, then add as much prepared chalk as may be sufficient to form a thick smooth paste; afterwards add, very gradually, a small quantity of the water, which must be well mixed with the other ingredients in a mortar. Add two or three small lumps of camphor, and allow the mixture to stand in a lightly covered vessel for a fortnight or three weeks, with occasional stirring. The almost clear supernatant fluid may then be poured off and filtered if necessary. It should be kept in well-corked or stoppered bottles.

I had some large preparations which had been preserved in upwards of a pint of this fluid, for nearly twenty years, and the solution remained perfectly clear and colourless. Some dissections of the nervous systems of insects have kept excellently; the nerves retain their white appearance, and have not become brittle. Two or three morbid specimens are also in an excellent state of preservation, the colour being to a great extent preserved, and the soft character of the texture remaining. I had one preparation mounted in a large gutta-percha cell, containing nearly a gallon of this fluid.

A solution of wood naphtha or pyroacetic spirit in water, has been recommended by Professor Quekett, and forms an excellent preservative solution, in the proportion of one part of the naphtha to ten of water. The solution is often a little cloudy, but may be made quite clear by filtration after the mixture has been allowed to stand still for some days.

One great advantage of these aqueous preservative solutions is that the natural appearance of the structure is very slightly altered. The solution, however, after a time renders many of the more delicate structures more or less granular.

**103. Carbolic Acid.**—A solution of carbolic acid in distilled water preserves many animal and vegetable preparations exceedingly well. The water will only take up a small quantity of ordinary carbolic acid, but the preservative qualities of the weakest solution are very great. One part of carbolic acid to a hundred of water is sufficient.

Perfectly pure carbolic acid is now made, in very large quantity, by Messrs. Bowdler and Bickerdike, of Church, Lancashire, and is sold under the name of *Absolute Phenol*, for 6s. or 7s. a pound. It may be obtained in large or small quantities, of Mr. Marchant, Berners Street, Oxford Street. This preparation is much more soluble in water than the liquid carbolic acid. Besides preventing decomposition of animal and vegetable tissues, the phenol effects a curious change in the properties of ordinary water. A mere trace (less than one thousandth) causes the water to froth, and to retain air-bubbles in suspension for a much longer time than they are retained by ordinary water. Such very

dilute solution wets dry surfaces and runs into minute crevices more thoroughly than common water, and, at the same time, runs off from surfaces more completely, leaving a very thin but even layer of moisture upon the surface. Glass may, in this way, be perfectly and uniformly wetted with water. Drops of carbolic acid water are smaller and less easily formed than in the case of the same water without carbolic acid. For these and other reasons, minute traces of carbolic acid improve many of the fluids used for the preservation of microscopical specimens.

**104. Solution of Chromic Acid.**—A solution of chromic acid is well adapted for preserving many microscopical specimens. It is particularly useful for hardening portions of the nervous system previous to cutting thin sections. The solution is prepared by dissolving sufficient of the crystallized acid in distilled water or in glycerine, to render the liquid of a pale straw colour.

The crystallized acid may be prepared by decomposing 100 measures of a saturated solution of bichromate of potash, by the addition of 120 to 150 measures of pure concentrated sulphuric acid. As the mixture becomes cool, crystals of chromic acid are deposited, which should be dried and well pressed on a porous tile, by which means the greater part of the sulphuric acid will be removed, and the crystals obtained nearly pure.

**105. Preservative Gelatine.**—This substance was first employed for preserving microscopical textures by Mr. H. Deane, who gives the following receipt, and directions for its preparation :—Gelatine, 1 ounce ; honey, 4 ounces ; spirits of wine,  $\frac{1}{2}$  ounce ; creosote, 6 drops.

Soak the gelatine in water until soft, and to it add the honey which has been previously raised to the boiling-point in another vessel. Next, let the mixture be boiled, and after it has cooled somewhat, the creosote dissolved in the spirits of wine is to be added. Lastly, the mixture is to be filtered through thick flannel to clarify it.

When required for use, the bottle containing the medium must be slightly warmed, and a drop placed on the preparation upon the glass slide, which should also be warmed a little. Next, the glass cover, after having been breathed upon, is to be laid on with the usual precautions. See p. 82.

**106. Gelatine and Glycerine.**—A mixture of gelatine and glycerine makes a very valuable medium for preserving different animal and vegetable structures, and supersedes the last preparation. It may be prepared as follows :—A certain quantity of gelatine or isinglass is allowed to soak for some time in cold water, until it swells up and becomes soft. It is then placed in a glass vessel and melted by the heat of warm water. It may be clarified if necessary, by first adding to the cool gelatine a little white of egg, then boiling the mixture, and filtering

through fine flannel. To this fluid, an equal quantity of strong glycerine is added and the two are well mixed together. This mixture may be kept for any length of time, and a very slight heat is sufficient to render it perfectly fluid. This, as well as many other mixtures can be made most perfectly upon a large scale, and I therefore recommend the observer to purchase what he requires, instead of making it. The gelatine and glycerine, prepared by Mr. Rimmington, operative chemist, of Bradford, is the best medium of the kind I have used. It may be obtained in small bottles free by post for 1s. 4d.

**107. Gum and Glycerine.**—Mr. Farrants many years ago suggested the following valuable preservative medium which will be found useful for mounting many objects :—Picked gum-arabic, 4 ounces by weight ; distilled water, 4 ounces ; glycerine, 2 ounces. The medium is to be kept in a stoppered bottle and a piece of camphor or a few drops of phenol may be added to the solution with advantage.

**108. Goadby's Solution.**—This is made of several different strengths. That most generally useful is the following :—Bay salt, 4 ounces ; alum, 2 ounces ; corrosive sublimate, 4 grains ; boiling water, 4 pints. Mix and filter. This solution for most purposes may be diluted with an equal bulk of water. For preserving delicate preparations it should be even still more dilute. Goadby's solution used to be much employed for preserving anatomical specimens, but as it tends to render tissues hard and opaque, it is not adapted for the preservation of structures which are to be examined in the microscope, and has, therefore, fallen out of use as a preservative fluid for microscopical specimens.

**109. Burnet's Solution** consists of chloride of zinc, is a powerful antiseptic, but not adapted for the preservation of microscopical specimens.

**110. Chloride of Calcium.**—A saturated aqueous solution of chloride of calcium, free from iron, has been much recommended for preserving specimens of bone, hair, teeth, and other hard structures, as well as many vegetable tissues. A solution of chloride of calcium was recommended by the late Professor Schröder Van der Kolk, of Utrecht, for keeping sections of the spinal cord and preparations of nerves. Many of these, through the kindness of my friend, I had an opportunity of seeing and can testify to their excellence.

**111. Alum and other Salts.**—A solution of *alum* in the proportion of one part of alum to sixteen of water has been found to answer pretty well for some substances. Gannal's solution, which consists of one part of *acetate of alumina* dissolved in ten parts of water ; solution of acetate of potash ; solutions of *common salt* (one part to five of water, with a little camphor), *corrosive sublimate*, *persulphate of iron*, *sulphate of zinc*, and solutions of several other salts, have been recommended as preservative fluids, but although adapted for the preservation of animal sub-

stances, they cannot be employed for microscopical specimens, in consequence of their tendency to render the textures very opaque and granular. Mr. A. E. Verrill ("Silliman's Journal," March, 1865) recommends a solution made with nitre, rock salt, and arseniate of potash. My own experience, however, has led me to discard all solutions containing salts for microscopical purposes.

**112. Arsenious Acid** has been recommended, and Dr. Andrew Clarke used to preserve specimens of lung and other structures in an aqueous solution of this substance.

**113. Arseniuretted hydrogen** gas has also been recommended for the preservation of animal substances, but it is not adapted for microscopical preparations. Dr. Richardson kept animal matters from decomposition by immersing them in an atmosphere of *nitrogen*, which was prepared by placing a piece of phosphorus in a stone jar containing common air, and provided with an air-tight cover. By this means the oxygen is soon exhausted, and no decomposition can take place (?).

Some of the preservative solutions which I have referred to may be obtained of Mr. Swift, of University Street. The mode of using them will be described further on. Every microscopist engaged in any special enquiry will of course alter the composition of these solutions in any way experiment may show to be advisable. Great improvements doubtless may be made in many preservative solutions. A series of exact observations of the effects of the different fluids upon the same textures is much to be desired, and this is one of the questions upon which amateurs might contribute very valuable information.

#### CELLS FOR PRESERVING MICROSCOPICAL SPECIMENS.

All objects intended for microscopical observation should be protected by a cover of thin glass. This cover prevents the entrance of dust, and protects the object from the effects of exposure to the atmosphere. The fluid in which many objects are placed for examination would rise in vapour which would condense upon the object-glass, and give rise to great inconvenience were it not prevented from evaporating by a thin glass cover. If the thin glass, however, should press upon the object placed upon the glass slide, the distinctness of the specimens would in many cases be impaired, or the structure might be entirely destroyed—an inconvenience which may be prevented by placing some insoluble substance slightly thicker than the object, between the glasses. A little cavity may be made in many ways in which a specimen, dry or with its preservative fluid, may be placed, and afterwards covered with thin glass without risk of injury from pressure. This is termed a cell. Cells may be composed of various materials according to the thickness which may be necessary and according to the nature of the substance to be placed within them.

**114. Paper Cells.**—For *dry objects* an efficient cell is readily made with a ring of paper or cardboard fixed with gum or glue, or certain other cements, to the glass slide. A circular hole may be punched out of a piece of cardboard, wood, mill-board, or gutta-percha, and thus the rim of the cell may be formed. Or a vulcanized India-rubber ring may be cemented to a slip of glass. Many other devices will occur to any one who wishes to make neat cells for holding small objects mounted in the dry way. If, however, the cell is intended to contain fluid, it must be made of some substance impervious to moisture.

**115. Shell-lac Cells.**—Bell's cement thickened with crushed shell-lac dissolved in a very small quantity of methylated spirit may be used for making thin cells, by proceeding as follows:—The clean slide is warmed and placed on the "turn-table," § 116, pl. XX, fig. 5, p. 54; a *full brush* of the thickened cement is then made to strike a circle. The slide is held over the spirit lamp until bubbles are given off, when it is placed horizontally on a warm surface to dry; when *nearly set hard* it is removed, allowed to cool a little, and a piece of thick plate glass, previously wetted, is pressed carefully on the circle of cement until flattened equally. These cells can be kept ready for use of various thicknesses. If the object be mounted in glycerine in one of these cells, and is not likely to be injured by a slight heat, it is best after placing down the thin cover and cleaning the edges carefully, to gently warm the slide and press the cover equally on the cement. If properly managed the cover generally adheres to the cement, and after being further strengthened by the application of a *thinner* solution of the same cementing medium, it will be found that an excellent joint has been made through which the glycerine will not escape. This plan for making thin cells for glycerine preparations, was devised by my friend Dr. Maddox.

**116. Brunswick Black Cell.**—A very thin cell may be made by painting a ring of Brunswick black or gold size upon the glass slide, and then allowing it to dry. The best form of Brunswick black cell is the circular one, which is so easily made by the aid of Mr. Shadbolt's excellent turn-table, p. 54, pl. XX, fig. 5. The slide is placed on the little brass wheel which is made to revolve, while a brushful of Brunswick black is held at the proper distance from the centre, according to the diameter of the cell required, as described in the last section. If a thick layer is desired the slide may be gently warmed, in order that the layers of Brunswick black applied may dry quickly.

**117. Marine Glue Cells** may be made according to the same plan. In order to make such a cell, a glass slide is warmed upon the brass plate, § 72, and when hot enough a small piece is allowed to melt upon the slide, and moved round and round in the position in which the wall of the cell is to be. When the glue has been allowed to cool, any superfluity may be removed from the slide with a sharp knife. The

surface may be made level by rubbing it gently upon a piece of emery paper laid on a piece of plate glass or other perfectly flat surface.

**118. Cells made of Tinfoil, Brass, and Copper.**—A piece of tinfoil may be cut out, so as to form a slightly thicker cell, and may be fixed upon the slide with marine glue, as in fig. 6, pl. XXI, p. 76. Tin cells are now made of every thickness by Mr. Collins. They form the cheapest kind of cell. Cells have also been made of thin pieces of brass or copper, but these metals are easily acted upon by certain chemical solutions and are less satisfactory than tin cells.

Cells may also be made of ebonite, gutta-percha, India-rubber, sealing-wax, and many other substances. Of all materials used for the purpose, glass is the most suitable, and as cells of peculiar form are sometimes required for special purposes which cannot be purchased, the observer should be able to construct glass cells for himself.

### *Of Glass Cells.*

**119. Cutting and Grinding Glass.**—In the manufacture of cells presently to be described, glass is required to be cut with a diamond and ground perfectly smooth at the edges. Moderately thick glass is cut with the ordinary glazier's diamond, pl. XX, fig. 6, or with that cheap and ingenious substitute made in America and consisting of a minute wheel of hardened steel. If the observer requires to cut plate glass, a larger diamond than that in ordinary use is necessary. The *thin glass* used for covering objects and for making thin glass cells, is cut with the writing diamond, pl. XX, fig. 8, which makes a scratch sufficiently deep to permit of the glass being broken off very smoothly. The *circles* of thin glass may be cut by carrying the diamond round openings which have been turned in pieces of brass. Of these many different sizes may be made so that circular pieces of thin glass of any required diameter may be easily cut, fig. 9, pl. XX.

**120. Stone for Grinding.**—Glass can be *ground* upon a perfectly *flat stone* with emery powder or fine sand and a little water, or, instead of the stone, a flat *plate* composed of pewter may be used, as was recommended by Dr. Goadby. The emery after a time becomes embedded in the pewter, and thus a very efficient surface for grinding results. The pewter plate may be cast in the form of a flat circular disk, which can be placed upon a pivot and made to revolve rapidly in a horizontal direction by means of a multiplying winch connected with it—an arrangement which is desirable when it is important to save labour.

**121. Of Drilling Holes in Glass.**—In the construction of many forms of cells it is necessary to drill holes through thick glass. This may be effected with an ordinary sharp-pointed file if the end be moistened



from time to time with a little turpentine. The operation is of course more quickly performed with a drill, the point of which has been rendered very hard. A more efficient plan is described in § 125.

**122. Cementing Glass together with Marine Glue.**—The surface of glass to which a cement is to be applied should always be roughened by grinding, as the cement adheres much more intimately to a slightly roughened surface than to the polished glass.

Glass is cemented together with marine glue, and in making large built glass cells, the edges are united by means of the same substance, which can now be readily obtained. Formerly gold size, Canada balsam, and other cements were employed, but these are all inferior to marine glue. The manner of applying the marine glue to the glass has been already alluded to. The glass must always be warmed upon a flat brass or iron plate, fig. 1, pl. XVII, p. 48, so that the heat may be applied gradually and equally. It must not be touched with cold fingers, or it will crack in various directions, but must be held with wooden forceps, or with ordinary forceps, the extremities of which have been protected with pieces of cork, in the manner described in § 82, p. 52, or in the holder, fig. 2, pl. XXI, p. 76. When the pieces of glass of which the cell is to be composed are warm enough, a little glue cut into small pieces is allowed to melt in the position in which the glass is to be fixed. When it is melted, the glass is applied and pressed down upon a flat deal board, so as to squeeze out as much marine glue as possible and make a good joint.

The student should make for himself a plate glass stage. A piece of thin plate glass is cut out by the diamond about four inches by two. The edges are to be ground smooth and a narrow strip of glass cemented to one edge with marine glue. This is to support the ordinary glass slide. A glass stage of this description protects the microscope, especially when acids or corrosive fluids are used, fig. 1, pl. XXI, p. 76.

**123. Cleaning off Superfluous Glue.**—While the slide is yet warm, much of the glue may be scraped off with an old knife and small chisel, pl. XX, fig. 7, p. 54, after which a little *solution of potash* (the *liquor potassæ* of the shops) will soften the remainder. It may then be very readily removed with the aid of soap and water and a nail brush. Or the whole cell may be soaked in equal parts of liquor potassæ and water,—but it must be borne in mind that if the cell be soaked for too long a time in strong solution of potash, the glue between the glass will become softened and the joint will not be sound. The potash must always be carefully washed away, to prevent the chance of the glue being softened after the cell is complete.

**124. Cells made of Thin Glass.**—The neatest and most perfect *shallow cell* is formed by making a hole of the required size in a piece of thin glass. This used to be effected as follows:—Many pieces of

thin glass were glued together with marine glue, and when cold a hole was drilled through them all. Lastly they were separated from each other by heat, and cleaned with potash in the usual manner.

**125. Simple Methods of Perforating the Thin Glass.**—Thin glass cells may, however, be readily made by every microscopist for himself, according to either of the following plans:—My friend, Dr. Temple Frere, takes a small piece of thin glass, and with the writing diamond scratches a line corresponding to the piece of glass he wishes to remove, next a bradawl or other sharp instrument is placed in the centre of the space, the glass being laid upon a perfectly flat surface, such as thick plate glass. A sharp tap upon the bradawl with a light hammer causes it to perforate the glass, but the cracks made in it do not generally extend beyond the line marked with the diamond. The fragments of glass are then carefully removed piecemeal with a pair of fine forceps, and the cell is complete. In some cases, however, I fear it will be found that in point of fact, the cracks do pass beyond the line, and thus the chance of removing the fragments from the centre is much diminished.

In order to perforate the thin glass in making thin glass cells, Mr. Brooke takes two firm brass rings, ground perfectly flat, the diameter of one being a trifle less than that of the other. The piece of thin glass to be perforated is firmly pressed between them, and the writing diamond carried round so as to scratch each surface. The circular piece is then removed by a slight tap upon the surface on which the smallest circle has been scratched.

The method which I have been in the habit of employing for many years is this: A square or circle of thin glass is cemented with marine glue to one of the circular or quadrangular rings of glass used for making deep glass cells, and alluded to in § 127; the hole in the centre being the exact size of that required to be made in the thin glass, pl. XXI, fig. 3, p. 76. When the marine glue is cold, a file is forced through the centre of the thin glass. The cracks thus produced will not run across that part of the glass which has been well cemented by the marine glue. The edges are next to be filed square, and the thin glass only requires to be warmed in order to remove it from the cell. It may now be fixed upon the slide at once, or cleaned with potash and kept with others until it may be wanted.

**126. Deep Glass Cells.**—If a cell a little deeper than any of the above should be required, we may proceed in a different manner. See pl. XXI, fig. 4. A piece of plate glass of the proper thickness is to be cut with the diamond or steel instrument for cutting glass, to correspond with the outside of the cell. Next, from each side of this piece of glass, a strip of the required width is to be removed, and from its ends, corresponding strips are to be cut off. The central portion is then taken away, and the strips are *inverted* upon the slide upon which they are to

be fixed with marine glue, care being taken to mark them in the first instance, so that they may exactly fit in their proper places. The marine glue is allowed to run well into all the corners. In this way a capital cell may be very easily and quickly made. Cells of various sizes and depths can be manufactured upon this principle. The surface of the glass rim should be ground upon the stone, and the superfluous glue removed in the ordinary manner.

**127. Small Deep Cells for Injections.**—By drilling a hole in a piece of plate glass, by cutting off sections of various thickness from thick glass tubing, or from thick square glass bottles, or from vessels moulded for the purpose,—excellent cells of various dimensions, and admirably adapted for mounting injections and other purposes, are made; but when the preparation is of considerable thickness, deeper cells than any of those to which I have alluded will be required. These may be made in glass, gutta-percha, and some other substances. A *round* or *oval concavity* may be ground upon the surface of a piece of very thick plate glass. Different forms of small deep glass cells are represented in pl. XXI, figs. 5 to 9. Moderately deep glass cells may be made also by grinding holes of the size required through thick plate glass, fig. 9.

**128. Built Glass Cells** are those which are constructed by joining together, at the edges and ends, separate pieces of glass with marine glue or some other cement. The simplest form of built glass cell has been already described above.

Good cells may be made from thick plate glass, the edges of which are ground perfectly square before they are united together and to the glass slab with the marine glue. Dr. Goadby used to make cells upon this principle of very large dimensions. Many cells of this description may still be seen in the Hunterian Museum of the Royal College of Surgeons. They may be obtained of Mr. Dennis, of St. John's Street Road, who is most skilful in this department, and has succeeded in making plate glass boxes in this manner large enough to hold several quarts of fluid.

Large plate glass cells may be constructed as follows:—A strip of plate glass is cut off, of the proper height for the sides of the cell. From this, two pieces are to be cut off the desired length of the sides, and two pieces for the ends. The flat surfaces of these are to be cemented with marine glue, and the edges ground perfectly flat together, fig. 2, pl. XXII, p. 78. The ends are also to be very carefully ground square. The grinding is to be effected with the aid of sand on a perfectly flat stone, water being added from time to time. Some prefer a thick metal plate cast perfectly flat. Emery powder may be used instead of sand. When the grinding is completed, the several pieces are to be separated from one another by carefully heating them on the hot plate. When cool they may

be placed in proper position and the corners properly cemented together with marine glue, pl. XXII, fig. 3, p. 78. When the four sides have been thus joined together, each surface is to be carefully ground flat, on the stone, and the cell may then be cemented to the plate glass bottom. If preferred, the upper side, on which the cover is to be placed, may be ground flat afterwards. In order to increase the strength of these cells and to diminish the chance of leakage, it is well to cement small pieces of glass in the corners, and narrow strips outside, at the point where the sides are attached to the glass slab, pl. XXII, fig. 4.

These cells, of course, take some time to make, but they are exceedingly neat, and have but one serious drawback—a slight liability to leak, which is hardly to be wondered at when the number of the joinings is taken into consideration, but if they are carefully made with very good marine glue this objection is overcome.

**129. Deep Glass Cells made by bending a Strip of Glass in the blow-pipe flame.**—Many years ago I devised another plan for making large cells. A long strip of glass of the proper width was bent to form the angles in the blow-pipe flame, and the extremities were cemented together in a similar manner. The bending cannot be readily managed if the glass is much more than half an inch in width. The ordinary plate glass is very liable to crack as it becomes cool, but if *flatted flint glass* be employed the operation is simple enough. This glass, as well as the deep glass cells above referred to, may be obtained at Messrs. Powell's glass works, Whitefriars. The cell made in this way has the disadvantage of not being perfectly clear, for the flint glass is not perfectly flat. If flint glass could be flatted, ground, and polished like plate, it would be of much value to those who mount large objects in deep glass cells, pl. XXII, fig. 5, p. 78.

**130. Moulded Glass Cells.**—Of late years moulded glass cells have been much employed for anatomical preparations, and the absence of joints renders them preferable to any form of built glass cells. Large moulded cells are now made in Germany, the sides of which have been ground and polished, and thus a preparation can be seen within, almost as clearly as if the sides were composed of plate glass. These cells can be obtained for a much lower price than the built cells, and are, of course, not so liable to leak. They may be purchased at the glass works, Whitefriars.

**131. Gutta-Percha and Ebonite Cells.**—Gutta-percha may be moulded in a wooden case, and forms excellent cells where transparent sides are not required. Preparations have been preserved for many years in large cells of this description. Gutta-percha is most useful for joining glass tubes to flat cells as may be required in forming cells for special purposes, pl. XXII, fig. 1.

*Ebonite Cells.*—Excellent cells may be made out of the preparation

of India-rubber known as vulcanite or ebonite. They may be turned to any size and thickness required. Dr. Maddox used such cells in 1861. Mr. W. H. Hall also recommends these cells for small microscopical specimens. They may be purchased of Mr. Bailey, of Fenchurch Street, at 6*d.* a-dozen.

**132. Round Cells.**—My friend and colleague, Dr. Guy, has lately proposed a form of cell which possesses many advantages over those in common use. These are circular, and may be made of bone, metal, gutta-percha, or glass, of various depths, and to suit transparent and opaque objects. Several forms have been made. They are all of the same external diameter, and are made to fit into a rim of equal size in a flat plate of wood, or metal, which can be placed in the field of the microscope. A small cabinet will contain many more preparations mounted in this manner than on the ordinary slips of glass. Dr. Guy has had some circular labels printed for these cells upon which the names of the preparations may be written, and as these are of different colours the various microscopic objects can be readily classified.

**133. Troughs for Examining Zoophytes.**—These are deep but very narrow glass cells, the two surfaces consisting of very thin glass, so that the higher powers may be brought sufficiently close to the objects. The opening is above, so that the cell with living animals within may be placed upon the stage of the microscope, when the instrument is inclined, without any fluid escaping. It is convenient to have a glass partition in these troughs, by means of which objects may be placed in different parts of the cell. A convenient size is three inches long, an inch and a half deep, and a quarter of an inch in width. Such cells may be purchased of Mr. Swift and other microscope makers.

**134. Animalcule Cage.**—A very convenient substitute for a cell is the apparatus called animalcule cage, pl. XXII, fig. 7. By means of its sliding cover a stratum of fluid of any required thickness can be obtained, and small living animals can be conveniently fixed in positions suitable for observation. For the examination of deposits in fluids this form of cell is also very convenient.

**135. Growing Cells.**—In many investigations upon the lower forms of vegetables and animals which live in water, it is necessary to watch the same specimen for a considerable time. Some plan must therefore be adopted by which the living object can be freely supplied with fresh water and air. Numerous forms of *growing cells* have been proposed, but I shall only refer to two or three which appear to me to be most advantageous. The following brief description of an improved growing-trough by its ingenious deviser, Professor Smith, of Kenyon College, United States, is taken from "Silliman's American Journal of Science," September, 1865, also "Magazine of Natural History," vol. XVI, 1865. The whole slide is a trifle more than one-eighth of an inch in thickness.

Fig. 1.

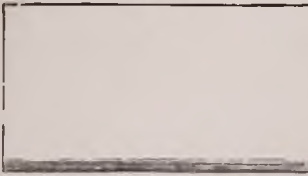
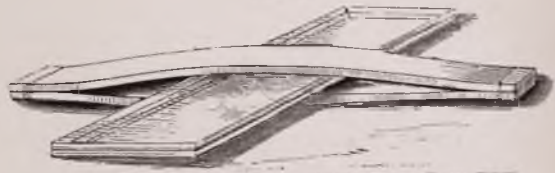


Plate glass stage, for examining objects when immersed in acids or corrosive fluids. p. 72.

Fig. 2.



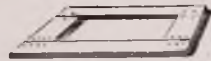
Holder, constructed of two pieces of whalebone tied together or riveted at both ends. p. 73.

Fig. 3.



To illustrate the manner in which thin glass may be perforated for making thin glass cells p. 73.

Fig. 4.



Illustrates a simple way of making a moderately thick glass cell p. 73

Fig. 5.



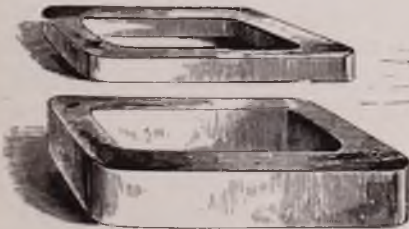
Small cells for preserving injections and other thick preparations. p. 74

Fig. 6.



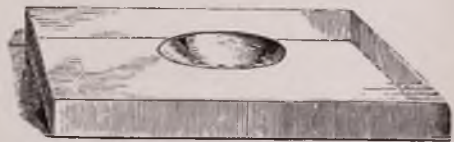
Thin glass cell for examining deposits from fluids. p. 71.

Fig. 7.



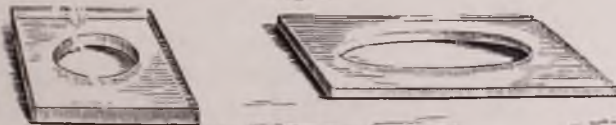
Large deep glass cells, for preserving opaque preparations. p. 74.

Fig. 8.



Concave glass cell, made by grinding out a cup-shaped cavity on the surface of a piece of very thick glass. It is afterwards polished. p. 74.

Fig. 9.



Glass cells made by grinding out the centre of a piece of plate glass. p. 74.



It consists of two rectangular glass plates  $3 \times 2$  inches, and about  $\frac{1}{8}$  of an inch thick, separated by thin strips of glass of the same thickness, cemented to the interior opposed faces. The upper plate has a small hole drilled through it. One corner of the upper glass is removed, and a small strip of glass, which is cemented to it in the proper place, prevents the thin glass cover placed over the edge from sliding off. To use the slide, the space between the two plates is to be filled with clean water introduced by means of a pipette, and a drop is also to be placed in the hole to remove the air. The object being put on the top of the slide, and wetted, is now to be covered with a large square of thin glass, the whole at the same time being covered. The slide can now be placed upright, or in any position, as no water can escape. It is, in fact, only a new application of the old principle of the bird fountain. As the water evaporates from under the cover, more is supplied through the hole, and from time to time an air bubble enters. Thus a constant circulation is maintained.

Mr. Richard Beck has made one or two alterations in the growing cell of Professor Smith ("Quarterly Journal of Microscopical Science," April, 1856). The annoyance caused by the water line obscuring the view, as sometimes happens in Professor Smith's growing cell, has been entirely obviated, and one or two other improvements have been effected. Dr. John Barker, of Dublin, has contrived a very convenient, efficient, and cheap growing stage, which has the advantage of allowing the use of the ordinary glass slides. A full description of this will be found in the "Quarterly Journal of Microscopical Science," January, 1867. Any one can make this growing stage for himself with very little trouble. A segment of a largish circle is cut in a plate of stout glass to form the stage. To one end of this is attached, by means of marine glue, a small flat glass bottle in which two little holes have been drilled. Such bottles may be obtained of Mr. Baker, of Holborn. When water is put into the bottle, it is conveyed from one of these holes to the thin glass cover under which the object is to be kept moist, by means of a narrow strip of talc which acts as a conductor. By this arrangement, any object under observation may be kept moist for the space of a week, or longer, if desirable. Dr. Barker's growing slide is represented in pl. XXII, fig. 6, p. 78.

For some time past I have been in the habit of employing an arrangement which is simpler than either of those above referred to, and which has proved very efficient. A small piece of glass tube is fixed with the aid of marine glue to one end of an ordinary glass slide, *a*, fig. 8, pl. XXII. This is the reservoir for the supply of water. It is covered with a piece of thin glass, but a small opening is left at one side sufficiently large to allow a fine thread of silk or cotton to conduct the water from the reservoir to the specimen placed in the centre of the



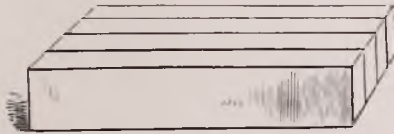
slide. The stratum of fluid containing the living bodies can be obtained of the required thickness by placing hair or pieces of fine glass rod between the thin glass and the slide. In some cases it is necessary to apply warmth, and keep the bodies under examination at a certain temperature for a considerable time. The method of warming the slide is described in another part of this volume.

Fig. 1.



To illustrate the manner in which cells of a peculiar shape may be made. The lower part is made of plate glass, to which the tube is attached by gutta percha. This apparatus was made for examining the circulation in the branchiae of a proteus. The smaller tubes were for the purpose of supplying the animal with fresh water. p. 75.

Fig. 2.



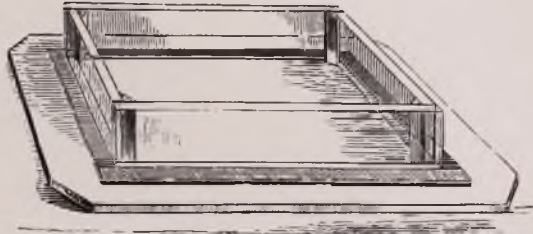
Shows the manner in which the sides of built glass cells are cemented together in order to be ground perfectly flat. p. 74.

Fig. 3.



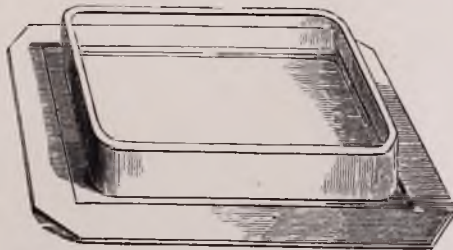
Shows the way in which the angles of a built glass cell are joined together. p. 75.

Fig. 4.



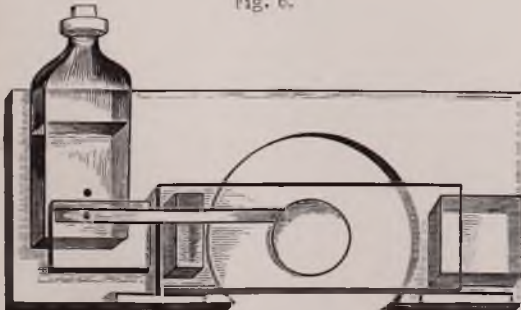
Large built glass cell. p. 76.

Fig. 5.



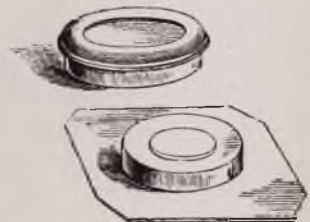
Deep glass cell, made by bending a piece of glass in the blowpipe flame. p. 75.

Fig. 6.



Growing cell, designed by Dr. Barker. p. 77.

Fig. 7.

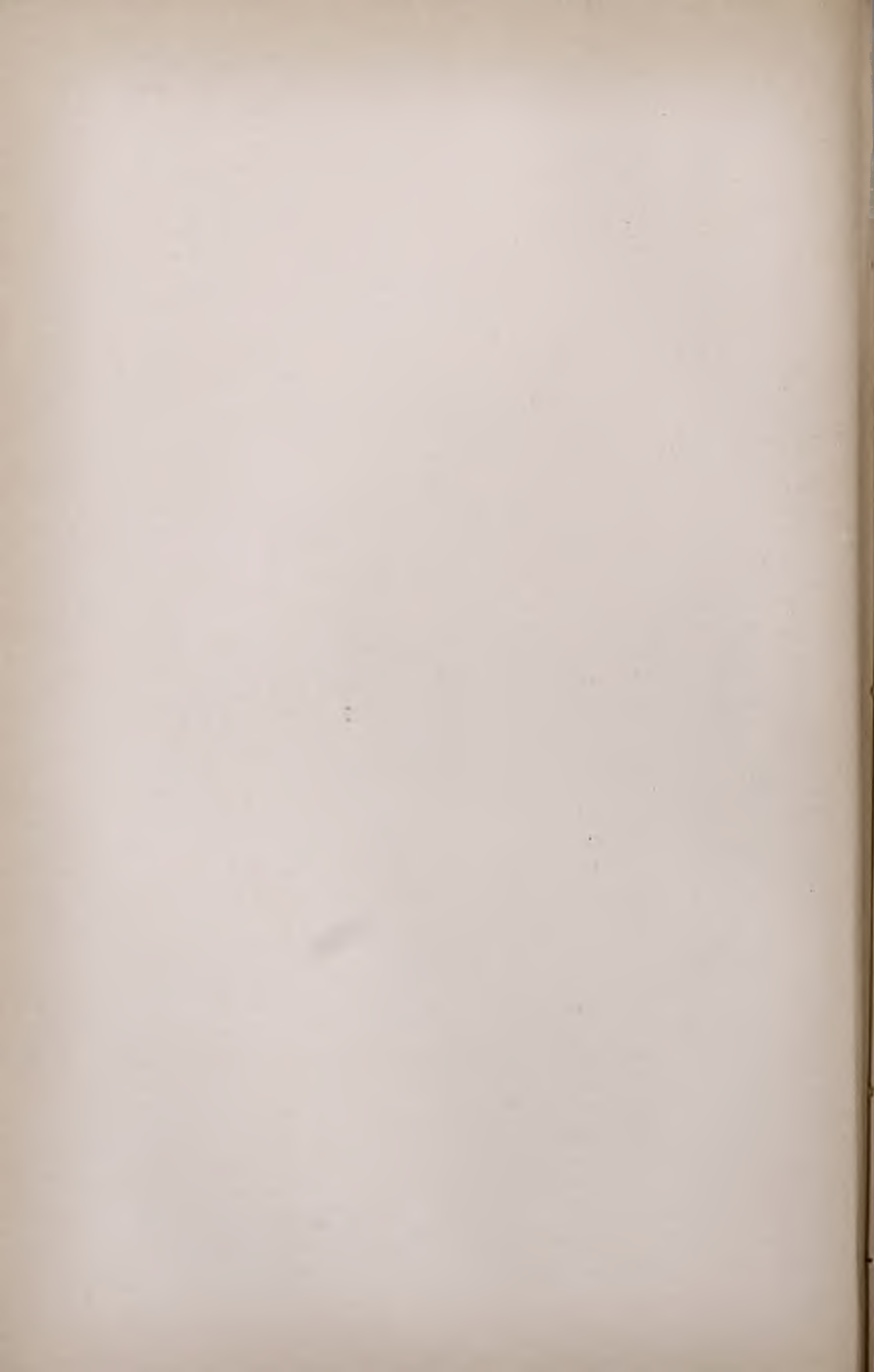


Animalcule case for examining deposits from fluids. pp. 78, 101.

Fig. 8.



Simple arrangement for conducting water to living bodies under observation. p. 77.



## PART II.

OF EXAMINING, PREPARING, AND PRESERVING OBJECTS FOR THE MICROSCOPE—DISSECTING—CUTTING THIN SECTIONS—SEPARATING DEPOSITS FROM FLUIDS—OF INJECTING THE HIGHER AND LOWER ANIMALS—OF COLOURING THE BIOPLASM OF LIVING MATTER, AND OF TINTING THE FORMED MATERIAL.

OF THE IMPORTANCE OF EXAMINING THE SAME OBJECTS IN DIFFERENT MEDIA—AIR, WATER, AND CANADA BALSAM.

The observer will gain very important information if he will subject such specimens as the following to examination in four different ways: granules of fine sand or powdered gypsum, potato starch, or arrowroot. 1. The surface of the object may be examined by *reflected light* brought to a focus upon it by means of a bull's-eye condenser, pl. XIII, fig. 3, p. 22.—2. The light may be *reflected* upon it from a *Lieberkuhn*, pl. XV, fig. 1, p. 26.—3. The light may be transmitted through the object after it has been reflected from the surface of the mirror, pl. XIII, fig. 1.—And, 4. The object may be placed under the influence of *polarized light*, with and without a selenite plate. The conclusion arrived at with reference to the nature of the structure which has been submitted to these four modes of examination, should be contrasted with the idea which would have been formed of it if an observation had been made by one mode of illumination only.

But further the observer will discover that many objects require to be studied in different media before an accurate idea of their general structure can be formed. It is in many instances of the utmost importance not only to examine an object by *reflected light* as well as by *transmitted light*, but to observe the peculiarities of appearance when it is surrounded with *air*, or immersed in *water*, or placed in a highly refracting fluid, such as *glycerine*, *oil*, *turpentine*, or *Canada balsam*. Not less valuable is the information we derive from the application of certain *chemical reagents* (part IV). The method of investigation must vary according to the degree of *transparency or opacity*, *density*, *refractive power*, and *chemical composition* of the specimen. The object must also be examined first with the aid of low, and afterwards with high magnifying powers.

**136. Different Appearances of the Same Object examined in Air, Water, and Canada Balsam, by Transmitted Light, and under the Influence of Reflected Light and Polarized Light.**—In pl. XXIII, p. 80, specimens of the same structure (spherical crystals of carbonate of lime and octahedra of oxalate of lime) magnified in the same degree, are represented.

*In Air.*—In fig. 1, pl. XXIII, p. 80, crystals of carbonate of lime, and in fig. 7 octahedra of oxalate of lime are shown by *transmitted light* in air mounted in the dry way, and it will be noticed how very dark and thick the outer part appears, and how impossible it is to make out the structure of the former crystals.

*In Water.*—In figs. 2 and 8, pl. XXIII, the same crystals are seen in water. The outer part of the crystals of carbonate of lime is still very dark and thick, but a few lines may be observed radiating from the centre of the crystals towards their circumference, although not very distinctly.

*In Canada Balsam.*—In figs. 3 and 9 the crystals are shown immersed in Canada balsam. The outline now appears as a sharp well-defined line. In the case of the carbonate of lime a number of narrow lines are seen radiating from the centre of each crystal towards its circumference; in fact the crystal really consists of a congeries of minute acicular crystals.

*By Reflected Light.*—In figs. 4 and 6 the crystals are represented as they appear when examined by reflected light. The globular form, and yellowish colour of the carbonate of lime, are very distinctly seen, and the surfaces of the crystals generally seem slightly rough, some appearing to be covered by minute elevations.

*By Polarized Light.*—In fig. 5 another preparation of the crystals of carbonate of lime is seen under the influence of polarized light. Each crystal exhibits a black cross which alters its position and appearance as the *analyser*, pl. XVII, fig. 2, p. 24, is rotated.

The above important points might be illustrated by a vast number of other substances. I cannot too strongly advise the observer to subject various microscopical structures to examination in *air, water, and Canada balsam*, and by *direct* or *reflected*, as well as under the influence of *transmitted light*, and in some cases by *polarized light*.

**137. Of Air Bubbles, Oil Globules, and Globules of Crystalline Matter.**—It is of the utmost importance that the observer should make himself familiar with the appearance of air bubbles and oil globules as soon as possible, for he will often meet with them, and if not acquainted with their characters he may make the most ridiculous mistakes in describing specimens.

*Air Bubbles* in water have a very wide dark outline: indeed, small air bubbles appear like round black spots. This appearance is very

DIFFERENT APPEARANCE OF THE SAME OBJECT.

PLATE XXIII.

Fig. 1.



Spherical crystals of carbonate of lime, examined by transmitted light, in air. p. 80.

Fig. 2.



The same, in water. p. 80.

Fig. 3.



The same, in Canada balsam. p. 80.

Fig. 4.



The same, viewed by reflected light. p. 80.

Fig. 5.



The same, under the influence of polarized light. p. 80.

Fig. 6.



Octahedral crystals as seen by reflected light. p. 80.

Fig. 7.



Octahedra in air, by transmitted light. p. 80.

Fig. 8.



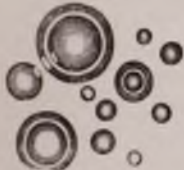
Octahedra in water p. 80.

Fig. 9.



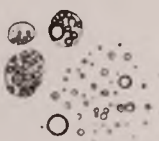
Octahedra in Canada balsam. p. 80.

Fig. 10.



Air bubbles, in water. p. 81.

Fig. 11.



Free oil globules and collections. p. 81.

Fig. 12.



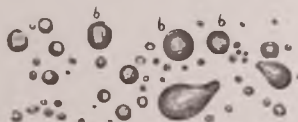
Oil globules. Milk p. 81.

Fig. 13.



Oil globules in collections, and cells containing oil globules. p. 81.

Fig. 14.



Oil globules from milk. a masses formed by two or more globules running together. p. 81.



characteristic, and every observer ought to be thoroughly familiar with it. Air bubbles of various sizes are represented in pl. XXIII, fig. 10, p. 80.

*Minute Air Bubbles* may be obtained as follows :—A little moderately thick mucilage is to be placed in a small bottle and well shaken up with the air. When many bubbles have been included, a drop is to be transferred to a slide, covered with thin glass and submitted to examination under various powers, first, the inch, and then the quarter of an inch.

*Oil Globules* in water, and in aqueous fluids, also present a peculiar and well-known appearance. The outline is sharp, and dark, and well defined, but not nearly so wide as that of the air bubble, because the difference of the refractive power between the oil and the fluid, although very great, is much less than that which exists between the air and the fluid medium which contains it. Every one should compare carefully air bubbles in water with oil globules in water under the microscope. Oil globules within cells, and free oil globules of various sizes, as seen in milk, are represented in pl. XXIII, figs. 11 to 14.

Oil globules of various kinds and sizes should be submitted to microscopical examination under various powers. Certain kinds of fatty matter contain much crystalline fat, as stearine or margarin, which is not a pure substance. These crystallize spontaneously from the more oily fatty matters. By the action of acids and other agents many fats are decomposed and the crystalline fatty acids are set free. Many slightly soluble earthy salts crystallize under certain circumstances, especially in mucus and viscid fluids in the form of *globules* or *spherules*, which often closely resemble oil globules, from which they may be distinguished by their hardness and by their chemical characters. See pl. XXIII, fig. 2. The illustrations in this plate should be carefully studied.

#### HOW TO EXAMINE AN OBJECT IN THE MICROSCOPE.

**138. For Beginners only.**—Any one who purchases a microscope probably endeavours to look at some object through it as soon as it comes home, and of those who make the attempt some, perhaps, fail completely, because they are not acquainted with the principles enunciated in the preceding pages. The observer will, I think, actually gain time if he will go through the tables at the end of the volume; but if too impatient and eager for action, he may proceed to work at once as follows :—

1. Place the microscope in the position represented in fig. 3, pl. XIII, p. 22, the eye-piece being adapted to the microscope. Carefully screw the low power object-glass (the two-inch or inch) on the body, supporting it with two fingers of the left hand, while the finger and thumb of the right are used to screw it home. Care must be taken *a*, not to let the object-glass fall down, and *b*, that the glass is not smeared



with moisture by touching it with the finger. Turn the mirror out of the way and permit the dark part of the diaphragm to occupy the field, or place a piece of perfectly flat black paper over or under the aperture.

2. Take a dry bread crumb, about the size of a small pin's head, place it on a glass slide, and the slide upon the stage of the microscope.

3. Place an ordinary wax candle, or French or other lamp, in such a position that the upper surface of the crumb of bread may be lighted up, or use the bull's-eye condenser, so that a strong light is condensed upon the object, as in pl. XIII, fig. 3, p. 22.

4. Screw down the body of the microscope until the object comes into focus and is seen distinctly.

The crumb of bread is examined as an *opaque object by reflected light*, and peculiarities of its surface are alone made out.

5. Alter the position of the lamp, if necessary, and so arrange the mirror that the light may be reflected from it, and caused to pass through the object (transmitted light), fig. 1, pl. XIII, p. 22. Prevent the light from illuminating the surface as before. The object seems very dark and little that is definite can be discovered.

6. Break the crumb up into several smaller pieces. This may be easily effected with the aid of a penknife. Most of the particles appear angular. They seem dark because they are too thick for the light to pass through them, but here and there one appears more or less transparent.

7. One of the transparent pieces being in the field, remove the inch power and screw on the quarter of an inch object-glass, and examine the crumb. Still the appearance is not very definite or satisfactory, and little information is gained with regard to the structure of the crumb or of the nature of its component particles.

8. Next screw up the body of the microscope, and remove the slide from the stage. Carry a drop of water with the aid of a pipette (p. 100) or a glass stirring rod, to the specimen, and cause the minute crumbs of bread to be wetted without their position being much altered. Carefully apply one of the pieces of thin covering glass, p. 71, after breathing upon the surface which is to come into contact with the fluid. The thin glass may be held in forceps or between the finger and thumb, and, by using a needle or a knife, may be allowed to fall upon the wet crumbs very gradually, as represented in pl. XXVI, fig. 4, p. 100. The superfluous moisture is to be removed by the aid of the handkerchief, or with a piece of blotting paper, so that no water will drop from the slide when it is placed upon the inclined stage of the microscope.

9. When the crumbs have soaked for a few seconds, give the thin glass two or three smart taps so as to crush them a little and make them spread out.

10. Bring the specimen as near the centre of the field as possible,

and screw down the body of the microscope until the object comes into focus. Many new facts are now learnt.

- a. A number of small, oval, circular, angular and perfectly transparent particles are seen for the first time.
- b. The dark indefinite appearance before observed is no longer noticed.
- c. Each transparent particle has a sharp and dark outline. Some are cracked, others exhibit irregularities of surface, while in some an indication of concentric lines may be observed. These bodies are starch granules or corpuscles of various sizes, modified by the heat of the oven. They appear clear and transparent now they are *examined in water*, instead of being black and opaque as when they were examined before *in air*, because the refractive power of the water approaches more closely to that of the starch granule than the air.
- d. Probably some black spherical bodies or very wide and dark circular rings will also be observed here and there. These are air bubbles, pl. XXIII, fig. 10, p. 80.

11. Examine the thinnest possible shaving of deal wood or of a cedar pencil, and of mahogany or oak, a fragment of blotting paper, a piece of cotton and linen scraped as fine as possible, a small pinch of flour, ordinary starch, common pepper, cayenne pepper, powdered mustard, in the same way as the bread crumbs, taking care to allow them to soak in a drop of water for an hour or more, so that they may be perfectly wetted.

12. Subject pieces of moist tea leaves, very thin sections of potato and the peel of the potato, the skin or interior of an orange, lemon, or other fruit, a piece of rhubarb, cabbage, or other vegetable, taking care that in all cases the pieces *are small enough*. A small portion of yeast or the mould upon any object from a damp cellar will furnish instructive objects. They can easily be subdivided with a sharp penknife.

I strongly recommend the beginner to examine various specimens of jam and preserved fruits. As these vegetable tissues have long soaked in syrup, they have become exceedingly transparent, and are admirably fitted for microscopical demonstration. The spiral vessels, woody, and cellular tissues, can be obtained without any trouble, and the minute structure of the different vegetable tissues can be most clearly demonstrated. Moisten the specimen with syrup, not with water.

The observer will probably, in the first instance, take far too much of the substance for examination, and he will find it excellent practice to bring under observation specimen after specimen, each one taken being smaller than the last. Pieces so small that they may be taken up on the point of a needle often afford more information than

larger portions. The specimens will require to be moistened with a little syrup before the thin glass is applied, and this will have to be pressed down firmly upon the specimen, a pin being used for the purpose. The steel pins with round glass heads, used by ladies as shawl-pins, are most useful instruments for the microscopist. The small ones will be found more convenient for some purposes than the long ones.

The thinnest possible sections of any of the textures mentioned above can be cut with a sharp thin knife, p. 50. Various candied and preserved fruits will furnish excellent microscopical specimens. Candied lemon peel, preserved ginger, plums of various kinds, may be cut with a very sharp knife, and the thinnest possible section removed, which may be transferred to a little clean syrup or glycerine for examination. Cheaper vegetables, introduced to deceive purchasers, can be easily detected by microscopical examination; and if most of those who could use a microscope would examine carefully the various articles consumed as food, the science of adulteration and imposition would soon become obsolete.

The action of syrup and glycerine on tissues will be more fully discussed in part VI.

**139. Precautions to be observed in working.**—And now I must give a few words of advice to the young observer not to work too long at a time or with high powers, and recommend him to be careful not to illuminate the object more intensely than is necessary to enable him to see it clearly. A retina, which would work well for half a century, soon becomes rendered less sensitive or permanently damaged by a strong glare thrown upon it for several hours a day. To avoid strain, the habit of keeping both eyes open during observation should be acquired as soon as possible, and the observer should observe sometimes with one eye and sometimes with the other. Although the eye improves very much by practice, it may be seriously damaged by straining it injudiciously. At first the observer should work for half an hour only at a stretch, and if he finds that he is not fatigued and external objects are seen quite distinctly, as to form and colour, immediately the eye is removed from the microscope, the period of observation may be gradually increased until it reaches two or three hours a day, but I think it unwise to work uninterruptedly for a longer time. It is a good plan not to work regularly every day, at least for the first year or two. With care an eye which was at first weak may be inured to prolonged exertion and improved in sensitiveness, and may, perhaps, be used for the greater part of life without damage.

It is remarkable how little some persons suffer from microscopic or telescopic observation, but it is quite certain that many cannot work for long without great risk of seriously injuring their sight. No general rules, therefore, can be given which will apply to all. I have myself

often worked with very high powers and with a very brightly illuminated field, straining the eye to the utmost in the hope of seeing more than was at first observable. I kept this up for some hours at a time for several years, I am happy to say, without any very serious impairment of sight, but I would not recommend any one to subject himself to the same risk unless he allowed himself to pass through the same gradual process, using first only low powers, moderate light, and working only for a short time, and slowly increasing the magnifying power, the illumination, and the period of study as he felt he was able to stand it.

**140. General Considerations with reference to the nature of the Medium in which Tissues should be placed for Examination.**—If the structure be dry and very thin, or if it is required only to make out any general points with reference to its outline, or the character of its surface, it may be examined in air. So also many structures subjected to examination by low powers, and by reflected light, exhibit the general arrangement of their component parts very satisfactorily when mounted perfectly dry.

If, however, the texture be delicate and moist, and readily destroyed by careless manipulation, it is generally desirable to examine it in some aqueous fluid when quite fresh. The character of the fluid must vary in different cases according to the density and properties of the fluids which bathe the tissues in their natural state. Water answers well in many instances, but the microscopical character of some textures are completely altered by water, or even altogether destroyed by it. Other tissues are so dark and opaque that they are not well displayed in water. Soft and cell-like structures become distended by it, but it does not follow that when this happens it depends upon a "cell," or bladder closed at all points, being distended. It does not prove that the cell has a membranous wall, for a mass of jelly may be made to swell out just like a "cell." If the jelly be made with a dense fluid, the more limpid water will pass in and mix with it. The jelly "cell" thus becomes distended by this flowing in or osmosis, and often to such a degree as to be invisible. To prevent this result, it is necessary to immerse the structure in some fluid approaching in density to that in its interstices, or in its interior.

To make a simple fluid, in which to examine delicate moist tissues, a little white sugar or salt may be dissolved in the water (five to fifty grains to two tablespoonfuls of water). Saliva, the vitreous humour, serum, or white of egg, from their viscosity do not permeate readily and so alter the tissue. They are, therefore, advantageous media. But of all substances soluble in water, glycerine is one of the most useful to the microscopist. With glycerine he may obtain a fluid of any density, and of various degrees of refracting power. Moderately strong solutions of glycerine preserve animal and vegetable structures for any length of

time. If soft tissues be immersed in strong glycerine or syrup, the water they contain passes out and the tissue shrinks, and all appearance of structure disappears. But the very same texture may be immersed in the strongest glycerine, and all the details of the most delicate structure displayed if only the strength of the glycerine be increased very gradually, as I have explained more fully in part VI. Glycerine is to moist tissues what Canada balsam is to textures which are capable of being dried, without their structure being impaired. The most dense, opaque, and ill-defined structures, immersed in glycerine become clear and transparent; and anatomical peculiarities which were before indistinct, or not observable, become demonstrable without difficulty. Another advantage is, that by the addition of a little water all the original characters of the tissues are restored.

Further observations upon rendering tissues which are more or less opaque, transparent, will be found in part VI.

**141. Of Examining and Preserving Specimens in the Dry Way.—**

Any specimen examined, or preserved permanently, as a dry object in air, must be protected from dust by being covered with thin glass, and the pressure of the latter upon the specimen must be prevented by the interposition of small pieces of cardboard at the edges of the thin glass, slightly thicker than the specimen itself. Objects may be mounted in the dry way in many of the cells described in §§ 114—131; but a simple cell made of wood or cardboard is sufficient for all practical purposes. The round vulcanized India-rubber rings cemented to the glass slides with damar or solution of Canada balsam in benzol make capital cells for mounting such preparations.

The thin glass cover must be attached by a little very thick gum or by a paste made of gum and flour or chalk. Any cement used for this purpose must be viscid, or it will run into the specimen and completely spoil it.

Among unorganised substances, there are many objects which may be mounted or preserved with advantage in air. Many crystalline bodies found native, and some crystals derived from the organic and inorganic kingdoms artificially prepared, may be examined or preserved permanently in air. Many of these present very beautiful appearances. Arsenious acid, common salt, benzoic acid, uric acid, crystals of the vegetable alkaloids, such as salicine and many crystalline salts—bone, teeth, hair, horn, the scales of butterflies, of the podura and many other insects—are structures which may be examined in air and mounted dry. The general structure of many vegetable preparations may be demonstrated in the same simple manner. The petals of many flowers, different forms of vegetable cellular and vascular tissue, the epidermis, hairs, and other parts of plants, the seeds and seed vessels, spiral fibres, the stones of fruits, sections of wood, of the pith from the stem of various plants,

pollen, the spores of ferns, mosses, and fungi, are examples of vegetable preparations which may be examined and preserved in air.

Thick objects preserved in the dry way can be examined by *reflected light* only, but very thin dry tissues, like the epidermis from different parts of plants, may be examined by reflected or by transmitted light.

**142. Examination of Substances in Fluids.**—In choosing a fluid in which the specimen is to be immersed, its chemical composition, its transparency and its refractive power must be considered. The different preservative solutions described in pp. 64 to 69, may be used for the preservation of a variety of objects in fluid. If we wish for a fluid closely resembling water, but possessing the property of preserving the specimen, we may use the *solution of naphtha and creosote*, § 120, or *naphtha and water*, or carbolic acid and water. If we require a fluid of higher specific gravity, some of the saline solutions, diluted with a proper quantity of water, may be used. If we wish for a solution which refracts highly, we may employ glycerine, or a mixture of glycerine and gelatine. Glycerine, it is often said, is not suitable for preserving fibrous tissue and many delicate textures which would be rendered too transparent. The objection is purely theoretical, for I have preserved such textures perfectly well in glycerine.

If a fluid is required which has the property of hardening the structure, a solution of *chromic acid*, *bichromate of potash*, *corrosive sublimate*, or *diluted alcohol* may be employed. *In all cases the substance should be immersed for some time in the fluid, in which it is to be preserved, before being mounted permanently.* The cell made of *Brunswick black* or the thin glass cell, or other forms described in §§ 116—131, may be chosen according to the dimensions of the specimen. The object and fluid being placed in the cell, the thin glass cover is applied, with the precautions recommended in p. 82. The superfluous fluid is removed with a piece of blotting paper, or a soft cloth, and after the edges have been allowed to dry a little, they are anointed with a thin layer of *Brunswick black*.

Almost every organised structure, and especially the soft moist tissues of the bodies of animals, may be advantageously preserved in fluid. It has been said that the solution employed in preserving a structure should resemble as nearly as possible in density and refractive power, the fluid which bathed it during life, but it is a fact that many even exceedingly delicate structures may be examined in fluids of high density, as syrup or glycerine, and peculiarities may be made out which are not to be demonstrated when they are examined in water or serum.

*Of mounting Specimens which may be examined on both sides by high Powers.*—In mounting some specimens it is desirable to arrange so that either side may be submitted to examination by high powers. This

may be effected by having thin glass circles of  $\frac{7}{8}$  of an inch in diameter, and others  $\frac{5}{8}$ . The last may be of thinner glass than the first. The specimen with the fluid preservative medium being placed upon the larger circle, the smaller one is applied and cemented to the first in the usual manner. When dry the mounted specimen may be protected in a slide made of cedar wood, of the same dimensions as the ordinary glass slides, and placed with them in the cabinet. These cedar wood slides have holes made in them just large enough to admit the glass circles, which are kept in their place by little circles of paper fixed with gum. I have mounted hundreds of specimens in this manner, and not a few have been preserved for twenty years.

A modification of the above plan has been adopted for very delicate specimens by Dr. Edmunds, who has described the method of proceeding in the "Journal of the Quekett Club" for May, 1878, p. 23. Slips of dry cedar  $\frac{1}{20}$  inch in thickness are cut 3 inches  $\times$   $1\frac{1}{2}$ , and a  $1\frac{1}{4}$ -inch hole is made with a sharp centre-bit, cutting through a dozen slips at a time. The edges are smoothed with fine sand-paper, and then with strong paste or mastic varnish slips of bank-note paper are strained over the opening—the edges of the paper being extended round the edges of the slip. When dry the stretched paper is to be punched out with a  $\frac{5}{8}$  inch gun punch, and the thin glasses are cemented in with a ring of varnish. The objects are set upon a  $\frac{3}{8}$ -inch circle of .005 inch glass, and are covered with a  $\frac{5}{8}$ -circle—the latter just filling up the hole punched through the paper drumhead.

**143. Examination in Canada Balsam, Turpentine, and Oil.**—The well-known Canada balsam has long been a favourite medium for the preservation of microscopical specimens, on account of its penetrating and highly refracting properties. Turpentine possesses very similar properties, but from being a limpid fluid, it is far less useful than Canada balsam. Canada balsam may be kept in an iron or tin vessel of the form represented in pl. XXIV, fig. 1.

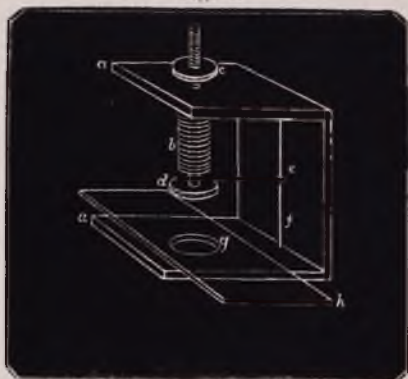
All preparations to be mounted in Canada balsam must be thoroughly dried before being immersed. The desiccation must be effected by a temperature of not more than from 100 to 200 degrees. For the purpose of drying tissues, we may employ the water-bath alluded to in § 73, or we may place the specimen under a bell-jar close to a basin of strong sulphuric acid or chloride of calcium, which substances have the power of absorbing moisture in an eminent degree, pl. XXIV, fig. 5. Many textures in process of drying include a number of air-bubbles in their interstices, and it is often very difficult to remove these. To effect this object, the preparation may be allowed to soak some time in turpentine, and the removal of the air is often much facilitated by the application of a gentle heat. If the air cannot be removed in this manner, the preparation immersed in turpentine, may be placed under

Fig. 1.



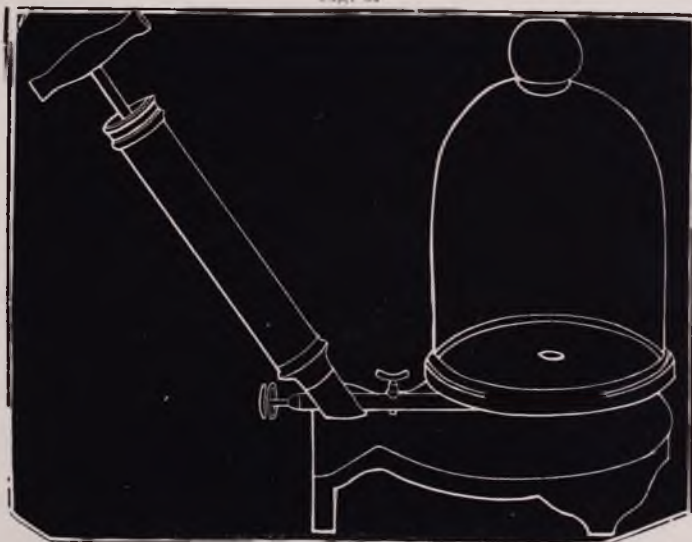
The can for containing Canada balsam. pp 76, 88.

Fig. 2.



Instrument for applying graduated pressure to objects under thin glass. p. 88.

Fig. 3.

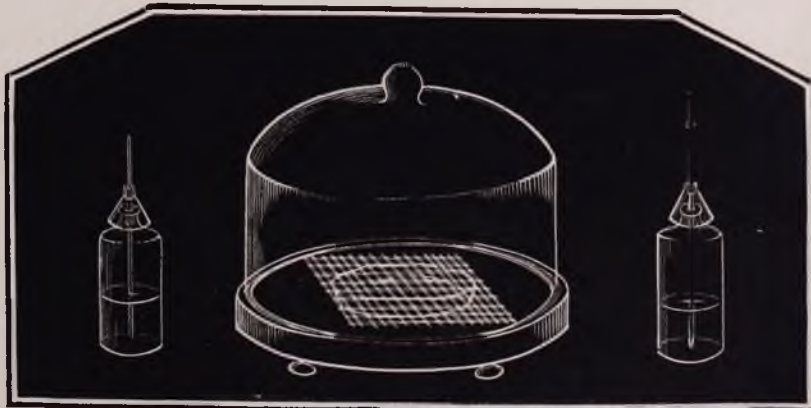


Air-pump, for removing air from microscopical specimens. p. 97.

Fig. 4.

Fig. 5.

Fig. 6.



Test bottle, with stirring rod and cap to prevent entrance of dust

Glass shade, with sulphuric acid and wire gauze support for drying objects. pp. 88, 121.

Pipette inserted through cork or stopper of test bottle.





the receiver of an air-pump. As the pressure is removed the air rises to the surface and the fluid rushes in to supply its place. A convenient and simple form of air-pump is represented in pl. XXIV, fig. 3. A much cheaper and simpler apparatus has been recently made by Mr. Swift at the suggestion of Mr. Gardner of the Quekett Club. This consists of a chamber large enough to contain two or three glass slides, with which a good strong exhausting syringe is connected. The arrangement is represented in pl. XXV, fig. 5, p. 92. When the thin section of tissue has been thoroughly dried, and the air removed, it may be necessary to slightly remoisten it with turpentine before it is placed in the balsam.

In mounting a thin section of bone or other hard dry texture in Canada balsam, the following steps are taken: the glass slide having been warmed upon the brass plate, a small quantity of a solution of dry and old Canada balsam in benzol or chloroform is placed on the slide upon which the specimen is to be mounted. The specimen already moistened with a weak solution in the same medium, or with turpentine or oil of cloves, is then placed in proper position with the aid of a needle. A few air-bubbles may perhaps collect upon the surface of the balsam solution, in which case the slide is to be moved from side to side with a slight rotatory movement, when the bubbles may be seen to collect in one spot upon the surface. They may be made to burst by the application of a warm needle, or completely removed by touching them with a cold wire to which the portion of balsam including them will adhere. All bubbles having been removed, the thin glass, which has been perfectly cleaned and slightly warmed on the brass plate, is taken in a pair of forceps,—and, one side of it being allowed to come in contact with the balsam,—is permitted to fall very slowly upon the specimen, in such a manner that the balsam gradually wets the thin glass, without including air-bubbles. The thin glass is then pressed down slightly with a needle, and the slide placed in a warm place. The benzol gradually evaporates, leaving the balsam which seems to undergo no further change if the solution has, in the first instance, been properly prepared.

The feet and hard parts of the fly and other insects, and the ova of small insects may be mounted in the solution of Canada balsam. The shells and hard parts of the covering of many of the lower animals, the palates of various mollusks, such as the limpet, and many fresh-water species, the coriaceous coverings of insects, their antennæ, stings, eyes, feet, wings, the scales of their wings, the tracheæ penetrating every part of their organism with their spiracles or external openings, and in some cases the entire insects themselves, the scales of fishes, sections of bone, teeth, horn, hoofs, claws, nails, specimens of various kinds of hair, are examples of objects derived from the animal kingdom which may be examined in this manner and mounted permanently if desired.

If the observer wishes merely to ascertain how a structure looks when examined in a highly refractive medium like balsam, he may use turpentine, which can afterwards be dissipated by evaporation.

*Canada Balsam dissolved in Benzole.*—In order to prepare this solution, which is far preferable and easier to use than ordinary balsam, the Canada balsam is to be dried by a moderate heat (under 200° F. in an oven) till it becomes hard and brittle. The dried balsam may then be dissolved in benzole.

*Gum Damar* is now much used, but I do not think it is as good as balsam. Equal parts of damar and gum mastic may be dissolved in the benzole. The limpid solution may then be filtered without difficulty.

*Moist Tissues* which cannot be dried without damage, and are to be mounted in Canada balsam solution, must be specially prepared as follows:—The section of the hardened tissue ready for mounting is to be soaked in moderately strong alcohol, and then transferred for a few minutes to absolute alcohol. It is next quickly removed from the very strong alcohol and floated upon the oil of cloves, oil of lemons, or other essential oil, or on turpentine until the alcohol has been expelled and the oily medium imbibed. It is lastly transferred to the Canada balsam or damar fluid, left for a time until every part of it is imbued and placed on the glass slide.

*Common Olive Oil* is an advantageous highly refracting medium for examining certain structures in. The entozoa which may often be obtained from the oily sebaceous matter squeezed from the follicles of the skin of the nose or scalp, should be immersed in oil. They can generally be found in the wax from the ear. Castor oil is also used.

Some tissues may be made to present different appearances although mounted in the same medium. Thus, bone exhibits very different characters when immersed in Canada balsam, according to the manner in which it is mounted. In every part of one specimen, small black spots of irregular shape may be seen. From these a number of minute dark lines radiate, and inosculate pretty freely with corresponding lines from other spots. In another preparation the entire section may appear perfectly clear, and its structure nearly uniform throughout. The first appearance is produced when a section is at once mounted in old viscid balsam; the second when it is immersed in fluid balsam, after having been previously well wetted with turpentine. The cause of these striking differences of appearance is interesting and worthy of attentive study. The little black spots (*lacunæ*) and dark lines (*canaliculi*) were formerly considered to be small solid bodies, and the spots were improperly termed *bone corpuscles*. They consist in truth of little cavities or spaces in the bony tissue, and contain air. In the second specimen the highly refracting oil of turpentine passed up the canaliculi and into the *lacunæ* driving out the air, thus rendering the tubes and spaces in-

visible. These lacunæ or spaces contained, in the fresh bone, little masses of bioplasm or living matter (nuclei), but when the bone had become dry, the moist material dried up, and air rushed into the lacunæ and canaliculi to supply its place. The great difference between the refracting power of the air contained in these little cavities, and that of the surrounding bony tissue, gives rise to the dark appearance, just as a minute air-bubble in water is made to appear as a minute black ball, while a large one seems to have a very wide black outline. The above remarks upon the structure of bone apply of course to the dead and dried tissue only.

OF PREPARING TISSUES FOR MICROSCOPICAL EXAMINATION—OF DISSECTING AND OF CUTTING THIN SECTIONS OF TISSUES.

**144. Of Making Minute Dissections under Water.**—Minute dissections are usually carried on under the surface of fluid with the aid of small scissors, needles, or small knives, and forceps. If the preparation has been preserved in spirit or other solution, it must be dissected in the same medium, but in ordinary cases clear water may be used. The microscopist should be provided with a few small dishes, varying in size, and about an inch or more in depth. The large built cells, pl. XXII, figs. 4, 5, p. 78, make very good troughs for dissecting under the surface of fluid, but small circular vessels are made on purpose.

**145. Loaded Corks.**—The object to be dissected is attached to a loaded cork by small pins, pl. XXV, fig. 2, p. 92. The "loaded cork" may be made as follows:—Take a piece of flat cork rather smaller than the cell, and then cut a piece of sheet lead about the thickness of a half-penny, and a little larger than the cork. The edges of the lead are then folded over the cork and beaten down slightly with a hammer. The lead may afterwards be filed with a rough file.

The object being fixed upon the cork and placed in the cell, fluid is poured in until it just covers the surface, pl. XXV, fig. 1. A strong light is then condensed upon it by means of a large bull's-eye condenser, or a large globe full of water. I have always found that delicate dissections could be made with the greatest facility without the aid of a dissecting microscope, provided a strong light was condensed upon the object. Occasional examination of the dissection with a lens of low power is advantageous; but if a lens be employed during the dissection there is great danger of accidentally injuring the specimen, as it is impossible to judge of the exact distance of the needle point beneath the surface of the fluid. Minute branches of nerves or vessels may in this way be followed out; and small pieces of the different tissues into which they can be traced may be removed for microscopical examination with a pair of fine scissors, pl. XIX, figs. 5, 6, 7, p. 52. Membranes

may be dissected from the structures upon which they lie without any difficulty. By this plan the nervous system of the smallest insects can be readily dissected. The mode of proceeding is represented in pl. XXV, fig. 1.

**146. Tablets upon which Dissections may be Pinned out.**—Many preparations require to be arranged in a particular position previous to being mounted as permanent objects. *Slabs of wax* are usually employed by anatomists for this purpose, but when transparency is required the dissections may be attached by threads to thin plates of *mica*. The best slabs are made of a mixture of *wax* and *gutta-percha*, in the proportion of one part of the former to two of the latter. The ingredients are to be melted in an iron pot, over a clear fire, and well stirred. When quite fluid, the mass may be poured upon a flat slab and allowed to cool. Thin cakes of about the eighth of an inch in thickness may be thus obtained, and they can easily be cut with a knife to fit the cells intended for the preparation. Pins or small pieces of silver wire may be inserted into these slabs, and will adhere firmly although the slabs are very thin.

#### *Cutting thin sections of Soft Tissues.*

**147. Of Section Cutters, or Microtomes. Of obtaining Thin Sections of different Textures for Microscopical Examination.**—The knives, scissors, and instruments required for cutting thin sections of soft tissues by hand have been described in pp. 51, 52. Many are represented in pls. XVIII, p. 48, and XIX, p. 52.

It is scarcely necessary to observe that for cutting very thin sections of such different textures as muscular fibre, gland structures, and other soft tissues, a process is required different from that which is applicable for cutting thin slices of such tissues as hair, horn, bone, or teeth.

Where thin sections of no very great extent of tissue are required they may be obtained by scissors, p. 51, by the ordinary scalpel, p. 50, by the double-edged knife, or by Valentin's knife. Whenever a thin section of a soft tissue is made, the instrument employed must be thoroughly wetted with water, and the section, after its removal, carefully washed, by agitating it in water, or by directing a stream of water upon it from the wash-bottle, pl. XXVI, fig. 5, p. 101. This washing is absolutely necessary to remove from the surface of the sections particles of debris, which would render the appearances indistinct, and interfere with the clearness of the specimen when it was subjected to examination in the microscope. The section may then be transferred to the fluid in which it is to be examined or preserved. If the specimen be immersed in glycerine, alcohol, or other fluid, the knife must be wetted and the specimen washed with the same, and the specimen must

Fig. 1.



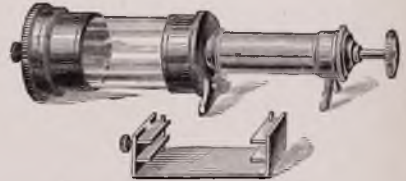
Arrangement for making minute dissections under water. p. 91.

Fig. 2.



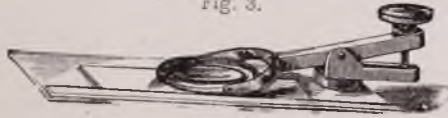
Loaded cork upon which objects for dissection may be pinned out. p. 91.

Fig. 5.



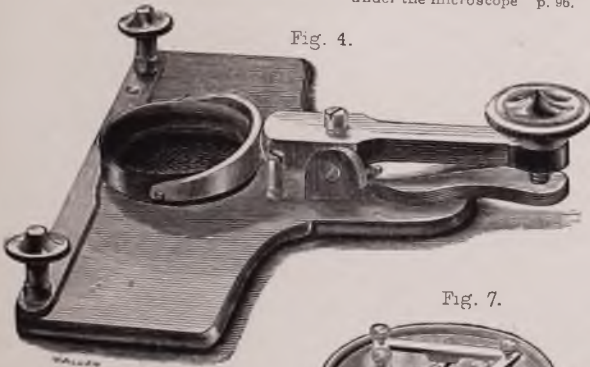
Small air pump, suggested by Mr. Gardner of the Quekett Club and made by Mr. Swift. p. 89.

Fig. 3.



Compressorium for pressing or tearing up tissues under the microscope p. 96.

Fig. 4.



An improved form of compressorium (Mr. Higley). p. 96.

Fig. 6.



Instrument for cutting thin sections of wood, &c. p. 89.

Fig. 7.



Freezing microtome, as suggested by Mr. Williams of the Quekett Club, and made by Swift. p. 91.

Fig. 3.



Fine saw for sawing bone and other hard tissues. p. 93.



be allowed to soak for some time in the medium before it is examined. Small watch glasses or the little china dishes in which moist colours are sold, are very convenient for the purpose of soaking tissues in fluid previous to examination. They must of course be carefully covered by glass shades to protect them from the dust.

*Of Bedding Tissues previous to cutting Thin Sections.*—Under ordinary circumstances before a thin section can be cut the tissue requires to be hardened. The best method adopted for this purpose is that of soaking for some time (from one to four weeks) in weak solution of chromic acid. Many observers have used alcohol, and other media have been recommended. The tissue when properly hardened is removed to the section cutter, but before thin sections can be satisfactorily obtained, it is usually necessary to “bed” the hardened tissue in some medium that can be melted at a comparatively low temperature but which becomes hard on cooling. Many *bedding preparations* have been suggested. A mixture of wax and oil has been used. Dr. Rutherford recommends a medium made of five parts of solid paraffine, which may be obtained in the form of paraffine candles, and one part of hog’s lard.

The piece of tissue to be bedded may be freed from adhering moisture by blotting-paper, and then fixed with the aid of a pin in the centre of a small paper cup, corresponding in size to the opening of the section cutter. The paraffine, or wax and oil, having been carefully melted in a water-bath, is to be poured out and allowed to cool, when the paper may be torn away and the mass with the embedded tissue removed to the section cutter. For very delicate tissues Stricker recommends a strong solution of gum which may be hardened in alcohol after the tissue, also hardened in the same medium, has been immersed in it. The hardened gum with the contained tissue is then to be bedded in paraffine in the manner already described.

*Microtome.*—The original form of the microtome or section cutter in long use, for making sections of wood and other vegetable tissues has been described in former editions of this work. But many improvements have been recently made in this instrument. Stirling’s improved section cutter has been further improved by others. Dr. Rutherford has added an indicator, by which the thickness of the section can be estimated, as well as an arrangement for freezing tissues which are being operated upon. This instrument has been made by Mr. Hawksley, and latterly by Mr. Baker. Further improvements have been introduced as regards the table, some observers preferring steel to the ordinary smooth surface of brass, while Mr. Needham has had a microtome made with a plate glass surface. As regards the form of knife, an ordinary razor has been recommended. Dr. Mathews has improved the knife by having the shoulder ground down flush with the rest of the blade. It is,



I think, better to have the knife or razor separate, and not to move on a hinge joint fixed to the table of the section cutter.

For researches on the structure of the brain and spinal cord, these section cutters are invaluable, and by the aid of sections cut by them most important facts connected with the course and distribution of nerve-fibres will unquestionably be determined. I am surprised that the course of individual nerve-fibres, has not been followed, say through a single convolution of the brain, or in a portion of the spinal cord, for it is certainly possible to do so at this time. From a well-hardened piece of brain or cord, numerous sections might be removed one after the other, and each one carefully mounted in the same position, and in the same manner. By examining these one after the other, it would be possible to trace many fibres in their course through a piece of nervous matter, as much as half-an-inch in thickness. With the aid of careful sketches it would be even possible from the facts learnt by examining the individual sections to give an accurate representation of the course taken by the fibres.

*Freezing Tissues prior to cutting thin Sections.*—The plan of freezing tissues for obtaining very thin sections is an excellent one and henceforth will no doubt be very extensively employed. Dr. Pritchard has recently suggested a most convenient plan for freezing tissues and cutting very thin sections when congelation is complete. By this process thin sections of perfectly fresh tissues may be readily obtained. Dr. Pritchard's instrument consists of two parts—(1) a metallic cylinder fitted with a wooden handle ; (2) a cap of thick felt.

(1) The metallic cylinder, which is solid throughout, should be made of copper on account of its conductivity, but gun metal, or even brass, will answer the purpose sufficiently well. Its exact size or shape is not of very much consequence, so that it is large enough and convenient to handle. The following dimensions are recommended : diameter of metal cylinder  $1\frac{3}{8}$  inch, length  $1\frac{3}{4}$  inch ; the diameter of the end of the wooden handle should also be  $1\frac{3}{8}$  inch ; the plug end should taper gradually, and the hole in the metal be a deep one, so that the plug may be pushed further in when the metal contracts on cooling. Both the wooden and metallic ends are made flat, so that the instrument can stand on either extremity ; on the metal surface are a series of half a dozen concentric shallow grooves.

(2) Is simply a cap of thick felt, such as is used for boilers being preferable, made so as to fit somewhat loosely over the machine (1).

Mode of using the machine.—Plunge (1) with metallic face downwards into a mixture of finely pounded ice and salt ; after remaining therein for three or four minutes, take it out and wipe with a clean cloth. The instrument has now been cooled down far below the freezing point, and on placing upon the metal plate a piece of soft tissue,

this immediately freezes to the machine. The cap (2) must now be placed over the metal, but not allowed to touch the tissue, which will then freeze throughout in a very short space of time, varying according to the size of the tissue, from a few seconds to one or two minutes. Now reverse the cap so as to leave the metallic top free, and, holding the whole in the left hand, cut the sections with the right by means of a sharp razor which has been kept cool in ice and water. Occasionally, the tissue may slip on the metal; when this is the case, remove the preparation, moisten it with gum-water, and replace it, when it will be found to adhere with much greater firmness. This slipping, however, very rarely occurs with perfectly fresh tissues, the grooves on the metallic surface tending to prevent it. The tissue will remain frozen quite long enough to make several score of sections, but should a thawing action set in, it may be covered with thin gutta-percha, and the machine again plunged into the ice and salt.

The cooling may also be effected by allowing a jet of condensed gas to play upon the metal for a few seconds. The nitrous oxide now so largely used by dentists, is sold in iron bottles provided with a stopcock, and is very convenient. A small jet has to be adapted, and then the whole is ready for use.

The advantages of Dr. Pritchard's little instrument are, first of all, its simplicity; and, secondly, the rapidity with which tissues may be frozen by its means. To illustrate the quickness of its action, it is only necessary to drop a little water on the cooled metal to convert it immediately into ice. The apparatus may be made by any instrument maker or metal turner for a few shillings, or it may be obtained of Mr. Baker, of Holborn, and Mr. Swift, of University Street, and other instrument makers.

Another efficient arrangement is obtained by fixing the old brass microtome represented in pl. XXV, fig. 6, p. 92, in the centre of a small thick wooden tub, so that the screw can be worked from below. The tub is filled with ice and salt, and the brass plate will be sufficiently cold in a few minutes to freeze small portions of tissue placed upon it. Lastly, the freezing section cutter has been further improved by Mr. Williams, whose apparatus is represented in pl. XXV, fig. 7, p. 92, and is to be obtained of Mr. Swift.

#### **148. Cutting Sections and handling Bodies under the Microscope.—**

With practice the observer may carry on a dissection under the microscope. It is not difficult to work under an inch, and under a half inch it is possible to dissect with the aid of a fine knife or very sharp needles. The erector, p. 7, must be employed, or the observer must learn to work although everything appears reversed. Various instruments have been proposed to aid the observer in dissecting or removing specimens which are highly magnified.

*An instrument for making sections on the stage of the microscope.—*

V. Hensen, who has made some beautiful observations on the organ of hearing of crustacea, has designed an ingenious instrument for making thin sections of tissues while in the field of the microscope. ("Schultze's Archiv," April, 1866, vol. II, p. 46.) Under a power of fifty diameters an extremely thin section of textures of a certain hardness may be made with facility. This instrument, which I have not yet seen, is made by Beckmann, of Kiel, and costs seven thalers, or about a guinea.

*Mechanical finger.*—Professor Smith has made an instrument which he terms a mechanical finger, of some value for some kinds of microscopical work ("Silliman's Journal," No. 123). By an arrangement of springs and levers a small bristle can be caused to move or take up any minute object while it is being examined under the object-glass. An object may be selected, raised from the slide, and held while a clean slide is placed in position to receive it. This instrument has been made by Mr. Baker, of Holborn. Dr. Maddox has suggested a slight modification, by which the instrument is somewhat improved and simplified. Although the mechanical finger may be of value in special investigations, the general observer will not require it, and the thorough student will probably acquire such dexterity in handling specimens while they are in the field of the microscope that he will not feel the want of any mechanical apparatus.

**149. Dissecting Tissues under the Microscope with the aid of the Compressorium.**—In many cases the observer may desire to dissect an extremely delicate structure *under the microscope*, for in this way much information can often be acquired with reference to the exact relation existing between the structural elements of the tissue. This object may be gained by means of a little instrument termed a *compressorium*, which consists simply of a convenient arrangement by which pressure can be applied to an object while under examination, pl. XXV, figs. 3, 4, p. 92. This pressure being applied gradually, the texture becomes frayed out as it were, and particular structures can often be teased out from a tissue, and demonstrated more distinctly than by any other method.

The structure of the compressorium is very simple. Many different forms have been recommended, one of the simplest consisting of a thick brass plate with a hole in the centre to admit the light. On one side of this is the fulcrum of a lever, the short end of which acts upon a circular ring carrying the thin glass to cover the preparation, while to the longer arm is attached a screw, which by being turned causes the thin glass to be pressed tightly upon the object placed upon a piece of plate glass fitted into the hole in the plate of the compressorium. A more perfect form of instrument has been arranged by Mr. Highley. It is represented in pl. XXV, fig. 4. The plate glass is, as was just stated, usually fixed in the hole in the brass plate, but it is more convenient to have a

ledge attached to one side, so that an ordinary plate-glass slide may rest upon it. With such an arrangement, the tissue to be examined can be placed as may be thought desirable, upon any part of the glass before it is removed to the compressorium. A very convenient form of compressorium is recommended by M. Quatrefages, in which it is possible to examine the object upon either side. The compressorium has also been modified by Mr. Ross so that the object may be placed between two pieces of thin glass, and either side of it subjected to examination under very high powers. Mr. Beck, I think, improved upon the plan adopted by Mr. Ross.

Messrs. Powell and Lealand have made for me upon this plan an excellent compressorium that may be used with very thin glass, and is so constructed that both sides of the object may be examined. By the aid of this instrument I have been able to gradually fray out tissues by increasing the pressure from day to day and thus follow out the most delicate ramifications of nerve fibres amongst the elements of the tissue.

**150. Cutting Sections of Tissues which have been previously dried.**

—There are, however, many tissues of which sections cannot be obtained in this simple manner. It is almost impossible to cut sections of soft membranous textures perpendicular to the surface, sufficiently thin for examination. In such cases, we may pin out the texture upon a board when perfectly fresh, and expose it to the atmosphere, or over sulphuric acid under a bell jar, pl. XXIV, fig. 5, p. 88, until it is quite dry. Thin sections may then be cut very easily, and upon being moistened with water they will resume their recent appearance. The very delicate nervous tissue of the retina may be cut into very thin sections by drying the eye after it has been cut open, and pinned out flat on a board. The vitreous humour is not to be entirely removed, as it protects the retina and dries up with it. Very thin sections of the skin of various animals, certain vegetable tissues, and of many other textures may be obtained by this process. This method of cutting thin sections has however given place to the process of freezing and cutting with the microtome, p. 94.

**151. Hardening the Tissue.**—Some textures require different treatment in order to render them sufficiently hard to enable us to cut thin sections. Boiling in water is sometimes useful for this purpose. Some tissues may be hardened by being soaked in alcohol, or chromic acid, or in Muller's fluid (sulphate of soda 1 part, bichromate of potash 2, water 100). Not a few require special modes of treatment, which are applicable to them alone. See part VI, where the use of various solutions for hardening and their composition is described.

*Cutting thin Sections of Hard Tissues.*

**152. Of Making Thin Sections of Dry Bone.**—For obtaining thin

sections of bone, a totally different process is requisite. In the first place, a section as thin as possible is removed from the bone with the aid of a thin sharp saw, pl. XXV, fig. 8, p. 92. This may be made somewhat thinner by a file, and afterwards ground down to the required degree of tenuity upon a hone. The best stones for this purpose are the Arkansas oil stones or the Turkey stones which have been ground perfectly flat. The section may be kept in contact with the stone by the pressure of the thumb or finger, or with a piece of cork, by which the skin of the finger may be saved, or lastly, it may be rubbed between two hones, one of which is much smaller than the other.

The section is to be ground down with the aid of a little water, and when sufficiently thin it may be subjected to examination in the microscope. It will, however, be found, that the beauty of the tissue is completely obscured, owing to the number of scratches upon its surface. These may be removed by rubbing the section first upon a very smooth dry hone, and afterwards upon a piece of plate glass. After the piece of bone has been properly polished, no lines will be seen upon it, when it is examined in the microscope.

**153. Teeth.**—Sections of dry teeth cannot be advantageously prepared in the manner just described, owing to the very brittle nature of the enamel. The better way is to grind the tooth down with the aid of a dentist's lathe until a section sufficiently thin be obtained.

Sections of *fresh* bone and teeth may be prepared moist so as to show many very important points in their structure and mode of growth, according to the plan described in part VI. After they have been soaked for some time in glycerine and acetic acid (10 drops to the ounce), very thin shavings even of enamel may be obtained with a strong sharp knife. The calcareous matter may be dissolved out from specimens by hydrochloric acid diluted with water or glycerine (1 part to from 3 to 10 parts), and sections of the decalcified matrix easily cut with a sharp knife.

**154. Sections of Shells** of many of the lower animals, and the hard shells and stones of fruit may be made in the manner above described by grinding on a hone, but very hard textures, such as fossil wood, must be obtained of the lapidary. See also "Of examining minerals and fossils," in part III.

**155. Horn and Hair.**—Thin sections of horn and textures of this description may be cut without difficulty with a sharp strong knife, pl. XIX, fig. 4, p. 52.

*Hair.*—There are many ways of obtaining thin transverse sections of hair. A number of hairs may be united together with a little gum or glue, so as to form, when dry, a firm hard mass. Thin sections of this can be readily made, with a sharp knife, and in any direction, transverse, oblique, or longitudinal, and the individual pieces may be

separated from each other, by the application of a drop of water. These may be mounted in fluid, or dried and preserved in glycerine, or Canada balsam, § 143. Another method is this:—The hairs are to be placed between two pieces of cardboard, or between two flat pieces of cork, and when tightly pressed in a vice, thin sections of the hair, including the cardboard and cork, can be obtained with a sharp knife. For cutting thin transverse sections of hair, my friend, the late Professor Weber, of Leipzig, adopted a very simple expedient. He used to advise that the beard should be shorn very closely, and then after a few hours shorn again. In this way excessively thin sections of hair in great numbers may be obtained without difficulty. After being removed from the lather, they are to be well washed in distilled water and dried at the ordinary temperature. The razor should be well sharpened.

**156. On Cutting Sections of Wood and Textures of that Character.**

—Thin sections of various woods and other textures of a certain degree of firmness may be cut with the aid of the simple microtome, which is represented in pl. XXV, fig. 6, p. 92. After having been allowed to soak for some time in water, the wood is placed in the hole, and kept in its position by the side screw. Upon turning the side screw the wood is forced above the brass plate. A clean section is now made with a sharp strong knife or razor. By turning the screw beneath, very slightly, the wood is forced above the surface of the brass plate, and thus a section of any required thickness may be obtained. *See* also p. 94.

ON THE SEPARATION OF DEPOSITS FROM FLUIDS.

Before we can ascertain the nature of a deposit suspended in a fluid, it is necessary to separate as much of it as possible, and to collect it into a small space. Diffused as the deposit often is through a large bulk of fluid, the observer would scarcely be surprised if he failed to distinguish it, when a drop was placed under the microscope.

The ordinary method of separating deposits from fluids is by filtration. The arrangement of the funnel and the mode of folding the paper, for filtering, are shown in pl. XXVI, figs. 1 and 9, p. 100. Filtration, however, will not answer for microscopical purposes, when a mere trace of deposit has to be collected from a large quantity of fluid. Moreover, particles from the filtering paper often become mixed with the deposit and thus the specimen may be spoilt by the presence of extraneous matters. It will, therefore, be necessary to adopt some other expedients.

**157. Conical Glasses.**—In order to collect the deposit for microscopical examination, the fluid containing it is placed in a conical glass, the lower portion of which is narrow. It should not, however, terminate in an actual point but rather in a slightly rounded extremity. After

standing for some hours, the deposit falls to the narrow portion of the glass, and may be removed with the pipette. A useful form of conical glass is represented in pl. XXVI, fig. 3.

**158. The Pipette** consists of a glass tube, about ten inches in length, the upper extremity being slightly enlarged, so that the finger may be conveniently applied to it, and the lower orifice contracted, so as to be about one-tenth of an inch in diameter. It is convenient to have a ridge around the glass tube, about three inches from its upper extremity. This enables one to hold the tube firmly between the thumb and middle finger, pl. XXVI, fig. 2.

**159. Removing the Deposit with the Pipette.**—The removal of the deposit is easily effected. The pipette is held by the middle finger and thumb, while the index finger is firmly applied to its upper extremity. The point is next plunged beneath the surface of the fluid and carried down to the deposit, a portion of which will rush up the tube if the pressure of the finger upon the upper extremity be slightly relaxed. The deposit having entered the tube, the pressure is re-applied, and the deposit contained in the pipette can be removed from the bulk of the fluid, pl. XXVI, fig. 3.

**160. On Separating the Coarse from the Finer Particles of a Deposit.**—Many deposits, by being diffused through a large quantity of water, may be separated into several portions according to their density. The fluid, with substances suspended in it, is well stirred, and, after being allowed to stand for a very short time, all but the deposit is poured off into another vessel. In this the fluid is again allowed to stand for a short time, and again poured off. This process may be repeated several times. In the first glass, only the coarser particles will be found; in the second, slightly finer particles; in the third, still finer ones, and so on; a longer period being allowed for the subsidence in each successive case. The coarse particles may also often be separated from finer ones by straining the deposit through muslin.

Various preservative solutions, which I have already described, are applicable for preserving deposits from fluids. Many sedimentary matters may be mounted in Canada balsam.

**161. Separation of Deposit when very small in Quantity.**—Where the deposit is exceedingly small in quantity, and diffused through a great bulk of fluid, a slight modification of the above plan must be resorted to. The pipette, containing as much of the deposit as can be obtained, is removed from the glass vessel containing the bulk of the fluid. Its contents are prevented from escaping by the application of the finger to its lower orifice. The upper extremity is then closed with a small cork. Upon now removing the finger from the lower orifice, of course no fluid will escape. The pipette is allowed to stand with its mouth downwards upon the glass slide, in which position it may be permitted to remain

Fig. 1.



Small retort stand, with funnel and beaker arranged for filtering. p. 94.

Fig. 2.



Pipettes made of glass tubing. p. 100.

Fig. 3.



To illustrate the mode of using the pipette p. 100.

Fig. 4.



To illustrate the manner in which the thin glass is allowed to fall gradually upon an object mounted in fluid. p. 82.

Fig. 5.



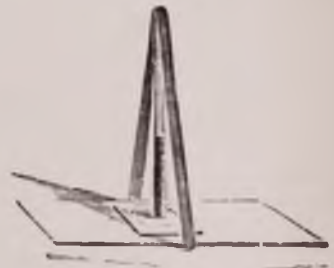
Wash bottle. p. 101.

Fig. 6.



Mode of collecting deposit upon a glass slide from fluid contained in a pipette. p. 101.

Fig. 7.



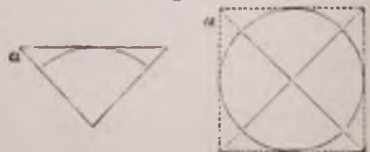
Shows the manner in which a very small quantity of deposit may be obtained from a fluid by placing it in a test tube and inverting it over the glass slide. It is kept in position by an india-rubber band. p. 101.

Fig. 8.



Corked tubes for containing prepared tissues, &c. p. 101.

Fig. 9.



Mode of folding filtering paper. p. 99.





some hours, either being suspended with a string or allowed to lean against some upright object. It is obvious that under these circumstances the most minute deposit contained in the fluid will at length gravitate to its lower part, and be received upon the slide, without the escape of much of the fluid. Or the sediment, having been allowed to subside in a conical glass, may be poured into a very narrow test tube. Upon a glass slide being applied to the open end, the tube may be inverted, and the deposit will gradually collect upon the slide. The arrangement will be understood by reference to fig. 6, pl. XXVI, p. 100.

According to either of the above methods any insoluble substances diffused through fluids can be easily collected for the purposes of the microscopist. Shells of the diatomaceæ may be collected for microscopical examination by being diffused through a considerable quantity of water, and after subsidence, separated in the manner above described.

**162. Examination of the Deposit.**—The deposit removed by the pipette may be transferred to the thin glass, tinfoil, or Brunswick black cells, §§ 115 to 118, and submitted to examination in the microscope. The animalcule cage, p. 76, will also be found very convenient for the examination of deposits from fluids, and it serves the purpose of a compressorium when a very great amount of pressure is not required. It is important that the shoulder of the animalcule cage upon which the cover fits should be at least as wide as the one figured in pl. XXII, fig. 7, p. 78, otherwise when the glasses are not cleaned immediately after use, solutions which have been examined are apt to dry and thus the removal of the cover without fracture of the glass is very difficult.

**163. Wash-bottle.**—In many operations, especially in washing deposits previous to microscopical examination and in filtration, the wash-bottle used by chemists is of great use, as by it a stream of water of any required degree of force can be easily directed to any particular point, either for the purpose of washing away foreign particles, or for removing part of the deposit itself. The wash-bottle is also of great use in preparing sections of soft tissues for observation. It is made by inserting a cork into an ordinary half-pint bottle. Through the cork pass two tubes, bent at the proper angle. The longest terminates in a contracted orifice, while its other extremity reaches down to the bottom of the bottle. The shorter tube reaches only to the lower part of the cork, pl. XXVI, fig. 5. By blowing through the shorter tube, air is made to press upon the surface of the water, which is thus driven up the longer tube and may be projected upon any point desired.

The observer must have a stock of *small tubes*, about two inches in length and a quarter of an inch in diameter, like those used by homœopaths for the preservation of their globules, fig. 8, pl. XXVI, and several small *watch glasses* of different sizes.

## OF INJECTING VESSELS.

The arrangement of the minute vessels or capillaries distributed to the various textures of man and animals is not to be demonstrated in all instances without special preparation, in consequence of the transparency of the walls of the tubes. Indeed, in an ordinary examination of many a tissue in the microscope, one often fails to detect the least trace of any structure, although it may be almost entirely composed of distinct fibres and vessels. Some even yet maintain the opinion, that the capillaries are to be looked upon in the light of mere channels in the interstices of the tissues, rather than as tubes, with their own proper walls. But if this view were correct we should not meet with the perfectly circular outline which the section of a capillary vessel that has been properly injected invariably presents; nor should we be able to obtain capillaries completely isolated from other tissues, as we may sometimes succeed in doing.

**164. Of Natural and Artificial Injections.**—Sometimes the capillary vessels remain turgid with blood after the death of the animal, and a *natural injection* results. Natural injections, however, are accidental and cannot be obtained with any certainty in the case of every texture. In order, therefore, to investigate the arrangement of minute transparent vessels of any kind, it is necessary to colour them or to resort to the process of *artificial injection*, by which a certain quantity of coloured material may be forced into them. In some cases by simply making a hole in the tissue and inserting the point of the syringe, the injection may be forced at once into the minute vessels, but in the case of the tissues of man and the higher animals, we can fix the pipe of the syringe into a large vessel from which the injection will pass to smaller ones. From a large arterial trunk, the injection will often immediately penetrate to the smallest vessels and sometimes even return by the veins.

The injecting material employed may be *opaque* or *transparent*, *coloured* or *colourless*. In the first case the injected preparations can only be examined by *reflected light* as an *opaque object*, p. 22, while transparent injections may be subjected to examination by *transmitted light*, p. 23, as well as by *reflected light*. Examples of opaque and transparent injections in which different substances have been employed as colouring matters, can be purchased at all the microscope makers. See list at the end of the volume. Every student is, however, strongly recommended to learn to make injected preparations for himself.

**165. Instruments required for Making Injections.**—The different instruments required for making artificial injections are the following:—

An *injecting syringe*, of about the capacity of one ounce or even half an ounce, pl. XXVII, figs. 4, 5. The piston of the injecting syringe should be covered with two pieces of leather, which may be very easily removed and replaced, fig. 1. The first piece, *a*, is applied and screwed down with a brass button, *b*. The piston is then passed down the tube and forced out at the lower opening. The second piece of leather, *c*, is then put on, and fixed in its place by another button, *e*. In the syringes now made for me by Mr. Matthews, the piston consists entirely of metal. I have found syringes of this description work perfectly for twenty years. The necessity for re-leathering is obviated, but they are rather expensive.

Mr. Robertson of Oxford has lately added a second collar, fig. 5, pl. XXVII, p. 104, to the injecting syringe, so that the two first fingers can firmly hold the syringe while the piston is raised and depressed with the thumb. By this little alteration the syringe can be filled and entirely worked with the right hand, while the left is quite free to hold the pipe in the right position.

*Pipes*, of different sizes, to insert into the vessels, figs. 10, 11, pl. XXVII. The tubes of the smaller pipes should be made of silver.

*Corks*, of the form represented in fig. 3, for the purpose of plugging pipes while the syringe is being filled with injecting fluid. A stopcock, fig. 9, is also useful for the same purpose.

*Forceps*, of the form shown in fig. 2, which are known to surgical instrument makers as *bull's nose forceps*, for stopping up any vessels through which the injection may escape accidentally.

*A Needle*, of the form of the *aneurism needle* used by surgeons, for passing the thread round the vessel to tie it to the pipe which is inserted into it, fig. 12. This needle may be made of an ordinary darning needle which has been carefully bent round after having been heated in the flame of a lamp. The *thread* which is used should be strong but not too thin, as there would be danger of its cutting through the coats of the vessel.

**166. Injection Cans.**—Size or gelatine is used as the material in which the opaque colouring matter is suspended. It must be melted in a water-bath and strained immediately before use. The copper injecting can forms a very convenient apparatus in which to melt the gelatine. There are five cans in the bath, represented in fig. 6, pl. XXVII, so that injection may be very conveniently transferred from one into the other, while all may be kept warm over an ordinary lamp.

**167. Methods of obtaining the Pressure required for Successful Injection.**—The requisite amount of pressure for forcing the injection into the finest capillaries may be obtained by several different methods. The old plan was to use the thumb to press down the piston of the syringe, but of late years instruments have been devised by which a very even

and constant pressure may be obtained, and which can be graduated as the operator may desire.

1. A long glass tube is prepared to contain the injecting fluid, and arranged so that it may be kept perpendicular. To the lower end is attached a piece of  $\frac{1}{4}$ -inch India-rubber tube furnished with a stopcock which fits into the injecting pipe. The pressure of the column of fluid in the tube, which should be three or four feet high, is sufficient to cause the injecting fluid to enter the capillary vessels. Pl. XXVII, fig. 7.

2. The injecting fluid is placed in a vessel three or four feet above the table, and a syphon tube which may be entirely composed of India-rubber or partly of glass is immersed in it.

3. A glass vessel may be arranged upon the principle of the wash-bottle, p. 101, pl. XXVII, fig. 7, pressure upon the surface of the liquid being produced by the aid of an India-rubber bottle compressed by a weight or spring, or by pouring mercury into the tube which reaches nearly to the bottom of the flask. The other tube must of course also dip below the surface of the injecting fluid while to its upper free end a piece of India-rubber tubing provided with a stopcock at its extremity, must be adapted.

4. The pressure may be applied to the surface of the fluid by distending with air an India-rubber bottle.

5. Various ingenious arrangements have been devised in which a column of mercury supplies the pressure required to force the fluid through the capillaries. The mercury is made to compress the air in one bottle which is connected with others containing the injection by glass tubes. In this way several injections may be made at the same time. Any means by which air may be made to exert graduated pressure on the surface of fluid may be employed for injection. Condensed air or gas may be used for the purpose, a good stopcock being provided for governing the emission. Each vessel containing injection has a piece of India-rubber tube proceeding from it, and is provided with a stopcock to fit into the pipe.

Other very ingenious arrangements have also been suggested, but after having tried many different methods of proceeding, I find that upon the whole, the ordinary injecting syringe is the most successful as well as the cheapest, the most convenient, and the most simple instrument, and it is very easily kept in good order. It need scarcely be said that by no mechanical means can such varieties of pressure be obtained as by the aid of the muscles of the fingers and thumb, while the pressure can be instantly modified or removed at the pleasure of the operator.

The operation of injecting is described in page 114.

#### *Of Opaque Injections.*

Although by the old system of making opaque injections there is no

Fig. 1.



Shows the manner in which the piston of the injecting syringe is made air tight. *a, c.* pieces of leather. p. 87

Fig. 2.



Bull's nose forceps for closing an open vessel to prevent the escape of the injection. p. 103.

Fig. 3.



Corks for stopping the pipes while the injecting syringe is being refilled. p. 103.

Fig. 4.

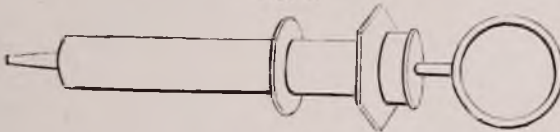


Syringe for injecting small animals or portions of tissue. p. 102.

Fig. 7.

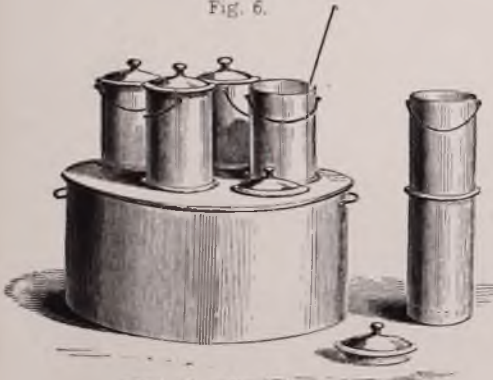


Fig. 5.



Improved small injecting syringe as suggested by Mr. Robertson. p. 103.

Fig. 6.



Can for heating size. It may also be used as a water-bath for drying objects, or for conducting evaporation. p. 103.



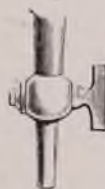
Apparatus for performing the operation of injecting by the pressure of the injecting fluid. p. 104.

Fig. 8.



Performing the operation of injecting. p. 98.

Fig. 9.



Stop cock and injecting pipe which fit on to the syringe. p. 102.

Fig. 10.

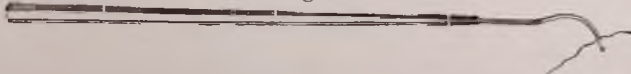


Fig. 11.



Injecting pipe with orifice near point pp. 102, 109.

Fig. 12.



Needle for passing thread round a vessel, the cut end of which is to be tied on an injecting pipe. p. 103.



chance of making out new points in the structure of tissues and organs, and the process is now seldom adopted, I shall give directions for making these injections, in case some of my readers may desire to prepare specimens. To make a perfect vermilion injection undoubtedly requires a degree of skill which any one may be proud to possess, but it is quite certain that little which has not been already demonstrated long ago will be discovered by the process.

**168. The Size** should be of such a strength as to form a tolerably firm jelly on cooling. If gelatine is employed it must be soaked for some hours in cold water before it is warmed. About an ounce of gelatine to a pint of water will be sufficiently strong, but in very hot weather it is necessary to add a little more gelatine. It must be soaked in part of the cold water until it swells up and becomes soft, when the rest of the water, made hot, is to be added. Good gelatine for injecting purposes may be obtained for two shillings a pound.

**169. Colouring Matters.**—The colouring matters usually employed in making opaque injections are the following:—*Vermilion*, *Chromate of Lead*, and *White Lead*. Of these, vermilion affords the most beautiful preparations, but chromate of lead properly prepared is much cheaper, and it may be obtained in a state of more minute division. White lead forms a good colouring matter, but its density, and its tendency to become brown and black when exposed to the action of sulphuretted hydrogen, formed in the decomposition of the tissues, are objections to its use.

**170. Vermilion** of sufficiently good quality can be purchased of artists' colourmen for six or eight shillings a pound. If upon microscopical examination a number of very coarse particles be found in the vermilion, it will be necessary to separate these by washing in water in the manner described in § 160.

**171. The Chromate of Lead** is prepared fresh as required, by mixing cold saturated solutions of acetate of lead and bichromate of potash. The yellow precipitate is allowed to settle, and after the clear solution of acetate of potash resulting from the decomposition has been poured off, the yellow sediment is shaken up with warm water, again permitted to settle and mixed with warm strong size or gelatine. After being strained through muslin the mixture may be injected into the vessels.

**171.\* The Carbonate of Lead or White Lead** is also better if freshly prepared by mixing together saturated solutions of acetate of lead and carbonate of soda. The precipitate is to be treated as the former one and mixed with size.

In preparing opaque injections, the observer should bear in mind that the colouring matter should be well mixed with the size, otherwise the vessels will not be uniformly filled, and it is better to employ a small



syringe rather than a large one, as there is not so much chance of the colouring matter separating from the size before the mixture is forced into the vessels. In all cases the mixture may be made in a mortar, poured into one of the injection cans, fig. 6 *a*, pl. XXVII, and *strained into another through muslin just before it is injected* into the vessels of the animal.

**172. Size of the Particles of the Colouring Matter used.**—The size of the particles of the different substances employed in making opaque injections is represented in pl. XXVIII, and if the different figures be compared with one another, it will be observed that those colouring matters which have been recently prepared are in a much more minute state of division than those which have been kept for some time. The appearances represented were obtained by examination with a power of 215 diameters.

Opaque injections are represented in pl. XXIX, figs. 1, 2, p. 108.

**173. Of Injecting Different Systems of Vessels with Different Opaque Injections.**—It is often desirable to inject different systems of vessels distributed to an organ with different colours, in order to ascertain the arrangement of each set of vessels and their exact relation to one another. A portion of the gall-bladder in which the veins have been injected with white lead, and the arteries with vermilion, forms a beautiful preparation. Each artery, even to its smallest ramifications, is seen to be accompanied by two small veins, one lying on either side of it. A beautiful injection of the gall-bladder is represented in pl. XXIX, fig. 1.

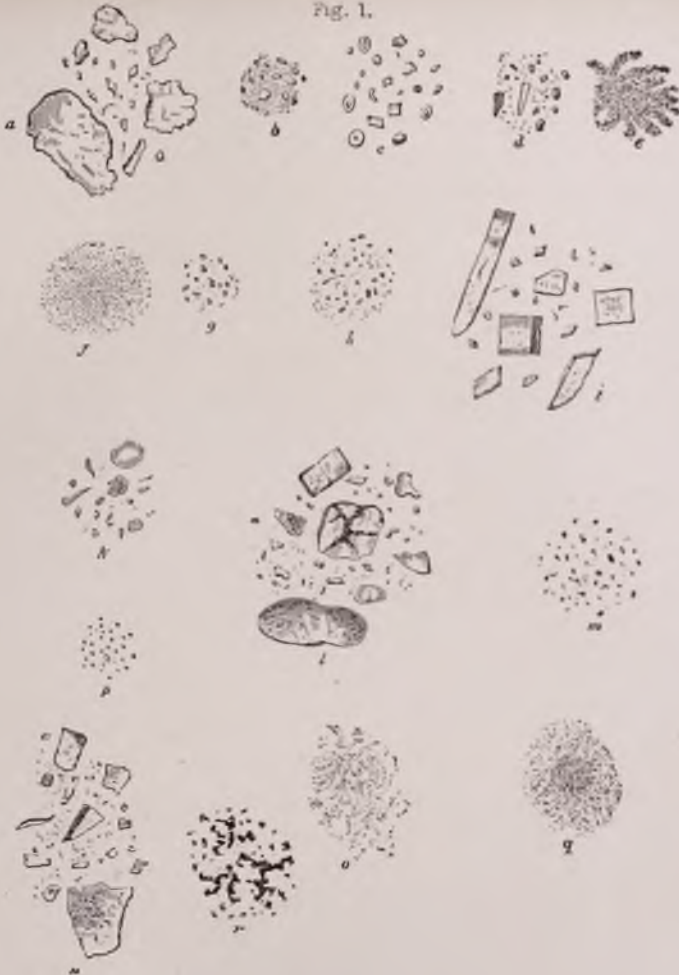
In an injection of the liver, four sets of tubes may be injected with the following different colouring matters:—The artery with *Vermilion*, the portal vein with *White Lead*, the duct with *Prussian Blue*, and the hepatic vein with *Lake*. Many opaque colouring matters besides those above-mentioned may be employed for double injections.

#### *Of Transparent Injections.*

**174. Advantages of Transparent Injections.**—Nearly thirty years ago I abandoned the old plan of making injected preparations, in favour of the method of using transparent injecting fluids which are miscible with water in all proportions. Besides the matter for giving colour, I added to these fluids solutions which exert a preservative action upon the tissue with which they come in contact, and in some instances substances which had the property of rendering certain elements of the tissue more transparent or opaque were added. By this new plan of injection most important advantages are gained. Not only are the vessels injected with colouring matter, but—

1. The fluids in the vessels are at once altered and preserved by

Fig. 1.



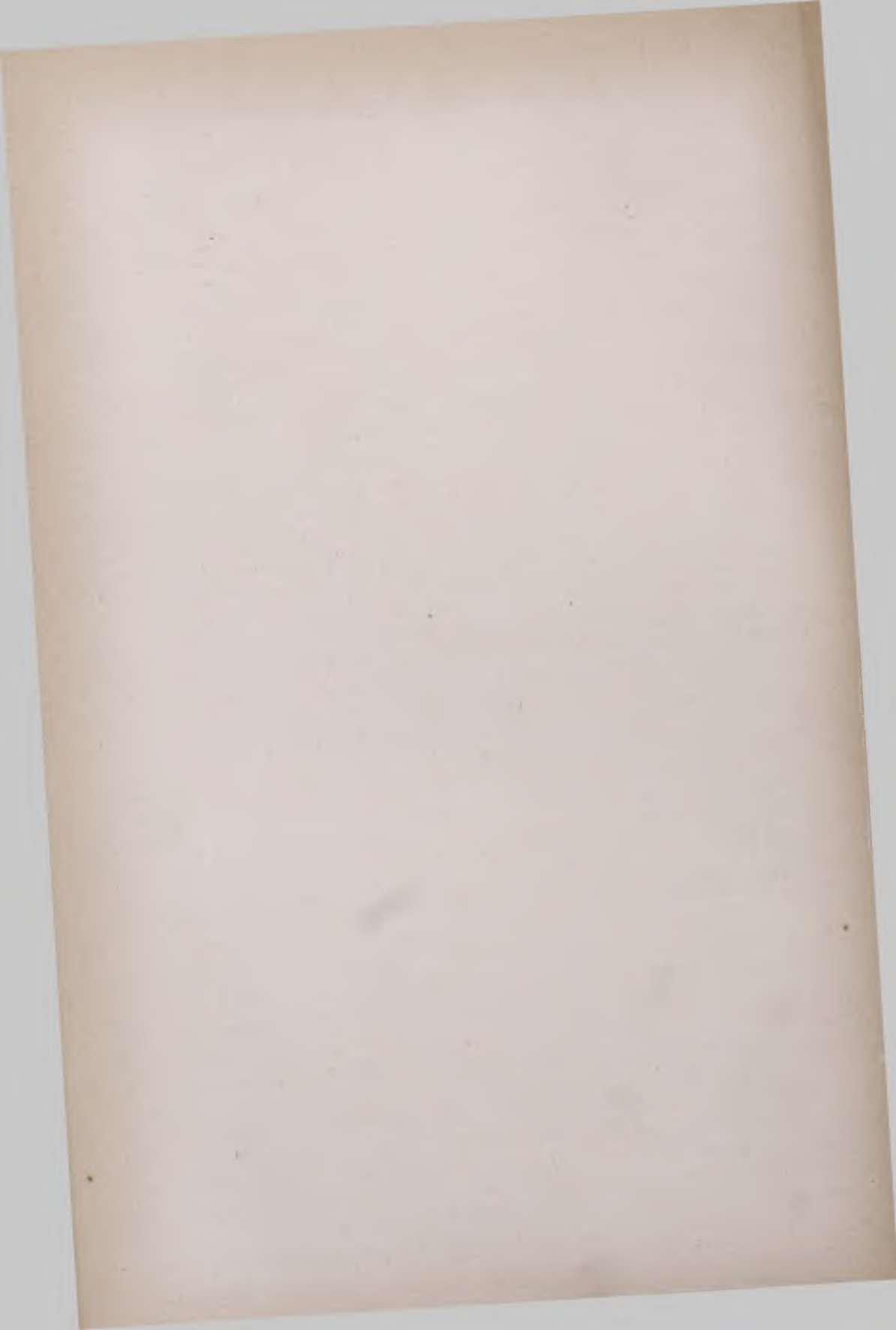
Colouring matter used for injecting, showing the comparative size of the particles. *a* precipitated chalk in a dry state. *b* chalk recently precipitated. *c* whitening. *d* Prussian blue, as purchased. *e* recently precipitated Prussian blue. *f* freshly precipitated carbonate of lead. *g* dried carbonate of lead. *h* freshly precipitated binoxide of mercury. *i* dried binoxide of mercury. *k* indigo. *l* vermilion, as purchased. *m* levigated vermilion. *p* pure carmine. *n* dried chromate of lead. *r* freshly precipitated chromate of lead (hot solutions of bichromate of potash and acetate of lead). *o* freshly precipitated chromate of lead (cold solutions). *q* lamp black.  $\times 215$ . p. 106.

Fig. 2.



Lymphatics injected with Prussian blue. From the portal canal. Liver. Ox.  $\times 15$ . p. 118.

[To face page 106.



the injection and decomposition, and changes in these as well as in the tissues are completely prevented.

2. Certain tissues are rendered more distinct than in the natural state.

3. Every structural element of the tissue can be demonstrated as well as the vessels.

4. Tissues prepared by this process can be subjected to examination, by powers magnifying more than 3,000 diameters. *See* part VI.

5. All tissues thus prepared may be mounted in aqueous preservative solutions, and the most delicate structures retained in their integrity.

6. By this process of injection alone can the alteration of the most delicate tissues, which occurs very soon after death, be prevented.

Transparent injections are represented in pl. XXX. Figs. 1, 2, and 3 show the vessels well distended with injection. The structure of the coats of the small artery, fig. 2, is well seen—indeed, the individual muscular fibre-cells are quite distinct. In fig. 3 the capillaries are distended with transparent injection, and every one of the bioplasts in the walls of the little vein and capillary vessels is clearly demonstrated. It will be seen that this new process of injecting is based upon several important principles, which will be more fully enunciated in part VI.

Of late years carmine fluid has been much used for transparent injections, especially in Germany; but although many of the specimens thus prepared are very beautiful, the process adopted is open to objection. The specimens *are mounted in balsam*, and thus the structure of the tissues external to the vessels is not to be clearly discerned. Moreover, the vessels with the contained injection have become much reduced in diameter in consequence of being hardened or dried, and generally, the appearances seen cannot be regarded as natural. It is almost certain that all that can be learnt by such modes of preparation, has been already learnt. If the investigation is to be carried further, it is necessary that the tissue be prevented from undergoing post-mortem change, and that it be preserved in some *viscid aqueous fluid*, which will support the delicate structural elements. The only mode of preparation by which injected textures can be subjected to examination by the highest powers, and which permits of all the several structures entering into their composition being displayed in the same specimen, is that which I am advocating in conjunction with the staining process, and which is fully described in part VI.

In order to inject the vessels for investigation by transmitted light several different substances may be employed as injecting fluids; but if it is desired to study the *tissues* as well as the *arrangement of the vessels*, the points just adverted to must be borne in mind, and the particular plan recommended in part VI will be found advantageous.

**175. Injection with Plain Size and with Size and Glycerine.—A**

tissue which has been injected with plain size, when cold is of a good consistence, so that thin sections may be easily made with a sharp knife. Many important facts may be learnt from a specimen prepared in this manner which would not be detected by other modes of preparation. A mixture of equal parts of gelatine and glycerine is, however, much to be preferred, and the specimen thus prepared is sure to keep well. Very thin sections of spongy tissues like the lung may be most successfully made after injection with strong gelatine or gelatine and glycerine.

**176. Colouring Matters for Transparent Injections.**—The chief colouring matters used for making transparent injections are *carmine* and *Prussian blue*. The former may be prepared by adding a little solution of ammonia (liquor ammoniæ) to the carmine, and diluting the mixture until the proper colour is obtained, or it may be diluted with size. The latter by adding an acidulated persalt of iron to a solution of ferrocyanide of potassium. The first solution will be alkaline and the last acid.

**177. Advantages of Employing Prussian Blue.**—In order to inject satisfactorily the most minute vessels of a tissue, and at the same time to demonstrate their relation to adjacent structures, we must be provided with an injecting medium which possesses the following properties:—The fluid must be of such a consistence that it will run readily through the smallest vessels. It must contain a certain amount of colouring matter to render the arrangement of the vessels distinct, but must be sufficiently transparent to admit of the examination of the specimen by transmitted light. The colouring matter must not be *soluble* like the ammoniacal solution of carmine above referred to, for in that case it would permeate the walls of the vessels and colour the tissues indiscriminately, and would thus prevent the vessels from being distinguished from other textures. Though insoluble, the particles of which the colouring matter is composed should be so minute as not to exhibit distinct granules when examined with the highest powers, for if that were so, the specimen would have a confused appearance. The fluid in which the colouring matter is suspended, must be capable of permeating the walls of the vessels with tolerable facility. It must possess a certain refractive power, and a density approaching to that of the fluid by which the tissues are bathed in their natural condition. Its composition ought to be such that it may be employed without the application of heat.

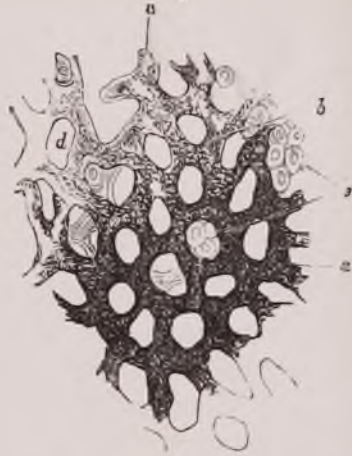
The injecting fluid must not escape too readily from the numerous open vessels necessarily exposed in cutting a thin section of the tissue for examination, and particles accidentally escaping ought not to adhere intimately to the surface of the section, for if they did so, the specimen would be rendered confused and indistinct, especially if submitted to examination under high magnifying powers. The fluid employed ought

Fig. 1.



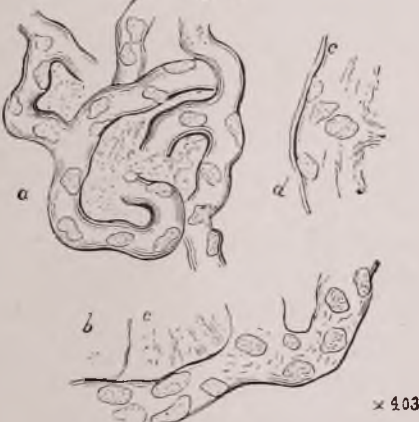
Vessels of gall bladder. A double injection of arteries and veins. p. 106.

Fig. 2.



Capillaries of the liver injected with chromate of lead. (Raney.) p. 106.

Fig. 3.



Capillaries injected with Prussian blue fluid. From the kidney. p. 121.

Fig. 4.



To illustrate the mode of injecting a piece of intestine. pp. 115-135.

Fig. 5.



Capillaries of grey matter. Brain of Guinea pig. Injected with size and carmine. German preparation, mounted in Canada balsam. No nuclei to be seen on the vessels. The injection in the vessels much contracted. No nerve cells to be seen in the intervals. x 215. p. 121.

Fig. 6.



Capillaries. Grey matter. Brain of Guinea pig. Injected with the Prussian blue fluid and preserved in glycerine. The nuclei of the capillaries seen distinctly, as well as the nerve cells of the grey matter. At a a small artery with the nuclei of its muscular fibre cells. x 15. p. 121.



to have preservative properties, or at least should not in any way interfere with the preservation of the specimen. The injecting fluid ought not to undergo any alteration by being kept for some time, and it should be cheap and capable of being readily prepared.

*The Prussian blue fluid*, which consists of an insoluble precipitate, so minutely divided that it appears like a solution to the eye, fulfils all these requirements. The particles of freshly prepared Prussian blue are very much smaller than those of any of the colouring matters employed for making opaque injections. For nearly thirty years I have employed Prussian blue as the injecting fluid, and according to my experience it possesses advantages over every other colouring matter. It is inexpensive. It may be injected cold. The preparation does not require to be warmed. No size is necessary. The injection penetrates the capillaries without the necessity of applying much force. It does not run out when a very thin section of the tissue is made for examination, neither do any particles which may escape from the larger vessels divided in making the section, adhere to it and in this way render obscure the structural peculiarities of the various elements of the tissue. And lastly, the most minute capillary vessels of a tissue or organ, or of a part of an organ, may be perfectly injected in the course of a few minutes.

Specimens prepared in this manner may be preserved in any of the ordinary preservative solutions, or may be dried and mounted in Canada balsam. I give the preference to glycerine, § 100, or glycerine jelly, § 106. The preparations may be subjected to examination with the highest magnifying powers. After having tried very many methods of making a blue injecting fluid, I have found that the two following answer admirably. For very fine injections the mixture may be diluted by adding three ounces of glycerine. *See also part VI.*

I would most earnestly recommend all who are fond of preparing injected specimens to employ transparent injecting fluids, and to endeavour, by trying various transparent colouring matters, to discover several which may be employed for injecting different vessels of the same animal. I feel sure that by the use of carefully prepared transparent injecting fluids, many new points in the anatomy tissues will be made out.

**178. Prussian Blue Fluid.**—*Composition of the cheap ordinary Prussian blue fluid for making transparent injections* :—

Glycerine	...	...	...	...	...	1 ounce.
Spirits of Wine	...	...	...	...	...	1 ounce.
Ferrocyanide of Potassium	...	...	...	...	...	12 grains.
Tincture or Solution of Perchloride of Iron*						1 drachm.
Water	...	...	...	...	...	4 ounces.

\* *Tinctura Ferri Perchloridi* and the *Liquor Ferri Perchloridi* of the British Pharmacopœia, of 1867, are of the same strength and consist of one part of the strong *Liquor Ferri Perchlor.* to three parts, by measure, of spirit or water.



The ferrocyanide of potassium is to be dissolved in one ounce of the water and glycerine, and the tincture of sesquichloride of iron added to another ounce. These solutions should be mixed together *very gradually* and well shaken in a bottle,—*the iron being added to the solution of the ferrocyanide of potassium*. When thoroughly mixed, the solutions should produce a dark blue mixture, in which *no precipitate or flocculi are observable* by the unaided eye. Next, the spirit and the water are to be added very gradually, the mixture being constantly shaken in a large stoppered bottle. The tincture of perchloride of iron is recommended because it can always be obtained of nearly uniform strength in any part of the world. It is generally called the *Muriated Tincture of Iron*, and may be purchased of the druggists. In cases in which a very fine injection is to be made for examination with the highest powers, half the quantity of iron and ferrocyanide of potassium may be used.

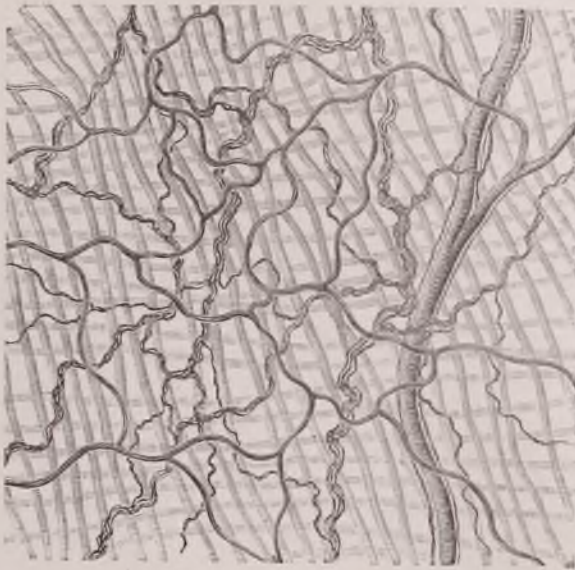
It has been remarked that as the colour of *Turnbull's blue* is brighter and is not liable to fade, it is to be preferred to the Prussian blue. The latter does not, however, lose its colour if a little free acid is present in the fluid in which the preparation is preserved. I have many specimens injected with Prussian blue, which have retained their colour perfectly for nearly thirty years. One advantage of the Prussian blue over other fluids is, that the ingredients required to make it are very cheap, and can be readily obtained everywhere. Capillaries injected with the Prussian blue fluid under different magnifying powers are represented in pl. XXIX, figs. 3, 6, and pl. XXX.

**179. Turnbull's Blue.**—My friend, Mr. B. Wills Richardson, of Dublin, has introduced Turnbull's blue in preference to ordinary Prussian blue. Ten grains of pure Sulphate of Iron are to be dissolved in an ounce of glycerine, or better, in a little distilled water and then mixed with glycerine, and thirty-two grains of *Ferridcyanide of Potassium* in another small proportion of water, and the solution mixed with glycerine. These two solutions are then gradually mixed together in a bottle, the iron solution being added to that of the ferridcyanide, and thorough mixture ensured by frequent agitation. The other ingredients are added as in the case of the Prussian blue fluid. This modification may be adopted in all cases in which I have recommended the ordinary Prussian blue. The proportions given in the text are, however, unnecessarily large, and I find that the following makes a good fine injecting fluid:—

Ferridcyanide of potassium	...	...	10	grams.
Sulphate of iron	...	...	5	„
Water	...	...	1	ounce.
Glycerine	...	...	2	ounces.
Alcohol	...	...	1	drachm.

VESSELS INJECTED.—SMALL ARTERY, VEIN, AND CAPILLARIES.

Fig. 1.



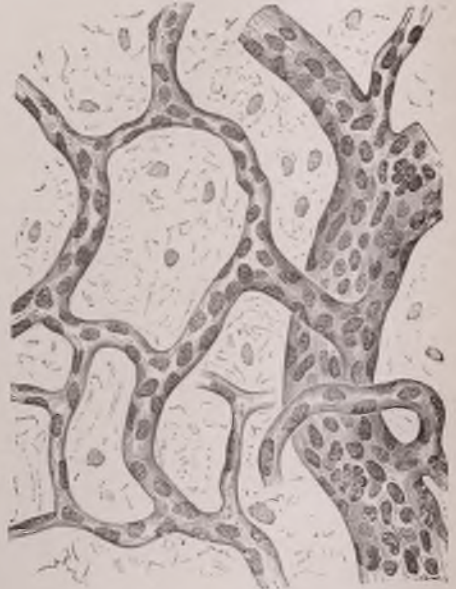
Myohybrid muscle of the hyla, showing very fine muscular fibres (not wider than blood corpuscles), capillary vessels, and networks of fine dark-bordered nerve fibres  $\times 130$ , and reduced to 65 diameters. p. 107.

Fig. 2.




A healthy artery from the kidney of a child, 3 years old, showing muscular fibre cells and longitudinal nuclei of elastic fibres and epithelium within.  $\times 215$ . p. 107.

Fig. 3.



Small vein and capillary vessels, showing bioplasts which are probably concerned in the absorption of materials from the blood and from the tissues. Fiamater, Lamb.  $\times 215$ . p. 107.

$\frac{1}{1000}$  of an inch,   $\times 215$ .



**180. Carmine Injecting Fluid.**—By the late Mr. Smee, Professor Gerlach, and others, a solution of carmine in ammonia was successfully used for making minute injections. The ammoniacal solution may be diluted to the required tint and injected. This fluid is applicable to injecting very delicate vessels, as those of the brain. If much force be employed, the ammoniacal solution transudes through the walls of the vessels, and tinges all the neighbouring tissues indiscriminately.

The ammoniacal solution of carmine is much improved, and its tendency to transude diminished, if glycerine and a little alcohol be added.

Professor Gerlach was the first who used a carmine injecting fluid. The beautiful carmine injections made in Germany are prepared with Gerlach's fluid, or a slight modification of it. I take the receipt from the excellent work of Dr. Frey ("Das Mikroskop") :—

Carmine ...	...	...	...	77 grains.
Water ...	...	...	...	70 grains.
Liquor ammoniæ	...	...	...	8 drops.

The carmine is to be dissolved in the ammonia and water, and the solution left for some days exposed to the air, and then mixed with pure gelatine, made by dissolving a drachm and a half of good gelatine in a drachm and three quarters of water. Lastly, a few drops of acetic acid are added to the mixture, which is injected warm.

**181. Acid Carmine Fluid.**—After trying a great many different combinations in order to make a good acid carmine injecting fluid, I found the following answer the purpose exceedingly well :—

Carmine ...	...	...	...	...	5 grains.
Glycerine, with eight or ten drops of	acetic or hydrochloric acid	...	...	...	} ½ ounce.
Glycerine ...	...	...	...	...	
Alcohol ...	...	...	...	...	2 drachms.
Water ...	...	...	...	...	6 „
Ammonia,	a few drops.				

Mix the carmine with a few drops of water and, when well incorporated, add about five drops of *liquor ammoniæ*. To this dark red solution, about half an ounce of the glycerine is to be added, and the whole well shaken in a bottle. Next, very gradually, pour in the acid glycerine, frequently shaking the bottle during admixture. Test the fluid from time to time with blue litmus paper, and if not of a very decidedly acid reaction, a few drops more acid may be added to the remainder of the glycerine, and mixed as before. Lastly, add the alcohol and water very gradually, shaking the bottle thoroughly after the addition of each successive portion, till the whole is well mixed. This

fluid, like the Prussian blue, may be kept ready prepared, and injections may be made with it very rapidly.

**182. Dr. Carter's Carmine Injecting Fluid.**—For a carmine injecting fluid which will run perfectly freely through the most minute capillaries, and one that will not tint the tissues beyond the vessels themselves, Dr. Carter, of Leamington, has found the following formula to answer satisfactorily :—

Pure carmine ... ..	60 grains.
Liq. ammon. fort. (P. B.) ... ..	120 „
Glacial acetic acid ... ..	86 minims.
Solution of gelatine (1 to 6 water) ... ..	2 ounces.
Water ... ..	1½ „

The carmine is to be dissolved in the solution of ammonia and filtered, if necessary. With this mix thoroughly an ounce and a half of the hot solution of gelatine. To the remaining half ounce of gelatine the acetic acid is to be added, and the mixture dropped, little by little, into the solution of carmine, stirring briskly during the whole time (*“Archives of Medicine,”* vol. III, p. 287).

This fluid is admirably adapted for specimens which are to be mounted in Canada balsam, but not for those to be preserved in glycerine. The vessels are well displayed, but all the delicate nerve fibres are invisible.

Transparent injecting fluids of several different colours are very much to be desired, but although many experiments have been made in the hope of obtaining such, we are, as yet, restricted to two, the blue and the red. Thiersch has succeeded in making others, the composition of one of which, yellow, is given below. I have not myself met with much success hitherto in the use of these fluids, for if I employ them according to the directions given, I am unable to demonstrate the masses of bioplasm (nuclei), and various points of importance in connection with the minute structure of the tissues outside the vessels. When made according to the principles followed in the case of the Prussian blue fluid, the results obtained by means of some of the fluids recommended are by no means satisfactory, while, as the colour of some is affected by acids, the subsequent steps of the general process of injection I have adopted, cannot be carried out. They may, however, be useful to those who prefer to follow out plans of investigation resting upon different principles. *See* part VI.

An injecting fluid of a greenish tint may be made, according to the directions given on page 110, for Turnbull's blue, by employing different proportions of the ingredients,—1 grain or less of the sulphate of iron to 10 grains of the Ferridcyanide of Potassium.

Thiersch ("Das Mikroskop," 1865, von Dr. H. Frey) prepares a transparent yellow injecting fluid as follows:—

A.—A solution of bichromate of potash is made, in the proportion of one part of salt to two of water.

B.—A solution of nitrate of lead of the same strength.

One part of solution A is placed in a small basin and mixed with four parts of a concentrated solution of gelatine. Two parts of solution B are placed in another basin and mixed with four parts of jelly.

These are to be slowly and thoroughly mixed together at a temperature of from  $75^{\circ}$  to  $90^{\circ}$ , and then heated in a water-bath at a temperature of about  $212^{\circ}$  for half an hour or more. The mixture is then to be carefully filtered through flannel.

**183. Soluble Prussian Blue.**—Brücke recommends the following:—

Ferrocyanide of potassium, 217 grammes, dissolved in 1 litre of distilled water.

Perchloride of iron, 10 grammes to 1 litre of distilled water.

Sulphate of soda, a cold saturated solution.

One volume of each of the two first solutions is to be mixed with one volume of the soda solution. The iron and soda solution is then to be mixed gradually with the ferrocyanide and soda solution with constant stirring. The mixture is to stand for some hours, and the deposit collected on a filter. The deposit is then washed with small quantities of distilled water, until the filtrate runs through quite blue. The blue powder thus prepared is quite soluble (?) in distilled water. Brücke recommends that this be made into an injection with sufficient gelatine to ensure it setting into a jelly. After injection the preparation is to be thrown into spirit, and then hardened in alcohol 90 per cent. This last process, it may be remarked, will effectually destroy many delicate structures, and entirely alter all. Brücke states that the fluid bears chromic acid and bichromate of potash well, but says that all fluids containing glycerine must be carefully avoided. I recommend the student to inject with this mixture, and then try the Prussian blue fluid, the composition of which is given in p. 110, and compare the results.

**184. Of Injecting Different Systems of Vessels with Transparent Injections.**—The transparent injecting fluids which may be used for double injections, must have the same reaction. Thus the Prussian blue fluid, and the carmine solution without gelatine, p. 111, may be used for this purpose; but I have not yet been able to obtain other colours which answer as well as these. Good transparent yellow and green acid injecting fluids which might be used for double injection in cases in which the Prussian blue fluid was employed, are much wanted.

**185. Mercurial Injections** are not well adapted for microscopical

purposes, although mercury was formerly much employed for injecting lymphatic vessels and the ducts of glandular organs. The pressure exerted by a column of mercury a few inches in height is alone sufficient to force some into the vessels. The mercurial injecting apparatus consists of a glass tube, about half an inch in diameter and twelve inches or more in length, to one end of which has been fitted a steel screw to which a steel injecting pipe may be attached. The pipes and stopcocks must be made of steel, for otherwise they would be destroyed by the action of the mercury.

*Of Injecting the Vessels of the Higher Animals.*

**186. Of the Practical Operation of Injecting.**—It is generally stated that a successful injection of the vessels of an animal cannot be made until the muscular rigidity which comes on shortly after death, and which affects the muscular fibres of the arteries as well as those of the ordinary muscles of the body has passed off. I have, however, found that most perfect injections may be made before the muscular rigidity begins, that is, within a few minutes after the death of the animal. Most of my fine injections have been made less than five minutes after death, and in the case of very young animals, so complete has been the injection of the capillary vessels that where the capillary has not been fully developed, the injection has filled the pervious portion, and has penetrated to the very spot where the tube was commencing to be formed.

The student will find the process of injecting somewhat difficult at first, but although he may quite fail in the first attempts he makes, he must not give up, for this method of investigation is of the greatest advantage, and by it he will learn facts of considerable anatomical importance, and which cannot be determined by other means. Every one engaged in the investigation of the anatomy of tissues in health and disease, should be able to inject well. By employing the methods of proceeding recommended in the text, it will be found that with a little practice injections can be made without much sacrifice of time.

The steps of the process of transparent injection are very similar to those taken in making the opaque injections, except that when size is employed, the specimen must be placed in warm water until warm through, otherwise the size will solidify in the smaller vessels and the further flow of the injecting fluid will be prevented. Soaking for many hours is sometimes necessary for warming a large preparation through, and it is desirable to change the warm water frequently. The size must also be kept warm, strained immediately before use, and well stirred up each time the syringe is filled. But I strongly advise the student to begin to inject with the cold Prussian or Turnbull blue fluid, §§ 178, 179.

In the first place the following instruments, &c., must be conveniently

arranged, so that the operator may be able to take them up as he may require :—

The syringe should be thoroughly clean and in working order, with pipes thoroughly clean and pervious, stopcocks, and corks, pl. XXVII, p. 104, figs. 3, 4, 8, 9, 10, 11. One or two scalpels. Two or three pairs of sharp scissors. Dissecting forceps. Bull's nose forceps, fig. 2. Curved needle threaded with silk or thread, the thickness of the latter depending upon the size of the vessel to be tied, fig. 12. Wash-bottle, p. 101. Injecting fluid in a small vessel. Plenty of warm water if the injection is to be made with fluid containing size or gelatine.

The student is recommended to practise the process, by injecting the organs and animals in the order in which they are enumerated below, and not to proceed with the second until he has fairly succeeded with the first. In all cases the operation is to be conducted carefully, slowly, and without hurry, and very slight pressure is to be exerted on the piston of the syringe.

1. Kidneys of sheep or pig.—*Artery.*

2. Eye of ox.—*Artery.*—Two or three minutes will be time enough to make a complete injection of all the tissues of the eye of an ox. If the globe becomes very much distended by the injecting process, an opening must be made in the cornea which will permit the humours of the eye to escape, and thus space will be left for the complete distension of the vessels.

3. Rat, mouse, frog.—*Injected from the aorta.*

4. Portion of small intestine.—*Branch of artery.* All divided vessels being tied before commencing to inject, pl. XXIX, fig. 4, p. 108.

5. Liver. In one part a *branch of duct*; in a second, a *branch of artery*; in a third, *portal vein*; and in a fourth, *hepatic vein*.

The portal and hepatic vein, the artery and portal or hepatic vein, or the duct and portal vein may be injected with injections of different colours in one piece of liver.

**187. Injecting a Frog.**—Suppose the student is about to inject a frog. An incision is made through the skin, and the sternum divided in the middle line with a pair of strong scissors; the two sides may be easily separated, and the heart exposed. Next the sac in which the heart is contained (pericardium) is carefully opened with scissors, and the fleshy part of the heart seized with the forceps; a small opening is made with a narrow knife or by making a snip with the points of the scissors, near its lower part. A considerable quantity of blood will escape from the wound, and this is to be washed away carefully by the aid of the wash-bottle, p. 101. Into the opening—the tip of the heart being still held firmly with the forceps—a fine injecting pipe, previously ascertained to be thoroughly pervious, by blowing air through it, and then drawing into it some of the injecting fluid, is inserted and directed



upwards towards the base of the heart to the point where the artery is seen to be connected with the muscular substance. *Before the pipe is introduced, a little of the injecting fluid is drawn up so as to fill it.* If this were not done, the air contained in the pipe would necessarily be forced into the vessels, probably the capillaries would here and there burst, and the injection might fail. The point of the pipe can with very little difficulty be made to enter the artery. The needle with the thread is then taken in the right hand and the curved extremity carefully carried round the vessel. The thread is firmly seized with fine but well-made forceps, the needle unthreaded and withdrawn, or one end of the thread may be held firmly, while the needle is withdrawn over it in the opposite direction. The thread is now evenly drawn over the vessel, and tied so as to include the *tip of the pipe only*, for if the pipe be tied too far up, there will be great danger of its point passing through the delicate coats of the vessel.

The syringe having been well washed in warm water before commencing, its nozzle is plunged beneath the surface of the injecting fluid, the piston moved up and down two or three times, so as to completely force out the air, and the syringe carefully filled with fluid. It is then connected with the pipe,—which is firmly held by the finger and thumb of the left hand,—with a screwing movement. A little of the injection is, however, first allowed to flow into the wide part of the pipe so as to prevent the possibility of any air being included, and forced into the vessels with the injection.

The pipe and syringe being still held by the left hand, the piston is slowly and gently forced down with a slightly screwing movement with the right, care being taken not to distend the vessel so as to endanger rupture of its coats. The handle of the syringe is to be kept uppermost, and the syringe should never be completely emptied, in case of a little air remaining, which would thus be forced into the vessel, fig. 8, pl. XXVII, p. 104. The injection is now observed running into the smaller vessels in different parts of the organism.

**188. Of Injecting the Ducts of Glands.**—The modes of injecting which have just been considered, although applicable to the injection of vessels, do not always answer when employed for injecting the ducts and glandular structure of glands. As the ducts usually contain a quantity of the secretion, and are always lined with epithelium, it often happens that when we attempt to force fluid into the duct, the epithelium and secretion are driven towards the secreting structure of the gland, which thus becomes effectually plugged up with a material which is colourless. In such a case there is little hope of making out the origin of the ducts and their relation to the secreting structure. It is obviously useless, under these circumstances, to proceed in the usual manner and introduce an injecting fluid; for the greatest pressure which could be employed would

not be sufficient to drive the contents of the follicles and ducts through the basement membrane, and the only possible result of such an attempt would be rupture of the thin walls of the secreting structure and extravasation of the contents. As I have before mentioned, partial success has been obtained by employing mercury, but the preparations thus made are not adapted for microscopical observation.

I had long felt very anxious to make a thoroughly good injection of the ducts of the liver and to ascertain the manner in which they commenced in the lobule, and the precise relation which they bore to the liver cells. This anatomical question has long been under discussion among microscopical observers, and many different and incompatible conclusions have been arrived at by different authorities. In order to prove the point satisfactorily it was obviously necessary to inject the ducts to their most minute ramifications, and no one, as far as I was able to ascertain, had succeeded in doing this satisfactorily. After death the minute ducts of the liver always contain a little bile. No force which can be employed is sufficient to force this bile through the basement membrane, for it will not permeate it in a direction *from* the inside of the ducts. When any attempt is made to inject the ducts, the epithelium and mucus in their interior form with the bile an insurmountable barrier to the onward course of the injection. Hence, if a successful injection was to be made, it appeared to me to be necessary either to remove the bile from the ducts or to prevent it from entering them for some time before the death of the animal. Many years ago (1854) it occurred to me that any accumulation of fluid in the smallest branches of the portal vein or in the capillaries must necessarily compress the ducts and the secreting structure of the liver which fill up the intervals between them. The result of such a pressure must clearly be to drive the bile towards the large ducts and to promote its escape. Tepid water was, therefore, injected into the portal vein. The liver became greatly distended, and bile, with much ductal epithelium, flowed by drops from the divided extremity of the duct. ("On the Ultimate Arrangement of the Biliary Ducts, and on some other points in the Anatomy of the Liver of Vertebrate Animals"—"Philosophical Transactions" for 1856, page 375.) The bile soon became thinner, owing to its dilution with water, which permeated the intervening membrane and entered the ducts. These long, narrow, highly tortuous channels were thus effectually washed out from the point where they commenced as tubes, not more than 1-3000th of an inch in diameter, to their termination in the common duct, and much of the thick layer of epithelium lining their interior was washed out at the same time. When this part of the process was completed, the water was removed by placing the liver in cloths with sponges under pressure for twenty-four hours or longer. All the vessels and the duct were now perfectly empty and in a favourable state for receiving injection. The duct

was first injected with a coloured material. Freshly precipitated chromate of lead, white lead, vermilion, or other colouring matter may be used, but for many reasons, to which I have alluded, the Prussian blue injection is the one best adapted for the purpose. It is the only material which furnishes good results when the injected preparations are required to be submitted to high magnifying powers. Preparations injected in the manner described should be examined as transparent objects, p. 102. They may be mounted in the ordinary preservative fluids, but glycerine forms the most satisfactory medium for their preservation. Although they may be put up in Canada balsam, this medium is not advantageous for rendering the course of the ducts evident, or for showing distinctly the branches as they lie on different planes.

I have often succeeded in making most perfect injections of the ducts of the liver, which demonstrate conclusively the cell containing network of the lobule and its connection with the finest gall ducts. The injection may be seen around the hepatic cells as they lie in the tubes of the network.

**189. Of Injecting Lymphatic Vessels.**—It is very difficult to find a lacteal or lymphatic vessel and insert a pipe into it. When it is desired to inject these tubes, the pipe may be inserted into the large trunk of the thoracic duct, and sometimes the injection may be forced between the valves towards the fine branches of vessels. I have, however, found that by injecting water into the *blood vessels*, the lymphatics and lacteals of a part of the body or of an organ become distended by the transudation of the fluid, and in this distended state it is not difficult to make the pipe enter the vessel through a small opening made with sharp scissors. The pipe having been tied in the vessel, the water is absorbed as described in § 188, and the injection may then be forced in, care being taken to use very gradual pressure, so that the coats of the lacteal or lymphatic may be sufficiently stretched to allow the injection to pass between the valves, *without being ruptured*. In this way I have succeeded in making beautiful injections of the finest ramifications of the lymphatics of the liver. (“Archives of Medicine,” vol. I, p. 113.) Pl. XXVIII, fig. 2, p. 106.

Sometimes lymphatics may be injected by extravasation from a duct, and more rarely from a vessel. I have often injected the lymphatics of the liver when forcing the injection into the duct. Some observers think they have succeeded in injecting very minute lymphatic vessels and demonstrated that these are continuous with the capillaries. Such lymphatics are considered to ramify in the intervals between epithelial cells. It is, however, doubtful if the facts observed have received a correct interpretation.

#### OF INJECTING THE LOWER ANIMALS.

**190. Insects.**—Injections of insects may be made by forcing the

injection into the general abdominal cavity, whence it passes into the dorsal vessel, and by it is afterwards distributed to the system. The superfluous injection is then washed away, and such parts of the body as may be required removed for examination. Insects should be injected very soon after they have emerged from the pupa.

The water vascular apparatus, the vessels, and the digestive tube may be injected in many of the lower animals. In some cases good results will be obtained with size coloured with transparent colouring matter; in others it will be found better to employ the Prussian blue or carmine injecting fluid made with glycerine, p. 111. In injecting the digestive apparatus of some entozoa, as the liver-fluke, the pipe may be tied in, but as a general rule it is only necessary to make an opening into the vessel and insert the pipe, which must be held steadily while the injection is carefully forced from the orifice. In many fine injections a pipe of the form represented in pl. XXVII, fig. 11, p. 104, with a blunt point and a lateral opening, will be found of great advantage. Coloured fluids will rise in the vessels of most plants by capillary attraction, and occasionally the vessels of some of the tissues of animals may be partially injected in the same way.

**191. Mollusca.** (Slug, snail, oyster, &c.)—The tenuity of the vessels of many mollusca renders it undesirable to tie the pipe in them. The capillaries are, however, usually very large, so that the injection generally runs readily. In different parts of the bodies of these animals are numerous lacunæ or spaces, which communicate directly with the vessels. If an opening be made through the integument of the muscular foot of the snail, a pipe may be inserted, and the vessels injected from the lacunæ with comparative facility. The large vessels of the branchiæ may be readily injected with the aid of a pipe of the form referred to in the last paragraph.

Milne Edwards injected the snail by passing the pipe through an opening made with a sharp instrument at the base of the tentacle. In this case the injecting fluid passes into lacunæ or spaces and fills the venous system, but, as has been shown by Mr. Robertson, of Oxford, the arteries are not injected by this method (“On the Organs of Circulation of the Roman Snail, *Helix Pomatia*.”—“Annals and Magazine of Natural History,” January, 1867).

**192. Mr. Robertson's Plan of Injecting the Snail.**—This skilful anatomist recommends a different plan of proceeding. The snails are to be killed by drowning them in a jar quite filled with cold water, the mouth being closed with a piece of plate glass.

The vascular system is to be injected from the ventricle of the heart with size and carmine. The heart of the snail is easily found. It is enclosed in a sac which is situated at the posterior extremity of the pulmonary chamber on the left side. The position of the organs of the

snail has been fully described by Dr. Lawson, in a paper published in the "Microscopical Journal" for January, 1863. The injection introduced into the heart passes right round the body and returns to the pulmonary chamber. By this plan the arterial branches may be traced into the foot and to many other parts which were considered to be destitute of arteries. Mr. Robertson has arrived at the conclusion that in snails there exists a *closed capillary system communicating directly with the arteries on the one hand and the veins on the other, as is the case in man and the higher animals*; and he has completely failed to demonstrate the existence of any direct communication between the spaces or lacunæ in the various tissues and the vascular system. It is probable that in the mollusca the capillaries are arranged as in the higher animals, but they are wider, and their walls being so very thin it requires great skill to inject them without rupture, in which case extravasation will take place.

**193. Injecting Fishes.**—The vessels of fishes are exceedingly tender, and great caution is required in filling them. It is often difficult or quite impossible to tie the pipe in the vessel of a small fish. If we attempt to inject from the heart, the injection passes to the gills, but it is seldom that it runs through these and penetrates the systemic vessels. It is usual therefore to proceed thus,—the tail of the fish is cut off, and the pipe introduced into the divided vessel which lies immediately beneath the spinal column. In this simple manner beautiful injections of the systemic vessels of a fish may sometimes be made. In small fishes in which the vessels are too delicate to be tied, a good injection may be made by simply placing the pipe in the vessel. As the fluid is so cheap, a considerable loss is of no consequence.

**194. Of preparing Portions of Injected Preparations for Microscopical Examination.**—Preparations made by injecting colouring matters suspended in water or gelatine may be mounted in various preservative fluids, or dried and placed in balsam. When thin tissues, such as the mucous membrane of the intestines or other parts, have been injected, it is necessary to lay them perfectly flat, and wash the mucus and epithelium from the free surface, either by forcing a current of water from the wash-bottle (pl. XXVI, fig. 5, p. 100), or by placing them in water and brushing the surface gently with a camel-hair brush. Pieces of a convenient size may then be removed and mounted in solution of naphtha and creosote, in dilute alcohol, in glycerine, or in gelatine and glycerine.

The most important points in injections of ordinary tissues may be shown if the preparation be dried and mounted in Canada balsam. The specimen must, in the first place, be well washed and floated upon a glass slide with a considerable quantity of water, which must be allowed to flow off the slide very gradually. It may then be allowed to dry under a glass shade, in order that it may be protected from dust. The

drying should be effected at the ordinary temperature of the air, but it is much expedited if a shallow basin filled with sulphuric acid be placed with it under the same bell-jar, p. 88, pl. XXIV, fig. 5. Or the specimens may be transferred from the water to spirit, and from this to oil of cloves, and then mounted in balsam. See p. 89.

Of solid organs, such as the liver and kidney, thin sections from the interior made in different directions, as well as portions from the surface, should be preserved. The sections may be made with the ordinary scalpel or with Valentin's knife, if one of half an inch or more square be required. The surfaces of the section should be well washed, and it may then be mounted in one of the methods previously described; but I much prefer to mount these specimens moist, and glycerine or glycerine jelly will be found the most suitable medium.

Specimens which have been injected with Prussian blue or carmine injecting fluids, the composition of which is given in pp. 109, 110, must be preserved in glycerine containing a trace of free acetic acid (5 to 15 drops to the ounce). The advantage of this plan is, that it enables us not only to observe the arrangement of the vessels, but also to study the bioplasm in their walls, pl. XXIX, p. 108, fig. 3, as well as the structures forming the tissue or organ. Moreover, specimens thus preserved may be easily removed and remounted without risk of damage, when required.

*Injected Specimens in Glycerine and in Canada Balsam.*—The observer will be surprised at the great differences observed in the same texture according to the method in which it is prepared. I have already adverted to the objections of mounting moist tissues in balsam. Although most of those who prepare specimens in this country and in Germany still pursue this plan for preserving their injections, it will, I am sure, be condemned as unsatisfactory by any one who has tried the method of mounting the specimen moist in strong glycerine. Not only are the bioplasts of the vessels for the most part destroyed by the process of mounting in balsam, but many very important elements of the tissue, and especially nerve fibres, are so changed that they cannot be recognised, or are completely obliterated. The capillaries themselves are so shrunk and changed that very wrong conclusions have been arrived at from examining balsam specimens. In figs. 5 and 6, pl. XXIX, p. 108, specimens of the very same tissue are represented prepared according to the different plans referred to, but magnified by the same powers. Let the reader observe the different diameters of the vessels, and note how many points are displayed in the moist preparation which are not to be demonstrated in the one preserved in balsam. The "extra vascular spaces" discovered in the latter result from the shrinking of the injection in the process of mounting. I feel, therefore, compelled to reject inferences arrived at from the examination of balsam specimens, and strongly advise the student not to be misled by their mere sharpness and bright colour. Such preparations undoubtedly

enable us to form a general idea of the arrangement and number of the capillaries in different textures, and they may be preserved for many years without the slightest change in character. In these respects their merits must be admitted; but if we desire to learn facts concerning the relation of the capillaries to the texture lying in their meshes, the structure of the vessels themselves, or that of the tissues in which they ramify, we must study injections which have not been mounted in balsam, damar, or such media. Collections of balsam specimens are advantageous for trade purposes, but although the student may with advantage purchase a few specimens, the sooner he learns to make preparations for himself the sooner will he gain a knowledge of the structure of the tissues of animals.

**195. Of the best Mode of Destroying the Life of Animals intended for Injection.**—I have tried various plans of destroying animals intended for minute injection, and have found that in death by sudden shock the vessels remain in a relaxed state for a sufficient time after death to enable us to complete the injection. In some cases a good result is gained by destroying life in an atmosphere of carbonic acid, but I find that the very sudden death produced by a fall from a height, dashing on the ground, &c., is the most advantageous. Any small animal may be wrapped up in a cloth and thrown suddenly, and with some violence, upon the ground. In order to avoid rupturing any of the tissues, the animal must be well protected by several folds of the cloth. Swinging very rapidly through the air also destroys life very suddenly, without causing that sudden contraction of the muscles, which seriously interferes with the preparation of successful injections.

Good injections may be made *after* the *rigor mortis* has entirely passed off, and formerly no injections were attempted before this change had occurred. I have, however, found that by the time the muscles have again become relaxed the finer branches of the nerves have begun to soften or are entirely destroyed, and many delicate structures have become so much altered that it would not be possible for any one who was acquainted with their natural appearance to recognize them. Hence it is undesirable to put off the operation of injection if we desire to demonstrate in the specimens we are about to prepare any facts besides the mere arrangement of the capillary vessels.

#### ON STAINING THE BIOPLOSM AND FORMED MATERIAL OF TISSUES.

The plan of staining tissues artificially is one from which great advantage has been already derived, and it is probable that, by modifications of the processes already adopted, and by the discovery of new ones, many new and most important facts will be added to our knowledge. I have pointed out that the process of staining may be employed for

two very different purposes, and it is important that the student should have a clear notion of the objects to be gained by the process before he proceeds to carry it into practice. Staining may be employed :—

1. For colouring the invariably perfectly colourless, and often invisible *bioplasm* or *living matter* of any cell or tissue, at any age, in the case of vegetable or animal textures.
2. For demonstrating peculiarities in the build of the *formed material*, *cell-wall*, *intercellular substance*, or *tissue*, and for ascertaining the order in which the several parts of which it is composed have been laid down.

#### *Of Colouring the Bioplasm.*

**196. Of Colouring the Bioplasm or Living Matter.**—This living matter is in all cases in the natural state perfectly clear and transparent. It never exhibits structure, and is invariably colourless. It possesses an acid reaction, or, to speak more correctly, an acid reaction is always developed immediately after its death. Hence, if a coloured alkaline solution from which the colouring matter may be precipitated or fixed by an acid, be caused to pass into bioplasm which has recently died but has not yet undergone decomposition, the alkali is neutralised by the acid present, and the colour is retained. It is probably precipitated in a state of very minute subdivision, or combined with some of the constituents of the bioplasm to form a compound insoluble in weak acids.

The *tissue itself* or *formed material* being ordinarily bathed with an alkaline fluid does not take the colour, and hence by carrying out the process with due care the *bioplasm* or *living matter* may always be coloured while the *formed material* or *tissue* remains perfectly colourless. Any one can satisfy himself of this fact by placing upon a glass slide a few liver cells from any animal immediately after its death. If a drop or two of the solution of carmine in ammonia be allowed to flow over the cells, the nucleus or mass of bioplasm of each cell will be tinted in the course of a few seconds, while the outer part of the cell will not be affected.

Staining the bioplasm may be carried out long after the death of the animal if the development of an alkali by decomposition be prevented by alcohol or some other preservative fluid. Specimens intended for subsequent staining should be immersed in a preservative fluid *immediately after death*. In practice, however, it is always better to carry out the staining process at once.

From the above remarks, it must not, however, be inferred that living matter can be stained by alkaline colouring fluids only. Solutions of an *acid* reaction may be employed if the bioplasm be rendered *alkaline* in the first instance by soaking the texture in a weak solution of ammonia. I have prepared some beautiful specimens as follows :—An



alkaline solution was injected into the vessels, and after allowing twelve hours or more for the tissues to become thoroughly permeated, the finest Prussian blue (*see* part VI) was introduced. The latter passed into the very substance of the bioplasm, which was tinged much more deeply than the surrounding material. The liver cell may be thus impregnated with the blue in every part. It seems probable that by prosecuting more detailed enquiries in this direction, we may learn something concerning the physical arrangement of the matter constituting the formed material. The bioplasm may also be tinted with a fluid of neutral reaction, because, as I have shown, there are invariably currents tending *towards* the bioplasm as long as this matter remains in a living state; but the advantage of the alkaline solution of carmine is, that the alkali is neutralised when the solution passes into the bioplasm, and the carmine is fixed there. In endeavouring to draw correct inferences regarding the natural arrangement of the parts prepared in this way, it must not, however, be forgotten that the alkaline ammonia may have effected alterations in the formed material, and modified its structure in an important manner.

Specimens prepared in the manner suggested above enable us to prove the unsoundness of the old views concerning the supposed cell-wall and cell contents, and the incorrectness of more modern assertions concerning the slight importance of the "nucleus."

**197. Process of Staining followed by the Rev. Lord S. G. Osborne.**

—Welcker was, I believe, one of the first observers to employ a solution of carmine for the purpose of staining the nuclei of tissues, and Gerlach was an early and most successful advocate of this plan. It has been, but I think wrongly, stated, that Gerlach was the first who adopted the process. The date of Gerlach's work was 1858 ("Mikroskopische Studien aus dem Gebiete der Menschlichen Morphologie." Erlangen). But it was in June, 1856, that the Rev. Lord S. G. Osborne showed that nuclei were more deeply tinged by carmine than other parts of the cell. ("Vegetable Cell Structure and its Formation, as seen in the early stages of the Growth of the Wheat Plant.") *See* also the plate accompanying that paper ("Trans. Mic. Soc.," vol. V, pl. IV, 1856). Lord Osborne allowed the plants to *grow* in the carmine solution. The growing parts were stained most successfully. The method was not, however, applied to investigations on animal tissues.

**198. Gerlach's Method of Staining.**—Gerlach resorted to the carmine staining process for investigating the structure of animal tissues. He first used a concentrated solution of carmine in ammonia, and placed the sections of brain and spinal cord previously hardened by chromic acid, in the carmine fluid for from ten to fifteen minutes. They were then well washed in water for some hours, and treated with acetic acid. The water and acid were removed by immersion in alcohol. The

sections were afterwards mounted in Canada balsam. Gerlach found that dilute solutions (two or three drops of the ammoniacal solution of carmine to an ounce of water), and maceration for *two or three days*, afforded better results.

**199. The Author's Carmine Fluid**, for staining all forms of bioplasm of living things, is made as follows :—

Carmine, 10 grains.

Strong liquor ammonia,  $\frac{1}{2}$  drachm.

Strong glycerine, 2 ounces.

Distilled water, 2 ounces.

Alcohol,  $\frac{1}{2}$  ounce.

The carmine in small fragments is to be placed in a test tube, and the ammonia added to it. By agitation, and with the aid of the heat of a spirit-lamp, the carmine is soon dissolved. The ammoniacal solution is to be boiled for a few seconds and then allowed to cool. After the lapse of an hour, much of the excess of ammonia will have escaped. The glycerine and water may then be added, and the whole passed through a filter or allowed to stand for some time, and the perfectly clear supernatant fluid poured off and kept for use. This solution will keep for months, but sometimes a little carmine is deposited, owing to the escape of ammonia, in which case one or two drops of liquor ammonia may be added to the four ounces of carmine solution.

The rapidity with which the colouring of a tissue immersed in this fluid takes place, depends partly upon the character of the tissue and partly upon the excess of ammonia present in the solution. If the solution be very alkaline the colouring will be too intense, and much of the soft *tissue* or imperfectly developed formed material around the bioplasm will be destroyed by the action of the alkali. If, on the other hand, the reaction of the solution be neutral, the uniform staining of tissue and bioplasm may result, and the appearances from which so much may be learnt are not always produced. When the vessels are injected with the Prussian blue fluid before the staining process is adopted, the carmine fluid should be sufficiently alkaline to neutralise the free acid present. The permeating power of the solution is easily increased by the addition of a little more water and alcohol. In some cases the fluid must be diluted with water, alcohol, or glycerine, and the observer must not hastily condemn the process, or conclude, as some have done, that a particular form of bioplasm is not to be coloured. Those who speak thus have not given the plan a fair trial, and have not tried the effects of a solution containing a little alcohol or otherwise modified.

Notwithstanding the advantages of the above plan and its success in the hands of many observers, objections have been urged against it by some who, I venture to think, have not made themselves familiar with the practical details of the method. It has been said that the formed

material may be stained as well as the bioplasm. As every one knows, almost any thing may be stained. Hair, horn, wool, paper, &c., may be deeply dyed, even after they have been thoroughly dried. The important fact, however, is not that the tissue may be stained, but that the bioplasm of a tissue *may be deeply coloured, although the formed material which must be traversed by the staining fluid in the first instance is not stained at all.* This is the case with all bioplasm, and it seems to me a fact of far higher significance than is generally admitted. By the process of investigation described it becomes possible not only to distinguish bioplasm in all cases, but to show definitely the mode of formation of the tissue. And in many instances, by this method of proceeding, we can accurately determine which is the *oldest* and which the *youngest* portion of the tissue. Drawings of various tissues, in which the bioplasm has been stained by the above process, are given in plate XXX, p. 110, and in plate XXXI. (*See also the plates in part VI.*)

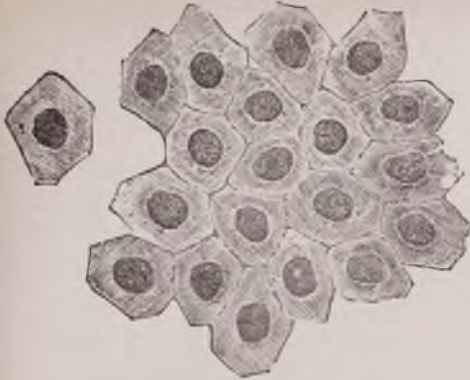
In a paper on the ova of the stickleback ("Microscopical Journal," January, 1867), Dr. Ransom has expressed himself against the plan of investigation I have followed. His objections, however, are not valid, and some of the remarks he has made prove, I think, that he has not succeeded in preparing specimens according to my method. I have replied to some of my friend's statements in a subsequent number of the journal.

Some direct that, when a tissue is too deeply stained, it should be washed in water or in spirit,—directions which clearly indicate that the authority has little practical acquaintance with the method, and is not acquainted with the principles on which the process rests. The suggestion would not be made by any one who was aware of the change induced by the colouring process, when properly conducted. Many of the remarks in connection with this matter could only have been made by persons who had never seen a preparation properly coloured, and who are not aware of the great value of the operation. Again, it has often been recommended that tissues should be stained with the carmine fluid after they have been hardened in chromic acid fluid, alcohol, and other media. Staining thus effected conveys little information, and may mislead the observer. But the most serious opposition to the adoption of the method of procedure I have recommended, and to the acceptance of the conclusions I have arrived at, is on the part of some who have quite made up their minds that all the phenomena of living organisms are due to *machinery* which is not to be demonstrated by this or any other process of investigation. For further details concerning these matters, *see part VI.*

#### *Of Staining the Formed Material.*

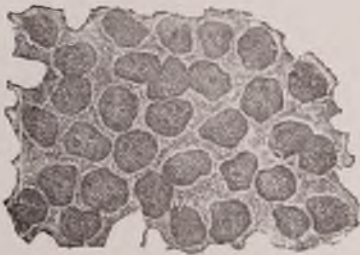
The coloured fluids referred to in the succeeding sections are em-

Fig. 1.



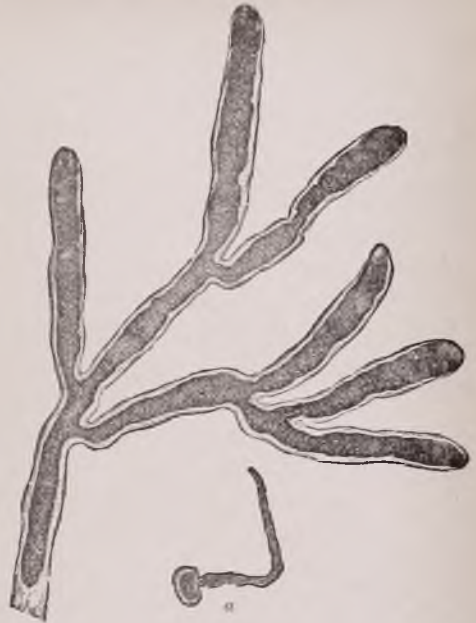
Cuticle of the newt, superficial layer, each mass of bioplasm is surrounded with a thick layer of formed material, constituting a fully formed cell. X 215.

Fig. 2.



Deep layer of the cuticle of the newt, consisting almost entirely of bioplasm with very little formed material. X 215.

Fig. 3.



The extremities of a rapidly growing branch of fungus from jam. The cellular wall at the end of each ramification is only just formed, and is so thin that it is hardly demonstrable. The bioplasm is abundant, and in this situation growth is proceeding very rapidly. a, a spore which has just commenced to sprout. X 400. 1869.

Fig. 4.



Small vein and capillary vessels. Ovum of turtle at an early period of development. All the vessels are filled with colourless blood corpuscles, which are stained with carmine in the preparation from which the drawing was taken. Developing connective tissue corpuscles and fat cells are also seen in the drawing.

of an inch \_\_\_\_\_, X 215.

[To face page 126.]



ployed for tinting the *tissue or formed material*, while the carmine fluid I have recommended, in § 199, is for staining the *bioplasm* only.

**200. Thiersch's Carmine Fluid.**—Frey ("Das Mikroskop") gives Thiersch's fluids for colouring tissues by carmine. Carmine, 1 part. Caustic ammonia, 1 part. Distilled water, 3 parts. This solution is to be filtered. The following solution is to be prepared in a separate vessel:—Oxalic acid, 1 part. Distilled water, 22 parts.

One part of the carmine solution is to be mixed with 8 parts of the oxalic acid solution, and 12 parts of absolute alcohol are to be added.

If the solution is orange-coloured instead of dark red, more ammonia is required, and the orange will become red. The orange colour may also be used for staining. If crystals of oxalate of ammonia become formed they must be separated by filtration.

**201. Thiersch's Lilac Colouring Fluid.**—Borax, 4 parts. Distilled water, 56 parts.—Dissolve and add, of carmine, 1 part.

The red solution is to be mixed with twice its volume of absolute alcohol, and filtered. The precipitate of carmine and borax is re-dissolved in distilled water, and is ready for use. It colours more slowly than the red solution.

**202. Anilin Colours.**—The beautiful reds and blues which have been lately so largely used as dyes, popularly known in this country as Magenta and Solferino, have been much employed by microscopists. The colour is not very soluble in water, but is readily dissolved by alcohol. A grain of the colour, 10 or 15 drops of alcohol, and an ounce of distilled water, make a dark red solution; or the colour may be boiled in water, allowed to cool, and then filtered. This fluid colours tissues very readily. Many exceedingly delicate and perfectly transparent *textures*, which are almost invisible in the natural state, can be most satisfactorily demonstrated by the use of this coloured fluid. The cilia of ciliated epithelium may be tinted while they continue to vibrate. As the substance of the cell becomes coloured, however, the action of the cilia ceases. Every kind of *cell wall*, *delicate membrane*, and *transparent tissue* may be tinted with these colours.

Magenta has been recommended by Dr. Roberts for showing a minute spot connected with the red blood corpuscles of man. ("On peculiar appearances exhibited by blood corpuscles under the influence of solutions of magenta and tannin"—"Proceedings of the Royal Society," vol. XIV, p. 481, No. 53, April, 1863.) The peculiar action exerted by magenta and tannin upon the red blood corpuscles has not yet been satisfactorily explained, but the late Dr. Hughes Bennett, of Edinburgh, told me that, with the aid of very high powers, he had demonstrated that the minute spot appearing after the blood corpuscles had been soaked in magenta exhibited angles, and he considered that it was in fact a minute crystal which had formed upon the corpuscles. This

explanation certainly does not apply to the spot which is developed in connection with *all* red blood corpuscles subjected to the action of tannin and other solutions.

**203. Blue and Violet Colours for Staining.**—Thiersch recommends the following fluid, the composition of which I take from Frey :—

Oxalic acid, 1 part.

Distilled water, 22 parts.

Indigo carmine, as much as the solution will take up.

Another solution of oxalic acid and water in the same proportion is required. One volume of the first solution is mixed with two volumes of the last and nine of absolute alcohol. The mixture is then filtered, and is ready for use.

An anilin blue fluid may be made as follows :—

Soluble anilin blue,  $\frac{1}{2}$  grain.

Distilled water, 1 ounce.

Alcohol, 25 drops.

This fluid is not acted upon by acids or alkalies. Frey strongly recommends a fluid of this description as very useful for colouring many tissues.

*Violet Staining with Hæmatoxylin.*—“The ordinary extract, hæmatoxylin, is rubbed down in a mortar with three times its bulk of alum, till both are reduced to a fine powder, and well mixed. A small quantity of distilled water may now be added, and the whole well rubbed together for 15 or 20 minutes. More water may now be added and the solution, after filtration, should present a somewhat clear dark violet colour. Two drachms of 75 per cent. alcohol may now be added to each ounce of the solution.”—“*Monthly Journal of Microscopical Science*,” December, 1872, p. 277. Frey prepares the above in this way :—An aqueous solution of the extract of logwood is to be mixed with a solution of alum (1 part of the salt to 8 parts of water) till the deep red colour has become violet. The fluid is then filtered. These hæmatoxylin fluids may be used for fresh tissues, and for tissues hardened by chromic acid or alcohol. Tissues colour very rapidly and very deeply, in from half a minute to 10 or even 15 minutes. They may be mounted in Canada balsam or damar.

**204. Tannin.**—Although tannin does not colour animal membrane, it alters its character to such an extent as to enable us to see many peculiar points of structure or arrangement not visible before, or it produces a chemical change upon the substance, from which we gain important information. Solutions of magenta and solutions of tannin have been much used in investigations upon the blood corpuscles. The action of tannin upon the red blood corpuscle is very peculiar; it has been specially studied by Dr. Roberts, of Manchester, as mentioned above. The solution is made by dissolving 3 grains of tannin in an

ounce of distilled water. One drop of blood may be mixed with 4 or 5 drops of the tannin solution and a portion of the mixture examined under the microscope.

**205. Solution of Nitrate of silver.**—Of late years nitrate of silver has been used for staining tissues. Recklinghausen and His have employed this plan with great success. A weak solution may be imbibed by delicate tubes, and part being precipitated in the tube, perhaps as a chloride or in combination with some albuminous material, subsequently becomes decomposed by the action of light. A very dark line results, and thus the position of a previously perfectly invisible minute channel may be clearly demonstrated. The *outlines* of epithelial cells and the *intervals* between them may be demonstrated by this process. Transparent connective tissue and the *outer part of cells* can thus be coloured, the *nuclei remaining perfectly colourless and transparent*. The bioplasm, by longer immersion, will also be coloured, and probably for this reason:—As long as the bioplasm remains alive it resists the action of the solution, but when it dies, the matter resulting from its death imbibes the solution which remains with it.

The appearances produced by staining with nitrate of silver may be made to vary very much by modifying the mode of procedure and the time which the preparation is allowed to remain in the solution. After soaking in the nitrate of silver solution for some time the specimen must be placed in distilled water, or in a weak solution of common salt, in order to wash away the nitrate which adheres to the surface or occupies the intervals between the cells. When this has been effected the specimen is exposed to daylight or sunlight until the requisite degree of blackening has been obtained. The strength of the solution employed may be varied according to circumstances. Recklinghausen uses a very dilute solution, consisting of 1 part of nitrate of silver to 400—800 of distilled water.

The structure of the cornea has been recently investigated by His, after the tissue had been prepared according to this plan. The so-called “intercellular substance” (formed material) only may be coloured, or, after the whole structure has been thoroughly impregnated with the solution, the latter may be removed from the formed material, while that taken up by the nuclei (masses of bioplasm or living matter) is retained, and may be decomposed by being exposed to light. In this case the nuclei or bioplasts appear very dark and are surrounded by a pale brown formed material. His thinks that when the nuclei are coloured, the precipitate of chloride of silver in the formed material is re-dissolved and absorbed by them. It remains, and is afterwards reduced by the action of the light.

**206. Solutions of Chloride of Gold.**—Weak solutions of perchloride of gold have been much used of late years for colouring nerve fibres, for



it has been found that delicate nerves thus acted upon exhibit, after exposure to light, a blue or violet tinge. A solution containing from .2 to 1 per cent. in distilled water should be made. The tissue, after having been soaked till it becomes straw-coloured, is to be washed, and then placed in very dilute acetic acid, containing 1 per cent. or less. The nerves become coloured in the course of a few hours. By this plan, Cohnheim professes to have made out very fine nerve fibres, which, he says, pass from the plexuses in the cornea to intervals between the cells of the conjunctival epithelium, and after reaching the surface of the structure end in *terminal free extremities*. I think, however, we should receive such statements with the utmost caution, and although Professor Kölliker has accepted the view, I cannot adopt it without much stronger evidence than has been advanced in its favour. Many considerations make me think it will turn out to be incorrect. Cohnheim's drawings alone excite doubt in my mind concerning the accuracy of his observations, and, at least in my hands, the mode of preparation recommended has not afforded results nearly so satisfactory as those I have obtained by adopting other methods of investigation.

Many modifications of the above processes of investigation have been tried by me. I have found some advantage from using glycerine with the fluids, but at present I have no special plan to recommend. While I fully acknowledge the accuracy of many of the drawings and descriptions given of the appearances resulting from the use of nitrate of silver and chloride of gold, I am not convinced that many of the interpretations and conclusions which have been given and accepted concerning the structures demonstrated, are true. Some will, I think, have to be much modified in the future. The dark lines resulting from the silver process, which have been considered in many instances to be the outlines of epithelial cells, as for example in small vessels, mark, I believe, the lines of junction of the several elementary parts of which the tissue of the vessel consists. So, too, with reference to specimens prepared with gold, I am disposed to think that many of the lines which are rendered so very distinct by the black deposit will be proved to have nothing to do with the transmission of nerve currents, and that certain of the conclusions generally received will turn out to be incorrect.

**207. Solution of Osmic Acid** ( $\text{Os.O}_4$ ) has been strongly recommended for demonstrating delicate nerve structures by MM. Schultze and Roudneff, because it tinges the white substance of Schwann and all forms of Myelin in various kinds of nerve fibres, of a very dark colour or almost black. Other textures are neither coloured so quickly nor so intensely, and often exhibit only a brownish tint. It is suggested that, with the aid of this substance, nerve fibres ramifying in various textures may be stained, and thus distinguished from other elements of the tissue. Solutions of various strengths may be employed but one part of

osmic acid in 100 of water is stated to be strong enough to produce the desired effect. I have tried this plan, but must confess that I have gained nothing by its adoption. I can show finer nerves and more clearly by other methods than any that I have been able to demonstrate either by the gold or osmic acid solutions.

**208. Other Metallic Salts.**—Tissues may also be impregnated with other solutions of metallic salts. Acetate of lead has often been employed. The tissue may be soaked for some time in a weak solution, or a weak solution with a little glycerine may be injected. When the tissues are well saturated, thin sections may be made, and, after having been slightly washed, they may be placed in a dilute solution of glycerine, through which sulphuretted hydrogen may be passed. Living plants will take up solutions of various metallic salts, which may then be precipitated in the textures or in the channels by the appropriate reagents.

**209. Modification of the foregoing Plans.**—The observer will perceive that the processes referred to under the head of "Staining the Bioplasm and Formed Material," are capable of almost endless modification. Every one engaged in a special investigation, will naturally try various modes of preparation. Having decided upon one which seems to offer considerable advantages, he will try various modifications until he meets with success. I have not attempted to give the minute recommendations of various observers who have employed some of these processes, but have merely indicated the general method of procedure. A few experiments will teach the observer more than the most minute instructions, and, however carefully directions may be given, it is seldom that any one succeeds the first time he endeavours to follow them out. Those who desire to do real work in this department must be patient, and must work on steadily, until they meet with success.

## PART III.

ON DEMONSTRATING THE ARRANGEMENT OF THE BIOPLASM (LIVING MATTER) AND THE STRUCTURE OF THE TISSUES (FORMED MATERIAL) OF MAN, AND THE HIGHER ANIMALS—OF THE TISSUES OF THE LOWER ANIMALS—OF THE DEMONSTRATION OF THE TISSUES OF PLANTS, AND OF PLANT CRYSTALS—OF COLLECTING AND KEEPING ALIVE THE LOWER ANIMALS AND PLANTS, AND OF EXAMINING THEM IN A LIVING STATE—THE EXAMINATION, DEMONSTRATION, AND MOUNTING OF MINERALS, ROCKS, AND FOSSILS—THE WORK TABLE—OF MAKING AND RECORDING OBSERVATIONS—OF THE FALLACIES TO BE GUARDED AGAINST IN MICROSCOPICAL INVESTIGATION.

Although all the tissues which constitute the bodies of man and the higher animals are developed from structureless, homogeneous, colourless bioplasm, they exhibit, in their fully formed state, striking structural peculiarities which the microscopical observer has to learn to recognise and demonstrate. As soon as he enters upon his investigation he will discover that the various tissues and organs of animals and plants for the most part are *compound*, and are made up of several distinct elementary structures. For example, the smallest portion of flesh or muscular tissue, which can be removed with a knife or pair of scissors, is composed of several distinct structures, which perform different offices, and are developed in a different manner. In the first place must be noticed the *proper substance* peculiar to and characteristic of every form of muscular tissue, in which the contractile property resides. Secondly, at least in most cases, we find a tube composed of perfectly clear, *transparent*, almost *structureless membrane*, and called the *sarcolemma*, in which this contractile substance, or sarcous matter, is contained. Thirdly, there exists a certain quantity of *areolar* or *connective tissue*, which, continuous in structure with the sarcolemma, connects together the elementary fibres forming a muscular bundle; and not unfrequently associated with this is a little *fatty* or *adipose tissue*. Fourthly, are the *vessels* which lie between the elementary fibres just described, in which the blood circulates while it supplies the proper nutritive elements to the tissues. In the fifth place we find nerve-fibres running in the same position as the vessels, for the most part connected

with the sarcolemma by delicate fibres of connective tissue, and at least in relation with some of the fibres, are lymphatic vessels. And lastly, the observer must learn to demonstrate that which is sure to be passed over by every one who is not acquainted with the methods of rendering it evident, and has been completely ignored by many excellent observers, and the existence of which in some tissues is even now denied by some authorities: the *bioplasm* or living matter from some form of which every structure in the body is developed, upon which every texture depends for the transmission of the fluids necessary to its maintenance during life, which alone saves the tissues from destruction, by which repair is rendered possible, and by the death of which the activity of those tissues, which is usually regarded as evidence of the living state, must absolutely cease. Bioplasm is seen in the drawings given in pls. XXX, p. 110, XXXI, p. 126, also in pls. XXXIII to XXXV, and in some of the plates in part VI this bioplasm has been represented as it appears when stained with carmine.

**210. General Observations on the Demonstration of Structure.**—

If, for instance, we examine such a tissue as muscle, that is the ordinary flesh of any vertebrate animal, we shall find that it is made up of several elementary structures which can be distinguished from one another. It is the object of the microscopical observer to demonstrate these several structures distinctly, and to ascertain how they are developed and how they come to occupy the precise relations to one another which obtain in every specimen of muscle. Each of these several elementary tissues has its special anatomical peculiarities, and individual properties and endowments. Each differs from the others in physical characters and chemical properties. Some refract light very highly; others, only in a very slight degree. One may be greatly altered or even destroyed within a very short time after the muscle has been removed from the body, or by the action of plain water, while others resist decomposition for a great length of time. All, however, agree in this:—that they are developed from structureless bioplasm, which, indeed, represents them all at an early period of development.

The characters of one elementary tissue may be demonstrated when the fully formed muscle is examined in water; a second, when it is immersed in syrup or glycerine; a third, when the specimen is mounted in Canada balsam; while the arrangement of the delicate, transparent, capillary vessels cannot be satisfactorily made out unless a particular plan of preparation be adopted, as described in page 102.

The chemist can detect a number of other compounds of the presence of which the microscopical observer, unacquainted with methods of chemical analysis, might ever remain unconscious, for these are dissolved in the juices of the muscle, and are, therefore, incapable of being detected by the eye alone.

The vast difference in the properties of the several textures above enumerated renders it very difficult to demonstrate all in one single specimen, for modes of treatment which favour the exhibition of one structure will often render another quite invisible. Hence, before we can hope to demonstrate satisfactorily the anatomical peculiarities of any one of these different textures, we must become acquainted with its general properties, and must consider the mode of examination likely to be most efficient in rendering its anatomical characters clear and distinct.

The walls of the smallest vessels are so thin and transparent that it is necessary to fill the tubes with some coloured fluid or material more or less opaque, if we wish to see the mode of arrangement of the vascular network, while this same process, as ordinarily followed out, precludes the possibility of tracing the finer ramifications of the nerves. Other elementary tissues may be hidden and compressed by the distended vessels. To demonstrate the nerves, the structures in which they ramify must be rendered as transparent as possible, by the application of a chemical agent, or by immersing the specimen in a highly refracting fluid.

In order to show the membrane in which the contractile *sarcous tissue* is contained, the muscular tissue must be ruptured within the transparent tube in a perfectly fresh specimen, or it must be squeezed out of it by pressure, or the sarcolemma may be slightly tinted. I have specimens preserved permanently which show not only the sarcolemma, but the disks of sarcous tissue separated from one another, but still retaining their relative positions within it. By adopting one method of demonstration it may be shown that the contractile tissue of the elementary fibre of muscle may be split up longitudinally into a number of minute *fibrillæ*, arranged parallel to one another; while under other circumstances it can be separated transversely into a multitude of *small disks*, or divided in both directions, in which case a number of small elementary particles of definite form and size results. By connection with contiguous particles, *fibrillæ* or *disks* are produced, according as the particles adhere to each other most intimately by their sides or by their ends. I might adduce many other instances of the necessity of studying the general character of tissues before any minute examination of the individual structures is attempted, but this is sufficient.

#### OF DEMONSTRATING THE DIFFERENT STRUCTURES OF THE HIGHER ANIMALS AND MAN.

##### **211. On Demonstrating the Anatomical Peculiarities of Tissues.**

—Now, some observers who have not sufficiently considered the different characters of the elementary structures of which the several

organs of the body are composed, have strongly objected to what they term *methods of preparation*, asserting that by these processes, structures are even *formed* artificially which have no real existence in the natural state of the part. For this view there is something to be said, though many of the data on which it rests are erroneous, and the conclusion, as a general one, is far removed from the truth. Doubtless, from the superficial examination of a dead tissue, we can form but an imperfect conception of the arrangement of its elementary parts, and their wonderful adaptation to the work they are designed to perform; neither can we form a correct idea of the changes taking place during life. Although there are media in which we can immerse a recent specimen for examination, which possess some of the characters of the fluid which bathes the tissue during its lifetime, even serum, which is probably the nearest approach to such a fluid, differs from the medium actually surrounding the primitive particles of the tissues in many important particulars, and those who rely upon the appearances of a specimen in serum, for being "natural," are probably mistaken.

Most of those who raise objections to the "preparation" of tissues, speak, not from actual observation and experience, but from theory. They fancy tissues *must* be more clearly demonstrated when examined in serum and such fluids than when put up artificially, but this is not invariably the fact, and those who talk so loudly about natural methods have not proved that the structures which we see after death in water, serum, and other simple fluids really exhibit the identical appearances they manifested during life, while it is quite certain that many of the more delicate tissues have never been seen by any one who has limited himself to the examination of tissues in the natural state. Erroneous views concerning the structure and action of the tissues of the body are being constantly augmented by dogmatic assertions about natural methods of investigation, which naturally receive the assent of the ignorant and all who prefer *à priori* arguments to the slower but surer evidence arrived at in the course of observation and experiment. The degree of opacity which is absolutely necessary for seeing some of the most delicate structures is quite inconsistent with their natural condition, and is the result of a change which has never been fully appreciated, though, perhaps, some idea of its nature may be formed by considering the different characters of fibrin in the circulating blood, and fibrin removed from the organism and coagulated, or those of albumen dissolved in the serum,—coagulated but transparent in many of the tissues,—coagulated and opaque after the addition of different reagents. Or, the coloured matter constituting the red blood corpuscles, say of the Guinea pig, and the marvellously beautiful tetrahedral crystals into which the corpuscles change within a quarter of an hour after their removal from the blood. The internal structure of many perfectly transparent textures cannot be

seen at all until artificial processes of colouring or coagulation have been adopted.

It is, indeed, a simple fact that in many textures nothing is to be discovered if the ordinary methods of examination are pursued, while by special processes wonderful nerve plexuses and other things most definite and most important may be demonstrated. Some objectors will, no doubt, assert that the fibres and their bioplasts and the most beautiful arrangements of tissue discovered have all been created by the processes adopted for the demonstration. The observer who studies for himself will soon see the absurdity of the dogmas such persons reiterate. The result of acting upon the injunctions they lay down would be complete stagnation of investigation and the indefinite postponement of the discovery of new facts.

From what has been just observed it must be evident, that the clear demonstration of the structure of any individual organ of the body is a somewhat difficult matter, and requires for its success considerable knowledge of the chemical and physical characters of the tissues, as well as patient investigation and earnest study.

I shall now describe the general method of examining any recent specimen in a fluid, and in succeeding sections the special methods for rendering distinct the several anatomical elements of the tissues will be alluded to.

**212. General Directions for the Examination and Preservation of a Soft Tissue.**—Suppose a portion of muscular fibre is to be examined under the microscope. A small piece may be removed with a pair of very fine scissors, and placed carefully upon the glass slide. With the aid of two needles it may be torn into very small shreds, and it should then be moistened with a little water dropped upon it from the finger, or from a pipette, or from the wash-bottle; or instead of water, a drop of serum, of syrup, or of glycerine may be added to it, but in this last case it should be allowed to remain in the syrup or glycerine for some time, so that it may be thoroughly permeated by the more dense solution. Next a square or circular piece of thin glass is taken up by a pair of fine forceps, gently breathed upon and applied to the surface of the liquid, the glass being brought into contact with it, first on one side, and then allowed to fall down very gradually with the aid of a needle or piece of fine wire placed underneath one edge, until it becomes completely wetted, pl. XXVI, p. 100, fig. 4. Lastly, any superfluous fluid is to be absorbed by a cloth, or a small piece of fine sponge or blotting paper, and the slide placed in the field of the microscope for examination. It is important to prevent the entrance of air bubbles, pl. XXIII, p. 80, fig. 10, during the application of the thin glass cover, and if any are visible in the tissue or surrounding fluid before it is applied, it will be better to wait a few minutes until they

rise to the surface of the liquid and burst, before the thin glass cover is allowed to fall in its place. While time is allowed for this to take place, the specimen should be covered with a small glass shade to prevent dust falling upon it, pl. XX, p. 54, fig. 1.

It is advisable not to remove too much of the fluid, for fear the thin glass should press so heavily upon the preparation, that the several structures of which it is composed should be squeezed together and the specimen thus reduced to a confused mass, in which nothing definite could be detected. The observer will find it very useful to place a piece of hair or hog's bristle, between the thin glass and the glass slide, by which means too great pressure will be effectually prevented. The same effect is obtained by using a glass cell, but it will be found, I think, that it is more convenient to pursue the plan just described in the case of very delicate tissues, than to place them in a glass or other cell. The student may also refer to §§ 136, 137, 138, and 142.

Whenever a specimen is to be preserved permanently in fluid, it should be immersed in the solution in which it is intended to remain, for several hours or days previous to being mounted, so that it may be thoroughly saturated with the medium in every part. The fluid may be placed in a moderately deep cell, in a watch-glass, or in a cup of one of the palates used by artists, from which it may afterwards be removed to the slide. The thin glass having been applied, and all superfluous fluid removed, a thin layer of damar, Bell's cement, or Brunswick black is to be carefully painted round the edge so as to cement the thin glass to the slide. When this is dry other layers are to be applied successively until the joint is considered quite tight. The cement adheres better to the glass slide if it is roughened previously by grinding in this part, or by being scratched with the writing diamond just where the cement is to be placed. All objects, except the very thinnest, if preserved permanently in fluid, should be placed in a cell, because there is a much better prospect of their being kept for a long time, than when placed upon the glass slide in the manner employed for examining the specimen temporarily. The chance of air getting into the cell is much diminished if the cement which is used possesses slight elastic power, so as to admit the alteration which necessarily takes place in the volume of the fluid under variations of temperature. For cements, *see* page 54.

Although every one should examine and prepare tissues for himself, some students, from want of skill or inclination, prefer to study specimens already put up. Series of specimens are prepared by Mr. Cole and others. The following may be obtained of Messrs. Parke of Birmingham. The first series contains twelve slides, arranged to lie flat, in case, and costs a guinea. 1. White fibrous tissue; showing nuclei, stained. 2. Elastic tissue; showing anastomosing network of



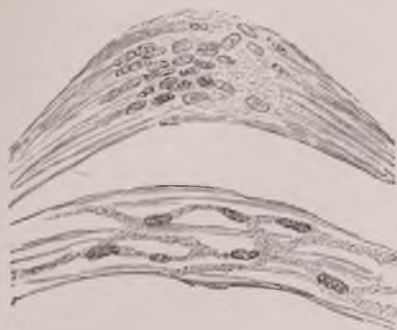
fibres. 3. Nucleated nerve-fibre; from sympathetic chain, tinted. 4. Muscular fibre, striated; vessels injected. 5. Ossifying cartilage; from vertebræ of human foetus. 6. H. section of human skin; showing H. section of hairs, with their relation to the fibrous stroma and glands, injected. 7. Human lung, showing epithelial lining of air cells, muscle and small bronchi, with columnar, epithelium, &c., tinted. 8. Human liver; showing vascular system of lobules, injected. 9. Human kidney, showing Malpighian tufts, &c., vessels injected. 10. Human small intestine; V. section, showing vessels of muscular coat, and villi, injected. 11. Human large intestine; V. section, showing tubular glands, and muscular coat, with their vessels, injected. 12. Human brain, cerebrum, showing vascular system, injected. The second series contains the following slides, and the case of twelve specimens also costs a guinea:—1. Section of bone, humerus of infant; showing periosteum *in situ*, Haversian canals, bone and marrow cells. 2. T. V. section of jaw; with tooth *in situ*, showing portion of gum, dentine tubes, and tooth pulp. 3. H. section of spinal cord; showing white substance of Schwann; central axis of Purkinje; nerve cells, &c., tinted. 4. V. section, human tongue; showing papillæ, muscular fibre, &c., injected. 5. Human lung, showing vascular system of air cells, injected. 6. Human stomach, V. section; showing vascular system of mucous membrane, &c., injected. 7. Human stomach, V. section, showing tubular glands, columnar epithelium of follicles, peptic cells, &c. 8. Human spleen, fœtal; showing Malpighian bodies, &c., injected. 9. Thyroid gland; showing vascular system of vesicles, injected. 10. Salivary gland; showing secreting cells, and vascular system, injected. 11. Section of ovary, from gravid uterus, with corpus luteum, injected. 12. Section of uterus; tinted, and vascular system, injected. It is proposed to issue other series illustrating the structure of the *respiratory organs, the organs of the nervous system, alimentary system, secreting system, &c.* Series of such specimens, healthy and morbid, are also to be obtained of Mr. Cole.

#### EXAMINATION OF THE SIMPLE TISSUES.

I propose now to refer very briefly to the methods of demonstrating the structure of the most important tissues of the higher animals, and at the same time I shall briefly allude to some of the most striking of their general characters.

**213. Areolar Tissue** is found beneath the skin, and mucous membranes, or from the external coat of the arteries of any small animal. From the calf or lamb excellent specimens of areolar tissue can be always obtained. In some situations it is lax and very abundant. It may be blown up with air, and dried to show the areolæ or spaces in which it is disposed, and which communicate with one another through

Fig. 1.



x 216

Formation of bundles of fibrous tissue. Areolar tissue  
Frog. x 216. p. 139.

Fig. 2.



Very simple form of connective tissue, with  
bioplasm (nuclei). x 130 p. 139.

Fig. 3.



x 215

White fibrous tissue from tendon. In water.  
No bioplasm visible. p. 139.

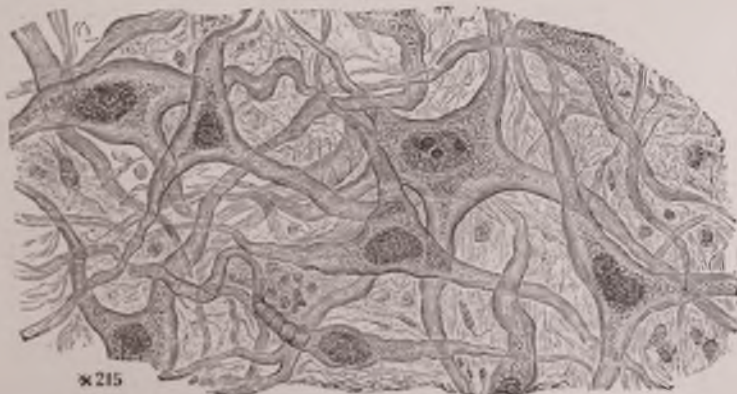
Fig. 4.



x 215

Yellow fibrous tissue from the ligament of  
the neck of a sheep. In water. No bioplasm  
visible. p. 139.

Fig. 5.



x 215

Muscular fibre cells and elastic fibres, from the circular coat of a large artery. The bioplasm  
is seen in the central part of each fibre. x 215 p. 139



the whole body. If the vessels be injected with plain size, the areolæ become distended with it, and when cold, very thin sections of areolar tissue may be easily cut, which show the arrangement of the fibres in the most beautiful manner. It consists of two elementary tissues—the *white fibrous* tissue and the *yellow fibrous* or *elastic* tissue; but it is often associated with adipose tissue, and in it vessels, nerves, and frequently lymphatics ramify.

The structure of areolar or connective tissue may be well studied in pieces removed from beneath the mucous membrane of the back of the tongue or throat, or in that which connects the mucous membrane of the stomach and intestine with the muscular coat. By staining carefully, the so called nuclei, the bioplasts which take part in the formation of the white fibrous tissue, of the yellow elastic tissue, of capillaries, and nerve-fibres may be distinguished. For this purpose it is, however, better to adopt the mode of preparation given in detail in part VI. A very simple form of connective tissue with its bioplasts is represented in fig. 2, pl. XXXII, p. 138, and the manner of its growth by the continual increase of the circles of fibres at their circumference, will be understood if the drawing be carefully examined.

**214. White Fibrous Tissue** can be readily obtained free from the yellow element in tendons and many fasciæ. In the former, its fibres are slightly wavy, but parallel to one another. It can be split up indefinitely, and does not appear to be composed of minute fibres. This fibrous appearance is destroyed by the action of acetic acid and alkalis, and is rendered less distinct if the tissue be soaked in glycerine. Upon the addition of water, the tissue resumes its ordinary appearance. White fibrous tissue is very opaque, and in order to demonstrate its characters well, it is desirable to cut a very thin section, unravel it with needles, and subject it to moderate pressure under the thin glass. In pl. XXXII, fig. 3, a portion of tendon is represented without its bioplasts, and in fig. 1, the mode of development from the bioplasts is represented.

**215. Yellow Fibrous Tissue** may be obtained, perfectly free from the white fibrous element, from the *ligamentum nuchæ*, a firm yellow cord at the back of the neck, of any animal—from arteries, or from the elastic ligament to which the retraction of the claw in the cat and other feline animals is due. It consists of circular fibres disposed to curl up very much, and not easily broken or destroyed by the action of reagents. Sometimes these fibres split transversely, as in the *ligamentum nuchæ* of the giraffe, giving rise to the appearance of transverse striæ. In areolar tissue the fibres are very long and branching, after the manner of a network; in the *ligamentum nuchæ* they are parallel to one another, pl. XXXII, fig. 4; in the *longitudinal* fibrous coat of the arteries they are parallel and extremely delicate; in the *circular* coat they are coarse,

and the material is often disposed in ragged laminæ rather than in distinct fibres.

The bioplasm of yellow fibrous tissue may be always readily demonstrated in the ligamentum nuchæ of the lamb according to the method of investigation described in part VI. These bioplasts, which are quite constant, are said by many observers not to exist, and were not figured in any drawings, as far as I am aware of, when mine were first published.

**216. Adipose Tissue.**—Adipose tissue may be examined by cutting off a thin section of the fat of any young animal, and placing it with a little water between two pieces of glass, care being taken not to allow the thin glass cover to press upon it. The surface of one of the smallest collections of fat cells which can be found, should be subjected to examination as an opaque object.

The mesentery, or fold of delicate membrane which attaches the intestine to the spine, of small animals, is the best place for obtaining good specimens of adipose tissue,—and being protected by the transparent covering, the relations and form of the fat vesicles are not altered. In this situation, too, the bioplasm of each vesicle may be demonstrated, and cells in every stage of growth can be easily found. Such a preparation, the vessels of which have been previously injected with Prussian blue fluid, will afford an opportunity of demonstrating all peculiarities of adipose tissue. About the intestine and near the kidneys of the newt and many other batrachia, there exist small collections of adipose tissue. The adipose tissue of frogs, toads, and newts, especially in the young state, is admirable for study. In batrachia generally, the adipose vesicles in the neighbourhood of the ovaries are much shrunken during the spring, when the ova are increasing in size, and at this time the bioplasm of each vesicle is beautifully distinct. The bioplasts of the fat cells may also be seen very distinctly, especially in starved fat cells, after treatment with a little acetic acid, pl. XXXIII, fig. 1. Ordinary adipose tissue with connective tissue containing much of the yellow element is represented in pl. XXXIII, fig. 3. Frequently the more solid portion of the fat will crystallise on the surface of the more oily, in small acicular crystals, which radiate from a centre forming a star-like mass, as seen in the figures 1, 2. Adipose tissue should be examined by low as well as by high powers (a two inch, or an inch, and a quarter of an inch object-glass), and by *reflected* as well as by *transmitted* light.

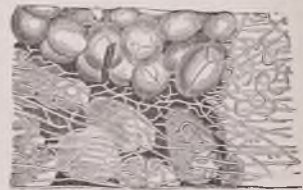
**217. Cartilage.**—The characters of cartilage are very easily demonstrated. A thin section may be placed in water or glycerine. Specimens should be taken from the larynx, trachea, the ear, the ribs, the articular cartilage of joints, and the fibro-cartilage between the vertebræ of any small animal, and from other situations. The ear of the mouse affords the best example of cartilage consisting almost entirely of cells.

Fig. 2.



Fat vesicles in which the crystalline fat has separated from the oily fat. p. 140.

Fig. 3.



Adipose tissue with areolar tissue. p. 140.

Fig. 1.



Adipose tissue showing fat vesicles with 'nuclei' or masses of 'bioplasm.' X 130. p. 140.

Fig. 4.

KITTEN, AT BIRTH.



Fig. 5.

SIX WEEKS OLD.



Fig. 6.

NEARLY FULL GROWN.



Fig. 7.

ADULT CAT.



Cartilage at different ages, showing the relative number of the masses of bioplasm and their relation to the matrix or formed material. X 215. p. 141.

Fig. 8.



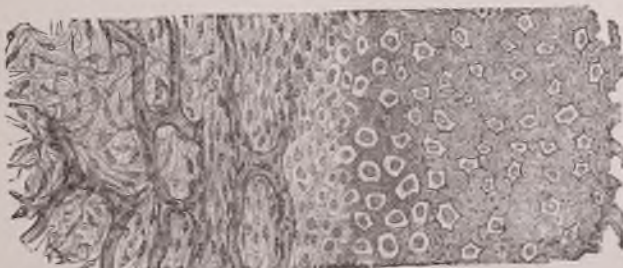
Section through temporary cartilage and fibrous tissue of tendon. From the os calcis. Kitten. X 700. p. 141.

Fig. 9.



Recently formed lacunae with bioplasm and canaliculi. Frontal bone. Frog. X 700. p. 142.

Fig. 10.



Thin section of recently formed bone with the periosteum. Observe the bioplasm. From the femur of a kitten. X 215. p. 142



The thin layer in the upper portion of the aural cartilage is very favourable for studying the nutrition and mode of growth of the cells, the intercellular substance or matrix being very small in quantity in this variety of membraniform cartilage. The observer should also study the characters of the permanent cartilage of some of the so-called cartilaginous fishes, particularly the common dogfish and the lamprey, which may often be obtained in the fishmongers' shops. The tail and other parts of the skeleton of the tadpole, of the frog, toad, or newt, are also well worthy of study. Specimens of cartilage keep very well in dilute spirit and water, creosote fluid, and many other solutions, but on the whole glycerine is to be preferred as the medium for their preservation.

The development of cartilage, and the changes by which it is converted into bone, may be successfully studied in the flat bones of the skull of a small frog, toad, or newt. The general changes occurring in the growth of cartilage will be understood by reference to pl. XXXIII, figs. 4, 5, 6, 7. See also my paper "On the formation of the so-called intercellular substance of cartilage, and of its relation to the so-called cells; with observations upon the process of ossification." ("Microscopical Journal," 1863.)

In pl. XXXIII, fig. 8, a drawing is given showing cartilage and tendon continuous with it. The white fibrous tissue of the tendon is seen to be continuous with the so-called matrix or intercellular substance of the cartilage, and exactly represents it.

**218. Bone.**—Sections of bones are obtained in the manner alluded to in p. 98. It is desirable to make sections of the whole extent of the compact tissue. The observer will notice in thin sections, even of young bones, spaces of very different sizes, resulting from the division of a number of tubes (Haversian canals) in which run the vessels, which are distributed to the compact tissue. Now it appears from the beautiful researches of Tomes and De Morgan, that this solid, hard, compact tissue is perpetually undergoing removal and repair. An Haversian canal increases in diameter by the gradual absorption of the concentric lamellæ of bone which surround it, and after a time, a large space is formed (Haversian space). When this space has reached a certain size, new bone is deposited, commencing at the circumference and gradually proceeding towards the centre, until the space has regained its small size and is again converted into a narrow canal. The *interstitial laminae* upon this view are very readily accounted for. They are, doubtless, the remains of old Haversian systems only partially absorbed. ("Phil. Trans.," 1853.)

The growth of bone may be investigated in young animals by mixing madder with their food. In a very short time (even a few days) the madder, which has an affinity for phosphate of lime, is deposited in those parts of the bone nearest to the vascular surface. Young pigs are



the best animals for experiments of this kind. The arrangement of the vessels may be studied in the bones of an animal which has been injected with Prussian blue fluid. It is well to add an excess of hydrochloric acid to the solution. After the injection is complete, the bone may be soaked in dilute hydrochloric acid (one of acid to five of water), to dissolve out the earthy matter, when the soft tissue which remains can be readily cut into thin sections in various directions with a thin sharp knife. It will be found better to soak the bone after injection with the Prussian blue fluid, in equal parts of glycerine and water, to which hydrochloric acid has been added.

Not unfrequently the vessels of bone are found distended with blood, thus producing a natural injection. It is difficult to cut and grind the section thin enough for examination without altering the masses of dried blood, but with care this may be effected. My friend Mr. White has given me some beautiful sections of the antler of the stag, prepared by him, in which all the Haversian canals still retain blood.

Sections of bone may be preserved—dry, in aqueous fluids, or in Canada balsam. The dark appearance of the lacunæ in sections of dried bone is entirely due to their containing air. Their apparent solidity led Purkinje, their discoverer, to call them *bone corpuscles*. The true nature of these bodies has been already explained in page 90, and every student should treat a thin section of dry bone while under a quarter of an inch object glass with turpentine, and see for himself the fluid running up the canaliculi and filling the lacunæ. Lacunæ with their masses of living matter or bioplasm are represented in fig. 9, pl. XXXIII.

The changes taking place in the development of bony tissue of a mammalian animal are well seen in fig. 10, pl. XXXIII. The figure, which is a very thin section through periosteum, vessels, subjacent soft tissue, and the compact texture of the bone itself, is well worthy of attentive study. On the left hand is the periosteum with the capillaries, then come the bioplasts, and to the right is the fully formed bone tissue.

#### *Examination of the Higher Tissues.*

**219. Examination of Muscular Fibre.**—For a full description of the minute anatomy of muscular fibre, I must refer to the various works on physiology and minute anatomy; and especially to the well-known papers of Mr. Bowman in the "Philosophical Transactions," 1840-41, and to the articles "Muscle," and "Muscular Motion," in the Cyclopædia of Anatomy and Physiology.

Two forms of muscular fibre have been described, the *striped* or *voluntary fibre*, or *muscular fibre of animal life*, and the *unstriped*, *involuntary*, or *muscular fibre of organic life*, the characters of which will be presently referred to. Both forms possess contractility, and

each contracts when touched, as may be proved by direct experiment under the microscope, or when the nerve fibres ramifying over it are touched or irritated in any other manner. Both are represented in the lower animals, but in many of the invertebrates all the muscular fibre is unstriped. The voluntary muscle alone is under the direct control of the will, while the involuntary fibre performs its functions altogether independently of volition. Both are very freely supplied with nerve fibres which ramify amongst the muscular fibres and form networks or plexuses around them, and their contraction is due to nerve influence.

Striped muscular fibre exists in all the voluntary muscles of vertebrate animals. Beautiful examples of striped muscle may be obtained from almost any member of the class of insects or crustacea. If specimens be taken from the members of the different vertebrate classes, certain characteristic peculiarities will be met with, and the muscular fibre of the crustacean, mollusk, and insect, differs from that of the higher animals in many important particulars. In order to subject a portion of muscular fibre to microscopical examination, it is only necessary to remove a small piece with a sharp knife or a pair of scissors. After tearing it up with needles, and moistening it with a drop of water or serum, the thin glass cover may be placed on it, and the specimen examined with different powers. The transverse striæ will often be rendered very distinct after the fibre has been allowed to macerate for some time in glycerine.

The general arrangement and form of the fibres in voluntary muscles are well shown in a transverse section of the pectoral muscle of a teal (*Querquedula crecca*), which has been put upon the stretch, and allowed to become perfectly dry. A section cut as thin as possible, may be re-moistened with water, and examined in the usual manner. The position of the vessels, their relation to the elementary fibres, and the character of the capillary network are easily demonstrated in specimens which have been injected with transparent Prussian blue or carmine injection.

**220. Sarcolemma.**—The muscle of the skate, as Mr. Bowman has shown, is remarkably well adapted for showing the sarcolemma, as the sarcous matter may often be ruptured. The investing membrane or sarcolemma remaining entire is thus easily demonstrated. A few of the long muscular fibres from the fin may be spread out on a piece of glass with the aid of needles, and in this operation the rupture of the sarcous matter in the interior is often effected. Sarcolemma is well seen in pl. XXXIV, fig. 3. This membranous tube may be also beautifully shown in the muscular fibres of a water-beetle, particularly in those of the large dytiscus, and also in the muscles of the common maggot of the blow-fly. See also p. 189.

**221. Branched Muscular Fibres.**—Several modifications of striped

muscle have been described of late years, and it is desirable to consider the best methods of demonstrating a few of the most important of these. Branched muscular fibres have been found in the heart, but the finest of them are not very easily demonstrated in the heart of man and the higher animals. Branching muscular fibres exist in great abundance in the tongue of the frog (as was first pointed out by Kölliker), from which organ they may be generally obtained as follows:—the tongue is to be separated from the animal, and boiled for a few moments in water; the mucous membrane is cautiously dissected off from a small portion, and a few minute pieces are to be carefully snipped off with scissors, from the edge of the tongue, just beneath the mucous membrane. These are to be torn with very delicate needles, and then examined with a quarter of an inch object-glass. In this manner very perfect fibres may generally be found. Care must be taken not to boil the tongue for too long a time in case the fibres become too brittle to admit of separation. These branched muscular fibres are beautiful objects. In good specimens they are seen to ramify after the manner of the branches of a tree, gradually becoming thinner, until each terminates in a delicate extremity, which is of a tendinous nature, and is incorporated with the sub-mucous tissue or *corium*. The transverse striæ may be observed in the thinnest branches, but gradually cease some distance from the terminal extremity of the fibre. Branched fibres also exist in the upper lip of the rat, and in other situations. Excessively delicate branched muscular fibres are to be seen in the fungiform papillæ of the frog's tongue. See drawings accompanying my paper in the "Phil. Trans." for 1864.

**222. Preparation of Muscular Fibre for Microscopical Examination.**

—The transverse striæ may usually be demonstrated upon a piece of fresh muscular fibre, and are often seen very distinctly in a portion of ordinary voluntary muscle that has been boiled. The ultimate fibrillæ are well displayed in the muscles of many of the lower cartilaginous fishes, especially the lamprey. The mode of cleavage can be very satisfactorily determined in the muscles of lizards or the cameleon, and the "ultimate sarcous particles" may be separated from one another if the muscular fibres of the common eel, or those of a young pig, be carefully torn up with needles.

I have often obtained beautiful specimens of striated muscular fibre from the back of the tongue, a few hours after a meal, of which meat has formed a portion. They are also to be found in beef tea, and in many of the meats and soups which are preserved in tins.

Amongst vomited matters or in the contents of the stomach of an animal killed two or three hours after a meal, beautiful specimens of striped muscular fibre may often be found. In the stomach, the fibres sometimes break up into the disks described by Bowman, and I have

obtained these disks by macerating the muscles of young animals for some time in strong acetic acid.

The "fibrillæ" often separate readily from each other in a portion of muscle which has been macerated in a solution of chromic acid. These "fibrillæ" present different appearances according to the degree of contraction of the fibre at the time of death and other circumstances. Some of them are represented in pl. XXXIV, p. 146, fig. 4, after some drawings by the late Dr. Martyn of Clifton.

The thin, narrow, muscular bands, immediately under the skin of frogs and other small animals, will be found to exhibit well the general anatomy of voluntary muscle, and beautiful preparations exhibiting the fibrillæ, have been obtained by Mr. Lealand from the pig. Transverse, longitudinal, or oblique sections of muscle may be made in the case of muscles which have been boiled, or hardened in spirit, bichloride of mercury, or chromic acid. The reagents of the greatest use in investigating the structure of muscular fibre, are a dilute solution of caustic soda, and acetic acid, which are employed more particularly in investigating the arrangement of the bioplasts in fresh muscle. Preparations of muscular fibre may be preserved moist in glycerine, glycerine jelly, chromic acid, or solution of creosote, pp. 66, 67, or they may be dried and mounted in Canada balsam.

The capillaries and the delicate nerve fibres distributed to voluntary muscle are well represented in pl. XXXIV, p. 146, fig. 1, and in fig. 2 the precise relation of the capillaries and nerve fibres to the contractile tissue of an elementary fibre is shown. In these drawings the bioplasm of the several tissues is also represented.

The movements of muscle during contraction cannot be studied in the higher animals and man but may be observed in many of the lower animals. *See* § 256. The mode of demonstrating the distribution of the finest ramifications of the nerves to muscle will be found described in part VI.

**223. Examination of the Muscular Structure of the Heart and Tongue.**—The muscular fibres of the heart will be found to exhibit the transverse striæ characteristic of voluntary muscle; but they are arranged in long bands, and upon carefully examining a well-prepared specimen, taken either from the heart of man or of most animals, frequent and distinct anastomoses and branchings of the fibres may be observed. There is no sarcolemma, for some of the muscular fibres of the heart are growing in circumference, while neighbouring ones which have reached their full size are being removed to make place for new ones which are constantly being developed and growing. In many cases a little connective tissue which corresponds to the sarcolemma may often be detected. Indeed it is probable that the so-called sarcolemma consists of the vessels and nerves and other structures with a very small amount of connecting substance between them.

In order to exhibit the muscular fibres of the heart, that of any small animal may be taken, and after it has been boiled for a short time in water, small pieces may be cut off, and carefully torn up with needles. The length of time which the boiling should be continued varies in different cases. Half a minute is sufficient for the hearts of very small animals; sheep's hearts may be boiled for a quarter of an hour. But the most perfect specimens of the muscular fibres of the heart may be obtained from the thin auricle of the heart of the frog, or better, that of the hyla, or little green tree frog. The auricle is sufficiently thin for observation, but the fibres are most distinctly seen after it has been soaked for two or three days in glycerine. Sections of the muscular substance of the tongue of man and the larger animals are readily made by drying the organ when perfectly fresh, and removing a very thin section with a sharp knife. The specimen is then moistened with water. It may be treated with different reagents, and afterwards preserved in glycerine, glycerine jelly, or other preservative fluid.

**224. Examination of Unstriated Muscle.**—Involuntary, smooth, or non-striated muscular fibre may be obtained from various situations, both in man and also in the lower animals. These fibres are most abundant in the alimentary canal, the uterus, the bladder, the ducts of glands generally, and large vessels, but they are also found dispersed amongst fibrous tissue in certain situations, particularly in the skin. There are also bundles of pale muscle connected with the hair bulbs, which may be demonstrated in some cases. The elongated cells, of which this form of muscle is composed, are also to be demonstrated in the small arteries, pl. XXXV, fig. 3, and veins, as well as in the trabecular tissue of the spleen. Involuntary muscle, which has hitherto been described as consisting of flattened bands, has been demonstrated by Professor Kölliker to consist of the elongated cells just referred to. The contractile fibre cells usually appear as flattened bands, or fusiform fibres, slightly wavy, and terminating at each end in a point. These bodies may be readily isolated by macerating small pieces of the muscular coat of the alimentary canal, &c., in dilute nitric acid, containing about twenty per cent. of strong acid. By a little teasing, with the aid of fine needles, separate cells may be readily obtained. Fig. 5, pl. XXXIV, p. 146, represents some of the contractile fibre cells from the small intestine. These cells may also be demonstrated in most of the lower animals; but it is worthy of remark that a portion only of the alimentary canal of some fish is surrounded by involuntary muscle, while it has been shown that the whole of the muscular fibre of the intestine of the common tench is of the striped variety (Weber). In the bladder of the frog we have as it were a natural section in which all the tissues of the organ may be seen and their exact relation to one another clearly demonstrated. The method of preparing the specimen is described in part VI.

Fig. 1.



Elementary muscular fibres from the diaphragm of the white mouse showing the distribution of nerves and capillaries to striped muscle. Four fibres with their transverse markings. *a*, sarcolemma. *b*, nerve fibres given off from the bundle *c* in the upper part of the drawing. *d*, capillary vessels. Masses of bioplasm ('nuclei') are seen in connection with the muscular fibres, with the nerves, and with the capillaries in all parts of the drawing. X 250. p. 140.

Fig. 2.



Elementary muscular fibre. White mouse showing fine nerve fibres and capillaries with the bioplasm distributed to them. X 700. p. 140.

Fig. 3.



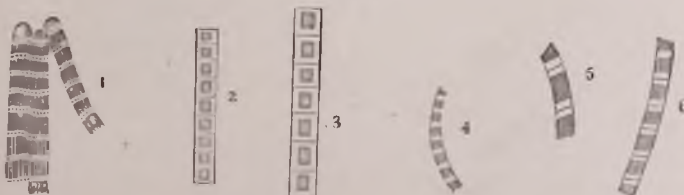
Sarcolemma of muscle, showing distribution of fine nerve fibres on external surface. Camelion. X 700, reduced one-half. p. 143.

Fig. 5.



Muscular fibre cells. Intestine. X 215. p. 146.

Fig 4



Various appearances exhibited by fibrils of muscle. After Dr Martyn. p. 145



**225. Examination of Arteries and Veins.**—The structure of arteries and veins may be well studied in any of the smaller vertebrate animals, especially in the frog. In mammalia beautiful specimens may be obtained from the mouse. The vessels in the mesentery, the pleura, and pericardium may be subjected to examination without difficulty, but the smaller arteries and veins of the *pia mater*, or vascular membrane of the brain, and those of the folds (choroid plexuses) of the same membrane in the cavities (ventricles) of the brain are more free from connective tissue and can be easily isolated, pl. XXXV, fig. 4.

The yellow elastic tissue of the arterial coats of the larger arteries may be demonstrated in any artery of a quarter of an inch or more in diameter. The fibres vary very much in character, sometimes appearing rather as an expanded elastic membrane perforated here and there, than as separate fibres. In the smallest arteries and veins, there is very little elastic tissue, but this is represented as muscular fibre. On the other hand in the largest vessels, the muscular fibres appear to have almost given place to yellow elastic tissue.

I have obtained beautiful specimens of the muscular fibre cells arranged circularly round the arteries by injecting the vessels with plain size, and gradually increasing the force so as to distend them as much as possible without rupture. In this manner the cells are as it were, gradually unravelled. When cold, thin sections may be very easily made in various directions, and even isolated fibre cells can be obtained. The arrangement of the muscular fibre cells in the smaller vessels is well seen in the small arteries from the frog and newt. See pl. XXXV, fig. 3.

The arrangement of the numerous nerve fibres distributed to the small arteries and veins may be demonstrated in the frog with the greatest distinctness, and in connection with the small vessels which supply the viscera numerous ganglia will be found from which bundles of nerve fibres may be traced in different directions. These often form plexuses around the vessels and give off finer bundles, and fibres may be followed even to the capillary vessels.

**226. Examination of the Capillaries.**—Capillary vessels are most important structures in all vertebrate animals, and as it is through the medium of these delicate thin walled tubes that every tissue and organ of man and vertebrate animals is nourished and relieved of the products of its action and decay, their arrangement and structure are worthy of the most attentive study. The mode of displaying their general arrangement by injection of the tissues and organs of the lower animals has been already described, pp. 102—108. The masses of bioplasm in connection with their walls vary in number greatly in different parts. In some textures the capillary appears to be almost entirely surrounded with them, pl. XXXV, figs. 1, 2, also pl. XXX, p. 110, fig. 3,



while in others a considerable interval of capillary wall exists which is perfectly free from them. These bodies are constant, and of the greatest importance. They vary much in size, being large where pabulum is abundant, and shrinking when but a small quantity of nutrient matter reaches them. They are connected not only with the changes going on in the tissue around the capillary but are in all probability intimately concerned in the selection and separation of various constituents from the blood. They are often seen to project into the interior of the capillary, and it seems not improbable that some of the bioplasm of the blood (minute spherical particles, some of which probably become white blood corpuscles) may from time to time be detached from them. Capillary vessels are supplied with nerve fibres. These may be demonstrated with great distinctness around the capillaries of the skin, tongue, and mucous membrane of the fauces of the frog or newt, pl. XXXV, figs. 5, 6.

**227. Examination of Nerve.**—The general anatomy of the trunk of a nerve is demonstrated without difficulty. It is better to take as thin a fibre as possible, and tear it up with very fine needles upon a glass slide. After the addition of a drop of serum, it may be covered with thin glass. The small nerve trunks of any small animal may be taken. The nerves of the frog are very large, and exhibit all the essential structures of nerve fibres, pl. XXXVI, fig. 1. A very fine nerve trunk should be examined in water, and then transferred to glycerine, and after remaining in it for twenty-four hours or more, re-examined. Although glycerine will be found an excellent medium for examining nerve fibres in, other media should also be employed, for microscopical observation should never be limited to specimens prepared according to one method of investigation only.

*a. Dark-bordered nerve fibres.*—If an ordinary spinal nerve be placed in a little water, a curious change takes place. The constituents of which the medullary sheath is composed exhibit two distinct lines (white substance of Schwann), a change which probably depends upon the fatty matter being partly separated from the albuminous fluid with which it was incorporated, pl. XXXVI, p. 150, fig. 3. Although the appearance in question is undoubtedly produced by soaking in water, the existence of a special highly refracting material within the *tubular membrane* and around the *axis cylinder*, cannot be questioned. If nerves be examined in syrup or glycerine, the double contour line is not seen.

The so-called *tubular membrane* can hardly be regarded as a special investment. It consists merely of delicate connective tissue in which sometimes one, sometimes several, nerve fibres are embedded, as shown in fig. 1. The so-called outline of this apparent tubular membrane is often due to the presence of a *fine nerve fibre*. This is easily proved in

Fig. 1.



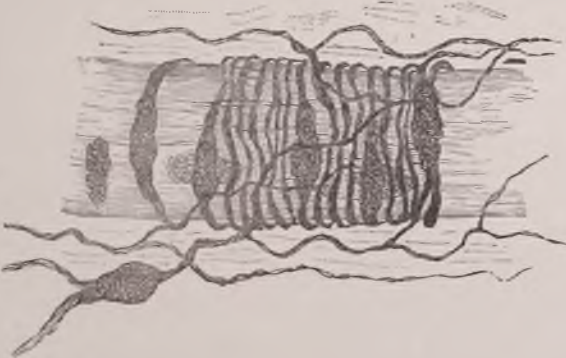
Nerves and capillaries from mucous membrane covering the epiglottis of man. Showing numerous bioplasts of nerves and capillaries. X 215. D. 137.

Fig. 2.



Capillary vessel from the mucous membrane of the epiglottis. Showing numerous bioplasts projecting into the interior of the vessel. p. 137.

Fig. 3.



Portion of very small artery, showing muscular fibre cells and nerve fibres. Frog. X 700. p. 137.

Fig. 4.



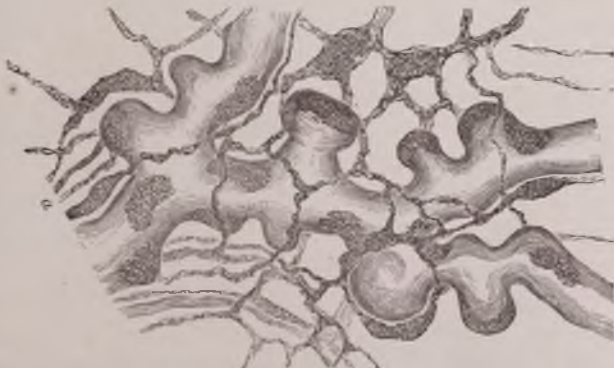
Minute artery passing into capillaries, from a healthy brain. X 215. p. 147.

Fig. 6.



Capillary with nerve fibres and bioplasts. Frog X 700. p. 138.

Fig. 5.



Capillaries with diverticula. Roof of mouth. Frog. Numerous fine nerve fibres with large bioplasts distributed to the nerves and vessels. X 700. p. 138.



those cases in which the outline is seen on one side only, pl. XXXVI, fig. 6. The very distinct fine nerve fibre, represented in many of my drawings, might have been mistaken for the outline of the tubular membrane if the specimen had been examined before it had been properly prepared and carefully mounted in glycerine, fig. 2.

The investigation of the manner in which nerves terminate is one of the most difficult inquiries that the observer can undertake. In many structures a nerve network of dark-bordered nerve fibres may be demonstrated without difficulty, but this is not the terminal network. The finest nerve fibrils have often been traced for some short distance and then lost. Some observers have on this account been led to conclude that the finest branches of the nerve fibres became as it were continuous in other tissues, or ended in the connective tissue of the part! I have shown that in all cases nerves lose their dark-bordered character, and exist as pale fibres which may be traced for a long distance beyond the point where the dark-bordered character ceases. These very fine pale fibres at last form with similar prolongations from other dark-bordered fibres a very intimate interlacement, plexus, or network of very fine pale fibres only, many of which are less than  $\frac{1}{100000}$  of an inch in diameter. This network is arranged in all cases upon the same type, but varies in complexity, extent, and relations in the various terminal nerve organs. In investigating the mode of termination of nerve fibres, the papillæ of the tongue of many of the lower animals, and especially the very simple filiform papillæ of the frog may be selected.

The general distribution of the larger branches of the sensitive nerve fibres beneath the skin, may be well seen in the ear of the mouse, after the very thin cuticular covering and subjacent texture have been carefully dissected off. In the dura mater and other fibrous membranes, I have seen many individual nerve fibres arranged so as to form with others a coarse network, a single fibre from which may often be traced for a very long distance.

The dark-bordered fibres often divide at the point where a bundle diverges from the trunk—one of the subdivisions passing on in the trunk, while another pursues a different and sometimes opposite direction in the bundle which leaves the trunk, and each of these again divides and subdivides further on. The fibres in these localities frequently leave their companions and pass a short distance with others, so that a network is in this manner formed upon the surface for instance of the dura mater and other membranes, and immediately beneath the skin. The mesentery of the mouse is a very good membranous texture in which to study the distribution of very fine nerves in a mammalian animal. Beautiful preparations showing the distribution of sensitive nerves may be obtained from the snout of the pig, mole, and other animals. At the free edge of the third eyelid of the frog is a most

extensive plexus of fine dark-bordered nerve fibres, which are arranged so as to form the most beautiful network.

But of all the situations for studying the terminal ramifications of sensitive nerve fibres, the thin membranous portion of the wing of the bat is the best. The cuticle may be easily stripped off after a portion of the wing has been soaked for a considerable time in glycerine. It is better to inject the vessels of the animal first with carmine and then with Prussian blue fluid before preparations are made. Further details will be found in part VI.

The finest terminal plexuses of nerve fibres may also be studied in the proper tissue of the cornea, in the fibrous tissue in the abdominal cavity of the frog, around arteries and veins, in the tongue, especially the papillæ of the hyla or green tree frog, in the mucous membrane of the pharynx, and in the lung and bladder of the same animal. The relation of the nerves to the corneal corpuscles, and their prolongations should be carefully noted, pl. XXXVI, fig. 4. This investigation, however, presents difficulties, and the student should not attempt it until he has succeeded in making good specimens of other textures. He will find the process, given in part VI, of great value in such inquiries.

*b. Pale, Grey, Sympathetic or Organic Nerve Fibres.*—Some authorities, until very recently, insisted upon the assertion that every true nerve is characterised by being *dark-bordered*,—exhibiting the double contour lines caused by the investment of the medullary sheath, the so-called white substance of Schwann. Remak, however, correctly described, nearly forty years ago, the pale grey or gelatinous nerve fibres of the organic or sympathetic system, but his views were strongly opposed by the majority of anatomical authorities, and his nerve fibres were pronounced to be mere connective tissue. They were afterwards ironically called *Remak's fibres*. In Germany, some years ago, many anatomists tried to reduce everything to what they called connective tissue, which to any ordinary observer seemed to be the least important tissue in the organism. Even now it is a matter of the utmost difficulty to get a fair hearing if you attempt to extract real and definite anatomical elements from this favoured indefinite connective tissue. However, it has been clearly proved that Remak's fibres are true nerve fibres, and that all nerve fibres before they reach their ultimate distribution, invariably assume the pale granular appearance of Remak's fibres. So far from the dark-bordered character being essential to nervous structure, the active peripheral portion, the really important part of every nerve fibre, *never exhibits it*. The white substance is a passive fatty albuminous matter which surrounds the conducting core of the nerve fibre and insulates it from neighbouring fibres and from the tissues amongst which it runs. It is peculiar to the trunks of nerves which connect the great central organs with the distant peripheral ramifications.

FIG. 1.



Dark bordered nerve fibres, dividing and subdividing, distributed to the muscles of the leg. Frog.  $\times 550$ , reduced one-half. p. 148.

FIG. 2.



Fine dark bordered nerve fibre, with fine pale fibres accompanying it. Skin of hyla.  $\times 700$ . p. 149.

FIG. 3.



Softened cerebral matter from the brain.  $\times 190$  p. 147.

FIG. 4.



Networks of fine terminal nerve fibres. Cornea of the green tree-frog. The connective tissue corpuscles, which are unconnected with the nerve fibres, are figured in the lower part of the drawing.  $\times 700$ , and reduced one half. p. 150

FIG. 5.

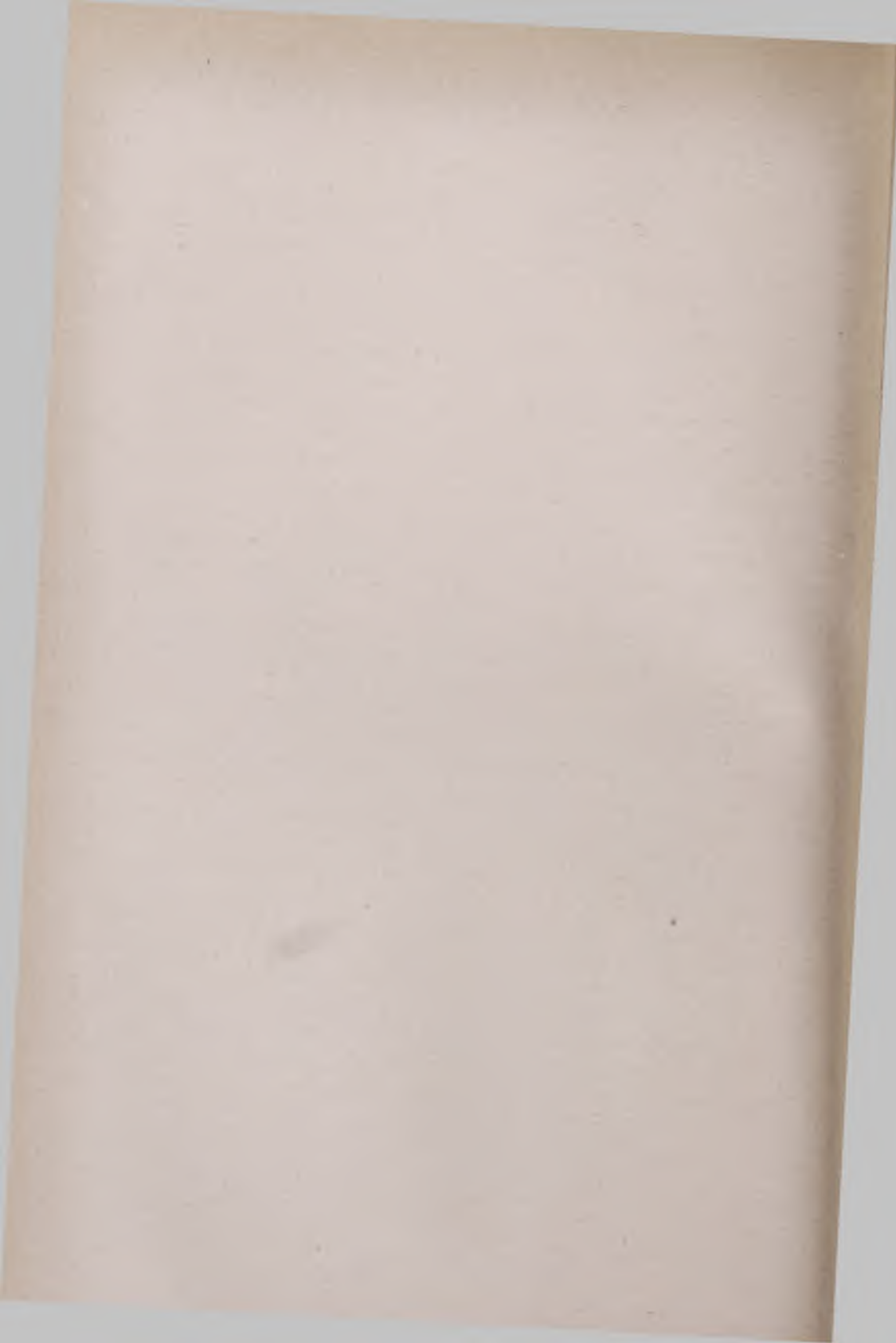


Cerebral matter in water. Showing the double contour of myelin.  $\times 215$ . p. 148.

FIG. 6.



Dark bordered nerve fibre, with fine nerve fibres running on one side of it. Frog.  $\times 700$ . p. 148.



Into many sympathetic ganglionic nerve centres, however, pale fibres are to be traced ; and not a fibre can be found with a medullary sheath in any part of the course of some of the nerve trunks. These sympathetic nerves in fact form an extended network or plexus which corresponds to the peripheral network of the cerebro-spinal nerves. The distance between their central origin and their peripheral distribution is so short that there is not that need of insulation that obtains in the case of the fibres coming from the brain and spinal cord. Sympathetic nerve fibres and their ganglia are represented in pl. XXXVII, figs. 1 to 4, and the mode of connection of the fibre with the ganglion cell is seen in fig. 3, in a sympathetic ganglion cell of the ox, and in that of the frog, in pl. XL, fig. 4, p. 152. Many observers, however, still maintain that the appearance, represented in my drawing, is due to the ganglion cells being enclosed in a capsule of connective tissue, and assert that some cells exist from which no fibres whatever proceed. These strange notions are still taught in many of our most celebrated text books, and are erroneously forced upon the mind by the repetition of incorrect illustrations.

It has been stated that no method of preserving nerve tissue has been devised which makes it worth while to mount preparations for the sake of displaying its minute characters, and this statement, strange to say, has been repeated in books devoted expressly to mounting objects. It need scarcely be said here that the most delicate of the nerve textures can be mounted permanently. Not only so, but new facts in connection with the ultimate arrangement of nerves can be demonstrated in specimens which have been kept for some time, and fine fibres become distinct and well defined which were quite invisible when mounted. There are in truth very few objects which cannot be preserved permanently, so as to show far more than can be demonstrated in them as fresh specimens. The use of chromic and acetic acids, and perchloride of gold in the investigation of nerve structures has been referred to in p. 129. Many nerve tissues may be hardened in Müller's fluid consisting of sulphate of soda 1 part, bichromate of potash 2 parts, and water 100 parts, or in the fluid which I have used for more than twenty years, consisting of chromic acid and bichromate of potash, one part of each or less to 100 parts of glycerine. *See* also the directions given in part VI.



EXAMINATION OF THE ORGANS AND COMPLEX TISSUES OF MAN AND  
THE HIGHER ANIMALS.

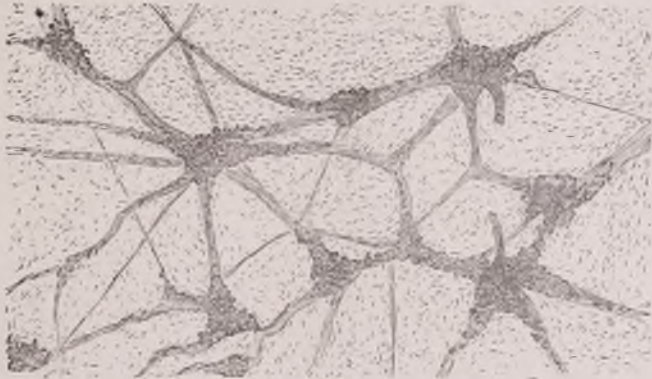
We now come to the consideration of organs which are made up of several different elementary tissues. The fact of the existence of these different textures almost suggests the conclusion that the same method of preparation would not be likely to be equally successful in the demonstration of the individual characteristics of them all.

The medium in which these different tissues are most satisfactorily examined, depends upon certain physical characters, their chemical composition, transparency and refractive power, and it is not always possible to demonstrate all the anatomical elements of which an organ is composed in one single specimen. The idea of an organ as it exists during life, is often formed by building up, as it were, in the mind the various structures, the arrangement of which has been demonstrated by several distinct methods of investigation.

**228. Examination of Serous and Synovial Membrane.**—Serous membrane is perhaps the simplest of the compound structures. This consists of epithelium, delicate subjacent tissue on which this lies, with connective tissue beneath in which the vessels and nerve fibres ramify. Serous membranes may be examined according to the general plan. It will sometimes be found difficult to demonstrate the delicate cells upon their surface. These can be seen in fresh specimens and in those stained with nitrate of silver. The epithelium of serous membranes is often of the pavement or tessellated variety, and appears to form one single layer. In many cases peculiar circular, oval, and sometimes angular spaces may be seen between the epithelial cells, in size about that of or more commonly less than the bioplasts of the cells. These have been regarded as openings or stomata, and it is considered by some that they communicate with the lymphatics, and that thus there is free communication between serous cavities and the interior of the lymphatic vessels. It is however very improbable that this hypothesis will turn out to be correct. Similar appearances exist in some forms of cuticle and mucous membrane in which cases the openings communicate with mucous or other glands, and are in fact the apertures through which the secretion escapes.

In order to examine the distribution of the vessels in synovial membranes, an injected specimen is necessary. The fringe-like processes which project into many of the joints are highly vascular, and a well-injected specimen forms a beautiful object. The vessels which run between synovial membrane and cartilage are very tortuous, and exhibit considerable dilatations and varicosities. The general characters of

Fig. 1.



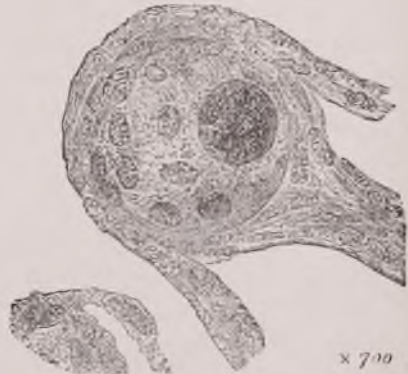
Ganglia and connecting bundles of pale, grey, or gelatinous nerve fibres in the connective tissue, beneath mucous membrane of the small intestine. Such ganglia exist in enormous number in the corresponding situation in every part of the intestine. Young bull.  $\times 29$ . p. 151.

Fig. 2.



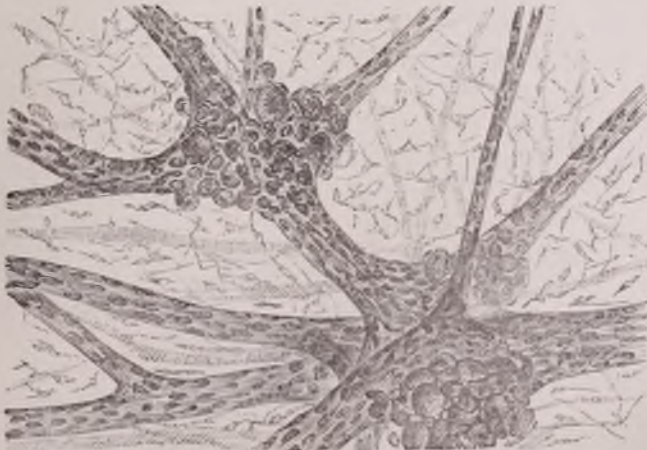
Portion of a ganglion on the side of a sympathetic nerve, showing ganglion cells and arrangement of the nerve fibres.  $\times 130$  p. 151.

Fig. 3.



One of the ganglion cells with nerve fibres connected with it from a sympathetic nerve distributed to the pericardium showing that the pale fibres are continuous with the substance of the ganglion. Ox.  $\times 700$ . p. 151.

Fig. 4.



Portions of two ganglia, with connecting nerve trunks. A portion of the specimen represented in Fig. 1, but more highly magnified.  $\times 25$ . p. 151.



the most important serous and synovial membranes are fully described in Dr. Brinton's article "Serous and Synovial Membranes," in the "Cyclopædia of Anatomy and Physiology."

**229. Examination of Mucous Membrane.**—Mucous membrane consists of one or more layers of epithelium, which rest upon a transparent and delicately fibrous texture. This surface tissue gradually passes into areolar tissue (*sub-mucous areolar tissue, sub-basement tissue* or corium). Into the latter structure muscular fibres, or their tendons, when these exist, are inserted. In it also ramify the vessels and nerves. The thickness of the mucous membrane and other characters of the several structures of which it is composed vary much in different localities.

The mucous membrane of the mouth, especially at the back part of the tongue of any small animal (kitten, puppy, mouse), should be subjected to examination, and the different structures enumerated in the text demonstrated by the student. It is desirable to inject the vessels with a transparent injection, and cut thin sections through the mucous membrane and subjacent structures with a sharp knife. The "basement membrane" is very easily demonstrated in one of the tubes of the kidney. On the anatomy of mucous membrane, the reader is strongly recommended to consult Mr. Bowman's article "Mucous Membrane," in the "Cyclopædia of Anatomy and Physiology."

**230. Epithelium.—Sub-mucous Areolar Tissue.**—The epithelium of mucous membranes is very easily demonstrated, and its character is found to vary much according to the locality from which it is taken. In order to obtain a specimen of epithelium from a mucous membrane, the student may gently scrape the surface of his own tongue or the inside of his cheek with a knife, and place what has been removed upon a glass slide. After moistening it with a little water, syrup, or a mixture of glycerine (1 part) and water (4 parts) which does not cause the cells to become turgid from osmosis, and so too transparent, the specimen may be placed in the microscope. This epithelium approximates in its characters to that of which the epidermis or cuticle is composed. The cells thus obtained vary in age; many are mature and some are very old, and partially destroyed by fungi and about to be cast off, pl. XXXVIII, p. 154, fig. 1. But now and then young cells from the deeper layers of the epithelium will be found, and the student should observe with respect to these that the living matter, bioplasm, or nucleus, is much larger, relatively and actually, than it is in the mature cells. The older epithelial cells in the mouth are invariably invaded by minute fungi, which grow and multiply therein in great numbers. Amongst the epithelial cells on the surface of the tongue, even of the healthiest persons, the observer will find millions of low vegetable organisms belonging to the algæ and fungi. The thin glass cover should not be allowed to press too heavily upon such a specimen. The pressure may be prevented by inserting one

or two pieces of hair or thin hog's bristles. The epithelium upon the surface of the tongue of the frog, toad, newt, and that lining the mouth of the serpent and some other reptiles is ciliated. See figures in pl. LI, also p. 158.

In many of the glands which may be regarded as cavities opening upon the surface of the mucous membrane and continuous with it, the epithelial cells are modified in structure and arrangement. They become "gland or secreting cells," and their formed material is resolved into peculiar substances, which constitute the *secretion* of the gland.

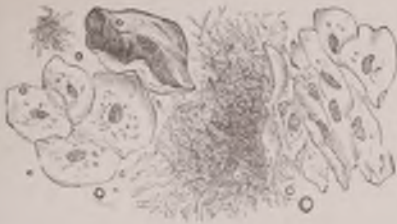
*Glandular epithelium* may be obtained from the tubes or glands in the mucous membrane of the stomach, from the liver, kidney, and other organs. The gland cell consists of a mass of bioplasm in the centre, around, or upon one side of which the formed material accumulates. This formed material gradually undergoes change, and the peculiar *secretion* of the gland results. We see, then, that the formation of the secretion depends really upon the bioplasm. Nothing, therefore, can be more incorrect than the assertion that secretions are *produced* by oxidation and other mere chemical changes.

*The mucous membrane of the stomach* should be studied in *vertical* sections, and in sections made at different depths *parallel with the surface*. The pig's stomach is a good one for examination. A very sharp knife is required. The thinnest sections may be obtained after drying the mucous membrane according to the plan described in p. 97, or the membrane in the perfectly fresh state may be frozen, and thus thin sections easily obtained. The sections are to be remoistened with distilled water, and made transparent by the addition of a little weak acetic acid or potash. Perhaps the best plan for obtaining good sections is to harden the mucous membrane in the mixture of chromic acid and glycerine referred to in p. 67, before cutting thin sections.

The sub-mucous areolar tissue may be very readily demonstrated by removing a small piece from the under surface of the mucous membrane with scissors, and tearing it up with needles. Beneath the hard cuticular mucous membrane of the œsophagus, there is an abundant layer of lax areolar tissue, which connects the lining membrane with the muscular coat beneath, and permits the greatest alteration of the form of the tube, during the passage of its contents, to take place. A small piece of this may be readily removed for examination. It consists of areolar tissue with vessels, nerves, and a few lymphatics. Not only are nerves found, but multitudes of nerve-centres as described below.

**231. VIII.—Muscular Fibres.**—One of the best plans of demonstrating the villi, which project from the surface of the mucous membrane of the small intestine is the following :—A stream of water is allowed to flow over the surface so as to cause the villi to fall in one direction. A clean cut is then made across the intestine, and the villi caused to fall in

Fig. 1.



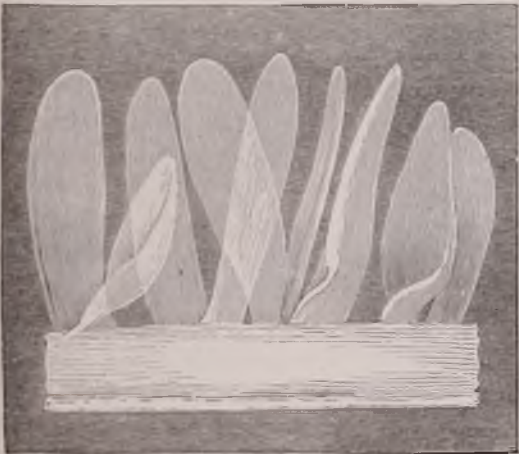
Epithelial cells from the mouth, with filaments and spores of vegetable growth (leptothrix). X 215. p. 143.

Fig. 2.



Epithelial cells from a villus. p. 143

Fig. 3.



Large flat villus of bird. p. 155

Fig. 5.



Summit of epithelial covering of a villus X 130. p. 155

Fig. 7.



Lacteals of villi injected After Frey. p. 154

Fig. 4.



Villi and follicles. p. 155

Fig. 6.



Injected villi, from the small intestine of a white mouse. X 130. p. 155

Fig. 8.



Arrangement of epithelium round a villus, as it appears in section. p. 155



the opposite direction by the stream of water. When a very thin section is removed from the freshly cut surface, one or two rows of entire villi will be readily obtained. Another method is to float a piece of the mucous membrane with the villi downwards upon the surface of the chromic acid hardening solution, p. 67. In this way the villi become firm and erect, and good sections of rows of villi may be obtained.

The epithelium is easily removed from the surface of the villi. Its arrangement is represented in pl. XXXVIII, figs. 2, 5, 8.

The *muscular fibres* are to be shown, it is said, by washing off the epithelium, and treating the villi with a solution of acetic and nitric acid, composed of about four parts of water to one of acid. Besides the longitudinal muscular fibres first described by Brücke, there are circular or transverse fibres, which I have demonstrated by the aid of the process described in part VI. The elementary structure of the muscular coat of the intestine may be demonstrated by soaking small shreds in nitric acid diluted with four or five parts of water, or according to the method of preparation often referred to and described in detail in part VI.

*The nerves* in the sub-mucous tissue of the stomach, and of every part of the small and large intestine of man and the higher animals are exceedingly numerous and connected with an extensive system of ganglia, discovered by Aeby, and of course pronounced by great authorities to be really only modified vessels, connective tissue or anything but nerves. There is, however, not the slightest doubt concerning the existence of this extensive system of ganglia, and entering and emerging nerve-fibres. Some of them are represented in figs. 1, 2, 4, pl. XXXVII. The student should make a special study of these ganglia, which are easily demonstrated in the young ox or sheep.

**232. The Lacteals** may be demonstrated when filled with chyle at the time of death. Their arrangement may be very satisfactorily observed in the villi of a rat or mouse which has been fed upon a small quantity of fatty food for some time before death. The animal should be killed by suddenly dashing it on the floor. It should be examined immediately, or the lacteals will become emptied before they are placed under the microscope.

The alimentary canal of the mouse is well suited to the purpose of microscopical investigation. The villi, in proportion to the size of the animal, are large and conical, and beautiful transparent injected preparations of them may be made. A small piece of intestine may be injected without difficulty according to the plan indicated in fig. 4, pl. XXIX, p. 108. After the vessels have been injected, the intestine is to be slit up and small pieces inverted upon the surface of glycerine containing a little acetic acid (1 per cent.). In this way the villi are made to stand up firmly from the surface of the mucous membrane, and they retain their



position when the specimen is mounted permanently, pl. XXXVIII, fig. 6. In fig. 7 villi in which the lacteals have been injected are represented. The movements of the chyle in the lacteals are referred to in p. 193, and the mode of demonstration described.

The examination of the various textures entering into the formation of the circulating organs has been already referred to in pp. 145 to 148, but the examination of the blood corpuscles may be conveniently discussed in this place. The method of investigating the phenomena of the circulation during life will be found treated of in p. 191.

**233. Blood Corpuscles** or globules, from the human subject are more fully described in "The Microscope in Medicine," pp. 253 to 270. Some are represented in pl. XXXIX, fig. 2. Their general characters, and especially their colour or refractive power, should be contrasted with oil globules of different kinds, air bubbles, and with microscopic fungi,—particularly the sporules of common mould, *penicillium glaucum*, and the yeast fungus. It is in some cases a matter of great practical importance that the student should not mistake fungi for blood corpuscles. The sporules of some fungi very closely resemble them. The common yeast fungus, in different stages of growth, is represented in pl. XXXIX, fig. 1.

Blood corpuscles are readily obtained by pricking the finger. *A very thin stratum of the fluid is alone required.* By drawing a needle across the thin glass under which the blood corpuscles are placed, they may be divided into many smaller globules. This proves that the red blood corpuscles consist of a mass of soft viscid matter, the outer part of which is somewhat hardened, and that they are not, as is still taught by some, cells, or cell-walls, containing a solution of red colouring matter. The blood corpuscles of some animals crystallize very readily. The student should place a drop of Guinea pig's blood under thin glass and study the changes which occur in the corpuscles during a quarter of an hour or twenty minutes (pl. XXXIX, figs. 3, 6), and consider while he observes the changes which take place whether the descriptions usually given of the red blood corpuscle are correct.

The sloth and the camel, among mammalia, are said to possess nucleated red blood corpuscles, but Dr. Rolleston was unable to verify this observation in an examination he made a short time since. His observations cannot, however, be accepted as conclusive, because the blood examined by him was *dried on a glass slide*. "Note on the Blood Corpuscles of the Two-toed Sloth, *Cholœpus didactylus*," "Microscopical Journal," April, 1867, p. 127. Red blood corpuscles of the frog are represented in fig. 4, pl. XXXIX, and in fig. 5 white blood corpuscles of the same animal.

**234. Measurement of the Blood Corpuscles.**—The red blood corpuscles of different animals vary greatly in size. The largest is found in

the Amphiuma, the smallest in the musk deer. The observer will also find that the red blood corpuscles of any one animal vary greatly in size, the smallest being so minute, and so very transparent as to be visible only if great care is exercised in the management of the light. The diameter of the blood corpuscles may be ascertained in the manner described in page 43. Most careful measurements have been made by Professor Gulliver, to whom I am indebted for a plate showing the relative sizes of the red blood corpuscles in nearly a hundred different Vertebrata ("The Microscope in Medicine," 4th edition). For the most extensive tables of measurement, and observations on the size and shape, of the red blood corpuscles, the reader is referred to Professor Gulliver's memoirs in the "Proceedings of the Zoological Society of London," June 15, 1875, and other numbers.

**235. Colourless Blood Corpuscles** should be very carefully studied by every microscopical observer. A few may always be found amongst the red blood corpuscles in a drop of blood obtained by pricking the finger, but if the blood of any very young animal be selected, multitudes will be found. In the ovum of the chick, turtle, tortoise, or snake the blood, though it may be red in colour, will be found to consist almost wholly of colourless blood corpuscles, pl. XXXI, p. 126, fig. 4. The colourless blood-corpuscle consists almost entirely of bioplasm or living matter, and while it lives it exhibits those movements which are so remarkable, and which are manifested by living matter only. See p. 204.

**236. Lung.**—There is not much difficulty in demonstrating the different tissues of which the lung is composed. Small pieces of perfectly fresh lung may be snipped off, and spread out upon the glass slide in the usual way, the preparation being moistened with water or serum. The addition of a little acetic acid causes the yellow elastic tissue to become very distinct. The boundaries and arrangement of the air-cells may also be readily shown.

No opinion with reference to the nature of the walls of the air-cells can be arrived at, unless injected as well as uninjected specimens are examined. The twisted and shrunken capillaries of the recent lung containing a few blood corpuscles, produce an appearance which is very likely to give rise to erroneous inferences with regard to the disposition and coverings of these vessels. Either the Prussian blue or carmine injecting fluid may be employed. A most instructive preparation of the lung, however, is made by injecting the vessels with tolerably thick transparent gelatine, which transudes through their walls, and fills the air-cells. After the lung has been thoroughly injected, it is set aside to get cool. Thin slices may be examined, and the vessels will be seen *in situ* apparently bare, and uncovered by epithelium. ("Physiological Anatomy," Todd and Bowman, p. 393. Mr. Rainey, in the "Medico-Chirurgical Transactions," vol. XXXII, 1849, p. 47.)

*Trachea and Bronchial Tubes.*—The *mucous membrane* of the trachea and bronchial tubes must be examined in the recent state by cutting thin sections with a very sharp knife. Beneath this mucous membrane is an abundant plexus of lymphatic vessels. In many cases these contain lymph corpuscles and fatty matter in a granular state, so that their arrangement may be easily made out. The lymphatics upon the surface of the lung, immediately beneath the pleura, may be also sometimes very clearly demonstrated. I have one specimen in which these lymphatics are completely distended with large oil globules and granular matter, so that the position of their valves is rendered very distinct, and the smallest branches can be followed into the intervals between the lobules of the lung. In this specimen the tubes certainly form a network, but in many situations appearances are observed which lead to the conclusion that these tubes also commence in cæcal extremities.

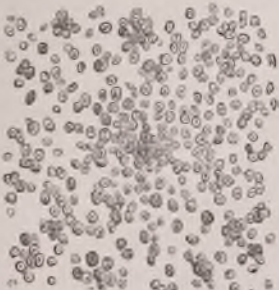
To obtain the ciliated epithelium of the air passages, it is only needful to scrape the surfaces gently, and, if necessary, the preparation may be moistened with a little serum, as water would very soon stop the movement.

**237. Salivary Glands and Pancreas.**—The best idea of the structure of these glands is obtained by subjecting one of the smallest labial or buccal glands, and Brunner's glands, which lie beneath the mucous membrane of the duodenum, to examination. The ultimate follicles and epithelium are very easily demonstrated in specimens which have been soaked for some time in glycerine. It is often troublesome to trace the continuity of the duct with the follicles, in consequence of some of the latter covering its terminal portion. The ducts of the salivary glands and pancreas may sometimes be injected if the organs have been subjected to firm pressure in a cloth for some time previously, so that as much as possible of the fluid they contain may be absorbed, and thus the entrance of the injection into the ultimate follicles favoured. Good sections may often be obtained from specimens which have been hardened in alcohol and soda. The arrangement of the capillaries is easily made out in specimens injected with transparent blue or red injection. If the vessels are injected with gelatine only, very instructive sections may be made.

The nerve fibres are distributed as networks around the follicles of the gland. The finest fibres ramify outside, and no branches of nerves become connected with the secreting cells of the gland as has been asserted. Pflüger, and those who support him, appear not to be aware that much finer nerve fibres may be demonstrated than are represented in his drawings, and at a considerably greater distance from the dark-bordered fibre than the point where he makes the nerve pass into the epithelial cell.

**238. Liver—On Demonstrating the various Structures.**—To demon-

Fig. 1.



Yeast torulae from beer x 215. p 156

Fig. 2.



Human blood corpuscles x 215. p 156

Fig. 3.



Blood corpuscles, Guinea pig, undergoing change of form and becoming crystals p. 156

Fig. 4.

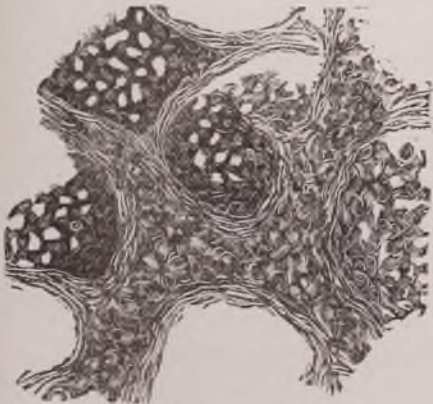


Red and white blood corpuscles. Frog x 700. p. 156

Fig. 5.

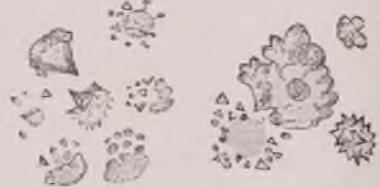


Fig. 7.



Portion of healthy human lung. Capillaries injected. x 130. p. 157

Fig. 6.



Disintegration of red blood corpuscles of Guinea pig's blood, and formation of crystals after application of a gentle heat. x 700. p. 156

Fig. 9.



Malpighian body and uriniferous tube of the newt's kidney. x 130. p. 162

Fig. 8.



Newt dissected to display the thin part of the kidneys. a, needle placed under the thin portion, which should be subjected to examination. p. 162



strate the different structures in the liver very different processes are required. If the cells alone are to be examined, a freshly-cut surface may be scraped with a sharp knife, and the matter thus removed placed in a drop of water or serum, and covered with the thin glass. The appearance of a cell wall is pretty distinct in water, but this is due partly to the difference in refractive power of the water and the material of which the so-called cell is composed, and partly to the action of the water itself upon this. If the cells be placed in serum or glycerine, they appear perfectly solid, and no envelope can be discovered, and in some cases sharp points are seen to project from different parts of the cell, a fact which renders the presence of a membrane almost impossible. The liver cell is in fact a mass of soft formed material the outermost part of which is undergoing change.

In order to demonstrate the relation which the different elementary structures of the liver bear to one another, it is advisable to cut a very thin section by means of Valentin's knife, from the organ when quite fresh. But the best plan is to cut very thin sections from portions of the gland which have been frozen. *See* p. 94. Or thin sections may be taken from portions of liver which have been hardened in alcohol, chromic acid, &c. The vessels of the liver may sometimes be demonstrated by washing the cells away from a thin section with a stream of water, and then treating it with a little dilute caustic soda. In specimens prepared in this way, however, the capillaries are often quite invisible. From the extreme tenuity of their walls in many cases, not a trace of them can be discovered—indeed the existence of the capillary wall can only be proved by filling the vessels with transparent injection in the first instance.

*Of the Lobules of the Liver, Vessels, &c.*—The investigation of the structure of the liver is somewhat difficult, owing to the numerous distinct tissues which compose the organ and their intimate connection with one another.

*Lobules.*—The liver is made up of a vast number of elementary organs about the tenth of an inch in diameter. These are called *lobules*, but they are not separated from one another by fibrous or other tissue, and no structure answering to the description given of Glisson's capsule, can be demonstrated in this situation in the livers of most animals.

Great confusion with regard to the nature of the "lobule," has arisen from observers considering the pig's liver as the type to which others should be referred, whereas its arrangement is exceptional and totally different from the human and most mammalian livers. Separate pieces of liver the size of half an orange may be injected without difficulty. In one the portal vein may be filled; in another the hepatic vein; in a third the artery, and in a fourth the duct, or two or more of these tubes may be injected in the same specimen. The portal vein, the artery,

and the duct run together, while the branches of the hepatic vein run by themselves, so that in sections where the vessels are large, the student will soon learn to distinguish the different tubes.

*Portal Vein.*—The general arrangement of the portal vein may be easily demonstrated by injecting one of the large trunks of this vessel with the Prussian blue injection. It is desirable not to attempt to make a very complete injection, but to leave the capillaries, in the centre of the lobules, in an uninjected state.

*Hepatic Vein.*—The injecting pipe may be placed in one of the large branches exposed on the cut surface of the liver. The injection runs very readily, and fills the capillaries in the centre of the lobules.

The portal vein may be injected in one part of a liver, and the hepatic vein in another part. Sections of the lobules in which the latter has been injected, of course form the exact complement of those in which the portal vein is injected. By injecting the portal and hepatic veins in the same part with different colours, both sets of capillaries may be shown in one preparation. Beautiful specimens of this kind may be prepared by injecting one vessel with the acid carmine and the other with Prussian blue fluid. See pp. 110, 111.

Thin sections may be cut by the freezing process (p. 94), or from the perfectly fresh liver, by Valentin's knife or by the double-edged scalpel. It is desirable to take several thin sections from the surface of the organ. The sections may be well preserved in glycerine.

*Artery.*—The surface of the liver is supplied by an extensive arterial network, and the portal canals also contain a similar network. The coats of the ducts are largely supplied with arterial blood, and the finer ducts are in close relation with numerous small branches of the artery. "Philosophical Transactions," 1833.

*Of Injecting the Ducts of the Liver.*—The method of injecting the ducts of the liver has been already referred to in p. 117.

Since the publication of my memoir in the "Philosophical Transactions" for 1855, and work upon the anatomy of the liver, in which this mode of investigation was described, several views concerning the arrangement of the ducts absolutely incompatible with my own have been advanced by continental anatomists. The plans which I followed have been repeated several times, and in every instance the results which I had already published have been confirmed. In 1867, I re-studied this subject, and succeeded in making several preparations both from healthy and diseased livers which are quite conclusive as to the continuity of the ducts with a cell containing network in the lobule as described in my first memoir. It is curious to observe how positively the assertion is repeated that the mammalian liver does not possess a tubular structure—Ewald Hering, of Vienna, after admitting that the vertebrate liver in general is to be regarded as a "reticularly arranged tubular gland,"

goes on to say that "all the oft-repeated accounts of a tubular structure of the mammalian liver, I must point out as erroneous (!). For instance, Beale's familiar representation, which is intended to demonstrate the tubular structure of the pig's liver, shows me plainly that a completely ruined (!) preparation was the foundation of it. The injection mass is extravasated out of the gall ducts, the liver cells are distorted from their natural position, and to such an extent destroyed. Beale has also investigated the liver of cold-blooded vertebrata, and this may have misled the distinguished microscopist in supposing (!) analogous circumstances for the mammalia." Now the specimen was not ruined; I saw what I affirmed, and have never advanced as demonstrations what are but suppositions. Further observations will probably convince Hering that the mistakes and suppositions are not upon my side. It would have been wiser on Hering's part if he had examined my specimens before venturing to make such ridiculous assertions concerning the blunders which he assumes have been made by me.

**239. The Anatomy of Glandular Organs more easily Demonstrated in the Lower Animals than in Man and the Higher Animals.**—In consequence of the great complexity of the structure of many of the tissues of the higher animals, the changes occurring in their minute structure very soon after death, and their extreme delicacy, anatomists have long been in the habit of resorting to the examination of textures in the lower forms of animal life in the hope of obtaining an insight into the structure and mode of action of corresponding tissues in the higher, and with considerable success. I can adduce no better illustration of the great value of such an appeal to the simpler forms of animal life than occurs in the case of the *kidney*.

*Kidney of Newt.*—In animals generally, this gland consists essentially of a vast number of long and highly tortuous tubes—which in the higher members of the class are packed so closely together as to form a firm and very compact organ, the general characters of which are familiar to all—and of vessels bearing a particular relation to these tubes. In such a kidney it is impossible, under ordinary circumstances, to follow an individual tube for any very great distance, as the observer will be convinced if he looks at a specimen in the microscope; but in the lower animals the kidney is less compact, and the several tubes are not so intimately connected together. Indeed, in many of them the kidney is prolonged into a thin, transparent, almost thread-like organ, which extends into the thoracic portion of the animal. In this situation in the common *newt* or *eft* (Triton or Lissotriton) we have, so to say, a natural dissection of the elements of the gland structure, and we may *demonstrate* an arrangement, the existence of which we can only *infer* by an examination of thin sections of the compact kidney of mammalia. The method of dissection is described in § 261 on Ciliary Movement, p. 194. Single



tubes, with the structures connected with them, may be traced throughout their entire length, for in this thin part of the kidney the tubes are quite separate from one another. I need hardly observe, that it would be vain to attempt to make such a dissection artificially. See fig. 8, pl. XXXIX, p. 158. A probe is placed under the thin thoracic portion of the kidney. If a piece of this be carefully removed from the recently-killed animal, the cilia lining the whole length of the tube will be seen in active vibration. Beautiful specimens, showing the continuity of the tube with the flask-like dilatation enclosing the vessels of the tuft, may be obtained from animals which have been injected with the Prussian blue fluid, fig. 9, pl. XXXIX.

Many other illustrations of the value of this kind of investigation might be adduced of equal interest and importance, but I must be content with strongly advising all those who desire to prosecute researches for the purpose of demonstrating the structure of any particular tissue or organ to investigate with great care its anatomical structure in animals considerably below mammalia, and especially in the lowest forms of life in which the particular tissue or organ in question has been proved to exist. We should endeavour to find it in its simplest condition, because the mind will be better able to appreciate the exact meaning of the structures which are superadded, and the more elaborate anatomical detail which obtains in the higher animals, than if the attention had been confined to the consideration of the most perfect examples of the structure.

In the examination of the mammalian kidney, the epithelium and fragments of the tubes may be readily obtained by scraping the freshly cut surface. In this manner also Malpighian tufts may often be separated, but it is impossible in this way to ascertain the relation of the different structures to one another, as by the process of scraping they are inevitably much torn. A thin section in which the relation of the several anatomical elements may be demonstrated, is obtained either with a sharp thin-bladed knife, or more advantageously with a Valentin's knife, by which means a section including both the cortical and medullary portion of the organ may be made. After washing the section very slightly, it may be placed with a drop of water between two pieces of glass, and examined in the microscope, a low power (an inch glass), being used first, by which the general arrangement of the tubes will be seen, and a quarter of an inch object-glass afterwards, by the aid of which the different characters of the epithelium in the straight and convoluted portions of the tubes may be clearly demonstrated.

**240. Basement Membrane, Matrix, and Vessels.**—Just at the edge of the specimen, a portion of a tube stripped of epithelium, and exhibiting the basement membrane very distinctly, may often be observed. The appearance which has been described as resulting from the presence of a matrix may be very clearly seen in a section of the kidney of

a mouse, or in that of many other rodents. Where the capillaries are injected with transparent injection, no fibrous appearance is to be detected; and I believe, at least in healthy kidneys, that the material resembling fibrous tissue, really consists of the walls of the tubes and the shrunken and otherwise altered capillaries.

Here and there, apparently upon the vessels of the Malpighian tuft, a few cell-like bodies are often seen. These have been described by some as epithelial cells upon the external surface of the vessel, but the researches of Mr. Bowman conclusively prove that the vessels are quite bare. The appearance of epithelium upon the surface of the vessel, is caused by the loops of capillaries being shrunken and collapsed. When distended with transparent injection, no such appearance is observable, but here and there a few very small granular cells are observed. Masses of bioplasm or nuclei, are connected with the walls of these vessels, as well as with other tissues, fig. 3, pl. XXIX, p. 108.

**241. Examination of Nerve-Ganglia.**—The ganglia of the organic or sympathetic system, and the ganglia on the posterior roots of the nerves, which probably are a part of the same system, should be obtained from young animals, for in adults and in those advanced in age, the quantity of connective tissue is so great as to hide many of the cells and render it impossible to trace for any great distance from the cell the very pale delicate nerve-fibres connected with them. In investigations upon the structure of these cells I have pursued the plan of investigation described in part VI, by the aid of which I was enabled to demonstrate that at least two fibres (one of which in the frog's ganglion cells was coiled round the other) came from every one of these ganglion cells, and that the fibres when they reached the nerve trunks pursued opposite directions. See fig. 4, pl. XL, p. 166.

Some good examples of ganglia of the organic system of nerves are also represented in pl. XXXVII.

**242. Examination of the Spinal Cord.**—Different parts of the cord may be examined in the fresh state, but in order to demonstrate the beautiful structure described and figured in modern works, we must have recourse to certain methods of preparation. The method of cutting very thin sections of the brain and cord is described on p. 94.

A weak solution of chromic acid is invaluable for investigating the structure of the cord. Segments of different parts are placed in the solution and allowed to harden, when very thin sections may be readily obtained and examined. The method of preparation followed by Mr. J. Lockhart Clarke, in his beautiful and highly important investigations on the structure of the spinal cord was the following:

A perfectly fresh cord was hardened in spirits of wine, so that extremely thin sections, in various directions, could be made by means of a very sharp knife. A section so made was placed on a glass slide,

and treated with a mixture composed of one part of acetic acid and three of spirits of wine, which not only makes the nerves and fibrous portions more distinct and conspicuous, but renders also the grey substance much more transparent. The section was then covered with thin glass, and viewed first by reflected light with low magnifying powers, and by reflected light with higher ones.

According to the second method, the section is first macerated for an hour or two in the mixture of acetic acid and spirit. It is then removed into pure spirit, and allowed to remain there for about the same space of time. From the spirit it is transferred to oil of turpentine, which expels the spirit in the form of opaque globules, and shortly (sometimes immediately) renders the section perfectly transparent. The preparation is then put up in Canada balsam, and covered with thin glass. By this means the nerve fibrils and vesicles become so beautifully distinct, that they may be clearly seen with the highest powers of the microscope. If the section be removed from the turpentine when it is only semi-transparent, we sometimes obtain a good view of the arrangement of the blood-vessels. This mode of preparation succeeds best in cold weather, for in summer, the cord, however fresh when immersed in the spirit, remains more or less spongy, instead of becoming firm and dense in the course of five or six days. The spirit should be diluted with an equal quantity of water during the first day, after which it should be used pure. Certain modifications of this mode of preparation may be sometimes employed with advantage by a practised hand ("Philosophical Transactions," 1851). These processes are more or less applicable to the investigation of the brain and some of the ganglia.

Mr. Clarke has since adopted a modification of his original plan, and has been kind enough to send me the following directions:—The spinal cord and medulla oblongata of man and the higher mammalia are to be cut into pieces of half or three quarters of an inch long, and steeped in a solution of one part of chromic acid in 200 parts of water, for three weeks or a month. It is then preserved for use in a solution of about one part of *bichromate of potash* in 200 parts of water. For hardening the convolutions of the cerebrum and cerebellum, the solution of chromic acid must be weaker than for the spinal cord or medulla oblongata, that is the proportion of one part of the acid to four, or even five hundred parts of water; but the portions of brain must be small, not more than half an inch thick, otherwise they become rotten before the acid has reached their centres. A little spirit added to the solution for two or three days, after the first day, will prevent this. The pure solution can then be renewed. Spirit of wine is used to wet the knife or razor in making sections, which should be washed in water, before they are placed in solution of carmine. When sufficiently coloured, the sections are again washed in water, and

placed for ten minutes or a quarter of an hour in strong spirit ; after which, if they be thin, they are floated on the surface of spirit of turpentine, where they remain until they are quite, or nearly, transparent, when they are removed to glass slides, on which a little Canada balsam has been previously dropped. If now they are examined under the microscope, the sections often show but little trace of either cells or fibres—a circumstance which seems to have caused Schroeder Van der Kolk, and some others, to abandon the method. If, however, the section be set aside for a little while, and treated occasionally with a little turpentine, the cells and fibres reappear, and present a beautiful appearance. Before the specimens are finally covered with thin glass, they should be examined at intervals under the microscope, to see whether all the details of structure have come out *clearly*; and if so, as much Canada balsam must be used as suffices for mounting. If the sections be of considerable *thickness*, it will be found best to place them in a shallow vessel, the bottom of which is kept simply wet with turpentine, which can therefore ascend through them from below, while the spirit evaporates from their *upper* surfaces, for the *principle* of the method is this:—to replace the spirit by turpentine, and this by Canada balsam, *without drying* the sections. The method at first is attended with some difficulty, and practice is necessary to ensure complete success. Experience, also, may suggest, according to circumstances, certain modifications of the *exact* process here given, which, to a certain extent, must be considered as general. This method is now generally adopted in investigating the structure of the brain and spinal cord, but oil of cloves, or oil of lemons, and some other essential oils, may be used with advantage instead of turpentine, and the specimens may be mounted in a solution of damar or Canada balsam in preference to the ordinary balsam. See pp. 88 to 91, and p. 57. Longitudinal and transverse sections of the spinal cord are represented in pl. XL, p. 166, figs. 1, 2.

**243. Examination of the Brain.**—The brain should be subjected to examination as soon as possible after death. In examining the fresh brain, small portions may be removed on the end of a knife, placed upon the glass slide, and moistened with a little serum, or weak solution of sugar, but it must be admitted little can be learnt by such a mode of examination, as the relation of the structures to one another is completely destroyed. For examining the arrangement and distribution of the nerve fibres, portions of brain should be hardened in the chromic acid solution, p. 67, when very thin sections can be obtained with a sharp razor. Dilute solution of caustic soda is also exceedingly useful for rendering the nerve tubes more distinct. The minute anatomy of the brain may be studied in man and in the higher animals, but the subject is too complex and difficult to consider in this work. The examination of the dura mater and arachnoid is conducted according to

the general plan already laid down. Very small pieces are removed, carefully torn up with needles, moistened with water, and covered with thin glass. The gritty particles (brain sand) in the pineal body, and those which are not unfrequently met with in other parts of the brain, and the *Hassall's corpuscles*, or *corpora amylacea*, may be separated from the brain substance by washing in a glass of water, in which they will sink to the bottom; the supernatant fluid may then be poured off, and replaced by fresh water. After this process has been repeated a few times, the bodies in question will become quite clean. They may then be examined in water, tested with appropriate reagents, and preserved in aqueous fluid, or dried and mounted in Canada balsam.

The vessels of the brain may be readily examined if the white or grey cerebral matter be first removed by washing a thin section with water. The addition of a little very dilute caustic soda renders the outline more distinct. The most beautiful specimens of the vessels of the pia mater, may be obtained by injecting the artery first with an ammoniacal solution of carmine, p. 125, and then with the Prussian blue fluid. For the details of the process, the reader is referred to part VI.

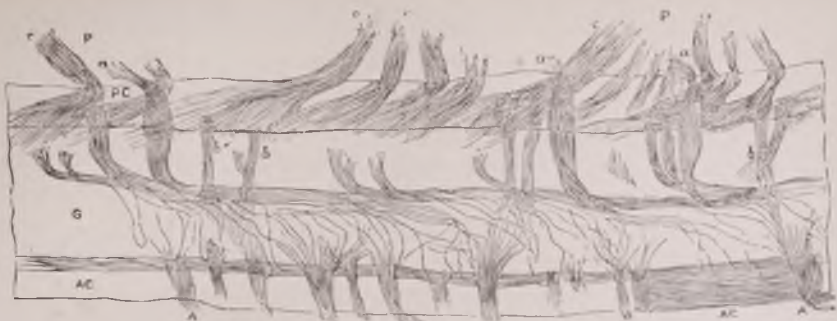
The investigation of the anatomy of the central organs of the nervous system is perhaps the most difficult which the student can undertake, and it is not easy to lay down principles for his guidance. Very much yet remains to be discovered with reference to the chemical solutions adapted to render the anatomical elements of these tissues distinct. There can be no doubt that modes of investigation will at length be found out which will enable us to demonstrate satisfactorily the exact relation to one another of the delicate structures which make the nervous system, the mode of their formation, and the precise way in which they attained the positions they severally hold.

If a portion of white cerebral matter be treated with water, the nerve fibres soon become changed in character, apparently in consequence of the partial separation of the oily from the albuminous constituents which are contained within the tubular sheath. The oily matter forms distinct and separate globules, often of considerable size, or it tends to collect in quantity in different parts of the fibre, which produces a beaded appearance. A similar change takes place in nerve fibres generally, if they are not examined very recently, or if they have been soaked for a short time in water. In figs. 3, 5, pl. XXXVI, p. 150, some of these changes are represented.

#### OF THE TISSUES AND ORGANS OF THE LOWER ANIMALS.

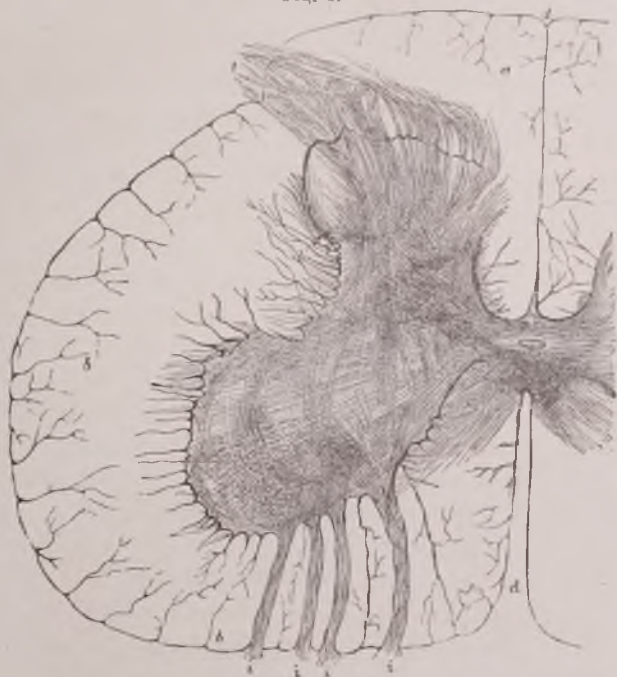
For the most part the tissues of the lower animals may be examined according to the principles which have been laid down for the demonstration of the minute anatomy of the various structures of the higher forms of life. The student will, however, meet with greater variety of

Fig. 1.



Longitudinal section through the spinal cord in the neck of a cat. *PC*, posterior white column. *AC*, anterior white column. *a, b, c*, grey substance between the white columns. *p*, posterior roots of the nerves, consisting of three kinds—*a, b*, and *c*. *A*, anterior roots of the nerves. *AC*, a portion of the anterior column, showing the arrangement of the longitudinal fibres. *p*, 165

Fig. 2.



A transverse section through one half of the lumbar enlargement of the cord, representing the course of the fibres of the roots of the nerves, and the transverse commissure through the grey substance. The vesicles have been omitted to prevent confusion. The fibres of the anterior roots, *a, b*, on reaching the grey substance, are seen to diversify and cross each other; and those of the posterior roots are seen intersecting each other in every direction. *p*, 165

Fig. 3.

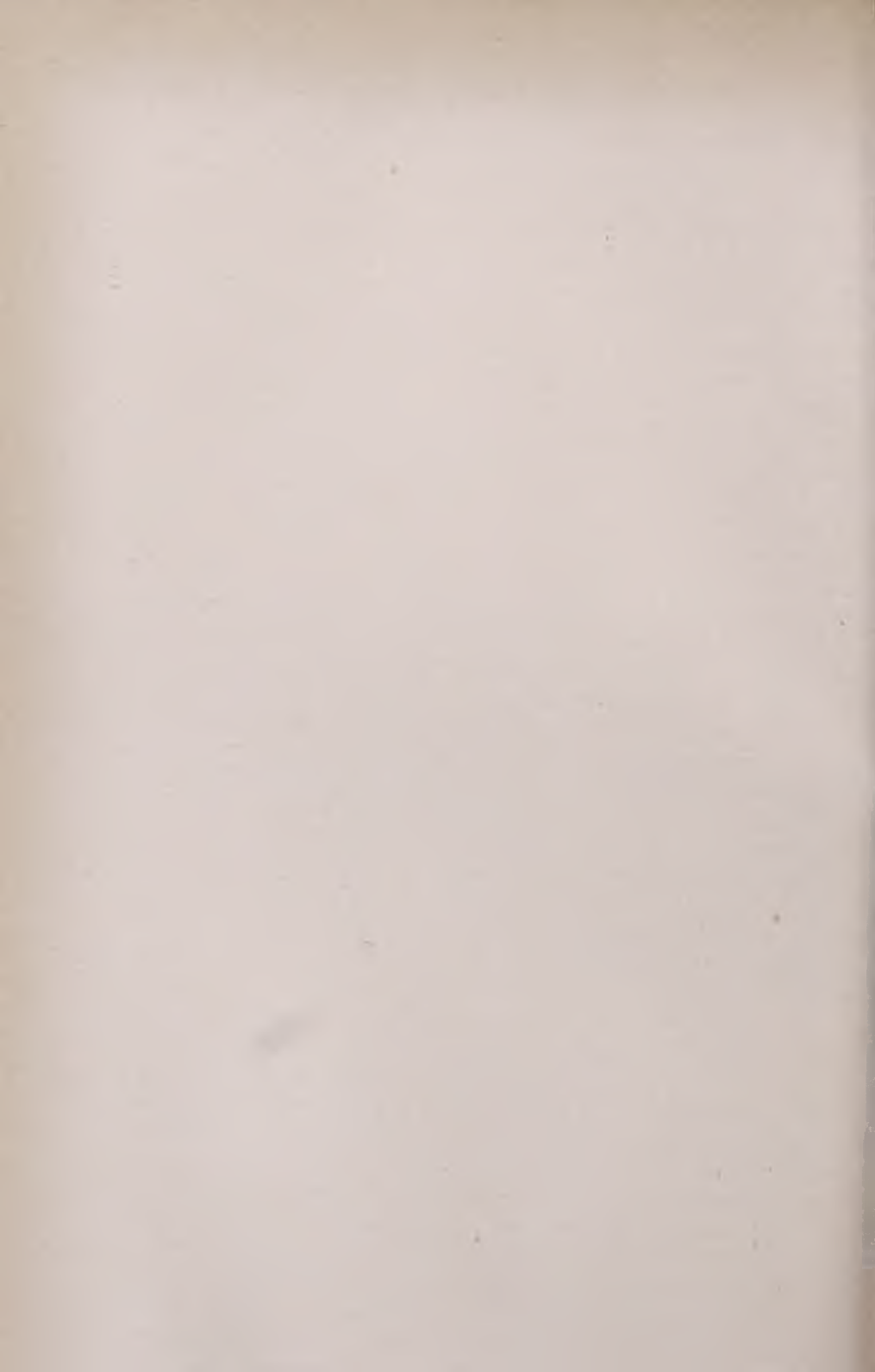


Division of a dark-bordered nerve fibre into pale fibres. On sarcolemma of muscle. X 700

P 149



Ganglion cell, with straight and spiral fibre connected with it, and pursuing opposite directions in the nerve trunk. From the hyla or green tree-frog. Observe the bioplasm in the cell and in the fibres X 700 *p*, 171



texture, and in not a few instances our knowledge of higher structures may be greatly advanced by the careful study of the corresponding tissues in creatures low in the scale. There are many textures which are indeed peculiar to the lower animals which do not appear to have any analogues among the higher, but which nevertheless are well deserving of the careful attention of the microscopist.

In researches upon the changes occurring during the development of tissues, facts may be ascertained in connection with the phenomena of the early periods of embryonic life which cannot so easily be made out in investigations upon man and among the higher vertebrata. The most delicate tissues may be studied in specimens which have been properly preserved in strong glycerine. Although it is generally stated that very transparent delicate tissues ought not to be immersed in this medium, it is a fact that even infusoria may be mounted in glycerine, and points in their structure demonstrated, which are not visible when they are immersed in water. It is, of course, necessary to use weak glycerine first and gradually increase the strength as fully described in part VI.

**244. Of Preparing the Tissues of Insects for Microscopical Examination.**—Many of the smaller insects may be mounted entire as dry objects, but the hard external covering of the body and limbs in many members of this class is better displayed if freed from the soft parts and preserved in Canada balsam. The soft tissues of small flies, beetles, and other insects may be entirely removed by the action of liquor potassæ in which they are perfectly soluble. The hard textures are at the same time softened, but not dissolved by this reagent. After very careful washing in distilled water the entire insect, or parts of it, may be dried in the position they are intended to take up permanently. But the better plan is to well wash the specimen in water, transfer it to alcohol, and at last to strong alcohol, then moisten it with turpentine or oil of cloves, and mount it in a solution of Canada balsam. The chloroform or benzol solution, p. 55, may be employed with advantage. For more full details of the operation the reader may be referred to Mr. Thomas Davies' little book on "The Preparation and Mounting of Microscopic Objects," p. 68. One of the most beautifully mounted objects of the kind that I ever saw was a pediculus preserved in balsam and put up by the late Mr. Topping for Mr. Bowerbank more than twenty-five years ago. In this specimen the nervous system and the nerves and muscles of the legs, antennæ, &c., could be well seen, and the ganglia in the head with the nerves to the eyes and parts about the mouth were beautifully distinct. Mr. Bowerbank traced nerves to the individual bristles and hairs of the animal. The results of his careful observations upon the specimen were published in a special memoir "On the brain and a portion of the nervous system of *Pediculus Capitis*."—London, 1873.



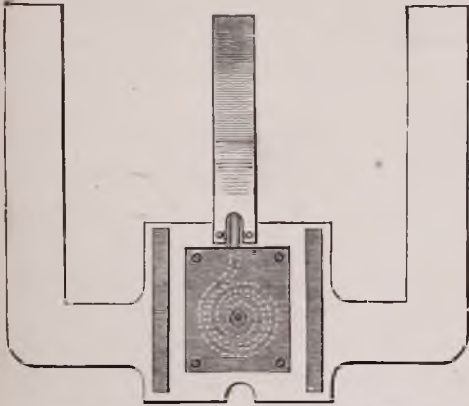
*The Egg Capsules* of insects exhibit very peculiar markings upon their surfaces which vary in every species. Even in those which are closely allied the greatest difference often exists. Insects' ova are represented in pl. XLI, fig. 5. The eggs may be examined as opaque objects according to the methods described in p. 85, or very thin vertical and horizontal sections may be made and mounted in fluid or in Canada balsam. Upon one surface of the eggs of many insects, and very clearly in some of the lepidoptera, an orifice surrounded with beautiful markings may be discerned. This is the micropyle.

**245. The Scales and Hairs** from many insects and crustacea are well worthy of attentive examination. The scales from the wings of various butterflies and moths exhibit beautiful markings. They should be examined in a dry state and also mounted in balsam. A series should be carefully mounted in precisely the same manner for comparison. The student will find that the scales of different parts of the body exhibit peculiarities of structure and surface marks. The scales of no two species are exactly alike.

The markings upon many of these scales are so delicate as to serve for testing the defining powers of the highest and most perfect object-glasses. Some of the most elaborate are obtained from the *podura*, a little hopping insect, common enough in some localities in and about old dry wood. In order to catch the *poduræ*, a little oatmeal may be placed on black paper and left some hours. It may then be transferred to a large clean basin, out of which the creatures cannot leap. Their scales may be mounted dry, in fluid, or in balsam. Broken scales often afford instructive preparations for examination with high powers. The reader is particularly recommended to study the appearance of the small scales of the *podura* when illuminated on a dark ground by the aid of Dr. Edmunds' paraboloid illuminator, p. 28.

**246. Tracheæ**, or air-tubes which are characteristic of the class of insects may be demonstrated very readily. If the inside of a common maggot, caterpillar, or fly be removed and covered with thin glass, numerous exceedingly fine dark lines will be seen ramifying almost everywhere, and forming networks. These are the tracheæ, and their black appearance is due to their containing air which refracts the light very differently from the other tissues and fluids by which it is surrounded. The explanation has been already given in the case of air-bubbles on p. 81, and in that of the lacunæ and canaliculi of bone in p. 90. But in this rough mode of examining the tracheæ, the student learns nothing concerning the elaborate structure and wonderful arrangement of these air-tubes. If some of the larger ones be dried and then moistened with turpentine or Canada balsam, it will be found that a spiral thread is closely coiled around every one of the tubes, by which arrangement they are kept pervious, so that air may circulate freely through them, and

Fig. 1.



Hot stage suggested by Max Schultze. p. 189.

Fig. 2.



Apparatus for keeping objects warm while being examined in the microscope. p. 189

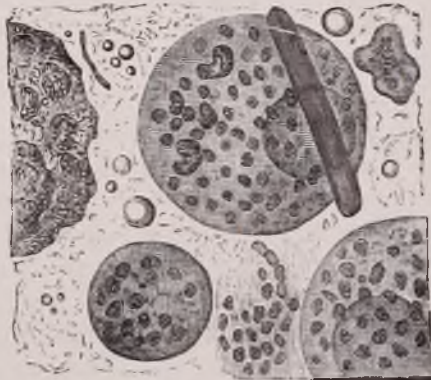
Fig. 3.



X 130

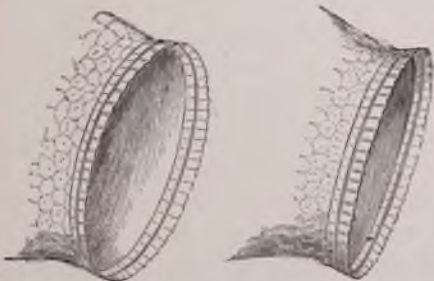
Demodex or entozoon from the follicles of the skin. Three varieties. p. 187.

Fig. 4.



Salivary corpuscles, bacteria, and bacteria ferms, and fine oil globules from saliva. The particles in the salivary corpuscles are in constant motion as long as the corpuscles are alive. X 1700. p. 207.

Fig. 5.

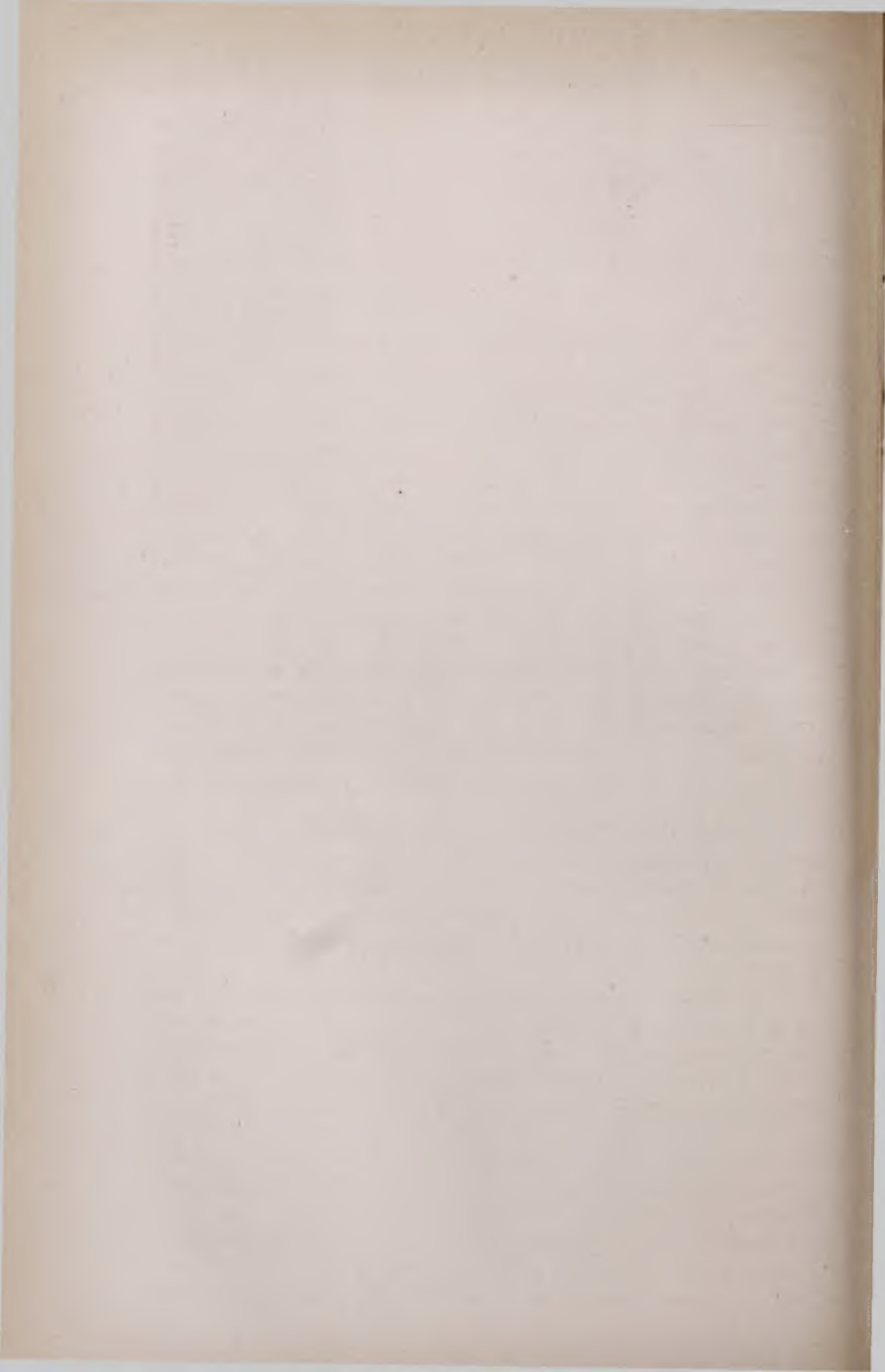


Portions of the egg of the common bed bug. The speculum which covers the orifice removed. Stereoscopic drawing After Mr. Wenham. p. 168.

Fig. 6.



Tracheae from an insect. X 215. p. 188.



thus reach the ultimate constituents of all the textures of the body. The minute structure of tracheæ, and the arrangement of the nerves which often accompany them, is best studied in specimens preserved in glycerine.

The tracheæ all open upon the surface of the body, by orifices termed *spiracles*, easily found in the common caterpillar, as they form a row on each side of the body. Every spiracle is guarded by a comb-like arrangement of firm chitinous or horny tissue which prevents foreign particles from passing into the tracheæ, while like a sieve it permits the free ingress and egress of air. The student should mount a series of specimens of spiracles from different insects.

**247. Branchiæ of Mollusca.**—The textures of which this form of breathing apparatus is composed may be demonstrated according to the principles already laid down in the sections upon the study of the structure of the tissues and organs of the higher animals. The arrangement of the vessels may be displayed by injection, p. 102. The method of demonstrating the circulation of the blood in these organs is referred to in p. 192. In many young mollusks the branchiæ are very beautiful. The action of the cilia with which the vessels are clothed is referred to in p. 193.

**248. Microscopic Shells** form beautiful objects for investigation; many may be mounted as dry objects, and examined by low powers. The remains of the animal organisms may be removed by boiling for a few seconds in a weak solution of potash or carbonate of potash. The shells must then of course be thoroughly washed in successive portions of distilled water.

The shells of foraminifera, many of which are to be found upon our ordinary sea weeds, may be prepared in the same way. This class of organisms has recently been very carefully investigated by Dr. Carpenter, whose memoirs in the "Philosophical Transactions" are worthy of attentive study. See also "The Microscope and its Revelations" by the same author.

**249. Sponges** are very interesting object for study, but not a few of them are difficult to investigate. Fully formed sponges consist of soft organic matters with multitudes of active living particles arranged round a skeleton which sometimes is hard and horny in texture, in some few species calcareous, but in most cases siliceous forming spicules of the most different and peculiar shapes. The general form of the sponge, the arrangement of the skeleton, the character of the organic matter, the rate of its growth, and the dimensions ultimately attained by it differ greatly in the various species.

Recent sponges may be examined in the living state, and some of the fresh water species (*spongilla*) are beautiful objects. The late Mr. Bowerbank spent many years of his life in the study of sponges, and con-

tributed during the past twenty-five years several valuable memoirs to the Transactions of the Royal, Linnean, and Microscopical Societies. Shortly before his death Mr. Bowerbank sent me some drawings from his monograph which he was then preparing for the Ray Society. Some of these have been beautifully engraved by Miss Powell. *See* plates XLII, XLIII, XLIV, XLV. The following directions were at the same time forwarded for insertion in this edition of my book :—

“The mode of preparing portions of sponges, either as microscopical objects or to ascertain their genus and species, is as follows: Thin sections of the dried specimens should be taken at right angles to the dermal surface and immersed in distilled water in shallow cells, from which the water should after awhile be drained off and the slice allowed to dry and to adhere to the glass. When perfectly dry they may be mounted in the usual way in rather thin Canada balsam, and the air entangled in the tissue extracted by an air-pump before the thin glass is put on. Thin slices from the dermal surface may also be mounted in a similar manner, and such specimens frequently exhibit beautiful reticulated structures. Spicula are best separated from sponges by boiling them in a test-tube with nitric acid until the sponge tissue breaks up. Some distilled water may then be added, and the spicula allowed to subside, when nearly all the fluid may be very carefully poured off, more distilled water being added so that the sediment may be thoroughly washed. Lastly, the water is to be again drained off, and after having been allowed to dry the spicula may be mounted in balsam.” *See* also p. 179.

#### OF DEMONSTRATING THE TISSUES OF PLANTS.

**250. Examination of Vegetable Tissues.**—The examination of vegetable tissues is conducted upon the same general principles as that of animal textures. The observer must take exceedingly small pieces for examination, and he will find great advantage if he dissects the buds of plants and selects some of the very young leaves just beginning to be formed. Where the tissue is very soft the dissection may be carried on with the aid of needles, the specimen being placed in a drop of fluid upon a glass slide. Thin sections in various directions may be easily made with a sharp thin knife, and the shavings thus obtained examined in water or other fluids. The method of cutting thin sections of woods has been already referred to in p. 99.

The spiral vessels of plants can in many instances be obtained by boiling the stem or leaves of a plant in water, pl. XLVI, fig. 5, p. 172. Those of rhubarb are very large, and may be selected for examination. Spiral vessels may be obtained from cooked fruit or vegetables, and beautiful specimens may often be found in jam. The spiral vessels in leaves may be beautifully shown by allowing some coloured fluid to

Fig. 1.



Hymeniacidon reticulatus, on a small stone. The sponge at *a, a*. The rest of the stone covered with small shells, &c. Nat. size, dredged by the Rev. A. Norman at Jersey.

Fig. 2.



A small piece of the reticulated dermal membrane of the sponge. Fig. 1 x 123.

Fig. 6.



Hymeniacidon fallaciosus. Nat. size. Fig. 5, spiculum of skeleton

Fig. 3.



Hymeniacidon albescens from Sark, with the basal sponge. Nat. size.

Fig. 4.



Fig. 5.

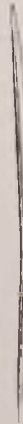


Fig. 7.



Hymeniacidon albescens from Torbay. Nat. size. Fig. 9, one of the large spicula from the skeleton, x 150.

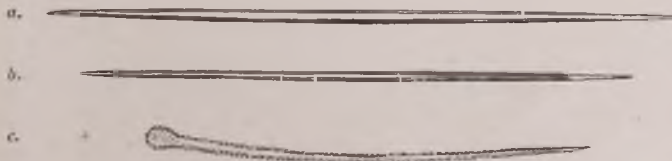
Fig. 8.



Fig. 9.



Fig. 10.



*a, b*, Spicula, Hymeniacidon perarmatus. x 150. *c*, Spined defensive spiculum from the same. x 150.

Fig. 11.



Equianchorate, tridentate retentive spicula, smallest and largest. x 300. From Hymeniacidon perarmatus



Fig. 2.



Interior of *Cyocalyptra Leei*, near the base of the penicillate organ, showing the spiculous fascicule radiating from the central axis of the sponge X 10.

Fig. 1.



*Cyocalyptra Leei* based on a small stone Nat. size

Fig. 3.



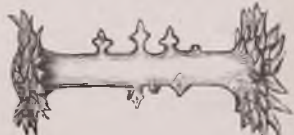
A portion of the dermal surface of the penicillate organ with its spiculous net work and porous areas X 80.

Fig. 5.



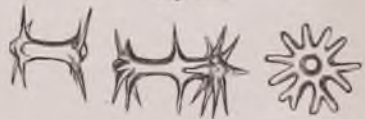
Two views of a rotulate spiculum Ovary. *Spongilla fluviatilis* X 80.

Fig. 6.



Spiculum Ovary. *Spongilla Meyeni* X 80

Fig. 12.



Three spicula from the Ovary of *Spongilla Parfitti*. Compare these with Figs.

Fig. 11.



*Spongilla Parfitti* from the Salmon Pool, Exeter. Half the specimen. Nat. size a, Skeleton spiculum of the same. X 360.

Fig. 7.



*Spongilla sceptrifera* from one of the Exeter reservoirs. Nat. size.

Fig. 4.



a. b.

a, Spiculum from *Cyocalyptra Leei*. X 80  
b, Spicuous Skeleton. *Spongilla Parfitti*. X 260.

Fig. 8.



a. b.

a, Minute sceptriferous tension spiculum from the interstitial membrane X 30. b, Skeleton spiculum. X 200 *Spongilla sceptrifera*.

Fig. 9.



*Spongilla Parfitti* from the river Exe. Nat. size.

Fig. 10.



*Spongilla Parfitti*, from Trews Weir, Exeter. Nat. size.



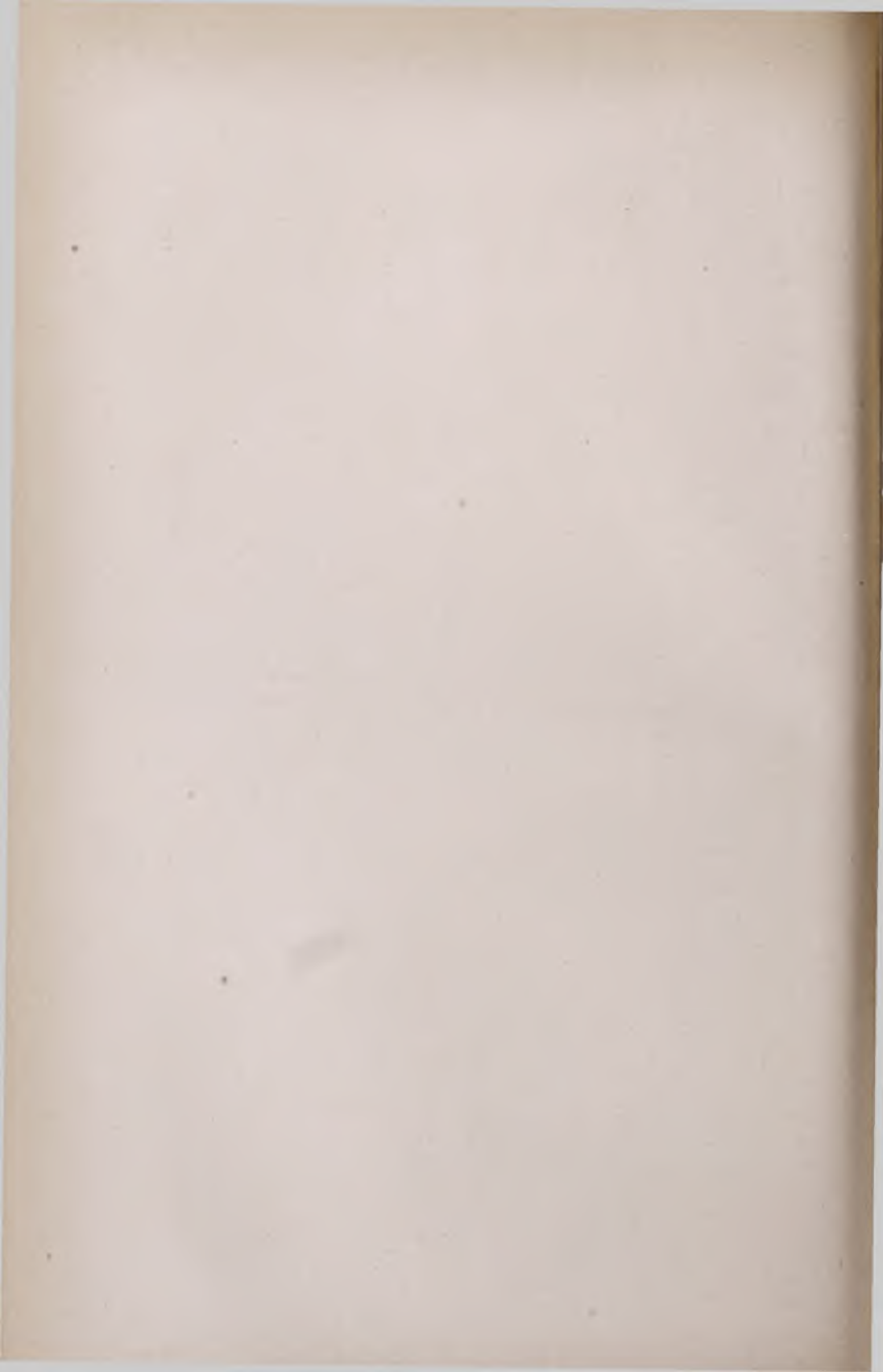


Fig. 1.



A large specimen from the river Orwell. Nat. size.

Fig. 2.



Section showing closed cavity below. Nat. size.

A large specimen with a small one at its base. Nat. size.

Fig. 3.



A group from the sea at Plymouth. Nat. size.

Fig. 6.



Short varieties of the sponge from Guernsey. Nat. size. The two lower figures are the same. The one to the left representing a section. Nat. size.

Fig. 4.



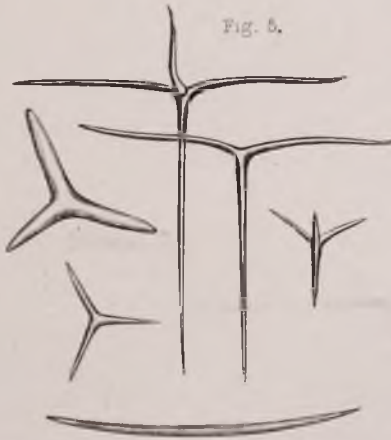
Portion of internal surface of *Grantia vesicellata* Fig. 2, a, pl. xlv. showing part of the ocular areas opening into the cloaca at a. X 50.

Fig. 7.



Portion of external surface of *Grantia vesicellata* Fig. 2, b, pl. xlv.

Fig. 5.



Triradiate spicula from the ciliary fringe, cloaca. X 80.

Fig. 8.



The three upper figures are specimens of *Grantia ensata* (Bowerbank). Nat. size. Below them, to the right, a young one on a stone. To the left, two of the spicula.

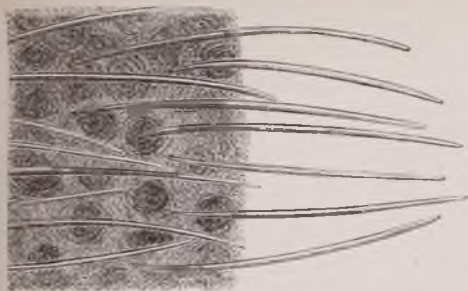
Fig. 9.



Spicula, from the ciliary fringe and other parts. X 80.



Fig. 1.



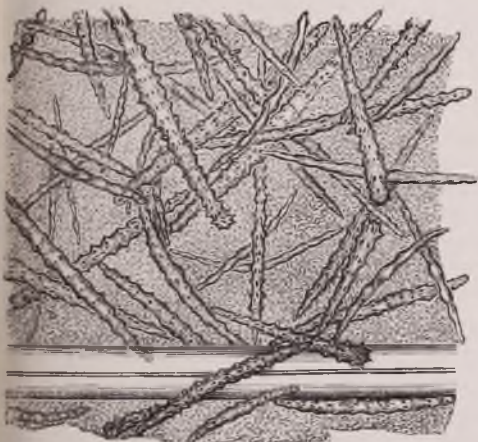
Portion of surface of *Grantia ensata*, showing defensive spicula on surface.  $\times 60$

Fig. 2.



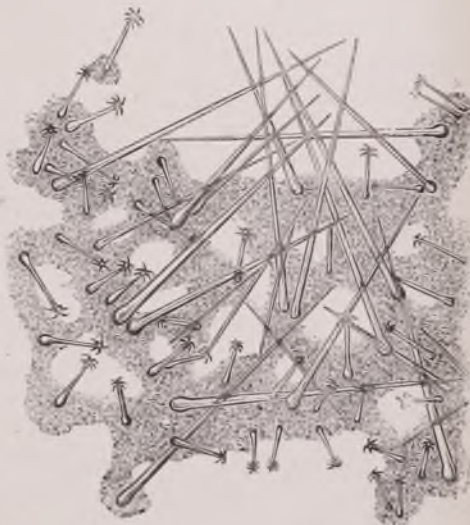
*Grantia tenuellata*. Nat. size. *a*, long spicula, showing clove-shaped cavity; *b*, external orifice. See pl. xlv., Fig. 4.

Fig. 3.



*Hymeraphia verticellata*. Spicula of the dermal membrane, with part of the shaft.  $\times 250$ .

Fig. 4.



*Hymeraphia stellifera*. Skeleton and external defensive spicula.  $\times 80$ .

Fig. 5.



Basal end of one of the large spicula of the skeleton of *Hymeraphia verticellata*.  $\times 250$ .

Fig. 6.



Columella of a *Fusus* encrusted by *Hymeraphia stellifera*. Shetland. Nat. size.

Fig. 7.



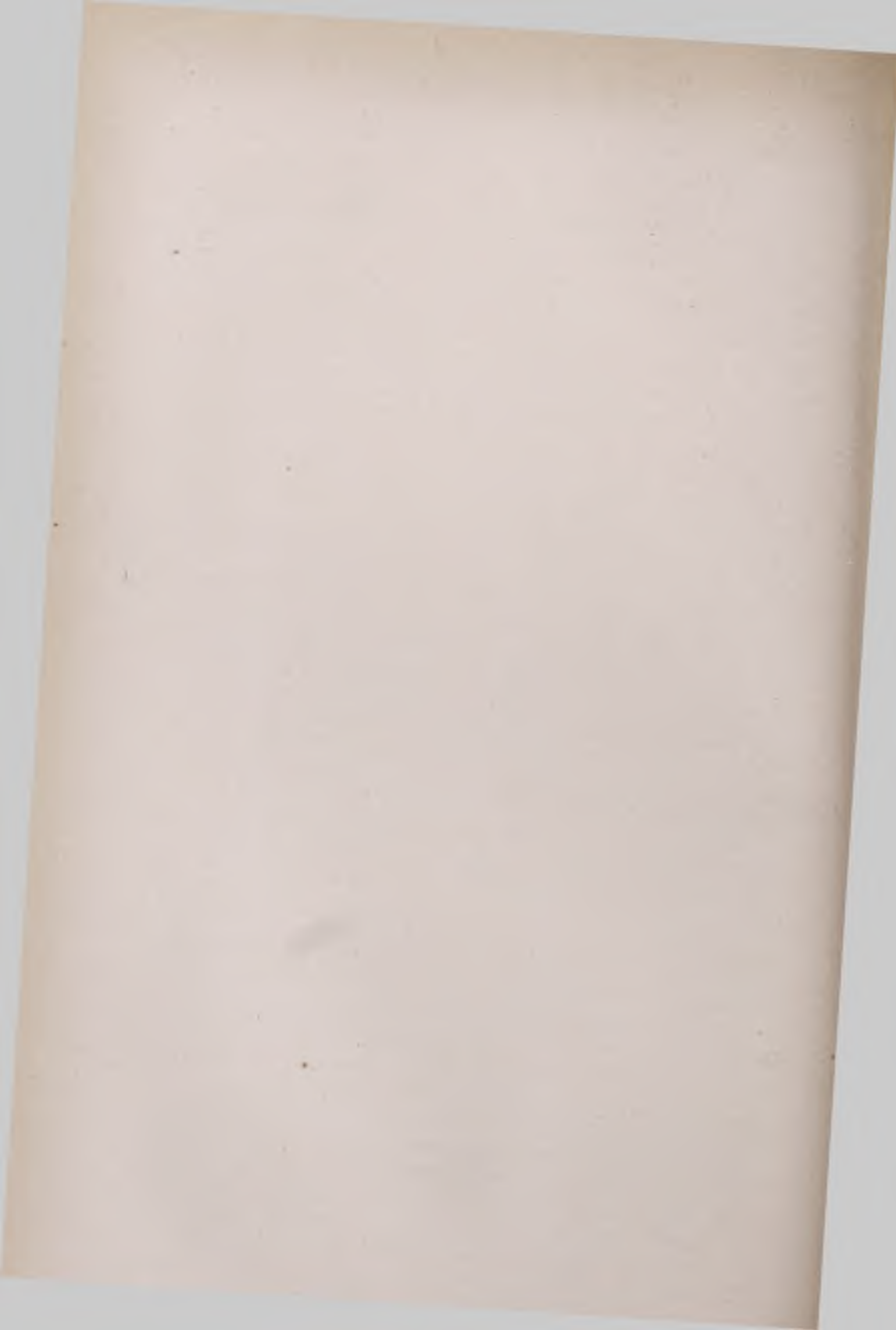
*Hymeraphia verticellata*. Nat. size.

Fig. 8.



*Hymeraphia stellifera* on the inner surface of a valve of *Docina lincta*. Shetland.

[To follow plate XLIV.]



enter them. If the stalk of a living leaf be placed in the fluid and evaporation from the surface of the leaf be encouraged by exposure in a warm place, the fluid will enter the vessels. If carmine fluid, p. 125, be used, the bioplasm of the cells near the vessels will be stained at the same time that the tubes are injected.

The cellular tissues of plants (certain leaves, flowers, fruits) are softened and at length destroyed by weak nitric and hydrochloric acid (one part of acid to from twenty to fifty of water), while the fibrous and vascular textures remain behind. In this way "skeleton" specimens of the leaf, flower, calyx, or fruit may be prepared.

Almost all vegetable tissues are most easily investigated when they have been preserved for some time in viscid media, which are miscible in all proportions with water. Leaves and stems when well saturated with syrup or glycerine are easily separated into their component tissues. They must first be placed in very dilute solutions, which may be concentrated by gradual evaporation, or the strength of the solution may be increased by the addition of small quantities of strong syrup or glycerine from day to day. The beautiful textures to be demonstrated in jams and preserved fruits have been alluded to in p. 83.

Very hard vegetable textures, such as the shell of the cocoanut, walnut, &c., may be cut into thin sections, according to the plan described in p. 98.

*Pollen grains* are among the most interesting objects. They are easily procured by shaking the anther of any flower fully expanded upon a glass slide, and may be mounted dry, p. 86, in aqueous fluids, p. 87, or in Canada balsam, p. 88.

*The external markings of the seeds* of plants are well worthy of attentive examination. The student may examine the seeds without any preparation whatever, as dry objects, p. 26, by reflected light. Many seeds may be at once recognised, and the species of plant to which they belong determined by the markings on the testa alone.

*The starch globules* enclosed in the cells of many seeds and some rhizomes exhibit great variety in form, size, and structure. Different kinds of starch should be submitted to examination, and every student should be familiar with the microscopical characters of wheat, rice, and potato starch, arrowroot, and Indian corn, pl. XLVI, p. 172, figs. 1, 2, 3, 4.

*The colouring matters* of leaves and flowers are contained in cells, and are formed by the bioplasm of each cell. Even in petals of different plants, of precisely the same colour, different kinds of colouring matter have been detected by Mr. Sorby. See "Spectrum Microscopic Analysis," in part IV, p. 269. The petals of many flowers may be preserved without difficulty, as they retain their characters when dried. They should, however, be covered with thin glass to protect them from the dust.

It the student desires to study the manner in which the colouring

matter is formed within the cell, he must examine recent specimens in glycerine, according to the principles laid down in part VI.

*Microscopical Examination of Lichens.*—The following directions are given by the Rev. W. A. Leighton in his elaborate work “The Lichen flora of Great Britain, Ireland, and the Channel Islands:”—“The successful study of lichens is not really so difficult as persons imagine if only they will bring to the work careful painstaking observations, delicate manipulation in dissection, and a microscope with a good object-glass of  $\frac{1}{4}$ -inch focus. The mode of examination which may be adopted is this:—moisten the apothecium with water, then applying a watchmaker’s lens to the eye, make with a sharp surgeon’s knife or scalpel a very thin vertical section through the centre of the apothecium. Place this on the lower glass of a compressorium, p. 92, pl. XXV, figs. 3, 4, in a drop of hydrate of potash (liquor potassæ) which assists in loosening the cohesion of the parts, and swells the spores to their proper shape, bring down the upper glass of the compressor with slight pressure, and place the whole under the microscope, increasing the pressure by turning gradually the screw of the compressor as may be necessary. A view is thus obtained of the asci, spores, paraphyses, structure, and colour of the hypothecium, &c., &c.” On the structure and examination of mosses, consult “The Sphagnaceæ or Peat-Mosses of Europe and North America,” by Dr. Braithwaite.

**251. The Crystals or Raphides** found in many vegetable tissues are well worthy of attentive study. They differ in composition and form in different plants, and it is possible to recognise some species by the character of the crystals alone. In the bulb scales of the *common onion* (fig. 25), in the leaves of the *hyacinth*, and many allied plants, crystals may be detected. Raphides are met with in only three orders of British dicotyledons: *Balsaminaceæ*, *Onagraceæ* (fig. 7), and *Rubiaceæ* (Gulliver), but they are commonly found in many monocotyledons. In transverse sections of the thick leaves of the India-rubber plant are collections of small crystals in large globules (crystaloliths) in special cells.

Professor Gulliver has paid great attention to the examination of plant-crystals, and to him I am indebted for the remarks in the present section upon this interesting and important subject, as well as for the beautiful drawings from which the engravings in plates XLVII and XLVIII have been copied. Professor Gulliver well remarks that “it would not be easy to over-estimate the beauty and importance of plant-crystals, or to explain why they have hitherto been the subject of so little attention and so much error in books of systematic and physiological botany and micrography. These crystals would afford endless employment for those interested in microscopic work at all seasons of the year, and are highly important anatomically and economically. They are very easily preserved, and may be obtained from parts of plants ever at hand. The prismatic forms are admirably

Fig. 1.



Very young cells from potato in which the deposition of starch is just commencing x 700. p. 171.

Fig. 2.



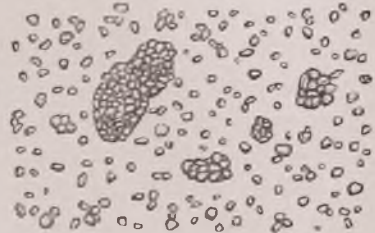
Potato starch x 215 p. 171.

Fig. 3.



Young cell from a potato, showing starch granules in its interior. x 350. p. 171.

Fig. 4.



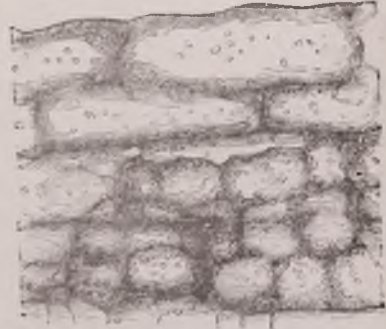
Rice starch x 215. p. 171.

Fig. 5.



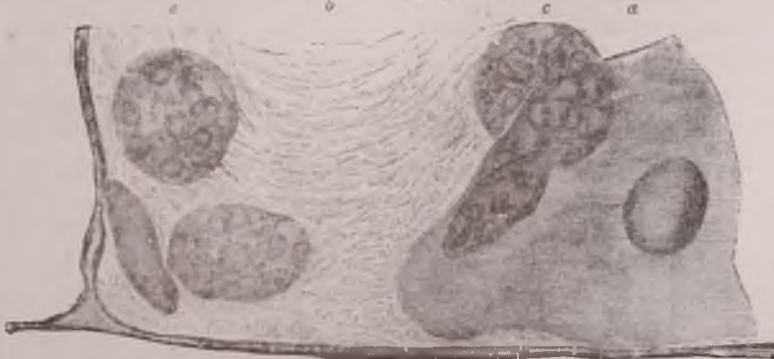
Portion of leaf, showing cellular tissue, fibres, and spiral vessels. x 215. p. 170.

Fig. 6.



Vallisneria spiralis, showing large and small cells with contents which rotate. x 130 p. 169.

Fig. 7.



Part of a cell in Vallisneria, showing circulation. The large mass, *a* with nucleus, is colourless and consists of bioplasm. The smaller particles (under *b*) are probably also of this nature. The round bodies, *c*, are masses of chlorophyll, which are in process of formation. x 2,800. p. 169





suites for experiments on the polarization of light." The treatment of this subject on the present occasion must be brief; it is drawn from the extensive researches of Professor Gulliver, which are cited in the Royal Society's "Catalogue of Scientific Papers," and have been since extended in the "Monthly Microscopical Journal," Dec., 1873 and 1874, and Sept., 1877. An examination of plates XLVII, XLVIII, from drawings made by him specially for this edition of my book, will afford good views of the chief forms of the crystals, which are as follows:—

"I. *Raphides*. Figs. 1–8, pl. XLVII.—Smooth, needle-like, with long rounded shafts tapering to points at the ends, devoid of angles, and occurring loosely together in bundles of about a score or more, commonly within a cell. Excellent examples occur in the orders Balsaminaceæ, Onagraceæ (fig. 7), Rubiaceæ, Mesembryaceæ, Dioscoreaceæ (figs. 1 and 2), Orchidaceæ, Vitaceæ, Lemnaceæ (fig. 4), Araceæ (fig. 6), &c.; and in the genera *Urginea*, *Ornithogalum* (fig. 3), *Hyacinthus*, *Asparagus*, *Hydrangea*, &c. *Raphides* afford such valuable characters that they must be sooner or later adopted in systematic botany, especially as they are often more fundamental and universal in the species than any other single diagnostic. Thus, in the British flora, Onagraceæ may be very truly and simply defined as Calycifloral Exogens in which *Raphides* abound; and in like manner still confining ourselves to *British plants*, the definition is good for the orders Balsaminaceæ and Rubiaceæ.

"II. *Sphaeraphides*. Figs. 9–17, pl. XLVII.—Globated forms made up of minute crystals or granules, and either smoothish, granular, rougher, or stellate from projecting crystalline tips on the surface; sometimes in cells forming an external skeleton of network or tissue like mosaic (figs. 16 and 17), occasionally suspended by a pedicel within a cell (fig. 12). Examples occur in numberless plants, such as Celastraceæ, *Mercurialis* (fig. 11), *Passiflora*, *Viburnum lantana*, *Rhubarb*, *Urticaceæ* (figs. 9, 10, and 12), *Aralia* (fig. 16), *Veratrum* (fig. 17), &c.

"III. *Long Crystal Prisms*. Figs. 19–25, pls. XLVII and XLVIII.—Acicular forms with angular shafts and tips, never occurring loosely in bundles, but either singly or two or more fused together, and for the most part firmly seated in the plant-tissue. Examples are regular in *Quillaja* (fig. 13), *Guaiacum* bark, *Sweet Orris*, and other *Iridaceæ*, bulb-scales of the onion family (fig. 25), in the ovary-coat of the *Thistle* (figs. 22 and 23), and several other allied *Compositæ* (fig. 24), &c.

"IV. *Short Prismatic Crystals*. Figs. 26–41, pl. XLVIII.—Cubical, or long and short squares, polyhedrons, rhombs, and many indefinite forms, though generally more or less prismatic, occasionally not at all so, or mere crystalline granules; occurring mostly in distinct cells, either spread in a tissue in the testa and other parts, or arranged in chains along the fibro-vascular bundles so as to form an internal crystalline skeleton of the plant. Examples: testa of the *Elm* (fig. 26), and of

Anagallis, calyx, &c., of Geranium (figs. 27-29), various parts of Liliaceæ, Amentiferæ (fig. 38), Leguminosæ (figs. 31-37). Well seen in the leaves of Dutch Clover, &c.

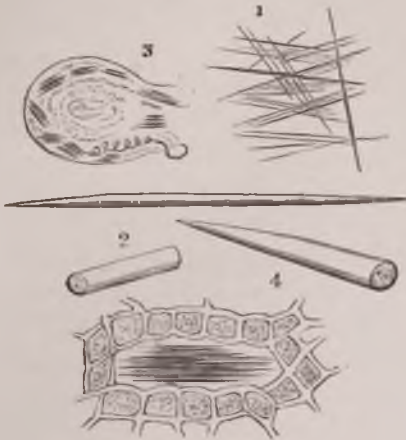
“The chemical composition of plant-crystals has been but little investigated. The late Dr. John Davy and Dr. Douglas Maclagan (*Ann. Nat. Hist.*, June, 1864), found that some Raphides and long crystal prisms consist chiefly of oxalate of lime, and others of phosphate of lime, in both cases occasionally with a little magnesia. In the hop and other Urticaceæ, Mr. Gulliver finds in the stem and leaves two forms of Sphaeraphides, one of oxalate and the other of carbonate of lime (*see* figs. 9 and 10). The use of the fore-named calcareous salts in the food of animals, from low invertebrates to high vertebrates, and as manure in the form of humus to plants, is obvious; and hence we see somewhat of the importance of these crystals in animal physiology, and in the philosophy of agriculture and gardening, and how rationally the microscope may be employed in the investigation of objects which nature has so lavishly provided for our pleasure and profit. The taxonomic value of Raphides has already been mentioned; and these and other crystals often afford good tests of the genuineness of vegetable drugs, and even a guide to their true botanical affinities. Had the classificatory significance of them been known, the jalap of our Pharmacopœia, which belongs to the ex-raphidian order Convolvulaceæ, could not have been so long and erroneously regarded as belonging to a species of *Mirabilis* in which, as in other Nyctaginaceæ, Raphides are abundant.

“The crystals are easily examined, either in thin sections of the plant or in fragments of it mashed to a pulp in water on the object-plate. Boiling the leaf or other part in a solution of caustic potass exposes the crystals and their cells most clearly. They make beautiful slides. Mr. W. H. Hammond, by staining and other means fully described in *Science Gossip*, June, 1878, has formed an extensive and admirable collection of such slides, most of which have been exhibited and explained at the meetings of the Canterbury Natural History Society.”

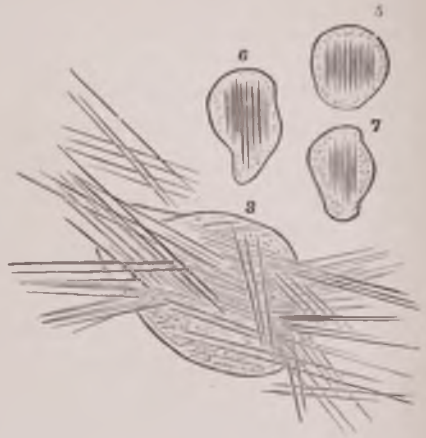
**252. Of Preserving Vegetable Tissues permanently.**—Vegetable tissues may be preserved according to the plans already given for animal tissues. Syrup and glycerine are excellent preservative media. The bioplasm of vegetable tissues may be stained with carmine, and the course of vessels and tubes may be demonstrated if filled with coloured fluids which they will imbibe by capillary attraction, especially if evaporation be promoted from the leaves.

Seaweeds which are to be preserved permanently should be allowed to soak for some time in pure water. Small pieces may then be removed and transferred to glycerine. Some of the most beautiful vegetable preparations which I have seen have been mounted in glycerine. The mixtures of gelatine and glycerine, and gum and glycerine will also be

Figs. 1 to 4.



Figs. 5 to 8.



1—RAPHIDES.—Fig. 1, From berry of *Tamus*. Fig. 2, The same more highly magnified, the upper crystal perfect, the two lower broken. Fig. 3, In the coat of the ovule of *Ornithogalum*. Fig. 4, In an intercellular space of an old frond of *Lomola trisulca*. Fig. 5, Within a special cell from the leaf of *Neottia spiralis*. Fig. 6, From the berry of *Fuchsia maculatum*. Fig. 7, From the berry of *Fuchsia*. Fig. 8, Bifurcated, From the leaf of *Richardia aethiopica*.

Figs. 9 to 14.



II—SPHAERAPHIDES.—Fig. 9, Carbonate of lime—*Parietaria*. Fig. 10, In the leaf veins, and pith of *Urtica oxacata* of lime. Fig. 11, From leaf of *Mercurialis*. Fig. 12, From leaf of *Parietaria*, common in urticaceae. Fig. 13, The same crushed. Fig. 14, Carbonate of lime in a cell with a unicellular hair—From leaf of *Leonurus cardiaca*.

Fig. 17.



Crystals in the centre of cells of the leaf of *Veratrum*.

Fig. 19.

Fig. 18.



One perfect and two broken long crystal prisms. From the wood of *Quillaja saponaria*.

Fig. 15.



From the ripe pulp of a pear.

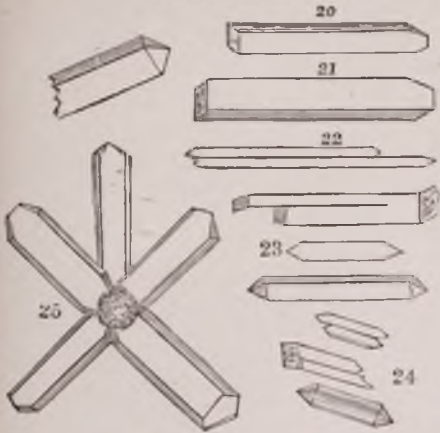
Fig. 16.



Crystal tissue. Crystals at the corners of the cells. From the fibre and leaf of *Aralia spinosa*.

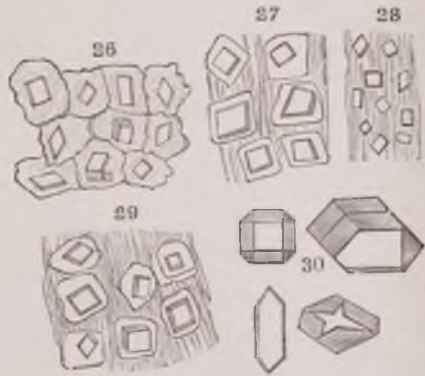


Figs. 20 to 25.



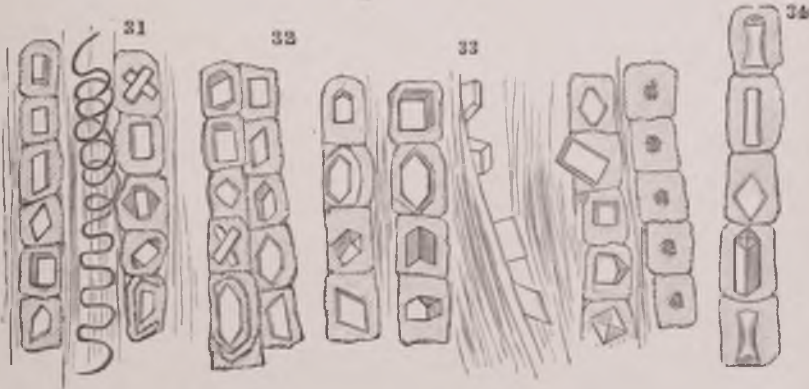
III—LONG CRYSTAL PRISMS—Fig. 20. From the leaf of *Hemiparrea*. Fig. 21. From *Fouquieria* *Asarota*. Fig. 22. Two crystals united, from the coat of the ovary of *Carduus lanceolatus*. Fig. 23. From the ovary coat of *Silybum marianum*. Fig. 24. From the ovary coat of *Centaurea nigra*. Fig. 25. Broken crystal and entire cross, From the bulb scale of shallot and other onions.

Figs. 26 to 30.



IV—Figs 26-30. SHORT PRISMATIC CRYSTALS from 1/2000 to 1/3000 of an inch in diameter. Fig. 26. Testa of elm. Fig. 27. Pericarp, *Geranium Roberianum*. Fig. 28. Testa of the same. Fig. 29. Pericarp of *Geranium phœnum*. Fig. 30. From testa of *Tamus communis*.

Figs. 31 to 34.



In Leguminosæ.—Fig. 31. In the suture of the pod of *Mimosa pudica*. Fig. 32. From the leaf of *Phaseolus multiflorus*. Fig. 33. From the liber of the same plant. Fig. 34. Crystalline fibre from the leaf of *Phaseolus multiflorus*.

Figs. 35 to 37.

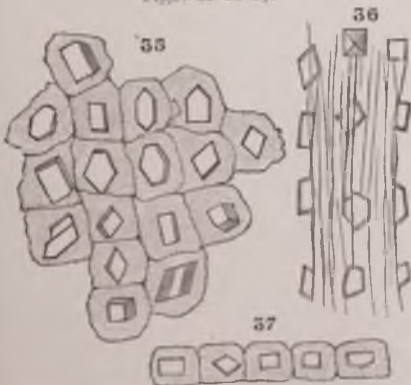


Fig. 35. Crystal tissue, calyx *Trifolium pratense*, between the nerves. Fig. 36. Crystals in the nerves of the same calyx. Fig. 37. Crystal fibre, from the leaf nerve of *Onobrychis sativa*.

Fig. 38.



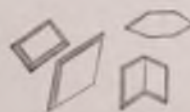
From the petiole of *Populus*. To the right are two cells, in the walls of which are crystals projecting into the cavities of the cells.

Fig. 39.



From the ovary coat of *Centaurea scabiosa*.

Fig. 40.

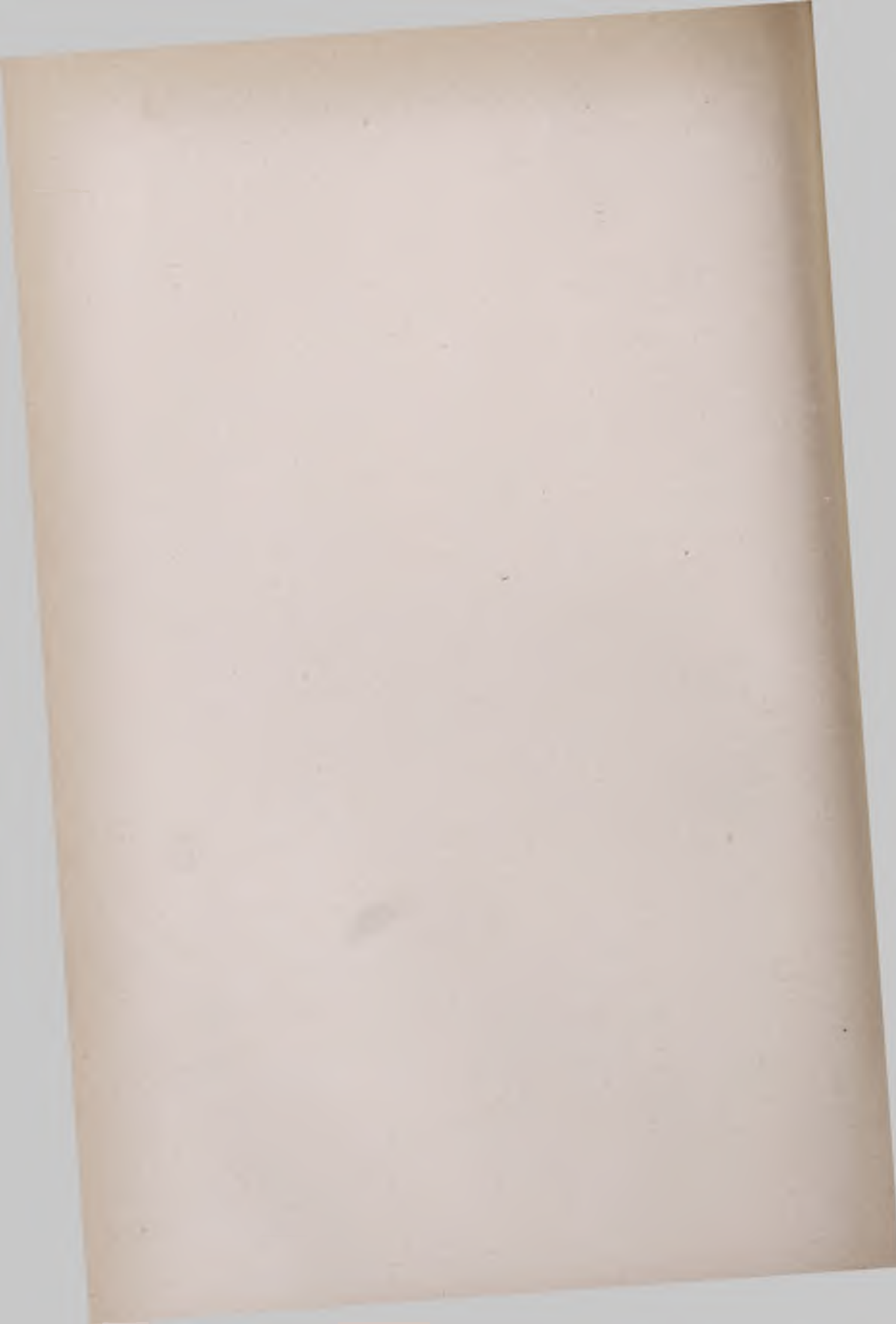


From the petiole of *Citrus*.

Fig. 41.



From middle of leaf of *Moss textile*.



found good media for mounting many vegetable structures, and chloride of calcium forms a useful preservative fluid in many instances. Creosote fluid, carbolic acid water, very dilute spirit and water, and even simple distilled water will preserve some vegetable tissues for a great length of time. The pith of the stem of various plants, the epidermis, and many other vegetable tissues, may be preserved as dry objects very satisfactorily.

**253. Of Collecting and Mounting Diatoms.**—In collecting diatoms and other organisms from pools, the pocket microscope described in p. 17, will be found very useful. A little of the sediment suspected to contain them may be placed in the animalcule cage and examined by the side of the pool. One of the hand microscopes, p. 17, or the waist-coat pocket microscope, described in p. 20, will be found a most valuable instrument for work of the kind. Low powers should be adapted. Every microscope used for this purpose should permit the object to be moved about, at least a three-eighths of an inch in every direction. The difficulties of effecting this are not great. On collecting diatoms, *see* p. 176.

The siliceous remains of the diatomaceæ may be separated from guano and other deposits as follows:—The organic matter and carbonate and phosphate of lime may be removed by boiling in nitric acid, and the remaining deposit diffused through water and collected as before described, but I much prefer to destroy the organic matter by burning the deposit in a platinum basin, and allowing it to remain for some hours at a red heat until the black carbonaceous matter has burnt off, leaving a pure white ash. The phosphates and carbonates may be removed with dilute nitric acid, and the deposit washed. In this way the shells are not so liable to be broken as they are when the deposit is boiled for some time in strong acid.

Siliceous shells of certain diatoms are represented in pl. LIII, p. 204, figs. 1, 2, 3, 5. There is much difference of opinion as to the cause of the markings in many of these. The skeletons of diatoms in Bermuda earth and other deposits of a like kind may be obtained by boiling the powder for a short time in a weak solution of potash and then washing in successive portions of distilled water according to the plan described in p. 100.

OF COLLECTING, KEEPING ALIVE, AND EXAMINING THE LOWER ANIMALS  
AND PLANTS IN THE LIVING STATE.

**254. Of Collecting and Dredging.**—To those fond of natural history, few things are more delightful than a ramble over the beach at low water for the purpose of collecting. Sea dredging adds not a little to the charms of boating, and by the aid of the dredge many interesting creatures may be caught, which never advance as high as low water mark. The apparatus required is described further on.

There are, however, many organisms which inhabit shallow salt water



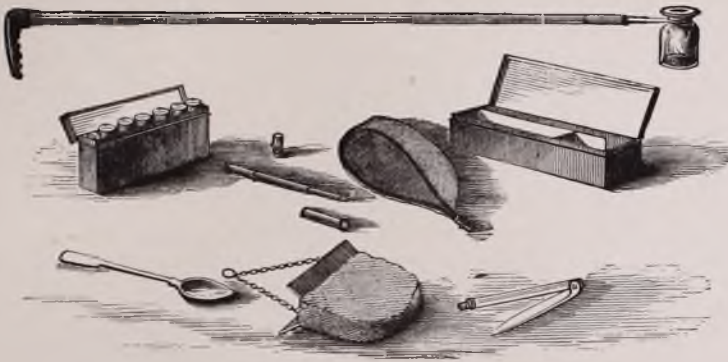
pools, of great interest to the observer, and these may be obtained at low tide without going out to sea. The apparatus required for taking these is very simple and equally adapted for fresh water trapping. The following appliances were arranged some years ago by Mr. Highley. Nothing can be more suitable for the purpose or more ingeniously designed. I therefore recommend the observer to provide himself with the following simple pieces of apparatus, which may be obtained of many of the naturalists or made at home.

*A walking stick* with a telescope joint, pl. XLIX, p. 176, fig. 1, so that its length may be doubled when required, for the purpose of reaching far out into ponds or deep down between rocks, ditches, or river banks. To the end of this stick may be screwed a *wide-mouthed bottle*, which is introduced into the water *mouth downwards*, after the manner of a diving-bell, and only turned upwards when near the desired object, and in such a way that it may be carried into the bottle as the water rushes in. The bottle should then be carefully brought to the surface. Such objects as are desired should be selected and removed by aid of a *pocket pipette*, fig. 1, and transferred to the tubes hereafter described.

The pipette consists of a glass tube drawn out to a point and cemented into a German silver tube, which is fitted with a cap, after the manner of a pen case, so as to protect the glass. Larger objects, such as water insects, young newts, &c., should be caught by means of a small *folding net*, which also screws into the stick. Tough weeds required for study, or which are covered with animal or vegetable organisms and parasites, should be cut away by means of a *weed knife*, fig. 1, pl. XLIX. This consists of two knife-edged blades, hinged to form a V-shaped tool, and is likewise adapted to the naturalist's walking stick. When it is desirable to obtain mud, shells, or other objects out of the reach of the walking stick, the *microscopist's dredge* may be advantageously employed. This is made after the manner of the larger one, described further on, and figured in pl. L, p. 182, fig. 4. The dredge is attached to one end of a length of stout whipcord, the other end being formed into a loop which is passed over the collector's foot. The intermediate length of string is carefully laid on the ground, coil upon coil, and the dredge is then thrown far into the water, and drawn over the bottom of the pond as it is dragged to shore.

Certain Desmids, Diatoms, and other objects which float upon the surface of water, are best secured by means of a *skimming spoon*, fig. 1, pl. XLIX. All these appliances may be packed into a little pocket case measuring 7 by  $2\frac{1}{2}$  by  $1\frac{1}{2}$  inches. A companion *collecting case* to this, contains six corked tubes and a pair of forceps. All objects of a similar kind should be selected by means of the pipette after each haul, and placed together in one tube, especial care being taken that no larvæ, likely to devour the specimens, be accidentally placed among

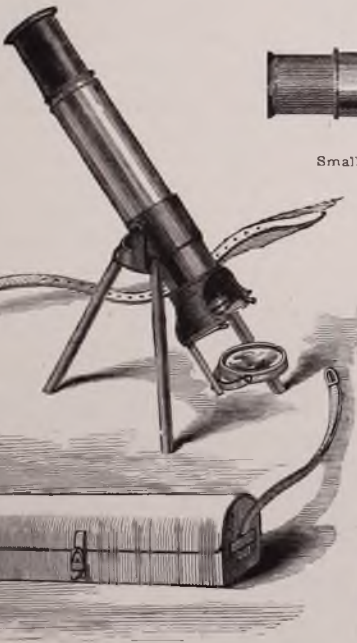
Fig. 1.



Instruments and apparatus for collecting diatoms, aquatic insects, plants, &c. p. 176.

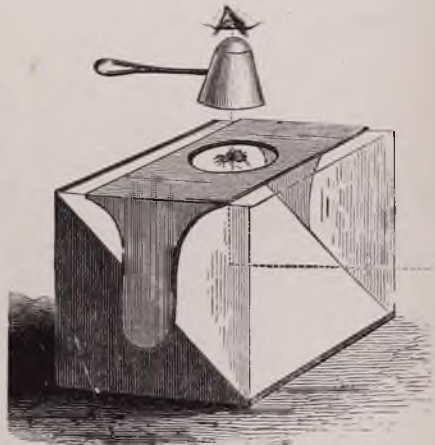
Fig. 2.

Fig. 3.



Small hand microscope, convenient for sea side p. 177

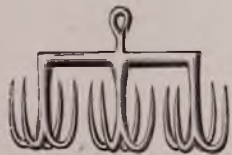
Fig. 4.



Field microscope (Mr Highley) and case. p. 176.

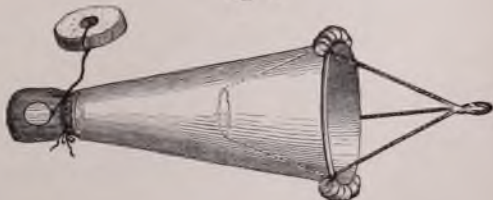
Modified Stanhope lens, arranged by Mr. Highley. p. 177.

Fig. 5.

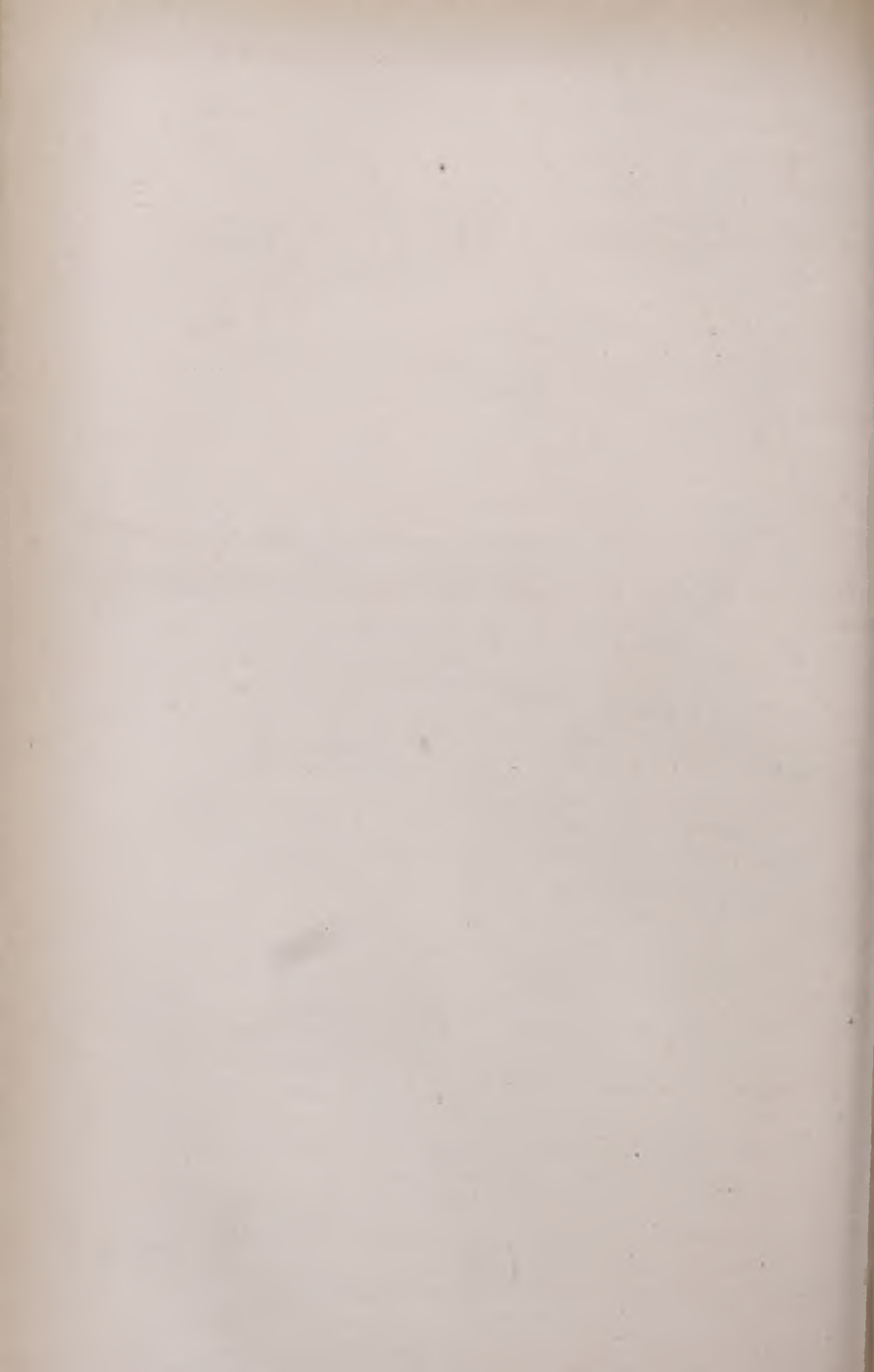


Drag hook for tearing sea-weeds up by the root. p. 177.

Fig. 6.



Surface net, improved by Mr Highley. p. 177.



them. To provide against collecting too many of the same species, it is as well to examine portions taken from questionable hauls by means of a lens (watch maker's loup, or a pocket folding lens), or if higher magnifying power is necessary, the microscope, fig. 3, pl. XLIX, or the waistcoat pocket microscope, pl. IX, fig. 7, p. 19. The inconvenience of holding the head upwards to the light in using the lens may be avoided by placing the object on a reflecting prism, as suggested by Mr. Becker. This idea was further carried out by Mr. Highley in the *reflecting live cage*, fig. 4, pl. XLIX, which consists of a plate of brass having an aperture into which a piece of thin glass is cemented, fitting by spring sides on to a rectangular prism, so as to permit varying degrees of pressure upon an object, or drop of water placed between the two glass surfaces. The top surface of the prism being held horizontally, or nearly so, light is projected from the reflecting plane of the prism through the object to the eye. For this purpose a form of lens giving a larger field of view in relation to the magnifying power than the ordinary Coddington lens had to be employed. An excellent microscope for this purpose has been recently devised by Mr. John Browning of the Strand. The implements already described are also employed for shore collecting; but for the purpose of removing objects attached to rocks, or the sides or bottoms of rock basins, a flat-faced geologist's *trimming hammer* and a *cold chisel* should be added.

For sea collecting, the *surface net*, the *draghook*, and the *dredge* are necessary. The *surface net* is a double conical bag made of "cheese net," or "bunting," stretched on a cane hoop, and supported by three pieces of cord, brought together at the point at which the *towing cord* is attached. The inner cone is more obtuse and shorter than the outer, and prevents objects once caught from being washed out again. At the bottom of the bag is fixed a glass bottle, and a bung is attached about a foot above it, to prevent it from sinking too deep, pl. XLIX, fig. 6. Mr. Highley advises that corks should be so placed at the mouth of the hoop as to insure the net being only half immersed. The hoop being pulled into an oval form, a wide mouth is presented to the waves. The net is towed astern or at the side in such a way as to be clear of the boat's or ship's wake, and the length of line is regulated to the strain created by the speed of the vessel. On drawing up the net, the bottle is thrust up through the hole in the inner cone, and its contents emptied into a bottle of similar size, with a screw cap, of which some dozen should be kept in a tray. Many interesting forms of crustacea, acalaphæ, &c., can be secured by this means upon any part of our coast, and without going far to sea.

The *Draghook*, fig. 5, pl. XLIX, p. 176, consists of three groups of stout iron hooks welded to a horizontal bar having an eye in the middle, to which a stout rope may be fixed. This is let down among the roots and fronds of the coarse seaweed, on which many microscopic animal

and vegetable forms are parasitic, and when well entangled the hook is forcibly hauled up with the captured specimens.

*The Naturalist's Dredge*, fig. 6, pl. L, p. 182, however, is the instrument which reaps the richest harvest from the sea. It is made of a wrought-iron rectangular frame, from which two *scrapers* project at an angle, on each side, and to which two handles, terminating with four links of chain, are hinged to each end so as to allow some freedom of motion, while not interfering with the dredge being easily packed into a small space. To this frame a fine meshed tanned net is fixed by copper wire, and to prevent this from being caught, when dragging over a rough sea bottom, it is guarded by two flaps of coarse sail-cloth which hang on either side. The mouth is made narrow to prevent heavy stones from entering. A rope is required which is strong enough to anchor the vessel in smooth water, and long enough to prevent the dredge skimming or bumping over the bottom, yet not so long as to lead to its being buried in soft sand or mud. The length of the rope should be about double the depth of the water to be dredged. The rope should be firmly tied *to one ring only*, and the ring of the other handle should be braced to its fellow by a piece of spun yarn, so that in the event of the dredge fouling, by putting extra way on to the boat the string will yield and allow the two handles to open, and thus the dredge will easily free itself. On lowering the dredge, it is evident that it is a matter of indifference which side rests on the ground, and in this lies the advantage of the apparatus referred to over the common dredge. It may be used in a rowing boat in smooth shallow water near shore, but a sailing boat is preferable in depths over ten fathoms. The towing rope is coiled up at the bottom of the boat, and its free end is made fast to one of the cross seats. The dredge is thrown over to windward near the stern, and when sufficient line has run out a turn or two is made round a "belaying-pin" to make it taut. The line should be held in the hand so that the owner can feel at once if anything goes wrong.

When the dredge is lifted, its contents should be emptied into a *sorting tray*, fig. 5, pl. L, p. 182. This consists of a coarse wire sieve C, which retains all large specimens, stones, &c., but allows small or delicate ones to pass into a perforated zinc sieve F, which retains all objects over  $\frac{1}{4}$ -inch diameter, but allows the sand or mud to be washed into the lower tray which is furnished with a double bottom formed of fine webbing stretched on a frame. The water poured over the sieves to facilitate this operation is carried off by a flexible tube. These trays should be so arranged that they will easily pack one into the other, the smallest of them being of sufficient size to hold the dredge, drag hook, and surface net. The outer tray being provided with a lid and straps, forms a packing case for the outfit. Convenient forms of portable microscopes with inclinable body, &c., suited for dredging excursions,

or for a shore-collecting sea-side expedition have been described in pp. 17, 21.

*Notes for collecting certain Specimens of Marine Natural History.*—The late Mr. J. S. Bowerbank had the following notes printed for the assistance of those on foreign stations disposed to help in obtaining specimens. Captains and other Officers in Her Majesty's Navy and Commanders of merchant vessels have frequent opportunities of contributing largely to our knowledge of marine natural history, with very little trouble to themselves, during their sojourn in distant parts of the world. Many valuable opportunities of obtaining rare and beautiful specimens have been lost for want of a few plain, simple directions for collection and preservation.

“*Sponges* may be procured either by dredging or by searching for them in the line of refuse matters thrown up by the sea at high-water mark. Those which have the fleshy animal matter in them are the most valuable. They should be well and quickly dried just as they come from the sea. They should never be washed in fresh water nor be compressed to get rid of the water or animal matter within them, but be simply drained and dried as rapidly as possible. Small and delicate ones only require being preserved in spirit. If the larger and stronger specimens have stones or dead shells attached to them do not remove them. The insides and outsides of dead shells and small pebbles often have on them thin sponges, like a dab of wet glue, such specimens are very desirable. Sponges differ to a very great extent in their general appearance, some are soft, flexible and branching; others fibrous and horny; or massive and fleshy; or massive and stony and very like corals; others are round or fleshy masses like small apples, but whatever may be their form they are all valuable as objects of natural history. They vary greatly in size and appearance, some of them not exceeding a quarter of an inch in height. Many of the smaller and most interesting species are found parasitical on small seaweeds and on horny branching zoophytes, such specimens should be carefully collected and preserved.

“The best mode of packing sponges when thus dried is to put them all together in a moderate sized packing case, disposing of the smaller and most delicate ones between the larger species. The best packing, when procurable, is small and flexible dried seaweed just as it is frequently found in the line of rejected matters at high-water mark. Such fuci frequently prove to be valuable and beautiful objects when subsequently properly prepared and mounted for the hortus siccus. Small and delicate specimens should never be packed in cotton wool, but if necessary they should be put into small boxes, with a little soft paper around them to prevent attrition.

“A boat's crew waiting for an officer on shore may frequently make

an extensive and valuable collection of sponges, zoophytes and fuci, from the rejected matters at high-water mark, in a very short time, and especially so, if in small creeks or bays.

“*Radiata*.—Star-fishes and sea urchins with very beautiful spines may be frequently found among sponges and zoophytes. The best mode of preserving the star-fishes, if they be large and fleshy, is to spread them out on a plate or saucer turned upside down. The plate being put in a small napkin or cloth which is gathered loosely together above the specimen is plunged gently into a vessel of boiling fresh water and kept therein for four or five minutes to coagulate the albumen. After this operation everything will dry readily and quickly. With smaller specimens immersion in boiling water from one to five minutes in accordance with their size will be sufficient. The sea urchins with spines should be prepared by immersion in boiling water for a time in proportion to their size and then dried as rapidly as possible. A few experiments with them will soon afford the necessary experience. The mud or sand brought up by the anchor or by sounding should be put, just as it comes up, into any convenient bottle with some sea water. A superabundance of common salt should then be added to it. Such mud or sand frequently contains rare and very minute corals, sponges and shells, of great value to microscopic observers. When convenient the reefs of rocks uncovered at low water should be examined. In the little pools of water small corals and sponges of various colours are very frequently found. These should be carefully removed and preserved as before stated. Sea slugs and other soft marine animals are also found in such places. They may be preserved in jars or bottles in a little water and a superabundance of salt when spirit is not handy or plentiful. The faces of perpendicular cliffs and rocky caverns often afford excellent specimens between high and low water marks, and rare and beautiful calcareous sponge parasitical on small sea weeds growing on the faces of the rocks are often to be met with in large quantities in such situations; but whether beautiful or not all such specimens should be preserved, as it frequently occurs that the least attractive are organically the most interesting and valuable. Small crabs and shrimps should be put into wide-mouthed bottles or jars with strong spirit, as salt does not preserve them effectually.”

To these remarks of Mr. Bowerbank I would add that many of the bodies alluded to may be preserved in glycerine, the strength of the fluid being very gradually increased as the specimens will bear it. The process is however very troublesome and suited only to very small specimens, but for these it possesses great advantages over spirit and the methods of preservation usually adopted.

The collector should examine stagnant pools, ponds, rivers, boggy ground, rock pools and basins on the sea shore, carefully searching the

sides and bottoms, the fronds of plants, or pieces of wood floating therein, for gelatinous or spongy masses, or palpable forms of vegetable or animal life, not forgetting to examine with a lens all scum floating on the surface of water, to see if it consist of, or has entangled in it objects worth preservation. Filamentous Desmidiæ, if diffused through the water, must be collected by aid of the gauze net. When gelatinous or cloudy masses are adherent to the fronds of water plants, the hand should be passed gently into the water, palm upwards to form a cup, and the fingers closed on each side of an invested leaf or stem; the hand should then be drawn upwards, so as to allow the plant to slip through the fingers close to the palm with an easy equable motion, and in this way remove from both surfaces any loosely attached organisms. Care must be taken to raise the hand very steadily through the water, in order that the captives may not be washed out of the concave palm. The water may then be poured into a cup or at once transferred to a bottle and carried away.

Water resting in the indentations made by the feet of cattle should not escape notice. The side of a pond towards which the wind is blowing is always the more prolific, especially if the sun is shining on the same side, and the shallows are usually richer in spoil than the deep places, because these are warmer.

The collector who intends to work thoroughly and for a considerable time, may use with advantage waterproof wading boots. He may follow the sea out as it recedes at the low spring tides, when the greatest amount of shore is left uncovered. The months of March and April, September and October having the lowest tides in the year are the best for the purpose of shore collecting. Those parts of the coast should be selected which are not uniformly formed of hard granitic rock and which are not composed of mud or soft chalk. Shores where ledges, crevices, rock pools, and basins, heaps of *débris*, and outlying caverns are to be found in abundance, should be selected. Holes in the sand should be searched for case building worms or boring mollusks. Large fish or marine animals left stranded by the recess of the tide may be examined for parasitic crustacea, which are very often found adhering to the gill-covers of fish. The masses of olive seaweeds covering the rocks should be turned over, or when pendant from overhanging slabs, they should be turned back, as they often shield such forms as attach themselves to the surface of rocks:—starfishes, ascidians, nudibranchs, eggs of mollusks, tube forming Annelids, Sponges, &c. Crevices should be searched for crustacea, starfishes, echini, wandering annelids; water-worn nodules for investing social ascidians, such as the Botryllidæ, or multivalve mollusks, such as chitons. Loose stones and large boulders should be turned over, as many crustaceans and annelids take refuge beneath them. Large tufts of corallina and other seaweeds should be



gathered from the edges of pools near low water, and placed in a jar of water as they harbour various small Entomostraca, Pycnogonidæ, Lucernaria, and many zoophytes. Outstanding rocks only uncovered at the lowest spring tides, and then usually only approachable by boat, should be visited in the hope of finding the only British representatives of the stony corals. Beyond such points, the sea bottom must be ransacked by means of dredge and draghook.

**255. Vivaria and Aquaria.**—Many of the lower animals and plants may be kept living in glass cases and glass jars, and will grow and multiply, figs. 1, 2, 3, pl. L, p. 182. Frogs, newts, lizards, many mollusks, insects and worms, air-breathing and aquatic, will live for a length of time in confinement, and some of them will flourish.

Vivaria are now made of various forms and sizes. Some are little boxes of only a few inches square while some are magnificent prisons of several feet in length provided with everything for the health and advantage of the inmates. The student may easily make such cages of glass, the pieces being joined at the angles by tape fixed to the glass with glue, for himself, for a few shillings, and in them may keep a number of objects of interest which will provide him with endless amusement and constant work. Vivaria of all kinds must be well ventilated. One side, or a part of each side, may be formed of perforated zinc or of some strong gauze. If the student desires he may arrange to have water in one part of his case. He may easily arrange a small fountain by adapting a piece of glass tube drawn out in the blowpipe flame to a piece of the narrowest vulcanised india-rubber tube, the other end of which is connected with a small reservoir of water placed on a shelf. Such fountains may now be purchased for a small sum in the Crystal Palace, Westminster Aquarium, and other places.

Cases for breeding insects and keeping them alive may now be obtained of many naturalists, and also at the Westminster Aquarium. Frogs, toads, and newts may be kept in glass cases to the interior of which air has access through wire gauze. At the lower part should be some water which may be placed in a saucer or basin with shelving sides. This may be made ornamental and adapted for plants if desired. The beautiful little hylæ or green tree frogs may be kept in well ventilated glass cases for years, if they are not roasted in the summer sun, or frozen in the winter. They must be fed upon flies and are particularly fond of blue-bottles. Gentles may be bought in quantity at the fishing tackle shops and may be kept until the flies come forth.

Fresh water aquaria may readily be formed by inverting propagating bell glasses carefully selected as to shape, in a turned wooden stand or in small dishes which have been filled with earth or sand. The bottom of the bell-glass should be filled with soddened rich black peat earth, worked into a paste, some loam and stones added, the whole being

Fig. 1.



Fig. 2.

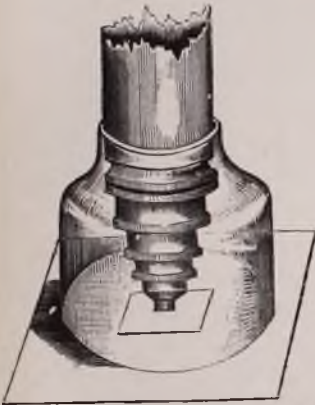


Fig. 3.



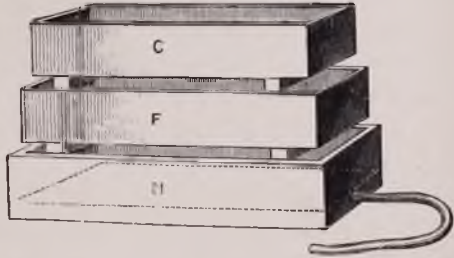
Small vivaria and fern case. p. 182

Fig. 4.



Recklinghausen's moist chamber. p. 178

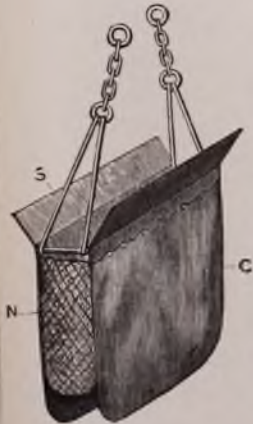
Fig. 5.



Dredging sieves, C and F, and draining tray, N. The dredge, Fig. 6, drag hook, Fig. 5, Plate XLIX, net, Fig. 6, all pack into N. Designed by Mr. Higbiey. p. 178.

Fig. 7.

Fig. 6.



Naturalist's dredge, as arranged to pack in N. Fig. 5. p. 178.



Simple form of sea-side microscope to pack in a small case.

[To face page 182.]



covered with a thick layer of fine well-washed shingle. Roots of *vallisneria*, *anacharis*, *Aponogeton*, or *Chara* may be then planted in the earth and the vessel carefully filled up with water. After the water first introduced has become quite clear, a few fresh-water mollusks should be added to keep down the growth of *confervæ*. Those species which feed rather upon decayed vegetable matter than upon the plants themselves should be selected, such for instance as *Planorbis corneus* or *carinatus*, *Paludina vivipara*, or *Amphibia glutinosa*. When the water has cleared and the plants are in good condition, which may be known by their giving off bubbles of oxygen gas, fish, water insects, &c., may be introduced. A plant or two of the floating "Frogbit" is useful for giving support to such species as come occasionally to the surface. Besides *Chara*, *Vallisneria spiralis*, and *Anacharis alsinastrium*, there are many other water plants. Perhaps the most beautiful is the *Aponogeton dystachion* which comes from the Cape, but is now cultivated in this country and throws up its fragrant flowers from time to time during the greater part of the year if the plant is strong and vigorous. The plants usually supplied to purchasers are too small and weak to grow, but if the student can get a good strong piece he will most likely succeed in growing it, even in London.

In the case of both fresh water and marine aquaria it must be borne in mind that a proper amount of light is required, and this ought to be admitted from above as well as on one side of the vessel. If there is not light enough, the plants droop and do not give off air bubbles, while if there is too much light there will be a more abundant growth of *confervæ* upon the sides of the vessel than the scavenger mollusks can keep under. It must also be borne in mind that animals must be kept in what has been called "amicable groups," or wholesale destruction will ensue.

Minnows, sticklebacks, and eels, are the fish best suited for fresh-water aquaria, but of course must not be kept in such as are used for watching the various stages of development of other animals. Small eels live well, and the student will be interested in watching the pulsations of the venous heart in the tail of these animals. Most fresh-water and marine animals, as well as the aquaria and glass cases for growing purposes, may be obtained of Mr. King, naturalist, Portland Road. Fern and plant cases may be easily made or purchased of Barr and Sugden, King Street, Covent Garden, and other horticulturists.

Marine aquaria require more attention in their construction than those for fresh water. A marine aquarium, capable of holding from five to ten gallons, is a convenient size and will succeed well. The bottom and sides should be of slate, the back and front only being of glass cemented into grooves made in the slate, not simply abutting against a shoulder and cemented, or a continual leakage may occur.

I have, however, made large aquaria by fitting plate-glass into an iron frame made of tolerably strong angle iron brazed together at the corners. The joints were made with the aid of the lime and India-rubber cement, p. 58. In this the glass was firmly bedded, and then a mixture of white and red lead was forced into the space remaining, together with some fine tow or cotton wool, a little more white and red lead being applied to make a smooth even edge. The whole was then left three or four weeks in order that the cement might become firm.

The aquarium should be covered with a glass top fitted to a beading of perforated zinc to admit air and keep out dust. The form should be such as to allow a large area of surface to be in contact with the air in proportion to the bulk of water. Rock work should be built up at the back so as to cut off an unnecessary amount of light, and should be arranged in such a way as to present tiers of resting places for the animals. The basis may be formed of coke, which is advantageous on account of its lightness, but this is to be faced with flakes of granite, limestone, and sand rock, put together with hydraulic cement. Time must be allowed for the cement to harden, and water should be poured in and changed several times in order to remove any soluble matters. It is, however, better not to use cement at all.

The tank so far prepared should in any case be first filled with fresh water to remove all soluble matters from the cement and rockwork. After resting for a day or two, the water must be drawn off with an India-rubber tube used as a syphon, and the bottom covered with well-washed shingle. The tank may then be filled up with sea water, or artificial sea water may be made with Tidman's sea salt in the proportion of about one pound to three gallons of water, the exact proportions being determined by aid of a hydrometer, which should stand at 1.026. Should the water be too salt the stem will rise till perhaps 1.030 of the scale appears above the level of the water, in which case more common water must be slowly stirred in. If, on the other hand, there is not sufficient salt, the stem will sink towards 1.020, and more salt must be added till the hydrometer registers the proper specific gravity of natural sea water. As evaporation causes the water to become concentrated, it should from time to time be tested with the hydrometer and the necessary amount of water added. The next step is to get the rockwork covered with the spores of seaweeds, by placing several small healthy tufts of *Ulva*, or *Enteromorpha* in various parts of the tank where they are fully exposed to light. In a short time minute vegetable growths will make their appearance. The growth on the front glass must be removed as fast as it is formed by a sponge tied to a stick. After this growth has appeared the tufts of weed may be removed. The amount of light admitted to the tank must now be carefully attended to, so as just to cause the evolution of bubbles of oxygen, without stimulating

the vegetation to an over-abundant growth which would cloud the water. Animals may next be introduced slowly and not in too great numbers, the lowest in organisation first, the higher forms when the tank is evidently working well, the living forms first introduced appearing healthy, and the water clear and sparkling. It is well occasionally, if not daily, to remove a portion of the water into a glass vessel and allow it to return to the tank through a fine jet, by which means the water is broken up into spray and air taken up. It is a good plan to use a glass syringe and forcibly squirt water upon the surface, by which operation many air-bubbles may be forced down to the bottom of the tank. There are various ways of effecting this important process of aëration of the water.

From the "Athenæum" for March 10th, 1860, the following extract from a communication by Mr. Highley has been taken. The very convenient arrangement described will be found well suited for a microscopist who is making a temporary visit to the coast :—

"I may mention a plan I have employed with great success when making temporary visits to the coast, which will be found very convenient to those who wish to classify the animal forms obtained for observation. I take a nest of German beakers (without spouts) and pack them in a zinc case: on my arrival, I fill them with fresh sea water, and place them in a sunny window; I then collect a number of limpets on whose shells enteromorpha and ulva are growing. These will be found to be small but vigorous plants. I remove the animals from the shells, and then drop one or more alga bearing shells into each beaker according to its size; in a short time the sides of the jars, especially the sides turned towards the light become coated with spores; the sides turned from the light I keep clean with a chisel-shaped piece of wood and a knob of sponge, so that whilst one half of each jar is covered with a green oxygen yielding coat, the other half is free for observing the animals that may now be placed in the beakers. Behind this protecting coat, red algæ will be found to thrive. In this way a number of aquaria may be speedily provided for our collections that will keep healthy for months, with a little attention.

"After the sides are properly covered with spores, the seaweeds should be removed and the jars placed on a table at such a distance from the window that the light impinges only on the coated half, taking care, however, that there is sufficient to stimulate the spores to throw off bubbles of oxygen daily. If on leaving a place I wish to take any specimens away with me, I pack these beakers containing them in a rough box, of a size suited to the number selected, with seaweed between the interstices and at the latest moment tie bladder over each jar, which I remove at the earliest opportunity after arriving at my destination."

Prawns, fish, actiniæ, &c., may be fed on shreds of beef. The beef

may be cut in thin slices and dried. Small pieces should be broken off as required, macerated in sea water for a few minutes, and when soft given to the animals. All dead plants and animals, slime, and effete matter of any kind should be removed by means of a pair of long box-wood forceps or with the help of a small saucer, as soon as noticed. With a moderate amount of attention, a marine aquarium may be kept for years (ten or more) without changing the water. Microscopes are specially constructed by Mr. Swift, Mr. King of the Portland Road, and Mr. Collins, for observing animals while living in aquaria. See p. 6.

The most useful books to the microscopist visiting the coast, will be found in the list at the end of the volume.

*Examination of Lower Animals and Plants during Life.*

Many of the lower animals and plants may be examined in the living state, the peculiar actions characteristic of the living state may be studied, and numerous highly interesting and important facts demonstrated. The student will find many of the smaller insects, more especially the aquatic larvæ, as for example, those of the common gnat, well adapted for this purpose. Small crustaceans, as the daphne and some of the fresh water shrimps, are exceedingly interesting objects, and are easily subjected to examination in the living state in the animalcule cage, p. 76, or under a compressorium, p. 96.

*Examination of Infusoria, &c.*—Suppose the student desires to submit some of the animalcules in water to microscopical examination, he may proceed as follows. A drop of the water is to be removed with a pipette, or upon a glass rod, or with the finger, and placed upon the glass slide. A bristle or thin piece of paper is placed in such a position as to prevent the thin glass from coming into contact with the slide and thus causing undue pressure; or the drop may be placed in a Brunswick black, or thin glass cell; or the animalcule cage already described, pl. XXII, p. 78, fig. 7, may be used with advantage. By the latter instrument, and also by the compressorium, p. 96, the larger infusoria may be kept still in a particular position for the purposes of examination.

To obtain specimens of the common infusoria all that is necessary is to expose some of the ordinary water in a light place in a warm room for a few days, when many different species will be found to have developed in great numbers. The water supplied to our cisterns contains rotifers and their ova. In order to obtain them the water may be kept for two or three weeks in a lightly covered glass vessel. If a little of the deposit be removed from the sides and examined in the usual manner many will be found.

*Vorticellæ and Rotifers* or wheel animalcules and many other forms may often be obtained by placing a small piece of a plant which has

been allowed to remain in the same water for some time, with a drop of the fluid in a glass cell. These organisms are often found attached to the edges of the plant in considerable number.

Fresh-water and marine zoophytes, too large to be placed in the small cells, or the troughs, p. 76, may be examined in flat watch glasses, or in one of the larger cells, represented in pl. XXII, p. 78. These may be examined with low powers (two inch, one inch) without any thin glass cover, but where the higher powers are employed a piece of thin glass must be applied in such a manner as to cover that part of the vessel in which the animals are situated, while at the same time a certain proportion of the fluid is freely exposed to the air; for if aëration were prevented, the animals would soon exhaust all the air dissolved in the small quantity of water in which they were imprisoned, and die of suffocation.

It is difficult to kill many zoophytes, and preserve them with the tentacles extended, but it is said that the retraction of the tentacles may be prevented by plunging them into cold fresh water. Various poisons, opium, hydrocyanic acid, chloroform, &c., have also been recommended for the same purpose, but a voltaic current effects the object most perfectly.

Cheese mites and other small acari should be examined with low powers (two inch, one inch) under the binocular, a strong light being condensed upon them with the aid of the bull's eye condenser or the parabolic reflector, p. 28.

Small spiders, many of the minute coleoptera and their larvæ, aphides, parasites of the common house fly, beetles, and many other insects, and a great number of the smaller insects common in fern cases may be easily examined, and some of the smallest of them are suitable for examination by reflected and transmitted light, under low and high powers, with the aid of the binocular, p. 14.

The *Entozoon* or *Demodex folliculorum* may be obtained by squeezing the sebaceous glands in the skin of the nose, or scalp of the human subject. Specimens may generally be obtained from the wax of the ear. If transferred to a little oil and covered with thin glass, the animals may be preserved alive for some time and their slow, sluggish movements watched, pl. XLI, p. 168, fig. 3.

**256. Of keeping Bodies moist while under Microscopical Observation.**—In order to study the changes occurring during the growth and multiplication of some of the simplest organisms which live in water, it is necessary to adopt some plan for preventing, or compensating for, the evaporation which takes place. This may be effected, as recommended by Recklinghausen, by adapting a piece of sheet India-rubber tubing to the glass ring fixed on an ordinary glass slide, the diameter of the ring being sufficient to allow a piece of thin glass to be placed



within its circumference. The upper end of the tube is tied round the object-glass of the microscope. Thus a *moist chamber* is made, and if one of Hartnack's "immersion lenses" be employed, observations may be continued upon a given object for a considerable time. The moist chamber is, however, better adapted for use with low than with very high magnifying powers. See pl. L, p. 182, fig. 4.

I have found that the same object is gained if the loss of fluid by evaporation is compensated for by conducting water from a little reservoir of water, fixed at one end of the slide, by means of a small piece of blotting paper or silk thread. In this way fresh water is supplied to the object as fast as evaporation takes place. By placing a little cement round two-thirds of the thin glass cover, sufficient space is allowed for the requisite access of air, while at the same time loss by evaporation is reduced to the smallest amount. By this arrangement the growth of the spongioles of plants may be very successfully studied.

A small quantity of fluid or semi-solid matter containing various kinds of living matter, may be preserved for some days without the death of the living particles it contains taking place, by the following arrangement. A small glass tube about half an inch in diameter and an inch and a half in length is prepared, the edge of one extremity being turned outwards in the blow-pipe flame, so that very thin membrane may be tied over it. The tube is so arranged that the membrane just touches the surface of some distilled water in a small dish or capsule. The whole may be placed in a hot-air oven maintained at a uniform temperature of 100° F. In this way I was enabled to keep living matter freely exposed to the air, whilst the loss by evaporation was balanced by the gradual flowing in of fluid from below through the pores of the membrane. In this way, I have succeeded in keeping alive masses of bioplasm from the higher organisms for some time longer than they would have lived under ordinary exposure.

**257. Of Keeping Bodies at a Uniform Temperature higher than the Air, while under Microscopical Observation.**—In order to study the phenomena of animals which naturally occur under the influence of a temperature considerably above that of the surrounding air, it is necessary to be able to raise the slide on which they or their tissues are placed to the proper standard, by artificial heat. This desirable object may be effected in many ways. By placing a brass plate upon the stage of the microscope, and allowing one end to project over the edge so that it may be conveniently heated by a spirit-lamp, any substance may be kept warm upon a glass slide, while subjected to microscopical examination. Max Schultze has recently contrived a brass plate which is fixed by clamps to the stage of the microscope, and extended at the sides so as to form two projecting arms beneath each of which a small spirit-lamp may be placed. A hole is made for the passage of the light.

Close to the place where the slide with the object is situated, is the bulb of a little thermometer, the stem of which is so arranged that the degrees can be readily read off. This apparatus has been made by Geissler, of Bonn, fig. 1, pl. XLI, p. 168. In conducting observations upon bodies which are warmed, the loss of fluid from evaporation must be provided against by the use of the moist chamber and immersion lens, or by the little reservoir and conducting thread, pl. XXII, p. 78, fig. 8, or by the arrangement described on p. 77.

Dr. Ransom, of Nottingham, has been long engaged in investigations which require the application of heat and cold to the object while under observation. He says, "The mode of using heat for those examinations I have found best so far, is recommended by M. Schultze, only in order to employ with it cold also, I have ordered one to be made of copper instead of brass, as the former metal is so much better a conductor, and I trust I shall be able with this new hot stage to preserve an object at any required temperature, and to read off easily the actual temperature which the object has from 30° F. to 160° F." The principle of this form of hot stage is to conduct the heat to or from the object, and not to use currents of air or water. It may be used not only for stimulating movements, but for watching the extremes upwards or downwards, which either arrest or destroy vital action. But it is not adapted for keeping up a uniform temperature for a considerable period of time. Such a stage must be separated from the microscope by a non-conducting substance.

A very simple plan for heating objects by hot air is indicated in fig. 2, pl. XLI, p. 168, but when it is necessary to regulate the temperature within a few degrees and maintain a uniform heat for some time a more complex arrangement must be adopted. In pl. XIV, p. 148, of the "Microscope in Medicine," I have given a figure of Dr. Sanderson's apparatus, which is very efficient and may be obtained of Mr. Hawksley, 300, Oxford Street. The stage is kept warm by the constant circulation of currents of warm water supplied by a boiler heated by a gas jet.

**258. Contractility of Muscle.**—The movement taking place in the particles of this tissue may be demonstrated in certain of the lower animals, in which it continues for some time after the tissue has been removed from the body. Mr. Bowman strongly recommends the muscular fibres from a young crab ("Philosophical Transactions," 1841). Many small transparent aquatic larvæ are also well adapted for observation. The phenomena of muscular contractility may however be most successfully studied in the broad muscles just beneath the skin of the common maggot or larva of the blow-fly, and as these can be always readily obtained, I recommend them for observation. The movements, which are very beautiful, continue for ten minutes or a quarter of an hour after the muscles have been removed from the body of the recently

killed animal, so that a specimen may be prepared and passed round the lecture room in one of the portable microscopes, p. 17. In the winter I have seen the contractions continue for upwards of half an hour. It is most instructive to examine these muscles during contraction under the influence of polarized light, with a plate of selenite. When the ground is green, the waves of contraction which pass along each muscular fibre in various directions, are of a bright purple. In other parts of the field the complementary colours are reversed. There are few microscopic objects, that I am acquainted with, so beautiful as this. With the aid of very high powers, the actual change occurring in the contractile tissue as it passes from a state of relaxation to contraction, and from this to relaxation again, may be studied, and for many minutes at a time.

In order to obtain the muscles, it is only necessary to slit up the larva, and after removing the viscera, to separate some of the muscles from the outer skin to which they are attached. They may be moistened with some white of egg, saliva, or better than all, a little of the fluid from the animal.

The student may thus gain information concerning the nature of *contractile* movement generally, in which there is invariably a repetition of alternating actions. Contractility has been confused with movement essentially different in its nature, which takes place in bioplasm or living matter, p. 203. The first affects various kinds of formed material only; the last is peculiar to bioplasm. Contractility is essentially interrupted. Vital movement is continuous. By the last, a weight may be raised higher and higher, and if the weight increases the force which raises it may increase also. Contraction involves yielding or relaxation. It is, as it were, a vibration to and fro—the alternate shortening and lengthening of a fibre. Contraction takes place in one definite direction only, and never alters. Vital movements occur in a mass of living matter, and may take place in any direction.

*On the use of Borax and Boracic Acid in studying Muscular Contraction.*—Professor Ernst Brücke, of Vienna, discovered that solutions of pure borax and boracic acid exhibit peculiar reactions upon albuminous substances. A 2 per cent. solution of boracic acid unlike most dilute acids does not retard the coagulation of the blood. In a solution of three parts by weight of pure melted boracic acid in 200 of water, muscular tissue removed from a recently killed animal will retain its contractile power for a much longer time than if immersed in pure water. In some experiments Brücke found that the muscles retained their contractility for twice the length of time. The muscles from the largewater beetle continued to contract under the microscope for upwards of a quarter of an hour after removal. Brücke also employs a 2 per cent. solution of boracic acid for studying the structure of the red

blood corpuscles. This acid has not yet been much employed by microscopical observers, but it is one which is likely to be useful in the preparation of many specimens. "Über das Verhalten lebendiger Muskeln gegen Borsäurelösungen." "Über das Verhalten einiger Eiweisskörper gegen Borsäure." "Über den Bau der rothen Blutkörperchen," von Ernst Brücke, Band LV und LVI der Sitzb. d. k. Akad. d. Wissensch, April, Mai, Juni, 1867.

**259. Of the Circulation of the Blood.**—I believe by the law of England, the man who ties with a thread or otherwise in any way interferes with the comfort of a frog for the purpose of studying the circulation of its blood in the vessels of the web of the foot does so at the peril of being taken up by the police and convicted before a magistrate of being cruel to an animal, and may be fined £50 for the offence. Although the inconvenience to the frog is not very great, there are many persons in the country, whose tender regard for the lower animals is such that they would certainly inform against anyone who unduly restricted the movements of a frog for the purpose of scientific observation. It is in these days a very hazardous proceeding on the part of anyone not licensed by Government to be cruel to animals, to study the circulation of the blood; but to show the phenomenon to several persons would be most dangerous. In former days we were allowed to examine the web of a living frog as follows, and were not considered cruel:—Selecting a young frog with a thin web, the body and one hind leg were loosely bound up in wet rags, the other leg being allowed to protrude. The body was then tied to the frog plate, and a piece of thread having been carefully tied to two of the toes, the webs were stretched over the glass at the end of the plate, and fixed in the proper position for observation. A drop of water was then added, and the web covered with thin glass. By careful observation of the circulation, first of all under a low power, and then under a quarter of an inch object-glass most important and highly interesting facts were learnt.

In cases in which it is necessary to conduct observations on the circulation with the aid of very high powers, it will in practice be found desirable to increase the length of the tube instead of employing object-glasses of very high magnifying power. A quarter of an inch object-glass may thus be made to magnify as highly as a twelfth, and as the distance between the object-glass and the thin glass covering the web is very considerable, there is not the same danger of serious derangement every time the animal moves slightly. Several different lengths of tubes may be adapted to the microscope body, which may be thus increased to the length of two feet or more, if desired.

If a small artery be brought into focus and the tip of one of the toes be very lightly touched, the artery is seen to contract immediately, and somewhat irregularly in different parts of its course. Sometimes a

few blood corpuscles are firmly compressed, and for several seconds the vessel remains so strongly contracted that not a corpuscle passes along it. By performing this instructive experiment, the observer will realise the effects of the wonderful contractile power of the coats of the smaller arteries, and will conclusively demonstrate that the afferent nerve fibres distributed to the skin of the foot generally, influence the nerve centres from which the nerves ramifying amongst the muscular fibres of the arterial coats take their rise. This is a beautiful instance of reflex nervous action affecting the vessels.

The circulation might also be studied during life in the capillaries of the tail of a small fish, minnow, stickleback, eel, carp, &c. The fish should be wrapped up in wet lint and loosely tied at one end of a glass slide, the tail being placed about the centre, and covered with a piece of very thin glass. Whether such a proceeding exposes the experimenter to a penalty of £50, I do not know, but in all cases the student must be careful not to hurt any creature for the purpose of gaining information. Maiming and torturing incidental to sport are permitted. Nothing is learnt by the process, but to learn anything from a lower animal subjected to pain is forbidden by Act of Parliament.

*Of the Action of the Heart.*—A more correct idea of the mode of action of the heart may be formed by watching its contractions in a small living animal under the microscope than in any other way with which I am acquainted. A young fish, or newt, or frog tadpole may be taken for the purpose, but I have found that a young snake removed from the egg exhibits the phenomena most beautifully. The blood may be distinctly seen as it eddies through the various apertures in passing to or from the different vessels and cavities of the heart. The undulating contractions of the auricles and ventricle of the heart ought to be seen. Under a two-inch power adapted to a binocular microscope, the movements of the heart may be studied most advantageously. I believe experiments may be performed upon a tadpole without breaking the law, but the experiments must not be continued from the tadpole into the frog stage of life. Before long no doubt the wrong will be redressed, and the protection afforded to the frog will be generously extended to the tadpole. Both frog and tadpole should appeal to Parliament and draw the attention of all conscientious Englishmen to the horrors of their position, and thus point out the flagrant inconsistency and injustice of the present state of the law.

The circulation in the tadpole has been well described by Mr. Whitney ("Transactions of the Microscopical Society," vol. x, p. 1, 1862). The animal should be starved for a few days before being submitted to examination, in order that the intestine may become transparent. The *branchiæ* of the frog tadpole or young newt may be examined in a flat glass cell specially prepared for the purpose, and by an arrangement of

tubes the animal may be supplied with fresh water while it remains under observation. In pl. XXII, fig. 1, p. 78, is represented a form of cell which I made many years ago for a proteus, but a cell for a newt or other animal may be made upon the same plan. The circulation of the blood in the capillary vessels of a mammalian animal may be studied in the thin membrane forming the wing of a young bat, or in the frænum of the tongue of the human subject, by the help of a microscope designed by Dr. Pritchard and described and figured in "The Microscope in Medicine," fourth edition, pl. XXXVI, p. 503.

The examination of the movements alluded to in this section, may be advantageously conducted with the aid of the binocular.

**260. Of the Movements of the Chyle.**—For studying the *movements of the chyle* in the lacteals, a mouse, rat, or young rabbit may be taken. The animal should be fed with a little lard beaten up with a piece of pancreas and a small quantity of bile, so as to form a soft pultaceous mass which may be strained through muslin. About half an ounce or less, of the cream-like fluid may then be injected by the aid of a small syringe into a flexible catheter which has been passed down the gullet into the animal's stomach. After a couple of hours, the creature should be pithed, stunned, or destroyed very suddenly, and a small portion of the mesentery with the intestine attached withdrawn through an aperture in the abdominal walls and submitted to microscopical examination with a low power.

**261. Ciliary Movement** is not peculiar to animals, but is also found among plants, at least during the early stages of existence of some of the lower forms.

Upon certain surfaces in the higher animals, and to a greater extent in the lower classes, we find that the cells which generally form the outer protective covering of more delicate structures, are provided with very active vibratile processes, or *alia*, which by their movements create currents often of some considerable power. These movements are sometimes required to promote the rapid removal of foreign bodies which would injure delicate surfaces if they came in absolute contact with them, or for promoting a constant change in the water by which the animal is surrounded. Cilia effect the latter object in the greater number of shell fish, which are stationary throughout life, and are not provided with an apparatus for promoting a continual change of the fluid which bathes the surface of their respiratory organs.

*Ciliary Motion* endures for a longer or shorter period after death, and is entirely independent of the nervous system. In the active bird it ceases very soon, but in the more slowly nourished, cold-blooded animals it often lasts for many days after death. Different forms of ciliary action may be observed among the different species of infusoria. It is, however, doubtful whether many of the very fine spine-like bodies,

the movements of which seem to be under voluntary control, ought to be regarded as cilia. The simple organisms of this class seem to possess the power of stopping the vibrations, but there can be no doubt that in vertebrate animals ciliary action is quite independent of volition. There is certainly no connexion between the cells of ciliated epithelium and the nerves.

Cells with ciliated epithelium in active vibration can always be obtained by scraping the back of the tongue or fauces of the frog, toad, or newt. Mucus is removed in which numerous cells are found. The thin glass cover must be prevented from pressing too firmly by inserting a small piece of thin paper beneath it. The student may also obtain very beautiful ciliated epithelium in active vibration from the branchiæ (gills) of the oyster or mussel. Some of the cilia from the latter situation are of very considerable length, and occasionally the vibration of a single cilium may be watched, in which case the observer may demonstrate the interesting fact that movement occurs not only at the base of the cilium, but in every part of the vibratile filament. *See figures in pl. LI, p. 196.*

Of all the ciliated structures, the newt's kidney is perhaps the most beautiful and the most remarkable. The tortuous uriniferous tubes in the upper thin portion of the kidney are lined in their whole length with ciliated epithelium, which continues in active motion for some time after the removal of the organ from the body of the animal. In order to display this wonderful object, we must proceed as follows:—After destroying the newt by decapitation, the abdominal cavity is laid open, and by turning the viscera to one or other side, the kidneys may be exposed. Towards the pelvis, the kidney presents much the same appearance as in the frog: but, upon tracing it upwards, it will be found to become gradually thinner, and to extend quite into the thoracic portion of the animal. It is this upper thin part of the kidney which shows the ciliary motion to the greatest advantage. *See pl. XXXIX, p. 158, fig. 8.* A probe, *a*, is represented in the drawing underneath that portion of the kidney which should be examined in the microscope. The thin portion of the kidney, above referred to, is to be very carefully removed from the body by delicate manipulation with fine forceps and a pair of scissors, moistened with a little water, or, what is still better, with some of the serum of the animal, placed in a large thin glass cell, and carefully covered with thin glass. The cell should be sufficiently thick to prevent any pressure upon the preparation. The secreting tubes lie upon one plane, so that a tube, throughout the entire length of which active ciliary motion is constantly taking place, may often be seen in the field of the microscope at one time, under a half-inch object-glass. After ciliary motion has stopped, the cilia are with great difficulty distinguished. Many of the tubes in the lower thick part of the kidney do not exhibit ciliary action, perhaps because

the cells are undergoing degeneration. I have been able to find tubes in every stage of wasting in newts which have been kept in confinement.

Ciliated epithelium may be obtained from the larynx and trachæa of man by coughing violently. The vibration occasionally continues for some time after the specimen has been transferred to the glass slide. The observer will be surprised at the enormous number of cilia projecting from a single cell; indeed it often happens that a mass is expelled which seems to consist of hundreds of long filaments, all in active vibration, radiating from a common point.

Ciliary action is, I think, due to changes going on within the cell, but probably very intimately connected with the currents which flow to and from the bioplasm or living matter, and the altered tension thus caused in the cell. Ciliary motion is not dependent upon nervous action, nor is it due to any disturbance in the surrounding medium. It cannot, I think, be regarded as a *vital* movement, although it is probably due to changes which are consequent upon vital phenomena. Cilia consist of "formed material," but the bioplasm passes into the hollow base of the cilium, and extends for some distance, figs. 3, 4, 5, pl. LI, p. 196. In the immediate vicinity of ciliated cells are sometimes observed cells with open mouths, out of which mucus and various substances, formed or secreted in the interior of the cell, pass. Pl. LI, p. 196, figs. 6, 7. In the formation of these products, nutrient matter from the blood, after passing through the attached extremity of the cell, is probably absorbed by the living matter. At the same time the outermost portion of the latter becomes converted into the peculiar contents of the cell, and thus the formed matter which has been already produced becomes pushed towards the orifice. I think that the movements of cilia are brought about by a somewhat similar series of changes, in which the bioplasm or living matter, usually termed nucleus, plays the active and most important part.

**202. Of the Movements of Minute Particles in Fluids, and of the Vital Movements of Bioplasm or Living Matter.**—Robert Brown, just fifty years ago, made known the fact that very minute particles of matter, *non-living* or *living*, suspended in water, exhibited movements. The particles which move and vibrate about one another are many of them too small to be measured. In fact, when examined by the highest powers of the microscope most of them disclose no definite form, and appear as minute dots. The movements of the particles in question have since been known as Brownian or molecular movements. They have been attributed to currents produced by evaporation—to the influence of heat, to external vibration, to "surface tension," and a number of other circumstances quite incompetent to give rise to them in some of the cases in which they occur. The subject has been very recently re-investigated by Professor W. Stanley Jevons, who, I think, correctly attributes the movements to electrical disturbance. I have



myself many times seen, unquestionably, electrical movements of particles, suspended in fluid, moving to and from the surface of an air bubble included in the fluid. The movements in question very closely resembled some of the so-called molecular movements, except as regards their very much greater activity. Professor Jevons speaks of the motion as *pedetic* from *πηδησις*, *leaping* or *bounding*, though I confess it seems to me that such words as *leap* and *bound* represent movements very far removed from the so-called *Brownian* or *molecular movements*. The latter phrase is, it must be confessed, equally objectionable, for the term *molecular* cannot be adequately defined, and is constantly used in very different senses by those who are most partial to it. It is applied to particles which any one can see, and to purely hypothetical particles existing only in a physical imagination, and it is also applied to the "machinery" discerned by Dr. Tyndall in living beings, but which no one else has been able to detect. Upon the whole, perhaps, the least objectionable term is *Brownian movement*.

The observer, who desires to gain a knowledge of the character of the movements, has only to mix a very small quantity of clay with pure water and examine a thin layer of the mixture covered with very thin glass under a power magnifying from 500 to 800 diameters. See Professor Jevons' paper "On the Movement of Microscopic Particles suspended in Liquids" ("Quarterly Journal of Science" for April, 1878).

Absolutely different from the constant vibrations of solid particles about one another are the definite continuous movements which characterise every form of bioplasm in which no structure, no molecules, can be seen. The movements in question are so active in some forms of living matter as to engage the attention of everyone who can use a microscope. These movements are at this time inexplicable, and are peculiar to living matter. To call them molecular is perversely to distort the meaning of the word, for clearly these vital movements are essentially distinct from any of the molecular movements known. If the Brownian movements are molecular, the vital movements cannot be included in that category. Vital movement may be studied in *amæba*, in the *mucus corpuscles* from the surface of the mucous membrane of the throat, in colourless blood corpuscles, of man and animals, in lymph corpuscles, pus corpuscles, and in some other particles of living matter. Let the observer carefully watch with his own eyes and understanding the movements of an *amæba*, and when he is conversant with the phenomenon as apparent under object-glasses magnifying from 300 to 1,000 diameters, let him search his books for an account of the changes he has seen, and for an explanation of the movement of the matter of which the living organism is composed. He will be surprised to find that contemporary scientific authority, backed by public opinion,

Fig. 1.



Ciliated epithelium, from the back of the tongue  
Living toad. x 700. p. 193

Fig. 2.



Portion of ciliated bioplasm. From the back of the tongue  
of the living frog. x 700. p. 193.

Fig. 3.



A few cilia, from the living frog's tongue, showing their connection  
with the bioplasm, which can be traced into each cilium  
x 2,000. p. 193.

Fig. 4.



Cilia, with bioplasm. Tongue of living frog. x 2,800. p. 193

Fig. 6.



Mucus-forming cell  
From the fauces of  
a frog, shewing the  
passage of the nutrient  
material to the bio-  
plasm, and the escape  
of the mucus (formed  
material) from its  
opercate suria  
p. 195.

Fig. 5.



Single cilium  
showing bioplasm  
prolonged into the  
interior. Frog.  
x 5,000. p. 193

Fig. 7.



Ciliated columnar  
epithelium, with  
bioplasm. p. 193.



has vouchsafed to decree that the movements are due to "molecular machinery," worked by "jelly guiding force."

*Diapedesis*.—Among the remarkable phenomena of living matter is the capacity of squeezing through small openings. A body the  $\frac{1}{2000}$  or an inch in diameter may pass through an opening or a pore perhaps less than the  $\frac{1}{100000}$  of an inch in diameter, and so indistinct that it cannot be demonstrated by the highest powers under the most favourable circumstances as regards demonstration. This movement is effected by a portion of the mass extending itself beyond the rest so as to form a very thin filament which moves into the aperture in much the same way as the rootlet of a plant moves and extends itself amongst the particles of soil, and pushes them aside as it increases in diameter and goes on elongating itself. The portion of living matter reaching the other end of the aperture increases in extent, as the thin line moving in one direction gradually accumulates. At last all has passed through, and the mass of living matter is seen on the opposite side, perhaps, of a membrane apparently destitute of pores. Its substance seems to have been traversed by matter which is certainly not fluid like water, but more or less viscid, and forms a coherent mass which, when suspended in fluid, appears as a well defined globule or corpuscle. This passing of a corpuscle through the capillary wall has been termed:—

*Diapedesis*, a word which comes from *Λία*, and *πηδάω*, to leap, dance, and though often employed, it appears to me to convey a very wrong idea of the phenomena. Of late years numerous observers following Cohnheim have affirmed that both white and red blood corpuscles make their way through the walls of capillary vessels in inflammation. The phenomenon is described by many as if it were constant, of great pathological importance, and to be proved to demonstration without difficulty. On the other hand, to others it seems only to occur occasionally, to be probably exceptional, and of little or no physiological or pathological importance.

I allude to it here because the student will find that the supposed demonstration is due at least in many cases to an error of observation. Even skilled observers and scientific authorities find it difficult to obtain a specimen which affords distinct evidence of the passage of a colourless corpuscle through the vascular wall. We may be very easily mistaken. In the first place, there are external to the vessels many corpuscles like colourless blood corpuscles. One of these lying over or under the vessel a little towards one or other side, looks as if it were half inside and half outside the vessel. Secondly, it sometimes happens that a capillary is slit or torn at a particular spot, when not one but many white and red blood corpuscles\* pass through the aperture. Thirdly, the bioplasts of the capillary walls are themselves sometimes swollen, and may be easily mistaken for colourless blood corpuscles

which have just passed through the capillary wall. On the other hand, any one who studies carefully the vessels, particularly of the frog, in tissues in which inflammation has been excited, will be struck by the great number of vessels which are completely filled with colourless corpuscles, though not one can be found which has passed through the vascular wall. And, lastly, I will direct attention to the fact that the thin walled vessels of the developing ovum are often found literally choked with colourless corpuscles, and yet over a wide area occupied by networks of vessels not one of the many millions of corpuscles seen has traversed the vascular wall. Where pus-like corpuscles are seen outside the vessels, they result from the enlargement and growth of minute bioplasm particles which are suspended in the liquor sanguinis, and have passed with it through the wall, and also from the growth and division of the bioplasm of the vessels and tissues. Pus corpuscles were not at an earlier period colourless blood corpuscles. I think, therefore, that *diapedesis* of blood corpuscles must be regarded as an exceptional phenomenon and of little consequence.

From the consideration of the vital movements occurring in the bioplasm or living matter of animals and man, we naturally pass on to that of certain very active movements characterising certain plants.

**263. Of the Circulation in the Vessels and Cells of certain Plants.—**

In some plants the circulation of juices of peculiar character may be very easily seen with the aid of low magnifying powers. One of the most striking phenomena of this class may be demonstrated in the sheath of the bud of the common India-rubber plant (*ficus elastica*) which bears so well the smoky atmosphere of large cities, and grows notwithstanding the bad influence of gas. Just as the leaf is bursting a portion of the red sheath may be removed, and if the thin edge be carefully placed in the field of the microscope under an inch or half inch power, the vessels with the contained white fluid in motion will be seen. With the aid of the half inch or quarter the observer will be able to demonstrate that the whiteness of the fluid, like that of milk, is entirely due to the suspension of countless little globules like oil. In the case of the India-rubber plant, however, these globules are composed of highly viscid material which becomes very sticky, and when dry, elastic. It constitutes the substance known as India-rubber. In the *Chelidonium majus*, a common hedge plant in chalky districts, similar phenomena may be seen.

*Cyclosis*.—The circulation or cyclosis of the contents of the *vallisneria*, *anacharis*, *chara*, and *nitella*, may be observed without any difficulty under a quarter or even a half inch object-glass. In all these the movement is due to the *vital properties* or *powers* of the bioplasm or living matter which moves round and round the cell; the hard cell wall preventing its escape, and rendering movements in a right line impossible.

If the plant is to be subjected to examination under the highest powers, however, certain precautions are necessary. The thinnest possible layer should be removed with a thin but very sharp knife, from the surface of a young leaf of *vallisneria* or *anacharis*, and the two thin pieces thus obtained must be carefully placed on the slide with a drop of water and covered with the thinnest possible glass, care being taken to prevent it from pressing firmly upon the freshly cut surface. It not unfrequently happens that cyclosis has entirely stopped in the cells submitted to examination, but after the fragments of the leaf have remained still for a short time the movement recommences, especially if slight warmth be applied; and it is a good plan, especially in winter, to place the sections which have been made, in water in a small corked glass tube, which may be carried in the pocket for a quarter of an hour or more before they are to be subjected to examination.

Facts of the utmost general interest and importance may be demonstrated in *vallisneria* by the aid of the highest powers. The stream which moves round and round the cell, and looks like pure water under a twelfth, is really found to include, if examined under a  $\frac{1}{25}$  or  $\frac{1}{30}$ , multitudes of extremely minute and apparently spherical particles, each of which is probably endowed with active motor power, pl. XLVI, p. 172, figs. 6, 7. The green chlorophyll masses are urged on by the actively moving particles of bioplasm. One portion of the active, colourless, moving matter is seen to outstrip another portion, amongst which it gradually blends and as it were incorporates itself, to be, in its turn, outstripped by other portions. The direction in which the contents move round the cell is shown in fig. 3, pl. LII, p. 200.

Solid particles of high refracting power, and easily seen, are often suspended in moving bioplasm, and appear to move of themselves, while in reality they are perfectly passive and are but carried in the moving stream. Sometimes these are formed from the bioplasm itself, sometimes they are foreign particles, perhaps bacteria or allied germs which have entered from without. Solid particles of various kinds may be seen commonly enough embedded in the transparent moving bioplasm of the ordinary *amæba*. Pus and mucus corpuscles, and many other forms of bioplasm, also contain extremely minute particles, the nature of which has not been positively determined, as well as foreign particles which become included by the mass projecting itself around them.

The hairs from the flower of the Virginian spider-wort (*Tradescantia Virginica*) a well-known garden plant, growing in London and large cities almost as well as in the country, are beautiful objects for studying the movements of the living bioplasm in the vegetable cell. The transparent matter in active movement contains many minute highly refractive particles, which enables one to detect the slightest variation of the direction in which the stream sets.

The moving streams are very narrow, changing their direction from time to time, meeting some and diverging towards others, so that a network of moving matter results, which lies upon the surface of and in part amongst the beautiful purple fluid which occupies the cavity of the cell, and gives its colour to the hair.

In pl. LII, p. 200, fig. 1, a branch of *Anacharis alsinastrum* is represented. It consists of long slender stems which bear a series of three narrow leaves of a pale green colour at intervals of about a quarter of an inch apart. The leaves when full grown seldom exceed a length of three-eighths of an inch. Fig. 4 shows the irregular shape and position of the cells in one of the leaves of this plant. The thickness of the central part of the leaf is composed of two layers of such cells, but at the margin only one layer exists. Fig. 2, represents one of the hollow spines or hairs at the margin of the leaf of the *Anacharis*. It appears that when the circulating corpuscles arrive near the apex of the spine where the cell wall is undergoing induration, as shown by a brown discoloration, they do not pass quite to the apex, but are invariably hurried across the cell, as seen at *b* in the figure. The three drawings above referred to, have been taken from Mr. Wenham's paper "On the Circulation in the Leaf Cells of *Anacharis Alsinastrum*" ("Microscopical Journal," vol. III, p. 281).

In pl. LII, fig. 2, is represented a hair or spine from the stalk of *Anchusa paniculata*, one of the Boraginææ. This is also taken from a drawing by Mr. Wenham ("Microscopical Journal," vol. III, p. 49). The mode of growth and circulation of the corpuscles, moved as I believe by the bioplasm, are well shown. These accumulate and gradually become converted into the tissue of which the spine is composed. Mr. Wenham well describes this process as follows: a dense current of corpuscles travels along one wall of the spine constantly returning by the opposite side *b, b*. At *c*, where the deposition occurs, there is a considerable accumulation, and at the boundary where they are converted into the substance of the spine a number are seen to be adherent. Often in specimens of this plant the deposition has been so rapid that there was not sufficient time for the complete condensation of the component corpuscles. In these instances a number of them have been caught and loosely enclosed in one or more cavities, as shown at *d, d*. The walls of these containing cavities do not possess a definite outline, because they are lined with corpuscles in all their different stages of transition. The course which the current takes in some vegetable cells is indicated by the arrows in fig. 3, after Dr. Branson.

*Vallisneria*, *chara*, *nitella*, and *anacharis* may be kept without difficulty in glass jars in our rooms, and *Tradescantia* will grow in pots outside the window, and flower freely even in London. If pale or white-flowered plants be selected for observation, the description above given

Fig. 1.



A branch of *Anacharis alternatiflora* p. 100.

Fig. 3.



Diagram to show direction of currents in cells of *Valoniopsis* p. 100.

Fig. 2.



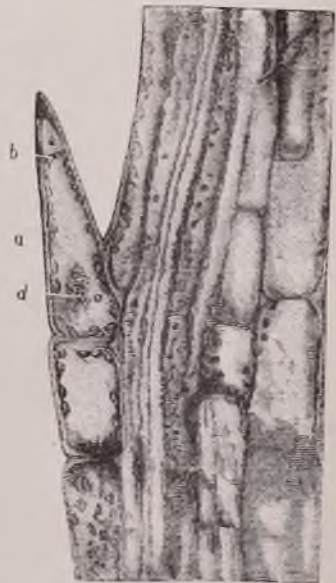
Hair or spine of *Anacharis* showing how hard material is deposited. After Mr. Wenham p. 103.

Fig. 5.



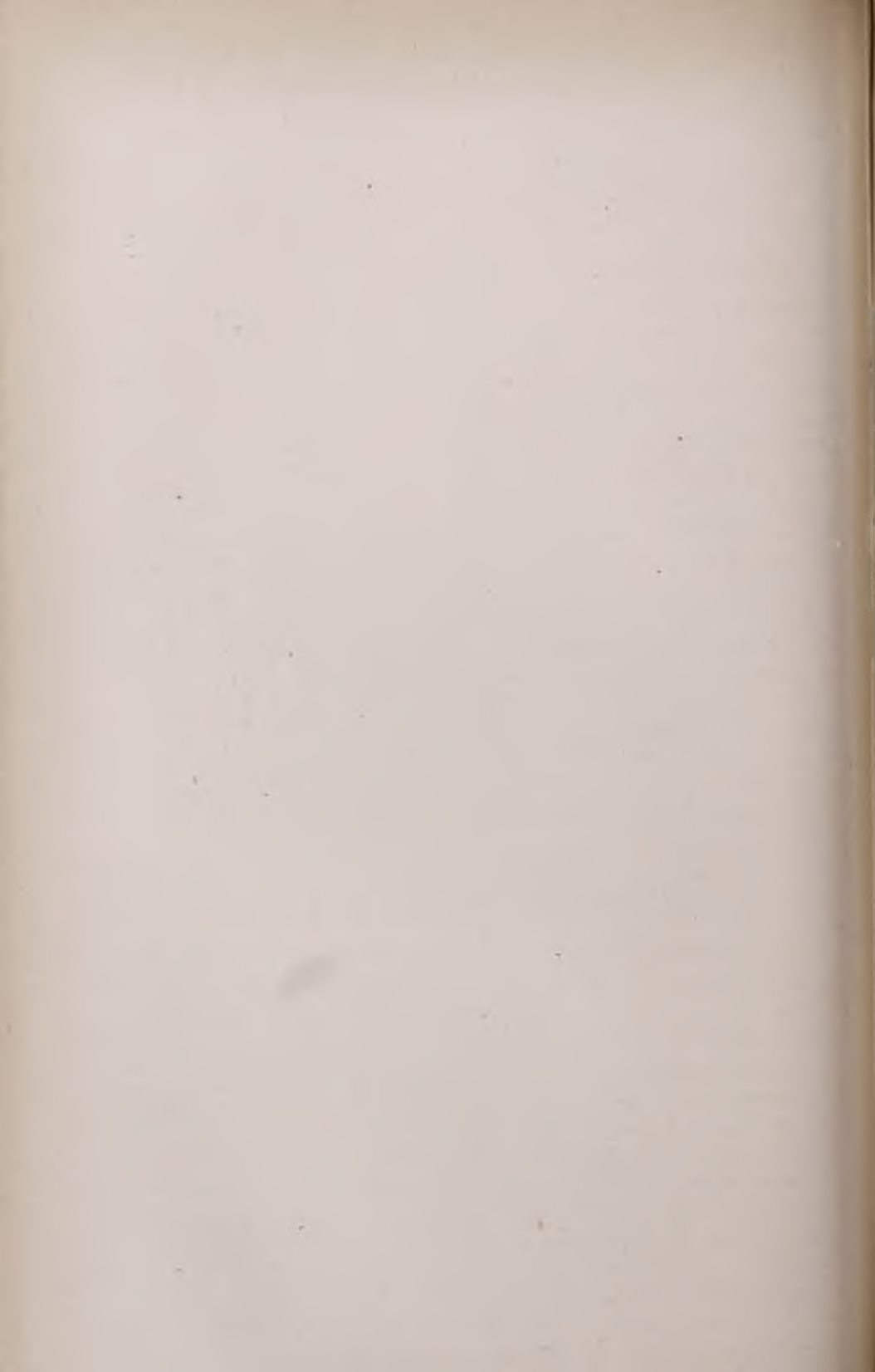
Cells of *Anacharis*. After Mr. Wenham p. 100.

Fig. 6.



Cells and hollow spine of *Anacharis*. After Mr. Wenham p. 100.





will apply except that instead of the fluid in the cell being dark purple—it is either very pale or colourless.

But the phenomenon is to be studied in a plant much more widely distributed and more easily obtained than any of those above mentioned, the common nettle, *Urtica dioica*. The cells of the stiff hairs upon a young leaf generally show cyclosis very distinctly, and the movement may be seen in the hairs of nettles grown in fern cases. In the young cuticular cells movement may also often be seen.

*Pollen Tubes.*—Of all the wonderful sights to be seen in the microscope, I think the growth of the pollen tubes is the most striking. If ripe pollen of a lily be placed in a little of the clear viscid fluid formed upon the stigma, and covered with thin glass and examined under a quarter of an inch object glass, or higher power, the pollen tube may be seen to extend itself while at the same time the fertilising particles suspended in the fluid within are seen in the most active motion. This phenomenon is to be seen in the pollen of many plants, but that of *Lilium auratum* or *Lilium speciosum*, as was noticed by a writer, I think in "Science Gossip," affords very satisfactory results. And now that both lilies are so common in this country, and can be well flowered in London, they are perhaps the best plants to obtain for this purpose.

The circulation in the cells of *Vallisneria*, and the movements of the cilia of small animalcules of ciliated cells under a high power with the new binocular of Messrs. Powell and Lealand, p. 15, once seen can never be forgotten, for the mind seems to have realised the actual state of things occurring during the life of the living thing, in a manner which before was not possible.

#### ON THE NATURE OF VITAL AND OTHER MOVEMENTS OF LIVING BEINGS.

I propose now to offer a few general observations upon the nature of the different kinds of movements which occur in living things, many of which have been referred to in the foregoing sections, and which are of the greatest interest from a philosophical as well as from a microscopical point of view.

Hitherto many of the movements occurring in living things have been referred to the supposed inherent property of *contractility*, and strange to say, the very authorities who never lose an opportunity of ridiculing and condemning those who attribute vital changes in things living to the influence of a peculiar force or power—*vitality*, do not hesitate to refer the movements taking place in contractile textures to the mystical property of *contractility*. Of course they give no definition of contractility, nor do they attempt to define what they mean by the word. They do not show in what this supposed property resembles or differs from other properties supposed by them to belong to primitive

matter. They do not even state whether this contractility may be manifested by things non-living.

By many well-known facts the unprejudiced have been convinced that the difference between *living* and *non-living* is absolute. The assertion that the *non-living* passes by gradations into the living is not justified by the present state of scientific knowledge, and is contradicted by facts of observation and experiment. Though widely taught in these days the statement is a false statement.

Some very remarkable phenomena which distinguish *living* from *non-living* matter may now be observed under the microscope with the aid of high powers. There is no department of natural knowledge in which a greater advance is to be noticed than in this, and the facts which have been recently discovered enable us to draw a sharp and well-defined line between living things and the various forms of non-living matter, whether of simple or of complex composition. If as investigation still further advances the facts already known are added to, and the conclusions arrived at from recent researches, supported by new observations and experiments—the inference that vital phenomena are due to the operation of some agency, force, or power in living matter, distinct from every kind of physical force operating in non-living matter will be irresistible, and will be received as true, notwithstanding the arrogant denunciations and the prophetic announcements of material evolutionists.

If the student studies this question carefully, he will, I think, find that much confusion has arisen from the attempt to account for several essentially different kinds of movement by one property, *contractility*. Thus any tissue which alternately becomes shortened or lengthened, gaining in one diameter what it loses in another, is said to be contractile, while on the other hand, that which moves in every conceivable direction is said to do so by virtue of the same property. It is not, however, very easy to see how two such essentially different movements, as repeated acts of contraction and relaxation within a definite space, and the actual moving away of a mass from one place to another place, can depend upon one and the same property. Essentially different movements occurring in living things really depend as would be supposed upon different circumstances and are not all of the same nature. The movements occurring in living beings may be arranged as follows:—

1. PRIMARY OR VITAL MOVEMENTS—*affecting matter in the living state only, as seen in the amæba, white blood corpuscle, and in bioplasin or living matter generally, pl. LIV, p. 206, figs. 1, 2.*

2. SECONDARY MOVEMENTS—the consequence of vital movements, or of other phenomena, acting upon matter which is not in a living state:—

*a. Ciliary Movements.*—Probably due to alterations in the quantity of fluid within the tissue, the changes in the proportion of fluid being brought about by the action of the bioplasm or living matter.

- b. Muscular Movements.*—Due to a disturbance (electrical or otherwise) in the neighbourhood of a “contractile” tissue—that is, a structure so disposed that its constituent particles shall be susceptible of certain temporary alterations in position, which alterations take place in certain definite directions only.
- c. Movements of Solid Particles suspended in Fluid in Cells, caused by Currents in the Fluid,* as the pigmentary matter in the pigment cells of the frog.—Due to the motion of the fluid as it passes into, or out of, the cell, through its permeable wall; this movement being dependent upon changes taking place external to the cell, occasioned by alterations in the vessels, and by other circumstances.
- d. Molecular Brownian Movements.*—Which affect all insoluble particles, *non-living* as well as *living*, in a very minute state when suspended in a fluid not viscid.

*Of the Primary or Vital Movements occurring in Living Beings.*

This kind of movement is peculiar to matter in the living state, and is not known to occur in any matter which has not been derived from matter in a living state. The movements cannot be imitated. They cease when death occurs, and having once ceased, they cannot be caused to reappear in the same particles of matter. Excellent examples of vital movements are presented in the common *amœba* and many other low forms of life, in the *white blood corpuscles*, in *mucus and pus corpuscles*, and less distinctly in the bioplasm (nuclei) of many tissues of the higher animals.

*Amœbæ* can always be obtained by placing a small fragment of animal matter in a wine-glass full of water and leaving it in a light part of the room for a few days. I have found it convenient to introduce a few filaments of the best cotton wool into the water. The *amœbæ* collect amongst the fibres and are by them protected from the pressure of the thin glass when placed on the glass slide for examination. An imperfect idea may be formed of the changes taking place in the form of the most minute *amœbæ* by reference to fig. LIII, p. 204, fig. 5. *Mucus corpuscles* in the mucus upon the surface of the mucous membrane of the air-passages, white blood corpuscles, and pus corpuscles, exhibit similar movements, fig. 7. Changes in form may be seen to occur slowly in the bioplasm of the cornea of the frog and other animals. Soon after death a shrinking or collapse of the soft bioplasm of all cells takes place, and this alteration has led to the idea that many masses of bioplasm (nuclei) lie embedded in spaces or vacuoles in the tissues. During life, and especially in the early and more active period of growth, the bioplasm or living matter is *continuous* with the tissue, and the shrinking and alteration in question are due to changes which immediately follow the death of this living matter.

The bioplasm of which ova consist is, in many cases, the seat of

active vital movements, which may be studied without difficulty. In the ova of the common water snail (*limnæus stagnalis*) complete rotation occurs, and the embryo from an early period is covered with cilia. Changes in form may be observed in the ova of amphibious reptiles, particularly the *frog* and *newt*. Those of the *pike*, *stickleback*, and many osseous fishes are particularly favourable for observation (Ransom). The stickleback can be easily kept by the microscopist in an aquarium. They sometimes breed in confinement, and the sort of nest which is made for the protection of the young and guarded by the male, is an object of great interest.

The movements in the bioplasm of the higher animals (mucus, pus) can be distinctly seen with a twelfth of an inch object-glass, but it is often necessary to examine one particular corpuscle very attentively, for half a minute or more. In some cases the changes in form are so slow that the observer who looks at the object for the first time cannot satisfy himself of the actual occurrence of the movement at all. It is absolutely useless to attempt observations of this kind in an off-hand, slap-dash manner. Those who desire to have the delight of pondering over such changes will gladly find the leisure to observe the facts. This is just one of those phenomena which, having been well seen once can generally be detected afterwards without much difficulty. Under the sixteenth, twenty-fifth, or fiftieth, the alterations in form can be studied very successfully, and there are few things more wonderful, or which will furnish more interesting matter for careful thought and for valuable and useful speculation.

The movements I have described in the last few paragraphs as *vital movements* I regard as *primary*, and think that the power of movement exists in connection with the matter of which each small portion of the moving mass is composed. It may be to some minds unsatisfactory to attribute the phenomenon to the influence of a power of the nature of which nothing is known, but it is surely better to do this for the present, than to assert that these movements are due to physical force, or to some "machinery" of the physical imagination, considering that in not one single instance can the phenomenon be explained by any known laws of matter or motion. Every unprejudiced person who thoroughly studies the movements and carefully thinks over the facts of the case, will, I feel sure, find himself compelled to admit that they cannot be accounted for in the present state of our knowledge, without assuming the existence of a *power*, which is peculiar and which may fairly be called *vital*, to distinguish it from every other force or power in nature.

*Of Growth and Multiplication.*—Almost inseparable from the consideration of the nature of the movements occurring in living things, is the study of the operations by which particles are added to and often lifted much above other particles in the process of *growth*,—a universal

Fig. 1.



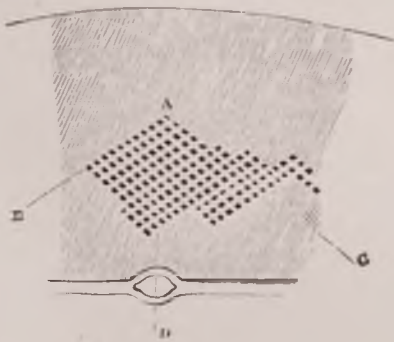
Shell of a rare diatom p. 174.

Fig. 2.



Shell of a rare diatom p. 175

Fig. 3.



Portion of shell of Pleurosigma. After Mr Hunt p. 175

Fig. 4.



The yeast fungus in various stages of development. After Dr. Hesse.

Fig. 5.



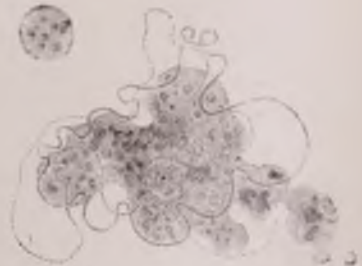
Diatom. p. 175

Fig. 6.



Very minute amoebæ from water containing a little dead animal matter. The smallest free particles exhibit the very active movements were less than the one ten thousandth of an inch in diameter. X 5,000 p. 203

Fig. 7.



Mucus corpuscle. Showing alterations in form during a minute of time X 2,000 p. 103.



characteristic of things that live. The observer who aims at studying the remarkable and highly interesting phenomena of germination, growth, and multiplication of cells or elementary parts in the tissues and organs of living beings, in health and disease, will find it absolutely necessary to investigate these processes in the simplest living organisms, where they occur under conditions far less complex than those which obtain as regards man and other vertebrata. He must exercise the utmost caution in drawing inferences from what he does see or rather thinks that he sees, and he must always bear in mind that great and irreconcilable differences of opinion exist among even distinguished observers, with regard to the general nature of the changes which take place when, for example, a spore of common mildew begins to grow, or an insignificant bacterium gives rise to new bacteria. How then is it likely that the mode of growth, origin, and multiplication of some of the highly complex structures formed in man, especially in the course of disease, can be described with anything like correctness and the causes of them fully explained to the student ?

It has been stated over and over again that living bacteria *originate* in decomposing matters, and one who has recently written on the subject thinks that he has seen the fibrillæ of muscle resolve themselves into such living bodies! It is always necessary to be on our guard against the acceptance of observations (!) of this kind. Those who have had much experience in the manufacture of pseudo-bacteria, could produce a number of objects and advance facts and arguments which would probably fully convince any inexperienced person that there was abundant evidence to prove that bacteria were but the modified particles of certain tissues, notwithstanding that, in truth, the evidence entirely points the other way. Perfect looking bacteria may be produced readily enough by gently warming over a spirit-lamp a little blood placed on a glass slide and covered with thin glass. From the red blood corpuscles under these circumstances numerous very narrow-jointed filamentous processes are seen to project, and from their constant vibration and molecular movements these might easily be taken for living bodies, pl. LIV, p. 206, figs. 4, 6. Sometimes they become detached and move about in a manner much resembling certain forms of bacteria. At the same time any one familiar with investigations of this kind would be deceived neither by the general appearance nor by the movements of these bodies. Living bacteria, like other living things, come from germs formed by pre-existing living things, like themselves.

The student will learn many most important facts by watching the germination of the common mildew, and studying the different appearances of the plant when developed under different circumstances, pl. LIV, p. 206, fig. 3. The student should also study the growth and multiplication of yeast-cells in weak syrup, pl. LIII, fig. 4. It is ex-



ceedingly instructive to watch the growth of the spongioles of a young plant (mustard seed, wheat, mignonette, or better, any much smaller seed), as they grow under the thin glass. Fluid may be constantly supplied according to the plan described in p. 77.

The observations of Dr. Drysdale and the Rev. H. Dallinger, published in the "Proceedings of the Royal Society," 1877, and in the "Transactions of the Royal Microscopical Society," should be referred to, and the ingenious arrangements adopted for maintaining an even temperature are especially worthy of study by those who intend to institute original enquiries in this department.

By dint of a little really careful observation the student will soon learn to distinguish purely vital phenomena from mere physical and chemical change, and will be able to judge concerning the value of the arbitrary dicta of those who persist in asserting that phenomena which have nothing whatever in common, are of the same nature and due to the same cause. Would no other conclusions have afforded support to the infallible views proclaimed concerning what has been termed unity?

*Of the Secondary Movements occurring in Living Beings.*

*Ciliary Movement* has been already referred to in pp. 193, 194, and muscular contraction in p. 189.

*Of Molecular Movements.*—When any solid matter in an exceedingly minute state of division is suspended in a limpid fluid, every one of the minute particles is seen to be in a state of active motion or vibration in the neighbourhood of other particles. These molecular movements have often been mistaken for *vital movements*. If some *bacteria* developed in any decomposing water be exposed to a temperature of 200° they are destroyed, but although quite dead, *molecular movements* still occur. If, however, the movements of the dead particles be compared with those of living bacteria, a great difference will be discerned. Probably many movements of particles occurring in cavities in crystals are of the same nature. See p. 235.

*Movements of Granules within Cells.*—The movement of insoluble particles from one part of a cell to another, as occurs in the radiating pigment-cells of batrachia (frog, toad, and newt), is probably due to alterations in the direction of the flow of fluid in the cells,—*from* the cavity of the cell *towards* the tissues, or *from* the surrounding tissue *into* the cell. If the capillaries were fully distended, fluid would permeate the walls of the cells and would pass into their cavity, in which case the insoluble particles would gradually become diffused and would pass into all parts of the cell; while, on the other hand, if the capillaries were reduced in diameter, and the lateral pressure upon their walls diminished, there would be, as is well known, a tendency for the fluid in the surrounding tissue to flow towards the vessels and pass into their in-

Fig. 1.



MOS. 12. Bioplasm and formed material. *a* the sarcolemma, *b* the contractile material. The arrows show the direction in which the masses of bioplasm are supposed to be moving. p. 202.

Fig. 2.



Portion of a fibre of yellow elastic tissue. *Lia mentum nuchæ* Lamb. The mass of bioplasm *a* is moving in the direction of the arrow; behind it the formation of yellow elastic tissue is proceeding. p. 202.

Fig. 3.



Various stages of growth of ordinary mildew. *a*, aerial spores. *b*, smallest germinal particles within these. *b* x, a spore bursting, bioplasm escaping. *c*, a spore enlarged by growth. *d*, a spore sprouting. *e*, an old spore, the formed material of which has much increased. The remaining figures show the mode of growth of the mycelium, and the fructification of the fungus. *p*, *q*, *r*. p. 205. (1859.)

Fig. 4.



Vibratile filaments and minute particles, consisting of viscid coloured matter. Blood corpuscles human subject, after being subjected to heat. Exactly resembling bacteria in appearance. X 1,200. p. 205.

Fig. 5.



Vegetable organisms. *a*, different forms of fungi. *b*, Bacteria. X 215. p. 205.

Fig. 6.



Curious spontaneous changes in form of red blood corpuscles of the frog. X 700. p. 205.



terior. In this case the quantity of fluid in the cells would become gradually reduced, and the insoluble particles would become aggregated together, and would collect in those situations where there was most space, as in the central part of the cell around the bioplasm. Moreover, in the last case, the flow of fluid, which constantly sets towards the bioplasm, would be instrumental in drawing the particles in this same direction, while, if the cell contained a considerable portion of fluid, the currents would pass between the particles without moving them. Evaporation, as it occurs after death, causes concentration of the insoluble particles towards the centre of the cells.

On the other hand, the changes in these pigment-cells of the frog have been considered by Professor Lister to be due to *vital actions*, and he agrees with Wittich and others who believe them to be under the immediate control of the nervous system. *Indirectly*, no doubt they are so, but I do not think that any experiments have proved satisfactorily that the nerves exert any *direct* influence upon the movements of the particles in these cells. It is well known that the nerves govern the calibre of the vessels, and thus influence the amount of fluid in the surrounding tissues, and in this indirect manner nerves may be said to affect the movements of the particles in the cells. The reader will find a full account of Professor Lister's experiments, and the arguments deduced from them, in his paper "On the Cutaneous Pigmentary System of the Frog," published in the "Philosophical Transactions" for 1858.

Some of the most remarkable movements of minute particles in so-called cells are seen in the corpuscles suspended in the saliva and derived from the follicles of the salivary glands. These movements can be seen with a good quarter of an inch object-glass, but to detect the moving particles themselves, an objective that magnifies upwards of five hundred diameters is desirable. I have attempted to give an idea of the appearances seen under a still higher power in pl. XLI, p. 168, fig. 4. The precise nature of these moving particles is unknown. They seem to be solid, and to be very freely moving in a fluid that cannot be viscid. They look very like bacteria germs, but whether they are of this nature and are the agents concerned in effecting the conversion of starch into sugar, as invariably happens if a little solution of starch be held in the mouth for a minute or two, is not certain.

#### ON THE PREPARATION AND EXAMINATION OF MINERALS, ROCKS, AND FOSSILS UNDER THE MICROSCOPE.

The articles under this heading, with the exception of those prepared by Mr. Sorby, F.R.S., have been very kindly given to me by my friend, Mr. Frank Rutley, of the Geological Survey, and will, I am sure, greatly enhance the usefulness of this portion of *How to Work with the Microscope*.

Within the last ten years a considerable amount of work has been done by means of the microscope, in the examination of thin sections of minerals and rocks, but although much has been written on the Continent, and especially in Germany, our own literature upon this subject is still but limited. Some valuable papers upon special branches of research have, it is true, been published in this country, together with one or two of a more general character, but as yet there is no English book upon the subject sufficiently extended to indicate the systematic course of examination which it is essential for the student of petrology to pursue. The few following pages are written rather to point out some of the difficulties which attach to the microscopic study of rocks, than to attempt, in the present imperfect state of our knowledge, to lay down with confidence propositions which may eventually prove erroneous.

The sedimentary rocks, such as *sandstones*, *slates*, *shales*, and *limestones* can easily be identified with the unaided eye, and when a microscopic examination of such rocks is resorted to, it is mainly for the purpose of detecting the presence of minute crystals or fragments of minerals which, in the absence of microscopic scrutiny, would often remain unnoticed, but whose presence may, in some cases, serve as a clue to the source from which the sediment composing the rock was originally derived, while in some instances minute crystals, which have subsequently been developed in the rock, are to be discerned under a high magnifying power.

Microscopic examination of limestones is also useful, inasmuch as many of these are composed, to a considerable extent, of the minute calcareous tests of *foraminifera*, and of other diminutive organisms, and instances occasionally occur in which fragments of sedimentary rocks lie embedded in lavas of various ages, and a determination of the geological horizon to which such organisms may be referred, is often a matter of considerable interest. The remains of the small organisms in limestones may be rendered perceptible under the microscope, either by examination of a surface of the rock by reflected light or by grinding a smooth surface and causing erosion of the rock with a weak acid, so that the organic remains are left in relief; also, by cutting thin sections of the rock and examining them by transmitted light, or, if the limestone be soft and friable, by macerating it in water and separating the small organisms by levigation. *See* p. 100.

It is the examination of eruptive rocks, and of rocks whose original structure has been modified by partial or complete rearrangement of their components by heat, whether derived from the contact or proximity of eruptive masses or from other sources, that will furnish the observer with many facts of great interest, for it is, indeed, scarcely possible to examine a section of any of these rocks without discovering numerous points of striking importance, while the polariscope, p. 220 (besides its value as

an instrument of investigation), displays the objects under conditions so attractive that the observer often feels compelled to copy an object which, if seen by ordinary illumination he would hardly take the trouble to record. On drawing and engraving objects, *see* p. 31.

The information to be given in the next few pages will be most conveniently arranged under the four heads:—i. Requisite Implements and Materials; ii. Hints on the Preparation of Sections; iii. Examination of Minerals; iv. Examination of Rocks.

**264. Requisite Implements and Materials.**—*Microscope.*—A good, strong, steady instrument, with a large stage, will be found most convenient. It should be supplied with a polariscope, the analyser fitting over the eye-piece so that it can be easily removed and replaced. A second analyser to screw above the objective is also useful at times, when good illumination is important or when it is not constantly necessary to remove the analyser. The polarising prism should also be fitted in such a manner that it can easily be removed. It ought to rotate readily under the finger. It is convenient to have the milled edge made rather thick, and it should be sufficiently prominent to be easily found and worked by the hand while the observer's eyes are otherwise occupied. Low power objectives, such as the *two-inch*, *one-and-a-half inch*, and *one-inch*, are the most generally useful for the examination of rock-sections. A higher power than the *quarter-inch* is seldom wanted. Objectives with small angular aperture are to be preferred, as they possess great penetration. The microscope should be provided with a neutral-tint reflector, or with a camera-lucida for drawing the outlines of objects (p. 33, pl. XVII, figs. 4 and 5), while a movable needle fitted in the eye-piece will be found useful for registering points when filling in the details. It is important that the microscope-stage should rotate concentrically.

A *bullseye condenser* or other good means of illuminating opaque objects is also necessary. A shallow metal or pasteboard tray with a hole cut in it serves to protect the stage of the microscope from emery mud and dust when unfinished sections are being examined. An ordinary glass stage-plate with a deep flange will answer the same purpose, p. 72, pl. XXI, fig. 1, p. 76.

A *common pocket-lens* is essential, as by its means minerals may frequently be identified with greater ease and certainty than when viewed under higher magnifying powers. This is especially the case with opaque minerals and those which possess a high metallic lustre.

A *dip lens*. This lens which is figured on pl. LV, p. 212, fig. 1, will be found most convenient for examining hand specimens of rocks, as by its use both hands are left at liberty, the one to hold the specimen and the other to use a graver or knife for scratching and testing the hardness of minerals. The lens should not be of less than an inch in focus.

The spring clip should fit the nose comfortably but firmly. The only care required in its use is to avoid cutting or puncturing the nose when using a knife upon a hard mineral. There is, however, but little risk of this, and the danger may be obviated either by using a sharp hook-shaped point, so that the stroke is made from, instead of towards, the nose, or by employing a lens of longer focus, but one which has about an inch and a-half focal distance is the most useful. This little clip may be improved upon by arranging it so that it will carry various lenses. The one which I first devised was made by Mr. Baker, of Holborn. A watch-maker's loup may be used for the same purpose, but to hold it well in front of the eye by the pressure of the muscles requires some practice.

*Wire gauze spectacles.* When these are not used there is some risk of knocking splinters into the eyes when chipping very hard rocks.

*A knife* with a good hard point for scratching minerals. A pair of large *pliers* for crushing off small fragments of stone. A *magnetic needle* and some *blowpipe apparatus* will also be necessary for the preliminary examination of minerals and rocks.

*A small hammer* with one end square and flat and the other end chisel-shaped is necessary for flaking off chips from rocks and minerals.

A small *cold-chisel* or for very soft rocks a *broad carpenter's chisel* will be found useful. The chips struck off for grinding into sections should be as thin and flat as possible, and it is better to devote a little time to careful chipping, in order to get a thin flake, than to expend much time in grinding down a thick one.

*A grinding lathe.* There are various patterns of machines suitable for grinding sections of rocks. Those worked by a treadle are most generally approved of. Machines of this description devised by Mr. J. B. Jordan, of the "Mining Record" office, are manufactured by Messrs. Cotton and Johnson, Grafton Street, Soho. Small machines, to be worked by hand, are now made in Germany, and may, I believe, be procured of R. Fuess, 46, Wasserthor Strasse, Berlin. Some of the German petrologists prefer to grind their sections by hand upon a cast-iron plate charged with coarse emery, and to finish in the same way upon a plate-glass slab, upon which fine emery is smeared, the whole process being performed without any special mechanical appliance. It is, however, scarcely possible to prepare sections of hard rocks without a suitable machine. In the grinding machines the work is performed either by a revolving leaden disc, which is smeared with emery powder and water, or by a prepared disc made of corundum or emery powder held together by some binding material. The discs or laps have a tendency to wear into hollow ruts, as it is scarcely possible to grind equally over every part of the lap. When these hollows become deep a new face should be turned on the lap, or a fresh one should be cast. The best emery to use on these laps is that known as No. 1. Slitting

discs for sawing thin slices of rock are supplied with these machines. The discs are of iron and the edge of the disc is charged with diamond dust; brick-oil or some other lubricant being used to diminish the friction when cutting. Some skill is, however, needful in order to charge the disc properly. The piece of stone to be ground is to be cemented with Waller's wax or red cement in a small metal cup, and the right degree of pressure must be maintained between the stone and the disc while the operation is being carried on, during which time the constant application of the lubricant is needful. It is, however, much cheaper and always much less troublesome to get slices cut by a lapidary, when slices are really requisite; but, in the majority of cases a good, well-selected chip answers every purpose, except in those cases in which it is necessary to make a section in a given direction through a rock, or parallel to some particular face of a crystal.

*A brass slab* is required upon which to finish the grinding of the sections. This should be perfectly flat. A slab of plate-glass will also answer.

*A small cup* or box with a little scoop or strip of tin or cardboard, for fine flour-emery, should be provided.

*A chuck-bottle.* The construction of this will be understood by reference to pl. LV, p. 212, fig. 5. It is to hold water for moistening the emery on the brass slab.

*Cork forceps.* These are very useful for firmly holding hot slabs of plate-glass. They may easily be made out of a large cork and an old pair of compasses as represented on pl. LV, fig. 6.

*An iron tripod,* and an iron, a brass, or a copper plate to rest on the top. Upon this, plate-glass slabs and slips, &c., are warmed by a Bunsen's gas jet, or by a small spirit-lamp placed beneath. See pl. XXIII, p. 48, fig. 1.

*Watch glasses* for holding turpentine, &c., for baths.

*A crochet needle* (lifting needle) pl. LV, fig. 4, with the hook filed off, or a knitting needle, will be useful for lifting sections from the bath.

*A penknife blade* fixed in a short handle for scraping away Canada balsam, &c., pl. LV, fig. 2.

*A three edged scraper* shaped like fig. 7, pl. LV, is also useful for removing balsam round the edges of covered preparations as it requires to be cleaned less frequently than a single edge.

*A piece of stout wire* (pushing bar) pl. LV, fig. 3, with one end flattened, or a small flat strip of metal, for pushing the section off its slab. This and the lifting needle may be made out of a piece of stout wire about five inches long, one end being sharpened and the other flattened. This small implement will answer perfectly well and will require no handle.

*A writing diamond* for marking slides as soon as the object is covered, and thereby diminishing the risk of any mistake in the labelling of the



section ; useful also in the event of the label becoming detached, pl. XX, p. 54, fig. 8.

*A small pair of forceps.*

*Old Canada balsam ;* the older the better.

*New Canada balsam* in a wide-mouthed, glass-capped bottle with a glass rod for dropping.

*Benzol*, in a stoppered bottle. *Turpentine. Paraffine.*

*Plate-glass slabs*, about  $\frac{1}{4}$  inch thick and 2 inches square. The edges should be roughly ground before they are used. *Ordinary plate-glass slips* 3 inches by 1 inch. *Thin glass covers*, ranging up to  $\frac{7}{8}$  inch diameter.

*Rags and dusters.*

**265. On Making Sections of Rocks and Crystals.\***—Comparatively little can be learned of the structure of rocks and minerals from the examination of fractured surfaces by reflected light. Flat polished surfaces show very much more, but nearly all the important facts can only be observed by examining thin sections by transmitted light. What is really requisite is to have portions sufficiently thin, flat, and smooth to transmit light. In some cases fragments of clear minerals may be broken thin and flat enough to show certain facts very well, when mounted in Canada balsam ; and in this manner we may easily study the fluid-cavities in quartz, or the structure of such rocks as obsidian and pitch-stone. In many cases, however, we must have recourse to carefully prepared thin sections. The details of the method of preparing these must necessarily vary according to the mechanical means at the disposal of each person, and much time may be saved by the use of machinery. I shall, therefore, give such a general account as may be used by any one who has not machinery at command, premising that it will be easy to modify it in detail, according to the facilities which each may possess for employing more expeditious methods.

In collecting specimens for examination, I find it convenient to break off portions from the rock as flat and thin as possible, so that they may be ground down at once ; for otherwise it may be requisite to saw off portions with a lapidary's wheel, or by means of a straight toothless saw of sheet-iron with emery. Having made the specimen of a convenient size and form, with one side flat, this must be ground down perfectly level and dressed off very smooth. I usually avoid using any polishing powder, since, if it were to work into cracks or cavities, it would be far more objectionable than any slight want of polish. If we attempt to grind down the surface on such a stone as should be used to finish off, very much time would be lost, and it is therefore best to use a series of stones of increasing fineness. I have generally used first fine emery on a plate of iron or zinc, then a kind of

\* For the first part of Section 265, as far as p. 214, I have to thank my friend, Mr. H. C. Sorby, F.R.S., who very kindly prepared it specially for this work.

Fig. 1.



Clip lens supported on the nose, so that both hands may be free to work.

Fig. 3.



Fig. 2.



Scraper, in handle

Fig. 4.



Inserting needle made from a crochet needle by bluing of the hook.

Fig. 5.



Fig. 6.



Cork forceps, for holding slips of plate glass, while hot.

Fig. 7.



Scraper for removing Caudata balsam from slides.



stone known by marble workers as "Congleton;" after that a soft piece of Water-of-Ayr stone, and finally finish off on a very hard and fine-grained piece of the same kind. However, since it may be difficult to procure such stones, a flat slab of fine-grained marble, or different kinds of slate may be used. What is wanted is to finish off the surface so as to be free from scratches and almost polished, with the hardest and the softest portions ground down to the same level. If not dressed smooth by slow grinding, the hard portions will stand out in relief; and when the section is finished, the soft parts may be all ground away before the hard are sufficiently thin, and the structure of the rock may be quite misunderstood. Having duly prepared one flat surface, it should be fastened down on a piece of glass with Canada balsam. This should be kept hot until it is so hard as to be just brittle when cold. I find it best to remove, time after time, a small piece, until it has become so hard that when cold, it can be rubbed to powder between the thumb and finger. The piece of stone should be made hot, but no hotter than needful, so that liquid may not be expelled from the fluid-cavities, and balsam should be spread over the flat surface, and kept hot for a while, which penetrates into the softer parts and hardens them. Before fixing the specimens on the glass, it is well to remove this balsam, and fasten it down by that on the glass. I find it much the best to use square pieces of glass. The usual 3-inch by 1 glasses are very unsuitable for the purpose; since they are much too long in one direction, and too short in the other. I use glasses  $1\frac{5}{8}$ -inch square, and generally make sections about 1 inch square, which is a very suitable size. Since the section ought not to be removed from the glass, care should be taken in grinding down not to scratch the glass. This may be avoided by fastening small bits of sheet zinc at each corner with balsam, and grinding the stone with emery until they all come flat down on the plate. The stone is then equally thin all over; and having removed the bits of zinc it must be further ground down on the stones until of the proper thickness, and the upper surface finished off in the manner already described. The thickness must depend very much on the nature of the rock. If coarse-grained and composed of comparatively transparent minerals,  $\frac{1}{100}$ th of an inch may not be too thick, whereas some very fine-grained and opaque rocks should be not above  $\frac{1}{1000}$ th of an inch. Of course it is requisite so to grind them down as not to break up or disturb the different constituents; and, since some parts may be very hard and some very soft, it is impossible to prepare perfect sections unless they are slowly ground down on a fine-grained stone, which may gradually wear away the hardest parts without injuring the softest. After having finished the section I find it often better to keep it some time before I mount over it a thin glass cover, in order that the balsam may become quite hard. I then melt

some balsam at a gentle heat on a thin glass cover of proper size, and just before I place it on, I wet the surface of the section with a drop of turpentine, which soaks into the pores so as to make it more transparent, and renders it much easier to fasten down the glass without any bubbles. This must be done at a very gentle heat, so as not to cause the section to break up by melting the balsam which holds it fast to the glass plate.

Sections of very soft rocks, which would easily break up in water, may be prepared in the same manner by hardening them with balsam. They should be first soaked with turpentine, and then with soft balsam, and kept hot until quite hard.

We may modify the above plan with advantage in preparing sections of such hard minerals as quartz. If ground down with emery and water, deep scratches are produced, and it takes a long time to remove them by means of the softer stones. This may be avoided by using fine emery paper, held flat on a piece of plate glass. After grinding down to nearly the proper thickness with emery and water, common English flour-emery paper may be used, which soon removes the deep scratches; and afterwards the surface may be almost polished by using the finest French emery paper employed in preparing steel plates for engraving; a perfect polish can then be easily given by means of rouge on parchment. Crystals of salts soluble in water may also be ground down and dressed smooth on emery paper, and finally polished with rouge in the same manner; but in many cases they may be examined without this preparation, and may be fastened on glass with balsam. Some are decomposed by contact with balsam, and must be kept dry in small covered cells; others may be mounted in a concentrated solution of the same salt, when it is desirable to retain the liquid enclosed in the fluid-cavities; and when very small they may be mounted in Canada balsam, or, if that be objectionable, in castor oil.

Sometimes the structure of a rock or other mineral substance may be studied to great advantage by grinding it to a suitable shape, moderately thick and flat, fixing one side to glass with balsam, and acting on the other with a dilute acid. If one part is soluble and the other not acted on, some valuable facts may be learned. As an example I refer to the *Eozoon Canadense*, which has lately attracted so much attention. One part consists of carbonate of lime, and the other of siliceous minerals insoluble in diluted acid; and when the former is dissolved a most beautiful and minute structure may be seen, which appears to be due to minute tubes and other open spaces filled with the insoluble minerals.

For the directions on preparing sections which follow, I am indebted to my friend Mr. Frank Rutley, of the Geological Survey, who

has had very great experience in the preparation of specimens, and has been good enough to furnish me with the following notes for this edition of "How to Work with the Microscope."

In removing chips from minerals, for the purpose of procuring sections, the size of the chip must in a great measure depend upon the size of the specimen; and, in the case of small crystals, it is sometimes advisable to cement one of the faces of the crystal to a slab of plate glass, and then carefully to grind down the crystal until a section parallel to that face is procured. The size of chips taken from minerals is also frequently restricted by cleavage planes, and it will be found convenient to split off pieces parallel to different directions of cleavage and to note any differences which such sections may present under the microscope. A pair of cutting pliers with strong jaws will often prove serviceable in removing pieces of mineral without damaging the specimen, as it not unfrequently happens that a sharp blow with a hammer dislodges crystals from, or even destroys, a good specimen. It is, therefore, advisable to avoid the use of the hammer as much as possible when dealing with cabinet specimens of minerals. Cabinet specimens of most *rocks* are, as a rule, rather improved than damaged by a little judicious chipping, especially if the specimens be good-sized ones. Where rocks present any schistose structure or any tendency to cleave in a given direction, it is, of course, easier to procure a thin and useful chip parallel to this direction. It is often interesting to make two or more sections from a rock which possesses a fissile structure: one parallel with the cleavage, the lamination, or foliation, and others in directions more or less at right angles to these planes. Soft rocks often disintegrate very readily during grinding, and it is then impossible at times to procure sections without previously subjecting the chip to a hardening process. Soft rocks may be rendered sufficiently coherent by steeping thin chips of them in a mixture of Canada balsam and benzol, or in a limpid solution of shellac in alcohol. A chip, if first steeped in turpentine and then dipped in Canada balsam and slowly dried, is also frequently rendered sufficiently coherent to yield a good section. Where these methods fail another plan, suggested to me by Mr. John Arthur Phillips, may be had recourse to. This consists in cutting an ordinary glass slip, 3 inches by 1, into three parts. One surface of the chip, previously ground smooth and prepared by one of the above methods, should then be firmly stuck by Canada balsam to the little square of glass, the other side of the glass being also cemented to an ordinary thick plate-glass slab, so that it can be conveniently held during grinding. This treatment obviates the necessity of removing the section from the glass on which it is ground. The square of glass carrying the section should then be removed from the lower slab by gently warming it, and it should next be cemented to an ordinary glass

slip and covered in the usual way. It is, of course, best to procure a section the full size of the little square of glass, but if this cannot be done, the marginal portions of the glass square which usually become scratched and ground, should then be hidden by painting a frame-work of Brunswick black over the disfigured area. In grinding hard rocks (and most eruptive rocks are sufficiently hard to stand the process well) the mode of operation is as follows:—

*Method of Preparing a Section of Hard or Moderately Hard Rock.*—

Select that portion of the specimen which appears most likely to show points of interest. Remove as thin and as broad a flake as possible from that portion of the specimen by a sharp blow with a small dressing hammer or by means of a chisel. Set either the original specimen or its label aside until the first stage of grinding is completed, and a label affixed to the glass slab to which the chip is attached. Take a brush, an inch or more in breadth, dip it in water and then dip it into some No. 1 emery powder: with this smear the leaden lap of the grinding lathe: set the lathe in motion, and then press the chip upon the revolving lap with the thumb and middle finger, or with the forefinger and middle finger. At first the chip will probably be jerked away, but a little practice will soon enable the operator to hold it firmly; as the lap becomes dry re-charge it with more emery and water. Wipe the chip clean and examine it occasionally, and, when a sufficiently good surface is obtained, give it a final wipe, taking especial care that no particles of the coarse emery are left adhering to it.

The next appliance required is the brass grinding plate, or a plate-glass slab about  $6\frac{1}{2}$  by  $4\frac{1}{2}$  inches in diameter. Some of the finest flour-emery should be procured and the chuck-bottle must be filled with water. Some of the emery should be scooped up and laid on the grinding slab and water jerked or chucked on to it from the bottle; the roughly ground surface of the chip of rock should now be placed on the slab and the grinding carried on by hand with a circular motion, the operator taking care to grind equally over every part of the plate. If this precaution be neglected the plate will soon cease to have a true surface and will then be useless. The grinding plate should be placed in a shallow tray of rather larger dimensions, as the emery mud gradually works over the edges of the plate. The chip should from time to time be wiped with a rag which has been kept free from coarse emery, and when a perfectly smooth and flat surface is procured the grinding may be discontinued. The next step is to light a Bunsen's gas jet or a spirit lamp and to place it beneath a metal plate supported by a tripod. Take a plate-glass slab about two inches square and a quarter of an inch or more in thickness (the edges should be roughly ground so that they will not cut the fingers), place it upon the metal plate and lay upon it a crumb or two of old Canada balsam, the older the better. The chip of stone should also be

laid upon the hot plate with its unground surface downwards. As soon as the balsam on the glass slab becomes viscid (it must not be allowed to boil) the chip of stone should be quickly lifted and placed with its smoothly-ground surface on the balsam—the glass slab should be then pushed to the edge of the hot plate, taken up with the cork forceps and placed upon a wooden slab or a piece of thick millboard. The chip should then be firmly pressed down on the glass slab with the ends of the corks on the forceps or with an ordinary wine-cork, and, as soon as the balsam begins to set, the under surface of the slab should be looked through in order to see whether the adhesion of the chip is perfect, if not, any air bubbles may usually be expelled by moving the chip about in a rotatory manner, heavy pressure being applied at the same time. The slab with the chip affixed should then be allowed to remain until quite cold, and a small label or number should be gummed on the back of the slab, and in one corner, so as not to intercept the view of the chip. The original specimen from which the chip was taken, and its label, may then be replaced in the collection. This may be regarded as the completion of the first stage, and the slab with its chip may be put by until a future time, or the second stage of operation may be commenced.

The lap of the grinding lathe is to be again charged with No. 1 emery and water, and as soon as the lathe is set in motion the chip should be pressed upon the lap, the fingers holding the edges of the glass slab. The glass slab should be kept in a horizontal position, or in a position parallel with the surface of the lap. Practice will decide the amount of pressure which may be conveniently imparted by the hands. The labour may sometimes be lightened, if the stroke of the machine be too high, by standing upon a low stool an inch or two in height. The chip should occasionally be wiped with a rag or washed in water to see what progress is being made. As soon as it is ground to about the thickness of a sheet of cardboard or thick note paper the process should be discontinued, the chip and its slab carefully freed from all traces of coarse emery, and grinding upon the brass slab with fine flour emery must be again resorted to. In the very latest stages of grinding a few drops of paraffine will be found serviceable, the section then working more smoothly and with but little friction, and thereby lessening the danger of stripping out small imbedded crystals or of otherwise disintegrating the section. In these later stages the section should be frequently examined under the microscope, being previously wiped, and the upper surface moistened with water or turpentine in order to increase its translucency. The stage of the microscope should, during these examinations, be protected by a small tray with a hole cut in it, the hole corresponding with the aperture in the stage but being less in diameter. A glass stage plate with a deep flange will also answer this purpose.



The ultimate thickness of the section must of course depend upon the translucency of the rock or mineral or upon the points which it may be considered most necessary to elucidate. This may be regarded as the completion of the second stage of operations, and it is often convenient to leave the section in this condition so that reagents may be applied, should any doubt exist as to the nature of the component minerals, &c.

The third and last stage consists in scraping away all hard balsam around the margin of the section and again placing the slab on the hot plate until the balsam which holds the section is quite viscid. While this heating process is going on the following apparatus should be conveniently arranged:—Cork forceps, pushing bar, lifting needle, knife or scraper. A watch-glass, half-full of turpentine and standing in the lid of a pill-box or other support. New Canada balsam, clean glass slip, clean glass cover, small forceps.

When the balsam is perfectly viscid, remove the slab from the hot plate with the cork forceps, holding the forceps firmly in the left hand. Take the pushing bar in the right hand and with it cautiously push or slide the section over the edge of the glass slab into the watch-glass containing the turpentine. This little turpentine bath should then be carefully heated, as by this means the balsam which adheres to the section is perfectly dissolved. A drop of new Canada balsam should next be placed on the glass slip. The section should then be lifted with great care by means of the lifting needle, it being allowed to adhere by one of its flat sides to the side of the needle, and it should be at once transferred to the glass slide and gently let down upon the surface of the balsam. The slide should be slightly warmed, another small patch of balsam placed on the top of the section, again slightly warmed, and the glass cover taken by one edge in the small forceps, passed over the flame to warm it, and allowed to descend gently on the balsam. Pressure may then be applied to the cover to expel the excess of balsam, which may be carefully removed with a knife, and the specimen is ready for examination.

**266. On Measuring the Angles of Crystals—Goniometer.**—I have already adverted to the principal methods of measuring objects, but have not discussed the mode of ascertaining the value of the angles of microscopic crystals in the microscope. The simplest instrument for the purpose is one which was arranged many years ago by Schmidt and known as *Schmidt's goniometer*. It consists of a cobweb stretched across the field of an eye-piece, and capable of being moved by an arm which passes round an accurately graduated arc. The cobweb line is placed parallel to one face of the crystal, the circle being moved round until the bar stands at zero. The latter is then made to rotate until the cobweb is brought parallel with another face. The number of degrees through which the bar has passed marks the angle of the crystal. It is

Fig. 1.



Crystal of nepheline containing a fluid cavity and crystals p. 235.

Fig. 2.



Crystal from the quartz of granite, with a fluid cavity p. 235.

Fig. 3.



Parabolic reflector of Mr. Beck, with Mr. Sorby's flat mirror, M. p. 237.

Fig. 4.

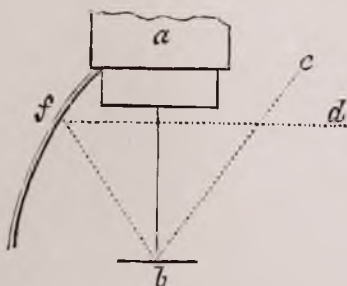
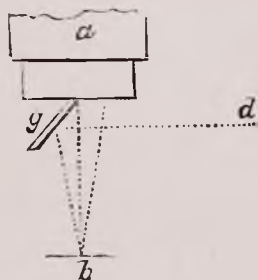
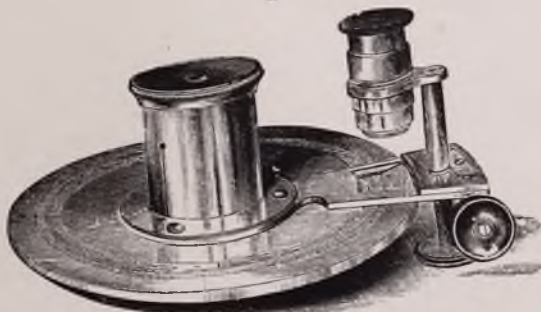


Fig. 5.



Diagrams to illustrate the different methods of illumination by Beck's parabolic reflector, Fig. 4, and Mr. Sorby's flat mirror, Fig. 5. *a*, object glass; *b*, an object; *d*, ray of light; *f*, point of the parabolic reflector at which it is received and from which it is reflected upon the object; *g*, flat mirror which reflects the light perpendicularly upon the object from which it returns to a point within the aperture of the object glass. p. 237.

Fig. 6.



Leeson's eye piece goniometer for measuring the angles of crystals. p. 219.

Fig. 7.



Crystals of cholesterine, consisting of exceedingly thin crystals, some lying perfectly flat. x 215 p. 219

Fig. 8.



Crystals of chloride of sodium, or common salt, in the form of cubes. x 150. p. 219.



absolutely necessary that in taking this measurement the crystal should be perfectly flat, for otherwise a false angle will be obtained. Crystals, some of which are lying perfectly flat while others are more or less tilted on one side, are represented in pl. LVI, figs. 7, 8, p. 218. Dr. Leeson has proposed a more perfect goniometer for measuring the angles of small crystals, which is copied in fig. 6 in the same plate.

Those who devote themselves to mineralogical or crystallographic investigations require special appliances for determining the optical properties of refracting bodies and observing the process of crystallisation in saline solutions, &c. Dr. Lawrence Smith, of Louisville, U.S., designed an instrument specially for such purpose, which he called the "INVERTED MICROSCOPE" ("American Journal of Science," second series, vol. XIV, 1852). The object-glass was placed below the mica, quartz, or glass plate that carried the solution to be crystallised, with the view of protecting the lenses from the corrosive action of acid vapours, especially that of hydro-fluoric acid, which also interfere with the definition of objects under examination. This arrangement was improved upon and more fully developed in its applications by Mr. Highley, who described the "Mineralogist's Microscope," figured in pl. LVII, p. 220, in the "Quarterly Journal of Microscopical Science," vol. IV, p. 281. It may thus be briefly described with the aid of the figs. 1 and 2. The general distribution of parts is shown in the first figure, when the instrument is arranged for ordinary microscopical observations. Fig. 2 displays the same in section arranged for optical investigations, and for measuring the optic axes in crystals.

On a central pivot screwed into a solid circular base rotates a plate that carries the body, prism box P, object-glass, and fine adjustment A: to the side of the base is fixed a square bar G, that carries the principal stage with its coarse adjustment, as well as the secondary stage into which fits the diaphragm, polarising bundle B, selenite plates, &c. A tube screws into the top of bar G, on which slides the mirror. The body slides into a socket attached to the prism box. Within the draw tube are fittings to receive glass tubes for examining with a Leeson's goniometer and minute stop, the amount of rotation in liquids that exhibit circular polarisation.

The prism P, that reflects the image of the object up the axis of the body at a convenient angle for observation, is contained in a solid brass box, on the upper surface of which are screwed the tubes and fine adjustment, A, that carry the object-glass, and one side is removable to allow of the prism being readily taken out and cleaned.

A semicircular arm works up and down the upright bar G, by means of a rack and pinion R, and supports the circular stage S, which for ordinary work is kept in a horizontal position by means of the clamp nut N. The stage has a projecting ring, within which a graduated plate

rotates when optical examinations have to be made: but which is ordinarily fitted with a plain metal plate that rises flush with the top of the axes of the stage. In this instrument the object has to be placed with the glass cover downwards.

A short body replaces the ordinary one for optical examinations; this is fitted with a tourmaline T, and a cell for a plate of calc spar C, when the instrument is to be used as a modification of Professor Kobell's stauroscope for determining crystal systems; and two lenses L L with a Jackson's micrometer M, when the instrument is required for the determination of the optic axis on the principle of Soleil's instrument.

An excellent microscope of good size and of great strength and steadiness and with all the appliances required for mineralogical investigation has been perfected by Messrs. Powell and Lealand, 170, Euston Road.

The Mineralogical Works of Dufrenoy, Delafosse, Descloizeaux, Groth, Naumann, and Grailich, and, for beginners, the little manual on "Mineralogy," by F. Rutley, may be consulted. The works of Zirkel, Rosenbusch, and v. Lasaulx, are most important to the student of micro-petrology.

**267. Of the use of Polarised Light.\***—Polarised light must not be used simply to show structure, or, as is too often the case, merely to show pretty colours, for it is a most searching means of learning the nature and molecular constitutions of the substances under examination. The action of crystals on polarised light as applied to the microscope is due to their double refraction, which depolarises the polarised beam, and gives rise to colours by interference, if the crystal be not too thick in proportion to the intensity of the power of double refraction in the line of vision. This varies much according to the position in which the crystal is cut, and, therefore, in a section of a rock different crystals of the same mineral may give very different results; but still we may often form a good general opinion on the intensity, and may thus distinguish different minerals whose intensity of action varies considerably. But besides this, the intensity, but not the character, of the depolarised light varies according to the position of the crystal in relation to the plane of polarisation of the light. There are two axes at right angles to each other, and when either of them is parallel to the plane of polarisation, the crystal has no depolarising action, and if the polarising and analysing prism are crossed, the field looks black. On rotating either the crystal or the plane of polarisation, the intensity of depolarising action gradually increases, until the axes are inclined to  $45^\circ$ , and then gradually diminishes till the other axis is in the plane of polarisation. If, therefore, we are examining any transparent body, and find that this takes place uniformly over the whole, we know that the whole

\* Section 267 was written by Mr. H. C. Sorby, F.R.S.

The illustrated microscope of the L. Smith, of Kingston Coll., N.Y., p. 99.

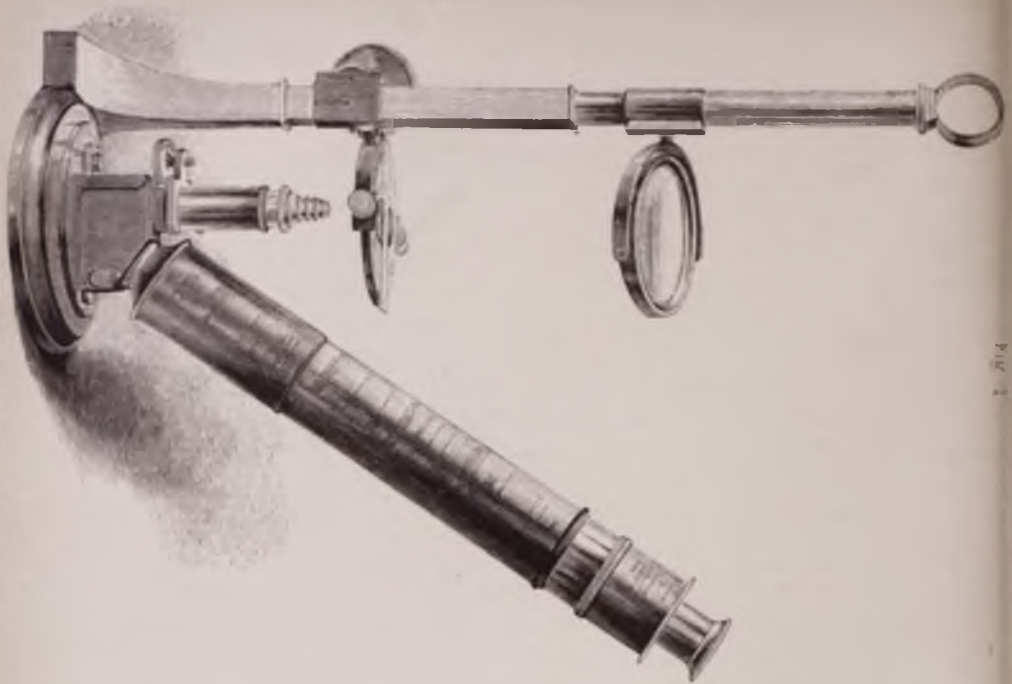


Fig. 1

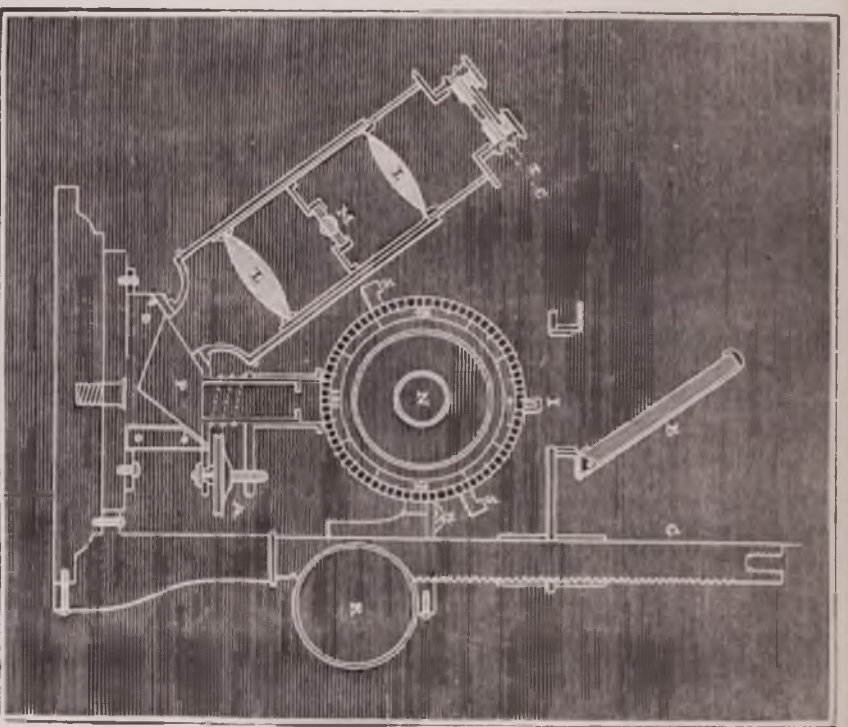


Fig. 2

*Mr. H. B. Scher's arrangement for a histological microscope, for measuring the angles of crystals*  
*is shown in a vertical section. A, the eye-lens; B, the object-lens; C, the stage; D, the slide; E, the slide-holder; F, the slide; G, the stage; H, the slide; I, the slide; J, the slide; K, the slide; L, the slide; M, the slide; N, the slide; O, the slide; P, the slide; Q, the slide; R, the slide; S, the slide; T, the slide.*



has one simple crystalline structure ; whereas, if it appears as it were to break up into detached parts, each of which changes independently, we know that it is made up of a number of separate crystalline portions, either related as twins, or quite independent of each other, as other facts may indicate. By using a plate of selenite of suitable thickness, we may also ascertain in what directions the crystal raises and depresses the tint of colour given by the selenite, and can thus determine the position of the principal axis of the crystal.

As an excellent illustration of the use of these principles, I may refer to the structure of pseudomorphs. We may often see in sections of rocks crystals which are much broken up either by mechanical violence or by incipient decomposition, and it might often be extremely difficult, if not impossible, to distinguish them from other cases where the external form is also that of a perfect crystal, and yet the material completely changed. In the former case polarised light will often show at once that all the different portions are in the same crystalline position, and related to the external form, but in the latter are arranged promiscuously, independent of the external form, or related to it as products of an alteration which extended inwardly from the outer surface or from irregular cracks. Occasionally most important theoretical conclusions depend on such a structure, and it may be almost conclusive proof of the metamorphism of masses of rock when other evidence almost fails.

Then, again, we must examine and bear in mind any definite order that may be found to occur in the arrangement of a number of crystals, since that may indicate important differences. This depends on the fact that crystals have a tendency to form with particular faces perpendicular or parallel to the surface on which they grow, depending partly on the nature of the substance, and partly on the secondary form which may be produced in particular circumstances. Such facts may show, for example, that some round bodies, like oolitic grains, have been formed by the external growth of crystals radiating from a central nucleus, whilst others, like those so common in meteorites, were formed in an entirely different manner, and have the structure of round bodies which crystallised afterwards.

**268. On the Anatomy of Crystals.**—Mr. Sorby well observes that it is the most important for an observer to make himself acquainted with what may be called the anatomy of crystals. Much might be said on this subject, and much remains to be learnt. A crystal in its most perfect state is bounded by definite and perfect planes, and has an uniform and simple structure throughout, as shown by its cleavage or by its optical characters ; but, though the external form may be very simple and perfect, its internal structure may be far from simple. Thin plates or large segments may occur, the material of which is not in the



same crystalline position as the rest, but inclined at different angles, according to the laws of twin crystals; and in some cases this gives rise to very remarkable characters, seen to great advantage in some of the constituents of meteorites. On the contrary, all perfect crystalline planes may be absent, and yet the ultimate structure may be that of a simple and perfect crystal, as shown by cleavage, or by the action of polarised light; and therefore it becomes necessary to understand what terms should be employed to express these facts. Shall we use the term *a* crystal to signify a body bounded by definite planes, which may have a very composite internal structure, or to signify a body of perfectly simple and uniform molecular constitution, which does not happen to have perfect bounding planes? In studying the structure of rocks it appears to me far better to use the term *a* crystal to signify the simplicity of ultimate molecular constitution, and to express the character of the external form by saying whether it is bounded by crystalline planes or by irregular surfaces, independent of the crystalline structure.

If we use this phraseology we may say that each detached plate of the echinoderm is *one* crystal, appearing as if it were made out of one simple crystal of calcite cut into the form and hollowed out into all the complicated structure characteristic of that kind of shell; and as an example of the very opposite fact, I may refer to certain crystals of native phosphate of lime, which have the external planes characteristic of that mineral, and yet are made up of a vast number of much smaller crystals, in no way related to the external form, and not bounded by crystalline planes. Such distinctions are amongst the most important in studying the microscopical structure of rocks, and from such facts the physical history of a rock may be deduced.

**269. Examination of Minerals.**—One very interesting point which has been disclosed by microscopic examination is this:—that minerals, which have been regarded as perfectly homogeneous and which have been analysed as pure specimens, are often seen to contain mineral matter of a different nature. This frequently occurs in the form of definite crystals, which are sometimes irregularly disposed and at others follow certain directions corresponding either with the internal structure or the external configuration of the crystal in which they lie. These little crystals are sometimes so minute that it has not yet been possible to determine the mineral species to which they belong, with anything like precision. Such diminutive and undetermined forms are spoken of as microliths, belonites, trichites, &c. Bodies of this description sometimes occur in the matrix of various rocks, and in some cases, where rocks have undergone absolute fusion, they form dense streams, which are seen to follow more or less tortuous courses through the section, and to sweep around the larger crystals and other impediments which may happen to lie in their path. Such structure is spoken of as

fluxion-structure, and it is not of uncommon occurrence in rocks of a vitreous character; when, however, these microliths become very numerous, the glassy character of the rock diminishes until at last it may become completely devitrified, and cease to exhibit the simple refraction which characterises glassy matter. Microscopic examination of minerals also shows that some of them contain lamellæ and patches of other minerals. This may be well seen in some sections of oligoclase, &c. It frequently happens that the mineral components of a rock exhibit no well developed crystalline forms; under such circumstances optical characters, angles of cleavage, hardness, colour of streak, &c., should be noted; these, in conjunction with the determination of the associated minerals, will often give a clue to the nature of the mineral in question, but at times the use of the blowpipe and chemical reagents becomes necessary, and it is well to determine the nature of a doubtful mineral before the section is mounted, otherwise it may be needful to remove the covering glass, a process which generally entails the re-mounting, and not unfrequently the destruction of a section. Where substances easily soluble in acids are present, it is better to apply the reagent to the section before it is ground very thin. It can then be quickly washed and subsequent grinding will usually remove all traces of the mischief which the reagent has done. The subject of fluid cavities, stone cavities, &c., which occur in some minerals, is treated of by Mr. Sorby, in page 235.

Those who intend to take up the study of petrology should possess a certain knowledge of mineralogy, and especially of the characters of those minerals which most frequently constitute rocks. An acquaintance with the leading characteristics of about a couple of dozen mineral species will enable the observer to work out the mineral composition of a considerable number of rocks, but he should begin by learning to determine hand specimens by the ordinary tests, given in text-books on the subject, before entering upon the microscopic branch of the work, as it is frequently more difficult to determine the nature of a mineral by means of the microscope than by the naked eye, a pocket lens, and a penknife. In work of this kind, we should remember that the microscope is our assistant when unaided vision fails us, and that, by employing that assistance needlessly, we are taxing pains to gain information by a difficult and, it may be, dangerous method.

A description of the simple means of determining ordinary minerals will be found in any good manual or text-book of mineralogy, and, therefore, only the microscopic characters of a few of the more common rock-forming minerals will be given here. Mr. Rutley's "Study of Rocks," published by Longmans and Co., may be consulted.

Among the most important of ordinary minerals are the feldspars; they crystallize in two systems, the *monoclinic* or *oblique*, and the *tri-*

*clinic* or *anorthic*. The former are spoken of as "*orthoclasic*" feldspars, because they possess two directions of cleavage at right angles to one another; the latter are known as "*plagioclastic*," because their cleavages do not form right angles. The crystals of the orthoclasic feldspars are frequently twinned, while those of the plagioclastic feldspars invariably show twinning. Fig. 5, pl. LVIII, represents portion of a crystal of plagioclase, from a rock occurring at Drumfin, in the Isle of Mull, as seen by polarised light. This twinning is often visible to the naked eye, but when viewed by polarised light, under the microscope, the structure is demonstrated by strongly-marked chromatic effects, the twin lamellæ appearing of different colours, which, on revolution of one of the nicols, are succeeded by their complementaries. In the orthoclasic feldspars twinning takes place upon two types, the one called the Carlsbad, the other the Baveno type; the latter is not of common occurrence, especially in microscopic crystals, but the Carlsbad type is constantly to be met with. The plane of composition, in this case, lies parallel to the clino-pinakoid. The diagrams, in fig. 3, pl. LVIII, will sufficiently explain its position.

In sections of microscopic crystals the position of No. 4 in fig. 3, pl. LVIII, is that in which these twins are best shown. Such sections would give the following appearances:—The shaded sides representing one colour, and the unshaded ones another. In crystals of orthoclasic feldspars there is sometimes a peculiar cross-hatched structure visible by polarised light, under the microscope, but its presence is more common in massive specimens than in small crystals. This structure, when developed, is very characteristic of *orthoclase*. These two sets of striæ run parallel to the ortho- and the clino-pinakoids of the crystals, or in the corresponding directions in the massive and cleavable varieties of the mineral. Untwinned crystals of *orthoclase* polarise in sheets of uniform colour when the sections are of equal thickness throughout, but if variable in thickness the tint varies. If the section be so cut that a portion of the crystal forms a wedge, then bands of colour will be seen by polarised light, the colours softening into one another; this, however, is a phenomenon by no means peculiar to orthoclase, but takes place in all doubly refracting wedges, and it is important to distinguish between these blurred bands, and bands which are bounded by sharp and definite margins, such as those which result from twinning, when twinned crystals are viewed by polarised light.

In the *plagioclastic feldspars* numerous twin lamellæ, lying side by side, are seen by polarised light. The twinning in this group of feldspars may take place upon several different types. On that known as the *albite* type re-entering angles, or rather very minute furrows, are caused on the basal planes of the crystal by a repeated hemitropy.

These striæ may even be seen clearly with the naked eye. The

Fig. 1.



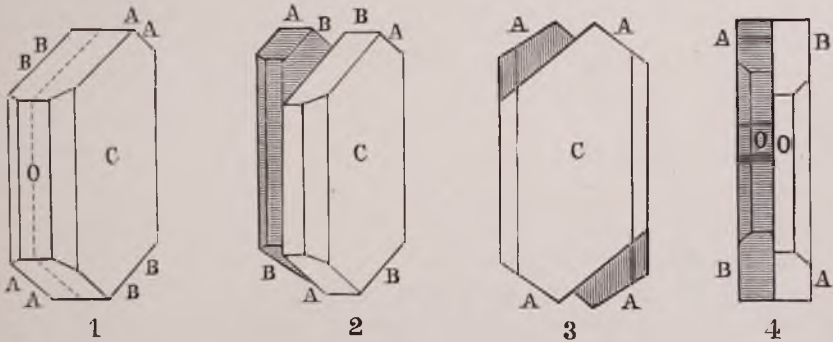
Nepheline of Katzenbuckel, near Heidelberg.

Fig. 2.



Crystal of Quartz in Quartz-porphry, from Dundhu, Arran.

Fig. 3.



Diagrams illustrative of the Carlsbad type of twinning.

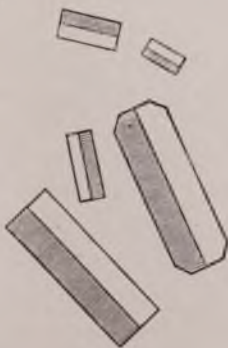
A, Hemidoma.

B, Basal plane.

C, Clinopinakoid.

O, Orthopinakoid.

Fig. 4.



Crystals of Sandstone, twinned on the Carlsbad type.

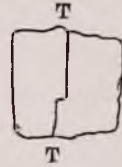
Fig. 5.



Plagioclase from a rock occurring at Drumfin in the Isle of Mull, as seen by polarized light.



bands are often very numerous, and are occasionally seen to end abruptly. The cause of their arrest is not well understood, but I have once or twice met with something of an analogous nature in orthoclastic felspars; the divisional line between the opposite parts of a Carlsbad twin being suddenly stopped, carried on at right angles for a very short distance, and again continued in the original direction, **T T**, as in the polished slice through a crystal of murchisonite, represented about the natural size.



The minerals, *leucite* and *nepheline*, which closely resemble felspars in their composition, crystallise, the one in the tetragonal, the other in the hexagonal system. The polarisation of the former never gives any chromatic effects, but merely bands of neutral tint and of different intensity, while in very minute crystals, such as those which help to form leucitophyr or sperone, there is no perceptible polarisation, the crystals behaving as a singly refracting substance, and becoming dark between crossed nicols. The boundaries of these diminutive leucite crystals are also very often hazy and ill-defined. Interesting inclosures of fluid cavities and crystals often occur within crystals of leucite, and are frequently disposed in a very symmetrical manner, either in a somewhat annular arrangement, according with the exterior boundaries of the crystal, or else in cruciform or, more rarely, radiate patterns. In some cases, long microliths or rods may be observed in leucite crystals, around the ends of which curious finely granular aggregations have formed.

Crystals of nepheline are characterised by sections which, if cut transversely to the longer axis of the crystals, are hexagonal in form, fig. 1, pl. LVIII, p. 224 (from the nephelinite of Katzenbuckel, near Heidelberg). These transverse sections become dark when the Nicol's prisms are crossed. When the crystals are cut parallel to the principal axis the sections result in parallelograms; they usually polarise in rather weak colours.

The foregoing remarks on nepheline are almost equally applicable to the mineral apatite (the crystallized phosphate of lime), but the latter usually occurs in long, often acicular, crystals, while those of nepheline are generally short, thick, and, as a rule, of larger dimensions. Relative size, however, should not be relied upon as a means of discriminating between the two minerals, since crystals of apatite have been found which far exceed in size any known crystal of nepheline. Fluid cavities and inclosures of microliths, crystals, and granular matter, are found both in apatite and nepheline. Apatite crystals are often very unequally distributed in the mass of rock, sometimes forming little colonies. Crystals of quartz, when cut transversely, also give hexagonal sections, but they may usually be distinguished with ease, by the strong colours in which they polarise. They often contain *fluid cavities*, crystals of other

minerals, and sometimes portions of the magma which surrounds them, as in fig. 2, pl. LVIII, which represents a crystal in quartz porphyry, from Dundhu, Arran.

*Calcspar*, which also crystallizes in the hexagonal system, generally polarises in weak colours. When it occurs in thin sections of rocks, filling vesicles or fissures, a well-marked twinning structure is often visible by polarised light, and which is said to occur in directions parallel to the face— $\frac{1}{2}$  R. As a rule, however, it is difficult to make out any definite crystalline forms in these secondarily developed aggregates of calcspar, which, both in veins and in amygdaloids, appear to consist of irregularly shaped patches, the twin lamellæ of the different patches running in various directions. This may be well seen in thin sections of marble.

The minerals *hornblende* and *augite*, both of which crystallize in the monoclinic or oblique system, are of such frequent occurrence in eruptive rocks that it is important for the petrologist to distinguish them when seen in microscopic sections. By ordinary illumination both appear green, the augite usually presenting an exceedingly pale tint. By revolving the lower nicol (polariser) beneath the section, it will usually be found that the hornblende changes to different shades of green or to reddish-brown colours, while augite, except in very thick sections, seldom shows any trace of colour-change (dichroism).

Doubtful cases often occur in which it is very difficult to discriminate between these two minerals, and recourse must then be had to the goniometer if any good transverse sections of the crystals occur, since the angle of the oblique rhombic prism in hornblende very greatly exceeds that which characterises augite. When good transverse sections of the crystals cannot be found, and especially when cleavage is ill-defined and the minerals are much altered, or even represented only by pseudomorphs, it becomes almost impossible to state whether such a rock contains, or originally contained, hornblende or augite, a difficulty out of which the other associated minerals will give us little safe help, paragenesis, in such a case, affording untrustworthy ground for discrimination, since both minerals are sometimes present in the same rock. *Diallage* and *bronzite* show little or no dichroism. The former constitutes one of the principal minerals in the rock known as *gabbro*.

*Schorl*, which sometimes occurs in granite and other rocks, especially near their margins or lines of contact, may generally be known by the almost, or quite, triangular sections which the prisms often present when cut transversely, and by the deep blue colour frequently displayed in thin sections by ordinary transmitted light.

The micas are also very important minerals, since they constitute a considerable proportion of some eruptive masses, both lava flows, dykes, and deep-seated masses. To distinguish the different species with precision, special appliances for examining their optical properties is

often needed. As a rule the dark coloured micas are those rich in magnesia, while the pale silvery ones are mostly potash micas. Micas may be distinguished under the microscope by their six-sided forms when the section lies parallel with the basal plane, and by the parallelograms which result from sections taken more or less transversely to the base, and which show, by fine parallel lines, the laminæ of which the crystal is composed. These sections transverse to the basal planes are usually strongly dichroic. This remark applies also to chlorite, but the strong green colour of the mineral serves to distinguish it from the micas. It frequently happens, however, that chlorite has its crystalline form poorly developed in rocks, often only little irregularly-shaped flecks, scales, and patches are to be discerned under the microscope, while, occasionally, the scales group themselves into fan-shaped aggregates or sheaves. There are many other green minerals more or less allied to chlorite, which, like it, occur as secondary or substitution products in rocks, and the difficulty of distinguishing between them has led microscopists to the adoption of the term "Viridite," which embraces them all and serves as a provisional name, until the different species can be recognized with certainty.

*Epidote* (silicate of alumina, lime, peroxide of iron, and magnesia), which seems very seldom to occur as a normal, but only as a secondary mineral in rocks, generally lines little fissures, or fringes small cavities. The crystals are usually grouped in radial aggregates, have a yellowish green colour, and exhibit considerable dichroism.

*Olivine* is a mineral of not uncommon occurrence in basalts and in a few other eruptive rocks (Lherzolite, &c.). The crystals usually have their angles rounded off, polarise in feeble colours, and frequently contain minute vesicles. Olivine is often partly or entirely replaced by serpentine or other hydrous magnesian silicates, under which circumstances it shows either fringes of altered matter along the margins of the crystals and along fissures in them, or else it exhibits the polysynthetic structure which is so characteristic of pseudomorphs, fig. 2, pl. LIX.

*Hematite* (peroxide of iron) when crystallized (specular iron) is generally of a red or orange colour when seen by ordinary transmitted light. Magnetite ( $\text{FeO}, \text{Fe}_2\text{O}_3$ ), limonite ( $\text{Fe}_2\text{O}_3\text{H}_2\text{O}$ ), and pyrites ( $\text{FeS}_2$ ) are nearly always opaque, and it is necessary to use reflected light in order to discriminate between them. Titaniferous iron is also of frequent occurrence in many rocks. Much of the magnetic iron is titaniferous, but, as a rule, the titaniferous irons give more or less hexagonal outlines, while magnetite generally shows only isometric forms. In some cases, however, long aggregates of octahedra of magnetite occur, and cubes of pyrites are sometimes so disposed as to form elongated rods, by the symmetrical apposition of cubes in straight lines. In addition to the minerals already mentioned, the student should



familiarise himself with many others which are of common occurrence and with the group of the zeolites, which are often present in volcanic rocks. The above is a mere sketch of a few of the principal rock-forming minerals; for further information the reader is referred to Zirkel's "Mikroskopische Beschaffenheit der Mineralien und Gesteine," Rosenbusch's "Mikroskopische Phisographie der Mineralien," and other continental works on Micro-Petrology. Several papers upon these subjects will also be found in the "Quarterly Journal of the Geological Society" (London), "The Memoirs of the Geological Survey" (England), "The Monthly Microscopical Journal," "The Transactions of the Royal Irish Academy," "The Geological Magazine," and the "Popular Science Review."

**270. Microscopical Examination of Rocks.\***—Rocks are aggregates of mineral matter either in an amorphous, cryptocrystalline, or definitely crystallized condition, the component particles or crystals being bound together by a cement or paste, in some cases similar to, in others differing from the individual components of the rock in chemical and physical characters. The object to be attained, therefore, by microscopic examination of thin sections of rocks is to ascertain the precise nature of the minerals which compose them, and to acquire information relative to the state of aggregation of the components, and any physical features of interest which they may present either individually or collectively. Rocks may conveniently be classed as *sedimentary* and *eruptive*.

### *Sedimentary Rocks.*

In the mineral composition of sedimentary rocks we find that from the earliest known, to the latest geological periods, there is little more than a repetition. Yet, although they vary but slightly in chemical composition, regarded qualitatively, and often quantitatively, they differ considerably at times in their physical characters, while the diverse nature of the fossils which they respectively contain, sufficiently point to the very varying conditions of depth under which they were originally deposited, and to changes in the distribution of animal and vegetable life, which have been governed by an almost countless series of changes in the relative distribution of land and water on the surface of the globe.

That the nature or facies of past and present subaqueous life has been, and is, at times considerably influenced by the character of the detritus which has been, or is now being, deposited at the bottom of seas and lakes, there can be little doubt: the colonization, the migration,

\* Sections 269 and 270 have been written by Mr. Frank Rutley for the present edition of this work.

Fig. 1.



Hornblende from Hornblende Schist, Michigan x 50.

Fig. 2.



Olivine from Basalt, Wollbach, near Adorf, Saxony. x 25.

Fig. 3.



Augite from Basalt, Oberbergen, Kaiser Stuhl. x 30.

Fig. 4.



Nepheline from Phonolite Wolf Rock, Cornwall. Long sect x 50.

Fig. 5.



The same as Fig 4 Transverse sect. x 50.

Fig. 6.



Magoclase from Basalt, Cleveland, Yorkshre polished x 25.

Fig. 7.



Titaniferous Iron, from Minette Seifersdorf, Saxony. x 120.

Fig. 11.



Magnesian Mica, from Minette, Saxony x 50.

Fig. 8.



Apatite from Syenite Hemsbach. x 55  
a, section x 110.

Fig. 9.



Magnetite from Felspar, Westmoreland x 50.

Fig. 10.



The same as Fig 9.

Fig. 15.



Hornblende from Phonolite, Eohgäu.

Fig. 12.



The same as Fig. 11. x 55.

Fig. 13.



Chlorite from Quartz, Zillerthal Tyrol. x 120.

Fig. 14.



Fig. 16.



Microtilites (Belonites) in Fichtstone, Arrau.

Fig. 17.



Orthoclase from Felspar, Westmoreland.



or the extinction of the submarine tenantry being closely connected with the nature of their feeding grounds, and with the diminution or increase of the depth between the surface of the water at which those grounds have stood at different times, coupled with other variations of physical conditions which have helped to render certain areas populous or sterile. No one, for example, who has seen strata hundreds of feet in thickness, which are almost or entirely devoid of fossils, and has then met with little narrow beds, belonging, perhaps, to the same series, but in which organic remains are densely crowded, can help feeling that such differences are due to physical changes, many of which are harder to explain than to believe in.

The sedimentary rocks may conveniently be classed as *argillaceous*, *arenaceous*, and *calcareous*. The first embraces mud; indurated mud, or mudstone; mudstone fissile in the direction of bedding, or shale; mudstone fissile in directions other than that of bedding, slate. These may also contain admixtures of free silica or calcareous matter, giving rise to sandy shales, calcareous slates, &c. Rocks of the argillaceous group, when free from such admixtures, consist chemically of hydrated silicate of alumina.

The *arenaceous group* of the sedimentary rocks comprises sands, sandstones, or sands in which the granules of silica are bound together by a cement either of silica, oxides of iron, carbonate of iron, carbonate of lime, &c.; grits in which the grains are coarser (as in the millstone grit), or in which the grains are no longer separable but form a fine-grained compact rock (as in the Denbighshire or Coniston grits), puddingstone and siliceous conglomerates, in which rounded pebbles of silica are imbedded in a matrix either of silica or of some other substance. The rocks of this group may also contain various admixtures of calcareous, argillaceous, and other matter.

The *calcareous group* includes all limestones friable and earthy, as chalk, &c., cryptocrystalline, as in some carboniferous and other limestones, or with a well-developed crystalline structure, as in statuary marbles. These may also contain admixtures of arenaceous or argillaceous matter, so that we may have sandy and argillaceous limestones.

By comparing thin sections of the rocks belonging to these three groups under the microscope, they may afterwards, as a rule, be easily distinguished from one another. By an examination of such sections of slate, it may be seen that the component particles have been re-arranged by pressure with their longest axes in the directions in which cleavage takes place, while in a section of ordinary shale or mudstone, the longer axes of the particles will be seen to follow the planes of lamination or bedding. The polarisation of the quartz granules in sandstones and grits sufficiently serves, as a rule, to distinguish them, while, in the calcareous group of rocks, when they are crystalline the twinning of the component

granules, or imperfectly developed crystals of calcspar, when viewed by polarised light, is usually well marked.

### *Eruptive Rocks.*

The eruptive rocks are generally divided into two groups :—

a. Those which contain over 60 per cent. of silica, and

b. Those which contain under 60 per cent. of silica.

The former have for the most part never reached the surface, or what at the time of their extrusion was the surface, but have solidified beneath more or less considerable masses of superjacent rock, while the latter have, as a rule, actually reached the surface and have often been poured out as lava flows.\* The rocks of the former group are often spoken of as plutonic, in contradistinction to the latter group which are called volcanic. It is, however, evident that the causes which tended to force upwards the rocks of the one, are identical with those which forced up the rocks of the other group; the fact of their reaching the surface, or not, having been governed by circumstances over which the chemical composition of the molten rock had no control, although those circumstances may have modified or changed the chemical, mineralogical, and physical characters of the ejected or pseudo-ejected matter.

Since these remarks are merely intended for the assistance of those who are just entering upon this branch of microscopic study, only a few of the most important rocks will now be dealt with. Among those which contain over 60 per cent. of silica, the *granites*, *syenitic granites*, *syenites*, *quartz porphyries*, and *felstones* are of most common occurrence, as eruptive masses and dykes, which have, as a rule, solidified deep beneath the surface of the earth, while *trachytes* and some of the *pitchstones*, *obsidians*, and *rhyolitic rocks* may be regarded as typical of the superficially extruded matter, or *lavas*, in which a high percentage of silica is present.

In microscopically examining sections of different *granites*, we find the same minerals frequently developed on a small scale, which we are able to identify (often with the naked eye), as occurring in the same rocks on a large scale, but in addition to this, we are at times able to detect the presence of other minerals, which would, from their minute dimensions, remain unnoticed; moreover, by polarised light, the feldspars which help to compose some granites are seen to be partly orthoclase and partly plagioclase. The micas will be readily recognized under the microscope by the foliated structure visible in sections cut transversely or obliquely to the basal plane, while the quartz, which is easy of recognition, will frequently be found to contain other minerals, such as

\* Some rocks which have actually reached the surface and have formed lava flows belong, however, to the first group, such as trachytes, rhyolites, &c.

crystals of *apatite*, mica, &c., together with minute lacunæ, filled sometimes with fluid, in which small bubbles and occasionally little crystals may be detected under moderately high powers. *Magnetite*, *pyrites*, and *titaniferous iron* are also of frequent occurrence in granites, but the number of different minerals which have been observed in rocks of this class, usually occurring in subordinate proportion to the more common components, is so great that an enumeration of them would here be out of place.

*Hornblende* is by no means an uncommon ingredient, and when occurring in tolerable quantity, the rock is spoken of as *syenitic-granite*. When *hornblende* entirely replaces the *mica*, the rock is called *syenite* by some petrologists, while others restrict that name to a rock whose chief components are orthoclase and hornblende. By the naked eye, as well as by means of the microscope, it may be noticed that granites sometimes contain different micas, such as *muscovite*, *biotite*, *lepidolite*, &c. The latter may be known by the red colour which it imparts to the blowpipe flame, while the two former species may usually be distinguished from one another by their difference of colour when seen by ordinary reflected light. It must, however, be borne in mind that there are other magnesia and lithia-containing micas besides biotite and lepidolite, although many of them are not, so far as we know, species of common occurrence.

In the *quartz-porphyrries*, or *elvans*, as they are sometimes called, we find that much of the quartz and felspar which they contain is so intimately mixed, that the matrix or paste of such a rock merely presents the appearance of a finely granular or cryptocrystalline aggregate of these materials, which, by polarised light exhibits, as a rule, a fine mosaic-like appearance, caused by the strong polarisation of the quartz and the less strong polarisation of the felspathic matter, or perhaps of some of the quartz. Such an intimate admixture of *quartz* and *orthoclase* is spoken of as *felsitic matter*, and it constitutes the principal portion of those rocks known as *felstones*, *felsites*, or *eurites*. These are sometimes *porphyritic*, through the development of crystals of *orthoclase*, *mica*, *hornblende*, &c., while the true quartz-porphyrries always contain clearly discernible crystals or rounded grains of quartz, and frequently well-developed crystals of orthoclase, mica, &c. It should be noted that, although separate names are given to the rocks just mentioned, their mineral and qualitative-chemical composition is pretty much the same and in some cases identical. Indeed, we may even trace the passage of *quartz-porphyrries*, or *elvans*, into *granite*, the former rocks usually forming spurs or dykes which have emanated from deep-seated granitic masses. It would appear, then, that these rocks vary rather in physical than in mineralogical or chemical character, and we may, therefore, regard the special names applied to them as indicative

of physical peculiarities, which have been governed by the various conditions under which these rock masses of approximately identical composition have solidified.

*Granulite*, *leptynite*, or *weiss-stein* may be regarded mineralogically as a granite in which the mica is absent, and, indeed, felstone, when free from mica, may be considered as a fine-grained version of granulite. The rock known as *minette* is composed in great part of crystals of magnesian mica imbedded in a felspathic matrix, in which also crystals of orthoclase have sometimes been well formed.

*Kersantite*, a rock typically developed in Brittany, differs from *minette* in the felspathic component being plagioclase instead of *orthoclase*. The whole of the rocks just alluded to have been met with only in the form of bosses, dykes, or intrusive sheets between stratified rocks, and they have never been observed as actual lava flows, but to say that rock masses of such composition have never reached the surface and have never consummated in a lava flow, would be one of those blind perversions of the truth which a forced and unnatural classification too often begets.

The *trachytes* are rocks analogous in composition to some of those of which we have already been speaking, and even though *sandine* be separated from *orthoclase*, and *tridymite* from *quartz*, as distinct mineral species, yet it is impossible to tamper with percentage composition, and it seems probable that in time trachyte will be recognized as the lava emanating from deep-seated granitic masses, and that the terms "*volcanic*" and "*plutonic*" will be regarded as obsolete expressions of measurement, not as those of a fixed and immutable boundary.

Phonolite or clinkstone is a greyish rock composed mainly of sandine and nepheline, together with a little sphene, and sometimes some pyrites. Interesting and well-illustrated papers have been written upon the Saxon phonolites, by Dr. H. Möhl, and on those of Bohemia, by Dr. Em. Boricky, while a description of the phonolite constituting the Wolf Rock, off the coast of Cornwall, by Mr. S. Allport, has been published in the "Geological Magazine." I may add, that the student of volcanic petrology will gain much useful information from a perusal of the papers lately written by Professor J. W. Judd, in the last-mentioned periodical.

*Pitchstone* and *obsidian* are rocks which, although somewhat variable in their chemical composition, approximate at times to *orthoclase*. They are all more or less vitreous in character, the obsidians especially. Rocks, however, of this class are sometimes found in such positions as to show that they belong to very old geological periods, and in such cases it is usual for them no longer to present a vitreous lustre but to appear perfectly dull. Microscopic examination shows that this process of devitrification has been brought about by various physical changes

which the rock has undergone, one of the most frequent of which is the development of microliths in the once glassy magma. It is true that in many, if not in most, pitchstones, microliths, often of very beautiful form, may be seen under the microscope, but in such instances they have no doubt formed during the solidification of the rock, and frequently represent such minerals as augite, hornblende, &c., while the little microliths, which sometimes utterly devitrify pitchstones, are subsequent developments. In the pitchstone from Corriegills, in Arran, beautiful fern-like microliths occur, which have been figured and described by S. Allport, in the "Geological Magazine." Some rocks belonging to this vitreous group are called perlites, from either the pearly lustre which some of them present, or from the fact that they consist of more or less perfectly-formed spherules or concentric shaly structures, which afford very interesting material for microscopic study. These vitreous rocks also frequently contain well-developed crystals of feldspars, micas, &c., and a fluxion texture is often visible in them, its presence being rendered apparent by means of the microliths which sweep through the stone in streams, curving gracefully round any larger included crystals which may happen to lie in their path.

*Pitchstones, obsidians, perlites, &c.*, occur either in dykes or as lava flows. For microscopic examination sections of these rocks should not, as a rule, be cut very thin, since moderately thick sections are sufficiently transparent, and by cutting them extremely thin, included spherules and crystals are often torn out.

Among the basic rocks, or those containing under 60 per cent. of silica, *basalt, diabase, leucitophyr, diorite, and gabbro* may be cited as the most important. The three first occur as lava flows, the two last mostly as intrusive bosses, but dykes of basalt (such as the Great Whin Dyke in the north of England) are by no means uncommon. Those who wish to study the different varieties of basalt in detail, would do well to consult the writings by Dr. H. Möhl, Dr. Em. Bořický, Professor F. Zirkel, Mr. S. Allport, and others. Typical basalt consists of *plagioclase, augite, and magnetite, or titaniferous iron*, but other minerals such as *magnesian mica, nepheline, olivine, &c.*, are often present, sometimes to the exclusion of one or more of the constituents which are considered typical. The *plagioclase* is usually regarded as *labradorite*. In *diabase chlorite* is present, but it is a mineral which has been formed at a period subsequent to the solidification of the rock, and is essentially an alteration-product. Mr. Allport regards *diabase* as a decomposing phase of basalt. The feldspars in the Saxon diabases are stated by J. F. E. Dathe to be *oligoclase*. It yet remains to be seen in how many rocks, hitherto called basalts, the feldspars really are labradorite. Indeed, if we admit that the labradorite may be entirely replaced by nepheline, and the rock may still be allowed to retain the name of basalt (nephe-



line basalt), it seems scarcely fair to deny that name to a similar rock in which oligoclase plays the part of labradorite, nor is this denied by recent writers.

The great difficulty in petrological nomenclature appears to lie in the impossibility of framing a definition for a rock which may vary very largely in the nature of its mineral components. Such definitions are necessary evils, since, in these classifications, we arrange separately a number of links which in nature seem to form an unbroken chain, so that our fanciful and often grotesque arrangement of them is more or less unnatural.

The *diorites* may be defined as rocks composed of *plagioclase*, *hornblende*, and usually *magnetite* and *titanic iron*. *Apatite* is often present and sometimes quartz, in which case the rock is spoken of as a "quartz diorite." *Gabbro* is a name which has borne many different significations, but it is now generally regarded as a mixture of plagioclase and enstatite, or plagioclase and diallage, together with other minerals, such as magnetite, apatite, &c.

The foregoing notes may serve to some extent to guide the beginner in his petrological studies with the microscope. Little or nothing has here been said about the crystalline schists and other metamorphic rocks, since a successful study of them can, as a rule, only be effected when observations upon them are made in the field, and the results compared with those furnished by microscopic and chemical investigation. The drawings in pls. LVIII and LIX, pp. 224, 228, may be of use to the beginner in helping him to recognise some of the more common rock-forming minerals under the microscope.

**271. Crystals of one Mineral enclosed in another.**—The enclosure of crystals of one mineral within another belongs to a long series of interesting facts, which have been fully described in a work specially devoted to the subject.\* Any one who has not examined the microscopical structure of some rocks, would hardly believe the extent to which this occurs. The minerals in erupted lavas are often full of minute crystals, and it is easy to understand why chemical analyses should frequently give such anomalous results. Care must sometimes be taken not to confound such included minerals with cavities. By using polarised light we are generally able to distinguish them, though it must be admitted that transparent crystals having no double refraction might appear very much like cavities *filled* with some liquid. The most satisfactory proof of the presence of actual cavities is the formation of a bubble when the temperature is reduced, but in other cases we should observe whether the enclosed form is that of an independent minute crystal, or very nearly corresponding in shape to that of the larger crystal, as is the case with cavities.

\* Sochting. "Einschlüsse von Mineralen." Freiburg, 1860.

**272. Of the Cavities in Crystals.**—The study of these cavities, remarks Mr. H. C. Sorby, constitutes a very important branch of enquiry, since by studying them we may often learn under what conditions the rock was formed, as I have shown in a paper published some years ago, in the “Quarterly Journal of the Geological Society,” vol. XIV, p. 453. The following is a short abstract of this memoir :

“In this paper the author showed that, when artificial crystals are examined with the microscope, it is seen that they have often caught up and enclosed within their solid substance portions of the material surrounding them at the time when they were being formed. Thus, if they are produced by sublimation, small portions of air or vapour are caught up, so as to form apparently empty cavities ; or, if they are deposited from solution in water, small quantities of water are enclosed, so as to form *fluid-cavities*. In a similar manner, if crystals are formed from a state of igneous fusion, crystallising out from a fused-stone solvent, portions of this fused stone become entangled, which, on cooling, remain in a glassy condition, or become stony, so as to produce what may be called *glass- or stone-cavities*. All these kinds of cavities can readily be seen with suitable magnifying powers, and distinguished from each other by various definite peculiarities. From these and other facts, the following conclusions were deduced :

1. Crystals containing only cavities with water were formed from solution.

2. Crystals containing only stone- or glass-cavities were formed from a state of igneous fusion.

3. Crystals containing both water- and stone- or glass-cavities were formed, under great pressure, by the combined influence of highly heated water and melted rock.

4. That the relative amount of water present in the cavities may, in some cases, be employed to deduce the temperature at which the crystals were formed, since the accompanying vacuity is due to the contraction of the fluid on cooling.

5. Crystals containing only empty cavities were formed by sublimation, unless the cavities are fluid-cavities that have lost their fluid, or are bubbles of gas given off from a substance which was fused.

6. Crystals containing few cavities were formed slowly, in comparison with those of the same material that contain many.

7. Crystals that contain no cavities were formed very slowly, or by the cooling from fusion of a pure, homogeneous substance.”

Independent of their connection with the origin of rocks, these fluid-cavities are very interesting as microscopical objects, since the small bubbles which they contain exhibit *spontaneous molecular movement*. As illustrations of such cavities, the reader is referred to figs. 1, 2, in pl. LVI, p. 218. In fig. 1 is a cavity in a crystal of nepheline, from

one of the ejected blocks of Monte Somma, and shows two different kinds of included substances, *water*—or rather a concentrated saline solution, from which small crystals have been deposited—and a *spherical bubble*. Fig. 2 is from the quartz of granite, with a very small bubble, which moves about freely in the fluid contained in the cavity. It is only when such bubbles are very minute that their movement is decided. When they are less than the  $\frac{1}{20000}$ th inch in diameter, they frequently swim about, as it were, in the liquid, and might be mistaken for minute animalcules. Brown, in a paper printed in 1827, showed that minute solid or even liquid particles contained in another liquid possess a natural molecular movement, quite independent of any currents, and this motion of the bubbles in fluid-cavities appears to me to be in all respects the same, except that the moving body is not a solid particle, but a gaseous globule. See p. 195. As far as I am aware no satisfactory explanation has been given of this curious phenomenon, and I can only suggest that it is in some way related to those molecular movements on which sensible heat appears to depend.

**273. Of the Microscopical Structure of Iron and Steel.**—The microscopical structure of iron and steel is best shown by polished surfaces slightly acted on by very dilute nitric acid. The section should be cut in the required direction by means of a saw, and ground or filed down to a convenient thickness, and fixed to a piece of glass. The upper surface should then be filed level, and dressed with coarser and finer emery paper, and afterwards ground smooth with a bit of soft Water-of-Ayr stone, about  $\frac{1}{4}$ -inch square. Every trace of roughness should then be removed by means of rouge and water on cloth; for unless the surface be extremely well polished the structure of some kinds of iron cannot be seen. It must not be that sort of polish which merely gives a bright reflection, but one which may show all the irregularities of the material, and is as far removed as possible from a burnished surface. All trace of the rouge should be washed off, and care used not to touch the surface with the fingers, which is then acted on with extremely dilute nitric acid. If the action be allowed to proceed too far, the most important points in the structure may be entirely obliterated; and therefore it is well to take the section out of the solution and examine it under water in a glass trough, and again act on it with acid, time after time, until the structure is seen to the greatest advantage. The section must then be well washed and quickly dried by wiping the surface with a handkerchief; and after slightly rubbing it on soft wash-leather, a thin glass cover must be mounted over it with Canada balsam.

Of course such sections must be examined by reflected light. For this purpose no illuminator is better than the parabolic reflectors supplied by Messrs. Beck, which were in fact first made for me, for that

special purpose. I afterwards added another small reflector, inclined at an angle of  $45^\circ$ , attached to a movable arm, so that we may see an object by direct reflection. The general construction will be seen from fig. 3, pl. LVI, p. 218, copied from Mr. Richard Beck's paper in the "Transactions of the Microscopical Society" (vol. XIII, p. 117). The small reflector is seen at *m*, with a semi-cylindrical tube *x*, to shut off the light reflected by the parabola. When the latter is used the small reflector is turned away by means of the milled head *w*, into the position indicated by the dotted lines. The difference between the two illuminations will be seen from figs. 4 and 5. When the parabola is used, light passing from *d* is reflected from *f*, fig. 4, and if the object *b* has a polished surface, is again reflected to *e*, quite outside the object-glass *a*, so that a polished surface appears black, whilst at the same time a rough surface appears white or coloured by diffused reflection. When, however, the small reflector *g*, fig. 5, is half over the object-glass, the light is reflected through the other half of the lens *c*, in such a manner that a polished surface appeared bright, and a rough surface comparatively dark. We can thus distinguish at once the difference between black slag and that very hard constituent of some kinds of steel, which remains so bright and polished after having been acted upon by cold diluted acids, as to look quite as black as the slag by ordinary illumination. In fact, I may say that in studying iron and steel such an illuminator is indispensable.

**274. Of Preparing Fossils for Microscopical Examination.**— Different methods of preparation are required in examining the various fossils. Many kinds of fossil bone and some forms of teeth may be prepared according to the directions given in p. 98. In cases in which silica is present the section must be made as described in p. 216. If very brittle, one surface of a thick section may be ground and polished. This is then to be cemented to the glass slide with Canada balsam, and the opposite side ground until sufficiently thin, when it may be polished in the usual way, wetted with balsam, and covered with thin glass.

Thin chips of flint and other siliceous structures often answer as well as thin sections ground and polished with a great expenditure of labour.

The structure of many fossils, the mineral matter of which consists of carbonates or phosphates, may be investigated after the salts have been dissolved out, or only softened by being soaked for some time in hydrochloric acid diluted with water or mixed with glycerine. Dr. Carpenter gives the following directions for demonstrating the structure of *Eozoon Canadense*:—"The minute structure of *Eozoon* may be determined by the microscopic examination either of thin transparent sections, or of portions which have been subjected to the action of dilute acids, so as to remove the calcareous shell, leaving only the

internal casts, or models, in silex, of the chambers and other cavities, originally occupied by the substance of one animal."

**275. Of Preparing Specimens of Coal for Microscopical Examination.**—Coal is one of the most difficult substances to cut into thin sections. It is so opaque that no structure can be discerned unless it is ground exceedingly thin, and so brittle that it often breaks up in the operation of grinding. It is said that the coal may be softened by maceration in a solution of carbonate of potash, when sections may be cut with a razor. The sections are partially decolorised by being gently heated for a short time in strong nitric acid. When of a brown colour they are to be washed in cold water and preserved in glycerine ("Micrographic Dictionary"). Cannel coal, being less brittle than ordinary coal, is more easily prepared.

THE WORK TABLE—OF MAKING AND RECORDING OBSERVATIONS—  
FALLACIES TO BE GUARDED AGAINST.

*The Work Table.*—Although beautiful work tables, furnished with every possible requirement, have been designed for microscopists, I think the student will find that an ordinary table, which is firm and steady, is all that he really requires. It should, however, be well made and provided with a few drawers, in which the student can place partitions for himself and arrange his instruments and apparatus in the most convenient manner.

The microscope should be always ready for use, and should stand on the table, covered with a glass shade, to protect it from the dust. This is far more convenient than the plan of keeping the instrument in its case, and going through the process of adapting the glasses, &c., and then removing them again, every time the instrument is required.

The object-glasses, eye-pieces, condensers, and other apparatus may be placed in a little cupboard, provided with shelves and having a glass door with lock and key.

Knives and scissors can be kept in a shallow box, having a glass cover. Drawing instruments in a second. Thin glass and glass slides with watch glasses, or little saucers, in a third. These trays should all be properly partitioned, and should be covered with a plate of glass to keep out the dust, and kept ready for use on the work table. A glass of clean water should always stand on the table, and some pipettes, stirring rods, and camel-hair brushes, all perfectly clean, should be provided. The injecting apparatus and instruments which are only required occasionally may be kept in one of the table drawers. A portfolio or pamphlet box is necessary for keeping drawing paper, cardboard, tracing and retracing paper, scales for measuring, small gummed labels for attaching to the slides, &c.

All things really necessary for ordinary microscopic work may be

obtained for two or three pounds, but it is easy, of course, to spend fifty pounds or more upon a microscope table and apparatus. I have myself always made use of an ordinary good strong library table, fitted with drawers underneath, and I think it would have been difficult to contrive anything upon the whole more convenient or better adapted for work. The microscope stands on the table, always ready for use, under a bell jar, and the lamp, fig. 5, pl. XIV, p. 24, with scissors, knives, needles, and other tools in frequent use, close by.

**276. Of Keeping Preparations in the Cabinet.**—Preparations mounted in the dry way, or in Canada balsam, may be kept upright, arranged in grooves, but all preparations mounted in fluid must be allowed to lie perfectly flat, otherwise there will be great danger of leakage. Cabinets, holding several hundred specimens, arranged in this manner may now be purchased of the microscope makers, for a very small sum, but if the observer is provided with deep drawers, they may be made available for the purpose, if a number of shallow trays of millboard are carefully arranged to fit them accurately. Each preparation should be named as soon as it is put up, and it is convenient to keep a number of small gummed labels always at hand for this purpose. Once or twice in the year a new layer of Brunswick black should be applied, and the specimens carefully examined to see that no leakage has occurred. The cases now generally sold are, I think, preferable to cabinets, and of the cases I have seen the most convenient are those suggested by Mr. Piper, and sold by Mr. Swift, Mr. Collins, and others. They are made for two, three, six, and twelve dozen specimens, costing respectively 2s. 6d., 3s. 6d., 5s. 6d., and 10s. Cases made of deal are also arranged on the same plan.

**277. Of making Observations upon Specimens in the Microscope.**—If, upon examination, a specimen does not appear to the observer to justify the description or drawing which some authority has given of a similar structure, he must not too hastily infer that the author has been recording the results of his imagination rather than observed facts. The conclusions which have been arrived at are probably the result of a very long and patient investigation, deduced from examining many specimens, perhaps under very different circumstances, after the application, it may be, of various chemical reagents, and after ascertaining the effect of different refractive media. From the remarks already made, some idea may be formed of the many different operations which are necessary to demonstrate conclusively the anatomy of a single tissue. The beginner must not, therefore, be hasty in deciding as to the exact nature of the object which he sees in the microscope; neither must he infer that what he has not been able to see does not therefore exist. His eye and mind will require much careful education before he can hope to be able to form a correct judgment concerning many things that he will meet with.

Some students are liable to fall into an error of another kind, but not less detrimental to forming habits of correct observation. Led away by their imagination, they think they see everything which has been delineated, or which they have heard described; the observations of authors are confirmed in the most positive manner, and expressions closely resembling those already employed are used by the observer who follows them. But, in fact, an author's own assertions are simply reiterated in favour of his doctrines by a believing follower, and no real confirmation of the accuracy of his views is advanced. In this manner errors have been intensified and propagated to an extent almost incredible, and it will require years of laborious investigation to overthrow statements which indeed never resulted from actual observation, which were erroneous from the first and ought in fact never to have been received. Sometimes a mere guess remarkable for ingenuity and novelty, but having no foundation in fact, is seized upon by a number of persons, and "supported" by so many assertions, misnamed observations, that it is soon received as true, and is perhaps believed in for years, until at last some one reinvestigates the whole question, and demonstrates the absurdity of the received doctrine.

*Of the Importance of making Sketches.*—The great importance of drawing has been already referred to. Even sketches in outline are of great value if the size of the object has been correctly registered. Mere plans are of great use in many cases and supersede the necessity of description. This subject has, however, been fully considered already. See p. 31 to p. 41.

**278. Of Drawing Inferences from Observations.**—No one engaged in the pursuit of any branch of natural science is more tempted to indulge in hasty generalisation than the microscopical observer. It is his duty, therefore, to avoid drawing inferences until he has accumulated a sufficient number of facts to support the conclusions at which he has arrived. True generalisations and correct inferences promote the rapid advancement of scientific knowledge, for each new inference may form the starting-point of a fresh line of investigation; but, on the other hand, every false statement accepted as an observed fact, assists to form a barrier to onward progress. Before the slightest useful advance can be made it will be necessary to go back, it may be for a long way, before we can hope to recommence with any prospect of success the onward course. Moreover, a much greater amount of evidence is always required to overthrow a false conclusion than is sufficient to propagate the original mistake; and there can be no task more unsatisfactory than that of being called upon to controvert the opinions and deductions of others, however desirable and necessary such work may be.

In any special enquiry I think it is a good plan *not* to make too many or very full notes during the progress of the investigation, but to retain in

the memory, as far as may be, the facts observed. When the whole matter is made out, but not before, the observer may begin to write and record his observations. Otherwise, imperfectly observed facts are liable to be set down as actual facts, and afterwards commented upon as if they were well-ascertained truths, and there is danger of the observer being gradually led more and more astray, until at length he commits himself to a conclusion totally at variance with the real truth.

Scientific enquiry should continually advance, and we ought to be able to extend researches from the point where they have been left by our predecessors, each succeeding observer adding to what his predecessors had discovered. In not a few instances must we feel the highest respect for the careful observations of the older observers, and I fear it must be reluctantly confessed, that many modern researches are not carried out with the same patience, painstaking industry, and conscientious care as theirs have been, and for this reason are likely to be but short-lived. Many recent observations strongly insisted upon and advocated with great vehemence, purporting to depend upon actual demonstration, have been set aside for others still more recent, and, if possible, more incorrect. False observation has, as would be supposed, created in some minds complete scepticism of all observation, and has deplorably retarded true progress. It is quite curious to notice how some writers condemn theory and commend what they term the observation of facts, as if it had been incontestably shown that results arrived at from cogitation and speculation must be invariably false, and those from "observation" as invariably true. But any one who has had experience in microscopical enquiry knows how difficult it is to prove that what he discerns is really the thing as it actually is in nature, and not a mere fanciful interpretation of his own. It is easy to assert a particular thing has been observed, but in many cases there is the greatest difference between the thing and what it is supposed has been seen. Many indeed have been the errors introduced by speculative thinkers, but I doubt whether more are not in these days advanced by self-styled practical observers, than by those whom the latter are ever ready to condemn as mere theoretical dreamers. A man says he has seen such and such a thing, and gives drawings of the thing seen. He explains to friends what he has seen, shows them the object in question, tells them what they are to see, and they, knowing nothing about seeing, but not liking to offend their friend, or being too lazy to trouble themselves about the matter, *say* they see the thing as they have been told it is to be seen. Such is the *evidence* which when duly chronicled and printed seems to amount almost to actual proof. But how many, many times has this process been repeated in the case of almost every doubtful anatomical point! The conclusion is almost forced upon the mind that the process of observing facts leads to results at least as unsatisfactory and as fallacious as the process of imagining and specu-



lating without observing at all. At this time what a mass of thoroughly conflicting evidence exists on many important matters, supposed to rest upon scientific observation and experiment! Three or four views are taught concerning first principles of anatomical and physiological science, each one being incompatible with the rest, but nevertheless supported by an immense amount of what purports to be evidence based upon observation. In such a case as this it is obvious that many of the statements must be false, and many of the supposed facts advanced must be errors; and yet with what pertinacity are such erroneous facts maintained, and how widely are they spread, as if indeed they were the most unquestionable truth! What an amount of work must be done, and what a length of time must elapse before false facts can be demonstrated to be really false and true facts proved to be really true!

Years must be passed in patient investigation before a man ought to trust himself as an observer of facts, and it is only by careful and unremitting exercise that any one can gradually acquire habits of attentive observation, and the power of thoughtful discrimination which alone renders his conclusions reliable. Indeed, though he labour hard and earnestly, he will scarcely have properly educated himself ere his powers begin to decay and he becomes liable to err from the natural deterioration in structure of the organs upon which the observation of the facts he observes entirely depends.

**279. Of Recording the Results of Microscopical Observations.**—Taking notes of microscopical observations is a subject of great importance. The observer must endeavour to acquire the habit of describing in words the appearance of objects under the microscope. This is probably not so easy as would at first be supposed, although undoubtedly many persons are able to describe what they see much more correctly, and with greater facility, than others. Accuracy in describing microscopical specimens can only be acquired by practice, and I think it a most excellent rule for a student, when he begins to observe, to take notes of the appearances of every object submitted to examination. The time is well spent, and much of what is so described is retained in the memory. The notes should be short, and should consist of a simple statement of points which have been actually seen. *Inferences* should be carefully avoided, and nothing should be stated without the observer being thoroughly satisfied of its accuracy. If he is not quite certain of any observation, he should express his doubts, or place a note of interrogation after the statement. The use of indefinite terms should be avoided as much as possible, and whenever any particular word is used, a definite meaning should be attached to it. Much confusion has arisen from the use of terms which have not been well defined. For instance, the word "*granule*" has been applied by many authors to a minute particle which appears as a small speck, even when examined

by the highest powers, as well as to a small body with a perfectly clear centre, and with a well-defined sharp outline, which would be more correctly termed a small "*globule*." So, again, the term "*molecule*" has been employed in some cases synonymously with "*granule*," though it would be obviously wrong to speak of a small globule as a molecule. It seems to me very desirable to restrict the terms "*granule*" and "*molecule*" to minute particles of matter which exhibit no *distinct form* when examined by the highest powers at our disposal, and the term "*globule*" to circular or oval bodies of all sizes which have a *clear centre* with a *well-defined dark outline*. Other examples of the use of insufficiently defined terms might be pointed out. If an observer makes use of a term which is generally employed without any definite meaning being attached to it, he should describe at length the meaning which he assigns to it, and should, of course, use it only in this one sense.

*Exactness of Description* should always be aimed at, and we must remember that with a little trouble this exactness may often be obtained with the use of a small number of words. That appearance of precision which is often affected by those who give long useless descriptions of what they have observed cannot be too much condemned. So, also, the practice of some of minutely describing the characters of every object in the field of the microscope without the slightest knowledge of the nature of any one of the objects presented to the view, has been the cause of much ridicule, and has brought microscopic observation into great disrepute. The publication of a very detailed description of a number of not very definite objects, the nature of which is undetermined, though sometimes regarded as evidence of careful and elaborate enquiry, is a most useless procedure. Some have thought to gain the credit of being accurate observers by carefully measuring every object they see in two diameters, and putting down in fractions or decimals the results of this useless ceremony. Such reports may be regarded as indications that the author has been thinking more of himself, and the importance of making an impression upon his readers, than of his subject. He wants to be credited with a character for extreme minuteness of observation, and instead of striving to advance the real interests of the science which he professes to serve, and endeavouring to excite in the mind of the reader a desire for more extended knowledge, and a longing to take part in a similar investigation, he is perpetually endeavouring to thrust himself into notice. He who feels a real love for his subject will try all he can to enlist others in the same service; he will endeavour to remove all difficulties of investigation, and will explain what he himself has learnt in language which shall be intelligible to all. Extreme minuteness in description is by no means an indication of accuracy of observation. Pretence of extreme accuracy has encumbered science with many unnecessary words, and earnest men

have been deterred from its prosecution. A certain mysterious air pervading the description of an observation, an evident desire to coin new words and indulge in statements couched in exaggerated language about the importance of the facts observed, are quite misplaced where all should be clear, simple, and intelligible to every one, and too often indicate indifference to the subject on the part of the author, and a want of proper consideration towards unlearned readers. That affectation of precision, and verbose pompous style of description, which have been fashionable among some microscopists, and which pervade the writings of several authorities in this imperfectly developed branch of investigation, have offended earnest persons who have devoted their lives to the prosecution of different branches of natural science, and have also greatly retarded the real progress of scientific enquiry. All this is but pretence, and not real, earnest, useful work. It is distasteful to every scientific man and discouraging to every student.

*Fallacies to be guarded against in Microscopical Investigation.*

Many mistakes have arisen in consequence of sufficient care not having been taken to prevent the introduction of various substances by accident. The most scrupulous care must always be observed in microscopical examination, and any foreign particles which may have accidentally come into contact with the preparation must be removed before it is mounted. The proceeding to be followed to remove the foreign matter, will depend much upon its nature. Mere dusting with a camel hair brush, washing with a stream of water, or picking out the object with needles, are simple plans which are often efficient in a general way, but in some cases other processes are required.

**280. Errors of Observation.**—It is of the highest importance that the student should do his utmost to avoid making and recording erroneous observations. Not only is the student liable to draw false conclusions from observations, but the observations themselves are frequently erroneous. I propose therefore, to direct the student's attention to a few instances in which difficulty and doubt may be experienced even by skilled and practised observers:—

*Of the Commencement and Termination of Tubes.*—The modes of commencement or termination of certain vessels or tubes have long been sources of dispute among observers. There are not a few instances where positive statements have been made that certain tubes commenced by cæcal or blind extremities; while contradictions equally positive have been advanced by others, who have affirmed that the very same tubes commenced as a network, and presented no blind extremities whatever. It would be generally supposed that such a point might be determined beyond all doubt if the tubes were injected with some

coloured material. But the supposition is not correct. Injection will frequently run up to a particular point in the minute vessels, while no force which can be employed will drive it further onwards. Here, therefore, it accumulates, and often to a very considerable extent; the portion of the tube above the constriction being considerably dilated by the pressure. Under these circumstances, owing to the extreme transparency and delicate nature of the tissue of which its walls are composed, it may be impossible to trace the further continuity of the vessel. Indeed, the vascular walls will probably be quite invisible in an unprepared specimen. The observer is thus led into the error of supposing that such tubes terminate in blind extremities, whereas they may really form a network with large meshes, or they may be continuous with tubular structures of a different character. In fact that which was taken for the termination or commencement of the tube may really be nothing more than a bulging in a central part of its course. In many thin sections of the kidney an appearance as if the tubes terminated in free blind extremities is produced in consequence of the convolutions lying in such a position that the recurved portion is immediately beneath the most superficial part of the tube. From a mere examination of the specimen it would be impossible for any one to say that this was not the case. In such instances the real disposition of the parts is only to be made out by a careful examination of the structure under different kinds of illumination and prepared in various ways. Thus the idea that the tubes end by blind extremities may be shown to be quite inconsistent with the appearances observed in specimens prepared according to a different method. Were I able to devote space to the consideration of this part of my subject, I might review the various methods in which a tissue may be examined, and show how by a consideration and comparison of the different facts observed, one is enabled at length to embody the results arrived at in the course of several different enquiries, and thus gain an accurate conception concerning the real structure of the part.

*On the Difficulty of Seeing Structures from their Transparency.*—Another fallacy arises from the great transparency of certain structures. Oftentimes a membrane may appear perfectly clear and transparent, while in reality it is covered with a delicate layer of epithelium, which only becomes visible when the tissue is immersed in some special fluid or treated with some particular chemical reagent. On the other hand, there are instances in which an appearance resembling that produced by the presence of a cellular investment is perceived where no cells whatever exist. A peculiar corrugated state of uninjected capillaries, and the bioplasts in the walls of the capillary vessels themselves, sometimes give rise to these mistakes. *Basement membrane*, from its extreme delicacy and transparency, is often only recognised by the folds into

which it is thrown, or by the debris and granular matter which is accidentally deposited upon it. Sometimes it becomes visible when immersed in a slightly coloured solution, instead of in perfectly pure water. Not only may blood and lymphatic vessels be completely passed over from their transparency, but I could adduce instances in which broad bands of connective tissue and bundles of nerve fibres existed in a specimen in great numbers, although they could not be seen when the ordinary methods of demonstration were employed.

*Fibres and Membranes Produced by the Action of Reagents artificially.*—On the other hand, by the action of reagents a fibrous appearance is sometimes produced which, without care, may be mistaken for actual structure.

The addition of acetic acid to many preparations frequently produces a swelling of the tissue, with the elevation of a clear membrane-like structure, which might be termed basement membrane, but which has really been produced by the action of the acid. Thus the outer uncalcified portion of the cells of the enamel of a young tooth, may be made to swell up into a transparent mass, which has been mistaken, I think, by Professor Huxley for a membrana performativa, which does not exist in this situation.

*A Fibrous Appearance Produced in Structureless Membranes.*—Clear, transparent, and apparently structureless membranes, when pressed, torn, and twisted, have a fibrous appearance; and delicate vessels, whose coats are perfectly transparent when pressed and collapsed, may be very easily mistaken for a form of fibrous tissue. Both capillaries and fine nerve fibres may be mistaken for fibres of elastic tissue. Indeed, capillaries uninjected and stretched, can only be distinguished from fine nerve fibres with difficulty. If any doubt exist in such a case, it may always be cleared up by injecting the capillaries of the part with a clear transparent material, like plain size, or the transparent injecting fluids, recommended in pp. 106 to 113, when, if the fibrous appearance is not real it will be lost; while if fibres really existed, they would still be visible. The presence of capillary vessels in a structure has been entirely overlooked in consequence of their being collapsed and shrunken, in which state they have been regarded as elements of the connective tissue.

*Collection of Oil Globules Appearing as if within a Cell.*—Oil globules in fluid not uncommonly form small and nearly spherical masses or collections, which become covered with a certain quantity of mucus or viscid matter and granules, originally contained in the fluid, so that the little intervals between the minute oil globules become filled up. The outline of the mass is perfectly clear, and sharp, and well defined, and from mere ocular examination it would be impossible to say that the oil globules were not enclosed in a cell-wall. A consideration of the circumstances under which such structures have been met with, will often

assist us materially in determining their real nature. Such "cells" may be prepared artificially without the least difficulty, and in some cases it would not be possible to distinguish by microscopical examination in water the artificially formed *cell* from the natural *cell*; and the process of staining the bioplasm, p. 123, would only enable us to form a positive conclusion in cases in which it was certain that the natural cells were quite fresh. It need scarcely be said, however, that with respect to the *formation* of these bodies no analogy whatever obtains in the two cases. Of the artificial cell the most external part was *last formed*. It was deposited around a collection of particles. But in the natural cell the outer part is the *oldest part*. It was produced *before* the matter in the central part of the cell was formed. No one at this time maintains that living cells are formed by the aggregation of granules, though some seem to think that a bacterium may be formed by the coalescence of already existing particles. Such persons must admit, however, that such simple organisms *multiply* by division, and thus they seem to affirm that living things may be produced by the coalescence of separate lifeless particles, and that they increase and multiply by the division of the resulting mass. It need, however, scarcely be stated that facts now known render such a doctrine untenable. See a controversy upon this subject in the "British Medical Journal," January, February, March, 1864.

*On the Accidental Presence of Extraneous Matters.*—Cleanliness is of the utmost importance in every branch of microscopical enquiry, and without great care many substances of extraneous origin will be introduced into the specimen about to be examined, and the observer may mistake the character of the objects accidentally introduced for those of the special objects under examination. For instance, particles of starch or other solid bodies may gain entrance into a texture submitted to microscopical examination, and the observer may draw the very erroneous inference that these bodies were embedded in the substance of the tissue, and that they were developed and grew in this situation.

When we consider how very minute are many of the structures rendered evident to the eye by the microscope, we shall scarcely wonder that many light substances are liable to come in contact with the specimen which is under examination. The cotton or flax fibres from the cloth, starch globules which adhere to the thin glass circles (for the small pieces are often kept in starch), portions of feathers, various kinds of hair, and oil globules are among the substances which are most frequently met with in examining different specimens, and I need hardly say, that their presence is purely accidental. That I am not advocating needless precaution, is shown by the fact that in a well-known and highly valuable publication printed a few years ago, a drawing of what was evidently a portion of feathers was described as a representation of

*lymphatic vessels*,—vegetable hairs were described as *nerve fibres*, and several other errors equally unpardonable were to be found. Now, such mistakes could only be made by a person utterly ignorant of the characters of some of the commonest objects with which every microscopical observer ought to be thoroughly familiar. I would strongly recommend every one to carefully study the characters of the substances of extraneous origin enumerated below before he attempts to make any original observations. He is sure to meet with the bodies in question from time to time, and the sooner he becomes well acquainted with their characters the better.

The following should be very carefully examined :—

Oil globules, milk, pl. XXIII, p. 80, figs. 11, 12, 13, 14.

Potato, wheat, and rice, starch; and bread crumbs, pl. XLVI, p. 172, figs. 1, 2, 3, 4, and pl. LX, fig. 3.

Portions of feather; worsted, pl. LX, fig. 3.

Fibres of flax; cotton, pl. LX, fig. 3, *e*; and silk of different colours.

Human hair, cat's hair, hair from blankets, fig. 3, *a, b, c*.

The scales of butterflies and moths, particularly those of the common clothes moth, pl. LX, figs. 1, 2.

Fibres of wood swept from the floor, fig. 4, fragments of tea-leaves, hairs from plants, vegetable cellular tissue, and spiral vessels, pl. XLVI, p. 172, fig. 5.

Particles of sand.

Many of these extraneous substances are figured in the plates I have referred to, and I beg the student will not only examine my drawings, but place actual specimens of all objects delineated under his own microscope.

In the examination of deposits from fluid we must bear in mind the possibility of the introduction of a small quantity of one deposit into another carried upon the extremity of the pipette used for examination, and in this simple manner much difficulty and confusion may be caused to the microscopist. The pipette should therefore be well washed immediately after it has been used, and the water in which it is washed should be very frequently changed. In taking fluids from different bottles and other vessels the possibility of introducing various substances must be borne in mind.

Fig. 1.



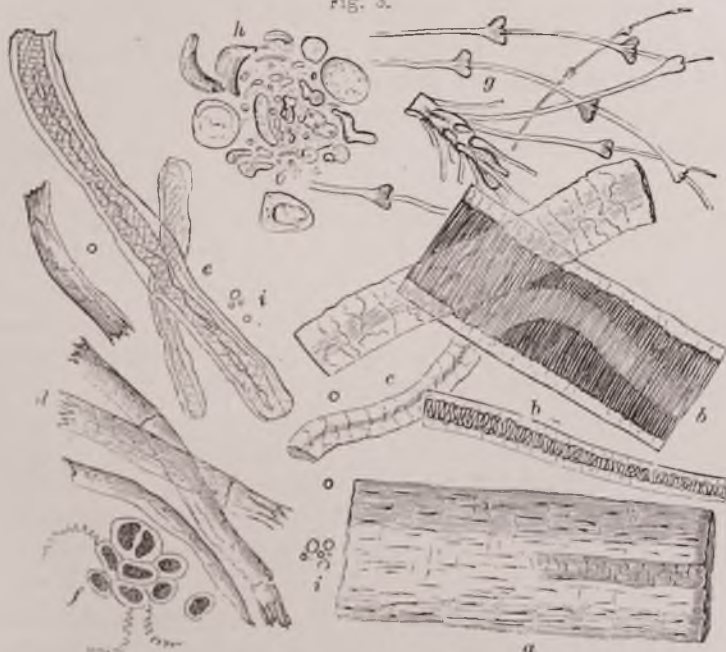
Scales from the wings of the common clothes moth. x 215.

Fig. 2.



Scales from the wings of the common clothes moth. x 500.

Fig. 3.



a. fragments of human hair b. cat's hair. c. hair from blanket. d. fibres of flax. e. fibres of cotton. f. fragments of tea-leaves. g. portions of feather. h. bread crumbs. i. free oil globules.

Fig. 4.



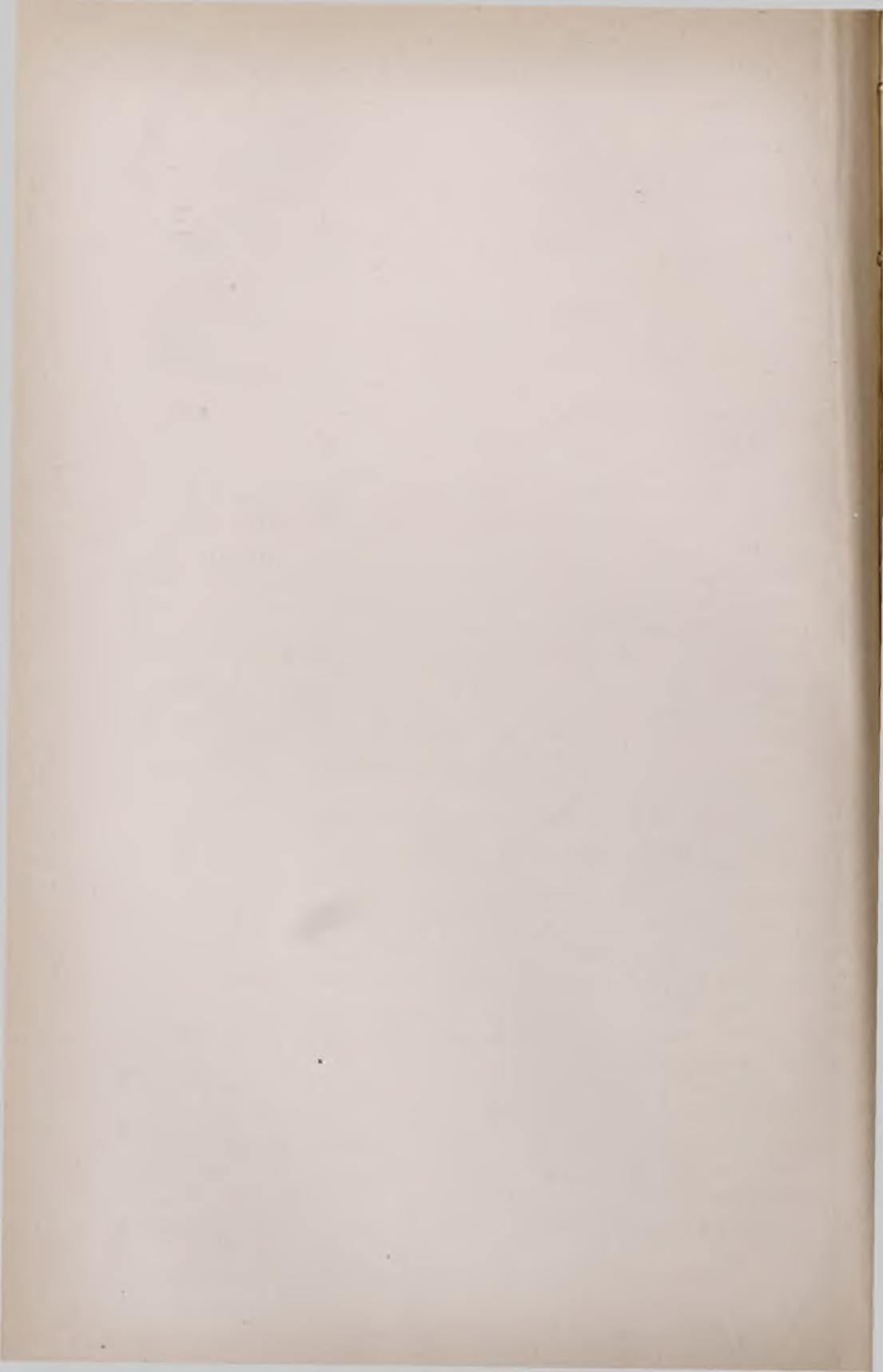
Fibres of deal wood swept from the floor x 215.

Fig. 5.



Particles of 'dust' removed from a ledge in a dwelling-room, consisting of particles of carbon, soot, starch granules, fibres of worsted. x 215.





## PART IV.

OF CHEMICAL ANALYSIS APPLIED TO MICROSCOPICAL INVESTIGATION—  
OF OBTAINING CRYSTALLINE SUBSTANCES—OF THE MICRO-SPECTRO-  
SCOPE AND OF MICROSCOPIC ANALYSIS.

OF THE ADVANTAGES OF CHEMICAL REAGENTS IN MICROSCOPICAL  
INVESTIGATION.

**Of Chemical Analysis in Microscopical Investigation.**—I have already referred to the influence which the refractive power of the medium in which any structure is immersed exerts upon its appearance in the microscope. We have now to discuss the advantages derived from the action of certain chemical reagents upon various specimens. This part of the subject is most important, and it is perhaps of all the various branches of microscopical research, that from which the greatest advantages may be expected to result. It is an investigation which will well reward all who earnestly devote themselves to its study. It is certain that great changes will take place in our views of the nature of many minute structures when chemical analysis shall be more intimately associated with microscopical enquiry.

Although by the microscope we can say that such a texture is granular, fibrous, opaque, perfectly clear, &c., we learn in such an examination nothing more of its nature. Since these appearances are manifested by several different materials, it is necessary to resort to a chemical examination to discover the nature of the substance to which the microscopical characters are due. If the chemical composition of any body having well-defined microscopical characters has been once made out, by resorting simply to microscopical examination, we shall be enabled to recognise it whenever we meet with it afterwards, without making a chemical analysis.

Some bodies always produce well-recognised crystals when treated with a certain chemical reagent, and we know that, although there may be in nature other crystals of a different composition, but of precisely the same form, these latter could not be produced under the same circumstances as the former; hence, in such a case we may feel as confident of the nature of the substance as if an ultimate analysis had been made of it.

Besides the ordinary uses to which they are applied, chemical re-

agents are useful in removing certain components of a structure which interfere with the demonstration of other constituents, in altering the character of certain tissues without dissolving them, as for instance by increasing their transparency or opacity, or in modifying the physical structure of textures in such a manner as to render it more convenient to cut sections or to perform other chemical operations necessary for the demonstration of their structure.

By an acquaintance with the behaviour of certain substances with particular chemical reagents, and the application of this knowledge to microscopical investigation, we are often enabled to distinguish peculiarities of structure, to ascertain the chemical composition of minute quantities of matter, and to demonstrate clearly the existence of compounds with the greatest certainty, which would entirely escape our observation if we subjected them separately to the most careful chemical analysis, or to the most searching microscopical scrutiny.

The application of chemical analysis to microscopical investigation, and the examination of crystalline forms in the microscope, have thrown a new light upon the nature of many physiological changes which are constantly taking place in living bodies in health, and have enabled us to investigate more satisfactorily the modifications which these processes undergo when influenced by circumstances interfering with or counter-acting healthy actions.

**281. Instances of the Use of Reagents.**—As an instance of the great advantage of the application of a few simple tests to microscopical investigation, I may refer to the different effects of ether upon fat globules (which are so commonly found in different tissues) and crystalline bodies composed of phosphate or carbonate of lime, which sometimes so nearly resemble fat globules in refractive properties, in form, and in general appearance, that mistakes have been often made concerning their composition. The application of a drop of ether has no effect whatever upon the salt, but dissolves the fat. Phosphate of lime is readily soluble in dilute acids, while fat is not acted upon by these reagents. Various insoluble saline materials not unfrequently prevent us from seeing the anatomical elements of which a tissue is composed. A knowledge of the nature of these often enables us to remove them. Suppose, for instance, the saline matter consists of carbonates or phosphates of lime or magnesia, we have only to add a drop of dilute acid to dissolve them completely and make the tissue sufficiently transparent to enable us to examine its structure.

The action of acids and alkalis is often very valuable in rendering structures transparent, which are too opaque for examination in the ordinary state. If a portion of tendon, composed of white fibrous tissue, pl. XXXII, p. 138, fig. 3, which is very opaque in its ordinary state, be immersed in acetic acid, or in a dilute solution of potash or soda, it soon

becomes clear and transparent. If the operation be conducted with certain precautions, many of its original characters may be brought back by subsequently neutralising the acetic acid with an alkali.

The cell-wall, or rather the outer part of the cell, which is in many cases too opaque to enable us to see the bioplast or nucleus in the interior, may be made by reagents so very transparent that the bioplast becomes very distinct and well defined. This change may be easily effected by either of the reagents alluded to in the last paragraph. Albuminous textures generally may often be rendered very transparent by the action of acetic acid, or by the addition of a drop of dilute caustic potash or soda.

### *Preliminary Operations.*

In the first place we should note carefully the general characters which the substance exhibits; its form, colour, size, weight, hardness, &c.; and fluidity, transparency, tenacity, &c., in the case of liquids. Portions of solid textures and the deposit from fluids must be subjected to microscopical examination, but their reaction should be always ascertained in the first instance.

**282. Reaction.**—The reaction of any moist substance is found out by testing it with a piece of blue, and reddened, litmus paper. If the matter be dry, or the reaction of a vapour is to be tested, the paper must be first moistened with a drop of distilled water. The *blue litmus paper* is *reddened* by *acids*, and the *red paper* is turned *blue* by *alkalies*. The reddened litmus paper is prepared by adding a very small quantity of acetic acid to the infusion of litmus into which it is to be dipped.

If an *acid reaction* is due to the presence of carbonic acid, the blue colour will be restored upon gently warming the paper upon a glass slide over a lamp, or upon a warm plate.

An *alkaline reaction* may depend upon the presence of *volatile* or *fixed alkali*. The red colour is restored upon warming the paper which has been rendered blue by the presence of volatile alkali (ammonia or carbonate of ammonia), while it is not restored if the change is produced by the presence of a fixed alkali (potash, soda, or their carbonates, or an alkaline phosphate, &c.).

The reaction of some objects under the microscope may be ascertained by adding a little solution of litmus or of litmus slightly reddened by the addition of a trace of acetic acid, according as the reaction is supposed to be acid or alkaline.

**283. On Filtering.**—The process of filtration is one which the microscopist as well as the chemist frequently has to perform. To filter a deposit from a solution, in quantity, is easily effected by the use of ordinary filtering paper, folded, pl. XXVI, p. 100, fig. 9, and placed in

a small glass funnel, fig. 1 in the same plate. But sometimes we find it necessary, in microscopical analysis, to filter the deposit from a single drop of fluid. This may be effected by cutting a very narrow strip of filtering paper, and bending it into a V-form, upon one of the glass slides. The drop is made to pass between the limbs of the V, and upon inclining the slide, clear fluid will gradually pass through the apex of the V, and can be conducted away to another part of the slide, by a very fine glass rod, where other tests may be applied.

**284. Evaporation and Drying.**—The evaporation of fluids, and the desiccation of organic solids, must always be conducted over a water-bath, otherwise there is great danger of decomposition occurring. For operations upon small quantities, the water-bath represented in pl. XVIII, p. 48, figs. 6, 7, will suffice, or the cans of the injecting apparatus, pl. XXVII, p. 104, fig. 6, may be removed, and basins placed over the holes.

In endeavouring to obtain crystals of organic substances, it is always advantageous to evaporate the solution over the surface of sulphuric acid under a bell-jar, pl. XXIV, fig. 5, or, what is better still, in vacuo, in an air-pump, pl. XXIV, p. 88, fig. 3, pl. XXV, p. 92, fig. 5. In some instances, the evaporation may be conducted by simply exposing the liquid, placed in a basin or watch-glass, and covered lightly with paper, to the air; or, where very slow evaporation is necessary, the watch-glass may be covered over with a bell-glass.

**285. Incineration.**—By incinerating a small portion of any organic substance, upon a piece of platinum foil, or in a platinum or porcelain crucible, we are enabled to ascertain whether it contains inorganic salts, or consists entirely of organic matter, in which case the substance leaves only a black residue, which burns off entirely after a short time. In order to obtain the inorganic constituents perfectly free from carbon, it is sometimes necessary to keep the mass at a dull red heat for an hour or more. The addition of a drop of nitric acid causes the rapid oxidation of the carbon. If, however, the temperature be too high, the process may be much retarded, in consequence of the fusion of some of the salts, as the phosphates and chlorides, and the inclusion of small masses of carbon, which are thus protected from the oxidising action of the atmosphere. The platinum basin or foil may be supported over the lamp upon coarse wire gauze or upon a piece of wire, bent in the form of a triangle, or upon one of the small rings attached to the spirit-lamp, pl. XVIII, p. 48, fig. 4. It may be removed from the lamp with the aid of an old pair of forceps.

**286. Apparatus.**—The chemical apparatus necessary for the microscopical observer is very simple, and the greater number of instruments have already been referred to. The following are among the most important pieces of apparatus:—

A few conical glasses of different sizes. Apparatus for taking specific gravities. Test-tubes of various sizes, arranged on a stand, pl. LXI, p. 262, fig. 5. Spirit-lamps, with various supports, pl. XVIII, p. 48, fig. 3, or, where gas is laid on, the gas-lamp, pl. XIV, p. 24, fig. 4. Glass funnels and filtering paper, pl. XXVI, figs. 1, 9, small porcelain basins, watch-glasses; a simple water-bath, pl. XVIII, figs. 6, 7, or the injecting can, pl. XXVII, p. 104, fig. 6, may be used, if several evaporations are to be conducted at once. A small platinum capsule, a strip of platinum foil, a blow-pipe, pipettes, pl. XXVI, p. 100, figs. 2, 3, and glass stirring rods, with a box of reagents in small bottles, pl. LXI, p. 262, figs. 2, 7, and test papers, complete the apparatus. All these may be obtained, packed in a box of convenient size, fig. 7.

**287. Microscope for Examining Substances Immersed in Acids and Corrosive Fluids.**—If preparations which require to be immersed in strong acid, be examined in the ordinary microscope, the fumes may injure the brass work of the instrument. Considerable inconvenience is also experienced in examining fluids while hot, in consequence of the vapour rising and condensing upon the object-glass, and thus rendering the object invisible. The ingenious microscope invented some years ago by Dr. Lawrence Smith, obviates these objections. This inverted microscope has been described in p. 219, and is represented in pl. LIX, p. 220, fig. 1.

#### REAGENTS AND THEIR ACTION.

The reagents necessary for the microscopist are not very numerous. They should be perfectly pure. Of the greater number only very little is required,—as much as may be kept in drachm or two drachm bottles; but of alcohol, ether, and one or two more, it is necessary to have a half-pint or more. The stock reagents should be kept in stoppered bottles of about the capacity of two ounces.

**288. Distilled Water** should alone be employed for dissolving substances to be tested, and for diluting fluids required by the microscopical observer.

**289. Alcohol.**—Alcohol of different strengths will be required for the purpose of dissolving certain substances, and for separating them from other constituents, which are insoluble in this reagent. If a weak alcohol is required, the strong spirit should always be diluted with distilled water, and it is better to prepare a considerable quantity at a time. It is convenient to have two or three bottles which will hold about two quarts each. The strength of each should be written upon a label attached to the bottle. The importance of alcohol as a preservative solution has been referred to in p. 64.

**290. Ether, Chloroform.**—An ounce or two of ether will be quite

sufficient for microscopical purposes. It should be kept in a stoppered bottle, provided with a glass cap, to prevent loss by evaporation. A little should also be kept in one of the small glass bottles with capillary orifices, p. 260, for the convenience of applying to cells containing highly refracting globules, resembling oil, &c., under the microscope. Chloroform must be kept in capped and stoppered bottles, carefully protected from the light.

**291. Effects of Alcohol and Ether.**—Alcohol coagulates albuminous matters. Bioplasm is always rendered granular by this reagent. Many transparent tissues are corrugated, and rendered more or less opaque by alcohol. It dissolves certain forms of fatty matter, resinous materials, and many kinds of vegetable and animal colouring matter.

Ether is of great use for dissolving various kinds of fatty matter. In many cases, however (as, for example, in common milk), the oil globule is covered with a caseous or albuminous investment, which protects it from the action of the ether. In this case it is necessary to add a drop of acetic acid, or solution of potash or soda, to dissolve the membrane, when the ether will at once act upon the fat.

Chloroform is a valuable fluid for dissolving Canada balsam, p. 57.

**292. Nitric Acid** of two different degrees of concentration should be kept, the strongest that can be procured, and a solution containing about twenty per cent. of the strong acid. This last is the acid most used by the microscopist. It may be prepared by mixing one part of the strong commercial acid with five parts of distilled water.

**293. Sulphuric Acid** is sometimes required undiluted, but a small bottle of diluted acid (one of acid to five of water) should also be at hand. The pure colourless acid should always be procured; it is to be purchased for about 1s. 6d. a pound, but only very small quantities are required.

**294. Hydrochloric Acid** may be obtained perfectly colourless. It should be kept in the pure state and diluted as required.

**295. Acetic Acid.**—Two specimens of acetic acid will be found convenient. One, a solution of the strongest acid which can be procured; the other, containing about twenty per cent. The last is prepared by dissolving one part of the strongest liquid acid, or of the pure *glacial acetic acid*, in five of water. The *glacial acetic acid* is now commonly employed for photographic purposes, and can, therefore, be very readily obtained. It possesses great advantages over other kinds of acid for microscopical purposes.

**296. Chromic Acid** is usually required very dilute. For the purposes of hardening tissues a watery solution of a straw colour will be found strong enough. It is easily prepared by dissolving a little of the crystallised chromic acid in distilled water. See p. 67.

**297. Effects of Acids on Organic Structures.**—The effects of the

application of cold strong acids to animal textures are very variable ; in some instances the tissue is completely destroyed, while in others scarcely any effect seems to be produced. The *mineral acids* generally coagulate albuminous tissues, and render their microscopical characters confused and indistinct. *Tribasic phosphoric acid*, however, is an exception to this. *Acetic acid* dissolves many of the substances allied to albumen.

The appearance of some textures is scarcely altered by the application of a strong acid ; for instance, the blood corpuscles shrink a little, but exhibit their usual form and general characters for some time after the addition of strong nitric acid, and the cells of the epidermis and nail, although turned of a yellow colour, are not destroyed ; the latter are separated somewhat from each other, and their outline is often made beautifully distinct. Most of the mineral constituents of the body, insoluble in water, are directly dissolved by the acids. Strong nitric acid is a useful reagent for demonstrating vegetable cellular structures.

*Acetic Acid.*—Acetic acid is one of the most useful reagents to the microscopical observer. It has the property of dissolving granular matter composed of albuminous material, and of causing the cell-wall and many kinds of formed material to become very transparent ; although it often renders the bioplasm darker and more distinct. In many instances the action of the acid upon the cell-wall is curious. This formed material becomes more pulpy and thicker, and approaches in tenuity and refracting power the solution in which it is immersed. In numerous instances, by adding a saline solution to cells which have been previously rendered transparent by acetic acid, they again contract, and the outline becomes distinct. In some cases, however, the outer part of the cells is actually dissolved by the acid, and the bioplasm is set free. Acetic acid is very frequently used to make epithelial structures transparent, in order that the arrangement of the minute vessels and nerves in papillæ, &c., may be demonstrated, as in the case of the tongue, skin, &c. Sections of preparations which have been hardened by maceration in alcohol, may require to be boiled slightly in acetic acid to render them transparent. The action of acetic acid on white fibrous tissue is very characteristic, as it converts it into a transparent jelly-like mass, in which a few bioplasts are visible. Upon the yellow element, on the other hand, this reagent exerts no action whatever.

Acetic acid may also be employed for testing crystalline bodies, as phosphates and carbonates. By it phosphate and carbonate of lime may be distinguished from oxalate of lime (all which are insoluble in water), the acid dissolving the two former, while the latter is not dissolved even if boiled with it. The action of acetic acid, upon any particular tissue, upon any form of cells, fibres, &c., that are subjected



to examination, should always be specially noted. Many tissues are quite insoluble in acetic acid, though they are not rendered opaque by it.

*Nitric Acid.*—Strong nitric acid dissolves albuminous substances, but first colours them deep yellow. Dilute nitric acid is much employed in microscopical research. An acid composed of one part of acid to two or three of water, forms a good solution for hardening some structures previous to cutting thin sections. The thin sections may sometimes be rendered very transparent by being treated afterwards with dilute caustic soda. For demonstrating muscular fibre-cells, nitric acid is a valuable reagent. For this purpose the solution should contain about twenty per cent. of strong acid, and the muscular fibre should be allowed to soak in it for some days, when small pieces may be removed with scissors, and after being carefully torn up with fine needles, subjected to examination.

When we wish to obtain a few of the follicles of a gland with their special ducts, or portions of glandular structure isolated from one another, it is a good plan to soak the tissue for some days in dilute nitric acid (one part of acid to six or seven of water), when the areolar tissue becomes softened. At the same time the gland structure is rendered more firm, and may be isolated very readily with the aid of needles. In this manner the gastric glands, the secreting follicles of the pancreas, and salivary glands may often be very satisfactorily demonstrated.

By boiling animal tissues in strong nitric acid, they become destroyed, while any siliceous constituents remain behind unaltered. In this manner, the siliceous skeletons of the *Diatomaceæ* may be separated from any organic matter with which they were combined. This is one of the processes employed for obtaining these beautiful objects, from guano.

*Sulphuric Acid.*—*Hydrochloric Acid.*—Concentrated sulphuric acid causes epidermic structures to swell up very much, and the cells to separate from one another so as to be readily isolated. Boiling acid completely dissolves them. In the examination of hair, strong sulphuric acid will be found to render the outline of the cells very distinct. *Hydrochloric acid* is usually employed for dissolving out the mineral constituents of certain tissues, such as bone or teeth. As a rule, it is better to use dilute acid (one of acid to three or four of water), in which case, however, a longer time must of course be allowed, than when the acid is concentrated.

**298. Solution of Potash** should be kept of two or three different degrees of strength. One, the strongest which can be obtained; another, made by mixing one part of the strong potash with three or four of water; and a solution consisting of one part of liquor potassæ

to eight or ten of water will be found of a useful strength for the examination of many preparations.

**299. Solution of Soda** is generally required very dilute. It may be made by mixing one part of the strong solution of the shops with five or six of water; but this, for many purposes, will require to be still further diluted. Or, about twenty-five grains of the fused soda may be dissolved in an ounce of distilled water.

**300. Ammonia.**—Solution of ammonia, made by mixing one part of the strongest liquor ammoniæ (British Pharmacopœia) with three of water, will be found sufficiently strong for all the purposes for which this reagent will be required.

**301. Effects of Alkalies on Organic Structures.**—The action of alkalies, even when cold in a very dilute state, is to dissolve most animal textures. Cell-membranes are frequently almost instantly dissolved, while the bioplasm or germinal matter appears at least in many instances to be altered very slightly.

Alkalies are also employed for dissolving certain crystalline substances which are occasionally found in animal tissues, such, for instance, as the urates. The action of potash and soda upon animal structures is very similar. Both dissolve substances of an albuminous nature, but the effect of soda is more gradual, and it has been found that for most purposes in microscopical research, the latter reagent possesses advantages over potash. The solution of potash required by the microscopist is the ordinary *liquor potassæ* of the pharmacopœia, and the solution of soda is prepared in the same manner. These solutions may be diluted with water to the required strength.

Potash and soda are employed where a tissue is to be rendered more transparent for the purpose of demonstrating the arrangement of the nerves or other anatomical elements not soluble or only dissolved after the lapse of time in this reagent. These solutions dissolve the layer of epithelium covering mucous membranes, or render it perfectly transparent, so that the arrangement of the structures beneath the basement membrane can be easily demonstrated. In investigating the arrangement of the nerves and vessels in papillæ and other structures, they are very valuable, especially the soda solution. For the purpose above-mentioned, the alkalies should be diluted with water. The changes are expedited by the application of heat, which, however, must not be too great, for fear of complete solution taking place. The structure may be heated with the solution in a test tube. Observations must be made immediately after the application of the reagent—for in a short time all the textures may become so transparent that every trace of structure seems to have disappeared.

Some animal textures become hardened by prolonged maceration in carbonate of potash, but this plan does not appear to be so generally

useful as others previously indicated. Epidermic structures are not much altered by this salt. The introduction of different chemical solutions by injection, will be discussed in part VI. I strongly recommend this plan of subjecting the tissue to the action of the reagent.

**302. Nitrate of Barytes.**—A cold saturated solution of the salt forms a test solution of convenient strength. It should be filtered before use. A solution of nitrate of barytes is employed as a test for sulphuric and phosphoric acids. The precipitated *sulphate of baryta* is insoluble both in acids and alkalies; while *phosphate of baryta* is readily soluble in acids, but insoluble in ammonia.

**303. Nitrate of Silver.**—A solution of nitrate of silver is prepared by dissolving one hundred and twenty grains of the crystallized nitrate in two ounces of distilled water, and filtering if necessary. Nitrate of silver is employed as a test for chlorides and phosphates. The *white* precipitate of chloride of silver is soluble in ammonia, but insoluble in nitric acid. The *yellow* precipitate of tribasic phosphate of silver is soluble in excess of ammonia, as well as in excess of nitric acid.

**304. Oxalate of Ammonia.**—Some crystals may be dissolved in distilled water, and, after allowing time for the solution to become saturated, it may be filtered. Oxalate of ammonia is used as a test for salts of lime. *Oxalate of lime* is insoluble in alkalies and in acetic acid, but soluble in the strong mineral acids. In testing an insoluble deposit for lime, it may be dissolved in nitric acid and excess of ammonia added; the flocculent precipitate is readily dissolved by excess of acetic acid, and to this solution the oxalate of ammonia may be added. The precipitation of oxalate of lime is favoured by the application of heat. Many deposits of phosphate are with great difficulty soluble in acetic acid, hence the necessity of first adding nitric acid, as above directed.

**305. Iodine Solutions.**—An aqueous solution is easily prepared, by dissolving a few grains of iodine in some distilled water, until it acquires a brownish-yellow colour. A solution of iodine is sometimes useful for colouring certain animal and vegetable textures, which are so transparent as to be scarcely distinguishable upon microscopical examination. In the examination of many such structures, great assistance will be obtained from the use of coloured solutions. Delicate textures, like the cell wall and basement membrane, &c., can be far better distinguished when a faint tint is communicated to them, than when perfectly colourless. When a membrane is to be made more distinct, it may be immersed in a little Prussian blue fluid, p. 109, the minute particles of which adhere to it, and enable us to trace its outline clearly. A weak solution of magenta answers the same purpose.

Iodine is principally employed as a test for starch which is rendered blue by an aqueous solution, even when very dilute. Albuminous

matters and tissues are coloured yellow by iodine, and vegetable cellulose receives a brownish-yellow tinge. The addition of sulphuric acid (one part of the strong acid, two parts of water) to albuminous matter stained with iodine, causes no change, but cellulose under the same circumstances becomes blue. In cases where substances allied to starch and cellulose (amyloid matters) are found associated with the albuminous matters, a purple, bluish, or greenish tinge results from the action of iodine and sulphuric acid.

A strong solution of iodine may be obtained by employing a solution of iodide of potassium to dissolve the iodine (one grain of iodine and three grains of iodide of potassium, to one ounce of distilled water or glycerine).

Schultz recommends the following iodine solution:—Zinc is dissolved in hydrochloric acid; the solution is permitted to evaporate in contact with metallic zinc until it attains the thickness of a syrup; and the syrup is then saturated with iodide of potassium. The iodine is next added, and the solution, if necessary, is diluted with water. Professor Busk gives the following directions for preparing this solution: one ounce of fused chloride of zinc is to be dissolved in about half an ounce of water, and to the solution (which amounts to about an ounce fluid measure), three grains of iodine, dissolved with the aid of six grains of iodide of potassium, in the smallest possible quantity of water, are to be added (“Transactions of the Microscopical Society,” vol. i, p. 67). I have employed a solution prepared in this manner, and can speak very highly of its utility. In making it, it is necessary to be careful not to *fuse* the chloride of zinc much, or to employ a very high temperature, as decomposition is apt to take place. In testing starch with this solution, it is advisable to add a very little water, as the solution frequently will not act in its concentrated form.

#### OF APPLYING TESTS TO MINUTE QUANTITIES OF MATTER.

**306. Method of Applying Tests to Substances intended for Microscopical Examination.**—The matter to be tested may be placed upon a glass slide, and, if necessary, a drop of water added, to moisten or dissolve it, as the case may be.

In these operations we usually require only a small drop of a solution, and it will be found most convenient, in applying the test fluid to the object, to take a drop from the bottle by dipping a stirring-rod into it, and withdrawing it immediately. Enough will adhere to the stirring-rod for the purpose required. The rod should not be dipped in a second time, without being first well washed in distilled water,—for if this be not scrupulously attended to, there is great danger of conveying some of the substance intended for examination, into the test bottle, in

which case the whole contents of the latter would be spoiled. Without great care in all our manipulations, there will be much danger of removing a portion of one substance from a glass slide and carrying it to specimens which are subsequently examined. Accidents of the kind can always be avoided, by not allowing the drop of the reagent to touch the specimen until the rod has been removed. The drop may be placed near the substance intended for examination, and then allowed to come into contact with it, either by inclining the glass slide, or by leading it with a very thin piece of glass or a platinum wire, to the matter to be tested.

**307. Bottles with Capillary Orifices.**—The various tests above referred to may be preserved in ordinary stoppered bottles, but I much prefer to keep them in small tubes with capillary orifices, from which only a drop, or a part of a drop, can be expelled when necessary. Several years since I arranged all the ordinary tests I required for microscopical purposes in small bulbs which were drawn off to a capillary point. They were provided with glass or gutta-percha caps. These bulbs, however, were somewhat inconvenient in consequence of not being made to stand upright, and Mr. Highley substituted for them tubes with flat bottoms and ground glass caps. *See* pl. LXI, p. 262, figs. 1 to 4. To fill these test bottles having capillary orifices I proceed as follows:—A little of the solution is poured into a small basin, the tube being inverted so that its orifice dips beneath the surface of the fluid. Heat being now applied to the body of the bulb, the air in the interior is expanded and partially expelled. As the bottle becomes cool, a certain quantity of the fluid rises up into its interior. Usually, however, it is not possible to introduce more than a few drops in this manner. The bottle is then removed and heated over the spirit-lamp until the drop of fluid in its interior is in a state of ebullition. While the steam is issuing violently from the orifice, the latter is again plunged beneath the surface of the fluid. As the steam within condenses, the solution rises up in the interior, and would completely fill the little bottle if it were maintained in this position, but when it is about three parts full it may be removed from the fluid. If it were completely filled it would be difficult to expel a drop of the fluid when required. A certain quantity of air, therefore, is allowed to remain within the bottle, and this being expanded by the warmth of the hand, the quantity of fluid required can be driven out at pleasure.

Mr. Highley has made a further modification by arranging the capillary neck in the form of a tubulated stopper, by the removal of which, fluid can be introduced as in filling an ordinary bottle, fig. 3, pl. LXI, p. 262. For microscopical purposes bottles with capillary orifices possess many advantages over the ordinary stoppered bottles in which tests are usually kept.

In the *first* place, a most minute quantity of the test can be obtained without difficulty, and there is no chance of more than the drop or two required escaping from the bottle.

*Secondly*, there is no danger of the reagent becoming spoilt by the introduction of various substances from without. If an ordinary stoppered bottle be used, a drop of the fluid must be removed with a pipette or stirring-rod, but if these should not be quite clean, foreign substances may be introduced, and the reagent spoilt for further operations. Carelessness upon this head will lead to the greatest inconvenience, and to serious mistakes.

*Thirdly*, testing by means of these little bottles can be conducted in a very short space of time, and a number of the test bottles filled with their solutions may be packed in very small compass, pl. LXI, p. 262, figs. 2, 7.

**308. Capillary Tubes with India-rubber tied over the Top.—**

Dr. Lawrence Smith recommends that the tests should be kept in bottles of two ounce capacity, and instead of a stopper, he inserts a tube in the form of a pipette, the upper open end of which is covered with a piece of vulcanised India-rubber, pl. LXI, fig. 6. By pressing this while the lower end is beneath the fluid, a portion of the air will, of course, be driven out, and a little fluid will rush in to supply its place as soon as the pressure is removed. The tube with the contained test solution may then be removed from the bottle, and by again pressing the India-rubber, a drop, or a portion of a drop, will be very readily expelled.

**309. Testing for Carbonate and Phosphate of Lime, Phosphate of Ammonia and Magnesia, Sulphates and Chlorides.—**Suppose the nature of the substances composing certain forms of earthy matter is to be ascertained. A small portion, about the size of a pin's head, is placed upon the slide, and covered lightly with a piece of thin glass. Next, a drop of *nitric acid* is placed near to the thin glass. The acid soon reaches the sediment, and the disengagement of a few bubbles of gas may be observed. These are, as it were, temporarily pent up by the thin glass. If there should be any doubt about the action of the acid, we may resort to examination in the microscope, when, if there be but very few bubbles, and these exceedingly minute, they may be detected without difficulty. The formation of the bubbles of gas indicates the presence of a *carbonate*.

The acid solution obtained as above described, should be neutralised with *ammonia*, when a faint flocculent precipitate may be produced. After this has stood still for a few minutes it should be covered with thin glass and examined under the microscope. The deposit which causes the opalescence may consist of amorphous granules and small crystals, which, if allowed to stand long enough, will take the form of

triangular or quadrangular prisms (phosphate of ammonia and magnesia, phosphate of lime).

If we wish to ascertain the presence of sulphates, a little of the nitric acid solution is treated with the test solution of *nitrate of barytes*. An amorphous precipitate of sulphate of baryta, insoluble in strong nitric acid and alkalies, takes place, if sulphuric acid be present. The presence of chlorides is detected by the addition of a little *nitrate of silver* to a drop of the solution of the deposit in weak nitric acid. The white precipitate of chloride of silver is insoluble in *nitric acid*, but is dissolved by *ammonia*.

The above will serve as examples of the method of detecting the presence of several different substances in a very minute quantity of matter. The indications obtained in this manner are quite as valuable, and may be relied upon with as much certainty, as if we were provided with a very large quantity of material to work upon. In a single drop of a composite solution, the presence of several different acids and bases may be detected.

**310. New Method of Microscopical Analysis.**—Since I have been in the habit of using glycerine as the basis of all my injecting fluids and preservative solutions, I have employed it as the solvent of all tests, and with the greatest advantages. The reactions are of course slower, but much more perfect. Crystals can be formed most readily by this process, and as the viscid solutions mix very slowly, most perfect crystals even of substances which crystallize with great difficulty in water, are frequently obtained. If glycerine be added gradually to many solutions of crystallizable matter crystals are deposited. The various tests may be dissolved in a little water and then added to strong pure glycerine. The iodine reactions can often be obtained most satisfactorily by this mode of proceeding. The solutions may be kept in the little glass bottles described in p. 260. Very strong solutions of the nitric and sulphuric acids cannot be obtained with the aid of glycerine, but it is seldom that a stronger solution than one part of acid to five of glycerine is required. If a very strong viscid solution of acetic acid be wanted, lump sugar instead of glycerine may be added to warm acetic acid in sufficient quantity to make a fluid of the consistence of syrup.

Glycerine may be employed as the universal medium for the examination, preservation, and qualitative analysis of microscopic objects. It need scarcely be said that glycerine and syrup are miscible, so that the viscosity of any fluid can be readily increased by the addition of sugar to it.

*Of obtaining Crystalline Substances from the Fluids and Textures of the Organism.*

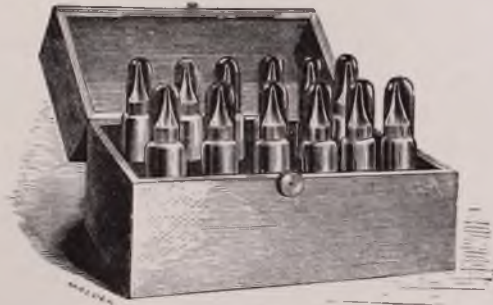
**311. Formation of Crystals.**—Some crystalline bodies are deposited

Fig. 1.



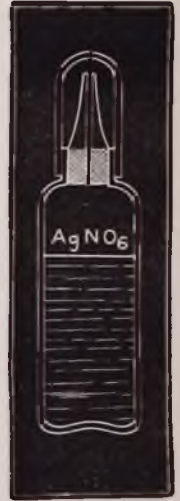
Bulb with capillary orifice for testing small quantities of matter. p. 261.

Fig. 2.



Reagent cabinet, containing twelve bottles with capillary orifices. p. 261.

Fig. 3.



Small test bottle, with capillary orifice. p. 260.

Fig. 5.



Test tubes and drainer. p. 263.



Rack for holding test tubes. p. 263.

Fig. 4.



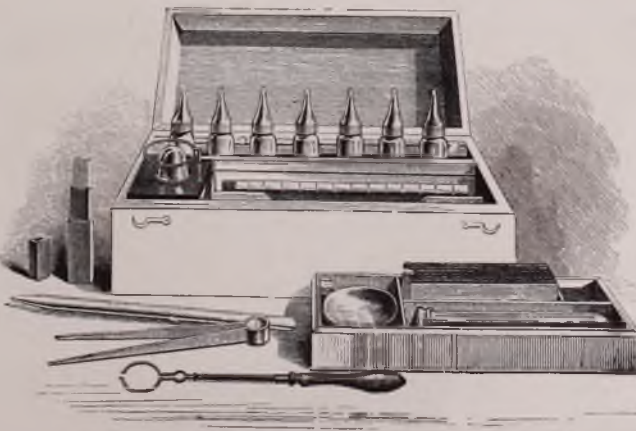
Test bottle, with capillary orifice. p. 260.

Fig. 6.



Pipette serving as the stopper to the bottle, *a*, vulcanised India rubber, by pressing which fluid may be expressed from the tube, *b*, ground to fit the neck of the bottle *c*, the orifice. p. 261.

Fig. 7.



Cabinet containing various apparatus for testing. p. 261.





from their solution in animal fluids by simple evaporation; others, less soluble, may be obtained by allowing the fluid to stand still in a shallow glass or porcelain vessel for a time, when certain changes occur in some of the constituents, which lead to the deposition of some substances in a crystalline form. Uric acid, for instance, cystine, leucine, triple phosphate, and some other crystals may be thus obtained. In other cases it is necessary to add some reagent which will promote the formation of crystals, while not unfrequently a long and it may be complicated chemical analysis is required to remove or decompose certain substances which interfere with crystallization. The addition of water in some cases promotes rapid crystallization, especially when the crystallizable material is dissolved in viscid organic matter. When water is added to the blood of some animals the hæmatocrystallin is dissolved out of the red blood corpuscles, and crystallizes as the solution is concentrated by slow evaporation. *See* pl. XXXIX, figs. 3, 6, p. 158. Instead of water, alcohol, ether, or chloroform, in which the crystals may be much less soluble than in water, is to be preferred in some cases.

Crystalline substances which are dissolved in animal fluids, may often be separated in a perfectly pure state by the addition of another fluid in which they are not so readily soluble. Glycerine may sometimes be used with advantage for this purpose. In all cases, the fluid should be added very gradually and plenty of time allowed for the formation of the crystals. At first nothing but an amorphous precipitate results, but the minute granules gradually assume the crystalline form, and at last perhaps become large and well formed crystals. Many organic substances soluble in alcohol, may be crystallized by the addition of ether, while some are precipitated from their solution in water, by the gradual addition of alcohol.

### **312. Influence of various Constituents upon the Crystallization.—**

In many instances, it is exceedingly difficult to separate some crystalline substances from other constituents by which their solubility is much increased, and the process of crystallization often prevented. The extractive matters of blood, and of many organic fluids, exert this influence in a marked degree, and it is only of late years that several new bodies of definite chemical composition have been separated from the so-called amorphous extractives. Creatine, creatinine, and some other well-defined crystals were formerly included under the indefinite term "extractives." Certain colouring matters of definite composition have also been separated, and it is very probable that as the methods of analysis at our disposal become improved, new crystalline bodies will be discovered in the extractive matters, and isolated in a pure form.

A very small quantity of extractive matter entirely prevents the crystallization of urea, while the presence of chloride of sodium or

common salt favours the separation of this material by forming with it a compound which readily crystallizes in large octahedral crystals even in the presence of extractive matters. The existence of carbonic acid in excess may cause carbonate of lime, triple phosphate, and other salts, to be held in solution. Excess of alkali prevents the precipitation of uric acid, and excess of acid, that of phosphate of lime. Fatty matters dissolve cholesterine, and serum possesses the power of retaining small quantities of the two last-named substances in solution. Some crystalline bodies which are soluble at the temperature of the body, crystallize when the solutions containing them are cooled thirty or forty degrees. The effect of dilution in retaining crystals in solution, need scarcely be alluded to. It follows then, that before we can detect, by microscopical examination, the presence of many substances, certain chemical operations are required either for the purpose of separating them from their combinations in the animal body, or for the removal of other substances which interfere with their crystallization.

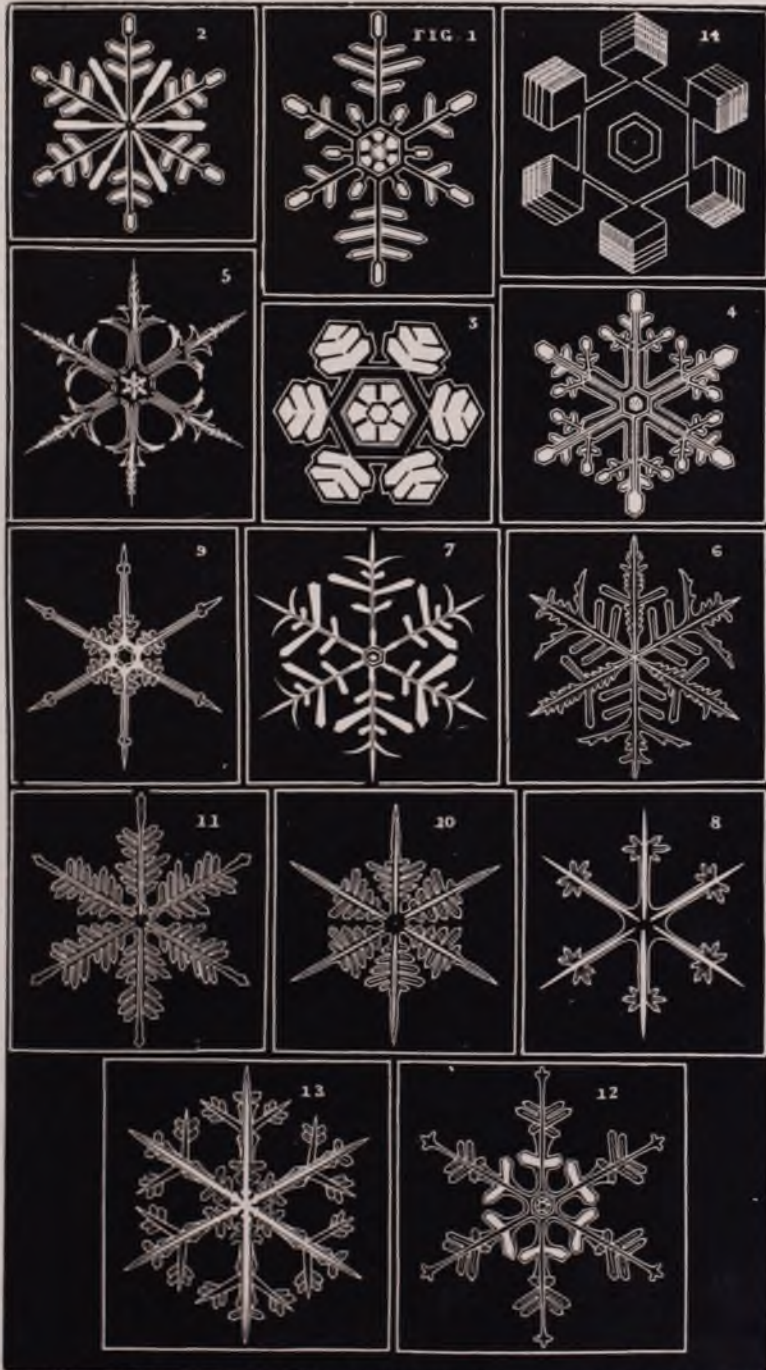
**313. Separation of Crystals from Animal Substances.**—In many instances this is a matter of some difficulty. If not very soon separated from the organic fluid in which they are formed crystals not unfrequently undergo rapid re-solution, or even become completely decomposed. If the crystals are not very soluble, the supernatant fluid, or mother-liquor, may be poured off,—the crystalline deposit washed with ice-cold water, and subsequently dried on filtering paper over sulphuric acid without the application of heat.

If the crystals will not bear the addition of water, as much of the fluid as possible must be poured off, and the remainder absorbed with bibulous paper, or they may be placed upon a porous tile, and dried over sulphuric acid in vacuo. In many instances we are enabled to wash the crystals with water holding in solution a little acid or alkali, or some alkaline salt, or with alcohol, ether, or some other fluid in which we know them to be quite insoluble.

In cases in which crystals insoluble in water are deposited in animal solids, they may be separated by agitation in water, when, being heavier than the water, they subside to the bottom, and the lighter animal matter may be removed by forceps, or if in a very minute state of division, poured off with the supernatant fluid. In other cases, the organic matter may be separated by straining, the crystals being washed through muslin.

**314. Of obtaining Crystals for Examination.**—In order to accustom himself to the necessary manipulation required for obtaining crystals, the student may evaporate a solution of common salt upon a glass slide, and when it has become sufficiently concentrated he may cover it with a small piece of thin glass, and allow it to cool. When cold the concentrated solution of salt may be subjected to microscopical examina-

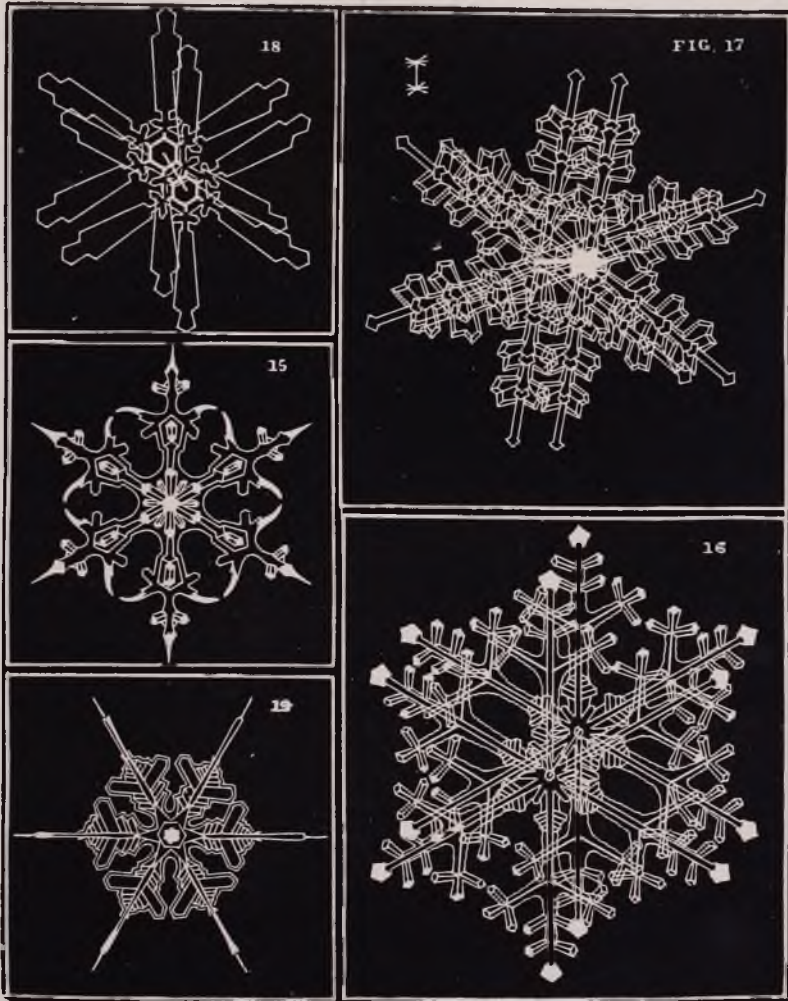
CRYSTALS OF SNOW.



Various forms of snow crystals, drawn by Mr. Glaisher in the winter of 1855.  
*Mic. Journ.*, Vol. III., p. 179.

common salt favo  
compound whic  
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Fig. 1.



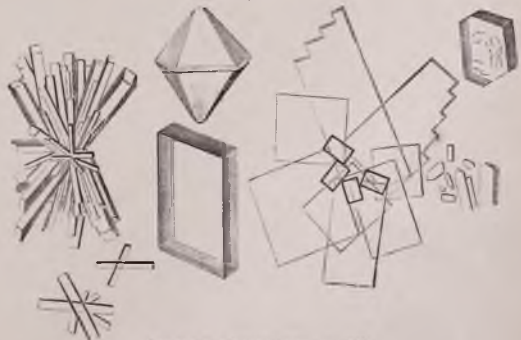
Various forms of double snow crystals, drawn by Mr. Glaisher. p. 265.

Fig. 2.

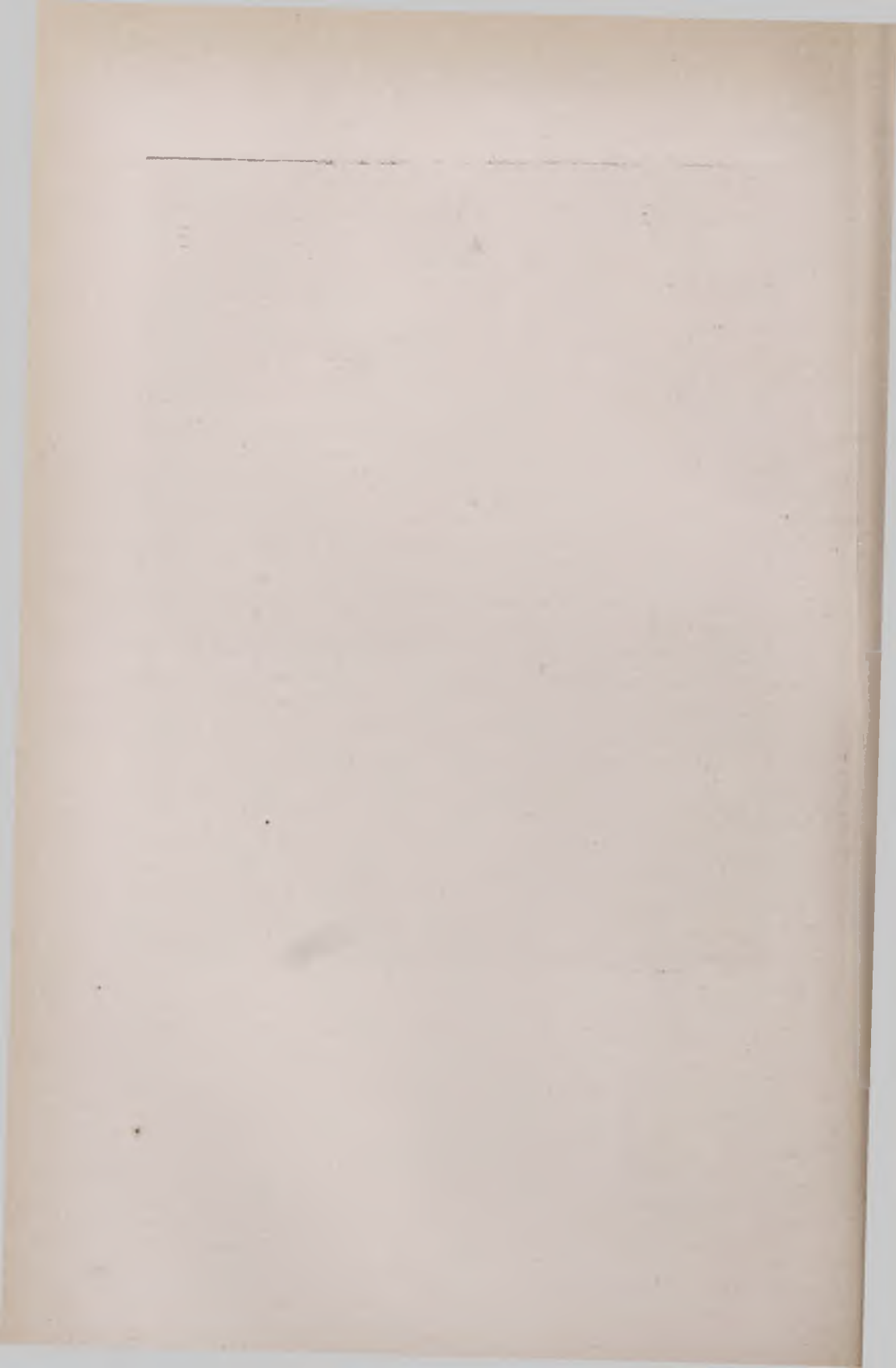


Dendritic crystals of chloride of ammonium. p. 265.

Fig. 3.



Crystals of creosote. p. 265.



tion, when it will be found that beautiful cubes of chloride of sodium have formed in the clear fluid, pl. LVIII, fig. 8, p. 218. Crystals of several salts may be made in the same simple manner, and from an attentive examination of them, much may be learnt. Phosphate of Soda, Phosphates of Soda and Ammonia, Sulphates of Potash and Soda, Chloride of Ammonium, Borax, Alum, Sulphate of Copper, Binioidide of Mercury, and a variety of other salts, can be readily obtained in microscopical crystals in this manner. Mr. Glashier has made some beautiful observations on snow-flakes. Copies of his drawings are represented in pls. LXII and LXIII, p. 264. Among organic crystalline substances of interest to the microscopist may be mentioned Quinine, Iodo-sulphate of Quinine, Salicine, Brucia, Oxalic Acid, and Oxalates, particularly Oxalate of Ammonia.

Different faces of the crystal, as it lies in the liquid, may be brought into view by slightly moving the thin glass cover with a fine-pointed instrument, such as a needle, while the preparation is in the field of the microscope. With a little practice, crystals may in this manner be made to roll round in the mother-liquor. Crystals which are precipitated by the addition of some reagent, such as nitrate of urea by nitric acid, must be examined in a little of the solution. The addition of water would, in many instances, destroy them immediately. Crystals of chloride of ammonium and creatine are represented in pl. LXIII, p. 264, figs. 2, 3. Other crystals are seen in pls. XLVII, XLVIII, p. 174, and LVIII, p. 218.

The influence of the crystals upon polarized light should be examined, and in cases in which the nature of the crystal has not been ascertained, its angles should be carefully measured, and accurate drawings made. The behaviour of the crystals with chemical reagents is next to be ascertained, and their solubility in water, alcohol, and other fluids must be noted. For these experiments different portions must be taken and separately tested in the manner referred to in p. 262.

A drop of the solution may also be rapidly evaporated nearly to dryness, and allowed to crystallize upon the slide without being covered over, when the substance will often be found to assume a variety of beautiful forms, such as crosslets, dendritic expansions, &c., pl. LXIII, p. 264, fig. 2, which vary according to the rapidity with which the evaporation has been conducted, and other circumstances.

Mr. Thomas Davies has obtained some beautiful results by crystallizing mixed salts, some of which exhibit a re-arrangement of crystalline form after fusion. A mixture of sulphate of copper and sulphate of magnesia, and sulphates of zinc and magnesia form good examples. They should be examined with the aid of polarized light and a selenite plate. See the copies of the photographs of the salts in Mr. Davies's second paper in the "Microscopical Journal" for July, 1865, p. 205.

By carefully crystallizing a solution of sulphate of copper at various



degrees of temperature, Mr. R. Thomas, of Oxford, has succeeded in obtaining a series of crystalline forms of a peculiar character. From the fact that throughout the series the crystals radiate from centres in a more or less spiral manner, Mr. Thomas has designated the process as "spiral crystallization."

The solution of sulphate of copper is evaporated by a moderate heat, until an uncrystallized film is obtained. This film being subjected (after the manner indicated in Mr. Thomas' paper, contained in the "Microscopical Journal" for July, 1866, p. 177), to a temperature of about  $60^{\circ}$  Fahrenheit, a number of foliated crystals, all radiating from centres, appear. There is in this stage a slight curve or twist in the radiation, and this constitutes the first stage of the spiral, as represented in pl. LXIV, p. 266, fig. 1. At a temperature of  $65^{\circ}$ , a further advance is seen in the direction of the spiral, fig. 2. At  $70^{\circ}$  (fig. 3) the spiral appearance is yet more distinct. While at temperatures of  $80^{\circ}$ ,  $90^{\circ}$  and  $100^{\circ}$ , the lines are smaller and more numerous, and the spiral more perfect and symmetrical, fig. 4. Fig. 3 shows a perfectly formed crystal which had been allowed to crystallize upon a slide, carefully protected from dust. Mr. Thomas believes that these crystals are in reality cones standing out in relief upon the glass slide. The changes in form which occur in crystals of the double salt of sulphate of magnesia and sulphate of zinc, upon the application of a gentle heat subsequent to crystallization have been also carefully studied by Mr. Thomas, of Oxford, whose figures are given in pl. LXV. See "Microscopical Journal" for April, 1866, p. 137. Mr. Hookham, of Summertown, Oxford, has studied this subject, and has prepared some beautiful specimens. From crystals prepared at a temperature of  $105^{\circ}$  some very interesting forms were obtained, being split up into sections by right and left hand twists.

**315. Examination of Crystals under the Microscope.**—Some crystals which have been entirely separated from the fluid in which they were originally deposited, may be examined in the dry way, in water, or other fluid in which they are known to be insoluble, or in Canada balsam; but as a general rule, it is necessary to examine the crystals as they lie in some of the solution in which they have been formed. When they have been obtained by allowing a concentrated solution to cool, some of the inspissated fluid must be removed with the crystals, placed upon a glass slide or in a thin glass cell, covered with a piece of thin glass, and examined in the usual way—a low power (an inch) being used first, and afterwards a higher power (a quarter). Although some of the crystals are of a large size, and may be well seen with a very low power, there are others amongst them which are exceedingly minute but most perfect in form. The crystals and mother-liquor should not be exposed to the air previous to examination, for in many instances water is absorbed, and partial re-solution takes place.

Fig. 1.



Foliated crystals of sulphate of copper, crystallized at 80°.

Fig. 2.



The same at 65°.

Fig. 3.



The same at 70°.

Fig. 4.



The same at 85° to 90°.

Fig. 5.



The same at 95° to 100°.

"Spiral" crystals of sulphate of copper, crystallized at different temperatures. p. 266. After Mr Thomas of Oxford. From the Mic Journal, July, 1866.



Fig. 1.



Fig. 2.



Fig. 3.



Fig. 4.



Fig. 5.

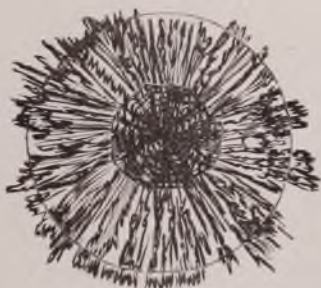


Fig. 6.



Fig. 7.

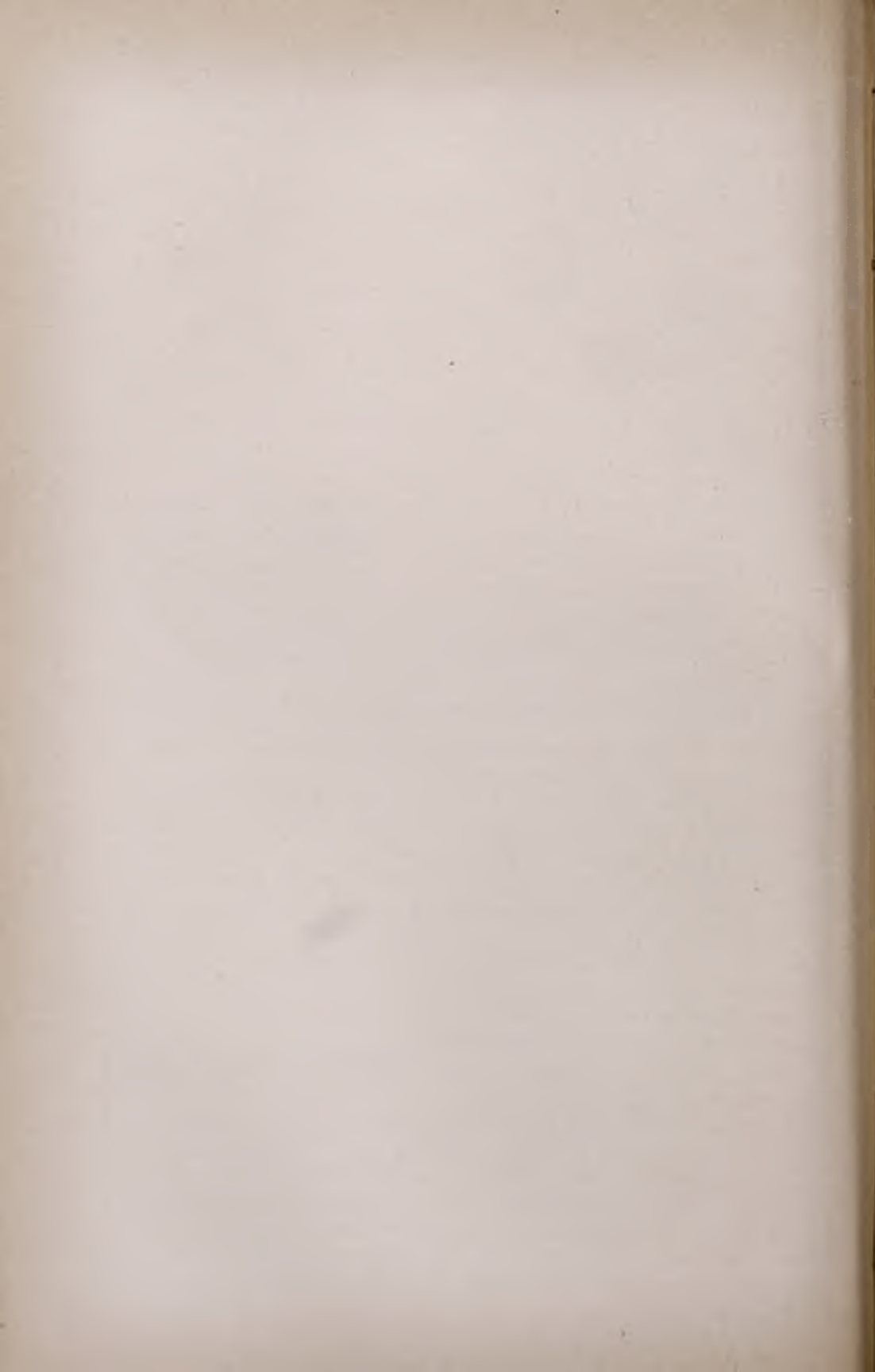


Fig. 8.



Double salt of sulphate of zinc and sulphate of magnesia crystallized at different temperatures, from 7° to 170°. The varied effects depend upon the loss of varying proportions of water of crystallization. p 206  
After Mr. Thomas, Mic Journ, April, 1866.

[To follow plate LXIV.



**316. Preservation of Crystals as Permanent Objects.**—The preservation of the more soluble crystals is attended with the greatest difficulty, except when they can be dried, in which state their characters under the microscope are often found to be imperfectly defined. Crystals which very readily deliquesce on exposure to air, must be dried in vacuo, removed quickly to a cell, the cover of which must be firmly cemented down at once. Some crystals may, however, be dried and mounted in Canada balsam; others, such as oxalate of lime, phosphate of lime, many carbonates, &c., can be well preserved in aqueous solutions, containing a little acid. Crystals which contain water of crystallization must be preserved in a drop of the mother-liquor; but in many instances they alter much in form, and when we come to examine them, instead of finding the great number of small, well-formed crystals, which were present when the preparation was first put up, nothing remains but one or two large ill-shaped ones. The concentrated mother-liquor often acts upon the cement with which the glass cover is fixed on the cell, and very soon air enters, and so the preparation is destroyed. Many crystals may be preserved in strong glycerine without much change taking place. I have some crystals of Guinea-pig's blood which have been preserved for many years in this medium and have undergone little change.

*Of the Hardening Properties of Chemical Solutions.*

**317. Of the Hardening Properties of Different Chemical Solutions.**

—The consistence of many tissues is so soft that it is absolutely impossible to obtain a thin section; while, by tearing off a small piece, the relations of the component parts is usually so much altered, that the specimen is useless for the purpose of examination. In this case our only chance is to harden the texture by some reagent in such a manner that, although its microscopical characters are not altered, a thin section may be readily obtained.

The solution employed for hardening a tissue will depend upon the character of the texture itself. Many tissues may be immersed in alcohol, others may with advantage be soaked in a weak solution of chromic acid. Various saline solutions are also sometimes employed, but in consequence of the alteration they produce, and the deposit they sometimes form in the interstices of the tissue, they are by no means well adapted for hardening textures from which microscopical specimens are to be made. Nitric acid and a solution of perchloride of iron have been employed for hardening some tissues, but they are not generally suitable. Tissues which are rendered too opaque for minute examination by the hardening process should be soaked in syrup or glycerine until sufficiently transparent, or a little solution of caustic soda or potash may be added to the section.

The hardening properties of the solutions referred to, depend upon their power of coagulating albuminous substances, and in the majority of instances the coagulation is associated with a certain opacity which renders the satisfactory examination of the tissue by transmitted light impossible, and as I have before hinted, it is absolutely necessary to render such a specimen transparent after the thin section has been obtained. It is obvious that before we submit many soft structures to microscopical examination, we ought to consider what chemical substances are likely to harden them in the most advantageous manner for cutting thin sections, and further, if by the process employed the section becomes opaque, we should further consider how transparency may be restored. The chemical nature of the substance to be examined, its physical properties, its refractive power, and its chemical composition, are points therefore with which it is most desirable every microscopic observer should be acquainted before he commences any special investigation.

I have succeeded in rendering the tissues of the embryos of mammalian animals so transparent that the smallest ossific points can be seen as soon as a trace of calcareous matter is deposited in the temporary cartilages. To displace such bony points at this early period by dissection would be a work of immense labour, and at the best the results would be very imperfect. Instead, however, of proceeding in this way, if we simply soak the entire organism in the alkaline solution, every centre of ossification will become beautifully distinct. The preparation is made as follows:—In the first place sufficient alcohol to receive it is to be treated with solution of soda in the proportion of from ten to twenty drops to the ounce. Next, the embryo is to be carefully suspended in the solution by a silk thread, and allowed to remain in the alkaline fluid for three or four days, or until it is so transparent that we can clearly see the ossific points in its bones. When this action has taken place, the embryo is to be removed and preserved permanently in weak spirit. I have a beautiful preparation of this kind which retained its characters for upwards of ten years. The principle of the action of the fluid may be thus explained:—alcohol alone tends to coagulate albuminous textures and render them opaque, while at the same time it hardens them. The alkali, on the other hand, will render the tissues soft and transparent, and, if time were allowed, would completely dissolve them. These two fluids in conjunction harden the texture, and at the same time make it clear and transparent. Many soft tissues may thus be hardened sufficiently to enable us to cut very thin sections. Preparations of this kind show how much may be effected by the use of very ordinary chemical reagents. By this simple process, a laborious minute dissection which would occupy many days is avoided, and there is no chance of losing some of the small ossific points, while

the structures are displayed far more distinctly than they could be by following any other method of preparation.

Doubtless many other fluids well adapted for the purposes of investigation will yet be discovered, and I strongly recommend observers to take up this branch of enquiry and endeavour to establish new methods of preparing textures which shall render their minute structure clearly demonstrable.

## ON SPECTRUM ANALYSIS.

By H. C. SORBY, F.R.S., &c.

**318. The Spectrum Microscope.**—Spectrum analysis, as applied to the microscope, must not be confounded with that branch of the subject which has yielded such admirable results in the hands of Bunsen, Kirchhoff, and other physicists. In that method of analysis it is the number and position of the narrow bright lines or bands, into which the light of the incandescent body is divided by the spectroscope, that enable the experimenter to identify each different substance. It is, in fact, the analysis of the *emitted* light, whereas in spectrum analysis applied to the microscope, it is the analysis of light which has been modified by transmission through the substance under examination, and it is the *absence*, and not the presence, of particular rays which makes the spectra characteristic of different substances. In this respect it is more analogous to spectrum analysis as employed in studying the chemical nature of the atmosphere of the sun or stars, as illustrated by the researches of Kirchhoff, Miiller, and Huggins, but the principles involved are materially different. The absorption bands in such cases are narrow, sharply defined lines, characteristic of absorption by gases, whereas those which play such an important part in researches with the spectrum microscope are usually broad, gradually shaded off on each side, and only in a few cases so narrow and sharply defined as to vie with some of the broader dark lines in the solar spectrum.\*

Confining then our attention to spectrum analysis as applied to solid and liquid substances, it may be said that the object of our researches is to distinguish substances by their colour, studied in the most accurate and scientific manner. Colour alone is, of course, often made use of as a criterion in qualitative chemical analysis, and is extremely characteristic of particular substances, even when seen in the ordinary manner; but when more accurately studied by means of the

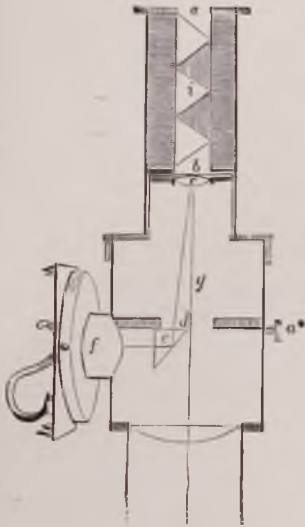
\* Though I was the first to publish a paper on spectrum analysis applied to the microscope, after having made use of it in various researches for nearly a year ("Quarterly Journal of Science," April, 1865, vol. II, p. 198), yet it is only fair to state that Mr. Huggins had independently thought of such an application ("Trans. Microscopical Soc.," May 10, 1865). [H. C. S.]



spectroscope it becomes incomparably more characteristic. The colour of a body, as seen with the naked eye, is the general impression made by the whole of the transmitted light, when all the rays are mixed together, and this total impression may be the same, though the compound parts may differ in a striking manner; and thus many colours which appear almost absolutely alike can be easily distinguished by their spectra. An ordinary spectroscope with small dispersion would suffice to study many of the facts, and even a prism and a narrow slit in a card could be employed; but in order to carry on the enquiries with entire success, it is desirable to have an instrument by means of which spectra of minute quantities of material can be examined, compared side by side with other spectra, and measured with considerable accuracy. All these advantages are secured by means of the spectrum apparatus applied to the microscope, made according to my plan by Mr. John Browning.

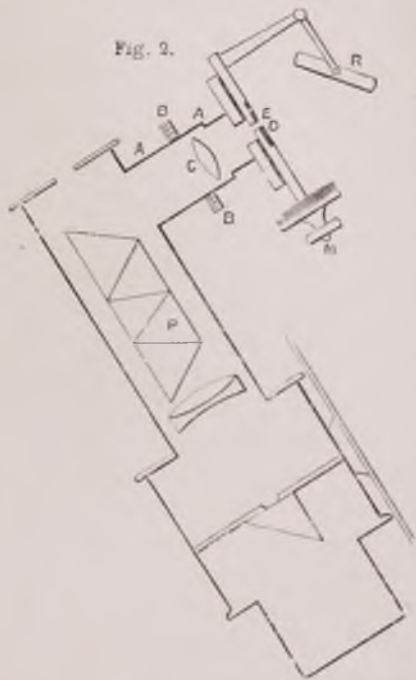
I have constructed a binocular spectrum microscope which is far more convenient in chemical testing, but is not suited for the examination of any substance less than  $\frac{1}{16}$  of an inch in diameter. I shall therefore confine myself to a description of the single eye-piece arrangement as being the most simple and generally applicable. Fig. 1, pl. LXVI, p. 27c, shows the more important parts of the apparatus. It is an eye-piece, fitting into the tube of the microscope, having the upper lens (*c*) made achromatic. At the focal point of this lens (*d*) is fixed the narrow slit of which fig. 2 gives, as it were, the ground plan; and this can be made broader or narrower by turning the head of the screw (*a*\*). A small rectangular prism (*e*) is fixed so as to extend over about one-half of the slit, and reflect the light coming through an aperture at (*f*) in the stage attached to the side of the eye-piece, as shown in fig. 1. The other half of the slit transmits the light passing up the main body of the microscope through the ordinary object-glass. When all is properly arranged and illuminated, in looking through the lens (*c*), a narrow line of light can be seen, one-half the length of which has passed through an object placed on the stage of the microscope, and the other half through any other placed on the side stage attached to the eye-piece; and, if the prism (*e*) has been properly adjusted, these two portions should appear perfectly continuous, without any break at their junction; but if not properly adjusted the line appears broken, and would then give false results if the spectra were compared together. Care should therefore be taken to see that the adjustment is correct. The analysing prism (*a b*) is compound, and fits over the eye-piece like a long cap. It consists of two rectangular prisms of flint glass, corrected for refraction by one rectangular prism of crown glass, and two others, with angles of about  $75^\circ$ . This combination gives direct vision, and an amount of dispersion which is admirably fitted for the purpose to which this in-

Fig. 1.



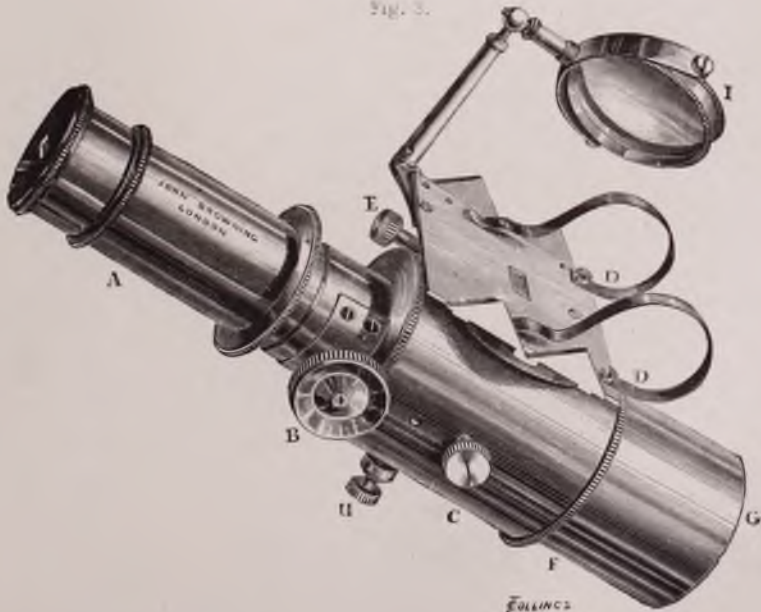
Mr. Sorby's spectrum eye-piece for the microscope, with arrangement for producing two spectra for comparison. p. 270.

Fig. 2.



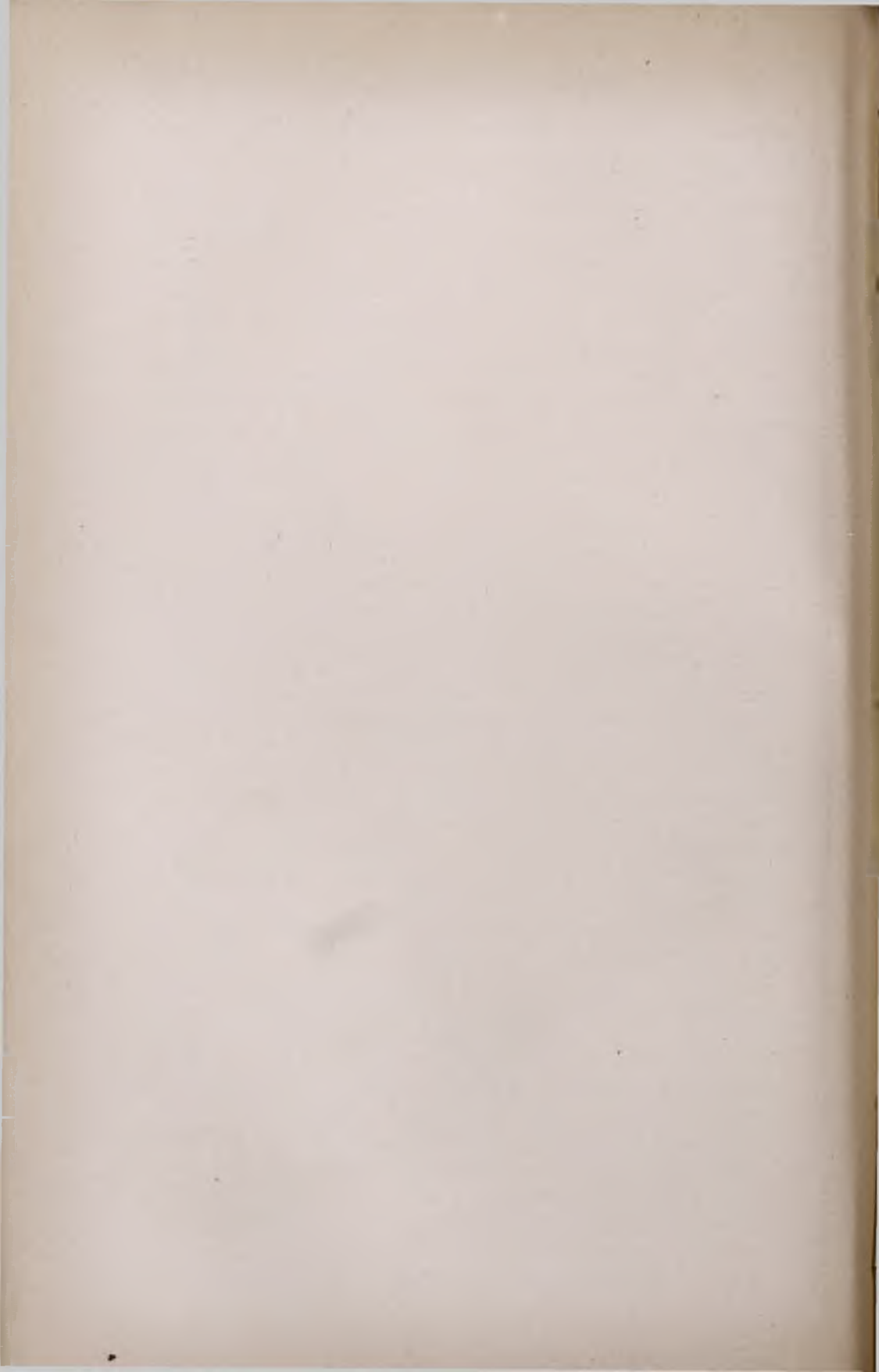
Upper part of a micro-spectroscope. A A, a small tube attached to the side with a puncture in the outer part. C a lens focused by the studs at M. The upper surface of the prism P is at right angles with the walls of the tube. From Mr. Browning's "How to work with the Spectroscope."

Fig. 3.



FOLLINGS

The micro-spectroscope with the latest improvements of Mr Sorby and Mr Browning. A, tube containing prism. B, milled head for adjusting focus of eye-lens. C, milled head connected with screw for adjusting the slit vertically. E, for altering breadth of slit. D, spring for holding small tube. E, for regulating slit of second spectrum. F, position of field-lens of eye-piece. G, tube which fits on to the microscope. From Mr Browning's "How to work with the Spectroscope."



strument is applied ; since it is sufficient to divide all the absorption bands seen in coloured solids and liquids, and is not so great as to spread them over too wide a space and make them very obscure, as is the case when the dispersion is great. Since the light which passes through the opening at (*f*) is not spread out over the same surface as that which passes through the object-glass, it would be far too bright, unless modified by means of a small shutter, opening and shutting with a screw. In each case this can be easily adjusted, so that the light from the two sources is equal, or may be made to vary for some special purpose. There is also a contrivance shown in fig. 2, which enables us to limit the length of the slit ; so that when very small objects are examined, no light shall pass except that which has come through them.

In using the spectroscope, a great deal depends on the slit being made up of a proper width. If the light be strong, it is best to have the slit only opened so much as to give a good clear spectrum, free from the irregular shading, due to unavoidable irregularities in the slit itself, which may be very conspicuous if the slit be very narrow. If day light be employed, and it is only rather feeble, the slit should be made wider, so as to admit more light ; but then, if made too wide, the colours of the spectrum lap over one another, and become indefinite. Much, however, should depend on the nature of the object under examination ; and, if it gives rise to very narrow absorption bands, the slit should be made narrow in order to give good definition. As a general rule the slit should be of such a width as to just indistinctly show the Fraunhofer lines in day light. It is also important to properly adjust the small slit under the side stage attached to the eye-piece. It should generally be made of such a width that the two spectra are of equal brilliancy, since otherwise the comparison would be inaccurate.

It is in all cases most important that no light should pass up the microscope, that has not actually passed *through* the substance under examination. If the object is small, unmodified light passes on each side, and this is reflected from the front of the object-glass down on the object and back again through the lenses without traversing its substance ; and thus an entirely false spectrum may be obtained, especially if the substance is dark coloured. This can easily be avoided by having a tube to fit over the object-glass, *see* fig. 6, pl. LXVII, which has a stop at the end with a hole in the centre (*a*), of such a width as not to limit the field of the microscope, placed at such a distance as to be within the focal length, so as to approach but not to touch the object when it is in focus. For a  $1\frac{1}{2}$ -inch object-glass the opening should be about  $\frac{1}{16}$  inch. Such a stop is also very useful in ordinary microscopical observations, when it is desirable to have no reflected light, and shows incomparably better the true colour of dark objects.

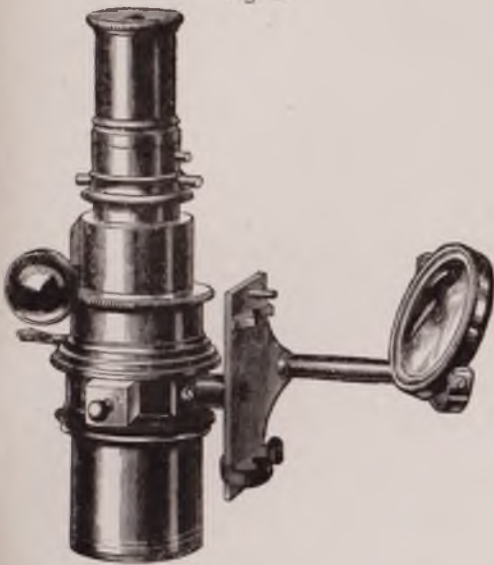
Recent improvements have been made by Mr. Sorby and Mr.

Browning, by which "every line or band in a spectrum when being measured is brought into the centre of the field of view. The jaws of the slit open equally, so that whatever their width may be, the zero remains unchanged. The micrometer is self-registering, and whole turns of the micrometer screw, as well as fractional parts, can be read off at the same time by inspection." The improved micro-spectroscope may be used for opaque as well as for transparent objects, and by its means, two spectra can be compared at the same time with one lamp. Moreover, the spectrum of the smallest object, or a particular part of any object may be obtained without difficulty. The most minute quantity of blood, adulterations of various kinds, and many substances in the fluids and tissues of animals, and in the juices and soft parts of plants, can be detected with certainty. The new micro-spectroscope is represented in pl. LXVI, fig. 3. The instrument, with the latest improvements and all the apparatus required, may be obtained of Mr. Browning, 63, Strand, London.

Having said so much with reference to the instrument, it will be well to describe the manner of preparing and viewing the objects; and this will be better understood if we first consider some of the general principles involved in this branch of research.

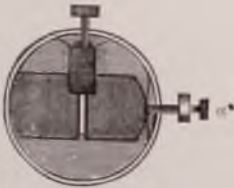
**319. Of Examining Objects in the Spectrum Microscope.**—Having properly arranged the instrument, if nothing intervenes to interfere with the white light employed for illumination, of course a simple and continuous spectrum is seen, with all the colours from the extreme red to the extreme blues and lavender; and, if a perfectly colourless and transparent substance be placed in front of the object-glass, no effect whatever is produced, and thus so to speak, all colourless bodies give the same spectrum and cannot be distinguished by means of their spectra. Coloured bodies are, however, those which are, as it were, black and opaque for certain rays, not allowing them to pass forward as light, but probably transforming them into heat or some other kind of force: and on placing such a substance in front of the instrument its presence is shown, not by the light which is still transmitted, but by that which it *cuts off*. It is, therefore, more simple and accurate to take into consideration the characters of the *absorbed* than of the *transmitted* rays, and in fact, the whole subject of qualitative analysis by means of the spectrum microscope, is founded on the relation between different substances and particular rays of the spectrum which they absorb, or so alter that they no longer pass forward as light. Unfortunately, it is not every substance which gives such a spectrum that its true nature can be recognised at once, but many are of such a character that they could not be confounded with any other yet known. These are those which absorb the light in narrow and well-defined portions of the spectrum, so as to give spectra with one or more definite black bands. The number,

Fig. 1.



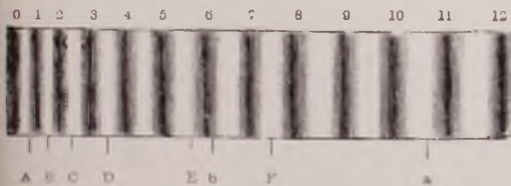
Micro-spectroscope made by Swift, after the Sorby and Browning instrument.

Fig. 2.



Arrangement for altering the length and breadth of the spectrum. p. 270.

Fig. 5.



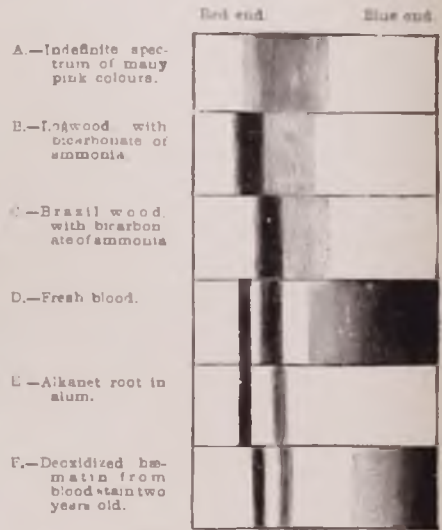
Scale for measuring the exact position of the absorption bands p. 276.

Fig. 7.



Wedge-shaped cell, for examining solutions in the spectrum microscope. p. 274.

Fig. 3.



Absorption bands produced by different substances. p. 273.

Fig. 4.



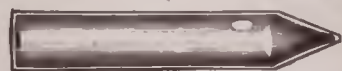
Cell for examining solutions by the spectrum microscope. Half the real size. p. 274.

Fig. 6.



Tube to fit over object glass to prevent reduction of extraneous light. p. 271.

Fig. 8.



Glass tube for containing solutions for examination under the spectrum microscope. Half the real size p. 274.



position, width, and intensity of these *absorption bands* are the most important data on which to form an opinion respecting the nature of the substance under examination. It must not be thought that these bands bear any relation to the elementary constituents of the substance—they are merely related to it as a definite compound in a particular physical condition, and may vary according to its state. For example, they often vary for the same substance, when solid or in solution; and even according to the nature of the solvent, besides being greatly modified by the presence of free acids or alkalies.

Fig. 3, pl. LXVII, p. 272, gives a few spectra, to illustrate the general subject. They are all of red or pink colours.

A is an indefinite spectrum, yielded by very many different substances, having a general absorption over the green, with no narrow absorption band.

B is the spectrum of a solution of logwood in water, to which bicarbonate of ammonia has been added, and C is the same in the case of Brazil wood; and the difference between the two is shown by the different position of a single well-defined absorption band.

D is the spectrum of fresh blood.

E is the spectrum of alkanet root in alum with a little alcohol.

F is the spectrum of deoxidized ammoniacal hæmatine.

These three show very well how closely related spectra may be easily distinguished by the different position and relative width and darkness of the bands.

Many coloured substances give spectra which do not enable us to decide with confidence what they are. Perhaps some half dozen substances may be known which would give the same result, and this spectrum may only serve to indicate to what group the colour belongs; but even then, supposing it be a solution, the addition of some reagent may at once show which particular substance is present. For example, solutions of Magenta and Brazil wood both give a single well-defined absorption band in the same position, in the upper part of the green, but ammonia produces no change in Magenta, and great change in the Brazil wood. Sulphate of soda then immediately makes the Magenta colourless, but does not change the Brazil wood except by gradual fading and decomposition. It is, however, extremely difficult to distinguish some substances, especially when mixed with other colours; but still by suitable methods many can be recognised without difficulty under most unpromising conditions. This, however, is more a question for a treatise on qualitative analysis by means of the spectrum microscope, than for one on the instrument itself and the manner of using it.

It must not be thought that an indefinite quantity of any substance will give a characteristic result. If too little is present, nothing definite



can be seen ; and, if there is too much, the most characteristic parts of the spectrum may be entirely obscured. For example, fresh blood gives two remarkably well-defined absorption bands in the upper part of the green ; but, if too little is present, these bands are very faint, and, if too much is present, all the light is absorbed, except the red and orange, so that the bands cannot be seen at all. In every case a certain amount of colour gives the best result ; and though at first this may appear difficult to arrange, yet after a little experience there is really no difficulty, especially if we make use of such small cells as are shown in pl. LXVII, fig. 4. These are cut from barometer tubes ; and I find that the most convenient sizes are  $\frac{1}{2}$  inch long,  $\frac{1}{7}$ th inch in internal, and somewhat under  $\frac{1}{2}$  inch in external, diameter. These are ground flat at each end and attached with Canada balsam near one edge of a glass plate, so that they may be examined either end-ways, by laying the plate flat on the stage of the microscope, or side-ways, by leaning the glass against the side of the object-glass. If then the colour is too deep in the line of the length, the tube can be turned, so that it may be examined side-ways, which, being equivalent to using  $\frac{1}{4}$ th the quantity, we can easily judge what amount would show the most perfect spectrum. The cells should be either filled level, or covered with a piece of thin glass. If the diameter of these cells be less than  $\frac{1}{8}$ th of an inch, it is difficult to fill and empty them ; and, if much wider than  $\frac{1}{8}$ th, the liquid is apt to run out when they are turned over ; but when of about  $\frac{1}{7}$ th wide they are easily filled and not a drop of liquid is lost even when they are turned upside down. Almost all kinds of testing can be carried on in these cells, and they may be easily washed out by means of a small stream of water blown out of an ordinary chemical wash-bottle, pl. XXVI, p. 100, fig. 5. Solid or liquid reagents can easily be added and stirred up by means of a moderately stout platinum wire, flattened at one end, and turned up square like a small hoe. The great advantage of these cells is that a very small quantity of material is required (which is most important in some investigations) ; but for some purposes ordinary test-tubes are very useful, and especially to place on the stage attached to the eye-piece and compare with objects on the stage of the microscope. These can be examined only at the sides, and the colour must, therefore, be diluted so as to show the best spectrum. Wedge-shaped cells like fig. 7, pl. LXVII, are also useful in order to study the effects of different thicknesses of solutions. Colours which do not materially change on keeping some time may be mounted in tubes, *see* fig. 8, about  $\frac{1}{2}$ -inch in diameter and 3 inches long, sealed up flat at the bottom, and drawn out capillary at its top, leaving a small opening through which the liquid may be introduced by means of an air pump, and afterwards sealed up with the blow-pipe. Many mineral salts can thus be kept for an indefinite period ; and even many animal

and vegetable colours can be kept for a year or more always ready for examination.

### 320. Examination of Blow-pipe Beads and Solutions in Cells.—

The coloured beads obtained by ordinary blow-pipe testing, can easily be examined by the spectrum microscope; and in some cases, give very satisfactory results. Some crystals also are excellent objects, and give striking spectra. It is easy to select such as give the best result, or to cut them wedge-shaped, and thus examine the effect of different thicknesses. Coloured glasses cut wedge-shaped are also very interesting, and are useful to compare with blow-pipe beads; but for actual research, no branch of the subject is so satisfactory, as the testing of minute quantities of animal and vegetable substances in the small cells. This includes the detection of blood-stains, which can be done with great ease and certainty ("Quarterly Journal of Science," vol. II, p. 198); the detection of adulteration in drugs and other substances met with in commerce; and the determination of the identity of, or the difference between, the very numerous colouring matters met with in plants. In a number of such practical questions, special methods may be employed with advantage; but in examining an unknown colouring matter, it is well to adopt a definite system, so as to be able to decide to what particular group it belongs. After a large number of experiments, I found that it is easy to arrange them in divisions founded on their solubility in water or alcohol. Thus—

	Division.
Soluble in water and not precipitated by alcohol ...	1
Soluble in water but precipitated by alcohol ...	2
Insoluble in water but soluble in alcohol ...	3
Insoluble in water and alcohol ...	4

Then we may divide 1, 2, and 3, into groups, founded on the action of sulphite of soda. The effect of this reagent is very remarkably related to the spectra. If the absorption extends from the blue end continuously, it produces no change, but if there is a detached absorption in the green or yellow separated from the blue end by a more transparent space, the sulphite in certain groups of colours removes this, and leaves the absorption in the blue unchanged. In some colouring matters this occurs in an ammoniacal solution, and these constitute my group A. In others, no such change takes place unless the solution be strongly acid, and these form my group B. This is usually quite independent of decomposition, and the colour is restored by the addition of ammonia. Those colours which are not immediately altered when the solution is acid, constitute my group C. By these reactions, mixtures of colours of the different groups can easily be recognised; and this alone may often be of great practical use. Then,

in order to divide these into sub-groups, I have recourse to the number of distinct absorption bands, when the neutral colour is dissolved in water or alcohol, or when ammonia is added to each. By this means we obtain a large number of sub-groups, which are of great use in practical researches. It would extend this account to an unreasonable length, if I were to consider this part of the enquiry in full detail, and I will therefore refer the reader for further information to my paper in the "Proceedings of the Royal Society" (1867, vol. XV, p. 433) for a complete account of the general method, and of those laws which indicate the presence of one or more colouring matters in a solution.

Mr. Browning has recently introduced a series of dyes for spectroscopic examination upon a glass plate, which are most conveniently arranged for observation. Twelve strips of dry gelatine, about a quarter of an inch wide and three-quarters of an inch long, each of which is imbued with a different dye, are placed upon a glass plate, which is kept in a small morocco case. Two or more plates may be superposed, and thus several spectra in which the absorption bands appear at the same time may be shown. Blow-pipe beads and crystals, various solutions in tubes and in gelatine, and other specimens for micro-spectroscopic examination may be obtained of Mr. John Browning, 63, Strand, London, who will forward complete lists of the series made by him to any one who requests to be furnished with them.

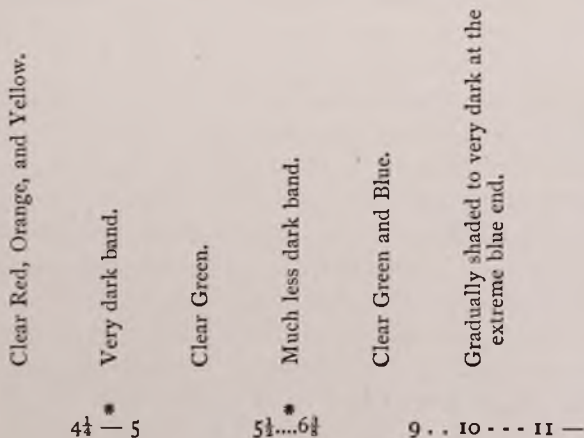
**321. Method of Measuring the Position of Absorption Bands.**—In order to measure the exact position of absorption bands, &c., seen in spectra, I have contrived a small apparatus which gives an interference spectrum, divided by black bands into 12 parts, all of equal optical value. It is composed of two Nicol's prisms, with an intervening plate of quartz, about  $\cdot 043$  inch thick, cut parallel to the principal axis of the crystal, the thickness being so adjusted that the sodium line is exactly at  $3\frac{1}{2}$ , counting the bands from the red end towards the blue. I have placed such standards in the hands of Mr. Browning and Messrs. Beck, who have undertaken to prepare others like them.

The characters of this scale will be better understood from fig. 5, pl. LXVII, p. 272.

In the spectrum microscope this spectrum is, as it were, in direct contact with that under observation, and the position of any absorption band can be easily measured to within  $\frac{1}{100}$ th part of the width of the whole spectrum. Such a system of measurement enables us to adopt a method by means of which spectra can be easily described in notes, or printed by means of ordinary types. In order to express the intensity of absorption, I make use of the following symbols :—

Not at all shaded		Blank space.
Very slightly shaded	. . .	Dots with wide spaces.
Decidedly shaded	. . .	Dots closer together.
More shaded	....	Very close dots.
Strongly shaded, but so that a trace of colour is still seen	} - - -	Three hyphens close.
Still darker	—	Single dash.
Nearly black	—	Double dash.

Except when specially requisite, only the symbols . . . - - - — are employed for the sake of simplicity, and then as signs of the relative, rather than of the absolute, amount of absorption; and it is assumed that there is a gradual shading off from one tint to the other, unless the contrary is expressed. This is done by means of a small vertical line over the figure (*see* No. 11, p. 278) which shows that there is a well-marked division between them. Definite narrow absorption bands are indicated by \* printed over their centre. This will be better understood by a description of the spectrum of deoxidized hæmatin:—



The following examples will show how simple or more complicated spectra may thus readily be printed and compared. I have chosen solutions of similar tint, in order to show that the spectra of those of nearly the same colour may be very different, or, if analogous, may differ in details, easily expressed by the symbols. The colour of each is given after the name. Nos. 1, 8, 9, 10, 11, 12, and 13 can be kept for a long time, sealed up in tubes, and the rest are easily prepared. In each case the spectra are those seen with solutions of such a strength as gives the most decided results, and shows the presence or absence of absorption bands to the greatest advantage:—

- |    |  |                       |  |              |
|----|--|-----------------------|--|--------------|
| 1. | Cudbear in alum.                               | ( <i>Pink</i> )       | 3 . . . . . 8                              | 11 . . . . . |
| 2. | Colour of elder berries with }<br>citric acid. | ( <i>Red Pink</i> ) } | 4 . . 5 $\frac{1}{4}$ —8 . . . 9 . . .     | 11 . . . . . |
| 3. | Brazil wood, with bicarbonate }<br>of ammonia. | ( <i>Pink</i> ) }     | 4 $\frac{1}{2}$ —5 $\frac{3}{4}$ . . . . . | 8            |
| 4. | Logwood, with bicarbonate of }<br>ammonia.     | ( <i>Pink</i> ) }     | 3 $\frac{3}{8}$ —5 $\frac{1}{4}$ . . . . . | 7            |

The next four are spectra of blood, produced by the successive addition of the various reagents, as in detecting fresh stains :—

- |    |   |                           |   |   |                       |
|----|---|---------------------------|---|---|-----------------------|
| 5. | Fresh blood.  | ( <i>Pale Scarlet</i> )   | 3 $\frac{1}{2}$ —4 $\frac{3}{8}$          | 4 $\frac{1}{4}$ —5 $\frac{3}{4}$          | 7 . . 8 . . . 9—      |
| 6. | Citric acid then added.                               | } ( <i>Pale Brown</i> ) } | 1 $\frac{5}{8}$ . . . . . 2 $\frac{1}{4}$ | 4 . . . . . 8 . . . . .                   | 9 . . . . . 10—       |
| 7. | Ammonia then added.                                   |                           | 3 $\frac{5}{8}$ . . . . . 4 $\frac{3}{8}$ | 4 $\frac{7}{8}$ . . . . . 5 $\frac{5}{8}$ | 7 . . . 8 . . . . 10— |
| 8. | Deoxidized hæmatin, from }<br>blood stain 2 yrs. old. | ( <i>Pink</i> ) }         | 4 $\frac{1}{4}$ —5                        | 5 $\frac{1}{2}$ . . . . . 6 $\frac{3}{8}$ | 9 . . 10 . . . . 11—  |

With these may be compared the two spectra which more nearly resemble those produced by blood than any I have yet seen :—

- |     |                       |                 |  |   |                 |
|-----|-----------------------|-----------------|--|---|-----------------|
| 9.  | Cochineal in alum.    | ( <i>Pink</i> ) | 3 $\frac{3}{8}$ —4 $\frac{1}{2}$ . . . . . | 5 $\frac{1}{8}$ . . . . . 6 $\frac{3}{8}$ . . . . . | 7 $\frac{1}{2}$ |
| 10. | Alkanet root in alum. | ( <i>Pink</i> ) | 3 $\frac{1}{2}$ —4 $\frac{3}{8}$           | 5 $\frac{1}{4}$ . . . . .                           | 5 $\frac{3}{4}$ |

The following spectra of compounds derived from chlorophyll, are as complicated as any I have met with :—

- |     |  |  |  |   |   |   |   |
|-----|--|--|--|---|---|---|---|
| 11. | Normal chlorophyll }<br>in alcohol.                                    | } ( <i>Deep Green</i> ) }              | 7 $\frac{1}{8}$ —2 $\frac{3}{8}$ . . . . . | 3 $\frac{1}{4}$ . . . . . 4 $\frac{1}{2}$ | 6 $\frac{3}{4}$ . . . . . 7 $\frac{1}{2}$ —         |   |   |
| 12. | Ditto, as decomposed by acids, or as found in some leaves.             |  | 1—2 $\frac{3}{8}$                          | 2 $\frac{3}{4}$ . . . . . 3 $\frac{3}{8}$ | 4 $\frac{1}{4}$ . . . . . 5 $\frac{1}{4}$ . . . . . | 5 $\frac{3}{4}$ . . . . . 6 $\frac{3}{8}$ . . . . . 7 $\frac{3}{8}$ | 8 $\frac{1}{2}$ . . . . . 9 $\frac{1}{2}$ — |
| 13. | Ditto, as decomposed by caustic potash, and then by hydrochloric acid. | } ( <i>Red-Green, Neutral Tint</i> ) } | 4 $\frac{1}{2}$ —5 $\frac{3}{4}$           | 1 $\frac{1}{2}$ —1 $\frac{3}{8}$          | 1 $\frac{7}{8}$ —2 $\frac{1}{8}$                    | 4 $\frac{1}{2}$ . . . . . 5 $\frac{1}{4}$ . . . . .                 | 9 . . . . . 10—                             |

In many cases the position of the centre of the absorption bands is very characteristic of the different substances, and we may easily express their differences by writing the division, group, sub-group, and position of the bands, in the following manner :—

- |              |  |
|--------------|--|
| Purple pansy | 1, A, aq <sub>0</sub> am <sub>1</sub> (4). |
| Brazil wood  | 1, C, aq <sub>1</sub> (5 $\frac{1}{4}$ ).  |
| Logwood      | 1, C, aq <sub>1</sub> (4 $\frac{3}{8}$ ).  |

These signify that the colour of the purple pansy is soluble in water and not precipitated by alcohol—that sulphite of soda removes the

absorption band when added to the ammoniacal solution—that there is no absorption band in the neutral solution, but that on adding ammonia a single absorption band is developed, whose centre is at 4. In the case of Brazil wood and logwood, they signify that the colour is also soluble in water and not precipitated by alcohol—that sulphite of soda has no action on either an acid or alkaline solution—that in each there is a single absorption band in the neutral aqueous solution, situated in different positions in the two colours, as shown by B and C, fig. 3, pl. LXVII, p. 272.

I trust that this brief description will show that in practical working a great deal may be easily expressed by very simple symbols. We may soon decide to which group and sub-group any colour belongs; and, if we had a table of various known colours, arranged according to these principles, we might often soon ascertain its true nature. Of course there are many points requiring special attention, which, as already remarked, more strictly belong to chemistry than to a work on the microscope; and therefore I have confined myself merely to an account of some of the leading principles involved in this method of qualitative analysis.

**322. Substances giving well-marked Absorption Bands.**—The following is a list of some objects, giving more or less well-marked absorption bands, which can easily be prepared for examination:—

*To be examined at once, not keeping well when diluted.*

Blood in water.

Magenta, in water or alcohol.

Mauve in alcohol.

Aniline blue in alcohol.

Brazil wood in water alone, and with bicarbonate of ammonia.

Logwood ditto ditto.

Blue Lobelia flowers in water.

*Keeping well for many months.*

Deoxidized ammoniacal hæmatin in water.

Alkanet root in alcohol, with a little acetic acid.

Alkanet root in alum, with a little alcohol.

Colour of red Cineraria flowers in syrup.

Cochineal in water.

Cochineal in alum.

Chlorophyll in alcohol.

Chlorophyll in alcohol, with a little hydrochloric acid.

*Keeping well, probably for an indefinitely long time.*

Permanganate of potash in water, sealed up in a tube of glass which contains no lead.

Urano-uranic sulphate in water.

Chloride of cobalt in water.

Chloride of cobalt in a strong aqueous solution of chloride of calcium.

Chloride of cobalt in absolute alcohol.

Crystals of binoxalate of chromium and potash.

„ perchlorate of potash coloured with a little permanganate of potash.

„ native phosphate of uranium.

„ acetate of uranium.

„ chloride of cobalt.

„ binoxalate of chromium and soda.

**322a. On Colouring Matters of Plants.**—Mr. H. B. Sorby has recently studied the changes that occur in the colouring matters in leaves and flowers of certain plants, and has pointed out the relation of the changes in question and the action of light during their development. When more developed under the influence of light, coloured compounds are formed which are more and more easily decomposed by the action of light and air. There seems to be some condition in living plants which reverses the reactions. Mr. Sorby also found that in the more rudimentary state of the leaves of the highest classes the colouring matters correspond with those found in lower classes. In the case of the petals of flowers the more rudimentary condition of the compounds is often found to correspond with those of some other variety, and to be due to a naturally arrested development of a particular kind. The greater prevalence of flowers of particular colours in tropical or colder regions and at different elevations may perhaps be explained upon these principles. Since the effect of the various rays of light is different, it becomes a question of much interest to decide whether an alteration in the character of the light of the sun would produce a somewhat different effect in the case of other classes of plants in which the fundamental colouring matters differed; whether, for example, light, with a relative greater amount of the blue rays, might not be relatively more favourable to the cryptogamia than to the flowering plants. So far this is a mere theoretical deduction; but, if proved to be true by experiment, it may at all events, assist in explaining the differences in the character of the vegetation of our globe at an early epoch, when perhaps our sun was in a different physical state to that which now exists, and the light, perhaps, more similar to that of Sirius and other stars of the higher and bluer type.

**322b. New Colouring Matter developed by Living Organisms, and giving very peculiar Spectrum Bands.**—Mr. Sheppard (*see* letter to the Rev. J. B. Reade, "Microscopical Journal," July, 1867, p. 64) discovered that a velvet like film found on stones lying beneath the surface

of water, containing oscillatoriæ, confervoideæ, and other forms, developed a bright red tint after it had remained for twenty-four hours upon a piece of greasy paper. Upon further investigation it was discovered that a portion of the film when mixed with white of egg, diluted with a little water and left to stand for a night, gave rise to a solution of the colour of magenta dye.

This remarkable colour is due to the action of some living organisms upon the albumen which becomes less tenacious in consequence. The colour is not developed when the vegetable organisms have become stale. Moreover the colour disappears when decomposition of the albuminous fluid takes place. The coloured albuminous solution was *dichroic*. It appeared red by reflected, and blue by transmitted light.

This coloured albuminous fluid is the only blue fluid known to Mr. Sorby which gives particular bands. Mr. Browning describes the spectrum as follows:—"Commencing at the least refrangible or red end of the spectrum, we find it cuts pretty sharply a short piece of the extreme red. Then we have a strong absorption band also in the red, corresponding to  $2\frac{1}{2}$  of the twelve lines given by Sorby's standard interference spectrum (pl. LXVII, p. 272, fig. 5). A second absorption band in the green commences at line 4, and tones off gradually into the spectrum just beyond line 5."

The spectrum of the fluid viewed by reflected light was found by Mr. Browning to be very different from the one by transmitted light just described. "A much larger portion of the red end is absorbed, but not so sharply. The strong band in the red is shifted towards the more refrangible end of the spectrum, cutting out the edge of the red, some of the orange, and most of the yellow. The second absorption band is wanting, but the greater part of the light of the spectrum is absorbed from a point between the fourth and fifth lines, and all the light is absorbed at the 7th. The part of the spectrum which should be yellow has a strong tinge of olive green."

*Blue Fluid resulting from the Decomposition of a Species of Nodularia.*

—Mr. G. Francis sent me from South Australia, in February, 1878, a specimen of a beautiful blue colouring matter dissolved in water and another in glycerine obtained by the decomposition of a confervoid plant which had proved very fatal to cattle and sheep. The fluids exhibit a very remarkable brownish red fluorescence, and give a broad absorption band corresponding to the yellow and adjacent red portion of the spectrum. Mr. Francis carefully investigated the matter and reported to the Government as follows:—

"I have the honour to report having inspected Lake Alexandrina with the object of ascertaining the nature of the bad state of the water, its cause, and remedy, if any; also effects on stock, &c. I find the evil to arise from an enormous development of an Alga, of the order of



*Confervæ*, belonging to the genus *Nodularia*, floating free in the water, without roots, and wafted hither and thither by the wind. This collects on the shores, forming the scum, acquiring consistence in shallow places sufficient to be semi-solid; cast on shore it dries into a green flake. I find this green scum when taken quite fresh to be poisonous, having destroyed a sheep with it by drenching, proving that the plant itself is deleterious, and that the poisoning arises from the plant, but it is highly augmented by its being in a state of decay and during hot weather. It is destroying sheep, horses, large cattle and dogs, also many pigs and some fish. I consider it an epidemic like rust (red). The plant is natural to and doubtless always exists in the Lake, but the present low depth of water, with the high temperature, has caused an abnormal production. Temperature of lake before this west wind set in, on 1st instant, ranged from  $76^{\circ}$  on surface at Milang,  $73^{\circ}$  at bottom same place,  $72^{\circ}$  surface mid lake. During a gale, being at Wellington, the river water there was  $74^{\circ}$ ; at Beaumont during a gale, in lake it fell to  $68^{\circ}$ , and at Milang to  $64^{\circ}$ . This state of things will doubtless last as long as the lake is low and the temperature high, but if the temperature should fall generally to below  $65^{\circ}$  I think the plant will die away. The Rev. Mr. Berkeley, the cryptogamic botanist, says of *Confervæ*, that ‘sometimes they abound to such an extent as to be extremely injurious, the smell is often disagreeable, and extremely unwholesome.’ I made enquiries respecting the health of the inhabitants as regards fever, ague, and diarrhœa, but heard of no complaints, the people being afraid to drink the water. As the stuff is blown about it does not collect in large enough quantities on the shore to contaminate the air, except at the immediate spot; this will I think prevent any sickness breaking out. The animals when sickened by it are first observed to be heavy and sluggish; they then get quite stupid, and take no notice of the whip or a kick, and if able to keep on their legs seem to forget themselves, and wander about quite unconscious of their actions; finally they drop, become convulsed, then weaken, and die calmly from sheer exhaustion of vital powers. Death is caused by blood-poisoning, the vital fluid being found to be black and uncoagulable throughout the whole body. Large quantity of serum around heart, which was flaccid, but not pale in colour; and in the abdominal cavity fully one and a half pints of serum were found. Brain not congested in substance, but the covering membrane very much so. The stuff must act as a ferment, and so disorganise the blood. It is totally and rapidly absorbed by the stomach in preference to and before the other food, as in all instances none was found in the stomach of the animals examined, not even in the sheep drenched with one and a half pints as thick as custard or porridge. I think there is but little hope of any medicine doing good, because the animal is generally too far affected for there to be any chance of

recovery. The plant is confined to the two lakes and does not exist either in the ocean or in the Murray River. That which appeared at sea must have passed out by the Murray Mouth during a northerly wind."

The plant is considered by Mr. Francis to be *Nodularia spurnigera*.—Mert. Payen.

## RECENT WORKS ON SPECTRUM ANALYSIS.

Spectrum Analysis, by Dr. H. Schellen, translated by Jane and Caroline Lassell, edited with notes by W. Huggins, with 13 plates, including Angstrom's and Kirchhoff's maps.

Lectures on Spectrum Analysis delivered before the Society of Apothecaries, by Professor Roscoe.

The Spectroscope and its Work, by R. A. Proctor.

On Spectrum Analysis applied to the Microscope, by W. T. Suffolk.

An Index of Spectra, by W. Marshall Watts, with a preface by Professor Roscoe.

The Spectroscope and its Applications, by J. Norman Lockyer.

How to Work with the Spectroscope, by John Browning.

## PART V.

ON TAKING PHOTOGRAPHS OF MICROSCOPIC OBJECTS — APPARATUS  
— ILLUMINATION — CHEMICAL SOLUTIONS — PRACTICAL MANIPULATION — PRINTING — PHOTOGRAPHS FOR THE MAGIC LANTERN.

Many improvements have been introduced in the method of taking microscopical photographs, and far greater perfection in the results has been obtained than was supposed to be possible some years ago. My friend Dr. Maddox has continued his experimental investigations and with continually increasing success; and many observers in Germany and France, as well as in America and in this country, have produced beautiful photographs of various kinds of objects. Some of the most perfect photographs of animal tissues I have ever seen were obtained by Mr. Hugh Bowman in 1875-6.

Very remarkable progress in this department was made in America in 1864. The authorities in the War Department recognising at once the high importance of photographic representations of microscopical specimens have issued a series of reports in which will be found the results of the researches of Brevet Lieut.-Colonel Dr. J. J. Woodward and Brevet Major Dr. F. Curtis. These reports are admirable. The drawings are beautifully executed, the paper well adapted for them, and the printing excellent, contrasting remarkably in all these points with the rough looking Blue Books issued under the authority of our Government. It seems to me very hard that British statesmen do not more distinctly announce that they fully appreciate the high importance of purely scientific investigation than has been the custom hitherto. Our Government clearly ought to take a very active part in advancing new methods of enquiry, particularly in connection with naval and military medicine and surgery. In the medical department of our army there are to my knowledge scientific men as able and as willing to devote themselves to scientific work as any in the world, but they have little opportunity, and little encouragement seems to be afforded by the high military authorities.

I append an extract from p. 149, Circular No. 6, Nov. 1865, War Department, Surgeon-General's Office, Washington, and hope that perchance it may be brought under the notice of some of those who alone

have power to forward or obstruct scientific progress in the departments under Government control.\*

“ With low powers no serious obstacle was encountered in obtaining excellent photographs of properly selected preparations. The higher powers offered difficulties most of which however have been overcome. In experimenting with the higher powers, the lined diatomaceæ were selected as test objects on account of their definite and well-known structure. With these the utmost success has been realised. A photograph of *Gyrosigma angulatum* (*Navicula angulata*) has been obtained, for example, magnified about 7,000 diameters in which the hexagons appear of the same size and nearly as distinct as in the cut, which was made by transferring to wood a tracing from the original photograph. In fact, any of the markings on the diatoms that are visible with the microscope can be photographed with the utmost clearness and ease, and the time has arrived when the inability to photograph alleged markings will throw doubts on the correctness of the observers who have supposed they saw them. The plan employed in the photographic work hitherto executed with high powers is as follows : The direct rays of the sun reflected in a constant direction from the mirror of a Silbermann’s heliostat (lent for the purpose by the Coast Survey), are condensed by a large lens upon the plane mirror of the microscope, whence they are reflected through the achromatic condenser in the usual way. Before reaching the achromatic condenser, however, the rays pass through a cell containing a solution of the ammonio-sulphate of copper of sufficient density to absorb nearly all the rays except those at the violet end of the spectrum. The light used, therefore, is essentially monochromatic, and contains, with enough illumination for agreeable vision, the greater part of the actinic force of the sun’s rays. The heating rays being chiefly at the other extremity of the spectrum are of course excluded and great actinic force is obtained, therefore, without any danger to the preparations, or the balsam used for cementing the object-glasses. The object-glass employed in the photograph of *Gyrosigma* above alluded to was a one-eighth of an inch, by W. Wales and Co., of Fort Lee, New Jersey. This glass is so constructed as to bring the actinic rays to a focus. At the bottom of the draw tube was placed an achromatic concave lens—the amplifier of Tolles (of Boston, Mass.), and an ordinary medium eye-piece com-

\* I believe that it would be most difficult, if not actually impossible for our Government at this time to issue a report of the character of that from which the extract is taken, supposing that the actual work had been done by private persons and placed at the disposal of the State. The paper of our Blue Books is too coarse, and the printing too rough for scientific memoirs. Let the reader, for example, compare the plates accompanying my report on the Cattle Plague, which were printed by Government, with those in the present work. The contrast between the text of Government and private works is still more striking.

pleted the optical apparatus. The eye-piece extremity of the microscope was thrust into one end of a long camera-box, the connection made light-tight by means of a black silk hood, and the image received on a piece of plate-glass, observed by means of a focussing glass, while the focal adjustments were made. As with the very long camera used, the arm of the observer cannot reach the milled head of the fine adjustment of the microscope, this head was grooved, and connected by a band with grooved wheel at the end of a long steel rod, the other extremity of which is near the observer, who, by means of it, can focus accurately with any required length of camera. There is nothing peculiar in the chemicals employed, and with ordinary collodion, and the high power above spoken of, from thirty to forty seconds' exposure was quite sufficient. On the foregoing devices most importance is to be attached to the employment of monochromatic light (the violet end of the spectrum), and the use of an object-glass constructed with special reference to the actinic rays. Both these points were suggested to me by Mr. L. W. Rutherford, of New York, so well known by his connection with telescopic photography, who has thought much, and made many satisfactory experiments in this direction. I believe, however, that the apparatus as above described, loses some of its advantages by the use of the eye-piece, which I propose to substitute by a lens of proper magnifying power, corrected, like the object-glass, in such a way as to bring to a focus the actinic rays. Such a lens is now in process of construction for further experiment. The pathological photographs hitherto satisfactorily executed in the Museum have chiefly been made with moderate magnifying powers, twelve to fifty diameters, though some experiments with high powers justify me in the belief that with the improvements above described, all that is desired in this direction can be attained. Among these experiments I may particularly mention a view magnified about four hundred diameters, of the polygonal cells and flat cholesterin tables of a cholesteatoma, which was found on the inner surface of the frontal bone of a soldier who died of epilepsy in the neighbourhood of Washington." Such an extract is enough to show the activity and usefulness of the department by which it is issued, and is in the highest degree creditable to those who performed the work, and to the Government which sanctioned and encouraged its prosecution.

**323. History of the Application of Photography to the Microscope.\***—Wedgwood and Sir Humphry Davy published, in 1802, experiments which must have been made some years previously, as Wedgwood died several years before this date. They obtained photomicrographic impressions on paper and leather, but these they were

\* Many of the sections which follow have been carefully revised by Dr. A. Clifford Mercer, of Syracuse, N. Y., who has kindly added much new matter of great importance.

unable to render permanent. These are believed to be, at the same time, the first experiments in photography and photo-micrography. (John Towler, M.D., in his "Silver Sunbeam;" Captain Abney, in "A Treatise on Photography," p. 2.) Mr. Dancer, about 1840, produced photographs of microscopic objects by the *gas microscope*, the images being taken upon silvered plates; also images of sections of wood, fossils, &c., were reproduced on paper and glass plates by means of the solar microscope. In 1841, Mr. Richard Hodgson obtained excellent daguerreotypes of microscopic objects. The Rev. J. B. Reade and the Rev. C. Kingsley and Mr. Talbot were early authorities in the employment of photography in connection with microscope observation. The Rev. J. B. Reade, then living at Peckham, as early as 1837 obtained and fixed photographs on paper, washed with silver nitrate and an infusion of galls. He succeeded by means of the solar microscope in photographing entomological specimens and sections of vegetable tissues. Two years later, in 1839, Mr. Reade exhibited more perfect results at a *soirée* given by the Marquis of Northampton, the President of the Royal Society. In the same year, it appears that some of his photo-micrographs were offered for sale at a bazaar at Leeds. (See a review in the "Medico-Chirurgical Review," July, 1864.) Dr. Donné, of Paris, in 1840, presented to the Academy of Sciences copies of various microscopic objects on daguerreotype plates. Moitessier, in his "La Photographie appliquée aux recherches Micrographiques," remarks:—"En 1845, ce savant (M. Donné) publiait, avec M. Léon Foucault, un magnifique atlas relatif à l'étude des fluides de l'économie, et contenant un grand nombre de figures gravées d'après des images daguerriennes."

In October, 1852, a paper by Mr. Joseph Delves was presented to the Microscopical Society of London, and in the following number of the "Quarterly Journal of Microscopical Science," some beautiful specimens of prints from Mr. Delves' collodion negatives were issued by the then publisher, Mr. Highley. This was one of the earliest publications in this country with photographic illustrations of microscopic specimens. Subsequently many workers appeared, among whom may be mentioned the following:—Highley, Shadbolt, Dr. Hugh Diamond, and Mr. Archer (1851), Busk, Hodgson, Durham, Maddox, Howlett, Bockett, Pollock, Wenham, Kingsley, Traer, Weightman, Davies, Parry, Wilson, Abercrombie, Taylor, Sanders, Viles, Herapath, Legg, Bowman; and in India, Gayer, Eddowes, and others. In France may be mentioned the names of Donné, Foucault, Nachet, Dubosq, Bertsch, Moitessier, Verroquier, Girard, Duchenne, Rouget, Lackerbaumer, Ravet. In Germany, Gerlach, Albert, Mayer, Kolman, Helwig, Reichardt, Stürenberg, Pohl, Weselsky, and Siebert, have illustrated memoirs with photographic plates. In Italy, Castracane. In Belgium, Neyt. In

the United States, Rood, Draper, Towler, Crehore, Dean, Rutherford, Woodward, Curtis, Seiler, Ward, Kempster, Deecke, Mercer.

Sir D. Brewster, in his article *Microscope*, "Encyclopædia Britannica," last edition, speaks very highly of some photomicrographs exhibited at the Academy of Sciences, Paris, in 1857, by M. Bertsch, the focal length of the objective used being half a millimetre. The objects, a diatom from guano magnified 500 diam.; two specimens of navicula, one  $\times 800$ , the other  $\times 500$ , the field being rendered nearly dark by oblique illumination; human blood globules  $\times 500$ ; and two pictures of salicine, taken by polarized light. M. Hartnach, Sir D. Brewster says, has constructed a complete instrument for M. Bertsch, the range being from 50 to 1,000 diameters, and from 50 to 150 diameters for opaque objects. The extreme detail, beauty of texture, and sharp delineation of the objects in the prints from Mr. Delves' negatives marked a very important step.

The frontispiece to former editions of this work was obtained by Dr. Maddox in the following manner, as described in a note to me:—"Prints selected from some of my negatives, representing objects magnified in various degrees, varying from the  $1\frac{1}{2}$  inch objective to the 1-12th, were placed on a card in such a manner as to try to balance each other in their effects, and such size of card adopted that when reduced *one-half*, it might correspond with the dimensions chosen by yourself for the plate. The card of prints being placed at the requisite distance, a Ross' 15-inch focus landscape lens was used to obtain the negative copies.

"To render the minutest line, especially in the *Pleurosigma angulatum*, well evident in the negative, it was necessary not to carry the development or intensifying process too far, or the lines became filled up and much obscured, hence the interspaces between the figures allowed a little light to pass; as this seemed detrimental and rendered the figures less effective in appearance, these parts have been painted out.

"The illustrations were photographed with the objective stated in the 'explanation.' The 1-12th objective was made by Mr. Wenham, and through his liberality placed at my service."

Many of these photographs require a magnifying glass to bring out their detail. My friend Dr. Dean, of Boston, U.S., sent me some very perfect photographs of sections of the medulla oblongata, taken with low magnifying powers. These are by far the most perfect photographic illustrations of structures from the higher animals that I have seen. ("The Grey Substance of the Medulla Oblongata and Trapezium," by John Dean, M.D., *Smithsonian Contributions to Knowledge*, 173. Washington, 1864.) These photographs were also successfully printed by photolithography. Dr. Duchenne, of Boulogne, also obtained some very successful results with anatomical structures, and M. Rouget has

employed the same means in the ordinary way and stereoscopically, to illustrate some of his views on minute structure. In 1865, Dr. A. Helwig, of Mayence, published his work "On the Crystalline Forms of Alkaloids, and their Sublimates," &c., illustrated by a large number of photomicrographs. Dr. Moitessier has also adorned his book on photomicrography, "La Photographie Appliquée aux Recherches Micrographiques, 1866," with three photograph plates of various objects.

Dr. Draper, of America, employed for many of the plates in his work "On Anatomy and Physiology," woodcuts from photographs of the microscopic objects, and Dr. Herapath, of Bristol, adopted a similar method for his paper on the Spicules and Plates of Synapta, published in the "Quarterly Journal Microscopical Science." Photography has been used by Dr. Maddox to illustrate a paper presented to the Royal Society, June, 1867; the photographs being made from an aquatic Larva whilst living.

Many anatomical specimens, however, cannot be copied by photography, especially if they be very thick. The yellow colour of the tissue in most instances precludes the possibility of making a photograph of it, as the transmission of the light is so much interfered with; and this is an especial objection in the case of injections viewed as transparent objects, for the tissue intervening between the vessels is often so yellow that these intervals in the photograph become as dark as the vessels themselves. My friend Dr. Julius Pollock nevertheless succeeded many years since in obtaining some very tolerable copies of injections of the distribution of the ducts in the liver. And Dr. Maddox and Mr. Hugh Bowman have been still more successful.

When only few copies of a work are required, the researches may be very cheaply illustrated by taking photographs of drawings. A large drawing of the object must first be made in the manner described in p. 33. From this a negative reduced to the proper size is taken, from which any number of copies may be obtained. In this manner I have illustrated my memoir on the Anatomy of the Liver, with upwards of sixty illustrations ("The Anatomy of the Liver," 1856). The results were not so satisfactory as they might have been, but as all the prints were prepared at home with very limited appliances, very good prints could not be looked for. When many copies of a work are likely to be required, this mode of illustration is not applicable, as the original cost of engraving would soon be covered; but when only a *few* copies of a *great number* of drawings are wanted, this plan possesses decided advantages.

From the improvements in the Albertype, Woodburytype, photolithographic, and other similar processes, there seems every chance that the cost of illustration will be materially lessened. Dr. Woodward has employed some of these processes, and Dr. Seyler has, by one of them,



illustrated his work, "Micro-Photographs in Histology, Normal and Pathological." (Macmillan and Co.) The prints are, however, photomicrographs, and not *micro-photographs*.

#### INSTRUMENTS AND APPARATUS FOR MICROSCOPE PHOTOGRAPHY.

Two methods of arranging the instruments and apparatus have been devised :—

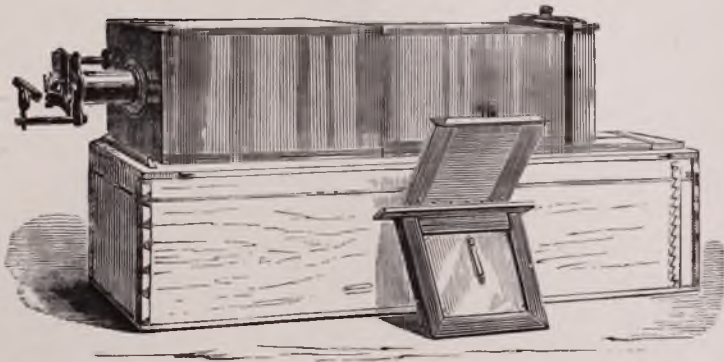
In the first, the ordinary compound microscope is placed horizontally in connection with an ordinary camera by inserting the eye-piece end (the eye-piece being removed) into the brass setting of a well-made portrait combination (the lenses having been removed), and the aperture around the body of the microscope perfectly closed by any simple method, as a card cap or cone of black cloth or velvet attached to both.

In the second, the ordinary microscope is dispensed with, the objective, stage, and mirror being adapted to the front of a well-made camera in the place of the usual combination ; proper arrangements being made for holding the object, supporting the mirror, and adjusting the different special parts. The pocket microscope described in p. 17, may be adapted to the camera.

**324. Camera with Object-Glasses and Stage adapted to it.**—The apparatus used by Mr. Delves was brought before the public by Mr. Highley, and very much improved by him. This form of apparatus attracted considerable attention at the International Exhibition, 1862. M. Duboscq also exhibited this arrangement. It seems to meet most requirements for moderate distances, but demands especial outlay. Mr. Highley has lately introduced further improvements, which make his apparatus still more perfect. See pl. LXVIII, fig. 2.

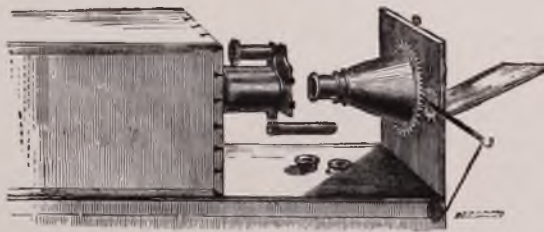
**325. Mr. Wenham's Arrangements without a Camera.**—Mr. Wenham dispenses with the use of the ordinary camera, and yet attains an equally good result. He recommends that a room be selected having a window or aperture with free access to sunlight. This is to be closed by a shutter having a hole about 3 inches in diameter ; upon the outside of this aperture is arranged a solar reflector or plane mirror, in such a manner as to be capable of being worked round its centre at the necessary angle, on the outside, by passing the hand through another hole in the shutter to the margin of which a flexible sleeve is attached. The microscope body is arranged horizontally on a table or bench, so that its axis corresponds to the centre of the aperture. The stage with the object slide clamped on it in proper position, is placed near this aperture on the inside, the light around the stage being shut off by a piece of black cloth. On the bench a vertical stand, consisting of a board with a heavy base, is placed at any desirable distance from the

Fig. 1.



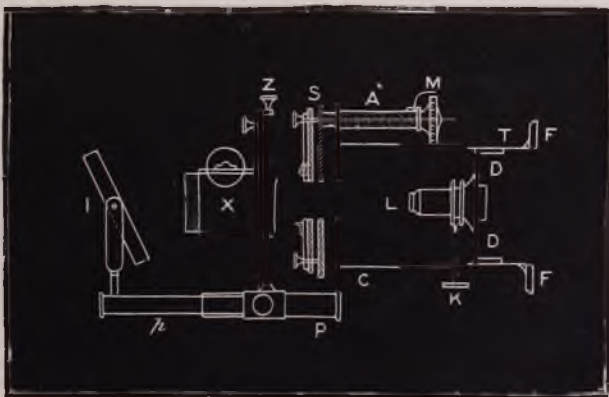
Photographic microscope camera used by Mr. Delves, arranged by Mr. Highley p. 290

Fig. 2.



Stage mirror condenser with adjustment to fit on the end of the above camera (Fig. 1).  
Mr. Highley p. 290.

Fig. 3.



Another arrangement showing the object glass, stage, fine adjustment, &c., with mirror and condenser. Mr. Highley. p. 290.



eye-end of the microscope ; this board is supplied with two "under-cut fillets" to hold the sensitised plate when ready. The mirror is first properly arranged so as to throw an equal illumination on the vertical frame-board, a card being previously placed in the exact plane to be occupied by the prepared plate. The image is now focussed on the card. If the operation of exciting the plate is to be performed in the same room, sufficient light for the purpose is admitted through a small pane of yellow orange non-actinic glass let into the top part of the shutter. When ready the card is removed and placed against the open end of the microscope tube, so as to cut off all light through it ; the plate is drained and placed on the vertical frame, the card quickly lifted and replaced against the end of the tube in periods varying, according to the time of exposure necessary, from part of a second to half a minute. The time required will vary according to the quality of the light, the sensibility to it of the collodion or other material used, and the facility with which the actinic rays pass through the object.

Mr. Wenham enumerates several advantages gained by this method. The length of base-board is limited only by the dimensions of the room. The ease with which any object can be included in a definite space. Facility in focussing. A means of so placing the card or sensitised plate at any angle to the axis of the microscope so that the surface may be made parallel to objects lying a little out of one plane. By having a series of paper stops at hand, parts situated in planes, slightly removed from each other, can be focussed and impressed alternately. While the first part is being impressed, the other part is stopped off ; this is then stopped off, the other part focussed and its image allowed to fall in its turn on the unaffected portion of the prepared plate. Again, the thicker and thinner parts of the same object may be exposed for different periods of time, by which a uniform intensity may be obtained in spite of the variable transparency of different parts.

For the low powers the plane mirror, but for the  $\frac{1}{2}$ -inch objective and higher powers some form of condenser is used, as a bull's-eye lens, about 3 inches diameter. But for the finer forms of objects, as diatoms, the bull's-eye lens is to be combined with a condenser of the form proposed by Dr. Woodward in April, 1861, for his binocular microscope. This consists of a set of three plano-convex lenses varying in diameter from about  $1\frac{1}{2}$  inch to  $\frac{1}{2}$  an inch, placed near to each other with their flat surfaces towards the object. These combined possess a very large angle of aperture. The small lens being made separable from the others, a large field of illumination could be obtained for the lower powers.

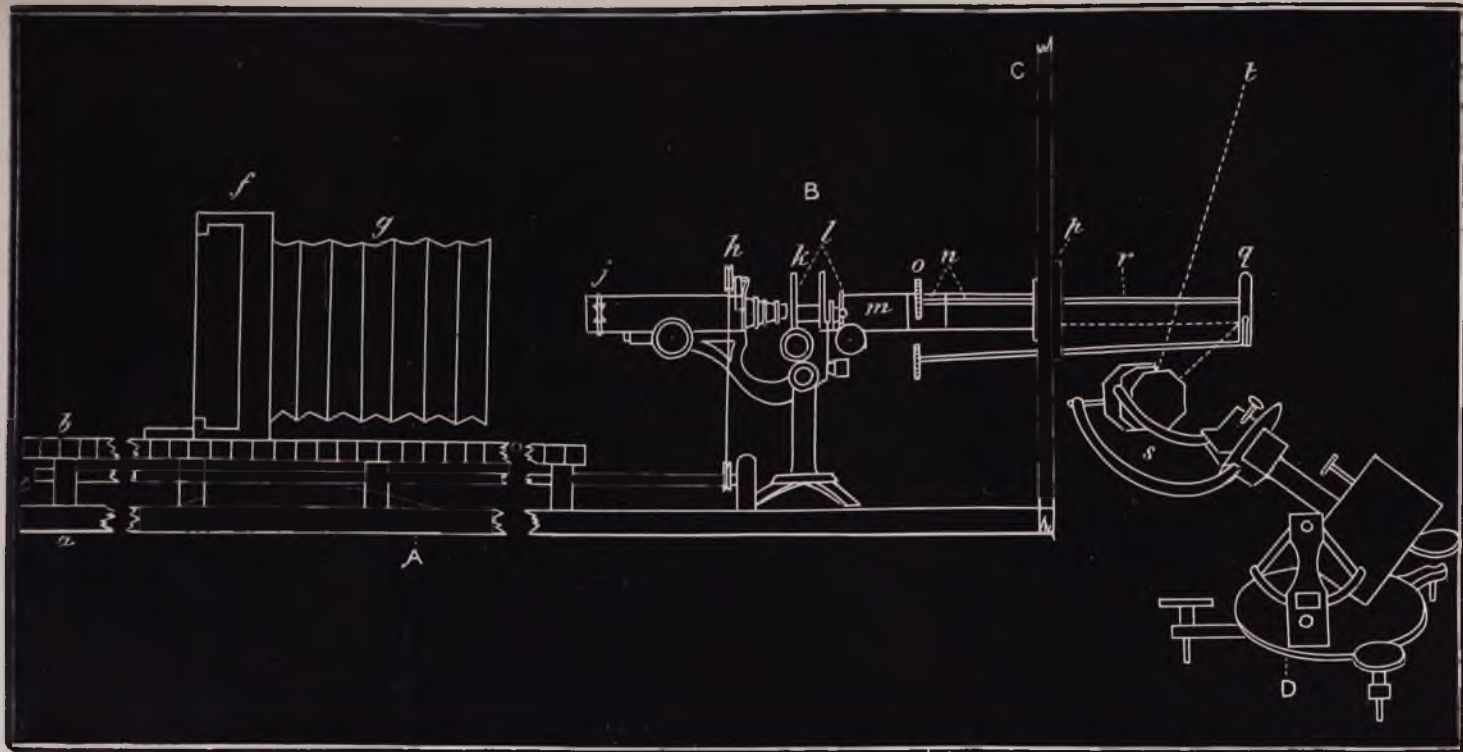
**326. Brevet Lieutenant-Colonel Dr. Woodward's Method.**—This will be a suitable place to introduce the plan adopted by Lieutenant-Colonel Dr. Woodward, at the Army Medical Museum, U.S., reprinted

in the British Journal of Photography for October 12, 1866. "A camera is not used, a dark room being found most convenient. The operating room has two windows, through one of which just enough yellow light is admitted to permit the movements of the operator. The lower part of the other window is occupied by a shutter about fourteen inches high, on which the blackened sash shuts down light-tight. In this shutter is a round hole an inch and a-half in diameter, from the inner side of which a brass tube of the same diameter projects into the room. On the outer side of the hole is a rod about twelve inches long, on the extremity of which the microscope mirror is duly centered. Two steel rods attached by hooks in the mirror and passed through the shutter, permit its position to be adjusted by a person standing inside of the room, without opening the window. A Silbermann's heliostat standing on a shelf just outside of the window, throws the sunlight steadily upon the mirror. Within the room a frame of walnut, ten feet long, is placed on a firm table perpendicular to the window. The microscope stands on the end of this frame next the window; its mirror is removed, being replaced by that outside the shutter. The microscope is placed in a horizontal position, and the tube carrying the diaphragm or the achromatic condenser fits into the tube projecting inward from the shutter, by which the sun's light reflected from the mirror outside is admitted. A black velvet hood covers the parts about the stage and objective of the microscope, and thus prevents the leakage of light into the room. Pl. LXIX.

"The plate-holder is movable backward and forward on the walnut frame on which the microscope stands, its maximum distance from the stage of the microscope being nearly nine feet.

"To permit ready focussing at distances greater than the length of the arm, a wooden rod three-fourths of an inch in diameter and capable of easy rotation runs the whole length of the right side of the frame. The milled head of the fine adjustment of the microscope is grooved, and a grooved wheel in the end of the rod permits the two to be connected with a band. The operator standing at any part of the frame can therefore manipulate the fine adjustment by simply turning the wooden rod in his fingers. The arrangements of light, position of object, coarse adjustment, &c., are made by the operator, who stands by the microscope, which has a suitable eye-piece adjusted, and observes the object in the usual way; afterwards removing the eye-piece and going to the plate-holder, the final focus is made by means of the wooden rod, the image being viewed with a focussing glass on a piece of *plate-glass* held in the same frame which is to receive the sensitive plate.

"The cell containing the ammonio-sulphate of copper hangs outside the shutter over the hole by which the light is admitted. It not



A represents a heavy walnut frame. *a* baseboard *b* framework upon which the frame for the plate-holder slides. (This is graduated into feet and inches) *c*, long focusing rod, rotating and carrying on its lower end a grooved wheel *d*. A silk cord *e* connects this wheel with the fine adjustment of the microscope *f*. The operator standing at any position along this frame can focus by turning the rod. *f*, frame to hold the plate-holder *g*, bellows camera, with open end to shut off any side light. **B** Microscope standing upon the baseboard *h* grooved wheel for fine adjustment *i*, objective, *j*, position of concave amplifier, *k* stage, *l* achromatic condenser *m* barrel of the same size as that which carries the objective. **C** Section of shutter fitting light-tight into a window, having a circular aperture the same size as the barrel of the microscope. Into this aperture fits the end of a sliding brass tube *n*, which forms a light-tight continuation of the barrel *m* of the microscope. At *o* is placed the cap holding the ground glass *p*, section of blue cell of ammonia-sulphate of copper, hanging over the aperture in the shutter. *q* mirror of the microscope. *r* steel rods which pass through the shutter by which the mirror may be adjusted from within the shutter. **D** Heliostat, standing outside the window *s*, mirror of heliostat. *t* direction of solar ray. p 292.



only excludes the unnecessary illuminating rays, but prevents danger to the objective from the concentrated solar heat, and permits the eye of the operator to view the objects about to be copied without fatigue or injury. Latterly a plate of alum has also been used to exclude solar heat, especially during any temporary removal of the ammonio-sulphate cell. The chemical processes employed are well known to all photographers. With the above apparatus, it has been found that the best defined pictures are obtained when the distance employed with any objective does not exceed three or four feet.

"The achromatic concave used as a substitute for the eye-piece, is a combination of somewhat more than half an inch transverse diameter, and about  $28^\circ$  angle, constructed like the objective to focus the chemical rays. It increases the magnifying powers of the objective about seven times. It has been found to perform well with both the  $\frac{1}{8}$ th and 4-10th.

"In photographing the soft tissues or other objects in which illumination with parallel rays produces interference lines, the ground glass is to be placed between the mirror and condenser. Of course there is considerable diminution of light, but this can be overcome for the higher powers by condensing the sun's light on the ground glass by a bull's-eye, or other similar contrivance. If the interference lines as seen by the eye do not disappear with one thickness of ground glass, two or more may be used."

Dr. Woodward, in the same article lays down the following principles:—

"1. To use objectives so corrected as to bring the actinic rays to a focus. 2. To illuminate by direct sunlight passed through a solution of ammonio-sulphate of copper, which excludes practically all but the actinic extremity of the spectrum. 3. Where it is desired to increase the power of any objective, to use a properly constructed achromatic concave instead of an eye-piece. 4. To focus on plate-glass with a focussing glass instead of on ground glass. 5. With high powers to use a heliostat to preserve steady illumination. 6. Where an object exhibits interference phenomena when illuminated with parallel rays, as is the case with certain diatoms and many of the soft tissues, to produce a proper diffusion of the rays by interposition of one or more plates of ground glass in the illuminating pencil."

Dr. Woodward sent me photographs of a part of a frustule of *Pleurosigma angulatum* taken by him. The original negatives were obtained in the one case by Messrs. Powell and Lealand's 1-50th, and magnified to 2,344 diameters; in the other case, by a  $\frac{1}{8}$ th, made by Mr. Wales, of Fort Lee, New Jersey, and used with his achromatic concave magnified to 2,540 diameters. Both of these negatives were afterwards employed to procure positives, and from these, by one en-



largement, the enormous magnitude of 19,050 diameters was obtained. The former gave, if anything, rather the sharpest picture, especially in the centre, the latter the flattest field with most excellent definition. These negatives were taken on collodion prepared plates, and the exposure given was seven minutes. They are convincing as to the excellence of the plan adopted, and the skill and patience of the operators, Drs. Woodward and Curtis. It remains to be seen whether by adopting other plans we may not get rid of some of the expensive parts of the apparatus, namely, the heliostat, and Dr. Maddox made some experiments in this direction, by means of a solar microscope. He found that an ordinary collodion sensitised plate, required an exposure of from 90 to 110 seconds strong sunlight in December and 70 seconds in May, *Pleurosigma formosum* being the object in the first case, *Pleurosigma angulatum* in the second. The magnifying power was 2,500 diameters. The  $\frac{1}{8}$ th object-glass was used with an achromatic concave, a large plane silvered mirror, a  $3\frac{1}{2}$ -inch diameter and  $8\frac{1}{4}$ -inch focus condenser, and a single pair of plano-convex condensers with a large central stop. Dr. Maddox considers that the lengthened exposure was due to the fact that the  $\frac{1}{8}$ th was made with four sets of lenses, the front being a single lens. With an excellent  $\frac{1}{8}$ th with three sets of lenses and an achromatic concave, made for him by Mr. W. Wales, of Fort Lee, New Jersey, U.S., especially for photographic purposes, the time of exposure was rather less; and with a triple condenser Dr. Maddox found that in June, 35 seconds were sufficient for *Pleurosigma angulatum* magnified 3,000 diameters, the ammonio-sulphate of copper cell being used. From a short experience with this instrument, both with and without the ammonio-sulphate of copper cell, he thinks a prism either according to the plan used in his smaller camera arrangement, or as adopted by M. Neyt and Count Castracane, preferable to a mirror for illumination with the high powers. To adapt this objective to ordinary use, Mr. Wales supplies a separate back set of lenses to replace the photographic set, which answers well, the workmanship in the construction of the mount being most perfect.

**Dr. Woodward's Improved Arrangements for taking Photographs of Microscopic Objects.**—The description of a more perfect and convenient plan than the one originally adopted by Dr. Woodward, at the Laboratory of the Army Medical Museum, Washington, U.S., is given below.

“For the sake of convenience a camera box and table are dispensed with, and the operating room having a window facing to the south, is itself converted into a camera by wooden shutters on the inside of the window, sufficient non-actinic light to enable the operator to move about freely being admitted through yellow panes in a sashed door. A small yellow pane is also let into one of the window shutters to enable

the operator to watch the sky during an exposure and see when clouds are about to obscure the sun. The microscope with its body in a horizontal position, stands on a shelf, on the inner window sill, its feet fitting into brass sleets to insure accuracy of position, pl. LXX, fig. 4. Covering the portion of the window towards which the microscope points is a stout immovable shutter, having a square opening to receive a movable piece which fits into it with a rebate, and is held in a position by four wooden buttons. An aperture is cut in this movable shutter (*see* fig. 1) of the same diameter as the short body of the microscope, and in a direct line with it; a light-tight connection is made between the two by a sliding brass tube (*b*) fitted to the shutter. This aperture can be opened and closed at will, to make the exposures, by a brass plate (*c*) playing over the outer face of the shutter on a pivot, which, passing through the shutter, is worked by a handle (*d*) from within the room.

“ This brass plate is sunk into a shallow space cut in the shutter so as not to project beyond its surface. Over the plate and covering the aperture is fastened the glass cell (*e*) containing the blue copper solution. Immediately below the edge of this cell a piece of brass tubing (*f*) thirteen inches long, is screwed to the shutter, carrying at its extremity the microscope mirror (*g*), accurately centered opposite the aperture in the shutter. This mirror is adjustable from within the room by means of two steel rods (*hh*) attached to its framework by ball and socket joints, and projecting into the room through small holes in the shutter. One of these rods moves the mirror upon its vertical, the other upon its horizontal axis. The heliostat stands on an iron shelf, outside the window, in such a position that its mirror is a few inches only distant from the microscope mirror and in a north-westerly direction from it, fig. 4, *a*.

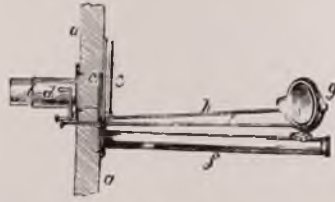
“ The frame for the plate-holder, instead of standing upon a table, is supported upon a narrow walnut car, running upon an iron track ten feet long, laid upon the floor at right angles to the plane of the window (*see* fig. 4). This car consists essentially of a base made of four pieces of wood joined together so as to leave an opening in the centre eight inches square, and two stout uprights, connected by a cross piece, which rise from the side pieces of this base and have a V-shaped way cut on their inner faces to receive the sliding sides of the top of the car. This top can thus be adjusted to any height, and clamped in position by wooden binding screws, so that negative plates of different sizes may be used if desired, and centered to the axis of the microscope body. The track (*see* fig. 2) consists of two wooden rails (*cc*) an inch high, screwed to the floor, upon which in turn are screwed flat iron rails (*bb*) whose inner edges project half an inch beyond the wooden rails. These iron rails are cast with a  $\Lambda$ -shaped projection on their upper faces, and

the base of the car is furnished with small brass wheels (*aa*) correspondingly grooved to run on these projections. The car can be firmly fixed upon the track at any position by the following means. Through a hole in the centre of the cross piece (*d*) connecting the sides of the car, runs a vertical iron rod (*e*) supporting at its lower extremity a cast cross iron piece with flat ends (*f*), which hangs transversely to the direction of the track through the central openings in the base of the car. The ends of this cross piece reach under the projecting inner edges of the flat iron rails (*bb*) and are made to clamp against their under surfaces by a nut with handles (*g*), screwing on the upper part of the iron rod, and binding on an iron washer on the wooden cross piece (*a*) through which the rod runs. The car can thus be fixed upon the track at any distance from the microscope within ten feet, and the distance that the surface of the negative is from the stage of the microscope in any given position is determined by a scale of feet laid off upon the floor close to one of the rails, and a scale of inches on the side of the base of the car (*see* fig. 4).

“ To obtain the final focus of the image upon the plate in the plate-holder, the following contrivance is used (*see* fig. 3). A perfectly straight cylindrical iron shaft (*a*), runs the entire length of the track, midway between the two rails, and at such a height as just to clear a groove on the under surface of the base of the car. This shaft has a shallow square groove cut in it along its entire length, and is supported at each extremity by brass bearings attached to the floor, in which it turns freely. To the posterior cross piece of the base of the car is fastened a bent brass bearing (*b*), projecting into the square opening in the base of the car and supporting two bevel gear wheels (*c*) working into each other. The upper and horizontal one of these wheels is turned by a vertical iron rod (*d*) attached to it, which is furnished at its upper extremity with a large milled head (*e*) and is supported by a collar (*f*) attached to the cross piece connecting the sides of the car. The lower and vertical wheel is pierced to allow the passage of the long shaft (*a*), and from the surface of the bore a small square iron tongue projects, exactly fitting the longitudinal groove in the shaft. By this means, no matter what may be the position of the car upon the track, the operator can rotate the shaft (*a*) through the pressure of this tongue upon the sides of the groove, by turning the milled head (*e*) connected with the bevel wheels. At the same time the car can be moved freely over the track, the iron tongue running smoothly to and fro in the grooves of the shaft. This long shaft (*a*) is made to turn the fine adjustment wheel of the microscope by the following means (*see* fig. 4). Attached to the edge of the shelf, upon which the microscope stands is a short iron axle parallel to the grooved shaft below, which turns freely in two flat brass bearings, and supports two

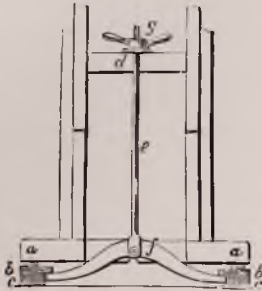
ARRANGEMENT FOR PHOTOGRAPHING MICROSCOPIC OBJECTS.

Fig. 1.



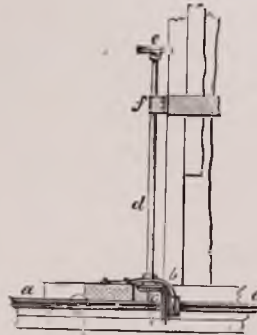
Section of moveable shutter with apparatus attached. *a* shutter; *b* sliding brass tube to join the short body of the microscope; *c* brass plate to close the aperture in the shutter; *d* handle to work the same from within the room; *e* glass cell containing the blue copper solution; *f* brass tube carrying the microscope mirror; *g* mirror; *h* *h* steel rods to adjust the mirror from within the room. P. 295

Fig. 2.



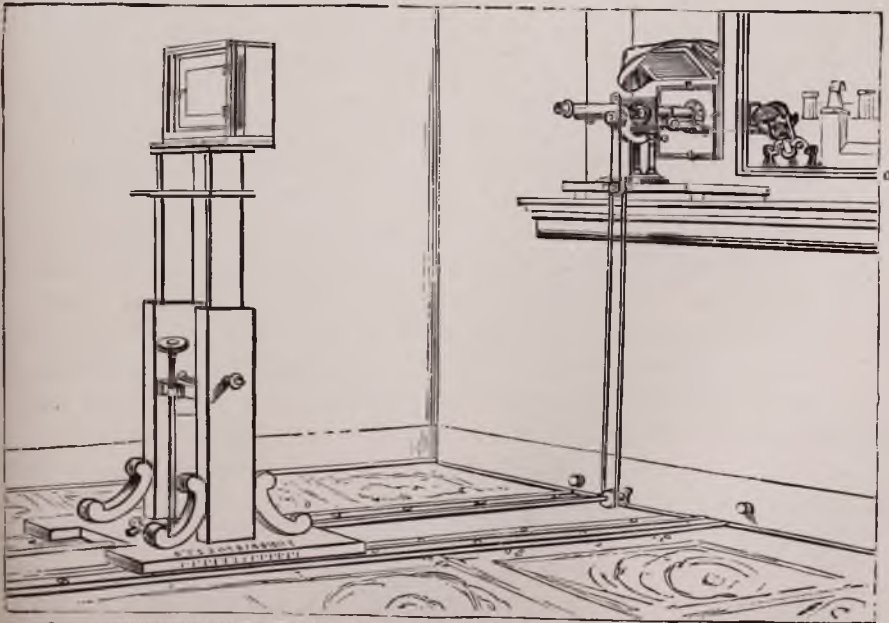
Transverse section of car and track, to show the rails and the apparatus for clamping the car to the same. *a* *a* small brass wheels grooved; *b* *b* flat iron rails with a A-shaped projection to fit the groove into the wheels; *c* *c* wooden rails; *d* cross-piece connecting the sides of the car; *e* vertical iron rod passing through the same; *f* cast iron cross-piece to clamp under the iron rails; *g* screw nut, with handles, to elevate the same. p. 296

Fig. 3.



Longitudinal section of posterior half of car, to show the apparatus for obtaining the focus of the image. *a* grooved iron shaft running the whole length of the track and passing under the car; *b* bent brass bearing supporting two bevelled gear wheels; *c* bevelled gear wheels; *d* vertical iron rod attached to the upper wheel; *e* milled head on the upper extremity of the same; *f* collar to support the iron rod.

Fig. 4.



General arrangement of Dr. Woodward's apparatus for taking photographs of microscopic objects as seen in the room. The heliostat is seen outside the window. *a* The mechanism of the several parts is shown in Figs. 1, 2, 3. p. 297.



wheels. One of these, a small brass wheel, is grooved and connected by a silk thread, removable at pleasure, with the fine adjustment wheel of the microscope, which is also grooved. The other, a large wooden wheel, is connected permanently by a flat leathern band with a similar wheel attached to the long iron shaft below.

“ The steps in the process of photographing by the above described apparatus are as follows :—The movable shutter, with the apparatus attached, is buttoned in position, the heliostat set in place on the shelf outside the window and properly adjusted, so as to throw the rays reflected from its mirror upon the microscope mirror at the extremity of the rod on the shutter. The window shutters may now be closed and need not again be opened. The microscope is then placed in the proper position upon the shelf inside the window, and the silk thread adjusted which connects the fine adjustment wheel with the wheel on the edge of the shelf. The operator then, sitting on a stool in front of the microscope, and inserting an eye-piece, views the object as in the ordinary use of the instrument. This he is enabled to do without discomfort or injury to the eye, since the light transmitted by the solution of ammonio-sulphate of copper, though *photographically* intense is *luminously* comparatively feeble, and is also deprived of a large proportion of its heat rays in its passage through that medium. While thus seated at the microscope, the operator makes the necessary adjustments of the stage, achromatic condenser, diaphragms, &c., having perfect control of the illumination by means of the steel rods attached to the mirror without the window and projecting into the room through the shutter. While making these adjustments he commands the fine adjustment wheel by the fingers in the usual way, the wheel readily slipping under the thread that connects it with the wheel on the shelf below. These adjustments being made, the best view and proper illumination of the object secured, the eye-piece is removed, and a black velvet hood attached around the edges of a hinged shelf projecting from the shutter (*see* fig. 4), is lowered so as to envelope all of the microscope but its body, thus preventing any leakage of light by the side of the objective. The operator now goes to the car, adjusts its position, noting its distance from the microscope by the scale on the floor and side of the base of the car, as already described, and clamps it firmly in place. He then sits down behind it and receives the image upon the surface of a piece of plate-glass held in the plate-holder, viewing it with an eye-piece held against the glass plate, whose focus corresponds exactly with the anterior surface of this plate. He next turns the milled head that operates on the apparatus for turning the fine adjustment wheel of the microscope, until the image, viewed as just described, appears in exact focus upon the surface of the plate-glass screen. The aperture in the shutter is then closed by means of the brass plate with handle inside the room,

the sensitive plate substituted for the plate-glass screen in the plate-holder, and the exposure made by opening and closing the movable shutter by the means already described. The time of the exposure is noted by the beats of a metronome, adjusted to strike at second intervals, the dimness of the yellow light in the room rendering the use of a watch inconvenient. Having obtained the negative, a stage micrometer is substituted for the object photographed, and its divisions, as projected upon a piece of ground glass held in the plate-holder, are carefully traced upon paper. By comparing these with a standard scale, the exact amplification of the object as represented in the negative, is readily calculated. Other negatives, representing the same magnifying power, can then be taken at any time by using the same objective and placing the car at the same distance from the microscope. The ordinary wet collodion process is the one used in the preparation of the negatives."

"A bright white cloud illumination is obtained by throwing the beams of light from the mirror on to a piece of greased ground glass placed in the short body of the microscope, below the achromatic condenser, by which the interference lines so often resulting from employing the unmodified sun's rays are destroyed, and long exposures with high powers permitted." In some cases Dr. Woodward omits this ground glass. The objectives and amplifiers, as made by Mr. W. Wales, of Fort Lee, New Jersey, "are specially corrected so as to bring to one focus the rays in the violet end of the spectrum, where the actinic power resides."

The violet light is also "obtained practically pure by interposing in the solar beam reflected from the mirror a shallow cell, with plate-glass sides, containing a solution of ammonio-sulphate of copper."

When other objectives have been used they have been the ordinary achromatic lenses of other makers; the 1-50th of Messrs. Powell and Lealand gave excellent results in the hands of Dr. Curtis, as proved by the prints sent to this country. Dr. Woodward lately forwarded to Dr. Maddox some observations for publication, on the result of comparative experiments made with a flint-glass prism and lens to increase the dispersion of the violet ray for the necessary exposure, and the ammonio-sulphate of copper cell, the light employed being the same, in both cases reflected from a plane mirror. It was found by using a sensitised collodion plate that the actinic power was in favour of the light transmitted through the cell; or, in other words, that the loss by dispersion was greater than the loss by absorption in its transit through the cupreous solution. The details of this judicious and well-directed experiment testify to the care bestowed on these matters at the Government Laboratory.

**327. Mr. Deecke's Arrangements, Method, and Object.**—Mr. Deecke,

Special Pathologist, New York State Lunatic Asylum, has in the main adopted the plan of Dr. Woodward. He uses a large heliostat, which moves on a car from a shelf outside to a movable stand in the room, while, when not in use, it is kept covered by a glass case. His condenser is 4 inches in diameter, has a focus of 18 inches, and can, by the aid of setting screws, be turned about a horizontal as well as a vertical axis. Projecting from it towards the heliostat is a cylinder,  $4\frac{1}{2}$  inches in diameter and 12 inches long, for excluding all direct rays from the sun. Projecting from it into the dark room is a conical tube, 14 inches long, tapering from 4 to 2 inches in diameter. The microscope rests on a stand, which can be made level by four screws. Between the condenser and the specimen-holder is placed a curette with parallel walls, of the finest plate-glass, which contains a weak solution of ammonio-sulphate of copper composed as follows:—sulphate of copper, 20 parts, water 100 parts, and liquor ammoniæ, q.s., to dissolve the precipitate at first formed, and then diluted to 300 parts. This curette is used while focussing, but just before the exposure of the sensitive plate, it is removed and replaced by its fellow, containing a solution of the same strength of potassio-sulphate of copper. The spectrum of the visual rays passing through the first corresponds closely with that of the actinic rays passing through the second. (For a fuller explanation, see Moitessier's work, pp. 183, 184, and 185.) By taking away the curette the specimen can be examined by ordinary light. The objective, which can be replaced by one of the various sizes of landscape or portrait combinations, is so mounted as to be easily centred by screws. Between the objective and the curette is a frame to hold the object, and which, by means of screws, centres the object and renders its surface perpendicular to the pencil of light. The distances between the condenser and the curette, the latter and object, and the object and the objective can be varied at pleasure. The screen and sensitive plate-holder are arranged on a car, so that they can be moved up, down, to the right, to the left, or inclined in any direction from the perpendicular, to compensate for any obliquity in the surface of the object. The screen is a piece of plate-glass, covered on one side with white and on the other with yellow paper. The holder will take a sensitive plate from 4 inches by 4 inches, to one 18 inches by 20 inches. The track on which the car moves is 40 feet long. A distance approaching this is only required when a landscape or portrait combination is used to obtain a large field. A contrivance of pulleys for focussing can be used at any point along the track. When the screen is some distance from the window the arranging of the object and coarse focussing is done near the window while the screen is seen by an opera-glass. When the exposure is longer than a second, the time is noted by a pendulum beating seconds. In shorter exposures, when very low powers are used, a guillotine arrangement stands just behind the objective, and as it drops allows a



slit to pass across the pencil of light. Only as the slit passes does any light from the objective reach the sensitive plate. The mechanism of the guillotine is such that it can be adjusted to expose accurately during one second, one-half, one-quarter, one-eighth, or one-tenth of a second. Sometimes, even when the landscape or portrait combinations are used, the field is not as large as required. In such cases, Mr. Deecke divides the object into square portions, by spider lines, and photographs each of these separately. The prints are combined to make photographs 18 inches or more in diameter. In this way exceedingly beautiful studies of the topographical anatomy of the nerve centres, the sole object of Mr. Deecke's photo-micrography, have been obtained. An important factor in these results is Mr. Deecke's skilful manipulation, with his own very large and most ingenious microtome, by which he is able to cut sections 1-400th of an inch in thickness, for slides 8×6 inches, through even the whole brain, and in this operation he loses only about 1·5 *per cent.* of his material. The specimens may be examined by all powers up to Wales' one-tenth of an inch.

**328. Camera applied to the ordinary Microscope.**—We may now consider the plans for employing the microscope and camera united. Mr. Shadbolt recommends the draw tube, if any, to be removed, and its place supplied with a lining of black velvet. The microscope is fixed horizontally on a board or table, and the body made to correspond to the centre of the aperture left on the removal of the lenses from the brass setting of an ordinary camera. The intervening space being closed in such a way as to exclude all entrance of extraneous light. The draw chamber of the camera is employed to vary the distance of the image from its object, but is usually deficient in length, hence some plan for elongating this chamber is needed. Many complain that when using the microscope in this way, some uncertainty in the centering, and liability to derangement when exchanging the focussing screen for the prepared plate are experienced. Gerlach adopts a very different arrangement. The camera is adapted to the top of the tube of the microscope which is placed upright, pl. LXXI, p. 304, fig. 1.

**329. Dr. Maddox's Camera.**—The instrument proposed by Dr. Maddox, and used by him, consists of a microscope having a compass-joint at the lower end of the stem furnished with coarse screws, &c. The stage slides along the stem, and can be clamped to it by a binding screw against a guide that runs along its length. This stage is provided with small rectangular movements attached to the part holding the object slide, and to its opposite side is fixed a stout tube to hold an achromatic or some form of condenser. The main part of the stem is hollow, and receives a strong tube furnished nearly in its entire length with a slot that works on an internal guide fixed inside the stem.

This tube carries at its near end an arm, at right angles to which a tube

about five inches long is screwed on the near side, and on the opposite side an adapter is fitted to receive the screw-end of the objective. An approximate focus is effected by sliding the stage along the stem, and the fine motion by a graduated milled headed screw-pin. This pin passes through the tube to which the arm is fastened, and engages in a thread cut in the solid end of the stem. A spiral wire coiled in the inner tube reacts on the arm when the milled headed screw is withdrawn.

The whole of these arrangements are fixed firmly by the screw and nut at the jointed ends of the stem, to a rectangular cross piece of 3-16ths iron bar about two inches wide, the screw passing through a hole near its centre. This cross piece is turned down at right angles on each side so as to bring the centre of the short microscope tube in the centre of the camera, then again turned at right angles and firmly screwed to a stout base-board of deal  $1\frac{1}{4}$  inches thick, 12 inches wide, and 48 inches long, and clamped at each end to prevent warping. This is supported over a wide movable triangle, having stout double-hinged triangle legs of a height convenient for the operator (3 to 4 feet), pl. LXXI, p. 304, fig. 2 A. About 12 inches from the end of the base-board where the microscope is fixed, is hinged a stout square frame with a sliding door having a central aperture to allow the end of the microscope tube to work through. The inside of the aperture is lined with leather, and a thick velvet collar is made to slide along the tube and abut against the aperture in the door, so that when in use the entrance of any extraneous light is effectually prevented. The frame with door is turned on its hinges, until it stands exactly at right angles with the axis of the microscope, and is kept firmly fixed in this position by two stout brass struts with clamping screws, that rise from the base-board on each side of the frame at an angle of  $60^\circ$ . At the opposite end of the stout plank is placed an ordinary camera with a movable door-front having a *large* central aperture. One end of an expanding bellows body is fastened to it, the other end being attached to the door that slides into the vertical frame. This bellows part is made of two thicknesses of black twilled calico, having pasted between them a corresponding sized sheet of stout brown paper, and folded into one-inch plaits when damp, then turned over square to the size corresponding to the sliding doors, the corners bent down like the bellows of a common accordion, and the overlapping edges which are turned so as to face the base-board are double sewn together throughout their length; or for this may be substituted a body of black calico, of treble thickness, attached at each end to the doors, and kept apart laterally by elastic bands sewn along its four edges, lengthwise. The camera is made to slide along the supporting board between wooden guides screwed to its upper surface near the sides, extending from the near end to the vertical frame. These have small holes at corresponding equal

distances of half an inch, and projecting from each side of the body of the camera is a pierced horizontal ledge of brass plate, about 5-8ths of an inch wide, that travels over the upper surface of the guides on the to and fro movement of the camera, a movable pin on each side fixing it in the place desired. These apertures are numbered according to the inches 1, 2, 3, &c., from the frame, and thus are of service to note the distance at which the sensitised plate is placed from it or from the stage. Memoranda being kept, the same ranges can be easily repeated. The draw chamber of the camera has its own focussing screw which is of use occasionally, but it is not necessary.

Two diaphragms of blackened stout card are placed within the chamber of this elongated camera, one near to the vertical frame or at the junction of the bellows part with it in front, and the other is placed in a grooved frame, that slides in a wide cut made in the inner surface of the underside of the draw part of the camera. This frame holder takes diaphragms with various sized apertures, according to the dimensions of the image of the object or the glass plates employed. Sliding this forward or backward in the camera alters the relative size of the field according as the camera is used expanded or closed. The camera is either dead-blackened, or lined with black cotton velvet, and the tube of the microscope inside is well covered with optician's charcoal black, or lined with black velvet, which is better. The mirror or prism is set on a separate arm fixed to the base-board in a line with the stem of the microscope, so that the axis shall correspond with the axis of the objective. The apparatus can be put together very quickly, or may be kept ready for use. It is of a size that permits of its being moved about easily, and it possesses considerable firmness.

The microscope portion can be supplied by any form of microscope that will take the horizontal position, and permit the eye-piece end of the work through the central aperture in the front of the bellows-chamber, provided means are taken to effect rigidity, and completely shut out the outside light around the aperture when working the rack for the coarse adjustment. Dr. Maddox prefers a tube shorter than the usual body of the ordinary microscope, which sometimes narrows the field too much when the camera is nearly closed on the vertical frame. The tube consists of two parts, one an inch in diameter fixed to the arm, the other  $1\frac{1}{2}$  inches in diameter, that slides through the aperture in the door. On the open end of the latter fits a dead blackened brass cap, from the inside, with a slight internal projecting ledge, which acts as a diaphragm with a large opening.

The description will be more easily understood by a reference to pl. LXXI, p. 304, which represents the instrument partly in section. The camera, when drawn out to its full range, however, has this objection: the operator is obliged to withdraw the head from the focussing screen

at the time of making any alteration in the fine motion. A lever arrangement has been used to obviate this, but if employed with the high powers it is extremely difficult to prevent a slight slip of the screw. Mr. Legg employed a lever crank and arm over the top of the camera, working on the milled head of the coarse rack and pinion motion. Professor Rood, of Troy, N.Y., also made use of a rod and lever beneath the camera, acting on the rack work, and a hinged mirror placed this side of the ground glass to receive the image transmitted to it while arranging the object on the stage plate, and attending to the illumination. Dr. Maddox, who has much improved the before-mentioned apparatus, after trying several methods for supporting the rod, gave the preference to that described under his method of working without a camera in a darkened room. The rod may be placed beneath the base-board, in which position it is less liable to accidental disarrangement, but in this case a stronger microscope will be required. Messrs. Powell and Lealand have lately made for me, according to some suggestions of Dr. Maddox, a stand which is steadier and possesses some advantages over that just described.

The chief requirements in any form of camera, independent of the objective and mode of illumination, are general facility of management, compactness within a moderate range of extension, correct centering, *freedom from vibration*, and the total exclusion of all light except that which enters by the object-glass.

### 330. Dr. Maddox's Arrangement for Working without a Camera.

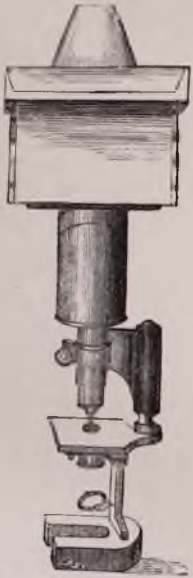
—In order to take photographs without a camera, a room has been fitted up by Dr. Maddox as a dark chamber, the top sash of the window being darkened, and the place of the lower sash when thrown up supplied by a shutter with a large central opening: an oblong aperture exists at the right side of the shutter, protected by a frame glazed with yellow glass, which slides up and down, and is kept in position by a spring. The aspect happens to be direct S.W., and, unfortunately, very much exposed to the strong south-westerly winds; therefore to try to prevent the tremor occasioned by such a large surface as the shutter affords, no part of the microscope *is fixed to it*, but rests on a long stout base-board, supported on four double triangle legs. The shutter end is clamped by two screws, and upright piece at right angles, pierced to permit the attachment of a  $3\frac{1}{2}$ -inch solar condenser with its small condensing lens, the mirror of which is passed through the aperture in the shutter. This is worked by a double milled head from the inside, the ammonio-sulphate of copper cell being placed between the mirror and the condensing lens. The base-board with right angled head-piece is brought *almost to touch the shutter*, and the light around the upright piece excluded by a thick curtain. The microscope, which is *a heavy one*, is placed horizontally. Depending from the screw, fastening the arm of

the instrument to the rack, is a stiff piece of flat brass, pierced at its lower part to support the end of a rod suspended beneath the base-board, and provided at the end with a grooved pulley of the same diameter as the milled head of the fine adjustment, which is also grooved, a small endless band connecting them. The depending piece passes through a slot cut in the base-board, equidistant from the sides, and permits the rack of the coarse motion being worked, or the movement of the microscope backwards or forwards, the rod following it. This plan was recommended in the last edition of this work. The rod is placed beneath the board to be out of the way, and not to interfere with the traversing of the frame which carries the screen or sensitive plate. This frame is made with a heavy base the width of the board, and has side clamping screws. By means of a central pin, between the two parts which form the heavy base, it is capable of slight rotation on its vertical centre, to compensate for any want of parallelism in the parts right and left of the object, or for stereoscopic negatives. The square frame is hinged to the top of this base, to allow of slight movement forwards or backwards, and it is supported at the sides by two brass struts which have a clamping pin on each side. To arrange for glasses of various sizes, two bars, undercut, slide up and down the uprights of the frame and can be fixed at any distance apart by clamping nuts. The movement of the frame will often help to secure a perfect parallelism with the object on the slide.

The screen may be either, 1, plane finely ruled plate-glass; or, 2, a collodion prepared plate washed over with a little albumen or tannin; or, 3, the plate employed occasionally by Dr. Maddox ("Some closely filtered stale milk, either with or without a little weak solution of gelatine, poured on a plate of glass set parallel, and dried quickly"); or, 4, the plate may be prepared as has been recommended for ordinary camera purposes by Mr. M. Carey Lea, of Philadelphia; thin well-boiled starch is filtered through muslin, then poured to the depth of the tenth of an inch on to a clean polished plate of glass, set level, and allowed to dry spontaneously, but quickly. It must not be put in a drawer, for fear of it drying too slowly and the surface being irregular. Or, 5, as in Mr. Wenham's method, p. 291, the image may be examined on a card, held like the glass screen or sensitised plate, by two springs from the transverse sliding bars.

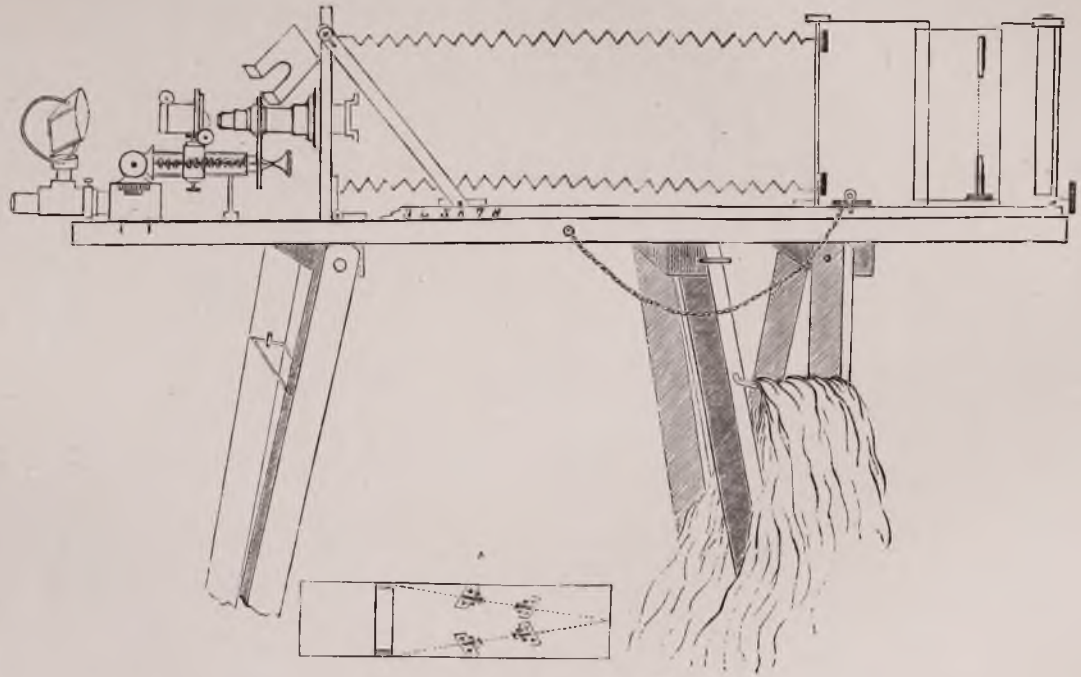
Dr. Maddox finds the general appearance of the image and the condition of the field to be best seen on the card; therefore he uses this placed before the screen and resting against the frame, to procure the primary focussing, the final adjustment being made by the rod and fine motion. When examining by the focussing glass, the image on the slightly opaque screen, or on a thick card substituted for it, a hand magnifier is used to examine the detail. In front of the exposed

Fig. 1.



Mode of adapting the camera to the microscope, adopted by Gerlach p. 229.

Fig. 2.



Photographic camera as arranged by Dr. Maddox, described in p. 300.  
A, under-surface of base board to show the position of the legs which support the camera.



plate a diaphragm is arranged to exclude extraneous light, while the parts about the stage of the microscope *are well protected* from the light diffused through the slide from the sub-stage condenser.

Although this plan is very convenient, and permits us to have everything to be ready at hand, it may be as well to point out some of its disadvantages. It is difficult to see the state of the sky; hence, after placing the sensitised plate in the frame, a cloud approaching unnoticed may at once obscure the sun and cause the loss of the plate. In the wet collodion process, dust is liable to settle on the surface. Again, for opaque objects which require a side illumination, as in the combined images for the stereoscope, the necessary deviation must be procured by prisms. Even if the Lieberkuhn with a portion of its surface stopped out, and the dark wells or stops, spot lens, or M. Nacet's cone be used, there will be considerable danger from leakage of light and a fogged plate. Moreover, the eyes become fatigued if kept long under yellow light.

The plan for using some form of draw camera is to a great extent free from these defects, and the method proposed by Dr. Moitessier in his work, to which allusion was made in the early part of this chapter, appears so useful, that I shall briefly notice the chief points. The microscope arranged horizontally, with a grooved bar projecting beyond the base-board to carry the mirror, sulphate of copper cell, ground glass, and diaphragm, is centrally attached to an expanding camera. The dark box or part where the focussing screen is placed, has one of the sides to open with hinges as a door, and the operator seated by the side of the instrument, with or without a cloth drawn over the head to exclude the surrounding light, examines the image from the side opening, either with or without a magnifying glass, the right hand being occupied in the necessary arrangement of the object and the illumination; the plate being ready in the dark slide, and the side door closed light-tight, it is inserted and exposed without loss of time.

Dr. Moitessier has likewise recommended a slide with adjusting motions, so as to expose different parts of the sensitised plate which without a camera box is placed immediately on the end of the tube of the microscope which is arranged vertically. Thus small but very perfect representations, adapted for future enlargement, or for being viewed in the stereoscope, may be secured. He also speaks highly of the immersion objectives. Dr. Moitessier also employs an ingenious method for rendering opaque objects with the horizontal microscope and low powers. The object is placed on the stage of a small vertical microscope, and the light thrown on the object by a small plane mirror from above, which receives the solar rays, after they have been converged from a larger mirror, by an achromatic lens. This and the small flat mirror are supported by, and slide on, an upright stem, to meet the necessary adjustments. The



objective is attached to the end of the microscope tube at right angles, a prism with total internal reflection being fixed at the junction. The focus is obtained by the rackwork acting on the small stage. For very low powers or securing the enlargement of only a few diameters, as in injected specimens and entire insects, a small portrait combination is attached to the microscope tube, and the prism placed in front of it at right angles.

**331. Arrangement of Drs. Abercrombie and Wilson.**—Drs. Abercrombie and Wilson, of Cheltenham, have met with great success with artificial illumination. These gentlemen use a blackened base-board 8 feet in length; the focussing box of an ordinary camera with its focussing screen, the microscope and illuminating apparatus being all kept in a straight line by side strips of wood. The microscope is movable on a sliding board and can be clamped at any distance, or the camera box and microscope made to approach or recede from one another singly or together. A couple of strips of blackened wood are attached to the eye-piece end of the tube of the microscope, and brought slightly diverging to the top of the camera. The whole of this part is covered with black velvet, pile inwards, and well secured from outside light at all parts, especially round the tube of the instrument. The base-board can be set on any steady table or support. The focussing screen is of glass covered with collodion, sensitised and covered with a solution of tannin. The draw tube of the microscope, if any, is removed and the tube lined with black velvet. The correction for the want of concordance of the actinic and visual focus is effected by what is called "turning out." The coarse or rack adjustment is left for focussing. By means of a lever arm which at one end clamps the milled head, and at the other is attached to a long rod resting at the side of the apparatus, a very delicate movement is obtained. The fine adjustment is left to regulate the compensation required between the chemical and visual foci, and to mark this more easily, a "dial plate of card" is attached to the body of the microscope, whilst a wire which is bent at one end so as to clip the milled head of the fine focussing screw, is at the other used as the index point for the divisions of the card.

The condenser recommended is a 3-inch focus bull's-eye lens, with its convex side to the source of light, and in conjunction with this the objective next below the one in use. Oil lamps, oxy calcium and magnesium lights have been used, but the last is preferred, and the wire is burnt in preference by successive flashes. To secure the point of light being in a proper position "a small telescope upright, of brass, regulated by a screw, is fixed to a block adapted to slide in the support common to the microscope and light; at the apex of the brass upright is fixed a small tin gutter or pipe of sufficient capacity to admit the wire easily and diverted down at an angle of  $45^{\circ}$ ." A movable stop with a

pin-hole aperture is recommended in the preliminary arrangement for securing the exact position. About  $\frac{1}{4}$  of an inch of the wire is exactly opposite the pin-hole.

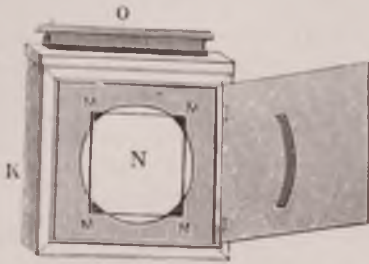
The camera is set to certain lengths, so as to give images of the objects of a definite size. The "turning out" consists in actually testing each objective for the number of turns or parts of a turn of the fine focussing screw by means of the dial card, to make the correction for the actinic focus. The same result may be obtained by withdrawing the focussing screen to the point where by trial the true actinic focus has been found. In the high powers this correction for the actinic focus may be almost disregarded. In the "Popular Science Review," No. 22, 1867, will be found an illustrated memoir by Dr. Wilson, in which full particulars have been given, and from which the foregoing remarks have been taken.

The time of exposure for wet collodion plates varies, and should increase according to the colour of the object, and the degree of enlargement. A tolerably light object, magnified fifty diameters, may need ten minutes with the oil-lamp. By placing a small vessel of warm water in the camera, to keep the collodion plate moist by its vapour, Drs. Abercrombie and Wilson have exposed plates forty minutes with success. Some of the prints from these gentlemen's negatives are remarkably good. They possess a peculiar delicacy in the half-tones and shadows, with much roundness of the objects, but the definition, as might be expected, does not quite equal, in some of the finest markings, prints obtained from sun negatives. However, all of the general characteristic appearances of the objects are exceedingly perfect, and the simplicity of the apparatus, and the immense advantage of efficient illumination in all weathers, are great advantages.

**331.\* Dr. Mercer's Instrument.**—Dr. A. Clifford Mercer, of Syracuse, New York, has constructed an instrument, the general arrangement of which will at once be clear, if the figure on page 309 be referred to. Instead of the usual base-board, the apparatus rests on a frame-work, as being less liable to warp, which is supported by legs. The front of the frame is circular, and its centre corresponds with a perpendicular axis, about which turns the bar with the mirror and condenser, and about which also turns the object-holder. The edge of the circular part is divided by degree marks. The bar and lighting apparatus can be fixed to illuminate a transparent object by light of any required obliquity, while, by turning the bar far enough round, it will light, in a similar way, opaque objects. The object-holder consists of two rings, between which the object slide is held by clips, with its covered surface resting against the ring towards the objective, the thin cover glass really entering the ring. The object is thus made to coincide with the surface of this ring, through which passes the perpendicular

axis before spoken of, and about which the object can, therefore, be turned, the axis really passing through the object. This is of great importance in taking stereoscopic photo-micrographs. The degree of inclination to the right or left is regulated by a screw on either side pushing perpendicularly against the condenser-surface of the ring towards the condenser. To keep the light at the same obliquity, the lighting-bar is turned to the right or left through the same angle as that through which the object is turned. To the ring towards the condenser a diaphragm is fastened (not shown in the figure), which also turns about the perpendicular axis. The cone of the condenser contains, at the large end, a convex lens and an ammonio-sulphate of copper cell, and at the small end a concave lens, which can be replaced by convex lenses, so that parallel, converging, or diverging rays can be thrown upon the object. (*See* pl. LXXII, fig. 8, p. 308, Moitessier's diagram.) The Rev. Mr. Read explains (*see* p. 311) how, in his condenser, the heat of the sun's rays may be much reduced, but in the convex and concave combination even more heat is got rid of, because, while the concave lens renders the inner cone of blue rays from the convex lens parallel, the less converging heat rays of the outer cone from the convex lens will be divergent after passing through the concave lens. If a thermometer bulb be placed in the beam of parallel rays from the concave lens, the mercury does not rise more than a degree or two, while the convex lens, without the ammonio-sulphate of copper cell or the concave lens, sets fire at once to a piece of paper placed at the focus. The mirror is mounted equatorially, in order that it may be easily moved by the hand. In order to keep the lighting-bar in the meridian, the circular part of the frame is of two parts, the one resting upon the other. The projecting end of the bar can be fixed to the under part of the frame, which is firmly supported on three legs, while the upper part, together with the camera-box, &c., turns about the same perpendicular axis already mentioned; thus we may obtain light of any degree of obliquity on the object that may be desired. The focussing is effected by means of a long rod, which rests on the top of the camera box, reaching from the plate-holder to the lever, which projects upwards from the focussing wheel. The focussing glass is first covered with a film of milk or starch, and when dry three or four half-inch spots, in a horizontal middle line, are to be made in the film, and the glass corresponding to the spots perfectly cleaned. The plate is placed in the sensitive plate-holder, the door and slides of which are open. The focus is first obtained as sharp as possible on the film. Through the upright part of the block, seen just behind the plate-holder, slips a tube fitted with an eye-piece and a low power objective. The block moves equally across the frame. The microscope is focussed on the film, and then moved to the right or left, to be opposite in turn

Fig. 1.



Photograph plate holder p. 322.

Fig. 3.



Side view of pressure frame p. 327.

Fig. 2.



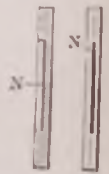
Pressure frame, used in photographic printing.

Fig. 4.



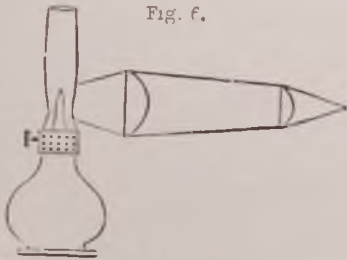
Pressure frame.

Fig. 5.



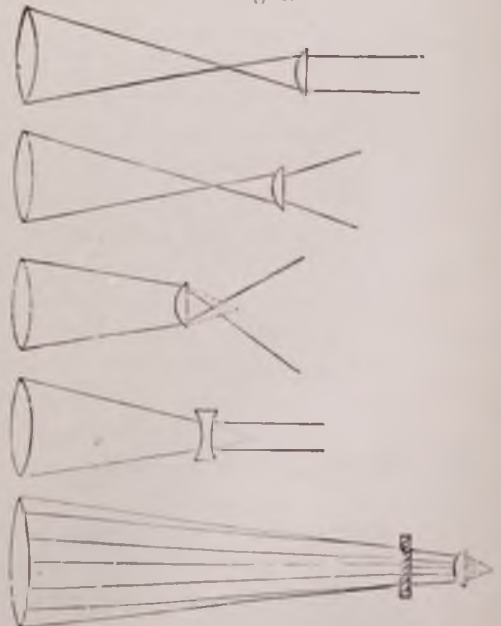
Sectional view of plate holders.

Fig. 6.



Arrangement of the lenses used for condensing the light of a lamp, as arranged by Mr Shadwell p. 310.

Fig. 8.



To illustrate the observations of Dr. Mohr on illumination and on the position of the condensing lens. p. 308.

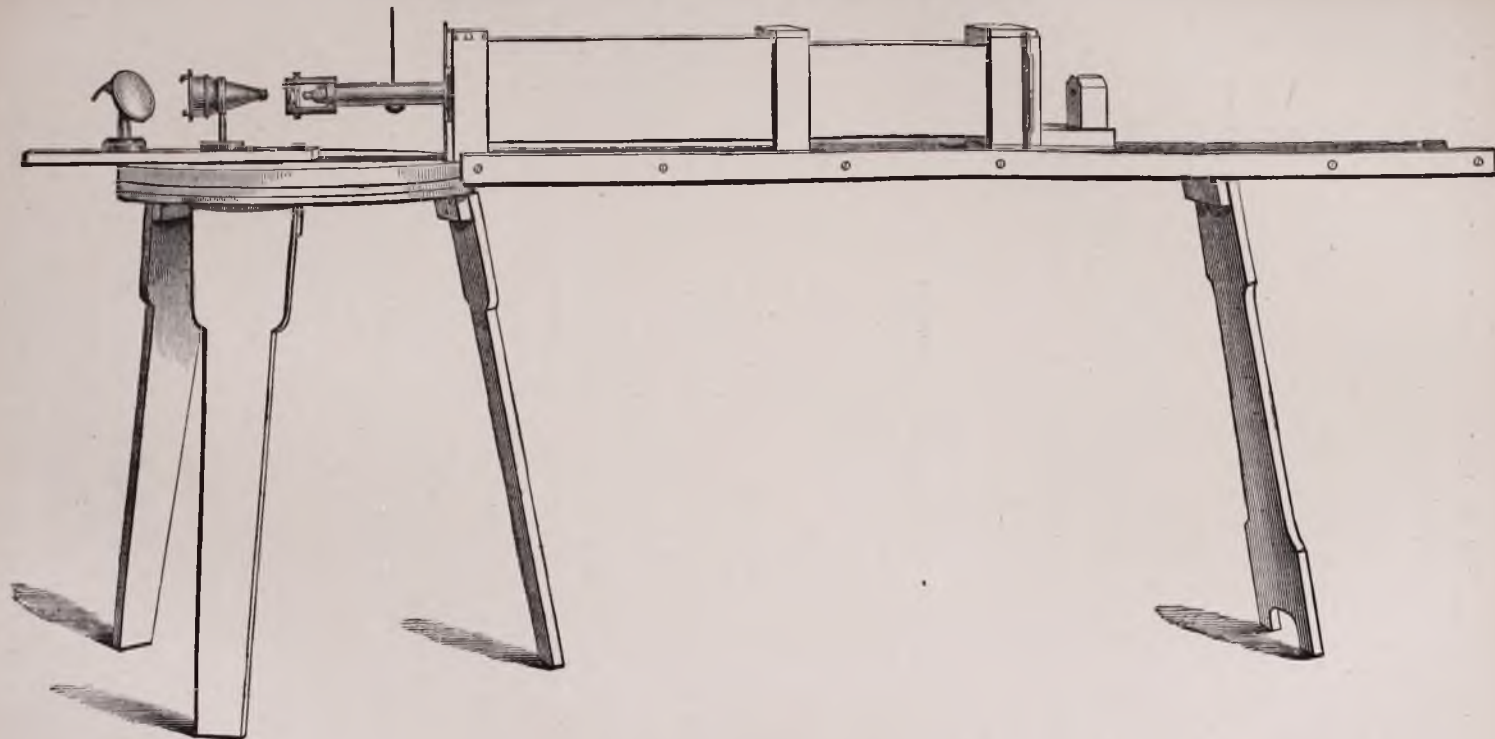
Fig. 7.



Arrangement for obtaining parallel rays as recommended by Gerlach p. 308.



DR. A. CLIFFORD MERCER'S APPARATUS FOR TAKING PHOTOGRAPHS OF MICROSCOPIC OBJECTS.



Dr. A. Clifford Mercer's arrangement for taking photo-micrographs. The instrument can be turned round in any position, as the strong stand to the left of the figure is constructed as a turn-table. See description on p. 308.—From a photograph by Dr. Mercer.

to the clean spots. When the image seen through these places is most perfect, the fine focussing is finished. The back half of the camera slips into the front half, to vary the distance between the objective and the plate-holder. The exposing is done by means of a thin brass shutter, which drops between two strong plates of brass, fastening the microscope tube to the front of the camera box. The shutter in the figure is at its highest point, and is held there by a block, seen just below it. No light passes from the tube into the camera box. If the block be withdrawn a little, the shutter falls until it strikes, with a dead stroke, a cushioned step at the end of the block, not seen, and allows the light to pass. If now the block be wholly withdrawn, the shutter falls until stopped by projecting shoulders at its upper end, and again no light is allowed to pass. The plate-holder is twice the necessary length, and so constructed that first the one half and then the other half can be exposed—a convenience of especial use in taking photographs for the stereoscope.

**332. Of the Illumination: Sunlight: Monochromatic Light: Polarising Apparatus.**—Both sunlight and artificial light have been used. Dr. Maddox, with the majority of observers, gives the preference to sunlight in all cases, and nearly always uses some form of condenser. He usually dispenses with the mirror, and substitutes one of Abraham's achromatic condensing prisms, placed at such a distance from the object (if used alone) that its rays should cross just before reaching it. Otherwise the intense heating power at the vertex of the cone of rays would damage the object, and might even uncement the lenses of the higher objectives, especially when the object is only enclosed between two pieces of the thinnest covering glass, and the focus very close. The prism he seldom employs alone, but places a condenser in the tube at the back of the stage. A small Coddington lens about  $15^\circ$  angular aperture, served him in the earlier part of his experiments. This was made to slide nearer or farther from the object. Latterly he has used Sollitt's achromatic condenser, as it furnishes a larger field and is more free from spherical aberration. This condenser, as described by the originator, consists of two achromatic lenses with their plane surfaces turned towards the object, and respectively of 2 and 4 inches focus, placed at the distance of  $1\frac{3}{4}$  inches apart with a diaphragm between them. The 4-inch focus lens has a diameter of  $1\frac{1}{4}$  inch, the 2-inch focus lens a diameter of  $\frac{3}{4}$  of an inch. Here then we have a body of light, and a field beautifully illuminated when used either with the plane mirror or the prism. A series of diaphragms slip into the cap covering the small lens, which is turned towards the object. Sometimes Dr. Maddox employs an achromatic doublet of about  $22^\circ$  aperture, or an achromatic condenser of larger angular aperture. Although theoretically the angular aperture of the higher objectives is narrowed by these

moderate apertures, practically the intensity of the illumination appears to compensate in a remarkable manner. The common plan is to use as a condenser the objective next below the one used to render the photographic image; but if any form of solar condenser be employed by which the rays become more concentrated, the greatest care must be taken to avoid injury to the lenses by the intense heat.

Dr. Maddox has lately used two large plano-convex lenses superposed with a large central stop—the method described by Dr. Woodward in one of his communications; also the condenser of two or three plano-convex lenses as recommended by Mr. Wenham, but with movable stops or diaphragms; the latter are placed nearer to or farther from the largest lens, the distance being regulated by trial. Professor Rood, of New York, for his higher powers employed a Wollaston doublet, having an angular aperture of  $44^\circ$  as a condenser. He used one of Liebig's silvered mirrors in place of the ordinary amalgam mirror. M. Neyt replaces the common solar reflectors by a large prism with parallax motions. To condense the rays an achromatic condensing lens of  $2\frac{3}{4}$  inches diameter is used, and to concentrate them still more, three other converging lenses are placed in its focus in such a manner that they can be used together or separated to meet the power of the objective. He likewise has the objective corrected to make the chemical and visual foci agree. In order to render infusoria stationary while they are photographed, M. Neyt uses a voltaic stage, so that he can make contact with the poles of a Daniel's battery or induction coil at the proper moment. The shock suddenly kills the little beings and enables him to secure an image, when otherwise, from their rapid movements, it would be impossible, and only in very rare cases would the living animalcule remain in the field of view, or in the desired attitude, for a sufficient time.

The Rev. Mr. Reade has proposed a very ingenious method of using his hemispherical condenser with a solar condenser. The rays furnishing light and those giving heat having different degrees of refrangibility, we have here the cone of light-giving rays formed within the cone of the heat-giving rays, the principal focus of the latter being at a greater distance from the lens than the former. When these rays are permitted to cross the axis, their respective situations are reversed. On arranging the hemispherical lens, so that it shall be separated from the principal focus of heat by the sum of its own focal length, the principal focus for light will be found at a greater distance than its own focal length; hence the heat-giving rays will be rendered parallel, and the light-giving rays will be made to converge to a second focus furnishing light of much intensity separated from the heating rays. Means for using an achromatic object-glass for the solar microscope without endangering its injury are thus supplied.



Professor Gerlach uses a plano-convex lens with a concave mirror. These are placed at such distances apart that the two foci meet when the convex surface of the plano-convex lens is turned towards the mirror, pl. LXXII, fig. 7, p. 308.

Dr. Woodward's plan has been already adverted to in pp. 291 to 298.

Dr. Moitessier gives the following method: the parallel rays from the solar mirror are received on a bi-convex lens and conveyed to the other extremity of the tube holding the lens, in which slides a smaller plano-convex lens, moved by rack and pinion. According to the position of the latter, the emergent rays are rendered either parallel or diverging if placed beyond the principal focus of the large lens. If placed within the luminous cone before being brought to a focus the rays are rendered more convergent, and this forms the general arrangement for high powers. If the small image of the sun thus formed be made to coincide with the surface of the object to be photographed, the phenomena of interference from diffraction are avoided, but this involves an alteration in the respective distances apart of the lenses for different objectives, or the same objective altered in its focus to correspond with any deviation in the distance of the screen. He likewise substitutes for the small condensing lens a diverging one placed within the focus of the large lens to procure a cone of concentrated parallel rays. These can be again rendered convergent by a small lens. He also receives upon finely ground glass the converging rays from a large condenser with a longer focus at some point before coming to a focus. This circle of light then becomes a radiant for the small condensing lens. Thus there is much less diffraction, and although the time of exposure is considerably increased, the plan meets the general requirements. The drawings represented in fig. 8, pl. LXXII, p. 308, will illustrate these different methods.

The mode adopted by the Abbé Count Castracane is to allow the solar rays to be refracted by a large prism, with a dispersive power capable of giving a wide spectrum before falling on the condensing lens; a diaphragm being interposed to allow passage only to the rays from the blue end of the spectrum. In this way homogeneous light, in which the actinic power is chiefly situated, is obtained, the defects arising from chromatic aberration are avoided, and a more perfect definition results. Dr. Maddox found when using the blue cone of rays formed by Abraham's achromatic prism, a great tendency in the object, if very thin and transparent, to be confused with the field, and the negative to be useless for obtaining positives for the lantern. Care is required not to employ any form of sub-stage condenser of a *larger angular aperture* than the objective in use. The objects should always be first selected, and the suitable objective adapted, and the mode of illumination arranged accordingly.

For such objects as are of a more or less non-actinic colour, as some entire insects, or their various parts, Dr. Maddox also tried a plan which consisted in giving to the supporting slide a coloured transparent varnish of the same tint, or by placing beneath the slide-holder a parallel plate of tinted glass chosen to suit as nearly as possible the necessity of the case. But the best results were obtained by using a slow collodion, a more acid bath, and giving a longer exposure, which was done without fogging. Some of these results were exhibited on the screen before the London Photographic Society in December, 1864, and the Microscopical Society in March, 1865. It should be borne in mind that when any coloured medium is placed between the mirror and objective, it has the greatest effect when placed at the part where the light is least concentrated. Also, that there is no conversion of white light, but simply a transmission of the blue and closely allied actinic rays when the ammonio-sulphate of copper cell or blue glass is used; hence the time of exposure must be augmented. It is desirable to obtain the monochromatic and actinic rays, which have not lost so much of their power by transmission and absorption; and it is just possible, in the case of objects which can be mounted in fluid, that a medium may be found which will allow us to employ the ordinary methods of illumination. It has also been proposed to focus through a screen of polished parallel blue glass, and to remove this when the sensitised plate is being impressed. Various media require different exposures under similar conditions of illumination; without a heliostat, rapidity in impression is necessary to the most perfect definition. The refracting power of the medium should correspond closely to the refracting power of the object. The time of exposure varies according to so many circumstances that it proves one of the chief difficulties in photomicrography. The distance of the object from the screen, its colour, the medium in which it may be mounted, the media through which the sun's rays are transmitted, the nature of the first incident or reflecting surface, the actinic power of the sunlight, which varies considerably at different hours in the day, the condition of the atmosphere, and the number of lenses of which the objective is composed—all influence the period of exposure. The last operates greatly, the lenses in the high powers consisting of only three sets, and the first a single front, as Mr. Wenham's,—being the most rapid.

In the ordinary Wollaston doublet the chromatic aberration is not corrected, but this does not cause any serious difficulty, as, by varying its distance, the blue or chemical end of the converging cone of rays can be used to furnish a field of bluish light. Some considerable care is needed in the adjustment of the condenser, so as to equalise the illumination and avoid sun spots when the mirror is used. Mr. Traer got rid of the latter by making the distance between the object and concave

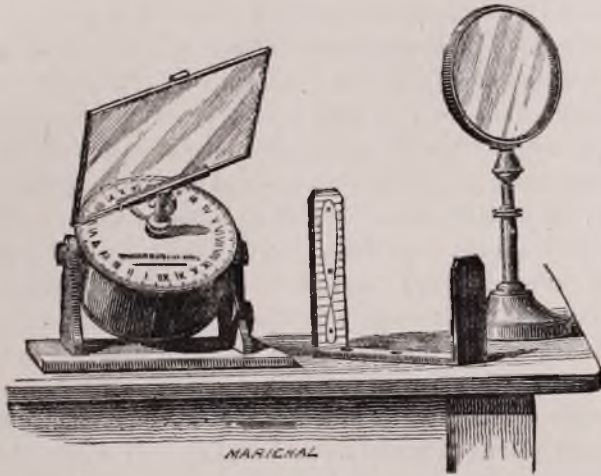
mirror rather more than its focus. Some make their focal arrangements in the objective, illuminating the object with daylight or a less intense illumination than is to be used in taking the photograph. Dr. Maddox found that by acting thus he seldom secured the best focus; he therefore prefers to focus in sunlight condensed upon the object, using an examining eye-piece.

The *polarising apparatus* may be used for the production of photographic images of some objects which from their great transparency and delicacy are not well rendered in the ordinary way, and of which some detail is lost by using common light. The polarising prism is as usual placed beneath the object, the analyser directly over or behind the objective, and the best appearance sought by the rotation of the lower prism. Mr. Thos. Davies, who has published in the "Microscopical Journal" for the years 1863 and 1864, many details connected with the application of photography to the delineation of delicate crystals, states that he finds, when the object appears best illuminated by the ray which has been reflected from the mirror and transmitted through the polarising prism, the image in the camera was often only partially distinct, and needed a readjustment of the mirror to procure an image that would develop uniformly. He employed a No. 1 eye-piece, and magnified some of the crystals, as those of tartar emetic, to 50 diameters; tartrate of soda, sulphate of copper and magnesia, and santonine, to 40 diameters. Excellent woodcuts from these photographs were given in the Journal to illustrate his observations. To these I must refer the reader.

**333. Heliostat.**—When using sunlight a heliostat is of great use, and for the best results, a necessity. Until quite recently this has been a very costly instrument, but the demands of photo-micrography and experimental science have brought into the market a number of cheaper forms. An instrument maker to the Government in Washington constructs one for 50 dollars. John Browning, in the Strand, sells a single mirror heliostat for 8*l.* 15*s.* Prazmowski, 1, Rue Bonaparte, Paris, offers a two-mirror heliostat for 200 francs. Professor Lawrence Smith, of Kenyon College, suggested to Dr. Maddox a simple arrangement for a two-mirror heliostat. On this suggestion were constructed the instruments of Dr. Maddox and Dr. Woodward, of which figures, with full descriptions, will be found in the "Monthly Microscopical Journal," vol. I, 1869, p. 27. One mirror is mounted at the centre of its back by a hinge joint to the south end of a polar axis. When the polar axis is brought parallel to the axis of the earth, the mirror is turned towards the sun, and inclined so as to throw the reflected rays parallel to the axis of the earth, or, in other words, in a line with the polar axis of the instrument, and then the polar axis is turned by the hand or by clock-work with the sun. The rays from the revolving mirror are reflected

steadily in the same direction. These rays are received by a second mirror, which reflects them horizontally.

A hand heliostat of this kind can be made chiefly of wood, by anyone, for a few shillings, and a woodcut of such an one is to be found in one of the numbers of the "Popular Science Monthly," New York, published two or three years ago. In the Prazmowski instrument the polar axis is fixed in the plane of the first mirror, and this mirror turns



Heliostat made by Prazmowski—From the "Transactions of the Royal Microscopical Society," 1879.

about the polar axis once in forty-eight hours. The instrument is self-adjustable for the latitude and longitude of the place where used. When in proper position, the revolving mirror reflects the rays steadily in one direction. The second mirror receives the rays and reflects them horizontally. The Browning instrument is more complicated, but has the decided advantage of saving the light lost by the reflection from the second mirror in the other instruments.

**333\*.** *Artificial Light.*—Mr. Shadbolt many years ago obtained some beautiful photographs by lamp light. A small camphine or paraffin lamp was placed so that the flame was in the axis of the microscope. A plano-convex lens, of about  $1\frac{1}{2}$  inches diameter, with its flat side to the lamp, and a second smaller one, of about 1 inch in diameter and 3 inches focus, were arranged so as to concentrate the rays of light without forming an image of the flame, pl. LXXII, fig. 6, p. 308. The first is placed at such a distance from the lamp as to make the rays converge slightly, and the other at a point where it will include all these rays and (in using high powers) the achromatic condenser, so that the lens may fall well within the cone of rays. In employing low powers the object is made to come within the cone of converging rays. The distance of the lamp from the lens nearest to it is best determined by the quality of the

illuminated field, which should be equally bright all over. The light should enter the objective at an angle not greater than its own angular aperture. To examine the image thrown on the ground glass of the camera, Mr. Shadbolt used a Ramsden's positive eye-piece. Mr. Legg, in 1859, made use of artificial light from a camphine lamp, concentrating the diverging rays by a 2-inch bull's-eye lens placed near to the source of light, and a second bull's-eye lens, about 3 inches in diameter, at a distance of an inch from the first, by which, with the 2-3rd and 4-10ths object-glasses, he could obtain images at 3 feet, in periods varying from 3 to 10 minutes. Mr. Parry, in making use of artificial light, placed a plano-convex lens of  $1\frac{1}{2}$  inches focus, with its plane side towards the object about 1 inch from it, and 4 or 5 inches from an argand gas burner. (The light from an argand paraffin lamp is preferable to gas.) To increase the flatness of the field, he fixed behind the posterior lens of the 1-inch combination an achromatic stereoscope camera lens with its flat surface towards the objective. Mr. G. Busk employed gaslight from an argand burner in 1854; and in November of the same year Mr. Wenham states that, although with the use of camphine and gaslight he was dissatisfied, yet the succession of electric sparks (about 100), from a small Leyden jar of 30 inches coated surface, gave actinic rays of sufficient intensity to produce a good impression on a sensitive collodion plate. The Rev. C. Kingsley with a special apparatus used the hydro-oxygen light and a screen of esculine. Mr. Bockett, in 1862, tried diffused daylight, allowing in some cases an exposure of from four to eight minutes. Dr. Maddox, in 1864, succeeded, by using the brilliant light emitted on the combustion of magnesium wire ( $1\frac{1}{4}$  inch) held in the flame of a small spirit lamp, and condensed by an ordinary condensing lens. Mr. Durham uses gas and daylight illumination with success.

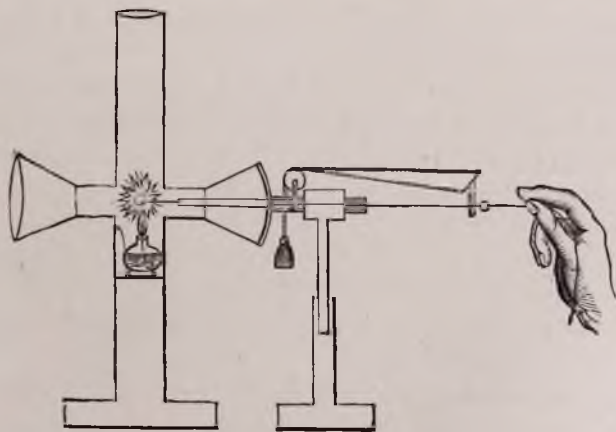
The Rev. St. Vincent Beechy, in his paper on Microscopic Photography, recommends very strongly the oxy-hydrogen light, and indicates a very simple method by which an ordinary good magic lantern can at a small expense be converted into use as a microscope camera for powers from 1 inch to the  $\frac{1}{4}$  inch. The Drummond light has been much used in France of late years. Whatever light may be employed, intense illumination should emanate from a small surface, so that it can be more successfully brought to a focus by a condensing lens or silvered reflector, singly or united.

Electric, magnesium, and oxy-hydrogen lights have all been used by Dr. Woodward with excellent results; the first by exaggerating light and shadow is best suited for delicate objects, showing slight contrast with the field, while the latter two are of special service in photographing soft tissues, no ground glass being required to prevent interference phenomena. In fact, Dr. Woodward shows that these lights can be

made to furnish photographs equal to those produced by the sun, a matter of considerable interest to observers living in cloudy countries or smoky cities. His lime cylinder revolves by clock work to bring fresh portions into the oxy-hydrogen flame.

Many useful hints on various subjects connected with microscopical photography will be found in the *Photographic News Almanack* and the *British Journal Photographic Almanack* for the last few years.

Dr. Henry Morton, of Philadelphia, has made a considerable improvement in magnesium lamps, by adapting a metal chimney, wide enough to prevent the flame from touching the sides; the bottom is closed up either by metal or by being placed in a dish of water. Opposite the ignited wire is a round hole in the side of the chimney through which the air enters, and striking against the flame increases its brightness and intensity in a very marked manner, thus effecting equal illumination at a much less expense. Following up this idea for ordinary use, Dr. Maddox has constructed an apparatus for using short lengths of wire in photomicrography, and which will be best understood by a reference to the figure. A stout tin tube, about 8 inches high and  $1\frac{1}{4}$  inch bore fixed in a wooden base, has at opposite sides at the exact centre of the microscope or camera tube, two apertures cut  $\frac{3}{4}$  of an inch in diameter, and two tubes 1 inch in length soldered in; in these short tubes slide the tubes of two funnels of tin,  $3\frac{1}{2}$  inches deep and  $1\frac{1}{2}$  in width, blackened inside. Again at right angles to the apertures of the two short tubes are two circular holes. Against the outer rim of the funnel nearest the stage is placed the plano-convex condensing lens, and against the rim of the opposite funnel a hemispherical concave reflector



with a central aperture. Beneath the short tube carrying the first funnel a portion of the eight-inch tube is cut tongue shape and turned in to support a narrow spirit-lamp. An arrangement is made in the

support holding the reflector by which a small tube can be passed through the central hole in the reflector, and by allowing a weight to fall steadily a short distance, a wire piston is carried along the tube, and projects the short piece (3 inches) of magnesium wire as it burns away, the ignited point being in the centre between the two funnels and at the foci of the condensing lens and silvered reflector. This plan requires a little experience to allow the necessary motion of the hand to compensate for the rate of burning, and might be constructed as self-acting, but practically it answers very well, and is easily made. Dr. Woodward's magnesium lamp has a chimney five feet long, consisting of muslin covering a spiral of stiff wire. The muslin goes in and out as the foldings of a bellows camera. The oxide, which has been troublesome by depositing on objects in the room when other lamps have been used, is in this lamp deposited on the muslin projections into the chimney, while the draft is kept up through the interstices of the muslin. Perhaps the lamp invented by Mr. Larkin, for consuming powdered metallic magnesium mingled with sand and allowed to fall in a stream through a small lighted jet of hydrogen gas might answer. Burning phosphorus and burning zinc turnings have also been tried.

The new developments in the way of electric lighting (Edison's for instance) may, perhaps, afford us more perfect artificial illumination for photo-microscopy than has hitherto been at our disposal.

**334. Of Focussing.**—Much care is required in focussing. A plan adopted by some is to use a simple lens set as a watchmaker's loupe in a card or wooden tube, of such a length that, when placed at the near surface of the ground-glass screen, the focus of the lens exactly corresponds to the opposite or ground side. Others employ an ordinary photographic focussing eye-piece. The best instrument is the positive eye-piece; for should the others not be truly set, there is danger of the focus catching the image either before or behind the screen. Some form of compound microscope may with advantage be employed, the focus of which is set to the exact thickness of the screen.

**335. Of the Object-glasses.**—Each objective, as furnished by our best opticians, is generally sent out not as a *photographic* object-glass, but as a microscope objective, and so skilfully have errors which arise from the thickness of the thin glass cover and non-achromaticity of the eye-piece been compensated for, that the illuminated field is without sensible colour, and the edges of the objects destitute of chromatic fringes. To accomplish this, the objective is left what is termed "over corrected."

When the photographer employs these over-corrected objectives, more especially the low and moderate powers, he generally finds that either his prepared sensitised plate must be moved further away from the plane at which the best visual focus was found, or else he must with-

draw his objective a slight distance from the object, so as to get the chemical focus and compensate for the amount of "over-correction" that has been given to the objective by the maker. This is not a fixed point, and may even vary in different object-glasses, furnished by the same optician, although of equal magnifying power, and even ground on the same tools. In the construction of some of the lower powers a plan has been adopted which, at the same time that it does not detract from their optical perfection, places the chemical variation at its lowest amount. In the higher powers, as from  $\frac{1}{8}$ th upwards, the difference between the visual and chemical foci is so small that it is seldom regarded, except in the most delicate work; but here the disturbance occasioned by the cover of thin glass placed over the object, requires the adjustment between the two posterior combined set of lenses, and the anterior pair, triple or single lens, to be made with the greatest nicety, as has been strongly advocated by Dr. Wilson. It is not possible to determine beforehand the amount of alteration in focus needed, and a series of trials will be necessary to establish what adjustment is requisite. The best plan is to select an object that has a slight thickness, with parts at a distance from one another, lying in three or four different planes. Set the objective to the best focus in the microscope, then place it in the camera; focus sharply for the part of the object nearest, and in the negative which is taken, observe if this part corresponds in definition, or if not, which plane of the object appears the sharpest. Let us suppose the furthest plane; then observe, by re-focussing, how many divisions of the milled-headed screw have been turned through to bring this part into as perfect a focus as was originally the nearest plane. This will give the variation for that objective under similar circumstances, and should be noted. If employed with the shallow eye-piece, to increase the magnifying power, with the loss of some definition, a different adjustment may be required. Mr. Shadbolt undertook a series of experiments for his objectives, made by Messrs. Smith, Beck, and Beck, when he employed artificial light, and found that:—

The $1\frac{1}{2}$ inch object-glass had to be withdrawn	$\frac{1}{50}$ th of an inch.
The $\frac{2}{3}$ rd	" " $\frac{1}{200}$ "
The $\frac{4}{10}$ th	" " $\frac{1}{1000}$ "

These can only be regarded as guiding marks for others. To obviate the inconvenience of focussing differently for the chemical and visual rays, Mr. Wenham, with his usual ingenuity, recommended a biconvex lens of low power to be carefully turned down to the proper size, and centred in a setting that could be screwed into the place where the posterior diaphragm or stop of the objective is usually placed; thus to lessen the over-correction and to bring the chemical back to the visual focus. He gives the following focal lengths of these correcting lenses:—



for Messrs. Smith, Beck, and Beck's  $1\frac{1}{2}$ -inch, a lens of 8 inches focus; for the 2-3rds, one of 5 inches focus, which is also applicable to the 4-10ths. Mr. Hislop advises that a dozen of these lenses, of different foci, should be at hand, and the one that is found to answer best in practice selected. Dr. Maddox has one of Messrs. Smith, Beck, and Beck's 2-3rds, beautifully corrected by them in this manner, and it gives surprising sharpness.

In giving the amplification of an object, the simplest plan, perhaps, is to divide the screen from the centre into inches and tenths, to measure the size of the image and compare it with the size of the object as given in the microscope with the micrometer, or to substitute the micrometer for the slide, taking care to let their surfaces coincide, and not to alter the correcting adjustment, as with the high powers and single fronts the alteration in size is very rapid.

**336. Stereoscopic Photographs.**—Seeing the advantage derived from the application of the stereoscope in viewing the dissimilar images of large objects taken at varying angles, it was natural to suppose that an effort would be made to produce stereoscopic images of minute objects. Professor Wheatstone suggests in the "Transactions of the London Microscopical Society," for April, 1853, a plan of procuring these at the necessary angles. He proposes that the tube of the microscope should have an independent movement of about  $15^\circ$ , "round an axis, the imaginary prolongation of which should pass through the object, it being indifferent in what direction this motion is made in respect to the stand." He proposes also a simpler method, which is, to make the object itself partly revolve round an imaginary axis within itself, from  $7^\circ$  to  $15^\circ$ , care being taken to render the illuminations equal, and avoid interfering shadows, so as not to produce pseudoscopic effects.

Mr. Wenham showed that images of objects could be produced with such a difference in the relative position of their parts when viewed, by stopping off the alternate halves of the object-glass, or the emerging pencils from the opposite halves of the eye-piece, that these images when recombined had a perfect stereoscopic character. Mr. Wenham placed a sliding stop with straight edges against the lens of the objective, so that it could be turned to cut off either the right or left portion of the lens.

Professor Riddell, of New Orleans, proposes to accomplish the same end by inserting, just behind the object-glass, a small equilateral prism, arranged on a central axis parallel to its polished faces and transverse to the axis of the object-glass, so that it can be inclined. The hypotenuse being placed coincident with the axis of the microscope, on making the necessary inclination, the appearance as of the object itself being moved, will be produced. When the image of the object has

been drawn with the prism in one position it is to be altered slightly, and the slide moved so as to bring the same part into the centre of the field of view, as at first. It will now have an altered aspect, corresponding to the difference in the point of view, equivalent to the number of degrees of the inclination of the prism which may vary from  $4^{\circ}$  to  $9^{\circ}$ . And if the two images of such a drawing, or photographic impression, be viewed stereoscopically, they will coalesce into a stereoscopic image.

Mr. Heisch, in October, 1862, recommended, as an adapter for the object-glass, one carrying a tube that can be turned half round by a lever outside. In this tube is another, provided with a stop, that cuts off half the pencil of light emerging from the object-glass; this sliding tube, when placed in proximity to the back lens of the objective, is so arranged that the field on the ground glass of the camera shall be equally illuminated in all positions of the stop. The image is thrown on a prepared sensitised plate for the first picture, the stop is then turned round until it stands in a direction opposite to the first position; the unimpressed half of the prepared plate is then shifted into the field, and in its turn receives the second image. The two resulting pictures furnish a stereoscopic effect. Mr. Heisch also suggested that in objects of thickness the near surface should be focussed for the one and the more distant for the other picture.

Dr. Maddox produced stereoscopic pictures on one of the plans proposed by Professor Wheatstone, and for this purpose he made a small  $3\frac{1}{2} \times 1\frac{3}{8}$  inch slide-holder of brass plate having a central aperture and a ledge at the top and bottom, in the direction of the length, turned up square at right angles. Opposite the centre, the ledges were pierced by a small hole about  $\frac{1}{8}$  of an inch from the angle of junction; two thin strips of spring brass cut to the width of the ledges, about  $1\frac{1}{2}$  inches long and slightly curved, had each a small hole drilled in the centre. Two pieces of hard wood were cut into equal triangles, and each was fixed on a brass pin in such a position that, when the little triangular blocks were resting with their obtuse angles on the upper surface of the brass slide, the other end of the pins passed through the hole in the small strips of spring brass, and then through the holes in the ledges. The pins were turned up at right angles to prevent them from being carried out of the holes by their springs. An ordinary glass slide with the object set up was placed between the springs (resting by its under surface near the edges on the upper or horizontal surfaces of the two small blocks), and clipped by them so tightly that they would not fall out, when the slide was placed vertically on edge. On depressing either end of the slide, the object could be made to assume an obliquity to the objective, equivalent to the angle found between the surface of the little triangular blocks and the edge of the depressed slide when resting on the plane of the brass holder. This method answered

very well for opaque objects illuminated by the Lieberkühn. The slide holding the object properly centred and focussed from the point where the least displacement of the focus appears on depressing each side equally and alternately, is now depressed and re-focussed if necessary, to furnish the first picture, then similarly treated on the opposite side of the centre to furnish the second. The resultant images give a stereopicture. If the left depressed view is taken on the right-hand side of the plate, and *vice versa*, the images need not be reversed after printing. Dr. Maddox used for transparent objects Mr. Wenham's and Mr. Smith's plan for stopping off alternately in front the right and left halves of the objective by a small cap with a semicircular aperture, equal generally to half the area of the front lens, while, with the highest powers, he only makes a slight alteration in the position of the object and incident light for the second picture. With the parabolic illuminator he did not succeed equally well. M. Nacet, jun., used his polished cone of glass with a central stop on its curved base (for obtaining oblique light in parallel rays) when photographing opaque and semi-opaque objects, as the Foraminifera, &c. Dr. Moitessier recommends this plan, the light being transmitted from the mirror through the cell of ammonio-sulphate of copper, then conveyed by the condensing lens on to a disc of ground glass, placed near the apex of the cone. Dr. Maddox has lately obtained stereoscope pictures of parts of *Pleurosigma formosum*, magnified 3,000 diameters, with Mr. Wales'  $\frac{1}{8}$ th objective and amplifier. See p. 294.

#### CHEMICAL SOLUTIONS REQUIRED.

It is of the first importance that the different solutions used in photography be perfectly pure; and observers are recommended to purchase their chemicals at houses of known celebrity, like that of Mr. Thomas, Pall Mall.

**337. Collodion.**—Supposing the collodion process to be determined on, the pyroxyline should be of the kind produced from hot acids, carrying just such an amount of water as will furnish to it when dissolved in its solvents, ether and alcohol, a fluid flowing freely, possessing considerable adhesive power to the glass, and free from fine net-like markings when dry. The collodion should afford when taken from the nitrate bath, not a very thick creamy layer, but such as is commonly employed for portrait purposes. If it be preferable to make the collodion, we subjoin the formula for cotton that will yield the above-mentioned film. Into a perfectly clean dry close-stoppered bottle, put—Iodide of ammonium in crystals;\* iodide of cadmium, of each, 8 grains; bromide of cadmium, 4 grains. Pour on these 13 drachms of

\* If the crystals of iodide of ammonium be at all damp, press them before weighing in folds of clean blotting paper.

absolute alcohol or redrawn alcohol, of sp. gr. '805, shake the bottle well; when dissolved, add—Pure ether, sp. gr. '725, 12 drachms. Weigh out 22 to 28 grains of dry pyroxyline, add it by little open tufts to the mixed fluid, shaking occasionally, then wash down the neck and sides of the bottle with 8 drachms of pure ether. Gently agitate so as not to soil the neck of the bottle, and set aside in a dark cool cupboard for three or four days, or longer; then carefully pour off, without any shaking, the half into a clean dry close-stoppered bottle for use, or better, into one of the 4 oz. capped pouring bottles, called "cometless." The formula given has been for only 4 oz. of collodion. The absolute alcohol can sometimes be a little increased. It is, however, better to use a "negative" collodion already prepared by a reliable manufacturer. Beginners will certainly obtain better results with such a collodion than with one of their own making.

**338. Nitrate Bath.**—The nitrate bath may be prepared as follows: Freshly distilled water, 4 ounces; re-crystallised nitrate of silver, 600 grains. Dissolve; test for acidity by blue litmus paper; if acid, neutralise by a little fresh pure oxide of silver, or by a few drops of a very weak solution of carbonate of soda. Dissolve in a drachm or two of water, iodide of potassium, 1 grain. Then drop into the solution a few drops of the strong solution of nitrate of silver until it produces no further turbidity. Wash the precipitated yellow iodide of silver, pour off the washings, and add the iodide to the strong silver solution; stir, make up the quantity of fluid to 20 ounces by distilled water, and filter, or allow it to settle, then carefully pour off close, and filter the remaining portion into a small bottle. This can be used in the after intensifying process, or if filtered through a washed filter, added to the stock for the nitrate bath.

The strong solution of silver is oftener alkaline rather than acid to test paper: if this be the case, add a few drops of a solution containing 1 drop of glacial acetic acid to 1 drachm of distilled water, until the test paper remains slightly reddened, or the same proportions of nitric acid in water may be used; the latter often works remarkably well with the bromo-iodised collodion, not giving at first intense but remarkably sharp clean negatives, permitting of a rather longer exposure to the strong sunlight without staining, and considerable intensifying qualities without blocking out the finest lines. To keep up the strength of this nitrate bath, add occasionally a plain solution of re-crystallised nitrate of silver in distilled water, in the proportion of 50 grains to the ounce. It is desirable to keep this nitrate bath perfectly free from dirt and substances likely to injure it. As there is considerable difficulty in obtaining the gutta percha baths without impurities, and the porcelain ones are sometimes too porous, a vertical glass bath with cover is much to be preferred. It is often desirable, after a full day's work, to pour

the nitrate bath into a clean bottle, allowing it to settle. The clear portion may then be carefully decanted into the bath, after it has been washed out, and the remainder filtered through a washed paper filter, the strength, if necessary, being made up by adding some of the 50-grain solution. In this way spots, pin-holes, or deposit are less likely to spoil transparent shadows. This bath in winter can be made stronger.

Mr. Clifford Mercer gives the following directions for making the bath :—A simple way of preparing a bath is to make a solution of pure nitrate of silver crystals, 40 grains to the ounce, in well boiled soft water. Filter the bath, render it very slightly acid by a drop or two of nitric acid, and then keep it in the dark for twelve hours or more. Just before using the bath for the first time, hang in the bath, in the vertical bath-holder, one or two plates of glass covered with a film of the collodion to be used. The strength of the bath can be tested occasionally by a nitrate of silver hydrometer and crystals of nitrate of silver added, as required, to keep the bath in summer a little less than 40 grains to the ounce, and in winter somewhat stronger than 40 grains to the ounce. It should be filtered occasionally, and always after an exposure to light. After the bath has been used for a long time, and the negatives are full of faults traceable to the bath and not corrected after allowing the bath to stand in the sun for a day and then filtering, the bath should be rendered distinctly alkaline by drops of ammonia, some water added, and the whole boiled down to one quarter of its original bulk. To this water and nitrate of silver must be added, to bring it up to the required bulk and strength. After being filtered, the fluid is to be slightly acidified with nitric acid, and collodion plates are to be suspended in it, as in preparing a new bath.

**339. Of the Developing Solutions.**—Preference is given by most photographers to the formula containing the protosulphate of iron, or the double salt of sulphate of ammonia and iron, with or without a little syrup from loaf sugar added at the time of using, as recommended by Mr. Hislop :—Crystallised protosulphate of iron crushed, 200 grains ; glacial acetic acid,  $3\frac{1}{2}$  to 5 drachms, or, Beaufoy's acetic acid of 30 per cent., 10 to 15 drachms. The amount of 10 ounces is to be made up with pure water, then 6 or 8 grains of acetate of soda are to be added, and the fluid filtered. More iron should be added to this developing solution in the winter months. It is best when a few days old. At the time of using, to make it flow freely on the surface of the collodionised plate, add of ordinary alcohol from 20 to 30 or 60 minims to each ounce of developing solution, according to the condition of the bath. Its strength is often varied from 10 grains to the ounce to even 50 grains in ordinary work, but in sun-light negatives, it is not necessary to use more iron than in the formula. Mr. Deecke says :—“For micro-photography (he means photo-micrography) the iron developer should be entirely

replaced by pyrogallic acid, with about one-half more glacial acetic acid than is generally recommended." The silver deposit on the iron-developed plates is more coarse than that on the pyrogallic acid plates.

The intensifying solution, useful for deepening more fully many of the details brought out by the iron developer, consists of:—No. 1. Iodine, 3 grains; iodide of potassium, 6 grains; water, 3 ounces. Mixed. No. 2. Pyrogallic developing solution, as made with acetic acid; pyrogallic acid,  $1\frac{1}{2}$  to 2 grains; glacial acetic acid, 20 minims, or Beaufoy's acid, 1 drachm; distilled water, 1 ounce. This is best when freshly made, or not more than a few days old. No. 3. Pure nitrate of silver, 30 grains; distilled water, 1 ounce. No. 4. Pure nitrate of silver, 20 grains; citric acid crystallised, 30 grains; dissolved in distilled water, 2 ounces.

**340. The Fixing Solutions** may be made as follows:—Hyposulphite of soda 4 ounces, dissolved in 4 ounces of water. This is to be used repeatedly until saturated with the dissolved out iodide and bromide of silver. Dr. Maddox, however, prefers a fixing solution made by dissolving about 8 grains of cyanide of potassium in one ounce of water. The latter should be marked POISON, and should be made of such strength as will clear the plate in a gradual manner in from one to one and a-half minutes, but it should not be strong enough to destroy the half tones. The same solution can be used repeatedly until it becomes too weak. It should not be exposed to the air. Mr. Deecke prefers "at first the employment of a weak solution of cyanide of potassium; and after this has been washed off, the negatives are placed for from five to ten minutes in a strong solution of hyposulphite of soda, from the use of which they acquire a beautiful clearness in the half tones."

#### PRACTICAL MANIPULATION.

**341. Cleaning the Glass Plates.**—The glass plates, whether of "patent plate," which is the best, or of "polished flatted crown," are first to have the sharp edges removed by a grooved roughening stone sold for the purpose; this is best done under a gentle stream of water from a tap, when the particles of grit or dust will be carried away: the plate is then dropped into a clean pan containing a hot solution of washing soda in rain or soft water. After lying in this for a little time, each plate is washed over back and front with a pledget of tow wetted with a saturated solution of washing soda, and then dropped into clean hot soft water. When all the plates have been treated in this way, they are taken out to drain, the water thrown away and fresh hot water poured into the vessel. The plates are singly dipped under the surface of the clean water, then wiped with chemically clean linen cloths, such as old napkins, one covering the left hand in which the plates rest, the other

being used to dry and polish the plate. These cloths are *not to be washed with soap and water*, but to be well washed out in *hot soft water*, containing a little soda. They are then to be well rinsed in fresh water and dried.

It is advisable to keep a stock of plates thus partially prepared. To further clean them, examine the plate along the edge, and if any very slight curvature exist, let this be taken as the surface on which the collodion is to be poured. Select three chemically clean dry cloths, fold one into double thickness, and on it hold the plate in the left hand, face down; with one of the other cloths polish well the back, breathing on it from time to time; then turn it face uppermost, have a little old collodion which may be slightly weakened with alcohol, place a pledget of clean cotton wool in a small cleft stick or whalebone, dip it into the old collodion, and pass it quickly and well over every part of this surface of the plate. With the same cloth that polished the back, rub this off briskly, then with the other clean perfectly dry cloth finish off the polishing, so that when breathed on, the surface may present a uniform dull appearance without any streaks; set it face down on a clean sheet of foolscap paper, or in a grooved well-closed plate box, the finished faces all looking one way. Thus prepare the number of plates required for immediate use. If to be kept a few hours, wrap them up in another fold of paper, place them in a dry drawer, always noting which is the perfectly clean surface. If of a larger size than 6 inches square, it will be more convenient to clean them on a proper polishing board. Cleanliness in this, as in the succeeding stages, is absolutely requisite. If no old collodion be at hand, a polishing liquid may be made by mixing Howard's precipitated magnesia, 20 grains; strong liquor of ammonia,  $\frac{1}{2}$  drachm; alcohol, 2 ounces. This, however, must be most carefully removed from the edges of the plates, or the bath will soon be rendered alkaline. Or the method adopted by M. Boetter may be adopted for cleaning chemical glasses. This is *strongly recommended* by Mr. Carey Lea:—Common sulphuric acid, 1 ounce; bichromate of potash, 1 ounce; water, 1 pint. The glasses are to be left in this solution for seven or eight hours, their surfaces being entirely covered by it. They are then to be rinsed well beneath a tap. The same solution answers many times. It is as well to see there are no cuts or abrasions on the fingers for this fluid to come in contact with.

When the operator is troubled by a peeling off of the collodion film during the chemical manipulation, it is advisable to coat the cleaned plates with albumen. For this purpose the white of an egg is to be beaten into a stiff froth and stirred into about a pint of water. This is to be allowed to stand for several hours, and then filtered. As the water drips from a rinsed plate, its surface is to be flushed with a little

of the albumen water, and the plate is to be placed on its edge to dry, out of the dust. A large number of plates can be prepared at once, and when dry, wrapped up with pieces of tissue paper, to protect the albumen. The albumen surfaces should all face one end of the pile, which should be marked with a cross. On the albumen the collodion film will stick. The albumenised surface should be the concave surface, if common glass which is not perfectly flat is to be used ; for then the spring on the door of the plate-holder, used during exposure, will tend, by pressing on the convex side, to flatten the glass.

**342. Arranging the Camera.**—Supposing the portable form of apparatus recommended by Dr. Maddox be selected, we proceed as follows :—A room is to be chosen which has a window with a south-west aspect, or at least one where the sun's rays enter during the greater part of the day. The end of the apparatus is placed outside the opened window in such a manner that the face of the prism is directed at right angles to the incident rays ; the legs of the triangle are set apart so that the whole stands firmly on the floor. The object being fixed, it is first carefully examined under the compound microscope, and if of any depth, the part in strict focus when the best general character of the object is attained, is well noted. The objective likewise being selected, is to be screwed into the neck of the microscope, and the achromatic condenser placed in the fitting on the under surface of the stage-plate. The blackened card diaphragm, according to the size of the field desired, is to be fixed in the diaphragm frame that works to and fro in the cut in the back part of the camera chamber, and the prism so turned that the sunlight is thrown on the ground-glass screen. Then the objective is brought into focus. The value of the prism is now apparent, for upon standing with the face towards its convex surface, and turning it on its own parallax motion, an intense image of the sun will be soon formed, as it were, on that surface ; the prism is then to be so arranged that the reflected images from the lens or lenses of the achromatic condenser and of the object fall centrally on the sun's image. If the field on the ground glass now appears equally bright in all directions, the achromatic condenser is slightly altered, to see whether any increase of illumination accompany the change ; if not, it is returned to its previous position. Should the images not fall into the line of the image of the sun, seen on the surface of the prism, some alteration must be made in the part which seems most at fault ; but when they all fall into it, and the distance of the prism is such that its converging rays just cross before reaching the object, the centring is probably correct. If the prism will not carry a cone of light sufficiently large and bright for the lowest powers, as 3 inches, it should be set aside and the plane mirror tried. The object, if on the ordinary 3 × 1 inch *slide*, is now placed on the stage, the camera bellows-body shut up. The whole apparatus, except



the parts to be exposed to the light, is covered with a large focussing cloth of black cotton velvet, the right hand is applied to the slide, and the eyes directed to the ground-glass screen under the focussing cloth; the object is now placed (as nearly as possible) in the centre of the field, and the approximate adjustment made. The rack-work of the condenser and the prism is to be altered until the best effect is produced. The proper position of the condenser is very important, and is often more troublesome to arrange than the focus of the object-glass. The object being well centred, the field perfectly bright and uniform, the velvet collar around the microscope tube must *abut closely* against the aperture in the door of the vertical frame: The camera is now to be withdrawn along the base-board from the near end, and the enlargement is to be closely watched. When this is determined on, the camera is to be fixed by the wire pins to the nearest hole in the two wooden guides. The image on the ground glass is to be studied through the focussing eye-piece; the graduated milled-headed screw of the fine motion turned until the same point as was previously noted is brought into a sharp focus. Should the over-correction of the lens not have been carefully corrected by a back lens, for the low powers, as previously advised, the necessary allowance, which experience has determined, must be made by turning back the screw of the fine motion, the number of divisions or parts required as marked on the milled head. If not known, the experiment must be conducted as before stated, in p. 296, and the particulars noted. A card covered with black cloth or velvet, with its lower edge turned at right angles and deeply notched, is now rested on the stem of the microscope against the end of the achromatic condenser, facing the prism, and this latter protected by a thick fold of chamois leather from the sun's rays. Care must be taken that neither surface of the prism is soiled by vapour or finger marks; nor must the concentrated sunlight be permitted to remain longer on the object than is actually required in focussing, or it may become uncemented, and if not injured, it may slip completely out of the field.

If the higher powers be used, needing the screw adjustment for the correction of the error introduced by the thin glass cover, we find it best to make this correction as nearly as we can when examining the object in the microscope, and then testing, with the collar set to that figure, the image of the ground-glass screen. If the image here seems moderately sharp, under the best focussing, a trial is made by shifting the collar a very little and watching the appearance of the image. Sometimes a very trivial alteration will bring out fine markings much more distinctly. The focus will also often require readjustment; but before making this, it will be as well to test a plate, when, should the negative be found defective in the parts most sharply focussed, another is to be taken after the objective has been withdrawn a little by turning

the milled-headed screw. It is often in this way that the qualities of an objective are discovered. Assuming that the plane of the greyed glass screen, and that occupied by the sensitised plate, *strictly* correspond, if the second image be out of focus, another trial must be made after the apparent necessary change learnt from a close examination of the negative, and the image on the screen has been made. When once correctly found, the division of the screw-collar and the distance in inches at which the camera stands fixed by the pegs are to be carefully noted by the figures on the guides, as necessary for that objective used at the particular distance with sunlight, and for objects covered by thin glass of the thickness in the case of the particular specimen photographed.

Dr. Maddox remarks that when the edges of objects under the higher powers present on the grey glass screen a faint tint of claret on the one side and of apple green on the other, that great sharpness will often exist in the negative; the errors of the pairs of lenses in such cases balancing one another as regards the actinic focus. The roughness of the screen will not in all cases permit of the eye determining under sunlight the best focus for the minute markings, and some fine diffusing surface must be chosen, as a well-washed sensitised collodion plate, flowed by a solution of tannin or albumen, or the surface of plate-glass covered by fine weak starch paste recommended by Mr. Carey Lea, or the serum of milk, as occasionally used by Dr. Maddox. Dr. Woodward employs plain glass, but unless a coloured medium intervenes, there may be some risk to the eye in working with the lower powers. The object may be focussed through a parallel polished plate of blue glass. Upon the whole the *finely* ground surface of glass has been found most serviceable for ordinary work.

Should the object be situated some distance from the thin covering, especially if much of the mounting medium glass intervenes, although the objective may appear to work fairly through the depth, it is seldom that the negative of the image proves satisfactory. In such a case it is better to remount the object or select another. Indeed, for the finer work it is most desirable that the objects should lie just beneath the under-surface of the thin cover. Diatoms and such bodies may be dried on the thin glass cover and photographed, or after having been dried, they may be placed on a drop of balsam warmed on the glass slide. If there be any vibration from unsteadiness of the apparatus, or from wind, the results will be unsatisfactory.

**343. Sensitising and Exposing the Plate.**—The suitable sized plate of properly cleaned glass being selected, the materials required should be conveniently placed in the dark room or part of the chamber darkened for this purpose, and lighted by a yellow light or a small oil lamp with yellow glass shade. An ordinary window light or lamp

shade may be made yellow by a covering of yellow tissue paper. The plate is held by its sides between the fingers and thumb of the left hand, face downwards, the back wiped carefully with a *dry* wide flat camel-hair wash tool, to remove small particles of cotton or dust. It is then taken by the left hand near corner, with the thumb and fingers of the left hand, or seized in the centre by a pneumatic holder, and the face dusted over with the brush. Before the corner of the plate, or the holder, is taken up by the left hand, care must be taken that the neck and lip of the collodion bottle are perfectly free from any foreign particles likely to be carried on to the plate by the stream of collodion. The finger is commonly passed over these parts to clear away any dirt. The collodion may now be poured with a steady flow on to the plate a little nearer to the left hand than its exact centre. While flowing the lower and upper left corners are to be gradually depressed, so that the collodion may be fairly brought to the edges of the plate, while at the same time the pool is being increased by pouring. The plate is then to be lowered so as to allow the fluid to flow to the right further corner, and from this into the bottle, the sides of the angle of plate being rested on the lip, the plate being rocked and kept slightly inclined. The lower part being, as it were, dragged against the neck of the bottle, the latter is to be closed. The plate is to be held horizontally by the pneumatic holder for ten seconds to half a minute, or even more, according to the setting quality of the collodion. If this occur slowly, it will be better to rest the holder on some flat place or shelf, so that the warmth of the hand may not cause unequal evaporation. When the collodion is just sufficiently set to take nicely the impression of a clean finger-tip gently pressed into the film near one edge of the plate, the plate is ready for the nitrate of silver bath. During the "setting," the collodion which has reached the back, or accumulated in excess along any edge of the plate, is to be removed. The plate is to be carefully detached from the holder and placed on the fluted glass or silver wire dipper, to be plunged at one gradual stroke into the nitrate bath. Here it is allowed to remain for one minute, then raised and lowered several times, so as to wash the surface well, and permitted to remain in the bath for one or two minutes longer, when the dipper with plate is to be steadily withdrawn. If the plate is withdrawn too soon it will have a gray streaked surface, as if oil and water had been poured on the plate. As soon as this appearance has given place to a perfectly smooth, glassy, gray surface, the plate is ready to leave the bath, no matter whether it has been in a short or long time. If the plate remain for a short time, part in the bath and part out of it, a disagreeable transverse line will be formed in the negative; therefore insert it with the "one gradual stroke" as above recommended. The plate being removed, it is to be rested by its lower edge on a pad of clean blotting-paper, the dipper

returned to the bath. The back of the plate frame, pl. LXXII, fig. 1, p. 308, is to be opened, and with the right hand the plate is placed face downwards in the frame, which should be dry and free of dust. The edge of the plate frame which is to be lowest in the camera should, from the introduction of the plate, be kept lowest, and that edge of the plate which was lowest in the bath should have now the same relation to the plate-holder; and, to go back a step, in introducing the plate into the bath, the edge along which the collodion film is thinner is to be selected as the one to be lowest, first in the bath and then in the frame-holder. The back is now closed, and the frame covered with a large piece of black calico, and rested against the wall or table. Next the observer adjusts the prism, removes the focussing screen, having glanced at the image on it, sets the covered card against the achromatic condenser, passes the slide-holder under the focussing cloth, into the position of the greyed screen, and *lifts carefully* the shutter of the frame, the hands being under the cloth. All is to remain for a moment or two, that vibrations may cease, the card then snatched without shaking, and quickly replaced, a period of from half to twenty-five or thirty-five seconds being allowed for the image to be impressed. The time must be learnt by practice. The shutter is gently closed, the frame withdrawn and replaced in the cloth, the focussing screen returned into its place, the card again removed, and the image observed. The prism may then be covered. The observer now returns with the slide-holder to the dark room, and proceeds to develop the picture. The purpose of the re-observation of the image is to see if the object and its focussing have not been in any way deranged, so that if the development is found to bring out a good image, the operation can be repeated without the necessity of returning to the camera before the second plate is got ready.

**344. Developing the Image.**—Let us suppose the plate to be a small one. First see that the nitrate bath is *carefully placed out of the way of all splashes*. Pour into a clean developing glass an ounce or more of the iron developing solution, add the necessary quantity of alcohol, or syrup and alcohol, and mix. Remove the plate from the holder, rest it face up on a levelled developing stand set in a large basin or pan, clip the left-hand opposite corners between the finger and thumb, and commence the second step by flushing the surface with some of the iron solution. Tip the plate, that the liquid may quickly flow up to all the edges, then move it gently about on the top of the stand; the light from the protected lamp or admitted through the yellow glass window falling nicely on the surface, watch for the appearance of the image; this, if all be correct, will increase steadily up to a certain point, but if left longer, the plate will begin to grey all over. *Just before this would take place*, tip up the plate to throw off the developer, flush the plate well with water from a jug or tap protected by a piece of flannel tied loosely over it, to remove

all the iron. Now examine the plate carefully by transmitted light from the window or lamp with yellow shade, and judge whether it be worth while to carry out the other operations. Reflush the plate again with water, pour off, and now pour on the fixing solutions—the cyanide of potassium is to be preferred. Let it pass all over the plate, and in less than a minute the plate will be cleared of the unaltered bromo-iodide of silver. Wash well front and back with clean common water, drain the plate for a moment, and pour on it along the edge sufficient of the solution of iodo-iodide of potassium to well cover the surface; allow this to remain on the plate until the grey colour of the image passes to a warmer tone (two or four minutes or more); pour off the fluid, examine it quickly with a hand magnifier by ordinary light. If the image now has the appearance of being in focus, wash the plate well with common, then with clean fresh rain or distilled water; let this stand on it whilst you pour into a *clean* developing glass about  $2\frac{1}{2}$ , 3, or more drachms of the pyrogallic solution; add to this from six to ten drops of the 30-grain nitrate of silver solution, add two to four drops of the nitro-silver solution, mix these by twirling the hand holding the developing glass, pour off the water from the plate, and carefully pour on along the edge or corner this mixed fluid, so as to flow to the edges; rock as before; after a brief period, according to the appearance of the image, return the fluid to the developing glass and pour on again; repeat this several times, just holding the plate in the intervals between the eye and lamp, to judge of the increased intensity, which, when it appears sufficient, should in the darkest parts permit the flame of the lamp or yellow window, to be just seen through. Now wash well with water, and finish with a little soft water. With a small towel wipe the back, and set the plate to drain in a plate-rack, attaching to the lower corner a small piece of blotting-paper, or the plate can be dried off at once over the lamp. It is sometimes difficult to judge of the real intensity gained under this treatment, when the image is observed by yellow light; therefore, after the flowing over of the iodide of potassium solution, the remainder of the operations can be conducted by the direct light of the small lamp, or any moderate diffused light.

Should the development have been carried a little too far, or should the fine transparent markings appear thickened or clouded, before setting up the plate to drain, flush it with a mixture of equal parts of the cyanide and iodide solutions and distilled water, then well wash. Under this treatment many of the minute spots and half-toned points become remarkably brightened. Some prefer to intensify before using the cyanide solution, by, first, under non-actinic light, after the iron developer has been *well* washed from the plate, pouring on the pyro solution, with a little alcohol, returning it to the developing glass, then adding the mixed silver solutions and repouring on and off the plate, until the

image has been brought up to the necessary intensity, when it is to be well washed, and then treated with the hypo-fixing solution or the cyanide. Or the operator may proceed to intensify after well washing off the iron solution, after clearing by cyanide or hypo solutions, using the pyro and silver solutions, without the previous use of the iodo-iodide of potassium solution. The fixing solutions are returned to their respective vessels (short wide-mouthed bottles or jugs are convenient), and can be used over and over again, adding a fresh quantity as occasion may require; but the cyanide solution must not be left exposed, for it soon loses cyanogen, and the vapours are deleterious. Keep the hands continually wiped in these operations. If the plate, after the application of the iron solution and cyanide solution, have the appearance of under exposure, the image indistinct in detail—or of being over exposed, the image of a too dark and uniform character throughout—or of being out of focus—it will not be worth while to proceed to further develop it; wash it and carry it to the light, examine it with the hand magnifier, as some part, not that specially focussed, may appear the sharpest and serve to indicate the alteration required on re-focussing. If any extraneous light should have entered, through defects in the camera or at the vertical frame, or from the slide-holder, or when preparing the plate in the darkened room, or before applying the fixing solutions; or if the nitrate bath and chemicals be not in perfect condition, the plate when cleared will appear fogged or misty, and not yield good prints.

Generally it is advisable, when the negative appears correct, to take a second one under the same arrangements, only re-arranging the prism; seldom can the exact relations be re-established, and after the rendering of another negative it may be found that the little alteration in the illumination, barely visible on the screen to the eye, has given a still more perfect character to the image, or further developed some of the finer markings.

**345. Of Increasing the Intensity of the Negative.**—There is much difficulty in obtaining a clean dense negative, which shall preserve distinctness in the finest markings. When the attempt is made to procure greater intensity by the intensifying processes, the fresh deposit of silver, with the shrinking of the collodion in drying, will often so completely close up these lines that their definition becomes lost in the print. To endeavour to still preserve these and add printing intensity to the negative, some employ a solution of bichloride of mercury. Dissolve in 2 oz. of distilled or soft water, 12 grains of the bichloride of mercury or corrosive sublimate; label the solution POISON. After developing with iron, washing and continuing the development with the silver and pyro solutions, fixing, and re-washing, the plate is flushed with the sublimate liquid (which is allowed to remain on until the image becomes of a dark grey colour if the solution be used weaker, 2 grs. to the oz. of water),

then well washed, and recovered with a weak solution of iodide of potassium, from 1 to 2 grs. to the oz. of water; this will give the image a dirty grey or green tinge, which will often dry of a darker colour. The bichloride can also be used after the iodide of potassium solution, taking care to wash the surface well before applying it, then again washing off with water, the plate may be covered with an old weak solution of hyposulphite of soda, or a few drops to half a drachm or more of the strong liquor of ammonia in half a pint of water, or sulphide of ammonium in water. Some employ iodide of mercury dissolved in iodide of potassium, and thus gain the advantage of using the mercury and iodide in one operation. In cases in which the bichloride has been used to add to the intensity, the negatives when dry often present a remarkable sharpness; but it is no uncommon thing to find that when the plate has been dried, spontaneously even, the moment it is handled the collodion flies and cracks often into the image; to prevent this it is requisite to pour over the plate, after the last washing, a weak mucilage or gum-water. In this case care must be taken to well dry the plate prior to varnishing, as gum is to a small extent an absorbent of moisture.

In the journals and manuals on general photography various methods are set forth to endeavour to procure by one operation sufficient intensity to print from. Mr. M. Carey Lea strongly recommends gelatine soaked, the water poured off, then acted on (without heat in all the operations) by sulphuric acid, the acid to be taken up by the gradual addition, when cool, of clean iron filings or thin iron wire, and the excess of acid finally removed by the acetate of soda. Others have proposed the solution of gelatine in acetic acid or nitric acid and the addition of this, from a few drops upwards, to the ordinary protosulphate of iron or ammonio-sulphate of iron developer, without the acetic acid (Dr. Towler's method). Some use honey or a little albumen added to the pyro-acetic and silver solution for the same object.

**346. Varnishing the Plate.**—When the plates are dry, clean off the edges with a damp cloth held on the forefinger nail, wipe well the back, and hold the plate before a clear fire until moderately warm to the back of the hand; take it by one corner and pour on the varnish (Soehnée is very good). Allow it to flow freely over the surface, and remain for half a minute or less on it, then pour back the surplus into the bottle from one corner, not rocking the plate; let it drain a little, then hold the plate towards the fire vertically, the edges from which the varnish was poured being downwards, and wipe them with a piece of rag or tissue-paper, to prevent a thickened line being formed and extending inwards as the plate dries. If intended for enlarging, it is far better not to varnish the plate in any way; but to prevent the surface from being injured, it may be flowed with weak albumen, then dried, and plunged into a dish of alcohol.

**347. Of Cleaning Old Plates.**—The soiled and used plates can be cleaned by the fresh use of washing soda; those varnished should be allowed to soak in a very hot strong solution of this substance, or rubbed with a pledget of tow dipped in nitric acid; or treated by Mr. M. Carey Lea's method. If they are to be used again they must be cleaned with great care.

PRINTING.

The negative, if it be preferred, can be handed to a professional photographic printer, who, however, should be acquainted with the character of the object, or its chief characteristics should be pointed out to him; otherwise a print may be returned bearing anything but a semblance to the real appearance of the object, as seen in the microscope; the tendency generally being to over-print and render a delicate object heavy and out of all character. We shall complete this chapter by offering such instructions as may at least enable the amateur to print for himself.

**348. Preparing the Paper, Exposing and Washing.**—Select albumenised paper, the best procurable, either Rive or Saxe, and such as is used for the finest cartes de visite. Cut the sheet into six equal parts or to the size convenient for sensitising, or according to the size of the negatives, taking care not to soil the surface with the fingers.

Take the paper by the diagonal corners, bend it slightly back and lower it gradually, without any stoppage, albumen side downwards, on a solution of nitrate of silver 60 to 80 grains to the ounce of water, and about one drop of nitric acid to four or six ounces of liquid. Be careful that no air bubbles are confined beneath the paper. To ascertain this, lift the corner by a pair of bone forceps. Allow the paper to remain from one to two minutes for the 80 grain solution, and three minutes for the 60 grain solution. The object is to form a chloride of silver as much as possible on the surface of the albumen. Pin up to drain, and append a piece of blotting paper at the lowest corner. When surface dry, if required at once, the drying may be hastened by placing the papers in a box lined with blotting paper and heated by a warm clean brick or corked jar of hot water. The paper must be prepared in non-actinic light, and can be preserved for future use in a preservative-case sold for the purpose.

The negatives are wiped on the back, placed face up in the printing frames, figs. 2 to 5, pl. LXXII, the sensitised paper put face downwards on them, then covered by a pad of red blotting paper or cloth, and the back of the printing frame properly closed. These frames, covered by a dark cloth, are carried to the window ledge or table at an open window, and placed so as to receive the direct sun's rays. After the edge of the paper is seen to be well browned or bronzed, the back of the printing frame can be carefully opened in diffused light, the print



quickly examined, the back reclosed, and the frame returned to the same position if not already sufficiently printed. Mr. Deecke displays great patience and skill in slowly printing in diffused light. He covers and uncovers part after part of the negative, to allow for the varying density of the different parts of the picture, due to the varying thickness or opacity of the corresponding parts in the microscopic object. Sometimes the printing is better if conducted in a north light, or under ordinary daylight instead of sunlight, according to the character of the negative. The paper and the prints are to be kept in dark boxes or drawers; but in the intervals, while waiting for the printing to go on, the prints are to be taken from the dark, and in diffused light trimmed, and then returned to the box or drawer. Much of the elegance of a photograph depends upon its being correctly trimmed. The best and simplest way of doing this is to lay the print, face up, on a plate of glass, to cover just that part of the print required, by a plate glass pattern, truly cut with a diamond, and with edges perhaps ground, and then to run a *sharp* knife at a single stroke through the paper close to each edge, in turn, of the pattern. When the printing is finished float the prints face downwards on a large flat dish of clean rain water, then on common water in another dish; afterwards plunge them under water in another deep vessel, allow them to remain for five or ten minutes, occasionally stirring them about, and relay another set. One of the above waters should, before putting the prints in, have a small pinch of common salt added, just enough to turn the prints to a bright red colour. (This contrasts with the colour the prints assume in the toning-bath, and enables one to better appreciate when the toning is sufficient.) They are now ready for toning. Some plunge them into water and change the water several times, but in this case the backs are wetted and the unchanged nitrate or chloride of silver admitted into the pores of the paper, which is not advisable. Before placing the prints in the toning solution it is as well to let them drain against the sides of the dish, if of small size; if larger, to at least wipe over the front and back with a glass rod, so as not to pass them into the toning bath in a very wet state.

**349. Toning.**—The toning solution is prepared as follows:—8 drachms of distilled water;  $7\frac{1}{2}$  grains of chloride of gold. If the solution is not to be used at once, 1 drop of hydrochloric acid is to be added to the above solution, which must be kept in a stoppered bottle in the dark.

Pour one drachm of the gold solution into a clean developing glass or measure, and add one ounce of distilled or soft water. Into another clean glass vessel put half an ounce of soft water, and 5 grains of bicarbonate of soda. Part of the soda solution is to be added to the gold, gradually stirring during the time. The solution is to be tested

with blue litmus paper. The addition of soda solution is to be cautiously continued, until the paper is no longer reddened. A drop or two more of the soda is then to be added, and the neutralised solution of chloride of gold poured into a clean small flat dish, and mixed with about 8 ounces of soft water. Set this near to the window screened by the yellow curtain or glass. Remove the washed and drained prints from the dish, and pass them into the toning solution, a few at a time. Here they are to be kept in motion: as they appear to darken, just lift the curtain aside and note the tint they have assumed by daylight, but they must not remain exposed to the light any time, or the white parts will be injured. The other dishes should likewise be attended to and covered over with a sheet of paper to keep the light from them. In the toning bath the prints gradually lose their red colour, becoming of a warm brown, then of a warm black, and, lastly, of a cold gray black colour. If the prints are removed when warm black, the photographs when finished will be of about the tone of pictures in the portrait galleries. If taken out sooner they will be more red; if later, more black. As fast as toned, the prints are passed into a dish of clean water. The toning should all be done, and the dishes and glass rods used in handling the prints put away before the fingers even touch the hyposulphite of soda. Even the dish containing the prints should be put on one side until the fixing solution is ready. The toning solution may be kept in a bottle, and the portion above the precipitate which falls, decanted each time it is used into the toning dish, a little of the soda and gold solutions being added at each toning. The quantity of the toning solution prepared must be in proportion to the size and number of prints, about 1 grain of gold to one full sheet of paper.

**350. Another Toning Solution.**—One grain of chloride of gold, or 1 drachm of the solution, is to be neutralised with bicarbonate of soda in 9 or 10 ounces of soft water, then half a drachm of the crystallised acetate is to be added. This is to be used the day after making; it keeps well, and can be strengthened by adding freshly made solution prepared somewhat stronger. Occasionally the neutral or alkaline solution of gold-bath will not act; but if the dish be set over a jug or basin of hot water, the toning action will commence, or a few drops of the chloride of gold may be added. Good toned prints have also been produced by using the weakened neutral solution of gold and soda, for the next lot of prints, adding some fresh solution of gold. Other toning solutions are made with hiborate, or phosphate of soda; also with acetate and chloride of lime.

The unaltered chloride of silver has now to be removed from the paper.

**351. Fixing.**—The fixing solution is made by putting into a gutta-percha dish, kept for this purpose only, according to the size and number

of the prints,—2 ounces of hyposulphite of soda to 8 or 10 ounces of soft water.

As a precaution, in case the hyposulphite should be acid, a small lump of chalk or whiting is to be added. Remove the prints from the water, drain well, if convenient, against the sides of the dish, then pass them singly into the fixing solution, keeping them there, in the case of a thin paper, for 10 minutes, and a thick paper for 15 minutes. They must be kept in motion. These different processes should be conducted more or less continuously so as not to lose time.

When the prints are removed from the hyposulphite, drain well, then pass them into a vessel of clean water, which should be changed often during the first hour, draining completely each time. They may then be left for 6 hours or longer, the water being changed every half hour, or kept under a gentle stream of water. They are to be finished by soaking them for a short time in hot water. After this they are laid face upwards on bibulous paper to dry. The hyposulphite solution should be used when freshly made.

**352. Of Mounting the Prints.**—The most accurate prints are those which are not mounted; because, in the mounting, the print becomes wider or longer, according as the print is cut across or with the length of the original sheet. The corners simply might be fastened to a stiff mount by flour or starch paste. If for any reason, however, the prints are to be mounted, dip them one by one into water, and pile them one on the other, face down, on a plate of glass. Thoroughly squeeze the water from the pile. Press a blotter for an instant to every part of the back of the top print, and then apply evenly to the back by means of a brush, somewhat thick, almost stiff starch paste. Lift one corner of the print with a penknife, and then the whole print by the fingers, turn it over into its proper position on the card or paper mount, and thoroughly press it home with a clean blotter. Thus treat each print of the pile in turn. To “finish” the mounted picture, photographers lightly sponge the front with a solution of French soap in alcohol, and after a few minutes pass the picture between hot polished steel rollers.

**353. Photographs of Microscopic Objects for the Magic Lantern.**—Although no means are yet known by which a minute object, magnified by the higher powers of the microscope, can be thrown upon a screen so as to be seen by a number of persons at once, almost the same result has been obtained by magnifying a photograph of the object in an oxy-hydrogen magic lantern. It may not be out of place to say a few words on the negatives best suited for enlargement, and the mode of enlarging to a moderate size. The negative should be clear without stains, and if containing only a single object—or objects separated,—the field should be only sufficiently dense not to allow any light to pass through in the period of time necessary to secure a

reversed copy or positive on glass. To effect this there are several ways. If to be of the same size, a sensitised, albumenised, or tannin prepared plate, dry, has the negative laid carefully face down on the prepared surface, and fixed as in a printing frame, or held very tightly, then exposed to ordinary day-light for a few seconds, or else for a longer period opposite a fish-tail gas-light. When impressed the negative is removed, and the image developed in the manner employed for the kind of film used. A very fine deposit is requisite, therefore the development should be gradual; great diversity of tone is procured by using various articles in the developer, or following its re-application, as honey, raspberry syrup, &c., or the image when cleared by cyanide of potassium or hyposulphite of soda, and well washed, may be toned by a gold-toning solution.

If to be taken on a wet plate, a proper copying camera or two draw cameras are commonly used: the negative, face towards the interior of the camera, is placed in the ordinary camera slide, and this inserted in its place and opened. A portrait combination is fitted to the opposite end of this camera if the negative is to be in any way enlarged,—if not to another camera, and the front lens made to face the negative; the two cameras are then fixed face to face, and the light round the aperture of the lenses and the junction with the additional camera made absolutely light-tight: the cameras thus fixed to any board are placed so that the negative faces a north light; by means of the rack and pinion of the combination, and the draw-part of either or both cameras, a sharp image of the negative is to be formed on the grayed glass of the second camera, and then received as in the ordinary manner on the prepared plate: a short exposure only is needed. It is as well to limit the field by placing a piece of thick black paper with the necessary sized and shaped aperture in it, on the back of the negative before placing it in the slide. Care should be taken to secure the negative in its position in case of accident. Or a copy can be made by placing the negative in a vertical frame supported on a table near an open window, and a large white card or mirror placed a little distance off, at an angle behind it, so as to illuminate the surface equally by transmitted light, and the ordinary camera used as in copying engravings or pictures,—care being taken that the reflected light from the screen is not thrown into the lens as well as transmitted through the negative. A proper copying camera is the best. In enlarging, some employ a special reflector, when the position of the negative must be arranged with care. The positive thus obtained can in its turn be made to furnish a second negative of a similar, larger, or smaller size.

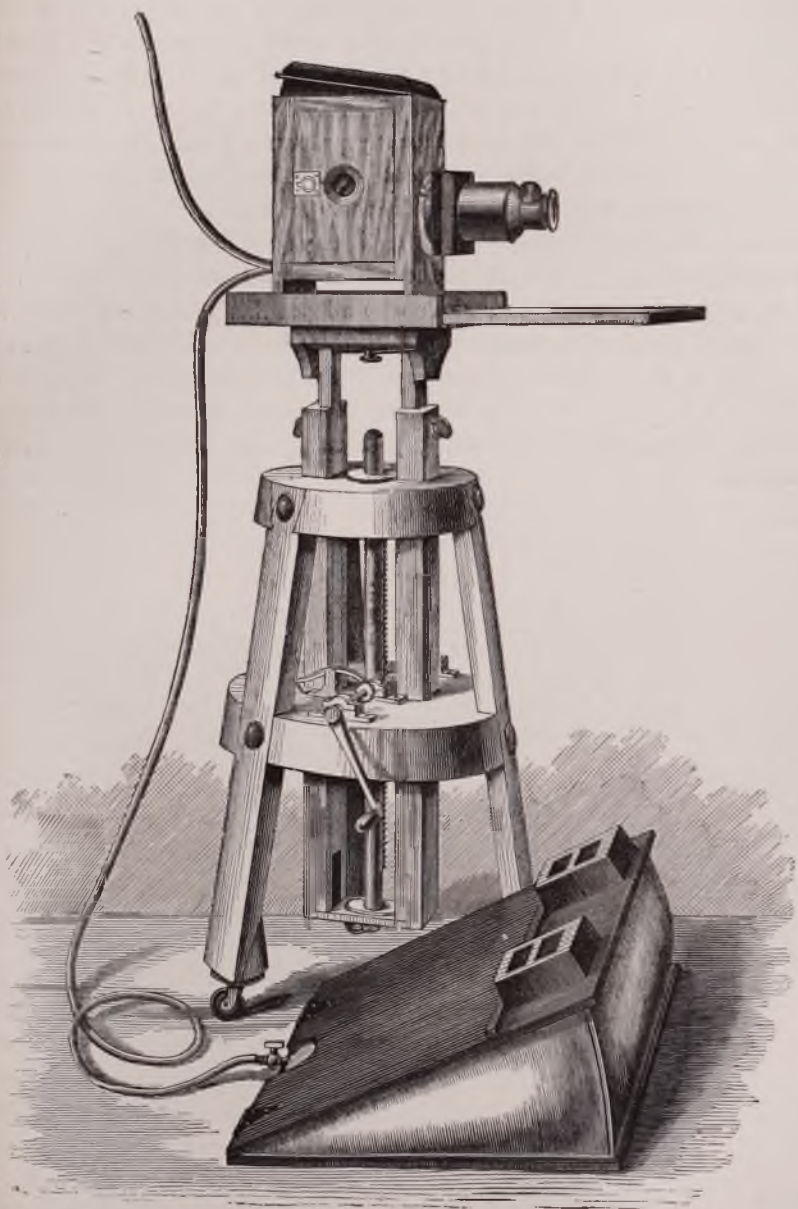
As these photographs abound in delicate detail, an oxy-hydrogen or electric lantern with achromatic lenses is necessary for their proper display. The lantern and arrangements for producing the light are

shown in pl. LXXIII. The lantern should be made of old seasoned mahogany, so that warping may not be produced by the very intense heat of the lime light. Behind the spring stage, which carries the photographic slide, M. T. T. Taylor has placed a combination of lenses,  $3\frac{1}{2}$  inches in diameter, called "the condenser." (See paper in Reports of the British Association.) The object of this arrangement is to collect and concentrate the light emitted by a cylinder of lime rendered incandescent by an ignited jet of oxy-hydrogen gas, upon the surface of the photograph, through which it passes, and then converges upon an achromatic combination placed at a proper focal distance in front. The rays on passing onwards diverge, and the enlarged shadow of the photograph is projected upon an opaque or transparent screen. By this means all the details of an object less than a pin's point in size may be shown with perfect definition, twenty feet in diameter. The hydrogen may be obtained from any house gas-supply by simply connecting the tap of a gas bracket by a piece of flexible tubing with the hydrogen tube of the jet. The oxygen is obtained by heating a mixture of chlorate of potash and oxide of manganese in a proper retort, and collecting the gas in a wedge-shaped gas-bag, after passing it through a washing bottle to purify it. Condensed oxygen may now be purchased ready for use in strong iron bottles. The stop-cock of the gas-bag is connected with the oxygen tube of the jet by flexible tubing. The jet is so arranged that it is impossible for any accident to occur in the shape of an explosion, the gases only being combined at the extremity of the jet. When house gas is not attainable the jet of oxygen may be forced through a spirit flame on to the lime ball, or if a small disc of seven feet in diameter is considered sufficient, such photographs may be shown by means of a paraffine or other hydrocarbon lamp, if the triple condenser and single achromatic lens be employed. The most intense light is obtained by replacing the house-gas (carburetted hydrogen) with pure hydrogen, and burning both gases under an increased pressure, and mixed in a suitable jet, just before being forced upon the lime ball.

**354. Iron Gas Bottles.**—The India-rubber gas-bags are now superseded by the use of iron bottles charged by means of condensing pumps with the gas to the pressure of 30 atmospheres. One bottle is equivalent in contents to six of the gas-bags formerly employed. These iron reservoirs are cheaper and last longer than the gas-bags, and in them the gases may be kept for any length of time. They are always ready for use; the cumbrous pressure boards and weights are dispensed with, and they are free from danger if purchased from a maker that can be relied on. (See Mr. Highley's paper read before the Society of Arts, January 4th, 1863.) Mr. How, of St. Bride Street, Ludgate Hill, provides the requisite instruments and apparatus. A list of books on photography of value to the practical operator will be found at the end of the present volume.

OXYHYDROGEN LANTERN.

PLATE LXXIII.



Oxyhydrogen lantern, with gas bag, &c., as arranged by Mr. Highley for throwing the photographs of microscopic objects upon a screen.

**354.\* On the Use of Gelatino-Bromide Dry Plates for Photo-Micrography.**—It is probable that the dry plates will be found very advantageous for taking photographs of microscopic objects. They are far more sensitive than the ordinary moist plates and, consequently, much greater care is required in manipulation, and especially in the arrangement of the dark chamber, for an amount of light which would not affect the ordinary plan would cause fogging in the plate or entirely interfere with the dry process. Messrs. Wratten and Wainwright, of 38, Great Queen Street, have recently prepared plates which are ten times as sensitive as ordinary wet plates. Professor H. Vogel speaks of the “astonishing results” obtained by this process. Dr. Clifford Mercer has seen an image produced, in the light of an ordinary gas light, in two seconds, and there is no doubt that the process is well suited for photo micrography. The observer who adopts this plan must, however, be extremely careful in following out all the details. Full description of the method of proceeding, together with the prepared plates and all the chemicals required, may be obtained of Messrs. Wratten and Wainwright, Photographic Chemists, 38, Great Queen Street, Long Acre, London.

## PART VI.

THE DISCOVERY OF NEW FACTS BY MICROSCOPICAL INVESTIGATION—  
 OF THE HIGHEST MAGNIFYING POWERS YET MADE, AND OF THE  
 BEST METHODS OF USING THEM—NEW METHOD OF PREPARING  
 SPECIMENS FOR EXAMINATION WITH THE HIGHEST POWERS—NEW  
 VIEWS CONCERNING THE STRUCTURE, GROWTH, AND NUTRITION  
 OF TISSUES—OF LIFE—OF THE STRUCTURE AND ACTION OF A  
 NERVOUS APPARATUS—BIOPLASM CONCERNED IN MENTAL ACTION.

IN this part of my book, I propose to consider how objects may be most satisfactorily examined with the aid of the highest powers yet made, and how the most minute structural peculiarities may be demonstrated. I shall venture to describe in detail the special methods which I have employed in my investigations upon the minute structure of various textures and upon the nature of the changes which take place in the course of development and growth of living beings. By the method of investigation referred to, not only may sections of any tissue be prepared sufficiently thin to be subjected to examination by powers magnifying upwards of 5,000 diameters, but the vessels of the tissues may be injected and afterwards displayed in the same preparations.

This part of my subject, the details of which have been introduced for the consideration of the more advanced student, should not be taken up by beginners, at any rate, before they have honestly gone through the tables at the end of this volume, and have perfected themselves in the various operations there indicated. When elementary principles and practical details have been thoroughly mastered, the observer may begin to practise the process of staining tissues, p. 122, and may endeavour to make exceedingly thin sections of tissues of varying degrees of softness, toughness and resistance, p. 92. In this way he will gradually be led on to undertake original investigations, and, in the course of the experiments he may make, no doubt, important improvements in the methods of preparation now in use will be devised by him. The student who desires to ascertain the truth concerning many scientific questions must not be deterred by any disparaging remarks on the part of authorities, however popular, concerning this or any other special method of investigation, for new processes are almost invariably condemned, and advance in this branch of microscop-



pical investigation labours under the serious disadvantage of being appreciated only by a very limited number of persons. Nor must the student who wishes to become a good observer, trouble himself about the imaginings of popular celebrities who proclaim all living things to be matter only, declare that vital actions are mechanical, and expatiate upon the mischievous tendencies of microscopical investigation to audiences as ignorant as themselves, and who do their utmost to excite prejudice against the use of an instrument by which anyone may conclusively prove, contrary to their dictum, that living beings are not in the least degree like any machine that is known and that there is no analogy between physical and vital phenomena. Unfortunately a considerable section of the public at this time insists that mechanical views concerning all life shall be taught far and wide, and therefore sustains and encourages and rewards with applause and notoriety those who obey its mandates.

**355. In Defence of the Use of very high Magnifying Powers.—**

Before describing the highest magnifying powers and the method of using them, it is unfortunately necessary for me to allude to objections which have been raised to their use and to endeavour to answer some of the most important. Some persons still persist in asserting that no advantage is to be gained from powers magnifying more than 300 diameters. Now, it would be a waste of time to answer the many frivolous objections which have been raised to this and other methods of observation, in Germany and elsewhere. It is obvious that every observer has a perfect right to work as he likes, while to praise any processes of investigation supposed to be advantageous and to condemn those considered objectionable is a privilege enjoyed by all. Some authorities disparage means of research which they themselves cannot or will not employ. Although for example it is perfectly obvious that the simplest and only efficient manner of introducing fluid into all parts of a tissue is to inject it by the vessels, some who do not inject refuse to admit that this is so. Moreover there are individuals who will maintain that those appearances can alone be trusted, and accepted as natural appearances, which result from observations upon tissues immersed in water. Now although it is true that nothing is gained by subjecting specimens immersed in water to the highest powers, it is quite certain that those authorities who maintain that everything ought to be examined in water, and assert that little is gained by the use of high powers, which they pronounce to be useless, are in error as regards the correctness of their contention as well as the grounds upon which it is based. To the use of water there are grave objections. Water alters many tissues extremely, and completely destroys some of the most delicate textures. Its limpid character renders it impossible to fray out many delicate tissues immersed in it, while an amount of pressure sufficient to make

tissues thin enough for observation with high powers causes their complete destruction. Notwithstanding all this, not a few observers still use water and solutions of which water is the principal ingredient, and refuse to adopt or admit any principles opposed to this plan. No wonder they condemn the use of high powers. Not content with working on in their own way, many do all they can to underrate the importance of observations made upon any principles with which they are not acquainted. If anyone makes out new points of structure by any new method, all that an authority who differs from him has to do, if he desires to upset his views, is to state that the structure described is not to be seen in specimens prepared in the "natural way," and that therefore the appearances are altogether fallacious and the conclusions drawn from them quite erroneous. If an *authority* simply denies the existence of what he has himself been unable to see, he is but too often implicitly believed, although he may not have taken the pains to try the only method of investigation by which the appearances in question could be seen. In these days if only a man gains reputation in one branch of science, the public allows him to usurp authority in others. He may have studied physics and chemistry for many years, and so become an authority on the question of spontaneous generation, and his dicta concerning contagious diseases of man and animals be accepted as final. Again, some authorities who have not seen points of structure described by others without denying the truth of their observations, content themselves with intimating that the new notions are not likely to be true, because the arrangement does not exist in a particular animal which they happen to have elaborately studied. But as regards progress, authority is of little consequence, especially in that department of science in which microscopical observation is included. Real workers observe and try to discover facts and leave *authority* to dictate and dogmatise to those who like to submit. The assertions often made are so astounding that nobody cares to contradict them. An article, not long ago, appeared in a well-known journal, in which it was asserted as a valid argument against the employment of high powers, that all the important discoveries in natural history and anatomy had been made with the aid of powers which did not magnify more than the quarter of an inch object-glass (200 diameters). It is only necessary to remark that the writer of this remarkable paper as well as those who agree with him, must be quite ignorant of the microscopic work of the last twenty years. If such journals as "Schultze's Archiv," or "Kölliker's Zeitschrift," or the "Philosophical Transactions of the Royal Society," or the "Microscopical Journal," be referred to, multitudes of observations will be found which prove the great advantages resulting from the use of high-power objectives, and in many branches of research.

It is not, however, to be wondered at that the introduction of new

and more refined methods of investigation should meet with considerable opposition, for in all departments of progressive knowledge are to be found persons who seem to consider it their special duty to discover as soon as possible any symptoms of too rapid advance, and oppose innovations with the utmost vigour. It is to be regretted too that sometimes the innovators and rebels of one period become the obstructives of a later time. Some of the warmest advocates of progress seem to mean progress in one particular direction and progress of one particular kind only. Other zealous innovators soon reach a period in their career when they tire of the constant change, and make the discovery that what some consider to be advance is really going back. Many more, regardless of the struggling crowds behind them, long to rest for a time in a position which they have at last gained after years of labour, though by resting they constitute themselves the opponents of scientific progress and the enemies of true science, for science can never rest without great danger of retrograding and losing much of what has been already gained.

Some there are, who considering themselves very far advanced, teach the public to believe that they are leading them on, when in fact they are trying to carry them back to a phase of thought which 2,000 years ago was behind the time. Some of these self-confident teachers wantonly condemn the use of the microscope, because the facts discovered by this instrument preclude the acceptance of a most extravagant and degrading form of materialism, which they profess. Notwithstanding the repeated exposure of many silly dogmas, the fanciful delusions of mechanical minds are still by some held to be superior to the facts of observation and experiment; and promises and potencies discovered in atoms abiding in some region beyond the range of physical investigation are accepted and advertised as a new revelation for the consolation of those who have faith in the material atom and its machinery.

In certain branches of microscopical enquiry very high magnifying powers are absolutely necessary. For example, in such investigations as those which have lately been carried on by M. Pouchet and M. Pasteur, many of the more minute organisms can only be seen by a power magnifying upwards of 1,000 diameters. Bacteria, magnified 1,800 and 3,000 diameters respectively, are represented in pl. LXXXII, p. 390, figs. 17 to 22. If still higher powers had been brought to bear upon the specimen, organisms still more minute than any represented in these figures would probably have been demonstrated.\* The most minute of such living organisms discoverable by a power of 10,000 linear, has been

\* My friend Dr. Child who has paid much attention to the subject referred to, makes the following remarks:—"The absolute necessity of using high magnifying power in attempting the solution of some of the problems which now present themselves to the physiologist is well shown in some of the recent investigations into the development of minute fungi. M. Pasteur has been in the habit of using an object-glass of 350 diameters, see his paper in the 'Annales de Chimie,' vol. LXIV."

living and growing for some time before it attained sufficient dimensions and density to be visible to us. I believe if magnifying power could be efficiently increased to ten times ten thousand diameters, we should only be able to see particles of living matter increasing in size, and giving rise to new particles, which in their turn would become detached, and so on. We should see nothing like the aggregation of particles, or the coalescence of already existing particles of inanimate matter, to form a mass of living matter. We should see, I believe, nothing but the increase in size and division of living particles already in existence, although we might be able to demonstrate germs of a degree of minuteness not yet thought of. But there is another matter of importance in the consideration of this subject, which has almost entirely escaped notice. Besides extreme minuteness in size, extreme tenuity or transparency interferes with the detection of an object. Now, the greatest difference is observed in object-glasses with regard to their power of rendering evident matter of extreme transparency differing but very slightly from the medium in which it is immersed. The best object-glasses will define clearly and accurately, bodies, which, from their transparency, are quite invisible under objectives only slightly inferior to the first. The use of imperfect glasses often leads to misconceptions. For instance some of the statements recently made with reference to the mode of formation of the lowest forms of life, by the aggregation of particles, has no doubt resulted from careless examination and imperfect definition; the real germs having existed for a long time amongst the granular material out of which it is supposed they were formed, but of such tenuity that they could not be recognised by the object-glasses employed, amongst a vast number of very distinct particles closely aggregated.

How entirely inadequate is an ordinary power for the purpose of proving the *absence* of minute organisms from a sample of fluid, is shown by the fact that some of the Bacteria figured in my paper in the "Proceedings of the Royal Society," vol. XIV, p. 171, measure only about the 1-85,000th of an inch. An object of this size when examined with a power of 350 would appear to the eye little more than 1-250th of an inch in diameter, and it is evident that any number of such objects might be easily overlooked. In confirmation of this view I may cite the experience of Professor Hallier, of Jena, who, though he confirms in the main the results arrived at by M. Pasteur, yet in his recent work, "Gährungs-Erscheinungen" (p. 50-51), insists strongly upon the necessity of using high powers in investigations of this nature. He has been in the habit of using powers of 1,000 and 1,500 diameters, and speaks of having met with organised bodies so minute as to appear as "mere points even when so examined (p. 70)." This it will be observed is quite confirmatory of my own observations as stated in the text.

Objects which would be passed over by the observer and remain quite unnoticed when examined by the most excellent ordinary powers will at once attract attention if much more highly magnified. If, therefore, high powers were of service only in bringing important but most delicate peculiarities of objects under observation—if by their use the attention were merely directed to minute points which would otherwise pass unobserved, it would be full and sufficient reason for employing them to carry out advanced work. In studying the peculiar structure of the lower forms of life, and especially the wonderful minute diatomaceæ, the use of very high powers is too obvious to require special notice here. Everyone who engages in original investigations concerning the minute structure of living beings, must acquire skill in the use of far higher magnifying powers than those which used to be considered necessary. The observer must always *begin* by using low powers, and as he improves in the *mode of making specimens* and submitting them to examination, he may advance to the use of the higher and the highest powers.

An entirely new field has been discovered for exploration, and a vast number of new anatomical facts will be elucidated during the next few years, by the aid of new methods of investigation, and the use of high powers. Original research in this department of natural knowledge is intensely interesting. Many of the points most open for enquiry involve questions of fundamental importance, which, when determined, will necessitate great changes in physiology. Minute anatomy has hitherto been far too little studied, and on the part of many influential persons who take a very narrow view of physiological enquiry, its prosecution is discouraged. Is it not obvious that we ought to have a thorough knowledge of mere structure before we begin to discuss action? Is it not often the case both in physiology and in medicine that the mere speculations of popular visionaries are received, and widely taught, which are in fact completely controverted by anatomical facts already demonstrated?

**356. Of the Twenty-sixth and of the Highest Magnifying Powers yet made.**—I include under the last term all objectives which amplify more than 400 diameters. In 1859, I was engaged in studying the arrangement of the nerves in voluntary muscle, and succeeded in preparing, by the process given in p. 357, some exceedingly thin sections, in which most delicate nerve fibres could be distinguished, as very pale and transparent threads. The appearance was such as to lead me to the inference that in many cases apparently single fibres, though not more than the 1-100,000th of an inch in diameter, really consisted of several exceedingly fine fibres. I desired, therefore, to examine the specimens with a more powerful objective, and I begged Messrs. Powell and Lealand to endeavour to make for me a glass with a magnifying power double that of the sixteenth, which they succeeded in making in the

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to the merit of his art and your verdict of the  
remainder of the series. We herewith enclose you  
a card to secure tickets.

MANAGERS OF WILSON'S NIGHTS ABROAD.

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year 1840. In 1860, I received from these makers the first twenty-sixth ever made. This lens magnified 1,800 diameters. I have now had great experience of its use, and can speak of it as a most excellent working glass. That it defines exceedingly well, and admits plenty of light, is obvious from the fact that it will allow of the tube of the microscope being increased considerably in length when the amplification of the object reaches nearly 4,000 diameters. By a *working glass*, I mean one which can be employed without great trouble or difficulty, and which does not require any elaborate arrangements with regard to illumination, adjustment, &c. In fact, my twenty-sixth works fairly even without a condenser of any kind, the direct light from the sky, or the common concave mirror, being used. There is plenty of room for focussing, although, of course, specially thin glass or mica must be employed, and the lens can be quickly brought down upon the cover without risk of breaking it. I have made and published many drawings of tissues of the higher animals magnified with this glass, and it need scarcely be said that, as it can be brought to bear upon textures of this class (even bone and teeth), thin sections of which are obtained only with great difficulty, it must be readily applicable to other departments of microscopical enquiry.

Object-glasses of very high magnifying power have been more recently made by other makers.

An objective of high magnifying power (a twentieth) with a single front lens was made some years ago by Messrs. Smith and Beck. The magnifying power was about one-third less than that of the twenty-fifth, and it appeared to me that the definition of the glass I examined was not so good. The amount of light admitted was, however, ample. Harnack's high power immersion objectives are among the best on the Continent.

It must be freely admitted that it is exceedingly difficult to accurately estimate the merits of one glass as compared with another, and there can be no doubt that an observer who has used one objective very much, especially if he has made new observations by its aid, is likely to be prejudiced in its favour. Unless I worked with an objective for a considerable period of time, I should not like to give an opinion as to its qualities. The difference between the working powers of the glasses of the best makers is, at most, very slight, and not to be demonstrated without the most exact and careful examination. At the same time, it is certain that the slightest advantage in defining power must not be underrated, for if the observer is enabled to see some scarcely perceptible, but nevertheless most important, points not observed before, he is amply repaid for the money he has laid out in the purchase of the object-glass. In not a few instances the very slightest advantage as regards seeing minute points in structure may necessitate a complete



alteration in the general views received as true, and even regarded as fixed and unalterable. Improvement in the means of observation is of the utmost importance, and, however slight, is almost invariably soon followed by the discovery of new facts.

**357. "Immersion" Twenty-fifth.**—As already stated in p. 8, Hartnack, of Paris, has made some excellent lenses of high magnifying power upon the "immersion" principle. Messrs. Powell and Lealand have recently made a twenty-fifth object-glass upon the same plan. It possesses the following advantages:—

1. A much thicker covering glass can be used than is possible with the ordinary 1-25th.

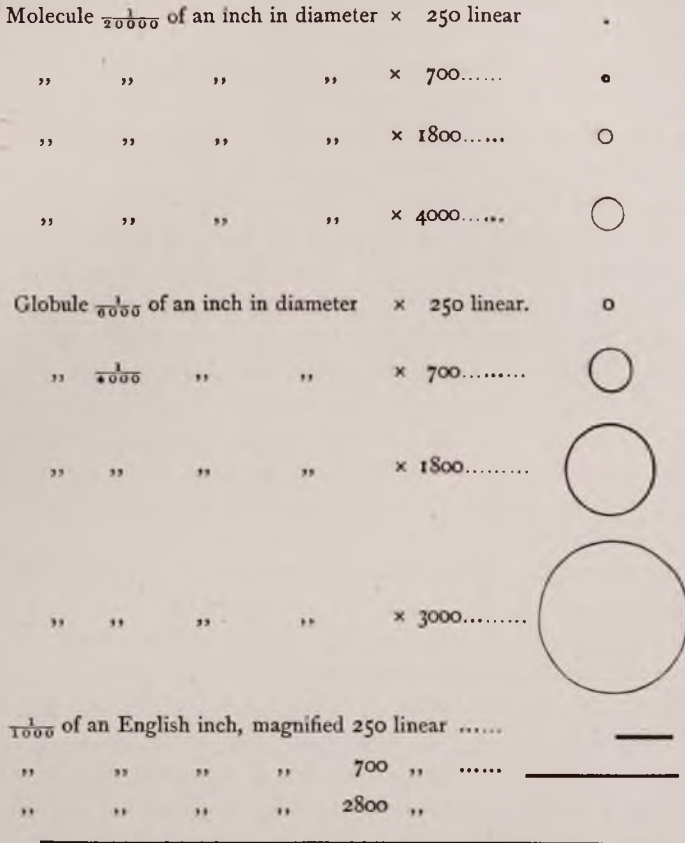
2. The specimen is much more highly illuminated, the same lamp, condenser, &c., being employed. The definition is, I think, slightly better, but the difference observed when examining sections of moist tissues is not sufficiently decided to enable me to speak at all confidently upon this point, though in the examination of diatoms, the podura scale, and such delicate objects, there can be no question about the advantage of water and especially of oil immersion high power objectives.

**358. Of the One-fiftieth Objective.**—In the last edition of this work I announced that Messrs. Powell and Lealand had succeeded in making for me a *one-fiftieth of an inch objective* which magnified very much more highly than the twenty-fifth. This wonderful glass was completed October 15th, 1864. It was found to define quite as well as the twenty-fifth, and no difficulty was experienced in obtaining plenty of light for the illumination of the objects ("Proceedings of the Royal Society," January 19th, 1865). Some drawings by this objective are given in my Report on the Cattle Plague, as well as in pls. XLVI, LI, and in several other plates in this work. There is less difficulty in bringing this glass to a focus than would be supposed, although of course delicate manipulation and some degree of patience and care are required on the part of anyone who determines to work with it.

**359.—Of the One-eightieth of an inch Objective.**—On June 24th, 1872, Mr. Thos. H. Powell completed the only eightieth of an inch objective ever made, and I believe this still remains the only one in existence. It has a magnifying power about one third more than the fiftieth, and defines at least as well as that glass. The circulation in the cells of the *vallisneria* as seen by this objective, without any covering glass, was several times shown by Mr. Powell.

**360. The Apparent Size of an Object under different Powers.**—The following circles may enable the reader to form an idea of the different sizes which the same object would assume in the microscope under the respective magnifying powers. The representations are approximative only. Below the circles some lines are represented to indicate the one-

thousandth of an inch as seen when magnified 250, 700, and 2,800 linear.



**361. Of the Covering Glass.**—The thin cover placed over the object may be made of a very thin plate of mica, but glass possesses several advantages. Messrs. Chance, of Birmingham, have lately succeeded in manufacturing in quantity glass sufficiently thin for the 1-50th. This is supplied by Messrs. Powell and Lealand. For the mere examination of specimens, thin plates of mica answer well, and they may even be used for permanently mounting the preparation; but as it is difficult to clean the surface without scratching it, it will be found better to employ thin glass circles as the covers of specimens which are to be kept permanently.

*Thickness of the Covering Glass.*—An instrument for measuring the thickness of the thin glass kindly given to me by Mr. Brooke, is represented in fig. 2, pl. LXXIV. The method of using it is too obvious to require explanation. The marks round the stem indicate tenths of a millimetre. The thickness of the ordinary thin glass is about 3 or 4 tenths of a millimetre, that for the 1-12th objective under two tenths,

and the glass suitable for the 1-50th is about 1-20th of a millimetre, or less than 1-500th of an English inch in thickness.

**362. Illumination of Objects Magnified by very High Powers.**—In using the sixteenth, twenty-fifth, and fiftieth, it is of the utmost importance to attend to the illumination. As already stated, the ordinary concave mirror gives light enough for the one twenty-fifth objective; but a light of greater intensity and superior in quality may be obtained by other methods. After having tried a great many different plans, I have decided in favour of the illumination obtained from a round wicked paraffine lamp, pl. XII, fig. 3, pl. XIV, p. 24, figs. 2, 3, brought to a focus by a condenser. The ordinary condenser answers very well if to the front glass is fitted a cap made of very thin brass having a perfectly round central aperture less than the 1-30th of an inch in diameter. Kelner's eye-piece, as before observed, p. 7, gives the brightest illumination, and if covered with a cap having an aperture of about 1-10th of an inch, the character of the light is all that can be desired for examining the most delicate tissues under the highest magnifying powers. Sufficient light is afforded for correct observation by this arrangement when the tube of the microscope is so lengthened that the amplifying power equals 10,000 linear. The condenser referred to in p. 31, with a stop upon the surface of the front lens as before mentioned gives an excellent quality of light, but the illumination is less intense than that obtained by the use of Kelner's eye-piece.

In using these condensers, it is most important to employ the *direct light* from the lamp. The microscope and lamp are to be arranged as represented in pl. LXXIV, fig. 3. I cannot explain why the illumination should be so much better than when the mirror is employed, but I am convinced that the quality of light produced is very favourable for the discovery of characters which are of the most delicate kind. I have detected exceedingly fine fibres by the aid of direct light which I could not see when the same specimen was examined in any other manner.

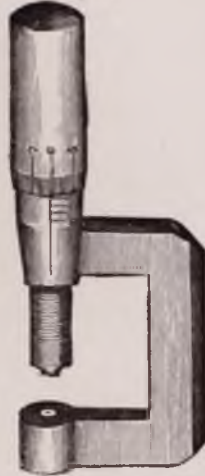
I have tried both the lime and magnesium lights, but they are not suitable for microscopical observation, the glare being too great, and the arrangements necessary inconvenient and troublesome, while paraffine, which can now be obtained everywhere without any difficulty, gives most satisfactory results at perhaps 1-50th of the cost. My friend, Mr. W. E. Kilburn, has increased the illuminating power of the paraffine lamp by causing a stream of oxygen gas to play around it. The gas is contained in a small bag which is placed under a weighted board. A piece of fine India-rubber tube connects the gas bag with a small metal pipe by which it is conducted just outside the wick of the lamp. It is probable that ere long we shall be able to use the electric light for microscopical observation, when very high magnifying powers are employed.

Fig. 1.



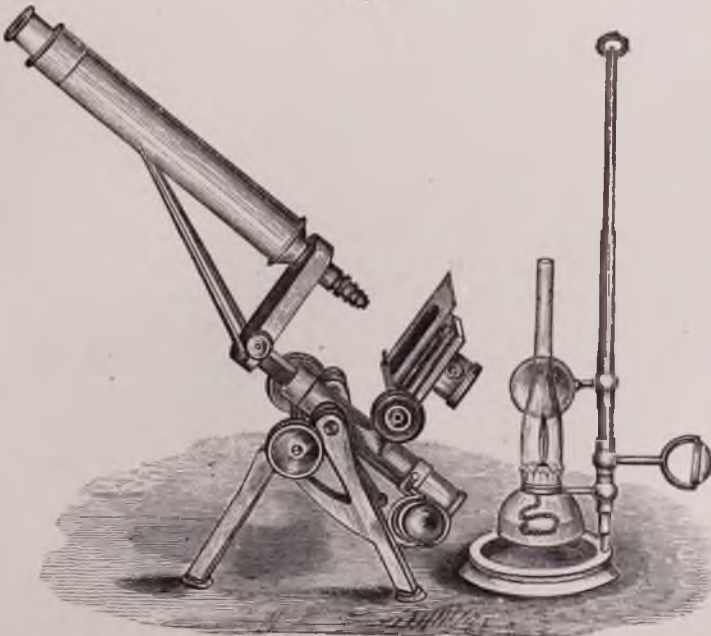
Little bottle for containing glycerine, or glycerine and acetic acid, required for mounting microscopical specimens  
p. 369.

Fig. 2.



Instrument for measuring the thickness of the thin glass.  
p. 351.

Fig. 3.



Position of microscope and lamp for viewing objects with high powers. The light passes at once to the condenser, instead of being reflected from the mirror. p. 352.



**363. Method of Increasing the Size of the Image without Altering the Object-Glass.**—Supposing the limits of magnifying power of the object-glass to have been reached, there are yet methods by which the dimensions of the image may be greatly increased. The eye-piece may be changed for a deeper one, or the distance between the object-glass and eye-piece may be increased. In practice, as stated in the early part of the work, I have found that the latter plan is so much more advantageous that I now never use a deep eye-piece. The twenty-sixth objective being applied, I have found that when the tube of the microscope is increased in length, so that from the lowest glass of the objective to the eye-glass of eye-piece, the distance measures 24 inches, the magnifying power corresponds to upwards of 10,000 diameters: when the length is 20 inches—to about 6,000: 15 inches—to about 2,600: 11 inches—to about 1,800. When the tube is thus increased in length, there is often some reflection from its interior which renders the image indistinct, an inconvenience which may be remedied either by increasing the diameter of the microscope tube to about  $2\frac{1}{2}$  inches, or by lining the ordinary tube with black velvet. Several different lengths of tube to fit into the ordinary microscope body at one end, and to receive the eye-piece at the other, will be furnished by any of the microscope makers.

#### OF DRAWING OBJECTS MAGNIFIED WITH VERY HIGH POWERS.

In delineating the appearances observed, I never represent a structure more highly magnified than is necessary to bring out the points, but I found that as I succeeded in improving my method of preparation, p. 357, it became necessary to resort to the use of higher magnifying powers in order to see distinctly what it was obvious might be rendered evident if only it could be more highly magnified. I am quite certain that great advantage will be reaped when powers far higher than any yet made, or thought of, shall be brought to bear upon well prepared specimens even of the ordinary tissues. The question of preparation is scarcely more than a mechanical one, and new and more exact means of preparing specimens are certain to succeed improvements in the optical part of the microscope.

It is extremely difficult to use the neutral-tint glass reflector with the highest powers, for the slightest vibration of the instrument causes confusion in the lens, so that, in practice, I have found it most convenient to measure the distance of the several parts of the object with compasses, in the manner described in p. 32. These general points being fixed upon the paper, the outline of the object is easily sketched in. In making delicate drawings some advantage is gained by limiting the extent of the luminous field by the ingenious arrangement devised by Mr. Slack. The *adjustable diaphragm* is inserted in the eye-piece. The

instrument can be obtained of Mr. Collins, and may be adapted to any eye-piece.

In making drawings of microscopical objects, it is usual to represent the image the size it appears when thrown upon paper, with the aid of the camera or neutral-tint glass reflector, at the distance of 10 inches from the eye, the arbitrary point at which the magnifying power of object-glasses is determined. If the image be taken at a point nearer the eye, it appears smaller, while, if at a greater distance, it appears much larger than at the arbitrary distance above stated. As already described, large diagrams may, indeed, be made, direct from the microscope, by placing the diagram paper at a distance of 3 feet or more from the eye, and tracing upon it, with a long pencil, the object as reflected from the neutral-tint glass reflector.

In practice, I have often found it impossible to represent, in drawings, lines as fine as those seen in the preparation. A certain coarseness is inevitable. The copied lines and markings appear rougher and thicker than the real ones. But this defect is to some extent remedied by drawing the object somewhat larger than it appears to be magnified at the distance of 10 inches from the eye; and, in order to obtain uniform results, I always draw the object the size it would appear, if copied on the same level as the stage of the microscope. The scale for measurement is copied at precisely the same distance. An objective which, at 10 inches, is said to magnify 200 diameters, will increase the image at this point to 215, and my 1-26th, instead of magnifying about 1,600 diameters, increases the image of the object to 1,800 diameters. By increasing the length of the tube of the microscope between 4 and 5 inches, I obtained an amplification amounting to 3,000 diameters, and the 1-1,000th of an inch becomes upwards of 3 inches in length. See p. 351. The tube of the microscope bears increasing four or five inches in length, even with the fiftieth, and in this way I have been able to see points in an object which I have failed to observe when using the twenty-fifth.

With the view of illustrating my observations with drawings resembling, as nearly as possible, the actual specimens from which they were copied, I have introduced illustrations coloured exactly as the specimens—the bioplasm being tinted with carmine and the vessels with Prussian blue. The coloured plates have been produced by double or treble printing, care being taken that the different sets of blocks are adjusted very accurately. This plan of coloured-block printing is much cheaper than lithographic printing, and has the great advantage over the latter that the drawings made by the observer on the wood blocks are engraved without any transfer. The blocks for colour printing are prepared as follows:—The drawing on the wood is carefully engraved in the usual manner. Of this wood engraving *three* electrotype copies are

made. From one of these every bit of work except that for the bioplasts is removed; from another, everything except the vessels is cut away; and from the third, the lines and work which represent the coloured portions of the vessels and bioplasts are taken away, all the outlines and shading being left. The first will be the red block, the second that for the blue, and the third the one from which the black is to be printed. For making these three sets of blocks the electrotypes must be treated as if they were wood engravings.

The ordinary gravers are used for cutting away the work not required in the several blocks. Although the copper is much harder than wood, with the aid of sharp tools the requisite work is soon completed. The blocks are set up by the printer just as ordinary wood blocks, the explanation of each cut being inserted in the form with the black blocks. When the complete pages—red and black, or red, black, and blue—have been set up ready for printing, an electrotype of each page complete may be taken at small cost, and from these, which can be adjusted very quickly, a large number of copies may be struck off. In this edition I have included several of such coloured plates, representing very different textures, so that the reader may be able to form an estimate of the advantage of the plan of illustration adopted.

NEW METHOD OF PREPARING SPECIMENS FOR RESEARCHES WITH THE  
AID OF THE HIGHEST MAGNIFYING POWERS YET MADE.

It has long been my conviction that real advance in our knowledge of minute structure depends mainly upon improvements that have been, and that yet may be made in the methods of demonstration. The arrangement of the elements of the tissues of man and the higher animals in the recent state is not to be accurately determined by examination in water, serum, vitreous humour, and other aqueous solutions usually employed for this purpose. In very many cases the refractive power of the tissue and other physical characters interfere with the clear demonstration of the arrangement of its constituent anatomical elements and their minute structure. In investigations concerning the arrangement of nerves in voluntary muscle, an independent reader will not fail to notice that different plans of demonstration have been employed by different authorities. This, in some measure, explains the great discrepancy of the results arrived at. It is also to be noticed that those who deny the truth of facts stated by previous writers, have not in all cases been careful to follow the exact method of investigation adopted by those whose opinions are supposed to be controverted.\*

In my memoirs upon the distribution of nerves to muscle, I stated that the arrangement described by me could not be seen unless a particular process of preparation was followed, yet my opponents have

\* See "An Anatomical Controversy," "Archives of Medicine," vol. IV, p. 161.



not adopted the plan pursued by me, nor have they even considered the principles upon which the success of that process depends. Nay, although I strongly insisted upon the importance of injecting, partly for the purpose of ensuring the equable distribution of the preservative fluid to all parts of the tissue, and partly to render it impossible that vessels should be mistaken for the fine nerve fibres, the capillary vessels have not been injected in specimens which it is supposed controvert my inferences. Many would suppose that it was the special duty of reviewers and commentators upon anatomical and physiological doctrines to direct attention to these facts, but, unhappily, there is no public scientific opinion, and the opinion of the man who has most friends, and who makes the greatest efforts to gain publicity, is the most likely to be accepted and taught. The mode of preparation I have advocated is not a mere hap-hazard plan, but is grounded upon information derived from numerous experimental observations made during twenty-five years. Some have endeavoured to overthrow my conclusions by describing how little they have themselves been able to discern, after rough processes of investigation totally distinct from any advocated by me. The positive denial often given to the existence of a particular arrangement really means, in many instances, merely that the individual who makes it has never seen the appearance in question. The wonder is, that anyone who has really earnestly studied any branch of microscopical enquiry should be able to persuade himself that he has seen all that has been or all that can be seen, and lay down the law and the facts just as if he was infallible.

I cannot venture to hope that many of the facts I have observed in connection with the minute structure of the central and peripheral nervous system, will be confirmed until the processes adopted by me have been followed by others, and I fear a considerable time will elapse before this is the case, for the plan cannot be successfully followed out on the first trial, and it is less trouble to condemn it than to master it. The process is not likely to be adopted by those who make specimens for sale, because it occupies more time than some other plans, while it is very doubtful whether the specimens, if prepared, would be more appreciated by purchasers or would sell at a higher price. My specimens may be seen and studied by anatomists interested in the matter, but it is not possible that they can be fully examined by many observers. Moreover, it so happens that working men have but few opportunities of examining each other's specimens, and when an opportunity does occur, there may not be time to investigate the specimens fairly. The consequence of all this is, that working in circles goes on to a terrible extent. Much labour is utterly wasted, and there is but very slow progress compared with that which would attend our efforts if observers generally were agreed upon the principles upon which minute anatomo-

mical observations should be conducted. Doubtless, many observers find out valuable methods of detail which satisfy themselves. In many cases it is hardly possible to communicate to others the practical details upon which success depends, and it is often exceedingly difficult to ascertain the real merits of any given process. At the same time I would remark that it is a question capable of being settled most positively, whether, for instance, nerves can be followed in tissues which are impregnated with syrup, glycerine, or some such medium, for a greater distance than when similar textures are immersed in water, serum, vitreous, &c., and whether or not more fibres and finer fibres can be seen in the former than in the latter case. A simple experiment will convince anyone as regards the truth in this matter, and if observers would prepare small portions of the same tissue in the two different classes of media, and compare the results, they would, I am sure, soon agree upon one principle of great importance in investigation. It is mainly with the view of encouraging free discussion upon this most important question, and in the hope that ere long some general process of investigation may be adopted, that I publish my own conclusions and describe somewhat minutely the process which I have for many years followed. I do not pretend that it is equally applicable to all tissues, or that it will succeed equally well in all hands; but I am confident that it is based upon principles of the utmost importance. From time to time I myself discover some improvements in detail; but the basis of the process remains the same and, as I have now been actively engaged in minute microscopical investigation for more than thirty years, it is scarcely possible that principles which have been adhered to for so long a time can be destitute of advantages.\* Moreover, in the hands of some of my pupils the plan has answered as well as in my own, and it has been followed out by some observers on the Continent, and also by some distinguished American observers. I have specimens of cartilage prepared according to this method which show the bioplasm masses in process of division.

**364. Conditions to be fulfilled in Demonstrating Minute Structure by the Highest Powers :**

1. Of many tissues, sections sufficiently thin for high powers cannot be obtained by the processes usually adopted. In order to make the specimen thin enough, *pressure* must be employed, and in many instances very strong pressure is required. Even by very moderate pressure, tissues immersed in water, serum, or in vitreous humour are utterly destroyed, and experience has proved that the requisite amount

\* An excellent illustration of the great importance of careful preparation is afforded by the reply of Mr. Gedge, of Cambridge, to the observations of Dr. Moxon, concerning the distribution of nerve fibres to the muscles of a culex larva.—“Microscopical Journal,” July, 1867, p. 193.

of pressure can only be employed if the tissue be immersed in, and thoroughly impregnated with, a *viscid medium*, which is not only readily miscible with water in all proportions, but with such chemical reagents as may be required to act upon one or more constituents of the tissue for the purposes of demonstration.

2. As many structures are exceedingly delicate, and undergo change very soon after death, it is necessary that the medium in which they are examined should have the property of preventing softening and disintegration, and should act the part of a preservative fluid.

3. In order that tissues should be uniformly permeated with a fluid within a very short time after the death of the animal, it is necessary that the solution employed should quickly come into contact with every part of the texture. This may be effected in two ways:—*a.* By soaking very thin pieces in the fluid, or, *b.* By injecting the fluid into the vessels of the animal.

4. As different structures require fluids of different refractive power for their successful demonstration, the medium employed must be such that its refractive power can be increased or diminished, unless for the medium fulfilling the first condition, another can be readily substituted which provides the latter requirements.

5. In investigations upon the changes which structure undergoes in the organism, during normal development and in the course of disease, it is necessary to distinguish between that part of the texture which is the oldest, and that which has just been produced—between matter in which active changes are going on, and matter which is in a passive state. It is only by such a demonstration that the direction in which growth takes place, and the point where new matter is added, can be positively determined.

6. It is most important in many investigations, that we should be able to clearly distinguish the vessels from every other constituent of the tissue, and it is necessary that the process by which this is effected should not interfere with the demonstration of all the tissues in the immediate vicinity of the vessels.

7. It is of the utmost importance, that the medium employed for demonstration should have the property of permanently preserving the specimens, so that observers should be able to exhibit their preparations to others.

*Glycerine and syrup fulfil the requirements mentioned in the preceding paragraphs.*

**365. Action of Glycerine and Syrup on Tissues.**—*Strong syrup* may be made by dissolving with the aid of heat, lump sugar in distilled water, in the proportion of about three pounds to a pint.

*Glycerine* may be used diluted or undiluted. It is necessary in many cases to employ the strongest glycerine. In this country we have

had the advantage of the beautiful preparation which used to be called Price's glycerine, which may now be obtained in large quantities and at a cheap rate. It is made of specific gravity 1240, and some specimens may be obtained of still greater density. Pure glycerine has been made to crystallise.

It has been said that glycerine and strong syrup are not adapted for preserving soft tissues, because the tissues shrink, and soft cells collapse in consequence of exosmose of their fluid contents. But I have many hundred specimens of the most delicate tissues, preserved in the strongest glycerine I could procure, and I should be glad if glycerine could be made of still greater density. There would be no difficulty in impregnating even very soft tissues with it. In fact, the objections urged are for the most part theoretical, and result from ignorance of some important properties of the tissues on the part of those who have advanced them. If objectors had simply tried the experiment, they would have found no difficulty whatever in carrying out the process. Tissues possess a considerable degree of elasticity, and although they shrink when immersed in a medium of much greater density than that with which they are impregnated, they gradually regain their original volume if *left in it for some time*. In practice, the specimen is first immersed in *weak* glycerine or syrup, and the density of the fluid is gradually increased, either by adding from time to time a few drops of strong glycerine, until it bears the strongest, or by allowing the original weak solution to become gradually concentrated by slow evaporation. In this way, in the course of two or three days, the softest and most delicate tissues may be made to swell out almost to their original volume in the densest glycerine or syrup. They become more transparent, but no chemical alteration is produced, and the addition of water will at any time cause the specimen to assume its ordinary characters.

*The hardest textures, like bone and teeth*, may be thoroughly impregnated and preserved in strong glycerine, p. 377. On the other hand the softest, most delicate, and most quickly changing animal tissues, like the gray matter of the cerebral convolutions, the delicate nerve textures of the retina, or internal ear, may be permeated by the strongest glycerine, and when fully saturated with it, dissection may be carried to a degree of minuteness which far surpasses that practicable if the attempt be made to carry on the dissection in any other medium. Nor is the use of glycerine and syrup confined to the tissues of man and the higher animals. I have made preparations from creatures of every class. The smallest animalcules, entozoa, polyps, star fishes, mollusks, insects, crustacea, infusoria, various vegetable tissues, microscopic fungi and algæ of the most minute and delicate structure, as well as the most delicate parts of the higher vegetable tissues, may all be examined, dissected, and preserved in these viscid media.

The slowest and most rapidly growing, the hardest and softest morbid growths, as well as embryonic structures at every period of development, even when in the softest state, may be kept and mounted in glycerine. The most delicate nerve fibres retain their character for at least twenty-five years in the strongest glycerine. I am, indeed, not acquainted with any animal or vegetable tissue which cannot with the greatest advantage be thus mounted. All that is required is, that *the strength of the fluid should be increased very gradually until the whole tissue is thoroughly penetrated by the strongest that can be obtained.* In many cases the tissues may be more effectually saturated with the glycerine by injection than by soaking. Glycerine has long been in use among microscopists for some textures, but I particularly desire that the fact that it is universally applicable should be generally recognised. Either glycerine or syrup may be made the basis of all solutions employed by the microscopical observer with the greatest advantage, and many points are to be demonstrated by the aid of these solutions which have hitherto escaped observation, while there is good reason to believe that very much may yet be discovered by the use of these substances.

**366. Of the Advantages of Viscid Media for the Dissection of Tissues for Examination with the Highest Powers.**—Minute dissection can be carried on in these viscid media with greater facility and certainty than in more limpid fluids. I can readily detach the most minute parts of tissues, separate the different structures in one texture, without tearing or destroying them, unravel convoluted tubes, and perform with ease a great variety of minute operations, which it would be impossible to carry out, if any of the ordinary methods of dissection were adopted.

With care in regulating the temperature, I can soften textures preserved in syrup or glycerine to the precise extent required for further minute dissection, and even very hard textures may thus be softened. After a time tissues so acted upon may by gradually increased pressure and careful manipulation be obtained in exceedingly thin layers, in which the relation of the anatomical elements to each other has been little altered, and in which it will be found that none of the tissues have been destroyed, or even damaged.

**367. The Carmine Fluid for Staining Bioplasm.**—The composition of this fluid has been already given in p. 125, where also will be found the directions for making it. The carmine fluid will be required to be made stronger or weaker in particular cases, and great advantage sometimes results if it be diluted with alcohol. The precise quantity to be added to obtain the best results can be ascertained by trying a few experiments.

The length of time required for successfully staining the tissue

varies much. The bioplasm of some tissues is coloured very slowly. That of fibrous tissue, bone and cartilage, even if very thin sections of the tissues be immersed, will require twelve hours or even more, but the bioplasm of perfectly fresh soft embryonic tissues, and of very thin sections of the liver and kidney, of thin sections of morbid growths rich in cells, may be coloured in half an hour. The bioplasm of the individual cells of the above structures, placed on a glass slide, may be coloured in less than a minute. I have often coloured the bioplasm of the fresh liver cell *in a few seconds*, by simply allowing the carmine fluid to flow once over a thin specimen placed upon a glass slide.

### 368. Glycerine Solutions and Syrup.

1. *Weak glycerine* of about the specific gravity 1050.
2. *The strongest glycerine* that can be obtained.
3. *Syrup* made by dissolving, by the application of a gentle heat in a water bath, 3 lbs. of sugar in a pint of distilled water. A weaker solution can be prepared, as required, by mixing water with the syrup.

Although I have found syrup of great value in many special investigations, I cannot recommend it for general use, in consequence of its liability to be invaded by numerous fungi, which often seriously damage or completely destroy the specimen.

**369. The Injecting Fluid.**—For injecting the finest capillaries in specimens which are to be mounted for examination under the highest powers, I have made a slight modification of the original Prussian blue fluid, the composition of which is given in p. 109. The following mixture has succeeded admirably in my hands, and I therefore strongly recommend it. It penetrates to the finest vessels, and may even be forced into developing capillaries which are only pervious in a part of their course. The fluid never forms a deposit. The specimens injected with it retain their colour perfectly, and the injected tissues can also be stained with carmine.

Pure glycerine, 2 oz. by measure.

Tincture or solution of perchloride of iron,\* 10 drops.

Ferrocyanide of potassium, 3 grains.

Strong hydrochloric acid, 3 drops.

Water, 1 oz.

Mix the tincture of iron with one ounce of the glycerine; and the ferrocyanide of potassium, first dissolved in a little water, with the other ounce. These solutions are to be mixed together very gradually in a bottle, and are to be well shaken during admixture. *The iron solution must be added to that of the ferrocyanide of potassium.* Lastly,

\* The *Tinctura Ferri Perchloridi* and the *Liquor Ferri Perchloridi* of the British Pharmacopœia of 1867, are of the same strength, and consist of one part of strong *Liquor Ferri Perchlor.* to three parts by measure of spirit or water.

the water and hydrochloric acid are to be added. Sometimes I add a little alcohol (2 drachms) to the above mixture.

This fluid (it is not a *solution*), does not deposit the slightest sediment, even if kept for some time, and it appears like a blue solution when examined under high magnifying powers, in consequence of the insoluble particles of Prussian blue being so very minute. If preferred, the Turnbull's blue may be used instead of Prussian blue, half the quantities of the ferridcyanide of potassium and sulphate of iron recommended in p. 110, being used. The hydrochloric acid may be left out. The glycerine and water in the proportions above given.

**370. Other Colouring Solutions with Glycerine.**—Many of the staining fluids given in pp. 127 to 131, may be prepared with glycerine. Thus, I dissolve *Nitrate of silver*, the Anilin colours, and many others, in glycerine instead of in water. The salt should be dissolved in a very little water in the first instance, and this solution added to the glycerine. Indeed, all the fluids I now use for preparing specimens contain syrup or glycerine as the basis.

**371. Glycerine and Water and Glycerine and Acetic Acid for Washing and Preserving thin Sections.**—After the specimen has been properly stained, small pieces are to be washed in a solution consisting of strong glycerine, 2 parts; water, 1 part.

After being soaked in this for an hour or two, they may be transferred to the following acid fluid:—Strong glycerine, 1 ounce; strong acetic acid, 5 drops.

After the pieces of tissue have remained in this acid fluid for three or four days, they will have regained the volume they occupied when fresh. Even very soft and pulpy tissues will gradually swell out and regain their original volume in the strongest glycerine.

*On Chemical Reagents Dissolved in Glycerine.*

It being established as a principle that, for minute investigation, with the aid of the highest powers, excessively thin sections of tissues must be immersed and thoroughly saturated with viscid media miscible in all proportions with water, it almost follows that reagents applied to such tissues should be dissolved in media of similar properties. For a long time past I have been in the habit of employing solution of potash, acetic acid, and other reagents, dissolved in glycerine instead of in water. Thus a complete chemical examination may be conducted upon tissues, solutions, or deposits preserved in viscid media. The reactions are most conclusive, but of course a much longer time is required for completion than when carried out in the ordinary manner. Ten or twelve hours must be allowed to elapse before the change is complete, and the process is expedited if the slide be placed in a warm place (about 100°).

**372. Acetic Acid Syrup.**—In some cases I have found the addition of very strong solutions of certain reagents necessary. For example, the greatest advantage sometimes results from the application to a tissue of very strong acetic acid. If the acid be added to glycerine in quantity, the solution will no longer be viscid, so that another plan must be resorted to. I thicken the strongest acetic acid with sugar, a gentle heat being applied to dissolve the sugar. Thus a very strong acetic acid solution of the consistence of syrup can be most readily prepared.

**373. Solutions of Potash and Soda.**—Solutions of potash, soda, ammonia, and other reagents, may be added to the strongest glycerine.

**374. Solutions of Chromic Acid and Bichromate of Potash.**—A most valuable mixture of this kind to the microscopist, is a solution of chromic acid in glycerine, and another is a solution of bichromate of potash in the same fluid. A few drops of a strong solution of chromic acid may be added, so as to give to the glycerine a pale straw colour. The bichromate of potash solution is prepared by adding from ten to twenty drops of a strong saturated solution of bichromate of potash in glycerine to an ounce of the strong glycerine. By this plan, the hardening effects of these reagents upon the finest nerve tissues are improved, while the granular appearance which is caused by aqueous solutions of these substances is less marked. Sometimes advantage seems to result from mixing a little of the chromic acid with the acetic acid solution of glycerine.

If desired, sugar may be substituted for glycerine in all the fluids employed, including the carmine and injecting fluids; but glycerine, although more expensive, possesses many advantages, and, as far as I am able to judge, is the best viscid medium to employ for general purposes. As already remarked, as regards syrup, great inconvenience is caused by the growth of fungi, especially in warm weather. Camphor, creosote, carbolic acid (the pure carbolic acid is now called absolute phenol\*), naphtha, prevent this to some extent; but it is a disadvantage from which strong glycerine is perfectly free. Sometimes, too, crystallisation occurs, and destroys the specimen. If a specimen which has been first immersed in a syrup fluid is to be transferred to glycerine, it must be borne in mind that the two fluids mix but slowly, so that plenty of time must be allowed for the thorough penetration of the medium used last.

I keep various tests, such as *alcohol*, *ether*, the various *acids* and *alkalies*, and other tests in the state of viscid solutions made with glycerine or sugar. The reaction of the iodine tests for amyloid matter, starch and cellulose, is much more distinct when employed in this way.

\* Absolute phenol, pure and crystallised, is now made in enormous quantities and may be purchased of Mr. Marchant, wax chandler, &c., Berners Street, Oxford Street, for five or six shillings a pound.



The texture to be tested is to be thoroughly saturated with the strong glycerine solutions, and then water is to be added. In the course of a few hours the reaction takes place very distinctly.

**375. Of the Injection of the Vessels of an Animal with Solutions of various Chemical Compounds dissolved in Glycerine.**—When it is desired to subject the tissues of an organ or of the body generally to the influence of certain chemical solutions, these last may be injected, and oftentimes the most perfect results are obtained in this manner. However carefully small pieces of tissues may be soaked in fluids the action is irregular. The process has often gone too far near the surface, while the interior often entirely escapes. But by injection, every part of the tissue is exposed to the action of the reagent, and almost precisely in the same degree. Many beautiful results are to be obtained by carrying out this plan, and to the skilled observer many experiments will occur which will be likely to lead to most important discoveries, particularly in connection with the subject of development. The calcareous matter of bone and other tissues may be dissolved out in the manner indicated, by very slow degrees, without the arrangement of the most delicate tissues being, in the least degree, disturbed, or the demonstration of their ultimate structure in any way interfered with.

*The Preparation of Specimens.*

**376. The Practical Operation of Preparing Tissues for Examination with the Highest Powers.**—The general plan which I have for many years followed is the same in principle for investigations into the structure and growth of all living forms, and for the demonstration of all tissues of all vertebrate animals and morbid growths the same details are requisite. I propose to describe the several steps of the process as conducted in the demonstration of the minute structure of the ganglion cells, described in my paper in the "Philosophical Transactions" for 1863, and of the papillæ of the frog's tongue, described in the communication presented to the Royal Society in June, 1864. The figures in many of the plates in this volume accurately represent the appearances observed under the highest magnifying powers. The process of preparation described below also applies to the mode of preparing specimens of muscular fibre for demonstrating the mode of distribution of the finest branches of nerve fibre.\* See plates XXXIV, XXXV, XXXVI,

\* "On the distribution of nerves to the elementary fibres of striped muscle."—"Phil. Trans.," 1860.

"Further observations on the distribution of nerves to the elementary fibres of voluntary muscles."—"Phil. Trans.," 1862.

"Further observations in favour of the view that nerve fibres never end in voluntary muscles."—"Proceedings of the Royal Society," June 5th, 1863.

"On the structure of the sarcolemma of the muscular fibres of insects, and of the exact relation of the nerves and tracheæ to the contractile tissue of muscle."—Royal Microscopical Society, June, 1864.

XXXVII, p. 408, *et seq.* Again, in the investigation of the minute structure of the brain, spinal cord, and ganglia of man and the higher animals,\* the same proceedings have been successfully carried out.

My researches upon the tissues of the frog have been principally conducted upon the little green tree frog (*Hyla arborea*), for extensive observation has proved to me that the tissues of this little animal are so much more favourable for investigation than those of the common frog, that it is well worth while for the observer to obtain specimens, even at the cost of 2s. or 2s. 6d. each.

The animal is killed by being dashed suddenly upon the floor, but it must first be carefully folded up in the centre of a cloth, so that the tissues may not be bruised or injured in the least degree. Next, an opening is made in the sternum, and the heart exposed. A fine injecting pipe, after being filled with a little injection, is tied in the artery. This part of the operation is conducted as fully described in p. 114, except that the Prussian blue fluid, given in p. 363, is used instead of the ordinary injecting fluid recommended in p. 109, but the operation is more difficult in the case of small frogs and *Hylæ* than in large specimens of the common frog. With a little practice, however, anyone at all skilful in ordinary dissection can successfully perform the operation. The injection ought to be complete in from twenty minutes to half an hour, and sometimes it may be carried out in less time than this. The injection being pale, cannot be very distinctly seen by the unaided eye, but if the operation has been conducted successfully, the tissues will be found swollen and the areolar tissue about the neck will be fully distended. The observer must not, however, attempt to inject a *Hyla* before he has succeeded in injecting the common frog perfectly, for the *Hyla*, being very small, and its tissues delicate and tender, it is somewhat more difficult to successfully inject than the common frog or the newt.

The injection being complete, the abdominal cavity is opened, and the viscera washed with strong glycerine. The legs may be removed, the mouth slit open upon one side, and the pharynx well washed with glycerine. If it is desired to prepare one organ only, this may, of course, be removed and operated upon separately; but I generally subject the entire trunk, with all the viscera, to the action of the carmine fluid. If the brain and spinal cord are special objects of enquiry, the cranium and the spinal canal must be opened so as to expose the organs completely, before the staining process is commenced. It is,

\* "On the minute structure of the grey matter of the convolutions of the brain."—*Proceedings of the Royal Society*, vol. XII, 671, 1863.

"Indications of the paths taken by the nerve currents as they traverse the caudate nerve cells of the spinal cord and encephalon."—*Proceedings of the Royal Society*, July, 1864.

however, better to adopt the plan described in p. 370, in investigations upon the brain and cord.

Just enough of the carmine solution to cover the entire trunk and viscera is to be placed in a little porcelain basin or gallipot. The specimen is then moved about in the carmine fluid, so that every part that is exposed may be thoroughly wetted by it. Sometimes slight pressure with the finger facilitates the imbibing process. The body is left in the carmine fluid for a period varying from four to six or eight hours, being occasionally pressed and moved about during this time, so as to ensure the carmine fluid coming well into contact with every part. By this time the blue colour of the vessels of the lungs, viscera, &c., will have entirely disappeared, and all the tissues will appear uniformly dark red. The staining is now probably complete. The excess of carmine fluid is therefore poured off and thrown away, and the preparation washed quickly with the glycerine solution, p. 364. This fluid may be preserved in a wash bottle, made according to the plan figured in pl. XXVI, p. 100, fig. 5, but smaller than this,—and projected upon every part so as to wash away all superfluous carmine fluid, pl. LXXIV, p. 352, fig. 1. The specimen is now placed in another little basin and some glycerine poured over it; it is then left for two or three hours, and a little more strong glycerine added. When, from six to twelve hours since the specimen was removed from the carmine solution have elapsed, the preparation is ready for the last preliminary operation. The glycerine used for washing it is poured off, and sufficient strong glycerine, acidulated with strong acetic acid (10 drops to 1 oz.), added just to cover it. In cold weather, the several steps of the process above referred to may extend over twice the period of time, but in summer, unless they are rapidly conducted, the tissues are too much softened, and are otherwise damaged. In the acid fluid the preparation may be left for several days, when a small piece of some vascular part may be cut off, placed in a drop of glycerine, and subjected to microscopical examination. If the injected vessels are of a bright blue colour, and the bioplasts of the tissues of a bright red, the specimen is ready for minute examination; but if the blue colour is not distinct, three or four more drops of acetic acid must be added to the glycerine, and the preparation soaked for a few days longer.

If the bioplasts are of a very dark red colour, and appear smooth and homogeneous, more especially if the tissue intervening between them is coloured red, the specimen has been soaked too long in the carmine fluid; but in this case, although parts upon the surface may be useless for further investigation, the tissues below may have received the proper amount of colour.

The tissues or organs to be subjected to special investigation may now be removed, and transferred to fresh glycerine; they may be kept in

little corked glass tubes, pl. XXVI, p. 100, fig. 8, and properly labelled. Generally, the tissue will contain sufficient acetic acid, but if this is not the case, one drop more may be added. In this way the tissues may be kept without deterioration for twenty years or more.

Suppose, now, the nerves with the small vessels and areolar tissue at the posterior and lower part of the abdominal cavity have been placed in one tube, and the prepared tongue of the *Hyla* in another, the former specimen may be taken from the glycerine and spread out upon a glass slide. If the specimen be examined with an inch power, numerous microscopic ganglia may be seen, pl. XCV, p. 416, fig. 4. Several of these perhaps are close to small arteries. Those which are most free from pigment cells are selected, and removed carefully by the aid of a sharp knife, fine scissors, forceps, and a needle point. This operation may be effected while the slide is placed upon the stage of the microscope. The *transmitted light* enables the observer to see the minute pieces very distinctly with the unaided eye, but if necessary a watchmaker's lens or a 3-inch power may be used. The pieces selected are transferred to a few drops of the strongest glycerine, placed in a watch-glass or in one of the little china colour moulds, § 85, p. 54, and left to soak for several hours.

The specimen is now ready for preliminary microscopical examination. One of the small pieces is placed upon a glass slide, in a drop of fresh glycerine, and covered with thin glass. The glass slide may be gently warmed over the lamp, and the thin glass pressed down upon the preparation by slight taps with a needle point. The specimen may now be examined with a quarter, and afterwards with the twelfth of an inch object-glass. A good deal of granular matter will possibly obscure the delicate points in the structure. The slide is again gently warmed, and, with the aid of a needle, the thin glass is made to slide over the surface of the specimen, without the position of the latter being altered. The thin glass is then removed and cleaned. The specimen is next washed by the addition of drop after drop of strong glycerine, containing five drops of acetic acid to the ounce. The slide can be slightly inclined while it is gently warmed over the lamp, in such a manner that the drops of glycerine are made to slowly pass over the specimen and thus wash away the *débris* from its surface.

*Dropping Bottles.*—The most convenient instrument for dropping the glycerine on the specimen is a little bottle, of two ounces capacity, with a syphon tube drawn to a point, and a straight tube, with an expanded upper part, over which is tied a piece of stout sheet vulcanized India-rubber. Pl. LXXIV, p. 352, fig. 1. Upon compressing the air, by pressing down the India-rubber, the glycerine is forced drop by drop through the syphon tube and allowed to fall upon the specimen. These little bottles can be obtained of Mr. Matthews, Mr. Collins, and Mr. Swift.

When several drops of pure glycerine have been allowed to flow over the specimen, the thin glass cover, after having been cleaned, is re-applied and pressed upon the specimen very gradually, but more firmly than before. Any excess of glycerine is easily removed by placing small pieces of clean blotting paper at the side of the thin glass. If the preparation looks pretty clear when examined with the twelfth, the glass cover may be cemented down with Bell's cement, p. 55, or with Damar cement, and the preparation left for several days in a quiet place. It may then be re-examined, the process of washing with glycerine repeated, and further pressure applied until it is rendered as thin as is desired. When this point has been reached, more glycerine with acetic acid is to be added, and a plate of mica or the *thinnest glass cover*, p. 351, applied, when it may be examined with the twenty-fifth. The process of thinning may be pushed still further if desirable,—and if only carried out very slowly by gentle taps or careful pressure with the finger and thumb, *from day to day*, the elements of the tissues will be gradually separated from one another without being smashed and destroyed. If there be much connective tissue, which interferes with a clear view of the finest nerve or muscular fibres, it may be necessary to immerse the specimen for some days in the acetic acid syrup, and then transfer it to fresh glycerine.

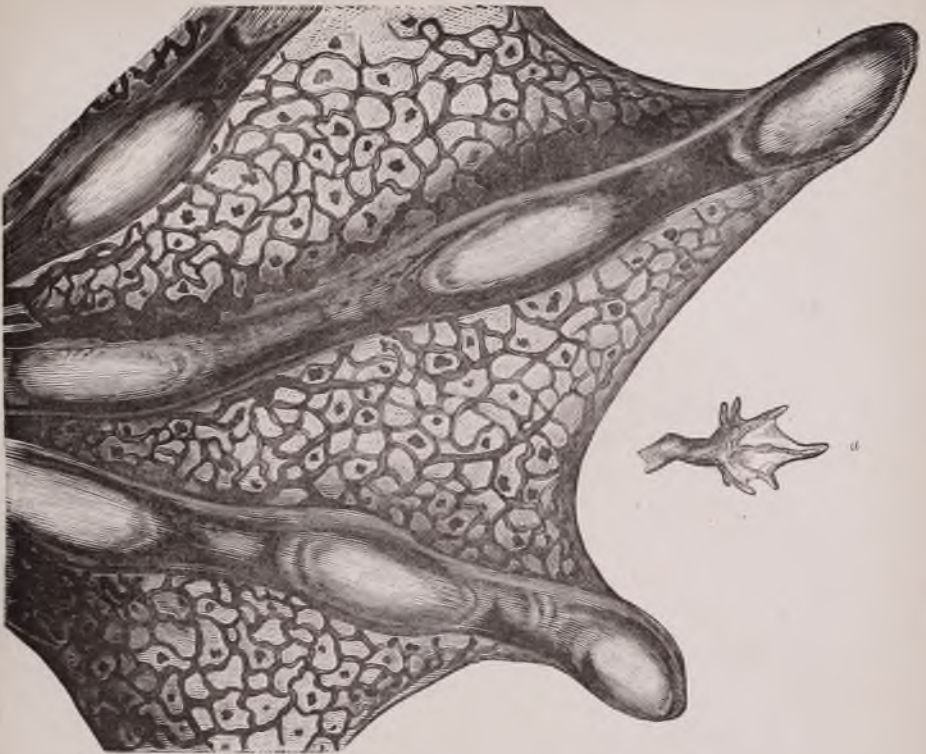
If the tissue does not sufficiently yield to the pressure it must be soaked for a longer time in the acetic acid glycerine, or it may be softened by being soaked for a short time in a weak solution of pepsine in glycerine, p. 379, using lactic acid instead of hydrochloric acid.

The success of this process above described depends upon the care and patience with which it is carried out. The most perfect results are obtained in cases where the washing, pressure, and warming have been very slowly conducted, and it is most interesting to notice the minute points of structure which are gradually developed and rendered clearer by the repeated application of a gentle heat, the specimen being subjected to a little firmer pressure and further soaking in a little fresh glycerine placed in a watch-glass.

Specimens of tissue prepared in this way can be transferred from slide to slide, and no matter how thin they may be, after having been allowed to soak in fresh glycerine they may always be laid out again perfectly flat upon another slide by the aid of needles. The action of these viscid fluids is most valuable, and I feel sure that by the processes above described,—the general principle of procedure being retained but the details modified in special cases,—many new and important anatomical facts will be discovered.

The papillæ of the frog's tongue are prepared for examination under the highest powers, the twenty-fifth and fiftieth, in the same manner. Small pieces of the mucous membrane being removed by sharp scissors, they are

Fig. 1.



Foot of young frog one inch and a half in length, with the webs stretched to show the circulation of the blood in the vessels during life X 12. The black spots are pigment cells a, The foot, natural size p. 373.

Fig. 2.



Vessels of the web of the foot of a young frog an inch and a half in length, injected. The arteries and veins can be distinguished in the drawing. X 40. p. 373.



transferred to glycerine, subjected to the same very gradually increased pressure, until the individual papillæ themselves are seen to be slightly flattened. It is possible from a specimen to remove a number of the separate papillæ on a needle point, transfer them to glycerine or to the acetic acid syrup, and then mount them for examination with the 1-50th object-glass. All the points I have described and figured in my memoir published in the "Philosophical Transactions of the Royal Society," 1864, may be demonstrated in several papillæ, *see* pls. LXXXVIII, LXXXIX, p. 412.

Thin sections of brain, spinal cord, &c., may be subjected to the same process for examination with the highest powers. The specimens illustrating my paper on "The indications of the paths taken by the nerve currents as they traverse the caudate nerve cells of the spinal cord and encephalon," published in the "Proceedings of the Royal Society," July, 1864, were prepared in the manner already described, but they were soaked for some months in a weak solution of glycerine and acetic acid. The most delicate preparations retain their characters for many months, and some for several years, so that in many cases the very preparations from which some of my drawings have been made, have been preserved for nearly twenty-five years, and may even now be compared with them.

Delicate specimens should be placed upon a circle of thin glass about  $\frac{3}{4}$  of an inch in diameter, instead of upon a glass slide. The circle is then mounted on a wooden slide in the centre of which a hole has been drilled of the proper dimensions to receive it. A ring of gummed paper is placed at the back of the slide and to this the round glass is fixed when the specimen has been covered with the smaller circle of thin glass, and the latter has been properly fixed in its place by cement. *See* also p. 87.

*Modification of the above Plan.*—I have more recently modified the foregoing process by injecting the alkaline carmine fluid into the vessels in the first instance for the purpose of staining the bioplasm of the tissues, and afterwards, when the colouring was complete, the acid Prussian blue fluid, so that all the bioplasts were seen of a bright red colour in the specimens, while all the capillaries were fully injected with the Prussian blue.

The carmine fluid employed should be stronger than that already recommended, p. 125, and it is better to add a little more alcohol. The following succeeds well for the frog and newt:—Carmine, 15 grains; strong liquor ammoniæ,  $\frac{1}{2}$  drachm; strong glycerine, 2 ounces; alcohol, 6 drachms.

This fluid is to be injected carefully with very slight pressure. It must be borne in mind that the alkaline ammonia is very apt to soften the delicate vascular walls. When the vessels are fully distended, the



preparation is to be left for from twelve to twenty-four hours, in order that time may be allowed for the carmine fluid which has permeated the capillaries in all parts of the body to soak through the different tissues and stain the bioplasm fully. Next a little pure glycerine is to be injected, in order that any carmine fluid still remaining in the vessels may pass through, or at least be so much diluted that carmine will not be precipitated in quantity by the acid fluid next to be introduced.

The fine Prussian blue injecting fluid, the composition of which is given on p. 363, is to be injected with the utmost care, for the vessels, particularly of young animals, having been somewhat softened by the ammoniacal solution of carmine, are very liable to give way if much pressure be applied. When the vessels are fully distended with the Prussian blue fluid, the injected preparation is to be divided into small pieces, and these are to be soaked in glycerine and acetic acid, as has been already recommended in p. 368.

Very beautiful specimens from every tissue in the body of a small animal (frog, newt, mouse, bat, small bird, &c.), may be prepared in this way; but as the operation of injecting has to be performed twice there is greater risk of rupturing the vessels. The student should therefore practise ordinary injection with transparent fluids before he attempts to carry out this process, or he will suffer disappointment.

**377. Demonstration of the Soft Tissues.**—To assist the student in his investigations upon the structure and arrangement of the tissues, I have introduced some illustrations of specimens of which the counterparts might be prepared by any observer who carefully followed the directions I have given. The series of drawings in pls. LXXV, LXXVI, LXXVII, LXXVIII, LXXIX, are representations of the tissues of the web of the frog's foot under very low magnifying powers. As the reader will notice, these are copied from specimens slightly magnified, while in pls. LXXX, LXXXI, LXXXVIII, LXXXIX, appearances observed under the highest powers which can be brought to bear upon the tissues have been delineated. An enquiry into the anatomical structure of such a texture as the web of the frog's foot is of great importance in its bearing upon broad questions of general interest, and should be undertaken by every one who desires to form from actual observation an accurate conception of the wonderful phenomena associated with the development, growth, and nutrition of tissues. It is probable that any one who prosecutes the investigation with care and intelligence will be gradually led on to make original enquiries in the course of which he may discover new facts of the highest importance. But before the student attempts to discover new things he should try to acquire the dexterity necessary to make specimens which clearly show the points indicated in the figures, all of which represent less than can be seen in the specimens, and are in every respect far less perfect and elaborate

than the specimens themselves. The most perfect drawing, after all, only roughly indicates what can be more clearly seen in the specimen, if the latter is as good as it should be, and as good as it can be made in these days.

Frogs are everywhere obtainable, and few creatures are better suited for minute anatomical investigation. Their tissues present many advantages for researches on the ultimate distribution of nerve fibres and for the determination of many anatomical questions. Few parts of the frog have been more carefully investigated than the web, but nevertheless I feel sure that in this thin membrane, particularly in the transparent web of the foot of young frogs, most important facts still lie hidden, as it were, waiting for elucidation until careful and industrious enquirers concentrate for a time their energies upon this comparatively limited area. Although the general distribution of the vessels is well known, there remains much to be discovered as regards their development and the precise relation of the little bioplasts or masses of living matter to their walls as well as to the various anatomical constituents of which the web is composed. As regards the finest ramifications of the nerves there is also much to be learnt by the careful investigation of well prepared specimens of the free edge of the web. By conjoint methods of enquiry—minute anatomical investigation upon some webs—and physiological experiment upon similar webs of living animals, I have gained important information concerning the action of nerves upon capillary vessels, and the changes in pigment cells, epithelium, as well as other structures during life may be thus studied. Such tissues as those of the frog should be studied again and again, and he who wishes to make himself an observer will examine the very same textures prepared in many different ways, as well as corresponding tissues in animals at different periods of life. This plan can be carried out most successfully in the case of the frog, as it is easy to procure animals at all ages, and the tissues of this animal can also be examined in the living state (*see* p. 191) with the greatest facility. The observer must, however, study in France or Germany, as in England all investigations upon living frogs are prevented by law, and the police have authority to seize any one detected in causing pain to a frog arranged for the purposes of scientific investigation.

Fig. 1, pl. LXXV, represents the vessels of the web of a young frog under a magnifying power of about ten diameters. Pigment cells are observed here and there in which the pigment granules are concentrated or collected together, instead of being diffused and spread through the fluid contained in the irregular ramifying passages which pass from cell to cell, and which thus form an extensive network. Some large pigment cells and their ramifications are well seen in pl. LXXVII, fig. 2, p. 376.

Fig. 2, pl. LXXV, represents the ramifications of the vessels of the web of the frog's foot as seen in an injected specimen. The tubes are

distended, and their diameter is much greater than in the living state when they are occupied with blood. In the living specimen it is easy to distinguish the arteries from the veins by the greater diameter of the latter vessels and the slowest rate of flow of the blood ; but in the injected specimen the arteries are distended and appear almost as wide as the veins. In the drawing, however, both sets of vessels are distinct, the veins being almost black, while the arteries have been shaded lightly. The observer will be able to follow the branches of the artery in many situations, and trace these to their ultimate divisions, which are continuous with the capillaries. The last may also be seen to converge here and there to form the venous radicles.

In pl. LXXVI, fig. 1, a portion of the vascular network of the foot of a young frog is represented. The vessel (*b*) running diagonally downwards across the field from left to right is a vein, while the narrower tube on a lower level is a branch of the artery (*a*). The capillaries have not yielded equably to the distending force of the injection, and are wider in some places than in others. This is often observed in injections of capillary vessels, and probably during life the degree of distension of the walls of the capillaries in different parts of the same tissue, and in the same parts at different times varies greatly.

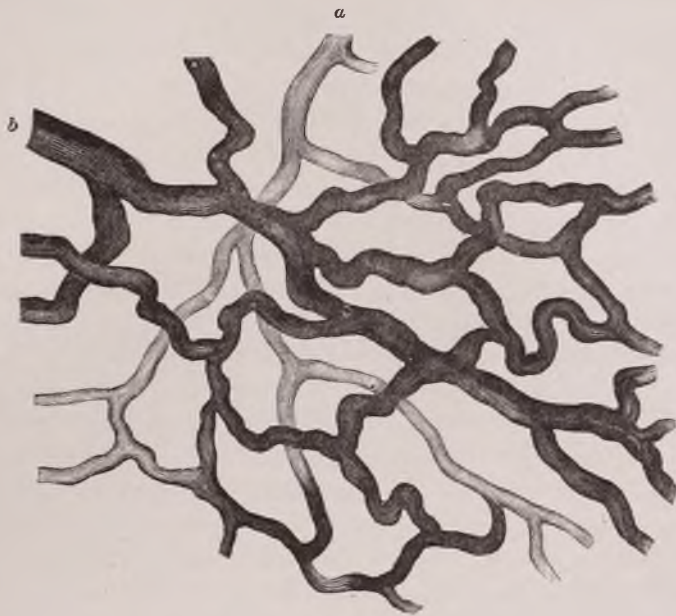
In fig. 2 the changes occurring in inflammation are well represented. A small particle of mustard was applied to the web, and in the course of a very short time the capillaries corresponding to the spot, and for a short distance round it, became much distended. As the blood in the capillaries accumulates it flows more and more slowly till at length it stagnates in the vessels. The web in this state was stained with carmine, transferred to glycerine, and preserved as described in p. 370. The vessels being "naturally injected." The colourless blood-corpuscles accumulate in the capillaries in great numbers, and these being coloured with carmine, a very clear and beautiful preparation results.

A minute vein from the inflamed area of the web of a living frog is represented in fig. 3, pl. LXXIX, p. 376. This drawing should be attentively studied. It was taken a few minutes after inflammation had been excited by the application of a piece of mustard paste, the size of a small pin's head, to the web. The nerve mechanism by which this change in the vessels is so quickly brought about, will be understood if the experiment described in p. 191 be referred to.

In pl. LXXVII, fig. 1, the general arrangement of the larger nerve-trunks in the web of the frog's foot is represented. The finer branches of nerve-fibres form networks of dark bordered fibres, the constituent fibres of which divide and subdivide, and thus two or three series of networks result, the finest of which represent the ultimate ramifications of the nerve-fibres. Some of these form lax networks about the vessels, others in the substance of the fibrous texture of the skin ; while upon

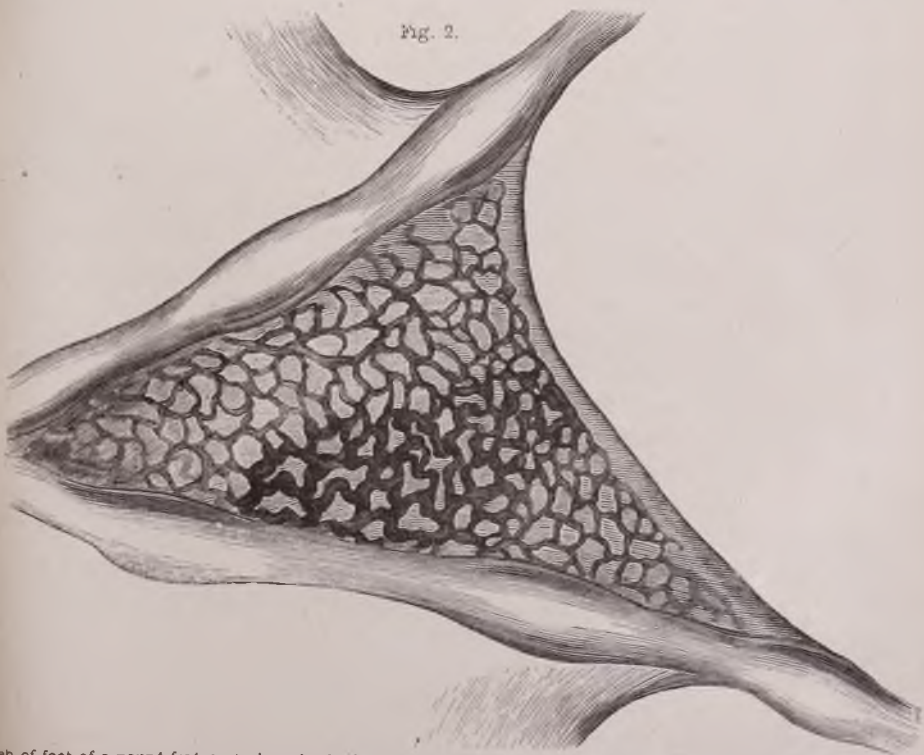
FROG'S FOOT.—ARTERIES AND VEINS.—VESSELS IN INFLAMMATION.

Fig. 1.



Vessels from the web of the young frog, injected. a, Branch of artery b, Branch of vein The arrangement of the capillaries is well seen x 130. p. 374.

Fig. 2.



Web of foot of a young frog an inch and a half in length, as seen during life. The shaded vessels are seen to be much distended with blood which is quite stagnant, a change which results from inflammation excited by the application to the web of a small piece of mustard the size of the head of a small pin x 20. p. 374.



the surface of the latter, just beneath the epithelium, are numerous papillæ, in which nerve-loops may be seen. Amongst the pigment cells complex networks of extremely delicate fibres in great numbers are to be demonstrated. No *ends* can be discovered, and I believe in all tissues and organs the ultimate ramifications are continuous fibres, connected with which here and there are bioplasts.

The general course of the trunks in the web is such that, as seen in the drawing, arches are formed by the meeting of branches from the trunks on each side of the web. In the drawing only a few of them are represented, but there are such numerous meetings and inosculation of the trunks and their subdivisions that complex and extensive networks are formed. These cannot be seen by the magnifying power employed in examining this specimen, and, in fact, the only branches indicated are large compound trunks of dark bordered nerve-fibres. Some idea of the real arrangement as it exists in nature may be formed if fig. 1, in plate LXXXIII, p. 406, be referred to. The ultimate distribution of the nerve-fibres, in several tissues of the frog, are referred to in the last sections of this book, commencing at page 411.

Fig. 2 is a representation of several large pigment cells, with their anastomizing prolongations in great number. These form frequent connections with those from neighbouring cells, and thus a network is formed. In the body of the cell is the bioplasm, around which is the pigment, consisting of minute granules suspended in fluid. The granules may spread with the fluid into all the tubular passages, as represented in the drawing, or they may collect about the bioplasm, forming a more or less spherical mass, by which the latter is completely obscured. In this case the radiating canals and communicating tubes shrink, and, as they only contain a little perfectly transparent fluid, are invisible.

In pl. LXXVIII, fig. 1, is a good drawing of capillary vessels from the foot of the living frog. Besides the colourless blood corpuscles seen here and there, the reader should note the manner in which the red blood corpuscles seem to race one another as they are pressed onwards by the force of the blood current, and are, here and there, squeezed together and bent round and twisted in various shapes, as they are driven through constricted portions and made to take a different direction in capillaries at right angles to the course originally taken by the blood. The cells of epithelium and their bioplasts, somewhat swollen by osmose, may be observed over the drawing, and to the right, at *a*, is seen the epithelium, which bounds the orifice of a cutaneous mucus gland, also shown in fig. 3, and in transverse sections of the tissues of the web in pl. LXXIX, p. 376, figs. 1 and 2.

Three pigment cells are seen in different parts of the drawing, fig. 1, pl. LXXVIII, the pigment granules, in two of them, being diffused in the

fluid and distributed through the branches of the cell, while, in the lower cell to the right, the granules are collected together, changes which may be readily observed taking place in the web of a young frog during life, and which I believe to be due to the varying amount of fluid in these cells and their ramifications, determined by the varying state of the blood and alterations in the force of the circulation. The changes in the pigment cells, and therefore the general colour of the skin are, as has been shown by many observers, under the influence of nerves and nervous systems, but I believe it is only in this indirect manner, through its influence on the vessels, that the nervous system controls or determines the concentration and distribution of the granules of pigment.

I have given in fig. 2 a drawing of all that can be seen of an artery and bundle of nerve-fibres, in the thin web of a young frog's foot, *during life*, examined under favourable circumstances and with great care. It will be noticed that the nerve-fibres are not distinct, while, as regards the artery, no definite structure can be observed—not a vestige of the muscular fibre cells can be discovered in any part of the drawing. This figure contrasts remarkably with fig. 3, which is from a specimen of the same tissues, but properly prepared in the manner described in p. 366. The observer will notice how much more distinctly the tissues are seen in the latter than in the former, and how many points in minute structure come out which were not to be discerned at all in the natural specimen. Both preparations were magnified with the same power, and may be fairly compared and contrasted. Not only may the individual nerve-fibres in the compound trunk be well seen, but the branches and the fibres constituting them may be followed without difficulty, and for a long distance. The structure of the arterial coats is well displayed, and by employing higher magnifying powers, various points of minute anatomical detail may be satisfactorily demonstrated.

In fig. 1, pl. LXXIX, is seen a transverse section of the tissues of the web of a full-grown frog, which is worthy of attentive study. If the observer desires to test his skill, let him endeavour to trace the course of the nerve-fibres, which bend down from the surface network, and after running through the fibrous tissues of the web, are spread out upon the other side. The large bundles of white fibrous tissue, which form the substance of the web and give to it strength and firmness, are seen cut across transversely. The capillary vessels are seen only upon the upper surface of the web, where it is very thin, but in its thicker parts are capillary networks, just beneath the skin of both surfaces of the web. In fig. 1 the layers of cuticular epithelium are partially detached.

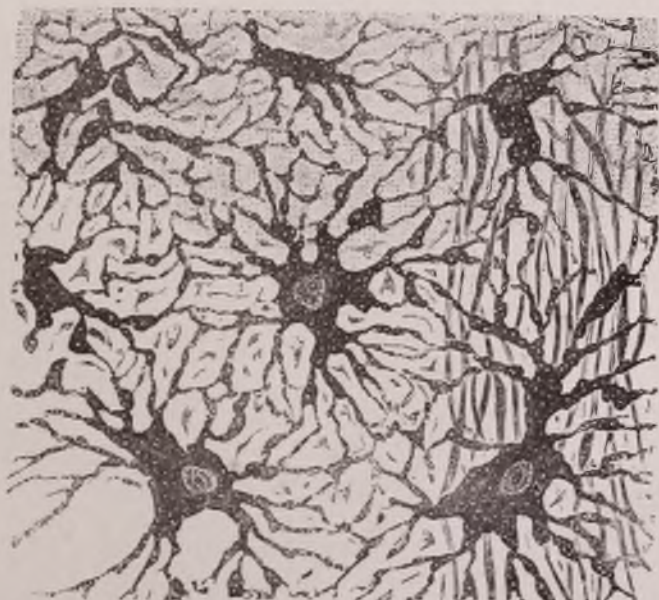
In fig. 2 is another drawing of a transverse section of the web. The capillary vessels on each surface of the web are more distinctly seen in this drawing than in fig. 1.

Fig. 1.



Arrangement of the trunks of nerve fibres and their branches in the web of the frog's foot. The ramification is such that networks are formed. From these trunks smaller branches come off, which meet and run together so as to form series of networks of finer fibres.  $\times 20$ . p. 374.

Fig. 2.



Large pigment cells from the frog's foot. The granules of pigment, suspended in fluid, are distributed through the radiating and anastomosing channels extending from the cells.  $\times 215$ . p. 375.





Fig. 1.



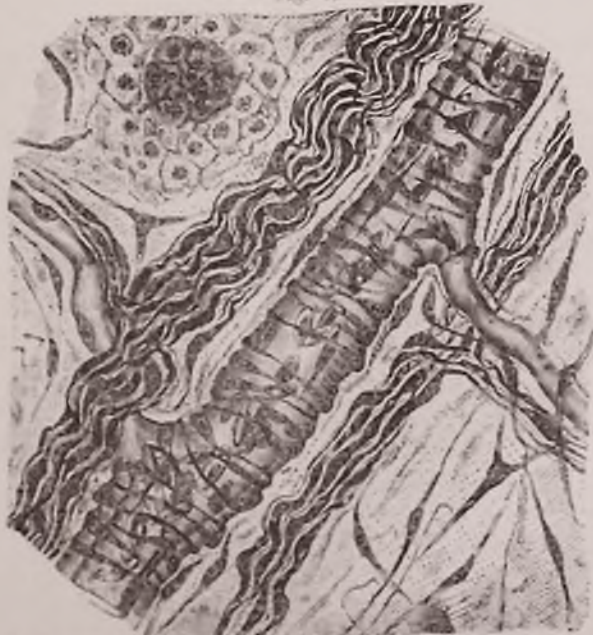
An entrance of a portion of the web of a young living frog. The cuticular epithelium is somewhat swollen by imbibition. X 100. p. 376.

Fig. 2.



Small vein and bundles of nerve fibres from the web of the foot of a living frog. The red blood corpuscles are moving rapidly in the centre of the stream, the white blood corpuscles are crawling along very slowly in contact with the walls of the vessel. X 215. p. 376.

Fig. 3.



Small artery and bundles of nerve fibres beneath epithelium of web of frog's foot prepared and mounted in glycerine. In the upper part of the drawing is a mucous secretory gland. X 215. p. 376.



FROG'S FOOT.—TRANSVERSE SECTIONS OF WEB.—VEIN IN INFLAMMATION.

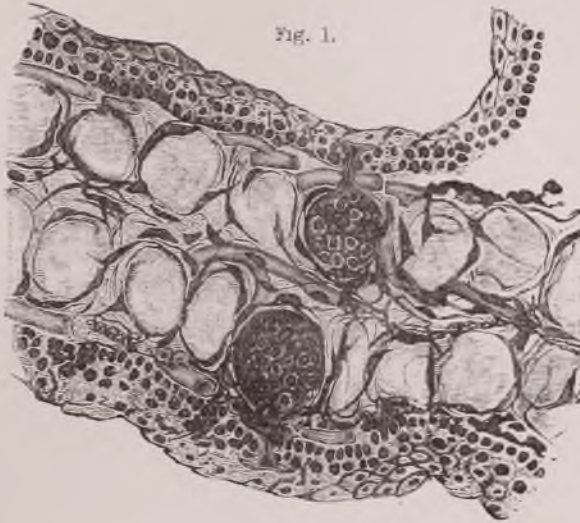


Fig. 1.

Perpendicular section through the web of the foot of an old frog, showing the epithelium on the two surfaces of the web. The bundles of fibrous tissue forming the substance of the web are seen cut across in the drawing. In the upper and lower part of the drawing are two glands which secrete the mucus poured out on the surface of the skin. X 130. p. 376.

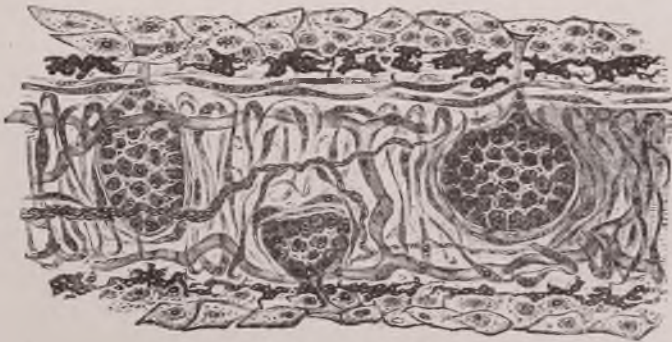


Fig. 2.

Perpendicular section through thin part of the web of the foot of a young frog, showing vessels and nerve fibres, cutaneous glands and epithelium, and pigment cells. X 210. p. 376.



Fig. 3.

Small vein in web of feet of very young living frog a few weeks after inflammation had been excited by mustard, showing great accumulation of the colourless corpuscles. X 215. pp. 373, 377.



In fig. 3 is represented a small vein from the foot of the living frog, in a part of the web to which a small piece of mustard had been applied a few minutes before. The small vein itself and the capillaries continuous with its cavity are occupied by colourless corpuscles, which adhere to the walls of the tube and obstruct the flow of blood.

The more minute investigation of some of the nerve tissues of the frog will be found described in page 370, and drawings are given of the fine ramifications of the nerves in the frog in plates LXXXIV, LXXXVII, LXXXVIII, LXXXIX; in an insect in plates LXXXV, LXXXVI; and in mammalia—the mole, the bat, and man—in plates XCII, XCIII, p. 414.

**378. Of the Preparation of Hard Tissues for Examination with the Highest Powers. Bone, Teeth, &c.**—The methods generally employed, p. 98, for demonstrating the structure of bone, teeth, and other hard tissues, only enable us to form a notion of the minute structure of the dead and dried texture. The bioplasm and soft formed material of the bone are dried up before the section is made. And yet these latter, which are represented in but very few of the drawings published in anatomical works, constitute the difference between the *dead* bone or tooth, and that which possesses the power of growth and change, and still remains an integral part of the living body. So far from the soft matter in recent bone being unimportant, it is the most important of all its anatomical constituents. It is by the bioplasm alone that all osseous and dental tissues are formed and nourished. From the arrangement of this soft living matter not having been generally recognised, the most erroneous ideas have prevailed, and still prevail, upon the formation and nutrition of these and other hard tissues.

Even now it is believed by some that the “dentinal tubes” are real tubular passages for conveying *fluids* to all parts of the dentine, and are thus subservient to its “nutrition.” But it is more than twenty years since Mr. Tomes proved most conclusively that these so-called “tubes” are occupied in the recent state by a moist but tolerably firm material (“Philosophical Transactions,” February, 1856). I have verified Mr. Tomes’ description, and am quite certain that the so-called tubes are not channels for the mere flowing up and down of nutrient fluid. On the structure of recent bone and teeth, *see* my lectures on “The Structure and Growth of the Tissues,” Royal College of Physicians, 1860, and “Bioplasm,” 1872.

Suppose a tooth is to be prepared for minute microscopical investigation, we may proceed as follows. The same plan is applicable to bone and shell.

1. As soon as possible after extraction, the tooth may be broken by a clean hammer into fragments, so as to expose fresh surfaces of the tissues. Pieces of dentine, with portions of pulp still adhering to them,

may be selected and immersed in the carmine fluid, and placed in a vessel lightly covered with paper, so that dust may be excluded. The whole may be left in a warm room for from twenty-four to forty-eight hours.

2. The carmine solution may then be poured off, and a little plain dilute glycerine added, p. 364.

3. After the fragments of teeth, the bioplasm being now coloured with the carmine, have remained in this fluid for six or eight hours, they may be removed, or the excess of fluid may be poured off, and replaced by a little strong glycerine and acetic acid, p. 364.

4. After having remained in the glycerine and acetic acid for three or four days, it will be found that the portions of soft pulp have regained the volume they occupied when fresh. They have swollen out again, though immersed in the strongest glycerine.

5. I have found that in many cases, when it is desired to study the arrangement of the nerves, it is necessary to harden the pulp by immersion in a glycerine solution, made by adding to an ounce of the glycerine solution of the acetic acid, two or three drops of a strong solution of chromic acid, p. 365. The fragments may remain in this solution for three or four days, and then be transferred to the acetic acid solution, in which they may be preserved for years with all the soft parts perfect.

6. The specimens are now ready for examination. Thin sections are *cut* with a knife from the fractured surfaces of the dentine, and should include a portion of the soft pulp. The knife should be strong, but sharp. In practice I have found the double-edged scalpels first made for me by Messrs. Weiss and Son, of the Strand, answer exceedingly well for this purpose, nor will the edge of the knife be destroyed so soon as would be supposed, pl. XVIII, p. 48, fig. 8.

7. The minute fragments of sections thus obtained are placed upon a slide and immersed in a drop of pure strong glycerine, in which they may be allowed to soak for an hour or more, and then examined under a low power (an inch). The best pieces are to be selected by the aid of a fine needle, and removed to a drop of glycerine containing two drops of acetic acid to the ounce, already placed upon a clean slide. The thin glass cover is then carefully applied, and the specimen may be examined with higher powers.

8. If it is desired to retain the specimen, the excess of glycerine fluid is absorbed by small pieces of blotting-paper, and the glass cover cemented to the slide by carefully painting a narrow ring of Bell's microscope cement or solution of Damar round it. When this first thin layer is dry, the brush may be carried round a second time, and after the lapse of a few days, more may be applied. Mounted in this way the specimen will retain its character for years.

**378\*.** **Softening Hard Tissues by Maceration in Glycerine and Acid, and on the Action of Pepsine.**—Hard tissues, like bone, dentine, and enamel, become very decidedly softened by prolonged maceration in glycerine, and if a few drops of acetic acid are added, the softening process may be carried still further, and yet without the calcareous matter being dissolved out to any perceptible extent. If desired, of course the calcareous matter may be in part or entirely removed by increasing the strength of the acid fluid in which the preparation is immersed. But, far short of this, the hard, brittle texture is so altered, that thin sections may be *cut* without any difficulty. Specimens prepared in this way may be examined by the highest magnifying powers yet made,—by which statement, of course, I mean to imply that more may be learnt by studying the minute structure of the tissues under such high powers (1,000 to 3,000 linear) than by the use of ordinary object-glasses.

I have also gained advantages in the investigation of the minute structure of hard tissues from the use of a solution of pepsine in glycerine, made as follows:—Ten grains of pig's pepsine, are carefully mixed with two drachms of distilled water, and five drops of strong hydrochloric acid added, and the solution is kept at the temperature of 100° for two or three hours, and then filtered. The clear fluid is then added to one ounce of strong glycerine. This solution may be kept without undergoing decomposition for a long time, in a stoppered bottle. When required for use, a small quantity is poured into a watch-glass or small wide tube, and the fragments to be acted upon introduced; the whole is to be kept at a temperature of 100° in a small hot-air or water oven for an hour or more. When sufficient action has been produced, the pieces are transferred to strong glycerine, slightly acidulated with acetic acid, and carefully examined at leisure. The pepsine I use is prepared from the pig's stomach by drying the mucus squeezed from the gastric glands, and then powdering it, and making an infusion, to which hydrochloric acid is to be added. The process is described in the "Archives of Medicine," vols. I and II. The pepsina porci may be obtained of Messrs. Bullock and Co., 3, Hanover Street, Hanover Square.

By this method most beautiful preparations of the ramification and the ultimate distribution of the nerve-fibres and vessels of the pulp may be obtained; and I know of no tissues in which the vast multitude of nerves and their close networks are to be more clearly displayed.

**379.** **The Preparation of Embryonic Tissues for Examination with very High Powers.**—Many of the softest textures may be investigated with the greatest facility after having been soaked in strong glycerine. In preparing these, the same steps which have been described in p. 361, must be carried out, but the glycerine used at first should be weaker, and its strength very slowly and gradually increased, either by adding



small quantities of strong glycerine from day to day, or by placing the specimen immersed in the original weak solution in a small basin over strong sulphuric acid under a bell jar, or *in vacuo*. Ova, at a very early period of development, can be prepared according to the principles indicated, and many important facts in connection with the first steps in the development and formation of tissues demonstrated with accuracy.

Some objections have been advanced by Dr. Ransom and others to this plan of investigation as applied to the *ovarian* ova of fishes. Dr. Ransom says, that the ammonia "dissolved the germinal vesicle and its contents." Upon experiment, however, I found that so far from this being the case, numerous bioplasts, not seen in ordinary specimens, were displayed, and many new facts not to be demonstrated by examining the ova in water, were discovered. In pl. LXXX, figs. 1 and 2 have been copied from Dr. Ransom's paper, while the remaining figures were taken from specimens prepared by me in the manner indicated. See my paper, published in the "Transactions of the Microscopical Society" for July, 1867, from which pl. LXXX has been taken.

Embryos of various ages may be injected with the Prussian blue fluid. The pipe cannot be tied in the vessels, as they are extremely soft. But if it is simply inserted, much of the injection will run onwards into the capillaries, and the escape of a certain quantity by the side of the pipe is a matter of no moment. It is often advantageous to harden the delicate tissue slightly by the addition of a little of the chromic acid glycerine solution, p. 365. When once the tissues have been fully permeated by glycerine, they may be dissected and manipulated in a manner which before was impossible.

In the same way, extremely soft textures, like those of which the *acalephæ* or jelly fishes are composed, or that delicate tissue entering into the formation of the vitreous humour of the eye of man and the higher animals may be prepared; and all the masses of bioplasm, series within series (nuclei, nucleoli, nucleoluli), many of which are passed over in ordinary methods of examination, will be most clearly demonstrated. The most delicate infusoria and the germs of these and of the lower plants may also be thus prepared and preserved.

The lowest as well as the highest vegetable tissues may be coloured according to the same plan with the carmine fluid, but it is sometimes necessary to dilute it with alcohol or with more water. The bioplasm of the spores and thalli of fungi, represented in pl. LXXXI, p. 386, has been coloured very satisfactorily. Fig. 1 is the same as represented in pl. LIV, p. 206, fig. 3, and illustrates the method of obtaining coloured plates referred to in p. 356. In fig. 2 are some growing yeast cells, well coloured and highly magnified, and the thallus of the yeast plant, represented in fig. 3, is growing at the extremities, and the bioplasm in these is more intensely coloured than in other parts.

OVARIAN OVA.—STICKLEBACK.  
SHOWING BIOPASM COLOURED WITH CARMINE.

Fig. 3.



Ovarian ovum, with large germinal vesicle. The yolk cracked and forming fissures radiating outwards.  $\times 100$

Fig. 1.



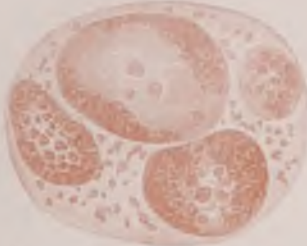
Free germinal vesicle, its spots unchanged. After Dr Ransom.

Fig. 2.



Free germinal vesicle, of which the wall is raised at one part, showing the 'colloid mass.' After Dr Ransom.

Fig. 4.



Germinal spots from a ruptured germinal vesicle  $\times 500$ . The ovum was  $\frac{1}{8}$  inch in diameter, and the germinal vesicle  $\frac{1}{16}$ .

Fig. 5.



Germinal spots, with new centres (nucleoli) within them, and more minute germinal spots in the intervals between them.  $\times 500$ .

Fig. 6.



Germinal vesicle, showing germinal spots all over the surface.  $\times 215$

Fig. 7.



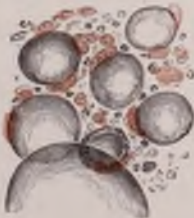
Most minute ovarian ova undergoing development, in the midst of a delicate tissue with cells.  $\times 500$ .

Fig. 8.



Supposed section of germinal vesicle, showing germinal matter throughout.

Fig. 9.



Globules of yolk, with bioplasm or germinal matter (nuclei). Advanced ovarian ovum.  $\times 215$ .

Fig. 10.



Extremely small germinal spots, consisting almost entirely of bioplasm.  $\times 1700$ .

$\frac{1}{1000}$ th inch  $\times 215$ .

"  $\times 550$ .

"  $\times 1700$ .



## THE AUTHOR'S VIEWS CONCERNING THE STRUCTURE, FORMATION, AND GROWTH OF TISSUES.

To aid in establishing general conclusions concerning the nature of those wonderful processes of formation and growth peculiar to things living, ought to be the aim of every one who devotes himself to the investigation of the minute structure of animal and vegetable tissues. But in these days, instead of being encouraged to follow the example set us by Harvey and Hunter and Bichat, observers are taught by popular lecturers to devote themselves to the mere observation and demonstration of facts. Many, therefore, spend their lives in the pursuit of fact-hunting, and never pause to enquire whether the facts they suppose they have discovered are facts, whether their work is of any use at all, and whether it teaches us anything, nor even ask whether the supposed facts affect in any way other facts already known. Fact multiplication, and accumulation, the adding of fact to fact, seems to be the sole aim of some ; and what a chaos is the fact-heap which has been raised in many departments of enquiry !

On the other hand, there are unscrupulous writers who never observe or experiment for themselves, and look upon fact-finding and experimenting as the inferior but necessary duty of an order of beings less fitted to survive than themselves, but developed for their particular benefit and use, so they are careful to keep in with the poor fact-finders, and use their results as if they were their own. From their intellects only proceed generalisations. They select the good facts from the bad ones, and construct generalisations for the instruction of humanity. But further, arrogant doctrinaires, who never made a practical observation or discovered a single fact, conscious of superior wisdom, graciously dictate the precise fields in which inferior minds are to work, and lay down the method of investigation to be pursued by the working fact-hunters, condescendingly remarking that as conclusions tend in this or that direction, more labour is required here, while it is useless working there, and new investigations should be immediately set on foot to prove the truth of this and that idea which has just been evolved in the recesses of their understanding. And the new philosopher is very wise in the method he pursues, for it is easier to frame a generalisation and then select from the general heap of known facts particular facts in its support, than to examine the facts themselves one by one, to separate the true from the false facts, to observe and experiment anew, and at last, after an honest survey of what is known, to endeavour to arrive at some general conclusion.

Formerly those who advanced new views to explain the phenomena of living beings, not only performed the work of fact-hunting but tested the value of every fact upon which they placed reliance, and only

deduced their conclusions after much patient investigation and experiment. But of late a far superior method of making generalisations has been discovered, and much of the old and slow testing and analytical work has been entirely discarded. Philosopher and Fact-hunter seem to have discovered that they may keep their offices quite distinct and yet work to each other's great advantage. A compact seems to have been entered into. The fact-finders consenting to act as the servants or tools of the philosopher, while he publicly acknowledges the high value of fact-hunting, and spreads the fame of the fact-finder as well as his own. Different schools of philosophy require differently constituted fact-finders, and as each new philosophy rises in popular favour, its own proper fact-hunters, reporters, generalisers, acquire the much-desired renown.

But how many errors now pass current as observed facts, and how many unfortunate generalisations mar the advance of real knowledge! This must be the case, if those who advance generalisations refuse to investigate for themselves, and practical observers confine themselves to mere observation and refrain from thinking and speculating concerning the facts they discover. Disadvantage to all knowledge must result from the attempt to draw a hard line between speculative thought and practical work. Useful hypotheses are more likely to emanate from sound practical observers and experimenters than from purely speculative thinkers, who are obliged to obtain all their facts second-hand, and whose training has in too many instances been such as to render them quite incapable of distinguishing real facts from apparent facts, and of estimating the value or worthlessness of the evidence adduced in favour of the accepted interpretation of any given fact or particular phenomenon observed.

In the hope of encouraging students to *think* as well as work, I have ventured to offer a short résumé of some views, which are founded on facts demonstrated by the methods of investigation described in this book, which is mainly devoted to practical subjects, and has been written with a strictly practical object.

In many parts of this book I have drawn attention to the great importance of special methods of preparing tissues. But in order to compare different textures and specimens of the same texture at different periods of its growth, a uniform process of preparation must be adopted, or, in other words, all structures which it is desired to compare with one another must have been subjected to the same methods of preparation, and must be examined under precisely similar conditions. It has been shown that all textures may be easily manipulated and examined under the highest powers when immersed in glycerine; and it has been proved that in every tissue obtained from a living being, *part* may be *deeply stained* while *part* is left *colourless*, although the whole has been freely

traversed by an alkaline colouring matter in solution, p. 125. The first material exhibits certain common characters throughout nature, while the last differs extremely in anatomical structure, physical properties, and chemical composition in the different organs and textures of animals and plants, and in the organisms of a lower character.

The matter which is coloured in the process above described is, broadly, that which has been termed in different textures *cell*, *nucleus*, *cell contents*, *protoplasm*, *endoplast*, *corpuscle*; while that which remains unchanged is that which is known as *intercellular matter* or *substance*, *cell wall*, *membrane*, *protoplasm*, *fibre*, *periplastic substance*, &c. Great confusion has resulted from the use of many of these words in different senses, and from the application of the same word to essentially different substances. *Protoplasm*, for example, has been applied to living matter, and also to the formed matter which has ceased to live, and by many physiologists, amongst whom may be mentioned Professor Huxley, in his paper on "The Physical Basis of Life," and in other communications. Now, when the carmine fluid is used properly, the living matter of the so-called cell, including the nucleus, is coloured, while the outer part of the cell and intercellular substance remain colourless. We can therefore in any texture, which has been properly prepared, distinguish the active *living growing matter* from the *passive formed matter*. As regards the former, it is often possible to demonstrate zones of colour one within the other, the *innermost* or the youngest being invariably coloured most intensely, and the outermost or the oldest most faintly.

By comparative observations upon the same tissues at different periods of growth, I have been able to demonstrate a continuous but gradually altering relation between the *formed material*, so-called *cell wall*, and the *bioplasm*, the so-called "nucleus," and have adduced many observations which establish the important point that all the *formed material* was once in the state of the *living matter* or *bioplasm* which alone receives the colour. So that in the formation of muscle, for instance, out of the lifeless nutrient pabulum in the blood, the matter which is to become muscle passes through these different conditions:—

1. That of a soluble nutrient matter, or pabulum, which is taken up by, and converted into:—
2. Bioplasm (nucleus, nucleolus, nucleolulus, and, in some instances, protoplasm), which gradually becomes resolved into:—
3. Imperfectly developed formed material which assumes the form of:—
4. Fully developed formed material, as fibrous tissue, cartilage, osseous tissue, muscular contractile tissue. This last slowly changes and is resolved into:—
5. Disintegrated formed material, which is gradually reduced to a

soluble state, and is by oxidation and other chemical processes, at length converted into new substances, some of which pass away, while others in their turn become pabulum for other kinds of bioplasm, such as the colourless blood corpuscles and lymph corpuscles, which are therefore the agents concerned in the removal of the disintegrated material.

It will be noticed that one very important point gained in the course of this enquiry, is the determination of the differences by which the bioplasm, or *active living growing matter* of all tissues, is distinguished from the matter which is *formed*, or which *results from the changes occurring in this*. The general conclusion was established in my lectures, given before the Royal College of Physicians, in April, 1861. I have since worked out changes occurring during the growth and formation of many tissues in detail, in the various grades of the higher animals and plants, as well as in the lowest and most simple living forms.

The material stained by carmine must be regarded as matter in a state of change. It is as different from pabulum as it is from tissue. It cannot be obtained from the first, nor can it be converted into the last, except it remain in the organism to which it belongs, and under the exact conditions favourable to the change. Bioplasm is not *tissue*, for it lives and grows, but it may at length undergo conversion into tissue. It is *living matter*, and in this state differs absolutely from matter in every other known state. Now, by the word *living*, I desire to imply that in this matter so-called phenomena of a peculiar nature are observed, which phenomena have not been explained. They cannot be accounted for by any known laws, they cannot be imitated artificially. And like phenomena have never been observed anywhere except in the living matter of living things.

Among the peculiar properties or powers of every mass of living matter, the following are the most important :—

1. The power of altering and appropriating certain soluble matters, and communicating to these, properties or powers of the same nature as those which the already existing living matter itself possesses.
2. The power of moving in all directions. The passage of one part of a living mass to another part, so that one portion may advance *itself* in front of another portion, or encircle another, and blend with it.
3. The power of causing the elements of matter to take up definite relations towards one another, so that definite compounds, perhaps not to be produced in any other way, and often exhibiting definite structure, may result, when the matter shall cease to live.
4. The power of infinite increase.

By observation the important conclusion is established that the formation of all tissues and organs, no matter how different their ultimate structure and office may be, is due to changes taking place in

matter in a very peculiar state, which cannot be correctly called a peculiar *physical* state, because no known physical state of matter exhibits any analogy to the living state. Nor is the latter in any way comparable with any other state in which matter is known to exist. The living state is exceptional and peculiar and stands alone. There is no transition from the non-living into the living state, but matter passes suddenly from one state into the other. Neither is there in any case a gradation from any form of non-living matter to any form of living matter.

The inferences above detailed enable me to describe very simply the structure of the most complex tissues and the changes which occur during their growth. It is not necessary to discuss in any given case what is "cell wall," "cell membrane," or "intercellular substance," "cell contents," "nucleus," "nucleolus," "primordial utricle," "protoplasm," "blastema." For every tissue and organ of every living thing consists of matter in two states:—*The living or germinal state and the formed and lifeless state.* All *increase*, multiplication, *division*, &c., is due to matter in the first state and to that alone. Living particles do not *aggregate* together to form one living mass, but one living mass may *divide* and *separate* into a vast number of distinct living particles, each of which may, by taking non-living matter into itself and changing the arrangement of its atoms, grow and become a mass like the first.

Every particle of the bioplasm or living matter comes from a pre-existing living particle,—and every piece of tissue, and formed matter of every kind derived from a living being was once in the condition of bioplasm.

Careful investigation of the relations which the *bioplasm* bears to the *formed material* at different periods of growth, and the careful study of these two kinds of matter in the various textures, teach us the order in which the various changes occur and the employment of other terms is rendered superfluous.

A résumé of my views will be found in my work on Bioplasm, and also in the Lumleian Lectures for 1875, "On Life and on the Nature of Vital Actions in Death and Disease." Brief extracts from my papers, and short notices, have from time to time appeared in a few journals and text-books. An excellent analysis extending over twenty pages will be found in the "American Journal of the Medical Sciences" for January, 1867, but by far the most complete notice of my views, and the clearest and most interesting account of their general bearing upon scientific problems of the greatest importance, will be found in Dr. Drysdale's "Protoplasmic Theory of Life." That these notions are not even noticed by the material philosophers will not excite surprise. In science, as in some other departments of human effort, it will be found that those who are always protesting that they alone are liberal, and





no jelly is capable of movement, and no living matter exists which is as incapable of movement as is every form of *jelly* that is known. Under certain circumstances the movements of the *amœba* cease, and a change is observed to take place upon its surface.

**381. The Conversion of Living Bioplasm into Formed Material.—**

The external surface of a mass or particle of *bioplasm* in contact with air or fluid becomes altered. In plain language, the layer of living matter upon the surface of a mass of bioplasm, which is in contact with fluid, or exposed to the air, soon dies. According to the precise conditions under which death occurs, different substances result. These formed matters may be solid, fluid, or gaseous. They may be soluble or insoluble in water. They may be soft or hard, coloured or colourless. They are *formed*, and their *formation* is in great part due to the relation which the elements of the living matter were made to assume towards one another, during the living state, or just before the death of the particle occurred. That relation is definite, so that from the same kind of living matter under similar conditions the same kind of formed substance results. The very same elements which lived in the living matter, always enter into the composition of the formed material, but their arrangement and their relations to one another is totally changed.

The mode in which the formed material is produced will be understood by reference to fig. 1, pl. LXXXII, p. 390. In *a*, *b*, and *c*, both bioplasm and formed material are undergoing increase. In fig. 2, the mass of bioplasm is dividing in the substance of soft formed material, a portion of which surrounds each of the resulting masses, as seen in fig. 3, but the formed material is perfectly passive—as passive as a mass of mucus, or jelly, or semifluid matter would be in which such self-moving, growing, dividing matter was embedded.

*The production of formed material* may also be studied in the conversion of the colourless blood corpuscles into the red. In the frog and newt, especially early in the spring, numerous colourless corpuscles will be found which at the outer part are undergoing change, the matter in this situation losing its granular appearance, and becoming smooth and tinted. As the corpuscle advances in age this process continues until at last the oval red corpuscle is seen to contain only a small portion of bioplasm or living matter in the interior, as represented in pl. XXXIX, p. 158, fig. 4. In mammalian animals generally, this change goes much further, and the whole corpuscle gradually undergoes conversion into semifluid coloured formed material, which however soon becomes a little hardened or condensed on the surface. Thus results a so-called "cell-wall." The fully formed mammalian red corpuscle consists of matter at first in a colloid state, but this ultimately assumes the crystallising property and readily undergoes crystallisation. In some instances, as in the case of the blood corpuscle of the Guinea-pig, this

change occurs within a very short time after the corpuscle has ceased to move, and without the addition of water or any reagent. When a drop of blood is withdrawn from the circulation of the animal and placed upon a glass slide this change takes place, and each red blood corpuscle forms a crystal, or many coalesce to form a large crystalline mass. In figs. 3, 6, pl. XXXIX, p. 158, some of these crystals formed from the red corpuscle of Guinea-pig's blood are represented.

Another simple case, showing the formation of formed material from bioplasm, may be studied in cuticle (man, frog, newt), or in the cells upon the papillæ of the tongue. At first there is but a very thin layer of formed material upon the surface of the bioplasm, and this is soft, so that the mass may divide, and each portion be invested with a thin layer of this soft formed material. Nutrient pabulum passes through the formed material to the bioplasm within, and a portion of the latter undergoes conversion into formed material. The bioplasm increases, while at the same time new formed material is produced. This is shown in figs. 4, 5, 6, pl. LXXXII. In the last figure, a thick layer of formed material has resulted, which only permits a very little pabulum to pass slowly through it. The entire cell does not, therefore, increase in size; but the conversion of bioplasm into formed matter still proceeds, so that at last a mere trace of the bioplasm remains, and this often dies and becomes liquefied and removed, leaving a space or cavity (vacuole) containing fluid, which marks where the living matter was situated.

Now the bodies represented in pl. LXXXII, p. 390, figs. 1 to 6, are termed cells. Cells of this simple character are very common, particularly in many vegetable textures. In these, however, the formed material is usually thinner except in the case of very hard vegetable tissue, when the whole "cell" consists of highly condensed and very dry and hard formed material, there being often a cavity in the centre, which was once occupied with bioplasm. Every cell that is growing and is capable of any active changes consists of a portion of bioplasm or *living matter*, around which is a layer of *formed material* or *lifeless matter*, varying in thickness in different cases. In all instances, however, this formed material has *resulted from the death of particle after particle of the bioplasm or living matter*. That the formed material is deposited as I have described may be proved by anyone who will watch the changes which occur in such a structure as ordinary mildew. These changes are represented in the drawings in pl. LXXXI, p. 386, fig. 1. The different figures of mildew, in various stages of growth, are careful copies from nature, and should be attentively studied with the aid of the explanations.

The bioplasm, which in some of the plates is known by its granular appearance, and in others by its being coloured red, is in fact, the only active part of the "cell." Nothing can be said to live which does not

contain bioplasm. In truth, the only part of us that is really living is the bioplasm, or living matter, of our bodies. In pl. LXXXIV, p. 408, and in pl. LXXXVIII, p. 412, fig. 4, are represented some growing muscular fibres. The masses of bioplasm are large and well formed. The so-called "nuclei" of the nerve and other fibres consist of living matter or bioplasm. In tendon, and various forms of fibrous tissue, the fibrous matter is the formed material (*see* pl. LXXXII, fig. 15). So also in cartilage the same simple distinction can be made between the bioplasm and the formed material. The so-called "intercellular substance" or "matrix" of cartilage, figs. 13, 14, is no more intercellular than the so-called "wall" of an epithelial cell is *intercellular*. "Of the formation of the so-called intercellular substance of cartilage, and of its relation to the so-called cells." *See* "Transactions of the Microscopical Society," March, 1863.

In young tissues the proportion of bioplasm to the formed material is invariably very great; compare the young nerve-cells, represented in pl. XCV, p. 416, figs. 2, 3, with the fully-formed nerve-cells in pl. XCIV, p. 416. Also observe the relative quantities of bioplasm and formed material in the young and advanced cells, represented in pl. LXXXII, p. 390, figs. 4, 5, and 6.

The bioplasm, or actual living matter itself, is invariably clear, transparent, and structureless, but it is usually seen to be granular. Granules are often suspended in it, and caused to move as the living matter moves. Sometimes it exhibits colour, but the colour does not belong to the bioplasm; it is suspended in it or mixed with it, but the bioplasm can in all cases move away and leave the coloured fluid or particles behind.

**382. Formed Material in Substance of Bioplasm.**—In the examples already adduced, the formation of the formed material takes place upon the *outer part* of the bioplasm, and as the cell increases in size the layers of formed material first produced are pushed out by those formed last. In many instances, however, formed material of another kind is deposited *amongst the particles* of the bioplasm. In pl. XLVI, p. 172, figs. 1, 2, are represented some of the young starch-holding cells of the potato. The so-called cell-wall is formed around the bioplasm, while the starch is deposited as small insoluble particles *in its substance*. In fact, by the death of particles upon the surface of the living matter, the *cellulose* "cell-wall" is formed, while, as a consequence of a similar change affecting the particles further inwards, *starch* results. Each starch grain is increased in size by the deposition of new matter from the bioplasm layer after layer upon the surface. In some of the cells no starch grains are formed in the interior, but instead, the "wall of the cell" is greatly thickened by the deposition of a closely allied material upon its internal surface, *layer within layer*.

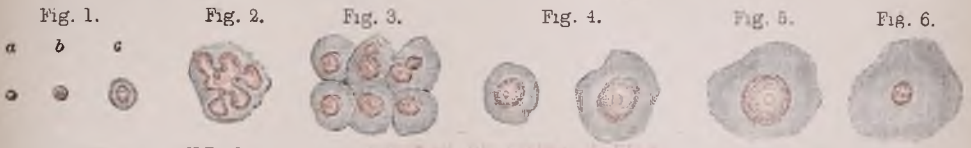
The starch grains lie embedded in the bioplasm, and are separated from the "cell-wall" by a thin layer of it. This part of the bioplasm which lies just within the cell-wall was known as the "primordial utricle" of the vegetable cell.

The fat cell, or adipose vesicle, is formed in precisely the same way, and fat may be deposited amongst the bioplasm of other cells, such as the cartilage cell, and in nerve and other cells in certain cases. The first formation of fat in a fat cell is represented in pl. LXXXII, p. 390, fig. 11.

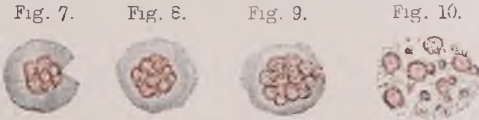
**383. Of the Nucleus.**—In the starch cell, and in the fat cell, and some others, the "nucleus" appears to take no active part in the changes which occur in the interior during the formation of the starch or fatty matter, and other substances which are deposited within cells, after the cell-wall has been formed. What, then, is this "nucleus," which is found in animal and vegetable cells, and of which many examples will be seen in the drawings in the plates? The nucleus consists of bioplasm or living matter. It may be regarded as a new centre, and it has arisen in a pre-existing centre of living matter. In many masses of bioplasm there are, in fact, two or three series of centres, one within the other. In one centre (nucleus) there may be one or a vast number of new centres (nucleoli). See pl. LXXX, p. 380, figs. 3, 5, and 8. The nucleus is in all cases composed of bioplasm or living matter, and it has appeared in bioplasm already existing. The power or force by which the development of centre within centre is determined, whatever its nature may be, always acts upon matter in a direction *from* centres. Particles of matter which have become living invariably move in this direction, and as they move farther and farther away from the centre, their power of animating lifeless matter becomes less, though in them new centres possessing increased power make their appearance. These new centres somehow acquire new power while remaining apparently quiescent. The process of acquiring vital power and the development of nuclei with high vital endowments is opposed to the process of taking up a large quantity of pabulum, and the rapid increase and multiplication of bioplasm.

**384. Of the term Cell.**—Not only has it been arbitrarily laid down that a "cell" involves the existence of a "wall," certain "contents," and a "nucleus," but distinct properties are still attributed to each of these parts respectively, although no one has ever been able to show that the offices assigned to them were really performed. A small particle of living matter, such as is represented in pl. LXXXI, p. 386, fig. 1 at *b*, will not fall under the definition given of a cell, nor is it possible, by any reasonable interpretation of the terms employed, to bring colourless blood corpuscles and a host of other objects into the cell category. To include these the definition must be totally changed, and the existence of cells must be admitted which have no walls, in other words, the very thing

THE CELL OR ELEMENTARY PART.—BACTERIA.



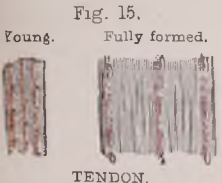
GROWTH AND MULTIPLICATION OF BACTERIA. CONVERSION OF BIOPASM INTO FORMED MATERIAL, AND ACCUMULATION OF THE LATTER.



Increase of Pabulum. RESULTS OF INCREASED ACCESS OF PABULUM.



FORMATION OF SPECIAL SUBSTANCES, OR SECONDARY DEPOSITS, FROM BIOPASM. FAT. STARCH. CARTILAGE.



TENDON.



PRODUCTION OF FORMED MATTER; ITS CONVERSION INTO SOLUBLE SUBSTANCES BY OXIDATION—SECRETION.



Bacteria undergoing germination p. 346. X 1800.



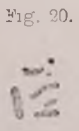
Bacteria shown in outline X 800. p. 316.



To illustrate the changes taking place during the nutrition of the cell. a, bioplasm; b, course taken by pabulum; c, old and young formed material which results from changes occurring on the surface of a.



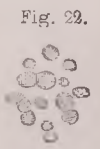
The most minute germs of fungi visible under a 1/10 of an inch object glass. The smallest is less than 1/100000 of an inch in diameter. p. 316.



Bacteria from the mouth. X 1800



Bacteria germs in old epithelial cells of the mouth X 3000 p. 348.



The same X 5000.



which makes the body a cell, is necessary and is not necessary. The difficulty of including many bodies under the old definition, combined with an implicit faith in its truth, has led many observers to affirm the existence of a "cell-wall," when none could be discovered, and at last some of the supporters of the cell theory have taken refuge in the doctrine that the "*cell-wall*" itself is fluid, and is capable of being stretched, and of running together like the film of a soap-bubble.

**Protoplasm.**—The moving matter of the colourless blood corpuscles, the granular matter around the so-called nuclei of muscle, the contents (in part or entire) of the vegetable cell, which I have termed living matter or bioplasm, have been called "protoplasm." Unfortunately those who have employed this word have not accurately defined what they desire to include under it. Mr. Huxley, not content with calling dead matter protoplasm, speaks of roasted and boiled protoplasm, but he does not give the details of the process by which he has succeeded in roasting and boiling living things.

The meaning of many of the terms generally employed in describing the structure of, and the changes taking place in, cells, becomes greatly modified from year to year, and in this way confusion and ambiguity are occasioned. Not unfrequently the same term is used in different senses in the same discourse.

**Bioplasm and Formed Material.**—To save a long and tedious discussion as to the meaning which should be assigned to the words in general use, I have been led, as the reader will have noticed, to use one or two new terms when speaking of the essentially different parts of the cell or tissue. I have applied the term *bioplasm* or *living matter* only to that which *lives, changes, converts, germinates, &c.\** *Formed material*, on the other hand, never possesses any of these properties. It *has lived*, but is now lifeless; it may *be* changed, but it cannot change itself. In nutrition, lifeless pabulum becomes living *bioplasm*, which becomes in its turn *formed material, cell-wall, or intercellular substance, or soluble, or gaseous matter*, as the case may be. Formed material may accumulate or it may be formed in a fluid state, and disintegrated as fast as it is produced. A most important point is this: that formed material of every kind was once bioplasm. New formed matter is deposited in one definite direction only, *from* the centre, or *from within*, so that in an ordinary simple cell the bioplasm is invariably within, then comes the *recently produced formed material*, and lastly the *oldest formed material*, which is therefore most external.

The reader will readily understand the views above given if he will attentively examine the figures appended in the text. *a.* The smallest visible particles of bioplasm or living matter. *b.* Small collections of

\* Roast mutton and boiled lobster may be protoplasm, but they most certainly are not bioplasm.



bioplasm, with a little formed material between them (as in mucus). In the small mass to the right, portions are seen to project, and if these became detached, each one would grow and give rise to new and distinct masses. *c*. A mass of bioplasm, with a very thin layer of formed material upon its external surface (cell-wall). *d*. Same as the last, but with a new



centre of growth (nucleus), which has arisen in its substance. The nucleus is now comparatively quiescent, but it is capable of assuming active growth. If *c* were exposed to unfavourable conditions, the whole would be destroyed, but under similar circumstances the nucleus already developed in *d* might alone resist these influences. The conditions

becoming favourable, the nucleus would grow and produce new elementary parts, even if all but this small portion of the original mass of bioplasm had been destroyed. *e*. Thick layers of formed material, the whole of which were at one time in the state of bioplasm. *f*. Secondary deposits commencing to appear amongst the bioplasm, as occurs in the case when fatty matter is precipitated amongst the bioplasm of the fat vesicle. Fat and other kinds of formed material appearing in a mass of bioplasm result from the death of particles of bioplasm itself. The fat is one among several substances resulting from the death of bioplasm. Some of these are removed, but the fat remains. *g*. A further stage of the same process. A large fat globule is now formed. *h*. Separate masses of secondary deposits, such as result in starch-holding cells, for instance. *i*. Deposition of formed material or secondary deposit in successive layers on the inner surface of the original capsule. Spaces or intervals in which currents are continually setting towards and from the bioplasm during its life, are left during the deposition of the formed material. In this way a starlike arrangement of pores results. *k*. Bioplasm, around and formed from which is formed material, granular in its character. The particles of this formed material are gradually being resolved into several substances, as occurs in the elementary parts of the liver (liver cells). *l*. Formation of fibres from bioplasm. *m*. Bioplasm belonging to and taking part in the formation of the walls of a tube.

**345. False Cells** can be made in many ways, and some of these so closely resemble certain natural cells that it would be difficult or impossible from mere microscopic examination to distinguish one from the other. A number of observers from this fact have been erroneously led to conclude that the cells formed in the living body are produced in the same way as these false or artificial cells. Many strange and fanciful conjectures of this sort have of late received considerable support, and some

of them have been advanced in favour of the dogma lately forced into considerable notoriety that the formation of all living things is due to physical and chemical operations only, and that the actions of all living things are mechanical.

It is most remarkable that in these days any persons can be found who will waste their time in attempting to prove that the "cells" of which the textures of living beings are made up, are formed by physico-chemical operations alone. The vague general assertions which have often been repeated, have been refuted over and over again, and yet many most confident persons continue to repeat the absurd blunders of the physico-chemical visionaries of a generation long since forgotten.

Every real elementary part or "cell" in nature passes through certain stages of being, and not one of any kind at an early period of its formation exhibits characters which entitle it to be called a cell. The advocates of the physical theory altogether ignore the series of changes which occur before any cell-form is attained. Because they can make artificially things something like dead cells, they infer that living cells are produced in the same way, forgetting that the characters of the advanced cell have only been gradually acquired, and by a portion of matter which they themselves would have said was not a cell at all. They forget, moreover, that the material out of which their cells have been made has the same composition as the manufactured cells themselves, while the living cell is made out of material differing entirely from it in composition. They take a little fatty albuminous matter and add to it a little water, and when they see under the microscope globular masses separate, they cry, "See how quickly our *cells* can be made out of ingredients which we can easily obtain." But the cell manufacturers ignore what every one ought to know, that out of matter in which neither fat nor albumen, nor even any allied substance, can be detected, a minute mass of clear transparent living bioplasm can take up certain materials, cause the elements of these to separate, and then recombine them to form albumen, fatty matters, and many other things.

The facts and arguments in connection with this question could be grasped by a child if they were stated fairly, but the statements made and the inferences drawn in many of our elementary text-books concerning cell formation are incorrect; and some of them, although utterly untenable, are repeated over and over again with determined pertinacity. The fact that many of the statements used in favour of the physico-chemical fancies should be received at all, proves that most readers are content to accept conclusions without studying or analysing the facts upon which they are based.

**386. Of the Nutrition and Action of the elementary part or Cell.**

—It may be interesting in this place to consider very briefly what goes on in the cell or elementary part during life when "nutrition" takes

place. Much misconception prevails in connection with this subject, in consequence of the term nutrition having been somewhat vaguely applied to the process by which the increase of the whole body, or a limb, or an organ, or a great part of a tissue is provided for. But here I shall restrict myself to the consideration of the exact phenomena which occur when a single elementary part or cell is nourished. It is generally supposed that when a tissue grows, certain matters existing in the blood pass from that fluid, undergo change, and are directly added to the tissue. In the nutrition of such a tissue as cartilage, it has been concluded that the matrix or intercellular substance is deposited directly from the blood, and that the masses of bioplasm or cells take no active part in the formation of the so-called matrix or intercellular substance. But cartilage matrix does not exist in a state of solution in the blood, and therefore it is incumbent upon those who hold the doctrine above-mentioned to explain by what means the pabulum becomes altered as it passes through the walls of the vessels, and how it is changed in its composition, and acquires the properties of the cartilaginous texture which lies in the intervals between the masses of bioplasm. It is quite certain that nothing like cartilage is to be detected already formed in the blood; and indeed those who teach that the process of nutrition is of the nature above indicated, are driven to attribute mysterious transforming powers either to the lifeless vascular walls, or to the equally lifeless tissue itself. One might as well attribute transforming powers to lifeless wood, or glass, or stone as to fibrous tissue, cartilage, bone, &c.

It will have been observed that according to the views I have advanced the changing transforming powers reside in the *bioplasm* alone. The facts brought forward by me in 1861, concerning the nature of the bioplasm or germinal matter have not been overthrown. I have endeavoured to show, not that the bioplasm acts upon matter which passes by it, and so changes it without undergoing change itself, but that the bioplasm itself changes, and that every kind of formed material and tissue must pass through the condition of bioplasm if tissue is to be produced, and that therefore in the formation of fibrous tissue, cartilage, &c., the order of change is this:—Pabulum from the blood is taken up by bioplasm, and certain of its elements become bioplasm, which in its turn is gradually resolved into formed material, and thus every kind of cell-wall, tissue, matrix, or intercellular substance, &c., is produced.

The existence of bioplasm *before the production of formed material*; *the continuity of the bioplasm with the formed material* in tissues in process of development; the fact that no case is known in *which formed material is produced without bioplasm*; and the demonstration that fluids will pass through a comparatively thick *layer of formed material, and reach the bioplasm in the course of a few seconds*,—necessarily forced upon me the conviction that pabulum invariably passes to the bioplasm, and that it,

or at least some of its constituents, undergo conversion into this living substance ; that from the already existing bioplasm the new matter acquires properties and powers which the matter alone did not possess. At the same time other and older portions of the bioplasm lose their active powers, die, and undergo conversion into *formed material*.

So that in every case of nutrition pabulum invariably becomes bioplasm, and the bioplasm, *not the pabulum*, is converted into formed material. I have been accustomed to state these facts as follows :— Calling the bioplasm, which in all cases is derived from pre-existing bioplasm, *a*, the pabulum *b*, and the formed material resulting from changes in the bioplasm *c*,—I say *b* becomes *a*, and *a* becomes converted into *c*, but *b* can never be converted into *c* except by the agency, and, in fact, by passing through the condition, of *a*, figs. 16, 23, pl. LXXXII, p. 390.

So far, then, the process of nutrition differs absolutely from every process going on in the non-living world, inasmuch as pabulum must pass into living bioplasm to become living, and formed matter must have once been in the living state. Every particle of formed material or tissue which, in many cases, constitutes the chief increase in weight and bulk during growth, *has passed through the state of bioplasm*. The formation of this bioplasm from the pabulum is the important part of the nutritive process and takes place alone in living beings. Similar changes occur in the nutrition of the simplest as well as most complex living creatures.

In nutrition, as it occurs in man and the higher animals, the food introduced into the stomach becomes dissolved, and the solution is taken up by the bioplasm of the villi, the chyle corpuscles, and the colourless blood corpuscles. Changes occur in these masses of bioplasm, and the products resulting form the pabulum for the bioplasm which takes part in the formation of the various textures.

It is implied in some of the text-books that the action of cells is due to the physical and chemical properties of the compounds of which they are made up. This view, though widely taught, is opposed, as has been shown, to facts that are known, and is indeed quite unjustifiable as a general statement of what goes on in cells or elementary parts. It is *only the outer portion* of the formed material of the cell which is the seat of physical and chemical change. It is here that the oxygen combines with the elements of unstable compounds. New substances, which often constitute the "secretion" of the cell, are formed. It will be observed that although mere chemical change occurs, the material which is oxydised is first *formed* through the agency of the bioplasm as has been already explained ; and this *formation* is a part of the phenomena of cell-life which cannot be ignored without misrepresenting the whole nature of the cell and the changes which take place in it. The statement

has been generally accepted that oxygen is necessary to life. But in fact the principal demand for oxygen in living beings arises from the necessity for chemical change and *destruction of material which is formed during the vital changes occurring in the bioplasm*, but which *ceased* long before the action of the oxygen began. Oxygen acts principally upon the surface of cells, that is, upon the oldest part of the formed material, rather than upon the bioplasm embedded in it. It seems that the formed material is prevented from accumulating round the bioplasm of many cells by external agencies, among which the oxydising action of oxygen is the most important. In this way the formed material becomes resolved into more soluble substances, which are at once removed. Were it not for the disintegration and removal of the formed material, the passage of pabulum through it and its access to the bioplasm would be greatly interfered with or prevented. Moreover, it is probable that the action exerted by the oxygen which reaches the bioplasm is upon matter suspended or dissolved in the fluid between the minute particles of bioplasm or living matter. Oxygen acts upon the *lifeless matter* of the cell. It does not *support life* directly, but is necessary to the continuance of life, because it alone can convert the products of death and decay into soluble substances, which can be easily removed. Fig. 23, pl. LXXXII, p. 390, will give some idea of the movements of fluid which occur in the cell during the changes above referred to.

A cell may undergo the most active change without altering in size. The absorption of pabulum and the production of new bioplasm may be compensated by the conversion of the latter into formed material, as the old formed material becomes oxydised and removed from the cell.

**386\*. Of the Nature of "Irritation" and "Inflammation."**—I must now make a few remarks concerning the wonderful effects which ensue from a change of the circumstances under which the "cell" is placed. Suppose the hard formed material which interferes with the access of pabulum to the bioplasm of a cell to be ruptured, or softened by the action of fluids, so that pabulum will more readily come into contact with the bioplasm—what happens? The latter will increase very fast. It will absorb the nutrient matter, and may even take up the softened and altered formed matter, which was itself produced from bioplasm at an earlier period. These stages are seen in pl. LXXXII, p. 390, figs. 7, 8. In fig. 9, the original mass has divided into several, and in fig. 10 these are seen after they have escaped. Being now freely supplied with pabulum, in consequence of the absence of the thick layer of formed material upon their surface, as in figs. 2 to 6, they grow and multiply rapidly. These changes are considered to result from what is called "irritation," and to constitute the essential phenomena of "inflammation." In what is known as *irritation*, the observer must bear in mind the fact that the access of pabulum to the

bioplasm of the cell is facilitated, for is not the protective external covering of formed material invariably removed or rendered more permeable by chemical or mechanical means whenever "irritation" or "inflammation" is said to exist? Such is, I believe, the action of the so-called chemical and mechanical "irritants." See a lecture on "First Principles." "Dublin Medical Press," 1863. I think, therefore, that we ought not to employ the term irritation as applied to individual cells at all, and would restrict its use to those cases only in which nerves and nerve centres are concerned. Although all medical writers have freely used this word, no one has explained exactly what he means by it.

The above view is capable of wider application. Heat acts as a "*stimulus*" to the development of the embryo chick, simply by facilitating *the access of pabulum to the bioplasm of the living embryo*. The heat *does not become the life*, for the life is there; but it is simply one of the conditions necessary for the manifestation of this mysterious active power, and for its communication to particles of non-living matter brought within the sphere of its activity. Without the influence of heat, the pabulum cannot get through the formed material to the already living bioplasm; but as formed material is expanded, and the permeating properties of the surrounding nutrient fluids increased by heat, the pabulum comes rapidly into contact with the living particles, and these communicate to it the same wonderful power they already possess.

## OF VITALITY OR VITAL POWER.

**387. Of Life.**—The formation of the various structures and peculiar and characteristic substances in living beings can only be explained if the operation of some force or power of a different order, and belonging to a different category from all other forces or powers influencing non-living matter, be postulated. To some persons, speculations concerning the nature of life will seem out of place in a work like the present, but I do not admit that speculation on the nature of things is the prerogative of physicists only, and I think that any one who has carefully studied the phenomena of living beings is likely to know more about life than he who investigates the inanimate only. The *vital* processes of *growth*, *formation*, and *multiplication* are peculiar to living beings. There is nothing like these processes in the non-living world, and they never occur unless bioplasm with its marvellous vital power is present. The formed material may be regarded as a product resulting from the influence upon matter of internal *vital*, and subsequently of external *physical* forces. Its properties are due partly to the changes occurring in the matter when in the living state, partly to the external conditions present when the matter passes from the living state, that is, at the moment of its death.

I have tried my utmost to account for the changes which take place in the living matter, as far as these can be ascertained by microscopical observation, by physics and chemistry, but, like all who have hitherto attempted to explain vital phenomena in this way, have signally failed. I have listened attentively to the various assertions made and repeated by Dr. Tyndall and others, concerning the physics of living beings, and have publicly requested Dr. Tyndall to explain what he means by the assertion that "man is a machine," and that all his actions are mechanical, but a contemptuous allusion to the principles of the institution in which I have worked is the only notice he takes. The public desires to be taught that "man is a machine," and Dr. Tyndall accordingly teaches this and a number of other very curious things concerning the nature and actions of living beings which he has discovered in his imagination, and the facts in support of which are to be discovered by observers about to be. Notwithstanding all the confident assertions, the prophecies, and the discernments of popular teachers, the reader must bear in mind that to this day not one single vital action has been explained or accounted for, or imitated in any form of non-living matter. The most absurd comparisons have been made for the purpose of supporting the ridiculous proposition that living beings closely resemble non-living machines. Over and over again cells have been compared with laboratories, but the *chemist* in these cell laboratories has been ignored; and with machines, the constructor of which, as well as the engineer and manager, has been entirely left out of consideration. Remembering Helmholtz's grim complaints about the imperfections of the eye, and the failings and faults of its constructor, it is pleasant to notice that more reasonable and more tenable views are now entertained with regard to the most important part of that organ. Kühne well observes that so long as it is maintained in its natural connexions with this epithelium (choroidal epithelium in which the rods are embedded), "the retina resembles not so much a photographic plate as a *whole photographic workshop*, in which the operator, by bringing new sensitive material, is always renewing the plates, and at the same time washing out the old image." ("The Photochemistry of the Retina and on Visual Purple," by Dr. D. Kühne, edited with notes by Michael Foster, M.D., F.R.S.). I quite agree with my friend, and would remark that the comparison will apply not only to the retina as a whole, but to every complete anatomical element of which it is made up, and also to multitudes of living anatomical elements which are not retinal. I commend this to the consideration of the materialists and to those imaginative physicists who evolve machines from their understanding and straight-way declare that such products of evolution actually exist in nature.

Whatever may be done in the time to come it is certain that at this time the facts of living beings can only be explained if we assume the

operation of some peculiar force or power which in its essential nature is distinct from every form of energy and all known physical forces. The facts of the case teach us that a peculiar agency or force compels matter to assume temporarily the peculiar state characteristic of all bioplasm or living matter, but of living matter alone. I venture to call this *vital power*. Although in the present state of our knowledge we can perhaps form no positive conception of the real nature of this wonderful power, any more than can be formed of the nature of gravitation, heat, or electricity—by studying the phenomena we discover that it is impossible to accept the view now very prevalent that vital power is but a peculiar mode or form of ordinary force, or corresponds to what we call the peculiar *property* of each different inorganic substance, by virtue of which it exhibits a constant crystalline form, a definite specific gravity, manifests a certain characteristic behaviour towards other substances, &c. Vital power, it is true, is only manifested under certain conditions which are fixed and definite, and are very different for different living beings; but how can this vital power be a result of the influence of conditions on inorganic matter, seeing that the matter was alive before it was exposed to the conditions in question? We are unacquainted with all the conditions absolutely necessary to life; but it is certain that external conditions might persist for any period without any form of life whatever being necessarily evolved.

Some will say,—vital power *must be* another mode or form of ordinary motion, because there is nothing else in nature that it can be! There is, it has been affirmed, but one power capable of giving rise to the phenomena we term *vital*, and this is *force* of some kind or other. But this is begging the question at issue, and it is a mere assertion not a demonstrated truth to affirm that *all* the forces operating in nature are but different modes or forms of that which has been called primary energy or motion. It is hardly yet proved that *all* the forces now recognised are mutually convertible. It is not known how many diverse forms or modes simple primary energy or motion may put on, but it is certain that many phenomena familiar to us, notably the operations of the mind, cannot be explained by what we yet know concerning the forces and properties of matter. On what grounds then can any one affirm that there is no power in nature capable of giving rise to vital phenomena except a form of force? There is nothing whatever in science which affords the least excuse for the presumptuous dogmatising which has been encouraged by the public for years past in connexion with this all-important matter, and it is a disgrace to public intelligence that the reckless attempts to carry us back to a degraded form of the philosophy of Lucretius have not been decidedly and publicly condemned.

How can vital power represent or correspond to any properties



manifested by ordinary inanimate bodies, seeing that it is capable of being *transferred* from complex particle to particle? Moreover, does not vital power control the manifestation of ordinary force, and, besides, give rise to the formation of certain compounds and structures which are destined to come into use, not as soon as they are formed, or soon after, but at some future time? A fully formed organ is not first represented by a microscopic germ of precisely similar structure, but by a mass without structure at all, and the fully formed tissues are preceded by the production of several less elaborate structures. Where, it may be asked, is to be discovered, the machine or non-living apparatus which is developed in this way? "Vital power" governs not only the present changes which present matter is to undergo, but somehow provides, as it were, in advance, for the carrying out of changes which are to occur at a future time in other matter. The formation of structures is prepared for long before the compounds are produced out of which those structures can alone be made. While ordinary force seems for the most part to affect masses from the surface, vital power acts from the very centre of the most minute particles—new power as it were ever *springing up anew in the centre of particles of matter already under the influence of vital power*. While ordinary force may change its form, it cannot cease or be annihilated; but there is no evidence to show that vital power changes its form, while, as far as is known, it does cease to influence matter though it may not be annihilated. There is no evidence whatever in favour of the view that vital power can undergo conversion into any other kind of power or force. No one has yet proved that when living matter dies the vital power changes its form, and becomes converted into any kind of force which is set free; and although it has been asserted that more force is taken up in the formation of a brain-cell of a man than in the formation of a vast quantity of vegetable tissue, there is no evidence in favour of such a hypothesis. It is but an authoritative dictum.

Numerous facts and arguments thus seem strongly in favour of the view that there exists in relation with every particle of matter that is alive a certain power characteristic of each different species of organism, and derived from a pre-existing particle, which exerts a special influence in determining the composition and properties of the substance that is to be formed. The power which determines the change which the matter is to undergo resides in, or at any rate affects, the bioplasm of the cell only. And we conclude that this power is not of the nature of ordinary force because there is no example of ordinary force producing any effects like it, or exhibiting any analogy with force phenomena known to us, and we, therefore, attribute these effects to the working of some power which exists, but which belongs to an order or class different from any that will include forces or powers whose workings are known.

Although, as was to be expected in these days of "positive" knowledge, these views concerning vital power have met with contempt and opposition, no one has yet explained in any more satisfactory manner the phenomena actually occurring in a living amœba or mucus corpuscle. There is no escape from the confession that we are not able to explain why the living matter moves and grows, making amœba material out of matter totally different in composition and properties. It is said to be unphilosophical to attribute the phenomena to amœba power, or amœba force, or amœba life, but as long as we remain ignorant and the question remains open, surely it is better to attribute the phenomena to a power we know nothing about than to assert that they are due to force, or to guiding forces. Mr. Huxley scoffs at the idea of vitality, and expects people to believe in his jelly-guiding forces and Bathybius.

An attempt at explanation by assuming peculiar power may be more blundering as well as more honest, inasmuch as it is a confession of ignorance, than the affirmation that amœba phenomena are due to the conditions under which the matter is placed, since we cannot define exactly what the "conditions" are, or to amœba-guiding forces, the effects of the supposed guiding forces exhibiting no likeness whatever to any known effects of any known form or mode of ordinary force. We do know that under no conditions with which we are acquainted can an amœba result except from an amœba, or part of an amœba, its ovum or germ.

But in order that those who read these words may clearly understand the points which have influenced my judgment, I shall now try to state the facts of the case more explicitly, and I hope some of my readers will endeavour to obtain from my opponents an adequate explanation of the facts which I can only account for upon the vital hypothesis I have advanced.

I see under the microscope a little clear, transparent, structureless matter, which moves in various directions. Portions of the mass project at different points around its circumference. Some of these are again drawn into the general mass, others become detached, never to join again. Each separate mass grows, or takes up non-living matter around it, which non-living matter or certain of its elements becomes part and parcel of the growing moving mass. The matter moves, and grows, and divides, and forms; and I find that everything that lives consists of matter like this, manifesting like properties.

I find no matter in nature which moves, grows, divides, or forms save that which came from matter which did all these things before it, and therefore I call all matter which does all these things *living*, and matter which does not do these things—which does not exhibit the phenomena of movement in all directions, growth, division, and formation, *non-living*. I want to know why the matter grows, moves, divides,

and forms. I am told that all this depends upon *force*, and that *force* is conditioned in the cell mechanism *just as* it is in the machine.

Then I urge that the living matter came from living matter like itself which lived before it, and this from pre-existing living matter; while, on the other hand, the machine was not derived from another machine, which after taking to itself iron and wood, or their elements, and other things entering into its composition, and thus for a time increasing in size, at length divided into two or more new machines.

Since force cannot of itself *form* the simplest possible machine or thing adapted to any definite end or purpose, what right have we to assert, contrary to all analogy, that force can form a particle of living matter which, mass for mass or weight for weight, is far more powerful than any machine ever made?

Lastly, as every machine results from the application of force *directed* by human intelligence and human will, is it possible that the elementary part which forms itself and performs of itself at least without human interference that which no machine has ever been made to do, can be *formed* by unintelligent, purposeless, designless force? Argument from analogy is no longer sustained by facts, but fancies from the realms of the imagination are advanced in its support. People are bewildered, and not a few deceived.

For even supposing living matter to be formed upon the same principles and to act in obedience to the same laws as the machine, we must surely assume that some substitute for intelligence and will directed the application of the force by which each atom was arranged in its proper place according to the work which had to be performed and the nature of the things to be made—for are not the springs, wheels, and beams, &c., of a machine made and placed, and kept in the places designed for them, by force directed by intelligence and will? Unless thus much be conceded there can be no analogy at all between a portion of living matter and any kind of machine, and if this be admitted, is it not curious that the will and intelligence and directing power, admitted to be necessary in the construction and action of the machine, should be denied in the case of the living machine, without which the non-living machine could not have been brought forth? But it must be further remarked here that it is a great mistake to compare the entire organism of man or animal with a complete active working machine. If any comparison at all is justifiable, it is each individual cell or each minute particle of living matter which contains as it were within itself *directing power*, and *matter to be directed and arranged*, which must be compared with the complete machine in actual work, including its superintendent.

If I study the phenomena of a machine and those of a living organism, I find that although the results of the working of the two

may be in some respects similar, the means by which the results are brought about are totally different in the two cases; and if I enquire how the machine was made and how the active organism was made, I find no analogy whatever between the two methods of genesis, for every machine is made in separate pieces, which are afterwards put together, and every organism results from changes in clear transparent structureless matter which cannot be made, and the particles of which cannot be put together so as to form an apparatus capable of doing anything. In short, no comparison can properly be made between any form of machine and any living organism.

Having regard to the facts as we know them to be, how, I ask, can we escape the conclusion that the principles upon which living matter grows and acts are totally distinct from those upon which machines are constructed and work?

But we are told that non-living matter which never manifests phenomena like those exhibited by every particle of living matter, passes by imperceptible gradations into this last. Yet no one has adduced examples of matter exhibiting the supposed gradations, and the assertion, like many other assertions of the same tendency, is a mere dictum without the slightest foundation in fact. The gulf which separates the simplest living monad from man is as nothing compared with that which intervenes between the highest and most complex form of non-living matter and the simplest living particle. Instead of a gradation there is an abrupt line, a chasm which cannot be bridged over—a gulf which becomes wider and deeper as knowledge increases. In truth, the difference is inestimable, immeasurable, infinite.

Scientific dogmatism prevails, and for the present will prevail, and the energetic disciples of the so-called new philosophy are encouraged and ably supported, and will continue to assert their formulæ in spite of facts and reason. "The sun *forms* the muscle—the sun *builds* the nerve." "The living force-conditioning machine is formed by force." "The living cell is a laboratory." Authorities less confident, and somewhat more cautious, unwilling to immediately subscribe to these bold doctrines, or commit themselves to such positive professions, reiterate the assertion that ere long new facts will be discovered, and then the truth of such and such wonderful generalisations recently expounded to an expectant world will be indubitably established on a secure basis. As if, where real knowledge is defective, anything save individual notoriety of the most evanescent kind is to be gained by any one putting himself forward as the only real and true prophet among scientific seers. The prowess shown by "positive" knight-errants in assaulting the "fictitious entities" which have so long and cruelly tryannised over the innocent and thoughtful must be admitted, and the disinterested longing exhibited by some of them to emancipate the human understanding from the

tyranny of imaginary powers which have so long enchained it, is indeed much admired. But are not these same deliverers, who exultingly snap the gossamer chains spun round us in the past by the fictitious entities and imaginary forces, ready to deliver us to be bound hand and foot with the heavy fetters forged by unimaginative relentless force, to be left powerless in unfathomable darkness where seeing, feeling, thinking, hoping, will be of no avail?

The physico-chemical revivalists have only added to the confusion which has long existed in men's minds concerning the nature of the actions going on in living beings, and in spite of all their professed care and exactness, they display the most glaring inconsistency by denominating phenomena, which are essentially the same, *vital* or *physical*, according as they occur in a living organism or outside it. A change taking place in a glass vessel on the laboratory table is *chemical*, while the very same change occurring in the body of an animal is to be called *vital*. Now, the name given to any phenomenon should be determined according to its real or supposed nature, and not made to depend upon the locality in which it is manifested. It would be as unreasonable to call a red thing blue when its position was changed, as to call a phenomenon *electrical* or *chemical* if it was manifested upon a table, and *vital* if it occurred in the organism of a living animal.

**388. Of Living and Dead.**—It will have been noticed that the word *vital* has been applied by me to changes and actions quite distinct from, and indeed in their nature opposed to, chemical, physical, &c., and I endeavour to define the precise seat of vital action, and to draw a sharp line between *vital* and merely *physical* and *chemical* phenomena. The terms *living* and *dead* have for me a meaning somewhat different from that commonly accepted. If my arguments are sound the greater part of the body of an adult man or animal, at any moment, consists of matter to all intents and purposes as dead as it would be if the individual itself were deprived of life. The formed material of the living cell is dead. The only part of the living elementary part or cell, and the only part of the living organism which is alive, is the bioplasm. Nothing can be regarded as alive or living but the bioplasm in which vital changes alone take place. The phenomena of imbibition, osmose, &c., in cells—even the contraction of muscles and the action of nerves, are probably in themselves physical actions, although they have been immediately preceded by, and are probably the direct consequence of, actions purely vital. But for the vital phenomena, these physical actions could never occur in the precise way in which they occur, nor effect the purpose they actually do effect. Were it not for vital action, osmose, muscular contraction, nerve action, &c., would of course cease. And having once ceased these actions could not be resumed unless the conditions were all reinstated exactly as they were before. The formed

material in which physical and chemical changes occur, could not have been formed without the previous manifestation of vital phenomena. We may go backwards as far as we can, but we shall always find vital actions intimately concerned in bringing about the condition of things necessary for the particular physical and chemical changes which subsequently occur. Of course, the above views have been treated with contempt by evolutionists who are confident that they and their doctrines are not only the fittest, but the only ones fitted to survive. In these days of implicit belief in continuous and uninterrupted physical changes and gradual transitions of forms, one expects little mercy and asks for none. I have but to draw attention to the results of actual observation, and the conclusions based thereupon.

It will be asked whether in nutrition the lifeless pabulum *suddenly* or *gradually* becomes living matter, and if the latter *suddenly* dies, and becomes formed material. It is generally taught that the elements of the former are *gradually* built up to form the tissue, and that the living body *gradually* passes into the condition of death. All that I have been able to demonstrate compels me to hold that the change from non-living to living, and from living to dead is sudden, and that there is no transition state whatever,—that matter is either living or non-living, and no intermediate state is possible. The bioplasm itself is probably not in any one part large enough to be measured, entirely living. There is matter which has lived, matter living, and matter which is about to live, but I imagine that the very instant the lifeless atoms come within the influence of the vital power of a living particle, they cease to be lifeless and live; and, on the other hand, the instant external conditions interfere with the continuance of the changes occurring in the living particle, it dies,—its atoms rush together in a certain way to form a definite compound which thus suddenly comes into existence, and may remain as it was formed, or continue to undergo further chemical change, or become resolved into a number of new compounds.

The old idea that a living thing in dying gives rise to a new life has been accepted in too literal a sense, and like many of the most vague of early notions concerning the nature of life still survives in philosophy humorously characterised by its disciples as *advanced*. The doctrine is even considered by many to represent the exact truth. It is supposed that before a plant springs from the seed, the latter becomes completely changed, its component substances disintegrated, and their elements rearranged. That then these elements become combined to produce new compounds and rearranged to develop new forms, while in truth the embryonic living matter which becomes the future plant exists in the seed from the first, and its growth from first to last proceeds according to the same principles. So far from admitting that a new being can spring from the products resulting from the decay and disintegration of one

existing before it, this is absolutely impossible. From the time when the seed was first developed in connection with the living parent plant to the time when it becomes or gives rise to a perfect living organism, living matter and of a particular kind has not ceased to exist during one moment of time. However dry and however old the seed may be, so long as it continues capable of germination it must contain living matter. The cells and fibres of the growing plant are due entirely to the growth and multiplication of living particles which were derived from the living matter of its predecessor—not to the rearrangement of elements resulting from the disintegration of any mere lifeless compounds entering into the formation of the seed or to the rearrangement of the elements of substances resulting by the death of any pre-existing living thing. If life which influences matter ceases but for an instant it can never be rekindled in that particular matter. The fact of continuity in vital manifestations cannot be argued away. There has been absolutely no break since the creation of living matter, and the new origin of life—spontaneous generation—is as improbable, may I not venture to say as *impossible*, as is the formation of matter anew.

Any theory of vitality which takes cognizance of the ordinary facts must in some way account for non-material psychical changes. Materialism simply ignores and denies what is obviously true. In every particle of matter that is actually alive, alteration in the position of molecules and in the arrangement of atoms unquestionably takes place. The materialist confounds the fact of the material change with its cause, and argues as if the rolling stone rolled of its own accord. The particles of matter must be set moving and be kept moving in their appointed way. Just before they begin to move the cause which is about to operate upon them must surely exist. The efficient cause of change must, at the time when and before the actual change begins, be there to operate, just as the disposition of circumstances which is to set a ball rolling must exist before the ball begins to roll. The force or power which causes the movement of the material particles about to become living exists in relation with matter already in a living state.

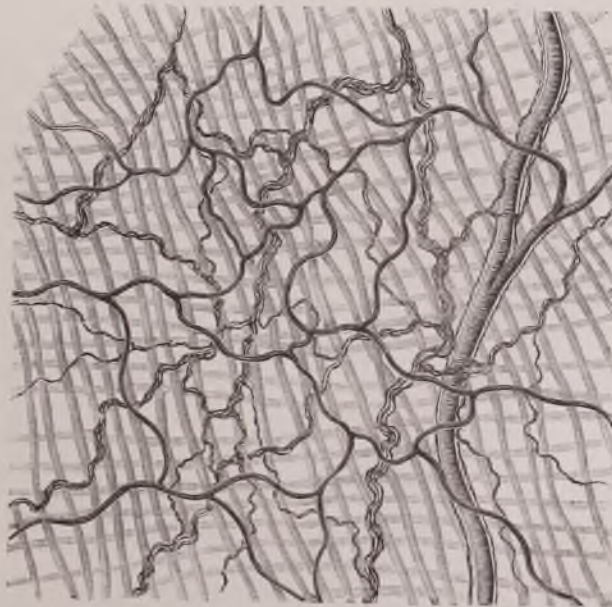
NETWORKS OF DARK-BORDERED NERVE FIBRES.

Fig. 1.



Networks or plexuses of dark bordered nerve fibres distributed near the free edge of the third eyelid of the common frog. X 220, and reduced to 110 diameters. p 375.

Fig. 2.



Myohybrid muscle of the bala, showing muscular fibres, capillary vessels, and networks of fine dark bordered nerve fibres. X 130, and reduced to 65 diameters. p 375





OF THE STRUCTURE OF A NERVOUS APPARATUS AS DETERMINED BY  
MICROSCOPIC INVESTIGATION WITH THE AID OF THE HIGHEST  
POWERS, AND SUGGESTIONS CONCERNING THE NATURE OF NERVE  
FORCE AND OF MIND.

In this department of minute research I have found the particular method of investigation advocated in p. 366, most useful. In studying the ultimate arrangement of nerve fibres and cells we have to use the highest powers, and to adopt the most delicate methods of preparation. The finer terminal ramifications of the nerve fibres are extremely delicate, and the bodies connected with them undergo rapid change after death. It is probable that when more perfect methods of preparation shall be devised, and still higher magnifying powers constructed and brought to bear upon them, many important questions in connection with the structure and action of nerve will be set at rest. Our views concerning the nature of nervous action will be necessarily much influenced by the general notion we may form concerning the origin and distribution of nerves. At this present time there is the greatest disagreement among authorities concerning fundamental questions. It is not even settled whether nerves terminate in ends or form continuous circuits. It is not known whether they influence tissues by reason of their being in structural continuity with them or merely indirectly, in consequence of currents passing along the nerve fibres situated at some short distance from the particles of tissue to be influenced. And it is doubtful whether the influence is produced by the passage of a continuous current varying in intensity, or by an interrupted current. Nor is there more accord as to the manner of origin of nerves in centres; some holding that the fibres invariably originate in cells, others that some cells have no fibres at all connected with them. And of those who admit the first proposition, some think the fibre comes from the body of the cell, others trace it to the nucleus, while some profess to have seen it emanating from the nucleolus. Again, concerning the fibres, which unquestionably originate in nerve cells, it has been stated that some pass into nerve fibres, while others have no special relation to nerves at all. But it would occupy much more space than it would be advantageous to devote to it, were I to attempt to give even a very brief summary of all or even the most important of the conflicting opinions now entertained. And if I were to limit myself to any one organ the reader would be equally bewildered by the conflict of opinion, and by the multitude of assertions which pass for statements of fact. And if he try to sift the evidence adduced in favour of the views propounded, he will completely fail, because they are said to rest upon observations which for the most part he will find himself unable to repeat.

**389. Of very fine Nerve Plexuses and Networks of Nerve Fibres, as seen under very High Powers.**—Every one agrees that the larger nerve trunks are in many instances so arranged as to form plexuses or networks, to which various names have been assigned by anatomists, according to their position, general form, origin, &c.; but it was supposed that in many cases nerves pursued an almost direct course from these plexuses and networks to their ultimate distribution, where according to some they terminate in free extremities, according to others ending in cells, or becoming continuous with the texture they influence. More careful observation has, however, demonstrated that all nerves before they reach their finest ramifications form microscopic networks or plexuses, arranged upon the same plan as the coarser ones above alluded to; and I have been able to demonstrate that the finest *ramifications* themselves constitute *plexuses or networks in which the component ultimate fibres are arranged in much the same manner as the dark-bordered fibres entering into the formation of one of the ordinary coarse anatomical plexuses.*

Careful observations upon the arrangement of particular nerve plexuses in the same texture at different periods of development have convinced me that the *ultimate terminal plexus* of the embryo becomes the plexus composed of coarser fibres of the infant and child, and the plexus made up of bundles of compound fibres of the adult. New *ultimate nerve plexuses* gradually come into existence as the constituent fibres of those previously formed grow and slowly become converted into thick nerve fibres. That a continuous development of new nerve fibres takes place in the adult is rendered almost certain by the facts demonstrated in many textures of man and the lower animals. The arrangement of nerve plexuses one remove from the terminal plexuses of the nerve fibres will be understood by reference to pl. LXXXIII, figs. 1 and 2. The arrangement is the same as regards sympathetic, and spinal motor and sensitive nerve fibres—except that in the case of the spinal nerves the constituent fibres of the plexuses one or more removes from the terminal plexus are dark-bordered.

Not many years since, numerous observers considered that no fibre could correctly be termed a *nerve fibre* which did not exhibit the dark-bordered character, and many real nerve fibres were regarded as fibres of connective tissue. But since I demonstrated the very fine nerve fibres in many different textures, and showed that in all cases the really active peripheral part of the nerve was the terminal plexus, composed of very fine compound fibres often less than the 1-100,000th of an inch in diameter, numerous memoirs have appeared in Germany in which the authors endeavour to prove that still finer fibres pass off from what I look upon as the terminal plexuses, and end or terminate in epithelial cells. Allusion has been made to some of these in pp. 410, 413.

FINEST NERVE NETWORKS UPON VOLUNTARY MUSCLE.

Fig. 1.



Distribution of lines: nucleated nerve fibres to the elementary muscular fibres of the Myo-hyoid muscle of the little green tree-frog (*Hyla arborea*). Drawn on the block by the author, from a specimen magnified 1700 diameters (the first twenty-fifth made by Messrs. Powell and Lealand). The diameter of each muscular fibre corresponds to that of a human red blood corpuscle.

Scale,  $\frac{1}{10000}$  of an English inch  $\times 1700$  diameters.

10000



Pflüger has arrived at the conclusion that the nerves distributed to the salivary glands end by exceedingly fine filaments in the epithelial cells or their nuclei; but I do not think that in this organ any nerve fibres pass beyond the surface of the connective tissue upon which the secreting cells lie. I have never been able to convince myself that nerves pass to the epithelial cells in any of the situations indicated, nor have I seen any preparations at all conclusive. On the other hand, there are many facts opposed to this view. Upon the whole, the evidence, so far, is strongly in favour of terminal networks beneath the epithelium of such tissues as mucous membrane and secreting glands. And as *secretion* (the production of peculiar compounds by bioplasm agency differing entirely from the materials out of which they were made) certainly takes place in many cases without nervous agency, much stronger evidence than any yet advanced ought to be adduced before the conclusion that nerves act directly upon the secreting cell is accepted.

In all cases, as far as I can ascertain, the terminal fibres of all nerves are homogeneous, becoming granular in the prepared specimens, and exhibiting nuclei at varying intervals, but distributed upon precisely the same plan as the coarser networks. As far as I am able to discover by observation, there is not such a thing as a true *end* to any nerve fibre. I must, however, admit that many of the observations which have been made in Germany during the last few years are opposed to my view. Memoir after memoir has been published for the purpose of proving that nerves exhibit terminal extremities in several motor and sensitive organs. As investigation proceeds, this controversy becomes more interesting and exciting. Although my opponents are many and powerful, the facts in favour of my own view are now very numerous and almost every new investigation I attempt enables me to add more to the number. My conclusions rest upon observations made upon many different tissues and organs of vertebrata differing widely from one another, as well as upon those of numerous invertebrate animals. I cannot therefore yield. I consider that numerous specimens I have made fully justify me in maintaining the general proposition that in all cases the terminal distribution of nerves is a plexus, network, or loop, and hence that in connection with every terminal nervous apparatus there must be at least two fibres, *and that in all cases there exist complete circuits into the formation of which central nerve cells, peripheral nerve cells, and nerve fibres enter.* All these elements are, I feel confident, continuous, but not in bioplasmic connection with each other. I propose now to illustrate the above general observations by one or two examples, and I shall select for illustration particular specimens which can be easily obtained, so that others may examine the very same structures and compare their results with those at which I have arrived.

**390. The ultimate Distribution of Motor Nerves to Muscles as seen under very High Powers.**—In pl. LXXXIV, p. 408, the ultimate arrangement of the finest nerve fibres in voluntary muscle is represented under the 1-25th, which magnifies 1,700 diameters. The ultimate nerve fibres form networks around the muscular fibres outside the sarcolemma. An explanation will be found beneath the drawing, so that it is not necessary to enter into a minute description in the text.

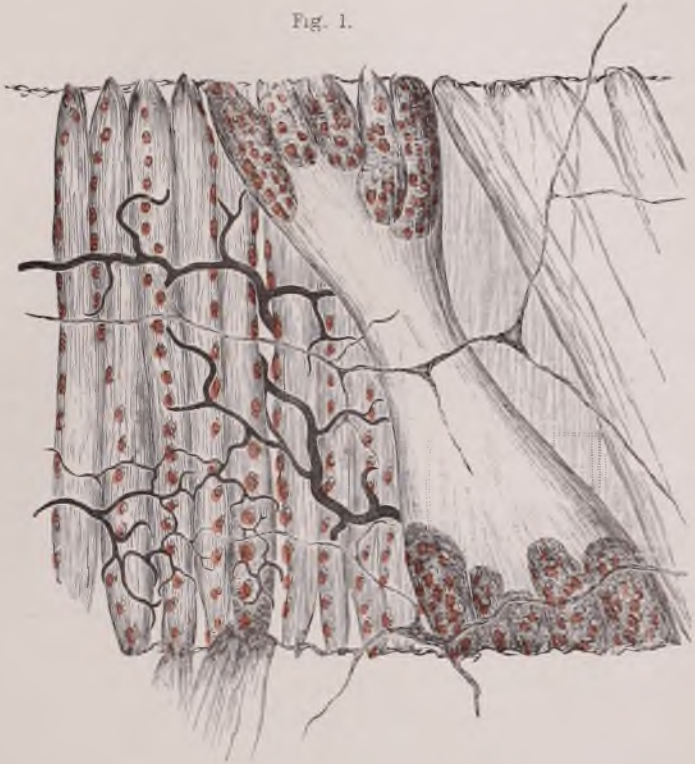
The nerves distributed to the muscular fibres of insects are much finer and more delicate than those present in vertebrate animals, and thus are far more difficult to investigate. Many writers have been led into fundamental errors concerning the structure and arrangement of nerve fibres in this class of invertebrata. What really is a compound nerve fibre, composed of very many individual fibres, has been regarded as a single nerve fibre, and so represented in drawings. Many of the bioplasts or nuclei of the finer nerve fibres have been entirely passed over. Muscular bioplasts have been regarded as bodies, in which muscular nerve fibres end. A plexus formed by the compound nerve trunk at the point where it reaches the sarcolemma, and is about to break up and spread over the surface of this membrane, pl. LXXXV, figs. 1, 2, 3, has been regarded as the terminal portion of a *single* nerve fibre *beneath* the sarcolemma and in contact with the muscular tissue.\* In plates LXXXV and LXXXVI the manner in which very fine nerve fibres are distributed upon the sarcolemma of insect muscle is well seen. The reader should refer to the full explanation under each of the figures. *See* also paper on the "Structure of the Sarcolemma of Insects," &c., "Microscopical Journal" for July, 1864.

The arrangement of the ultimate nerve fibres in involuntary or unstriped muscular fibre will be understood if fig. 1, pl. LXXXVII, be referred to. This is a drawing of a portion of the bladder of the frog, in which the finest ramifications of the nerve fibres are well seen. These nerve fibres form bundles and networks, having wide meshes in which the fine muscular fibres lie. Just beneath the epithelium, in well-prepared specimens, networks of delicate fibres probably concerned in sensation, may also be observed. Of the muscular fibres (not represented in the drawing) some are spindle-shaped, while others consist of three fibres radiating from a triangular central portion, fig. 5, pl. LXXXVI. It is obvious from the arrangement figured that the nerve fibres only influence the contractile fibre indirectly, for they are not anywhere *in actual contact with the contracting material of the fibre*, nor in any case can an *end organ* or any form of *terminal apparatus* be detected, nor are the nerves connected with the nucleus or with any part

\* Upon this subject see "Controversy," Archives of Medicine, vol. IV, p. 161, and a paper by Mr. Gedge, of Cambridge, in the July number of the "Microscopical Journal," 1867.

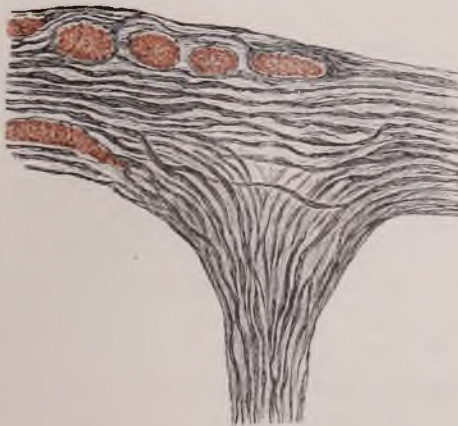
FINEST NERVE NETWORKS.—MUSCLE OF INSECT.

Fig. 1.



Arrangement of muscular fibres, nerves, and tracheæ of the common maggot. The contractile tissue of the muscular fibre in the centre of the drawing has been ruptured, and has contracted within the tube of the sarcolemma. A fine branch of the nerve trunk is seen to cross the sarcolemma and give off a still finer branch, which, after being followed for a short distance, appears lost upon the sarcolemma. If the nerve trunk be traced, many other branches distributed in a similar manner will be observed. The tracheæ, represented only in one part of the drawing on the left, are black. X 40.

Fig. 2.



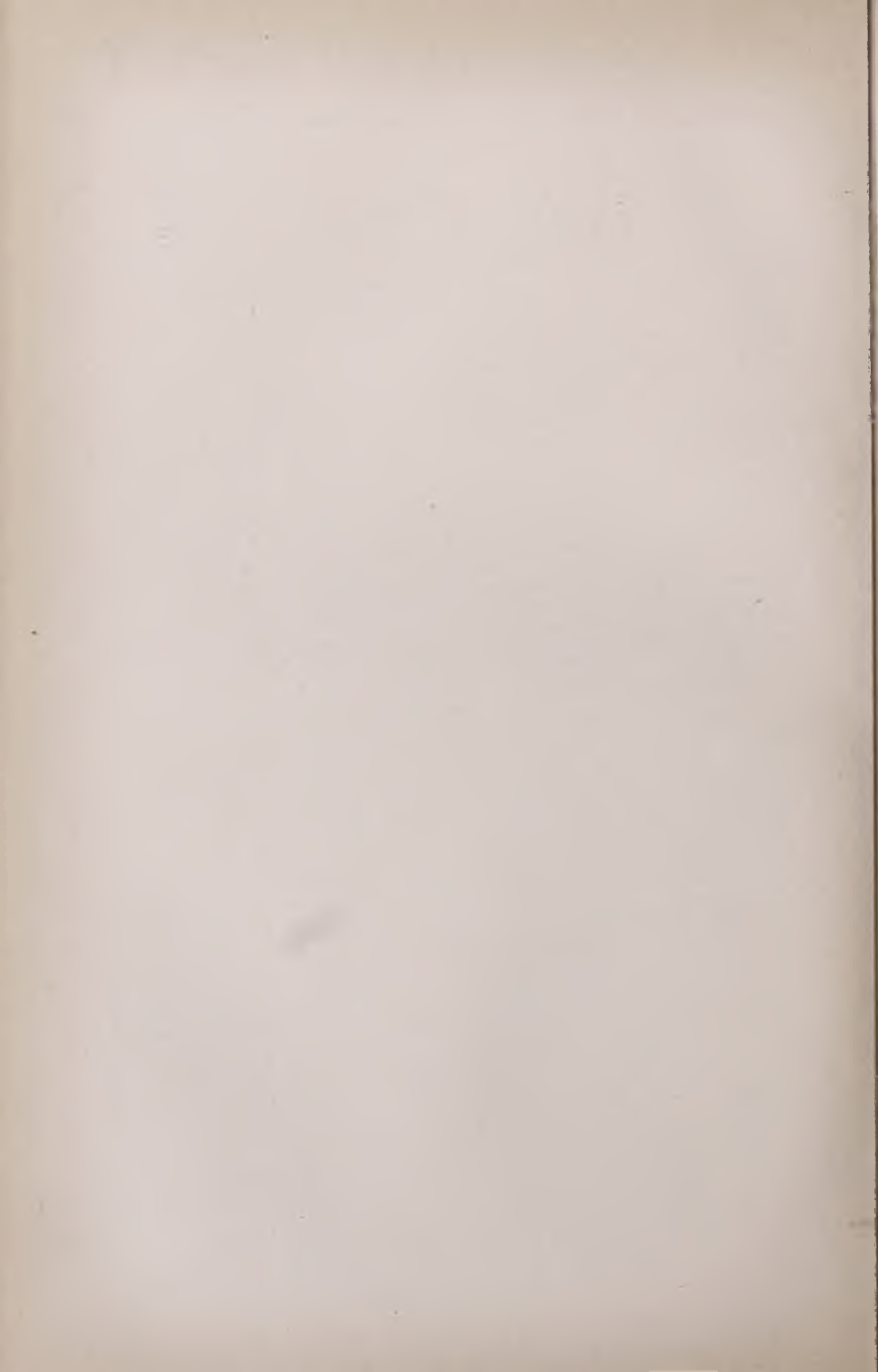
The point where the fine nerve trunk, which seems to be lost upon the surface of the sarcolemma in Fig. 1, leaves the larger trunk which crosses the muscle. Observe that the fibres of the fine branch divide into two bundles, which proceed in opposite directions in the nerve trunk. X 1100. p. 410.

Fig. 3.



Point where a fine bundle of nerve fibres becomes connected with the sarcolemma and divides into finer fibres, which ramify upon its surface. A fine trachea, *a*, is seen above and below it. This is one of the *nerven-hügel* of authors. X 700.





FINEST NERVE NETWORKS OF INSECT MUSCLE.—INVOLUNTARY MUSCLE.

Fig. 1.



Fig. 2.



Fig. 3.



Fig. 4.



The lower part of the fine fibre which seems to be lost upon the surface of the sarcolemma in Fig. 1, Plate LXXXV. The fine nerve fibres are seen to divide and subdivide forming a network or plexus upon the surface of the sarcolemma. The finest tracheæ are also seen to form a network.  $\times$  nearly 3000

Network of finest nerve fibres, showing their relation to the finest tracheæ  $\times$  1000

Fig. 5.



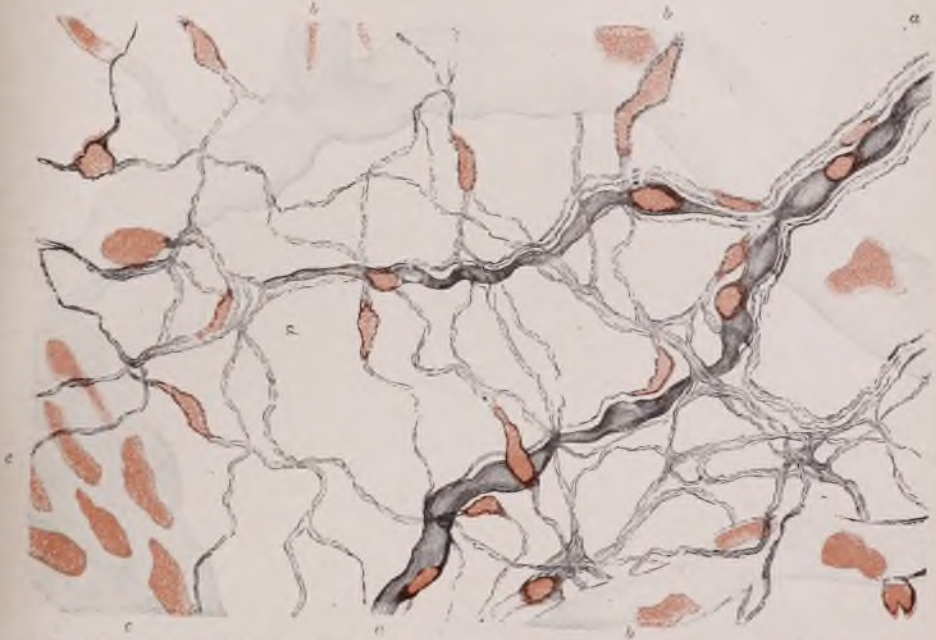
Spindle-shaped and tricaudate unstriped muscular fibre cells, with the fine nerve fibres distributed to them. Bladder of the hyla.  $\times$  900. p. 410.

[To follow plate LXXXV.]



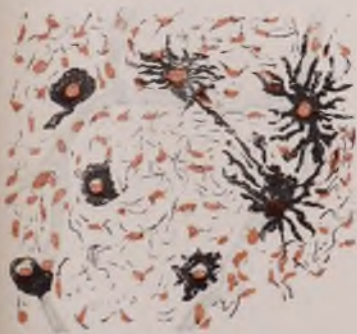
NERVE NETWORKS AND ULTIMATE DISTRIBUTION.

Fig. 1.



Nerve fibres distributed in the bladder of the liver of greenish frog. The vessels are injected with Prussian blue and the bioplasm of the nerves and vessels have been stained with carmalum. a, dark bordered nerve fibres; b, capillaries; c, a small vein. x 70.

Fig. 2.



Skin of frog, capillaries injected. On the left pigment cells with granules collected and on the right, two cells with the granules distributed. x 40.

Fig. 3.



Skin of frog just below cuticle, capillaries injected. Pigment cells with granules distributed in the intercommunicating channels. Bundles of nerve fibres are seen forming networks. The bioplasm stained. x 130.



of the muscular tissue itself. In the portion of tissue represented, the termination of the dark-bordered fibres in fine pale fibres is well seen, and the course and destination of the pale fibres running with the dark-bordered fibres should be particularly noticed, pl. LXXXVII *a, d.*

The arrangement of networks of nerve trunks in and beneath the skin of the green tree frog or hyla is well seen in fig. 3, pl. XXXVII. The ramifying pigment cells, with their anastomosing branches, are represented in the same drawing. Fig. 2 is a portion of the skin under a lower power, showing some of the pigment cells with granules aggregated, and others with the granules diffused in the fluid in the ramification of the cells.

**391. Nerve Fibres distributed to Organs of Special and General Sensation, under very High Powers.**—The ultimate arrangement of purely sensitive nerve fibres may be demonstrated in many of the terminal organs of man and vertebrate animals—such as the papillæ of the skin and mucous membrane in certain localities; but of all the special sensitive organs studied by microscopists, perhaps the large papillæ (the fungiform papillæ) of the frog's tongue is the most beautiful as well as the most convenient, not only for investigating the terminal distribution of purely sensitive nerve fibres and for demonstrating the essential structure of a highly sensitive organ, but for ascertaining the relations and connections which nerve fibres exhibiting different functions have with one another.

In the small portion of tissue constituting one of these papillæ we see *striped muscular fibres, capillary vessels, purely sensitive nerve fibres* forming an expanded terminal plexus or network at the summit of the papilla, *motor nerve fibres* distributed to the muscle, *nerve fibres around the capillary vessel*, and a few very fine nerve fibres ramifying in the connective tissue in different parts of the papilla. All these nerve fibres and plexuses are embedded in and held together by connective tissue, forming the body of the papilla, the summit of which is surmounted by a peculiar epithelium-like tissue, perhaps connected with the nerves and belonging to nerve texture, while its sides are covered with ordinary ciliated epithelium.

These papillæ have been studied by numerous observers, and, strangely enough, one of the latest writers has seen far less than many of his predecessors, probably because he has been less successful in preparing his specimens. Fig. 2, pl. LXXXVIII, is a copy of Hartmann's figure taken from pl. XVIII, "Müller's Archiv," 1863. It represents the mode of termination of the bundle of nerve fibres in the papilla according to this observer. It would probably be difficult to adduce a more striking example of the destruction of beautiful nerve textures by the process of preparation than was afforded by the specimen of which this drawing is a copy. The method of preparing the

specimen was fatal. Not only are the most interesting features of the papilla entirely lost, but the large dark-bordered nerve fibres are disarranged, and the most important part of them completely destroyed or rendered invisible. It is strange that any one should regard the appearances represented in the drawing as natural, or permit himself to conclude that the nerve ended so abruptly. No fine nerve fibres whatever could be seen, nor is a trace of the nuclei which are connected with these, and which exist in great numbers, left. It would, of course, be useless to examine such a specimen with high powers, for nothing further could be discovered than can be detected with low ones. As the same objectionable methods of inquiry are still advocated, it is not wonderful that those who adopt them have been led to the conclusion that high powers are useless, that appearances observed in specimens prepared according to other methods are fallacious, and that the observations of those who by adopting other plans of inquiry demonstrate new facts, are untrustworthy, and products of the author's imagination. It is not very likely that the author of such a drawing as fig. 2 will place any confidence in an observer who ventures to represent the things delineated in figs. 1, 4, pl. LXXXVIII, and the four figures in pl. LXXXIX, as accurate copies of nature. He concludes the latter has simply appealed to his imagination. This is the only way to defend his own position; and so many people are in these days ready to believe that an observer who professes to have seen what has not been seen before is but a fanciful speculator, and not an observer at all, that prejudice is easily excited against him, and erroneous views are received as true, and correct observations condemned or discarded.

It is quite certain that the most delicate constituent nerve fibres of the plexus in the summit of the papillæ of the frog's tongue (New Observations upon the Minute Anatomy of the Papillæ of the Frog's Tongue, "Phil. Trans." for 1864) can be readily traced by the aid of a twenty-fifth or fiftieth, if the specimen be prepared according to the directions given in p. 366. The *finest* nerve fibres thus rendered visible are indeed so thin and faint, that in a drawing they would be represented by fine single lines. Near the summit of the papilla there is a still more intricate interlacement of nerve fibres, which although scarcely brought out by the twenty-fifth, fig. 2, pl. LXXXIX, is very clearly demonstrated by a fiftieth. In this object the definition of the fibres, as they ramify in various planes one behind another, and interlace almost like basket-work, is remarkable, fig. 1, pl. LXXXIX. Moreover, the flat appearance of the specimen as seen by the twenty-fifth, gives place to one of considerable depth of tissue and perspective. So that a more correct view of the structure of these papillæ is obtained by examining them with a fiftieth of an inch than with a twenty-fifth, and even this investigation leaves many points unsettled, and which are

Fig. 1.



Compound and simple papillae of tongue of the hyla. *a.* epithelium-like mass at summit of papilla. *b.* ciliated epithelium at the sides of the papilla. *c.* ciliated epithelium covering summit of papilla. *d.* summits of two simple papillae, with nuclei connected with the nerves projecting from them. *e.* fine nerve fibres with their nuclei in the connective tissue. *f.* fine nerve fibres which may be traced to the nerve trunk. *g.* A muscular fibre freely branching. *i.* capillary, with its nerve fibres. X 210.

Fig. 2.



Drawing of the summit of one of the same papillae as represented in Fig. 1. After Hartmann, showing the supposed termination of the nerves. See p. 111.

Fig. 3.



Diagram to show the supposed arrangement of the nerves on the summit of the papilla in Fig. 1.

Fig. 4.



Muscular fibres at the summit of the papilla, showing the relation of the bioclasm to the contractile tissue, and the mode of formation of the latter by the masses of bioclasm. *a.* nucleus forming papilla. *b.* another nucleus connected with muscular tissue. *c.* nucleus of fine nerve fibre distributed to the muscle near the summit of the papilla. *d.* fine nerve fibre. X 1800.

Fig. 5.



The author's view of the arrangement of the ultimate nerve fibres.





NERVE NETWORKS.—BRANCHES OF NERVE FIBRES AND NERVE TRUNKS.

Fig. 1.

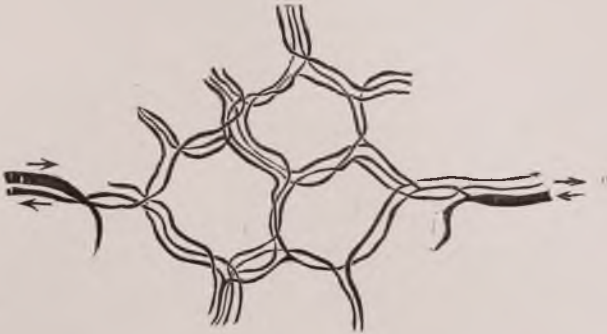


Diagram to explain the author's view of the arrangement of the finest nerve fibres composing the 'networks' *a a*, dark-bordered and fine nerve trunks.

Fig. 2.



Central and peripheral portion of a nervous apparatus showing sub-division of dark-bordered fibre at centre, *a*, and periphery, *b*.

Fig. 3.



Diagram to show possible relation of fibres from caudate nerve cells of the spinal cord, and fibres from cells in ganglia, as, for example, the ganglia on the posterior roots. *a* is supposed to be the periphery; the cell above *b* one of those in the ganglion. The three caudate cells resemble those in the grey matter of the cord, medulla oblongata, and brain.

Fig. 4.



Diagram of three papillae from the frog's tongue, to show the arrangement of the nerve fibres. Each papilla is connected with its neighbours by commissural fibres, as well as with the nervous centre.

Fig. 5.



Diagram to show course of nerve fibres in branch trunks.



worthy of more extended investigation. A small portion of this wonderful plexus is represented in fig. 3, under a magnifying power of 6,000 diameters, obtained by considerably lengthening the tube of the microscope when the specimen was under the one twenty-sixth.

The fine fibres resulting from the subdivision of the dark-bordered fibres soon divide into numerous branches, which form a highly complex plexus, the subdivisions of which are connected here and there with numerous nuclei, as represented in the upper part of the papilla, fig. 1, pl. LXXXVIII. It is impossible to follow these, but in figs. 3, 5, are diagrams representing the probable arrangement. Each papilla seems to be connected with the nerve centre by special fibres and with neighbouring papillæ by commissural fibres, fig. 4, pl. XC, p. 412. This arrangement, familiar to anatomists in the optic commissure, exists here and in all other nerve organs. The general arrangement of the vessels, muscular fibres, and other tissues, will be understood if the drawings in pl. LXXXVIII be carefully studied.

The finest ramifications of the nerve fibres in the corneal tissue are represented in pl. XCI, under a magnifying power of 1,800 diameters. The finest threads are seen running amongst the fibrous bundles of the corneal tissue between the ramifications of the branching and anastomosing channels connected with the corneal corpuscles. The preparation is unusually fortunate, and consists of a very thin and even section of corneal tissue, which has not been at all deranged in the process of preparation, cut parallel with and a little below the surface. The finest fibres are not the 1-50,000th of an inch in diameter, and they form networks amongst the fibres of the proper corneal tissue. In this specimen from the hyla they are certainly not connected with the corneal corpuscles or their ramifications. There is no reason to suppose they exert any direct influence either upon the corpuscles, their ramifications, their contents, or upon the proper tissue of the cornea. It is much more probable that these nerve fibres are afferent fibres, and influence the nerve centres from which the nerve fibres distributed to the small arteries near the margin of the cornea are derived. Indirectly, no doubt, these fibres are concerned in regulating the quantity of fluid in the canalicular network, and diffused through the proper tissue of the cornea.

A drawing of a beautiful section through the tissues near the tip of the nose of the mole is seen in fig. 1, pl. XCII. The vessels were injected with Prussian blue fluid, and the bioplasm of all the tissues carefully stained with carmine. Very thin sections were made and mounted in strong glycerine. Some of the best sections were further divided and rendered thinner by pressure and subsequent soaking in strong glycerine, as described in p. 368, when they could be examined with the highest powers, and the finest ramifications of the nerve fibres traced in some situations. The large hair sacs which lodge the short

but firm tactile hairs, seen in the drawing, are remarkable structures. Each is composed of a bag of firm, stiff, tissue like fibro-cartilage. This is perforated on one side at the lower part, and through the opening pass vessels, and a large bundle of fine dark-bordered nerve fibres. The vessels break up to form a capillary network around the bulb of the hair as seen in the drawing; sometimes, however, vessels also enter the sac at its lowest part. The bundle of nerve fibres spreads out in a brush-like manner as soon as it reaches the interior of the sac—the fibres passing in a direction upwards as they spread around the hair, and many divide so that the number of fibres greatly increases towards the central part of the sac. Further division and subdivision take place until an abundant plexus of exceedingly fine nerve fibres results. Connected with this plexus are numerous masses of bioplasm, so that in some situations what may be described as a soft pad or cushion results, and the fibres of this nerve cushion placed parallel with the hair must necessarily be affected by the slightest movements communicated to its tip. The fine ramifications of nerve fibres extend upwards to the narrowest part of the sac, whence in some instances a bundle of fine nerve fibres is seen to pass out and ramify with the nerves, forming a network just beneath the skin. I have made sections of the fine nerve expansion within the sac in various directions, and have demonstrated networks of extremely fine fibres with numerous bioplasts connected with them, but I have never seen any appearance which would lead me to suppose that the fibres formed free ends, or became connected with the tissue of which the hair itself is composed. The arrangement of the vessels is so clearly shown in the drawing, that further description is not needed.

The general arrangement of nerve fibres near their distribution is well seen in figs. 2 and 3, pl. XCII, from the bat's wing. These drawings illustrate the arrangement of the fine nerve fibres in mammalia generally, but from the smaller animals only can satisfactory specimens be obtained. There is no tissue in which such distinct demonstration of the ultimate distribution of fine nerve fibres and their relation to other tissues can be so readily obtained as in the bat's wing. Not only is the tissue in certain parts of the wing far thinner than can be obtained artificially, but upon the two surfaces of the fibrous membrane where the epithelial layers have been stripped off, extensive networks of nerve fibres can be discerned undisturbed by manipulation and lying upon one plane, whereas in sections of tissue, however dexterously prepared, so many nerve fibres are cut across, that it is not possible to follow any of them for even a short distance, or to demonstrate their exact arrangement, and their precise relation to the tissues amongst which they ramify cannot be defined. The student should particularly notice the dichotomous division of the dark-bordered fibres in figs. 2 and 3. These

FINEST NERVE FIBRES.—CORNEA OF THE HYLA.



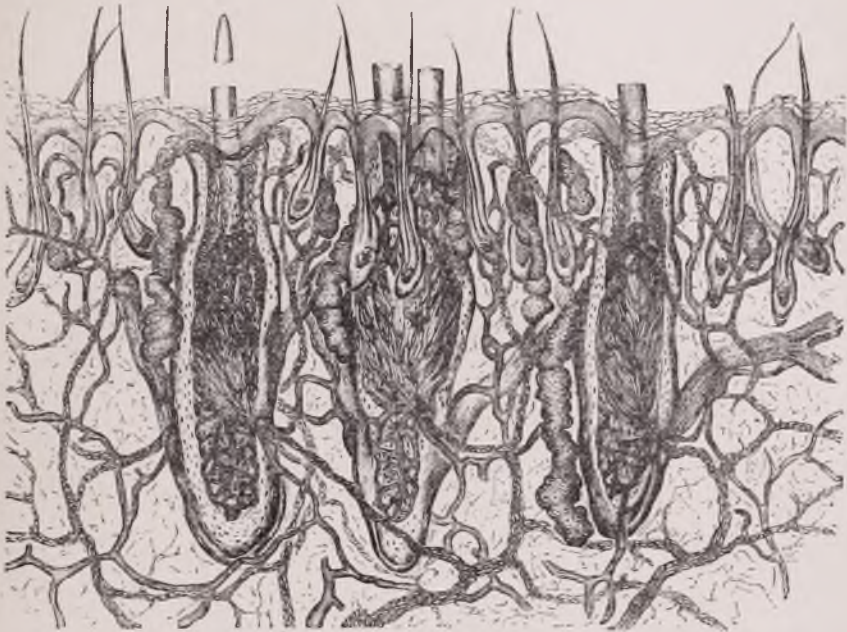
A very thin section parallel to the surface of the cornea of the Hyla or Green tree frog, showing connective tissue-capsules, and their communicating channels, and the distribution of the finest nerve fibres. A trunk of very fine nerve fibres from which numerous very fine nerve fibres may be traced running amongst the fibres of the corneal tissue in the intervals between the branching communicating channels, which run in every part of the corneal tissue. The specimen is magnified 1800 diameters. p 413

L.S.B., 1882



NERVE FIBRES.—MOLE'S NOSE AND BAT'S WING.

FIG. 1.



Tactile hairs and hair follicles. Perpendicular section from the mole's nose. The ordinary hairs with their follicles and the sebaceous glands. The vessels are also represented. A bundle of nerve fibres enters each sac at the lower part, but above the deepest portion of the hair bulb. Having entered the sac, these fibres freely divide and sub-divide, forming a soft dense nerve plexus around the hair. X 20. p 413.

Fig. 2.



Capillary vessels with very fine nerve fibres distributed to them. In the part of the nerve trunk represented, are seen some of the finest dark bordered nerve fibres less than the  $\frac{1}{1000}$  of an inch in diameter. From the bat's wing. X 700. p 414.

Fig. 3.



Portion of a bundle of fine nerve fibres from the bat's wing. Observe the division of the finest dark bordered nerve fibre in the Fig. and in Fig 2. X 700. p 414.





ULTIMATE NERVE FIBRES IN MUCOUS MEMBRANE.

Fig. 1.



Nerves and capillaries of mucous membrane of human epiglottis x 215. p. 415.

Fig. 2.



Mucous membrane of the human epiglottis just beneath the epithelium. A small portion of Fig. 1, but x 1700. The bioplasts connected with the finest nerve fibres and the manner in which the latter ramify are well seen. No true terminations or 'ends' are to be found. p. 415

[To follow plate XCII.]



divisions are very numerous, and occur at short intervals in all nerves as they approach their ultimate distribution, pl. XXXVI, p. 150, fig. 1. To such an extent do nerve fibres divide and subdivide, that in a short course from one fibre more than one hundred may result by division.

The distribution of nerves to capillary vessels is very easily shown in many vertebrate animals. The important fact that capillaries are supplied with nerve fibres was first demonstrated by myself in the frog, figs. 5, 6, pl. XXXV, p. 148. See my memoir "On the Structure and Formation of the so-called Apolar, Unipolar, and Bipolar Nerve Cells of the Frog." "Phil. Trans.," May, 1863. In fig. 2 the observer will see very fine nerve fibres distributed to the part of the capillary represented in the drawing. The arrangement is constant in all vertebrata, and I have endeavoured to show the office of these nerve fibres, and the part they play in regulating the flow of blood to the capillaries. See "Bioplasm," page 320.

The arrangement of the ultimate nerve fibres upon a highly sensitive surface in the human subject is represented in pl. XCIII. The drawings are taken from the mucous membrane covering the epiglottis, and give the appearances seen just beneath the epithelium. In fig. 1 the network of capillary vessels is shown, and many of the fine bundles of nerve fibres distributed to the mucous membrane are to be seen in the interspaces. These are represented as they appear under a magnifying power of 215 diameters. A very small part of this figure is shown in fig. 2, under the 1-26th of an inch object-glass, magnifying 1,800 diameters. The ultimate nerve fibres are seen in immense numbers, and here and there may be observed the oval bioplasts connected with them. The appearances represented are very distinct in very thin specimens, from which the epithelium has been very carefully detached before the preparation is covered with thin glass. Excessively thin sections, just including the surface of the membrane with its epithelium, are to be removed from the tissue after it has been hardened by prolonged soaking in glycerine and chromic acid, and bichromate of potash, p. 365.

OF THE STRUCTURE OF CELLS OR ELEMENTARY PARTS OF NERVE  
CENTRES UNDER HIGH POWERS.

**392. Of Spherical and Oval Nerve Cells.**—In the ganglia connected with the sympathetic nerves of the abdominal and thoracic cavities, in those on the posterior roots of the nerves, in the ganglia connected with the nerves of the heart and of many of the vessels of the head, neck, and trunk, of the frog—spherical, oval, and sometimes angular nerve cells exist, which contrast remarkably in their structure with the caudate cells referred to in the next section. Although from some of these cells fibres had been traced, until recently the opinion had been very generally entertained that the cells in question had but one fibre connected with each of them. Kölliker and others maintained that

some of the cells were *entirely destitute of nerve fibres*—that in short, *apolar, unipolar, and multipolar* nerve cells existed in the nervous system. It is, however, obvious that if the views advanced by me concerning the fundamental arrangement of a nervous apparatus are correct, *all nerve cells must have at least two fibres proceeding from them—must be bipolar, and therefore that neither apolar nor unipolar nerve cells anywhere exist.* Doubt was cast upon the correctness of the observation concerning apolar and unipolar nerve cells, and it was therefore necessary to re-investigate this matter with great care.

My observations were published in the "Phil. Trans." for May 7, 1863, and rendered the existence of apolar and unipolar cells so very doubtful, that some of those who had described them have since given up the notion, though they by no means assent to the general propositions which have been established by my investigations. I was able to show that what appeared to be a single fibre proceeding from a cell, really consisted of two fibres which soon diverged from one another, and *proceeded in opposite directions* towards their destination—a fact greatly in favour of the general views of the typical structure and arrangement of a nervous apparatus which I had been led to adopt from other observations. The fibres could be readily traced to the body of the nerve cell, where the straight fibre was seen to be continuous with the central portion, while the spiral fibre passed into the matter forming the circumferential portion of the nerve cell. By carefully studying the development of these nerve cells many points of great interest and importance, both as regards the structure and action of nerve centres, were ascertained. The reader may refer to the figs. in pls. XCIV and XCV, which have been taken from the original memoir. Amongst the fully formed cells are observed here and there some which are undergoing the process of development. Such embryonic cells are seen in the ganglia of full-grown as well as in those of young frogs. They are to be found at all ages and are being constantly produced at all times during the life of the animal, particularly during the spring, when the nervous system becomes renovated and is about to attain the highest state of functional activity it enjoys during the year. Observation has shown that a similar process of development and formation of new cells goes on in the sympathetic ganglia of man and the higher animals as well as in those on the posterior roots of the spinal nerves. *See my paper on Apolar, Unipolar, and Bipolar Nerve Cells, &c., "Phil. Trans.," 1863.* The facts above alluded to and some others lead me to think that formed material produced by the bioplasm of cells of this class is the very matter in which nerve-currents originate, chemical change in the formed material of the cell being associated with the setting free of the current.

In my work on Bioplasm (page 209 *et seq.*) I have adduced several facts and arguments which seem to me to render it very probable that

Fig. 1.



Very young ganglion cell Hyla. x 700.

Fig. 4.



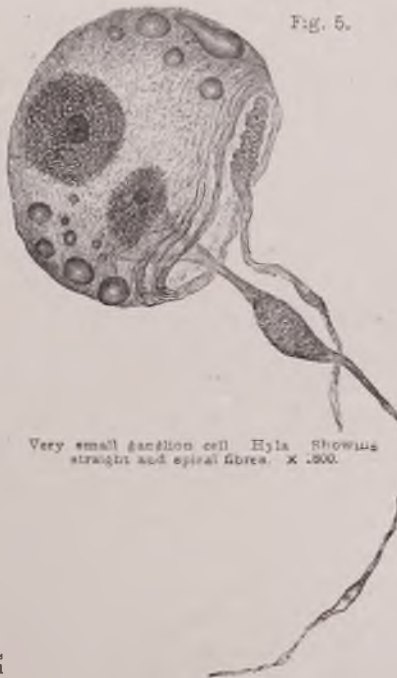
The lower part of a ganglion cell, with the nerve fibres running into it. The spiral fibre divides at the lower part of the figure into one dark bordered fibre and two fine fibres. Observe the nuclei in connection with the nerve fibres near their origin from the cell. x 1800.

Fig. 2.



Fully formed ganglion cell, with very distinct spiral fibre. Common size. x 700.

Fig. 5.



Very small ganglion cell Hyla showing straight and spiral fibres. x 1500.

Fig. 3.



Ganglion cell from the same ganglion as Fig. 1. x 700.

Fig. 6.



Fully formed ganglion cell from the same ganglion as Figs. 1 and 2. The arrangement and connections of the spiral fibre, with numerous nuclei, are very distinct. Observe the oil globules in the upper part of the cells. x 700.

100th of an inch | \_\_\_\_\_ | x 700.

100th of an inch | \_\_\_\_\_ | x 1500.

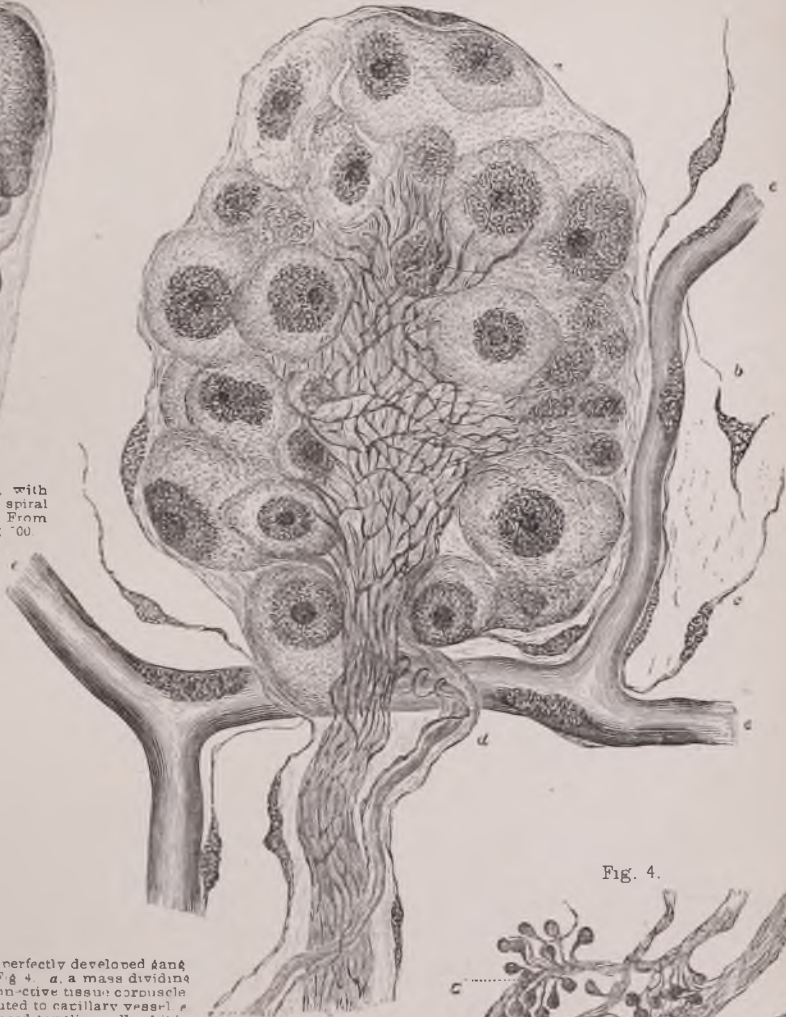


Fig. 1.



Ganglion cell, with straight and spiral nerve fibres. From the frog.  $\times 100$ .

Fig. 2.



The mass of imperfectly developed ganglion cells at *b*, Fig. 4. *a*, a mass dividing into two. *b*, connective tissue corpuscle. *c*, nerve distributed to capillary vessel. *d*, a more advanced ganglion cell exhibiting straight and spiral fibres; its straight fibre is much thicker than any in the bundle of fine fibres passing into the body of the ganglion.  $\times 1800$ . p. 416.

Fig. 3.



The ganglion cell marked *a* in Fig. 4.  $\times 700$  diameters. The mass is undergoing division, and from it a number of separate cells like the groups in Fig. 4 would result.

1000th of an inch | \_\_\_\_\_ |  $\times 1800$ .

Fig. 4.



Nerve trunks and ganglia, near the iliac artery. Frog.  $\times 40$ .





nerve force is, as was long ago supposed, really electricity set free in the course of chemical changes occurring in the formed material of spherical and oval nerve-cells. But it cannot be argued that if this be so, the conclusion affords support to any one of the many physical theories of life hitherto propounded. It is obvious that the special action of the nerve-current is dependent upon the arrangement of the fibres which transmit it, and the structure and properties of the organs upon which it exerts an influence. These things are determined, not by chemical or mechanical actions, but they are the direct consequence of phenomena occurring in the bioplasm, by and out of which all structures are formed, which phenomena in their nature are far away from the physical category.

The actual nerve-current is due to changes in the matter of which the outer part of the formed material of the cell is composed. Fatty matter is set free, and other chemical changes occur in the formed matter, which result in the development of a current, which traverses the continuous threads or fibres connected with the cell, just as the current of the voltaic battery traverses the circle of copper wire which is connected with the metallic elements of which it is made, and one of which undergoes active chemical change. The change in the matter of these cells occurs probably in a regular manner, but no doubt the accumulation and the tension attained by the current vary greatly and are influenced by the activity of the processes of nutrition and oxidation and other circumstances, and by the arrangements existing for the accumulation and discharge of the electricity.

**393. Caudate Nerve-Cells under very high Powers.**—The angular cells of the brain, medulla oblongata, spinal cord, retina, choroid, and found elsewhere, should, I think, be regarded rather as stations at which several currents taking many different courses intersect—where fibres for the conduct of nerve-currents decussate—rather than as organs in which currents are actually developed and set free. The seat of origin of the nerve-current, I believe, is in the spherical and oval nerve-cells already mentioned. Further, it is possible that in the angular cells secondary or induced currents may be excited in strands moving parallel with or encircling those which transmit the primary current.

The caudate nerve-cells of the spinal cord and brain have long been objects of attentive study. They are without doubt intimately concerned in the production of the highest nerve phenomena of man and animals. The structure of these cells is very peculiar. Certain granules, lines, and inequalities in their substance, particularly upon the surface, have long been familiar to observers; but in 1864 I found some cells in which the arrangement of lines at different depths, in the substance of which the cell was composed was very distinct. These lines could be traced, as is well represented in the figure in pl. XCVII, and shown diagram-

matically in fig. 1, pl. XCVI. They clearly passed from each of the fibres across the cell into every other fibre proceeding from it. I could not but conclude that these lines marked the paths taken by the several separate nerve-currents, passing in different directions, which traversed the cell. The fibres proceeding from the cell consist of the same material as that of which the cell itself is composed, and are, as it were, drawn off from it. The matter is not protoplasm, as has been so often affirmed, but consists of formed material. Although it is true that in many cases the fibres can be stained by carmine by prolonged soaking, they are not stained under the same conditions as the bioplasts, while the latter can always be deeply tinted in specimens in which the fibres are not coloured at all. It is quite certain that nerve phenomena are not due to continuity of the bioplasm of the nerve-cell through all the fibres which are connected with it, as has been supposed by some, nor even to continuity of a fluid or semi-fluid substance having mobile particles, as maintained by others. It seems to me that the older nerves should be considered as threads consisting of a material not widely different from fibrous tissue laid down or drawn out in a longitudinal direction, as during development and growth the so-called cells of different parts of the nervous system become more widely separated from one another.

Fine fibres resulting from subdivisions of the larger fibres leaving the cell, unite together to form single fibres, as represented in pl. XCVI, fig. 2. Thus is formed a dark-bordered nerve-fibre, *b, b, b*. Every one of these fibres again divides and subdivides as it approaches its peripheral distribution. The manner in which this occurs will be understood if figs. 2, 3, 4, pl. XCVI, and figs. 1, 2, 3, pl. XC, be attentively examined.

I do not think that the numerous caudate nerve-cells in the cortical portion of the cerebral convolutions are, as they have been regarded by many, sources of mental action, any more than the angular cells in other situations are the seat of origin of nerve-force. In these cells of the cerebral convolutions currents from different parts change their course, some fibres from a distance are caused to converge, while others diverge in different directions. The general arrangement of these cells is represented in figs. 3, 4, and 5, in pl. XCVIII, p. 428. See also p. 427.

The conclusions resulting from such investigations as those referred to in the last few sections cannot fail to impress all concerning the wonderful character of the apparatus required for the development of the very simplest nerve phenomena. They indicate that the effects produced should be attributed rather to the mechanism through which force works than to any mysterious or peculiar properties or powers of the force itself. It seems to me more reasonable, and more in accordance with known facts, to regard every form of nerve-force as electricity than to maintain, contrary to facts, that some day and somehow it will be discovered to



Fig. 1.

A diagram of such a cell as that represented in Plate XCVI showing the principal lines which diverge from the fibres at the point where they become continuous with the substance of the cell. These lines may be traced from any ONE FIBRE across the CELL, and one or more of them may be followed into EVERY OTHER FIBRE which proceeds from the cell.



Fig. 2.

Diagram to show the course of the fibres which leave the caudate nerve cells. *a a* are parts of two nerve cells, and two entire cells are also represented. Fibres from several different cells unite to form single nerve fibres *b b b*. In passing towards the periphery these compound fibres divide and sub-divide, the resulting sub-divisions passing to different destinations. The fine fibres resulting from the sub-division of one of the caudate processes of a nerve cell may help to form a vast number of dark bordered nerves, but it is, I think, certain that NO SINGLE PROCESS EVER FORMS ONE ENTIRE AXIS CYLINDER.



Fig. 3.

Diagram to show the possible relation to one another of various circuits traversing a single caudate nerve cell. *a* may be a circuit connecting a peripheral sensitive surface with the cell; *b* may be the path of a motor impulse; *c* and *d* other circuits passing to other cells or other peripheral parts. A current passing along the lines *a* might induce currents in the three other fibres *b c d* which traverse the same cell.

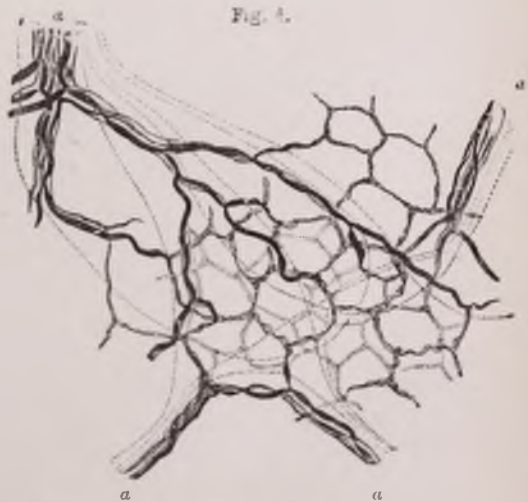


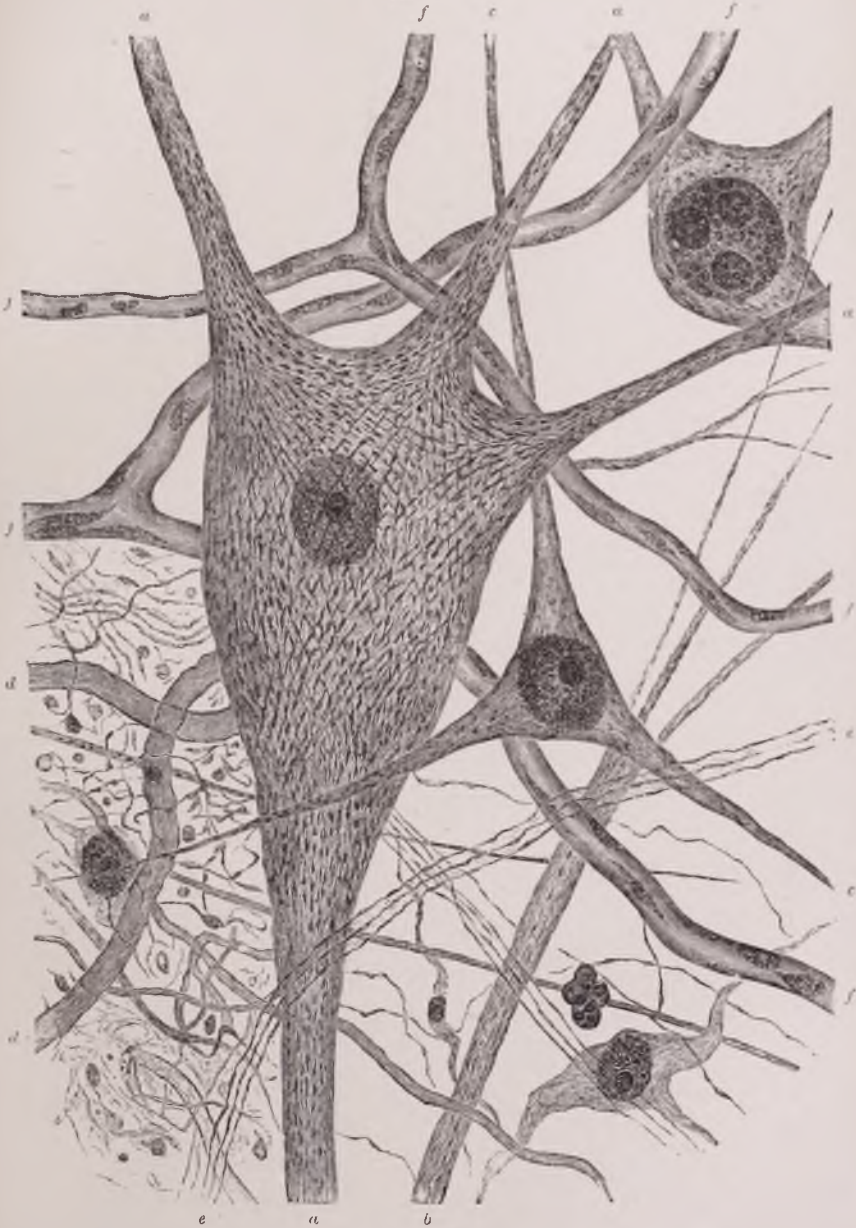
Fig. 4.

Drawn to show the manner in which plexuses or networks of fine nerve fibres are formed. The course of the numerous nerve currents to and from the trunks is indicated by the dotted lines *a a a*. *a a a*. a dark bordered nerve fibres.



COURSE OF NERVE CURRENTS ACROSS CAUDATE NERVE CELLS.

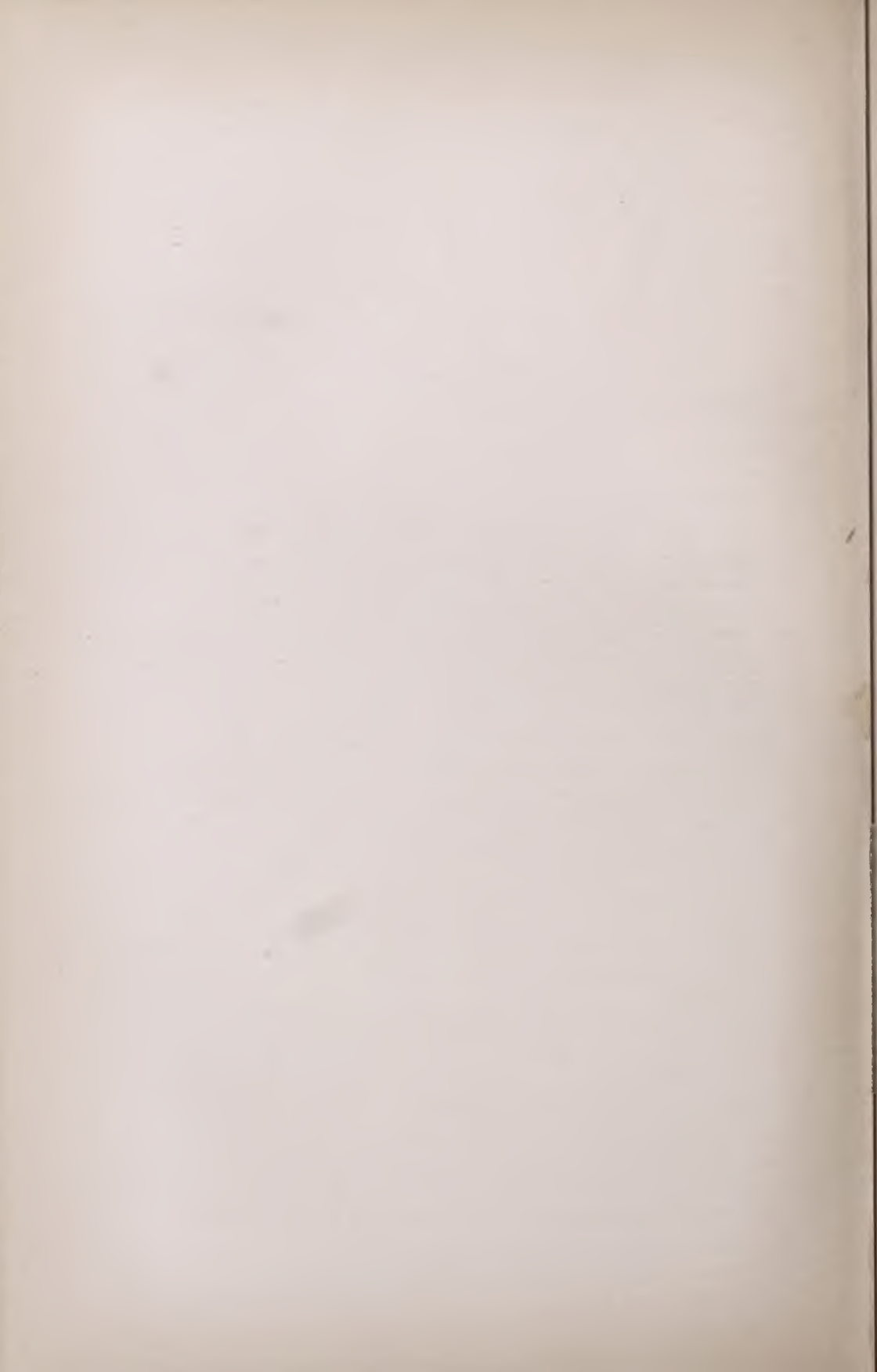
Fig. 1.



Large caudate nerve cell, with smaller cells and nerve fibres, from a thin transverse section of the lower part of the grey matter of the medulla oblongata of a young dog. The lines of dark granules resulting from the chemical action of acetic acid are seen passing through the very substance of the cell in very definite directions. Thus the cell is the point where lines from several distant parts intersect (Diagram, Fig. 1, Plate xcvi). It is probable that each of these lines is but a portion of a complete circuit (see Fig. 3, Plate xcvi). *a a a*, large fibres which leave the cell. *b* a fibre from another cell, dividing into finer fibres, exhibiting several lines of granules. *c c c*, fibres from a younger caudate nerve vesicle. *d*, fine and flattened dark bordered fibres. *e*, three fine nerve fibres running together in a matrix of connective tissue. *f f f*, capillary vessels.

Scale,  $\frac{1}{100}$  of an English Inch | \_\_\_\_\_ |  $\times 700$ .

[To follow plate XCVI.]



be some mysterious unknown correlative of ordinary force, of the nature of which no one knows anything, but concerning which it is supposed something or other has been discerned, or is about to be discerned, by some imagination. But if it is admitted that nerve-force is ordinary electricity, the problem of nerve-action is by no means solved; for it is obvious that the phenomena are due entirely to the peculiar arrangement of the nerve-cells and fibres which constitute each particular nerve mechanism for setting free and conducting the currents. It is not possible to conceive nerve phenomena without a special apparatus of very peculiar structure, and the nature of nerve-action is intimately connected with the structure and arrangement of this apparatus. The action even of a machine cannot be dissociated from its construction. Now the construction of the nerve apparatus and its maintenance in a state fit for action are due to vital power. The lowest, simplest, and least varied kinds of nervous action, like all other actions in connection with the living elementary parts of living beings of which anything is known, are intimately connected with *vital* changes in the bioplasm, and cannot therefore be said to be due to physical and chemical laws only. The contrary is affirmed by noted physicists, some of whom are not only quite ignorant of the minute structure and arrangement of nerve-organs, but coolly condemn the use of the only instrument by the aid of which any one can gain any knowledge concerning structural arrangement.

**394. On the Nature of Mind and on the Structure of the Highest Forms of Nerve Elementary Parts or Cells which are concerned in Mental Nervous Actions.**—When we ascend to the consideration of the higher and more complex nervous actions, we find reason for concluding that the vital actions perform a still more important part. In the brain of man we have probably the only example of a mechanism (?) possessing within itself not only the means of repair,\* but the capacity for improvement and the power of increasing the perfection of its machinery (?), not only up to the time when the body arrives at maturity, but long after this, and even in advanced life, when many of the lower tissues have undergone serious deterioration, and have long passed the period of their highest functional activity.

This wonderful and peculiar power of the nerve bioplasm connected with mental operations in man contrasts remarkably with the feeble capacity of renovation and improvement exhibited by that of man's tissues generally. While the bioplasm of many important tissues of the body of some of the lower animals, can reproduce complex textures, and even entire limbs. In all cases, however, the phenomenon is due not to structural peculiarities, but to the endow-

\* The mechanism which possesses within itself the means of repair has not yet been actually constructed, but it has been "discerned" by materialists.



ments of the bioplasm or living matter concerned—to purely *vital* powers, not to peculiarities of structure or composition.

The idea that action is in all cases determined by structure, and that matter with the most remarkable and complex endowments must be characterised by a peculiarly elaborate structure, though it cannot be discerned, has always been entertained, and still lingers among the many fundamental errors of the most popular, as well as the most reckless, speculators of the materialist school. Though in these days the fact of the utter structurelessness of the matter from which all living beings are evolved is pretty widely known and generally admitted, few seem able to divest themselves of the nonsensical supposition of mechanism and structure being somehow hidden in the structureless. It has been proved over and over again that under the highest powers the matter of the lowest forms of bioplasm with formative power, capable only of evolving the lowest, simplest form of tissue, fig. 1, pl. XCVIII, p. 428, cannot be distinguished from that of the highest form, fig. 2, from which the highest structures of the brain and the organ of the mind itself are to be developed. Nevertheless the most degrading mechanical dogmas ever evolved by materialist imagination have been recently revived as regards the nature and action of mind, and are freely taught to people who are unable to examine and criticise either the so-called facts, or the faulty and, in some instances, utterly groundless statements upon which the dogmas are supposed to be based.

It is, perhaps, not surprising that speculations concerning the nature of thought and life advanced by physicists whose methods have been restricted to those applicable to non-living matter, should always tend towards the conclusion that the living is but a form or mode of the non-living, and that exclusively physical principles must be held sufficient to explain *mental* as well as all vital phenomena, and that not only life but *mind* ought to be regarded as a mode of motion. Nor is it to be wondered at, that those who have prosecuted investigation by the aid of instruments for physical research, and according to the principles laid down by physicists for investigating the nature and properties of non-living matter, should have greater confidence in their own familiar methods than in any other means of exploring nature, and no one will feel astonished that among such are enthusiasts who believe in nothing but matter and its forces, and maintain that the only properties in existence are material in their essential nature. But it is surely very remarkable that a number of educated persons should have accepted the dicta advanced on these matters from the physical side, by over-confident and most positive physicists, as the final and absolute truth; while it is still more remarkable that the condemnation of microscopical enquiry by those, who, knowing nothing of microscope work, and forming the highest estimate of their own method, reject the observations and

opinions of observers who have steadily prosecuted investigations concerning the structure and action of living beings by means of the only instrument by which they can be studied, should have been acquiesced in and even encouraged, not by individuals only, but by bodies, whose duty it is to see that the exponents of conflicting views on great scientific questions, are treated with fairness and impartiality, and not to favour, and promote the spread of one set of doctrines to the exclusion of others which will turn out to be very near the truth.

To most of my readers the connection between philosophical questions and minute microscopical investigations will appear very remote, and I shall, no doubt, be rebuked for many observations I have thought it advisable to make in this work. Certain philosophers have, however, not only clearly seen the connection between minute investigation and philosophy, but have used facts ascertained by microscopical observation. And while the instrument, by the help of which the facts were discovered, has been condemned, some even speak reproachfully or scornfully of the possessors of the eyes and understanding, by the aid of which the work is done, and try to make people believe that they can extract all the facts required from physics, and their own imaginations. Among the least philosophical of the population is the modern preacher of material dogma, which seems to be his idea of philosophy.

Brain, the highest organ in nature, and one of the most complex of structures, is formed from matter which is *structureless*, and which cannot, by any known methods of physical examination, be distinguished from that which is to form the lowest and most simple forms of organic tissue. In spite of all that has been distinctly affirmed or obscurely intimated to the contrary, it is quite certain that every kind of living matter in nature is devoid of any characters which can be properly called structural, and that it is absolutely separated and distinct in kind from every form of non-living material. Nor is there any evidence of a material gradation from non-living matter to matter that is alive, and again from this, the lowest, to the highest living. Between different forms of the living, it may be right to assume a sort of gradation as regards *power*—the capacity for forming or producing. But such gradation, if admitted, cannot be due to any material properties of the particles, or to the chemical composition of the matter itself. The only thing that is certain is the existence of difference in power. The difference may be gradational, and the several differences in life-action in various creatures may be gradationally related to one another, but all this has yet to be proved. In the case of any particular organ or system of textures, in which an advance in complexity of structure, and as regards performance of function, can, it is thought, be traced from the lower to the higher vertebrata, as, for example, the gradation which, in the case of the nervous system, is held to establish a connection between low and

high forms, must, if it exists, be due to difference in power existing in relation with the living matter, by and out of which both the low and simple and the higher and more complex nervous systems have been respectively formed. No indication of such gradation in complexity of material constitution such as is seen in many of the series of chemical substances, can be shown to exist anywhere in things living. Indeed, from a chemical point of view, the substance of an amoeba is as exalted as that of the bioplasm of the brain-cell which took part in the conception of Hamlet or Paradise Lost.

Every man ought to be interested in learning in what particulars the phenomena occurring in his own body and in other living things resemble and differ from the phenomena of non-living matter. He who thinks at all must long to know whether the facts now known favour the conclusion that he is really distinct from the non-living and inorganic which surrounds him in overwhelming proportion, and out of which he knows that the body he lives in has been made, or whether, as is now so generally asserted, the doctrine must be accepted that transitional and changing forms of living beings establish a gradational and uninterrupted continuity between the lowest organic forms and the most highly endowed living matter, which gives to man his indisputable pre-eminence.

Men are told, and, in the most confident language, that all their actions, muscular, nervous, mental, are merely mechanical, and also that living is an attribute of all matter. The dogma that all nature is mechanical is in favour at this time, as well as the dogma that all matter lives. Both assertions are equally untenable, and the enthusiastic advocates of both propositions judiciously decline to define the meaning they attach to the phrases they employ. Using terms which may comprise opposites, contradictories, and incompatibles, they hope to escape being convicted of talking nonsense by ingeniously qualifying the words now with one adjective now with another, so as to entirely change the signification perhaps several times in the course of a short dissertation. But careful readers will hardly fail to detect the fallacy. It is easy to see that, for example, the word mechanical, as applied to a living thing, means something totally different from what is implied by the same word when used with reference to a machine. The *life* and *growth* of a stone are clearly something totally different from the life and growth of a tree, so that nothing is gained by employing the same words in both cases. In the assertions, the tree lives, the stone lives, any one can see that something very different is connoted by the word *lives*.

But the existing school of popular teachers will never tire of insisting that certain changes which occur in matter placed under certain known conditions, must be due exclusively to the properties of the atoms

of which the substances are composed, and will continue to assert that a class of phenomena, not one of which can be imitated in the laboratory, and which cannot be explained or accounted for, without admitting the exercise of a power of choice and selection associated with the matter, and the further admission that the action or change which does occur, might have been different, the matter and its forces, nevertheless, remaining the same.

Is it reasonable to maintain that properties which belong to matter for all time, and properties which no matter retains, except for a very short period, are equally due to the material properties of the molecules? A school of philosophy, which has now dominated in England for several years, has solved many difficulties with surprising facility. It shows that freedom of choice is but another mode of expressing necessity, and it has discovered that will is but a form of involuntary action. Philosophic atoms obey the inexorable laws laid down by physicists for their guidance. But other atoms there are, not yet discerned by physicists, which, not being under physical control, seem to choose their own way, or somehow determine in which of several different possible ways they will act.

The new philosophy is eminently a molecular philosophy. Everything is due to molecular action. We have molecular phenomena of the most diverse kinds and in very different situations. Molecules are concerned in the transmission of the mandates of the will. Molecules are disturbed in sensation. Molecules are transposed in thought, and yet the very teachers, who cannot describe a change without calling it molecular, not unfrequently find fault with the very methods of inquiry which alone can afford certain information concerning the changes they talk about, and by which only the accuracy of their assertions can be put to the test, and not only so, but the very authorities who talk so confidently about molecules, do not describe the objects to which they refer. This word molecular has not been accurately defined, and is used in a rough and general way as contrasted with that which is large, immense, but the difference is clearly one of degree only. Molecule is only another name for a little mass. The word is, however, used to impress upon the mind the fact that the very same laws which govern large masses, for instance the heavenly bodies, rule also very minute portions of matter, molecules,—and this is true. The difference as regards mass and its material properties is but a difference of degree. But when, as is the case, it is further sought to impress the mind with the idea that the molecule in a living state is *like* the molecule in a lifeless state, the whole question of life is begged, and a difference as absolute as difference can be is utterly ignored and disregarded, and people led to believe what is contrary to fact. On the other hand, the views at which any unbiassed mind would arrive after careful microscopic enquiry,

would not be in accord with the recent discoveries of the imagination of physical investigators concerning molecules and molecular action.

The philosophers who talk confidently about the mechanical phenomena of mind do not of course explain either the structure or mode of formation of the mind-forming machine, or discuss the mechanics of the thinking process. They do not even give an account of the mechanics of any single vital movement of any kind whatever.

Philosophers, indeed, affirm that no matter lives, because that which has been wrongly called living is, according to them, merely the performance of certain mechanical and chemical operations. Others, as I have said, confidently assert that all matter is alive, but neither one set nor the other affords the slightest information concerning the exact particulars in which the matter which lives or which performs vital acts, resembles or differs from the same matter when it has ceased to live, and can no longer perform any vital act whatever. Every living form does many things which no non-living things can be made to do, and the capacity for thus acting disappears with death. It is, therefore, idle on the part of mere authority to go on preaching its dogmas about the mechanical changes it cannot demonstrate, and the mechanical phenomena of particles which it is able to destroy, but which it is powerless to build up or construct. Authority may continue to refuse to admit, or may deem it expedient to deny that the living state differs absolutely and entirely from the non-living condition; but the truth remains, that in the living state of matter, whether it be the living matter of a growing fungus, or that concerned in mental action, material forces and properties are somehow governed and controlled, and in a manner not to be imitated by us or to be explained by anything known concerning non-living matter, while it is incontestable that the moment the matter ceases to live its capacity for manifesting its ordinary properties returns. After its death, matter never regains the power of doing what it did when it was alive. Science and reason are wrecked by those who reduce life and thought to mere mechanical action, and who declare they discern in mere matter all sorts of powers and capacities of which neither they nor any one else can obtain evidence.

It must be clear to anyone who thinks over the ordinary facts known to them, that a theory which will in any way account for the facts of mental action must include the admission of non-physical force, power, property, or influence, and I have shown that without such a factor the phenomena of the lowest living are as inexplicable as those of the highest. In fact, in all life we must admit the operation of a power or influence far removed from the physical category. This psychical factor, which, as Mr. Herbert Spencer says, "no physical research whatever can disclose, or identify, or get the remotest glimpse of," has never been explained away, and is the life of every living thing.

Such a factor has worked, and will ever work, in the matter of the lowest as in that of the highest living in nature. That any reasoning being should ground his denial of the existence of a psychical factor on the fact of the failure of every attempt to isolate, measure, weigh, or otherwise demonstrate it by physical research is as extraordinary, and it may be added as unreasonable, as is the suggestion of the possibility of thought being measured or weighed, or exhibited to an audience in the magic lantern, or otherwise demonstrated.

The process by which a particular muscular movement is determined is in its essential nature psychical. The movement of material particles in the matter concerned in mental action is clearly influenced by a determining governing agency not material. The perception of an impression must be psychical not physical, and the intellectual action which follows transcends every other phenomenon in nature except its cause. We must admit that material particles are made to arrange themselves in a manner not to be accounted for by anything yet discovered concerning their material forces and properties. It is unquestionably hard to form a conception of the manner in which material particles are brought under the influence of the supposed psychical factor, but we must allow that material changes are somehow brought under will, and seeing how many acts are undoubtedly under voluntary control, is it not more probable that will should control the movement of material particles than that inert matter and its properties should somehow develop will?

The movements of the lowest form of bioplasm are no more meaningless or purposeless undulations of a bit of jelly-plasm than are the oscillations of the matter of a mental bioplast. Even in the case of the *amœba*, the slightest movement proves the operation of some power not material, seeing that it cannot be imitated, and is unlike any movement known to occur in non-living matter.

The observer who carefully studies the striking movements of a small portion of living matter, as seen under a very high power, will not be easily convinced they are to be accounted for by any material properties of the component elements, any more than he will accept the statements which have been advanced for the purpose of convincing him that they are mechanical. Now every person of ordinary intelligence can, without much difficulty, study movements and other phenomena of living matter for himself, and after due enquiry and patient fact observation, will be able to judge how far the favoured doctrines of the day account for the observed facts. Let him determine whether the cant phraseology, characteristic of the period, in which we are assured that thought is due to molecular phenomena, is justifiable. The eloquent talk about the unbridged abyss between mind and matter deceives people by leading them to the inference that all is bridged over except

this abyss, and that the mysteries of the living are solved except the mysteries of the mind, which it is admitted have not been fully elucidated by physical investigation, and which cannot as yet be expressed in physical terms. By some, however, it is maintained that although the exact relation between molecules and morals has not yet been fully determined, it is certain that it will prove to be of a mechanical nature. Such statements can only have the effect of leading people to suppose that much more is known than is the fact. The reader, it is desired, should infer that it is only the mechanic of mind that is not fully understood, whereas the teachers are themselves well aware that the gap between chemical change and consciousness is no greater nor more inscrutable than that which separates an inanimate from a living particle. The materialist with some ingenuity misrepresents the whole matter. He has not the faintest conception of the molecular changes he talks about as proceeding in living matter, and he is as utterly ignorant concerning the mere movement of the lowest form of living matter, as he is concerning the nature of thought. It is to be hoped that before long the public will discover this, and no longer be misled and imposed upon by hypotheses based on the fictions of the imagination. A few writers taking a not ungenerous view of the causation of some of the curious intellectual flights towards the philosophy of the past attribute them to exceptional mental defects and disendowments such as distinguished from most of their contemporaries, for instance, Lucretius and Comte, who by some alienists have been regarded as the subjects of maniacal attacks.

Let anyone inclined to think that I have in any way exaggerated the extravagance of the mechanico-chemical doctrines which are now commonly entertained and widely taught, refer to an article in the very last number of the "Edinburgh Review" (No. 305, January, 1879), in which the public are told that the brain-pulp is destroyed and decomposed—burned by the agency of oxygen for the production of "brain force." The irresponsible author of such fanciful cerebration must surely be laughing at his readers. This mental cremationist who burns his brain-pulp, and expounds the physics of the soul, admits that one thing, however, has not yet been elucidated. Even this Edinburgh Reviewer confesses that he has not yet discovered "the plan by which the action of the unstable and combustible base of the brain convolutions is transmuted into the functions of the intellect"! (p. 83.)

Now, the idea we may form concerning the nature of mental action will necessarily be influenced, and in an important degree, by the conception we obtain from actual observation of the structure and arrangement of the anatomical elements which take part in the changes occurring in the brain during life. This conception will largely depend upon the method of preparation we employ for the purpose of demonstrating the

structure of the dead textures and cells connected with them. Assuredly there are no tissues in the body which exhibit greater differences in appearance than the nerve tissues when subjected to different methods of preparation. The solution of one of the highest problems presented to us may therefore depend in great measure upon the method adopted by a microscopic observer, in preparing a little bit of tissue for examination under high magnifying powers. Some, indeed, seem to think that considerations about demonstrating anatomical details are beneath the notice of those who aspire to what they themselves call philosophical views. If it were possible that truth could be evolved out of a man's understanding, it would of course be absurd to spend time in making observations which may after all often turn out to be fallacious; but is not such a notion opposed to all experience, and is it not certain that real progress in many departments of philosophical enquiry is dependent upon improvement in the methods of working? In truth the question of the nature of mind includes the question of the nature of life, and cannot be properly considered until the changes taking place in living matter generally, as well as the structure and precise arrangement of that part of the nervous system concerned in mental action, have been accurately determined. This investigation can be prosecuted only by skilled microscopical observers. In this way it would seem that advance in philosophy is in great measure dependent upon the results of accurate observations. And it appears to me almost certain that as our practical methods of demonstration are improved, many of the doctrines of the old philosophy which have been recently revived will yield to others of a very different character.

The great importance of the particular method of preparation advocated in this work in its application to the investigation of the tissue of the convolutions of the brain, is shown by comparing specimens so prepared with those which have been mounted in Canada balsam and such media as advocated by most authorities. In pl. XCVIII, fig. 5, is a drawing of a section of the gray matter of the brain, the vessels of which have been injected, *mounted in balsam*, and in fig. 4 is a similar section, the vessels of which have also been injected with Prussian blue fluid, and the bioplasm stained with carmine, but preserved in strong glycerine. In the last numerous cells can be distinctly seen which are not visible in the first, and the vessels, it will be noticed, exhibit an entirely different appearance in the two cases.

Near the surface of the gray matter of the convolutions of the brain, and occupying different planes, are countless small masses of bioplasm which sometimes after death are nearly spherical, but which during life are less regular in outline, perhaps stellate, each one having a number of delicate prolongations which connect it with many more, not with all those quite close to it, but with masses situated it may be



at a considerable distance off. In this way "centres" may be formed, but instead of being isolated or more or less separated from one another, the outer communications between the supposed centres are so very numerous that it is doubtful if the term centre can be correctly employed. Indeed the more carefully every part of the nervous system of man and the higher animals is explored, the farther we recede from the idea of several centres each with its definite function; and though undoubtedly broad divisions must be admitted, it must be borne in mind that in every one of these are nerve fibres and cells taking part in many and very different actions, with wide and very various connections.

The little transparent more or less spherical bodies with their delicate fibres, above referred to, can be well seen with the aid of an objective magnifying five hundred diameters or upwards, in very thin perpendicular and horizontal sections of the cortical portion of a convolution, the vessels of which have been previously injected first with carmine fluid and afterwards with Prussian blue, according to the plan described in p. 366. The injection of a portion of brain tissue, large enough for the purpose, may be effected by introducing a fine injecting pipe into one of the small arteries of the pia mater, but in all cases the specimen must be obtained very soon after death, for some of the anatomical elements of the cerebral convolutions undergo rapid change.

In p. 418, it has been already suggested that the angular cells in the cortex of the cerebral tissue like those in the spinal cord and other situations are not the sources of nerve power, but are rather concerned in the grouping of nerve currents running along various lines in very different directions. An idea of the general arrangement of these angular cells may be formed if figs. 3, 4, and 6 in pl. XCVIII be referred to. Fig. 3, which is in part schematic, shows how nerve fibres coming from many different points converge towards the base of each cell which gradually tapers at its upper part to form the one long tail-like process which runs as a single cord towards the surface of the cortex of the gray matter. In fig. 6, some of these fibres and their arrangement and connection with the cell are well seen. Before reaching the surface, however, the long fibre divides into multitudes of minute threads which pursue diverse courses, and dividing and subdividing as they do on very different planes it is not possible to follow any one of the excessively fine fibres resulting from the subdivision, for more than a very short distance. This much, however, is certain. Of the millions of small bioplasts which I believe to be the organs in which all mental action originates, many lie amongst these excessively fine fibres, some of which constitute the ultimate subdivisions of nerves connected with every point in every sensitive surface in the body, while others are motor fibres taking part in the execution of conscious movement. Through the

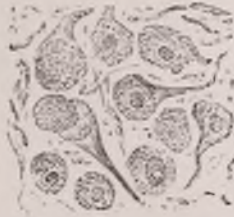
ELEMENTARY PARTS CONCERNED IN MENTAL ACTION.

Fig. 1.



Lymph on surface of peritoneum of intestine. Acute inflammation 4th day.  $\times 700$ . p. 420.

Fig. 2.



Anterior portion of cerebrum. Human embryo. 4th week.  $\times 700$ . p. 420.

Fig. 3.

NEAR PIA MATER.



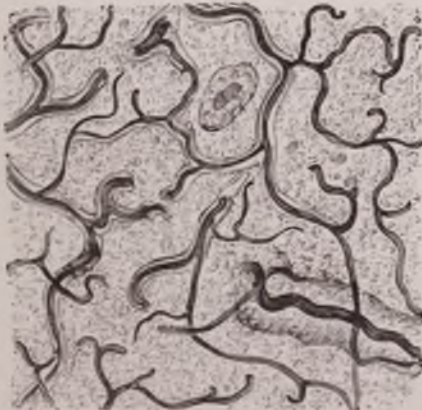
Vertical section through superficial part of grey matter of cerebral convolutions. Human subject. *a*, caudate nerve cells with long processes. *b*, This interval amounts to six inches in the drawing. *c*, bioplasts probably concerned in mental action. In part schematic.  $\times 350$ . p. 428.

Fig. 4.



Perpendicular section of grey matter of the brain, injected. Mounted in glycerine.  $\times 210$ . p. 427.

Fig. 5.



Section of the grey matter of the brain, vessels, injected. Mounted in balsam.  $\times 210$ . p. 427.

Fig. 6.



Angular caudate nerve cells from the grey matter of the brain of a lamb.  $\times 180$ . p. 428.



arrangement of these multitudinous threads result the marvellously complex actions of fibres and bioplasts requisite for the execution of even a very simple movement determined by the will, but influenced perhaps by impressions made upon the retina or other sensitive surface. Legions of nerve fibres or their extensions connected, for example, with different points of the retinal surface, must in certain situations in the cortex of the gray matter come into the immediate vicinity of corresponding legions connected with fibres and bioplasts taking part in sensation and voluntary motion. For the mind-bioplasts must be so arranged as to be influenced by and to influence at successive instants whole legions of nerve threads.

It might be suggested that the nerve current gives rise to molecular changes in the bioplasm, and that the molecular changes in the bioplasm influence the nerve current. But we must surely ask ourselves what we mean by molecular changes. Admitting, however, molecular changes, by what are these influenced? Does chemical change stand first in the marvellous chain of phenomena connecting will with muscular action—the action of oxygen as some think? In that case oxygen must be regarded as the cause and source of all action, and the very matter which causes the evolution of will, if will is not oxygen. Surely it is more in accordance with reason to attribute the phenomena of the bioplasm which differ entirely from any known phenomena of ordinary matter to some force, action, or influence peculiar to living matter, in short, to life.

All that I have been able to ascertain as regards the nature of bioplasm and its phenomena justifies the conclusion that this is the matter upon which the will actually and primarily operates, and that the nerve fibres, or rather the currents traversing the nerve fibres near to the bioplasts are affected by the moving matter of the bioplasm itself. The knowledge we possess concerning nerve fibres renders it impossible to accept the supposition that any of these are the seat of voluntary impulses.

The minute masses of bioplasm above referred to are so very favourably arranged for influencing the fine fibres, most of which are less than the  $1-1,000,000$ th of an inch in diameter, that it seems difficult to resist the inference that this is actually what happens during life. These fine fibres run in every conceivable direction. A vast number of nerve fibres taking very different routes may touch the same bioplast at different points on its surface. By the movements of the bioplasm in different directions different nerve fibres and sets of nerve fibres would be influenced. The movement I suppose begins in the particles of bioplasm and is caused by the direct and immediate influence of the vital power upon the matter. Particles of the bioplasm are made to move in a determinate manner, and according to the direction which the

wave of movement takes. Now this, now that, set of fibres will be as it were played upon by the bioplasm or living matter. Imagine a vast concourse of nerve threads in contact with different parts of the surface, several of which must be influenced by the slightest bulging of a very small portion of the surface of a single corpuscle. Imagine similar phenomena going on at the same moment in thousands of corpuscles producing temporary disturbance in many times as many thousands of nerve fibres, and a rough idea, I venture to think, will be formed of the actual phenomena which precede the occurrence of the actual temporary shortening of a few fibres of muscle.

When one wills to execute a certain definite movement, this is, I believe, what happens:—The immaterial agency, *psychical power, vital influence, will*,—call it what we may, causes, compels, necessitates, certain oscillations or undulations of the living matter or bioplasm. Certain definite movements follow, and the matter bulges and impinges upon the several nerve threads close to that part of its circumference. The current in these fibres is disturbed and thus an effect may be produced at a considerable distance. In an opposite direction a disturbance in the current in the nerve fibre propagated from a distance might act upon the bioplasm, the movement of which would influence the vital power. In some such manner I conceive a psychical change may cause, or be rendered evident as a material or molecular phenomenon. According to the direction in which a part of the mass of living matter is temporarily driven by the conscious life power which governs it, will depend what particular cords of the nerve mechanism are struck. If I am correct in the inferences to which I have been led, I must consider mind as the vital power associated with the most exalted form of bioplasm or living matter in nature.

The change I have attempted to give an idea of in the foregoing paragraphs is of a character coarse and rough compared with what goes on in the living matter itself just prior to the movement of its particles. But yet we ought to have a very definite and accurate conception of the phenomena in all their detail before we can venture with much chance of arriving at the truth to discuss the real nature of a mental act. As this enquiry would take me very far away from matters of observation, I must not pursue it here, but it will probably be generally admitted that further advance in the highest realms of thought is more likely to follow the discovery of new facts by skilful microscopical observers, than to be consequent upon the investigations of any other class of workers or thinkers.

## PART VII.

## THE CONSTRUCTION OF OBJECT-GLASSES—OF THE TOOLS REQUIRED FOR MAKING OBJECT-GLASSES—FORMULÆ FOR MICROSCOPIC OBJECT-GLASSES.

(By Mr. WENHAM, F.R.M.S.)

Of late years great attention has been paid to the construction of the higher objectives and many improvements have been introduced. The subject is one of great interest, and in case any of my readers may desire to try experiments in the construction of objectives, I have appended the directions given by Mr. Wenham, who has for many years been engaged in this work, and has made many important improvements. His directions, being entirely deduced from his own practical experience, are of great value, and will be studied with advantage by every one who proposes to engage in this work.

Mr. Swift has also kindly furnished me with some observations which will be found useful to any one who intends to take up the subject. These will be found on page 460.

The following sections from Mr. Wenham's memoirs have been reprinted with his permission, and in his own words, from papers published by him in the "Monthly Microscopical Journal," 1872, and in the "Proceedings of the Royal Society," 1873.

**395. General Remarks on Making Object-glasses.**—The directions for working glass surfaces to a correct figure, may appear to some too practical and characteristic of the workshop; but it is only by a strict attention and study of such details that perfection can be insured, and without their aid, the deductions of the mathematician must fail in their proof. Though the early training of a mechanical profession has familiarised me with such pursuits, yet I must confess that I am ignorant of the methods adopted by our best makers for working their minute object glasses; and, therefore, if some particulars may have the merit of originality, others are perhaps not in accordance with the most improved practice.

The first attempt to construct an object-glass ( $\frac{1}{4}$  in.) is recorded in the year 1850, on the then well-known form shown by fig. 1. The back lenses had an excess of negative aberration, or were over-corrected, to enable the adjustment for covering-glass to be performed by the separa-

tion of the front lens, which was under-corrected for that purpose. But on attempting to improve the correction by a difference in the

Fig. 1



radius of the concave flint of the triple front, it was shown that a considerable alteration was here required to effect a material correction for colour. Taking a ray at the focal distance from the front surface, and tracing its refraction through the triple, at all points it appeared to enter the concave surface nearly as a radius from its centre. Consequently, under this condition, the effect of the dense flint was partly neutralised.

It then occurred to me to try a single lens for a front. With this combination no satisfactory result could be obtained with respect to achromatism.

Early in the year 1850, Mr. Lister was occupied with experiments for the purpose of improving the higher powers, and then introduced the *triple back*, which has since so eminently proved to be the grandest step towards their perfection, allowing perfect correction to be obtained with the most extreme apertures.

Having received early information of this improvement, I set to work and again tried the single front in combination with the triple back, and constructed a  $\frac{1}{8}$ th on this system, which is considered excellent to this day. For several years I stood alone in my opinion of its advantages; but as numbers of our best object-glasses of the highest powers are now made with single fronts, I am in a better position for advocating this form, particularly as its success was found to depend upon a relative difference of focal lengths in the two back combinations not hitherto employed by others.

At first the single front with the back triple was not successful. Though colour was nearly corrected, there was a deficiency of aperture, and the combination was spherically under-corrected. On viewing another object under a thicker covering-glass, the definition was greatly improved. By placing other pieces of thin glass over the object, the front lens had to be drawn still closer to the others. This gave an increase of aperture and more perfect definition. A single front was then made, of the thickness which had been found to give the best result, ascertained from the measurements of the additional pieces of thin glass over the object, and the effect was all that could be desired. On finding that the correction for spherical aberration depended upon the thickness of the front lens, the path became easy.

Fig. 2 represents a  $\frac{1}{8}$ th of  $130^\circ$  of aperture constructed on this system, six times the size of the original. The curves are not given as

radii, but as the diameters of the circles in thousandths of an inch—for I thus note them down for the convenience of making and finding the steel gauges and to prevent divisions into two-thousandths, which would frequently occur in the corrections. The following are the curves:—back triple,—posterior of crown,  $\cdot 312$ ; three next surfaces, crown and concave flint,  $\cdot 440$ ; front flat, diameter of lens,  $\cdot 173$ ; density of flint,  $3\cdot 630$ ; ditto, of crown,  $2\cdot 437$ .



Curves or templates of middle:—Back,  $\cdot 233$ ; contact surfaces,  $\cdot 233$ ; front  $1\frac{1}{4}$  inch, or  $\frac{5}{8}$ ths inch radius; diameter of lens,  $\cdot 138$ ; density of flint,  $3\cdot 686$ ; ditto of crown,  $2\cdot 437$ .

Single front of crown,  $\cdot 100$  or 1-10th template; diameter of lens,  $\cdot 093$ ; thickness,  $\cdot 057$ , measured from the top; density,  $2\cdot 437$ .

The focus, or magnifying power, of the two back combinations is very nearly equal, and each  $4\frac{3}{4}$  times that of the single front; for I have found that if the middle is of shorter focus than the back, that it is difficult to obtain satisfactory correction. The lenses are fitted into their cells without shoulders, as their diameter is only just sufficient to admit the full pencil of rays, and their surfaces are utilised to the extreme edge, a desideratum that can always be secured by a proper mode of working.

The aperture of this object-glass is  $130^\circ$ , which is amply sufficient for a good working  $\frac{1}{8}$ th. In the triple back, the three cemented or contact surfaces are of the same radius, as I have not been able to ascertain that any material effect in the correction for spherical errors can be obtained by a difference in the two radii of the concave flint, and, therefore, for the sake of facilitating the workmanship, both faces are similar. I am aware, however, that some makers hold a different opinion, and make the incident-surface of the concave much deeper, and the other longer in due proportion. The front of the triple is flat; but as the perfection of an object-glass depends in a remarkable degree upon the radius of this surface, a plano-convex lens cannot always be applied as a rule, for the curvature depends very much upon the nature of the glass employed in the construction, and the distance at which the lenses are placed asunder.

The correction for oblique pencils, and flatness of field, are mainly effected by an alteration in this radius, ascertained from the appearances of a globule of mercury, hereafter to be explained. Also, for the convenience of working, the posterior and contact surfaces of the middle lens are of smaller radii, and the required negative correction for colour



is obtained by an alteration in the concave incident-surface of the flint. The back and middle lenses are worked as thin as possible. It is an easy matter to make convex lenses to a sharp edge ; but to insure the requisite thinness in the concaves, the edges are polished before the grinding is completed ; and this is continued till they are seen to be as thin in the centre as may be deemed practicable, without the risk of breaking them through.

In the construction of the highest powers of the microscope, or such as are composed of three distinct sets of lenses, it must be borne in mind that the magnifying effect is obtained principally by the front lens ; and the combined operation of the middle and posterior, is entirely corrective ; and their application in any combination must always be so considered, and not as a means of obtaining additional power. If the front of an eighth or one-twelfth is tested alone, it will be found to magnify nearly as much as when the other lenses are replaced.

The single front has the advantages of facility of construction, and a command of any required extent of aperture ; and enables object-glasses of higher power to be made than would otherwise be practicable. For example, the radius of the front lens of a 1-50th is 1-120th of an inch, and the diameter is 1-70th. The difficulty, if not impossibility, of constructing a *triple* of such almost invisible atoms of glass may be imagined.

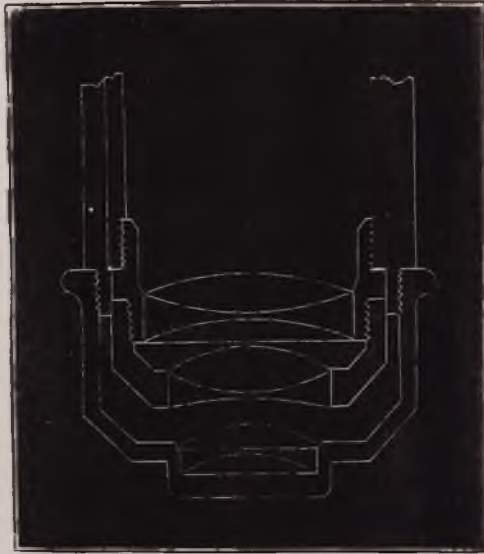
In May, 1856, I made the first 1-25th with a single front lens of 1-30th in diameter ; I am doubtful whether a triple front could be made even of this size, with any positive certainty of accurate workmanship.

From the  $\frac{1}{8}$ th and upwards, perfect correction may be secured with a single front. It is, however, barely possible to make a good 1-5th with this form, and in a  $\frac{1}{2}$ -inch it fails altogether ; there is a kind of secondary spectrum that cannot be got rid of. It is not easy to define all the reasons why it should succeed perfectly with the highest powers, and the correction be imperfect with the lower ones named. With smaller apertures the errors of spherical aberration cannot be so well corrected by giving thickness to the front lens ; and as there is considerable distance between this and the middle, the coloured rays from the uncorrected front are so far separated that any corrective action of the back systems is incapable of recombining them. When an object-glass is spherically under-corrected, the focus of the central rays is longer than that of the marginal ones, as in a simple lens. If all the rays are brought to one point, the interposition of a plate of parallel glass projects the outside rays to a greater distance than the central ones, and produces a similar effect to a concave lens, or that of over-correction ; and it is for this reason that a certain thickness of glass before, or in the substance of the front lens has such a remarkable

corrective power, which is most appreciable with a very large aperture. Where this is comparatively small, as in a  $\frac{1}{2}$ -inch, the influence of a thick front does not appear to be sufficient to enable the final correction to be obtained by this means alone. The anterior lens must, therefore, either be partly achromatised, or made of a glass of higher refractive and less dispersive power than any at present known.

It is well known that, in a doublet consisting of two single plano-convex lenses, both the spherical and chromatic aberrations are considerably less than in a single lens of the same magnifying power. I have for this reason proposed to construct the higher powers with two single lenses in front, of equal radius, as shown by the cut. The correcting thickness should be thrown in the first lens. If they are set in contact, the magnifying power will be nearly as their sum; they may therefore be made of double the radius, and consequently nearly twice

Fig. 3



the diameter, which, of course, would lessen the practical difficulty of working a 1-50th, and enable us to go even beyond this power. A partial experiment with a  $\frac{1}{4}$ th, having this "doublet" front, has proved that perfect correction for colour is the result. But in the form tried, the spherical aberration was so considerable, as to require an entire reconstruction, for which I have had no leisure; and though the entire success of the idea is yet unproved, I venture to record it, in case I may never be able to take up this subject again, as I am of opinion that a very perfect object-glass may be made of this form.

**396. Immersion Object-glasses.**—These combinations are under-corrected, and not suitable for use in any other way. The plan is an

old one, and objectives were constructed on this principle by Amici and Ross many years ago. That such lenses give brighter and clearer definition, with the highest powers, from the 1-12th upwards, is unquestionable.

**397. On the Observations requisite for Correcting Object-glasses.**

—For this purpose, a particle of mercury is placed upon a slip of black glass. A piece of watch-spring, or the thin handle of a spatula, is held up at its end by the fore-finger of the left hand, and slapped smartly down on the mercury, which is thus beaten into powder, in the form of numerous minute globules. Of these, a larger size is selected for correction of colour, and a minute one for ascertaining the errors of figure and centering, and state of the oblique pencils.

The globule must be illuminated by direct candle or lamp light, and not by daylight, as the latter will not allow perfect correction to be obtained. The light requires to be set as close as it can be, and, of course, in the highest powers, where there is little distance in front, it must be very oblique; but this is of no consequence, as it is not the globule itself, but the spot of light reflected from it, that is required to be seen.

The lens to be tested is adapted to the microscope, having the ordinary Huyghenian eyepiece. On placing the globule either in or out of focus, the luminous point expands into a ring. If the object-glass is under-corrected for colour, as in a single lens, the bright ring appears within the focus, the outer margin is red, and the inner circle green. If the lens is over-corrected, the bright ring appears *without* the focus, with the colours in the same order as before. A practical knowledge only, derived from these appearances, can determine the amount of concavity to be given to the flint, or difference of convexity in the crown, for obtaining the desired correction; but even in the most experienced hands it generally involves several alterations to secure perfect achromatism. When this is corrected as far as practicable, a pale-green colour only is perceptible beyond the focus. This arises from the secondary spectrum, or relative difference in the width of the prismatic colour spaces of the crown and flint, and seems to be a variable condition, according to the composition of the glass employed.

Though correction for spherical aberration is intimately related to that of colour—a single lens, when finally achromatised, being also nearly free from spherical error; yet, in a combination of three pair, when matched so as to be achromatic, this may be so considerable as to render the object-glass useless, and is oftentimes exceedingly troublesome to remedy. The error may arise from an improper proportion between the relative foci of the lenses—as the back being too long. I have before stated that, in the form that I have advocated, the spherical aberration is mainly corrected by giving thickness to the front

lens, and by properly adjusting the distance between them. In a glass spherically under-corrected the light from the globule is greatest within the focus, and when set out of focus speedily vanishes and becomes diffused; in the case of spherical over-correction the contrary appearances result. When the relative distance of the lens is rightly adjusted, the light spot expands equally, and is of the same intensity, for a short distance on either side of the focus, in which the globule should appear with a clear bright margin. The object-glass is now in a proper condition for testing errors of construction and workmanship.

To examine the condition of the oblique pencils, and consequent flatness and distinctness throughout the field, a small globule is selected, and brought to the edge, using the lowest eyepiece; if the bright point in the centre of the globule, when a little out of focus, approaches to the inner side of the concentric light-rings, as in fig. 4, it is termed

Fig. 4.

Fig. 5.

Fig. 6.



“outward coma,” and indicates that the front incident surface of the back triple is too *convex*. If, on the other hand, the bright spot is on the outer side of the rings, or next the margin of the field of view, there is “inward coma,” which shows that this same surface is too flat. I have previously remarked that this curve has a powerful effect on the flatness of field and perfection of oblique pencils, and for these no other correction is generally requisite than an alteration in this radius.

Before the glasses are finally cemented in their cells, they should be carefully tested for centering; for this purpose a very minute globule is selected, and placed exactly in the centre of the field. If the bright spot appears eccentric, with the rings thus (fig. 5), the pair of lenses which occasion the error should be shifted on each other while warm enough to cause the Canada balsam by which they are cemented together to yield, till on repeated trial the error is corrected. This is important, as the least fault of centering materially impairs the performance of an object-glass. But with the precautions that I have adopted in the construction, to be hereafter explained, errors of centering cannot occur.

There is yet one other globule test for object-glasses, to indicate

accuracy of workmanship, or whether the lenses are worked to true spherical surfaces. If the rings from a minute globule appear of an irregular wavy outline, as shown by the annexed cut (fig. 6), either approximating to a polygon or triangle, it shows that one of the surfaces at least that refracts the rays is of this form. Such workmanship is inexcusable, and those that cannot avoid it had better let glass-grinding alone.

Finally, there is an appearance that I have sometimes seen in our best object-glasses, when focussed away from a globule, viz., "Newton's rings;" this shows that in the contact surfaces of one of the pair of lenses, the convex is deeper than the concave, and bears hard in the middle. This may have no worse effect than loss of light; but still it is as well avoided.

**398. On the Quality of the Glass employed in the Construction of Object-glasses.**—Under this head I can offer but very little information, for in common with all other workers in this direction, I have merely made use of such various samples of glass as I have been able to procure. The whole secret of the ingredients used, their proportions and chemical constitution, is in the hands of the makers; and though the two or three of them who have paid attention to the manufacture have doubtless well studied the particular application of both the flint and the crown for the construction of microscope lenses, yet the best that we can procure falls far short of the requirements of the case for the very highest powers.

It is usual to denote the quality of flint-glass by its density, but this in reality forms no accurate criterion of its dispersive power. Formerly, under this impression, I procured a quantity of dense flint, made by Chance, of Birmingham—very hard, white, and free from ability to tarnish, and to all appearances as good a quality of glass as I had seen. Its density was 3·867, but on trial I found it unfit for the construction of the highest powers, as its dispersive power was lower than the Swiss 3·686, or even the 3·630 that I had employed previously, while its reflection was much greater. Some ingredient had been added which increased the refraction, and probably lessened the dispersion; and, of course, in a correcting concave, the latter quality alone is needed, and the lower the refraction the better.

The crown and flint employed in the one-eighth described at the commencement of this essay, of the respective densities of 2·437 and 3·686, had a relative dispersive power of 11 to 25; this having been very accurately determined by two prisms, whose angles were in this proportion, and which when superposed were perfectly achromatic. Faraday made some dense flint having a specific gravity as high as 6·4, but we have no information relating to its refractive and dispersive power.

We are thus somewhat ignorant of the material elements of con-

struction employed in the microscope object-glass; and it would be very desirable that a series of experiments should be made, with various combinations of all the known materials that can be used in glass-making, and the resulting compounds worked into equilateral prisms, and their refractive and dispersive powers tabulated, with the component ingredients. A few years back this investigation would have been a very troublesome and expensive one, by reason of the interference of the Excise laws, and the necessity of employing a regular glass furnace, to operate on large quantities at once, in order to lessen the effects of impurities. But now, by means of the recently-invented gas furnaces, the greatest possible heat may be commanded, under perfect control, and thus enable the operator to combine materials in very small quantities without the intrusion of impurities from the fuel and furnace-lining, or crucible, which may be of platinum. The results of the investigation would unquestionably be valuable, and we might possibly be able to discover compounds which would neutralise the secondary spectrum. The late Thomas Cooke has repeatedly stated that if, while viewing a difficult double star through a telescope, some one was to sweep away the secondary spectrum, he would scarcely be able to discover any improvement, either in light or definition. But I am of opinion that the case is different with a microscope object-glass, wherein, with the highest powers, every trifling error is so enormously magnified, and in resolving the most difficult tests the effects of irrationality are at times very apparent.

**399. Brass Cells for Object-glasses.**—For the brass setting of object-glasses, it is necessary that the worker should possess a good foot-lathe; if provided with a self-acting arrangement for chasing up the short screwed parts of the cells, this will insure greater accuracy of workmanship. The setting or metal work of an object-glass must always be made before the lenses are commenced; three steel gauges are to be first formed, of a width exactly corresponding to the diameter of the intended lenses; this gauge I make out of a piece of sheet steel, with three arms of the three diameters required. A chuck should be fitted to the lathe, and cut out to the standard thread now generally adopted for object-glasses; into this the brass setting is fitted, and each cell screwed on, and turned out in succession to the proper size. I leave no shoulders at the back of the cells, but bore them clear through.

Triblet tubing is not sufficiently accurate for the outer shell of the highest powers; it is better, therefore, to make this of one casting, and bore it out of the solid, from its own chuck, and finish to the size with a fluted rimer. I have always made the inner tube, containing the back lenses, to traverse to and fro, in preference to the front lens, as the object is not thereby lost sight of during the adjustment, which is performed in one-third of a revolution of the outer ring, which has an in-

clined groove cut in it, acting on a screwed pin connected with the inner tube. This plan is more simple in construction, and less liable to derangement than the one commonly employed.

**400. On Reducing and Dividing Masses of Glass for Optical Purposes.**—For this, the lapidary slicer and diamond dust are generally employed. Discs of glass are split into slices by the working lapidaries at such a trifling cost, that it is scarcely worth while for the amateur to attempt it. Should, however, a small and rare sample be immediately required for experiment, it may be readily sliced with a circular disc of soft iron, running in the foot-lathe, and fed with flour emery and water; the edge of the slicer must be frequently notched with the sharp angle of an old file. The sample of glass or mineral is cemented to the end of a staff, and held preferably in the slide-rest. If the screw of the rest is taken out and the slide made slack, the work can be thrust up to the slicer with the pressure of the fingers, and there is less risk of fracture from undue violence. The sliced glass is cut into squares, a little exceeding the diameter of the intended lenses, by means of a glazier's diamond, and the corners rounded off with a pair of optician's "shanks" or nibblers, which are a species of pliers, made, in preference, of soft iron, as this grips the glass without slipping, as hard steel would do. This instrument, of a larger size, is capable of removing slivers of glass from the edges of a plate upwards of one inch in thickness.

All glass is much softer than hardened steel; but if this is set to cut in a dry state, the heat generated at the working or abrading point softens the cutting edge, and speedily destroys its action; but if some turpentine is applied, this quite prevents the softening of the tool. In the lathe, or with a common Archimedean drill, holes may be drilled through thick plate-glass with surprising rapidity, if kept well bathed in turpentine. Masses of glass may also be turned in the lathe with a steel tool, if plentifully supplied with turps, and run at a moderate speed.

The first experimental parabolic condensers were made from plate-glass  $1\frac{1}{2}$  inches thick; pieces of this nibbled rudely to form, were cemented on to a chuck. The T-rest was next placed nearly on a level with the top of the work, and an old triangular saw-file, kept sharp *on one side only* by repeated applications to the grindstone, was then held on the rest, so as to attack the revolving glass slantways, or spoke-shave fashion, with plenty of turpentine. By these means the glass was quickly reduced to form, so as to fit the template; and the ridges left by the file were swept away by means of small leaden laps, fed with emery and water of increasing fineness. The polish was obtained by a rubber of willow-wood, cut crossways of the grain, used with crocus (peroxide of iron) and water, and at last a lump of beeswax with very fine crocus was employed for the final polish.

For working small concave lenses, as nearly as possible to their final

form, a great deal of accurate and skilful turning is required. For this delicate work steel tools are quite unsuited, and diamond points are invariably used. The common practice of mounting these has been to solder them with brass and borax, by means of the blowpipe, into the end of a steel tube about the size of a watch-key, leaving a hole behind to prevent the diamond from being blown out during the fusion ; but I have never found this method secure for small splinters. The brass has really no affinity for the diamond, but rather tends to avoid it ; and this is frequently only held in by the glaze or flux. The loss of several diamonds induced me to abandon this practice, and since adopting the following mode I have never lost one.

I take a piece of copper wire, about 1-12th of an inch thick, and drill a shallow hole in the end, of the size and depth required to contain the diamond, fig. 7. A piece of steel, turned out with a bell-

Fig. 7.

Fig. 8.

Fig. 9.



mouth, and hardened, is shown in fig. 8. This is spun rapidly in the lathe, a drop of oil is applied, and the end of the copper rod containing the diamond is pressed hard in, at the same time giving it a slight rolling motion. Speedily the copper is compressed tightly round the diamond, as in fig. 9, which becomes very firmly imbedded in the soft metal ; and if the operation is carried too far, the copper rises over the point and completely buries the splinter.

By mutual abrasion, the diamonds rapidly grind each other away, and two, mounted in wires in this way, may be kept mutually to a sharp point, by chucking one in the lathe and using another as a turning tool. In employing these diamonds for turning glass, no particular directions are needed ; they seem to cut rather better if the work is kept slightly moist.

The most convenient way, for the amateur, of reducing the substance, or giving the rough rounded form to small lenses, is a large plate of zinc and coarse emery and water ; iron is too hard, lead too soft, and copper poisonous.

#### 401. Of the Powders employed for Grinding and Polishing Glass.—

For lenses, emery is almost invariably employed for rough grinding and smoothing. For the latter operation it must be washed to various



degrees of fineness, as it is seldom sold in this state ; the sizes in commerce are merely sifted. Emery differs much in hardness and quality, according to the locality from which the ore is obtained. If it is full of small reddish particles, of a dull slaty appearance, it is soft, and deficient in the grinding property. The Guernsey emery is of this character, and very inferior to the Naxos, the particles of which have a steely appearance of uniform colour ; but this latter is difficult to obtain, as it is monopolised by some of the large plate-glass manufacturers. Three or four sizes are sufficient for the glass worker for roughing down and fine grinding ; but for smoothing, washed emery of several degrees of fineness are required. A portion of the flour of emery of commerce is placed in a bowl, or a common wash-hand basin, and well stirred up. At the end of ten seconds the water is poured into another bowl ; this is repeated several times, till no more can be withheld from the original quantity. This washed quantity is again separated into several other degrees of fineness, as at the end of one minute, five, twenty, and sixty minutes ; but, after one hour, a very small quantity is obtained from one pound of the flour of commerce. This being of value for the perfection of the final smoothing, or obtaining a semi-polish on the metal lap or mould itself, I have preferred procuring it from the "optician's mud," or refuse of the previous grinding operations. Taken in an unprepared state, this contains a large percentage of impurities, consisting of ground glass and metal particles from the laps ; it is, therefore, necessary to remove them. The first by boiling the mud with caustic potash, and after washing away all trace of the alkali, finally treating with dilute sulphuric acid. The finest portion only of one hour's suspension may then be separated and in a satisfactory quantity.

The polishing powders used by the workers of minute lenses, are putty-powder, or oxide of tin, and crocus, or peroxide of iron. The first may be obtained sufficiently good without any difficulty ; but after many trials, both by roasting the alkaline precipitate from sulphate of iron, and also carefully washing the crocus of commerce, I have given the preference to jeweller's rouge, sold by Acton, of Farringdon Street. In this form it is far too soft for glass polishing ; it must, therefore, be heated in an iron pot, and diligently stirred till the mass acquires a purple colour ; it is then of the requisite degree of hardness. Both this and the putty-powder must be washed, to separate gritty particles ; about five minutes will be sufficient. After obtaining all that can be suspended in this time, the residue may be levigated on an iron plate, with a soft iron spatula, and the washing continued at pleasure ; but the result of all the washings is sure to contain some gritty particles, which must be separated by repeated washings till nothing whatever will settle at the end of five minutes. Two sizes of crocus only are needed ; the last is obtained from the washed mass after one hour's suspension, and is

very small in quantity but of much value for obtaining the finest polish on prism work, either in glass or calc spar. The ordinary washed crocus, used alone, I have found too keen, and apt to cling to and raise streaks on the polishing laps ; I, therefore, always mix it with an equal part of the putty-powder, which quite remedies the evil ; an uniform mixture is best obtained by stirring them together with water.

**402. On the Production of Flat Surfaces in Glass.**—The most important tools required for the work are three circular cast-iron laps, about 6 inches in diameter, having a screwed boss at the back, similar to the face-chuck of a lathe. These must be first turned flat on their faces, and then scraped to a true surface, either from a standard planometer, as practised by engineers, or else the three may be scraped together till no error can be detected by their interchange. It would, perhaps, be out of place to give the details of this operation, which is described in most elementary works on mechanism. These planes, as left by the scraper, are not sufficiently smooth for the purpose required ; they must, therefore, be ground together. One of the plates is screwed down on a stud fixed in the bench or vice, and a wooden knob is fixed into the other to serve as a handle ; they are then rubbed together with fine emery and water, frequently interchanging the plates. It is a very difficult matter to bring these plates to an exact plane by grinding alone, and to keep them so during their continued employment. The test of their truth is, that after they are all wiped clean and dry and rubbed together, the three should present a mottled appearance, uniformly covering the whole of their surfaces. One cause of error is a natural tendency of the grinding-powder to collect unequally between them. This may be somewhat corrected by frequently wiping it away from the places known to be hollow ; and the grinding together should be performed with as little powder as possible at a time, and the strokes so managed as to abrade the high parts only. Practical experience is the best guide for this ; and a clever workman will soon learn in what way and direction to work his blocks of glass, &c., on the laps, with very little injury to their plane figure, or even for the purpose of correcting it. In consideration of the extreme accuracy required in the prisms for spectroscopy and other purposes, no pains should be spared in maintaining the perfection of these laps.

If a number of discs of glass intended for small lenses are required to be ground and polished to a flat plane, they must be cemented to a "block ;" this is frequently merely a piece of wood turned with a convenient knob at the back for handling ; others use a metal plate. Wood is handy for its lightness, but it is liable to warp during the polishing operation, and so shift the discs ; to obviate this, I screw a flat piece of slate to the face of the wooden block, with a few common wood screws.

The cement used for the glasses is either pitch hardened with some shellac, or common black sealing-wax. For a small series of discs, a block of about 2 inches in diameter will be found most manageable. The pieces of glass cemented on this are arranged symmetrically, leaving as little interval between them as possible. They are now roughed down on the zinc plate till they are all brought to one level; they are then washed with a nail-brush and well rinsed, and fine-ground on one of the laps, and next smoothed on a circular piece of cast-iron, but little exceeding the diameter of the block of discs. This smaller lap must be carefully ground to a true plane on the larger ones. A little of the finest washed emery and water is spread over this lap with a feather, and the glasses worked upon it in every direction, holding the lap in one hand and the block in the other, and occasionally turning both; this is continued till the emery begins to get dry, the glasses are then washed and wiped dry, and the smoothing proceeded with; but no more water must be applied to the lap. This is now moistened by simply breathing on it. In a few minutes the lap will again become dry; remove the block, and wipe all the emery away about  $\frac{3}{8}$ ths of an inch from round the circumference of the lap; breathe on it again; continue the smoothing, and also wipe the emery away from the outside till, finally, scarcely any is left, and the glass is nearly finished on the metal itself. If this operation is properly conducted, the glass will have a transparent surface free from scratches and greys, and so near a polish that a few minutes only on the polishing lap will be required. But one rule must be strictly adhered to, viz., never to polish a glass surface with any scratches in it. It is worth while to spend any amount of time in smoothing rather than do this, and the operation must be repeated again and again, till no scratch whatever can be discovered. It is quite evident that to obliterate a scratch by polishing, the whole surface must be worked away till the bottom of it is reached. This makes the operation long and very tedious, and is almost certain to injure the perfectly flat plane which has been obtained by careful smoothing.

It is a difficult and hazardous task to polish glass on hard metal, as the surface is very liable to tear up. Consequently, the usual system is to employ a soft and partly-yielding material, in which the particles of polishing powder may be imbedded. For facing the lap, I employ beeswax hardened with resin, and stir some finely-washed ochre into the melted mixture. The lap itself is simply a brass plate, about 3 inches in diameter, which screws on to the lathe mandril; some of the above material is poured on to this, and spread over a layer of about  $\frac{1}{16}$ th of an inch thick. When cold, it is turned off flat, and, to make it perfectly true, the whole face is scraped off at once with a hardened steel-cutting straight-edge. An old parallel cotter file will answer the purpose, ground from both sides like a blunt knife, and finally corrected on one

of the cast-iron laps with emery. A series of shallow grooves, about an eighth of an inch asunder, are now turned in the wax, and some cross scratches made radiating from the centre, from which a piece should be taken out. The polishing powder, consisting of a mixture of crocus and putty-powder, before described, should be mixed in a small gallipot with plenty of water, and applied to the lap with a feather. The lathe is now run at a pretty-quick speed, and the block of glasses worked over it in every direction with considerable pressure. If the smoothing has been properly done, as directed, a few minutes will suffice to give the requisite polish, which is seen to take place equally all over the glasses; but if any scratches should develop themselves, it is better to repeat the smoothing than attempt to polish them out. This same method is employed if the glass were one continuous plane instead of numerous pieces.

For minute prism work, where the size is required to be only just sufficient to transmit or reflect the pencils from a microscope object-glass, and the surface has to be perfectly up to a sharp edge, somewhat different practice must be adopted; for however carefully the smoothing or polishing may be performed, a rounding of the extreme edge always occurs. To obviate this, the edges must be guarded, as in the following examples;—A (fig. 10) is a prism to be worked to a very acute angle.

Fig. 10.

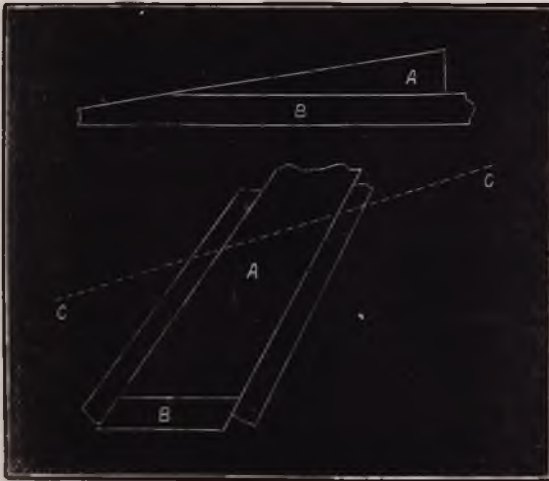


Fig. 11

A piece of glass (fig. 10), large enough for the purpose, having one side polished, is cemented with Canada balsam to a parallel plate of glass (B); they are then ground off together to the required angle and polished; the marginal error will be taken up by the lower end of

the under plate. It would be impossible to make an acute wedge of this figure in any other way, and when separated it will be found to have a knife-edge perfect in the extreme.

Another example may be described from my practice in making the first prisms for the binocular microscope. A (fig. 11) is an end view of the intended prism; this is supposed to have been a block of glass of larger size, with one polished surface cemented with Canada balsam on to the guard-plate (B); the front and back reflecting surfaces are then smoothed and polished; these are then covered with guard-plates, and the top emergent surface of the prism ground off and polished to the dotted line (C, C). It will thus be seen that every corner of the prism is protected during the working, and is kept absolutely perfect to the edge. The prisms were made sufficiently long to be cross-cut into three or four. The smoothing was performed in accordance with the foregoing directions, but the polishing lap was required to be much smaller. The one I employed was only  $1\frac{1}{2}$  inches in diameter. If a large lap is used, the polish is apt to commence on the margins of the glass; and if this is the case, a true reflecting figure will never be obtained. The polish should begin in the centre and spread to the outside. The proper angles for these prisms were set off by a graduated steel sector, and, as the measurements have to be taken from the back of the guard-plates, it is necessary that these should be exactly parallel; if not so, they must be ground on the surface-laps till all the edges gauge alike.

I may here remark that I am merely recording what has been my own self-acquired practice, and which is perhaps neither the most expeditious nor easy. My best apology must be, that I have always secured perfectly accurate results by these methods, and when a few only are required, I must confess that I do not see a better way. But the great demand that has arisen for binocular prisms has induced the makers to discover a plan of working them in blocks, a number at a time, the particulars of which I do not pretend to explain.

Some very excellent prism work is produced on the Continent, and as the mode of polishing is peculiar, it may be worth while to record it. Chevalier and Co., of Paris, through Messrs. Beck, politely sent me an explanation of the process, together with a sample of all the grinding and polishing materials used in their business. After the surface of the prism is smoothed, a piece of very thin, smooth paper (much resembling photographic negative-paper) is cemented by its extreme ends with a little gum or dextrine to the metal lap; a lump of yellow tripoli (labelled "Tripoli de Venise") is then rubbed dry over the paper, and the prism, also dry, polished thereon by hand movement; generally not more than two or three applications of the powder are required. I have tried this method with the identical paper and polishing material, but must state that, in my hands, the result has not been satisfactory for

accuracy, at least in very small prisms ; for larger ones it may answer better.

**403. On the Production of Spherical Surfaces in Glass.**—As the radii required in the construction of microscopic object-glasses are seldom very long, the templates for all sizes above 1-5th of an inch in diameter are usually made of steel, such as thin saw, spring, or busk-steel, not softened, but turned hard, as obtained. A hole is punched through the middle of a square plate with a centre punch, the whole is then rounded out with a taper rimer. The piece of steel is next broken round as near as possible to the size of the circle required, by clamping it in the vice and driving off the surplus metal round the edge with a chisel held close to the jaws. This steel plate is driven on to a mandril so as to turn true without any wobble. The lathe is run at a low speed, and the T-rest placed rather high near the top of the work, which is turned true with the common square graver held over-hand. The chamfered edge of the templates may form an angle of  $90^{\circ}$ . Every convex template should have its counterpart or concave ; the steel plate to form this is clamped flat on to a face-chuck by a ring with two opposite screws tapped into the plate. The inner circle is turned out with a side tool, consisting of an old saw-file ground to a point on the three faces. The turning is continued till the disc or gauge just drops through ; the inner edge is then chamfered from both sides.

Gauges below 1-5th of an inch in diameter are made from steel wire turned to the form shown in fig. 15, p. 451. The disc end is hardened by heating it with the lamp and blowpipe, and quenching it in oil, and the counter-gauges are most easily formed by a counter-sink rose-bit run in the lathe. The plate of steel is chamfered out alternately from opposite sides, by forcing it up on the socket of the back centre, till the disc will pass through ; the hollow templates are, of course, cut in half before they can be used.

An instrument for measuring the diameter of the discs, &c., is indispensable. It consists of a pair of sliding steel jaws, with a vernier and nonius capable of being read off to thousandths of an inch, and is sold by the watch tool makers.

The moulds for grinding minute lenses are always of brass ; they are also used in pairs. The concave is turned out to gauge, and the convex to the counter-gauge. For small radii the hard gauges are finally used for the last correction, as a turning, or rather scraping tool, and finished by grinding the two moulds together with the finest emery.

There is some difference in practice between the grinding of lenses for long and short radii. In the former, as for telescopes, the glasses are fixed, or have but a very slow rotary movement, and the concave tool is worked over them, either several at a time in blocks, or else, if a shallow curve is required, only on one single disc ; this is placed in

the centre, and a number of smaller pieces of glass planted round the circumference to support the figure, the whole being ground as one. But in the lenses to which this paper particularly refers, the concave tool is invariably caused to revolve rapidly, and the convex lens worked into it. For the longest radii and lowest powers the ordinary foot-lathe is suitable, but this is not so well adapted for grinding and polishing very minute lenses. A bow lathe, such as used by watch-makers for heading their screws and other purposes, is far preferable. This tool is represented half size in fig. 12, p. 451, and scarcely needs explanation; it has a hollow screwed mandril and T-rest, and is held in the vice by the tongue at the bottom. The pulley has three speeds, the smallest of which is  $\frac{3}{8}$  in. in diameter; it should also have a socket for carrying a fixed magnifier, under which the minutest lenses are turned. The best bow is an old fencing-foil ground down so as to be very thin and light. Catgut does not answer well for the string, as it soon gets frayed out over the small pulley. I have found the best packing-twine preferable. During work this is kept slightly moist, and rubbed with a piece of soap; in this way a length of it will outlast a day's work, especially if a little more twisted before it is attached to the wire hook at the top of the bow. A surplus stock of string may be wound about the guard, just above the handle, so that it can be drawn out as required.

The same rules for guarding the extreme edges of lenses should be observed, as described in prism-work, shown by the following examples. Fig. 13 *a*, represents a plano-convex lens which has been made and finished upon a flat disc of glass, to which it has been attached with hard Canada balsam. The two discs are cemented to the stick with black sealing-wax; the lens and supporting disc are rough ground on the zinc plate till they nearly fit the concave gauge; they are then ground in the brass mould till the lens measures very nearly the diameter required, leaving a small allowance for smoothing and polishing.

For double convex lenses, the disc of glass, cemented on a stick as usual, is first ground and polished on one side. A piece of glass tube of suitable size is selected for a handle, and the end of the bore ground out to a similar radius; the polished side of the unfinished lens is then cemented into this concavity, and the lens and tube ground and polished off together, as shown by fig. 13 *b*, taking the same precautions as before to work the lens up to the exact diameter required. The end lines show the rough disc as cemented down. By this method all the marginal errors are taken up by the glass tube-holder, of which an assortment of various sizes will be required, from a minute bugle up to half an inch in diameter. Before using the holders again for other lenses, the end must be ground out on each occasion, so as to increase the diameter of the cup. The lens, when taken out by being warmed, will have a knife-edge perfect in the extreme.

In minute lenses, some difficulty will be experienced in obtaining the measurements by means of gauge instruments, when near the right diameter. I therefore, for small sizes, always use the microscope with micrometer eye-piece, having previously taken the exact size from the diameter of the cell in which the lens is to go. This is very accurate and convenient. After the finished lens is taken out of the holder, if it should be found too large to enter the cell, it may be slightly cemented to the end of a wire, and twisted into a piece of the finest emery paper, held in a hollow form, and the keen edge is taken off till it passes through.

The single fronts for the highest powers, from their form, do not admit of being ground in this way. A piece of brass or steel is screwed into the mandril, and the end turned of a size to enter the cell into which the lens is to go; the end is turned flat, or rather slightly hollow, and the centre taken out. A piece of crown-glass is cemented by its polished side to the flat end, with the best orange shellac, and turned with the diamond point till it nearly enters the cell. The last finish may be given by fine emery paper wrapped round a flat piece of hard wood. The extreme end of the glass is then turned off flat, till it equals the thickness of the intended lens, from the apex to the flat, as measured by the jaws of the gauge; the lens is next turned off by the diamond to the curve required, as shown in fig. 14; and, finally, the chuck is removed, and the lens ground and polished in the mould as usual. In all cases of cementing lenses on to chucks in this way, care must be taken that they are well pressed down, so that the layer of cement may be of the same thinness all round, otherwise the lens will be tilted and out of centering from unequal thickness. When taken off, the lac may be cleaned off with alcohol.

A similar mode of chucking is employed for a plano-concave lens. The polished flat side of the flint-glass is cemented to the chuck, made just to enter the cell; but in order to appreciate the thickness in the centre, the circumference of the disc, after it is turned to fit the cell, is polished with a piece of hard wood and crocus. The concavity is then turned out a trifle deeper than the radius of the circular gauge, till a mere line of light only is observable by looking through the polished edges. The chuck is then removed from the mandril, and the lens thereon ground and finished on the convex tools.

For a double concave lens, such as is used for a triple back, the end of the chuck, instead of being flat, must be convex, to match the radius of the concave surface of the disc of glass that it is to receive, this having been previously ground out and polished independently in the usual way of cementing it on to a stick; but as the curves are shallow, it is best not to turn the disc down to the intended size at once, but leave it much larger than the cell or chuck (fig. 16), and after it is



polished as before directed, the chuck is again screwed into the mandril, and the lens turned down so as to fit the cell; this is done in order to avoid the marginal errors which would arise from working a shallow curve of small diameter.

The same precautions have to be observed in smoothing lenses as directed for prism-work; the finest emery is used, and the requisite moisture applied as required by breathing on the lens, taking care that the accumulation of powder is removed from time to time from where the centre of the mould has been dug out, otherwise this may contain some coarser particles that may cause scratches.

As before remarked, the moulds are made in pairs; the convex and concave are turned to their respective gauges, and then ground together. The diameter of the mould should always rather exceed that of the lens intended to be ground; and the centre, or "pip," is taken out; unless this is done, a prominence is left at this spot, which injures the work. During the smoothing, the two moulds should occasionally be worked together, as this greatly tends to insure the accuracy of figure of the lens; and after this is completely smoothed, the moulds should again be matched, so as to leave them with a polished surface, for a reason to be hereafter explained.

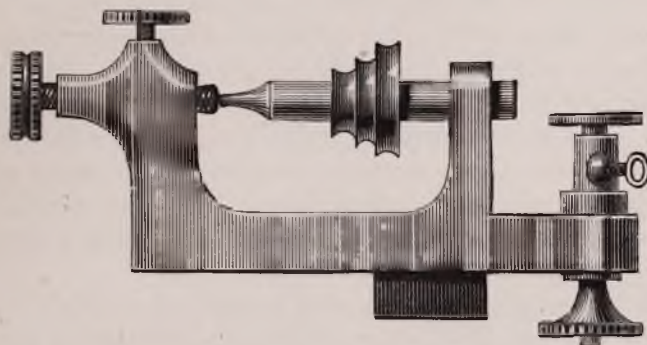
Having got our lens perfectly smoothed and figured, the next operation is the polishing. It is almost impracticable to perform this in the hard mould, and therefore various substances are employed of a less degree of hardness, in which the coarser particles of polishing powder may become imbedded. 1. For the larger sized lenses in microscope work, beeswax, hardened with some resin and finely-washed ochre, is very suitable, but for medium sizes this is too soft and yielding. 2. A mixture of shellac and washed putty-powder is therefore employed, which is very enduring. These are melted together and stirred diligently; the shellac is added until the whole arrives at the consistence of thick paste; and as the lac is apt to burn, to prevent this a lump of beeswax should be thrown into the mass. This does not actually mix with the other ingredients, but lessens the risk of spoiling the composition by overheating; when cool enough the mass may be rolled into sticks between two greased boards.

For the very smallest lenses, such as the fronts of a 1-25th and a 1-50th, the last composition is still too soft and fragile to maintain a true figure. The polishing mould is therefore, for these, made in the end of a rod of pure tin, which is cut out into a nearly hemispherical cup by the appropriate steel gauge; the "pip" is removed with a needle point.

The wax-polishing bed is turned out to the required radius, and finished by scraping with the steel gauge; but as the material is somewhat yielding, the lens soon plays to the mould and keeps its figure during the polishing.

The second composition is very hard and brittle, and does not yield at all, and as the body is composed of the hard oxide of tin, this would speedily injure the gauges if used as cutting tools. The method that I have adopted for forming the polishing moulds from this substance is as follows:—A lump of the material is fastened by heat into a ferrule, or hollow cup, running in the lathe; the end is then turned either convex or concave, and of a diameter suitable for the lens to be polished; the convex or concave mould, as required (which has been worked off at last near to a polish, as before explained), is then screwed on to a handle, and held in a flame till, when touched with the moistened

Fig. 12.



a.

Fig. 13.

b.



Fig. 14.

Fig. 15.

Fig. 16.



finger, it hisses smartly; a morsel of tallow is then put on the rough-turned composition to prevent adhesion, and the hot mould worked and rotated over it in every direction till cold; when removed the polisher will have taken the exact form of the heated mould, and have acquired a fine polish. For either convex or concave lenses the "pip" is taken out as usual, and it is advisable to make a few concentric scratches in the polisher if of large diameter.

As the mixture of crocus and putty-powder, recommended for polishing, is apt to cling in these moulds if applied at once, I first use the putty-powder alone; this cleans the hard polish off the face, and the operation may then be continued with the mixture.

One great advantage of this composition for a polishing mould is the decided way in which it maintains a true figure; for, unlike any other of the kind, it undergoes a very slight degree of wear, so that the face is always kept clean; and any number of lenses of similar form and radius may be polished in the same tool without having to alter or mend the figure, and perfect accuracy is the result. The composition is now generally known, but Mr. James Smith is the original discoverer of it. For the last degree of polish I sometimes rub a thin layer of pure soft beeswax in the mould, and smooth it down to form with the now finished lens; then a small quantity of the very finest washed crocus is applied and the lens worked therein for about one minute. The extra brilliancy of surface obtained in this way is quite appreciable and well worth the pains bestowed, as the operation is not continued long enough to run the risk of injuring the figure.

I have now only to give some directions for cementing the lenses together. The surfaces having been carefully cleaned, the two lenses are laid on a hot plate; a drop of Canada balsam is placed in the concave, the group of bubbles thrown up by the heat removed by a brass point; with this the convex lens (which is equally hot with the other) is lowered slantways into the balsam so as to avoid bubbles, and the two lenses are pressed together; they are now lifted off the plate with a pair of curved forceps held nearly horizontally, and shifted one-quarter round, and then dropped down again. This is repeated a number of times, and the two lenses being exactly of the same diameter, this operation must set them concentric as a matter of course. If the lens is a triple, the opposite surface of the concave must be cleaned and the balsam removed with strong alcohol (turpentine must not be used as it percolates the balsam too easily, and is apt to cause bubbles to appear at the edges), and the same operation repeated as on the other side. When the lens is cleaned with alcohol, and examined edgeways with a magnifier, the three lenses will appear quite concentric, and should just pass into the cell without requiring any force; and if the workmanship has been correct—viz., all the cells turned true from one chucking, and the concaves of equal thickness and concentric with their respective convex lenses, no errors of centering can occur. The usual way of correcting this is by tilting the lenses in the cells, in which they are cemented with Canada balsam; but at the best this is only to some extent substituting one error for another.

#### **404. New Formula for a Microscope Object-Glass by Mr. Wenham.**

—A pencil of rays exceeding an angle of  $40^\circ$  from a luminous point cannot be secured with less than three superposed lenses of increasing focus and diameter, by the use of which combination rays beyond this angle are transmitted, with successive refractions in their course, towards the posterior conjugate focus. Until quite recently, each of these separate lenses

has been partly achromatised by its own concave lens of flint-glass, the surface in contact with the crown-glass being of the same radius, united with Canada balsam ; the front lens has been made a triple, the middle a double, and the back again a triple achromatic. This combination therefore consists of eight lenses, and the rays in their passage are subject to errors arising from sixteen surfaces of glass.

In the new form there are but ten surfaces, and one concave lens of dense flint is used for correcting four convex lenses of crown-glass. As this might at first sight be considered inconsistent with theory, a brief retrospect of the early improvements of the microscope object-glass will help to define the conditions. The knowledge of its construction has been entirely in the hands of working opticians ; and the information published on the subject being scanty, this has probably prevented the scientific analyst from giving that aid which might have been expected.

Previous to the year 1829 a few microscopic object-glasses were made, composed of three superposed achromatic lenses ; but this combination appears to have been used merely with the intention of gaining an increase of power, in ignorance of any principle, and without even a knowledge of the value of angular aperture.

At this time the late J. J. Lister tried a number of experiments, and discovered the law of the aplanatic focus, and proved that, by separating lenses suitably corrected, there were one or two positions in which the spherical aberration was balanced. This was explained in a paper read before the Royal Society in 1829. In the year 1831 Mr. Ross was employed to construct the first achromatic object-glass in accordance with this principle, which performed "with a degree of success never anticipated."

Mr. Ross then discovered that, after he had adjusted the interval of his lenses for the aplanatic focus, that position would no longer be correct if a plate of thin glass was placed above the object ; this focus had then to be sought in a different plane, and the lenses brought closer together, in order to neutralise the negative aberration caused by covering-glass of various thickness. From this period the "adjustment" with which all our best object-glasses are now provided became established. Fig. 17 is the form of object-glass used at this time, consisting of three plano-concave achromatics, whose foci were nearly in the proportion of 1, 2, 3.

No greater angle than  $60^\circ$  could be obtained with this system in an  $\frac{1}{8}$  objective (the highest power then made) for reasons apparent in the diagram. The excessive depth of curvature of the contact-surfaces of the front pair is unfavourable for the passage of the marginal rays ; the softness of the flint-glass forming the first plane was also objectionable. In the year 1837 Mr. Lister gave Mr. Ross a diagram for an improved

"eighth," having a triple front lens in the form shown in fig. 18. By this the passage of extreme rays was facilitated; and in order to

Fig. 17.

Fig. 19.

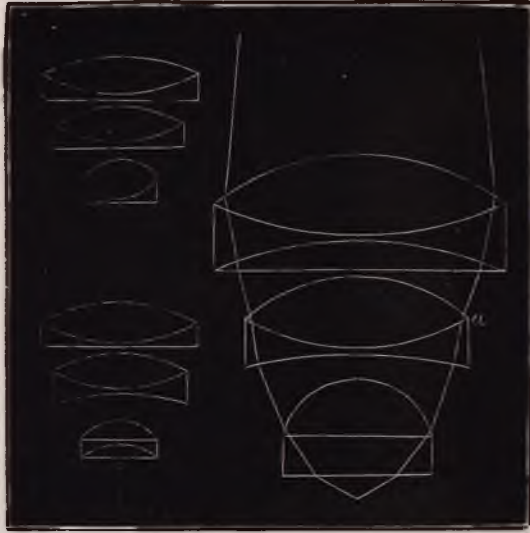


Fig. 18.

diminish the depth of curvature, a very dense glass was used, having a specific gravity of 4.351. Faraday's glass, having a density of 6.4, had been previously tried, but was abandoned on account of a difficulty in

Fig. 20.



Fig. 21.

working it. The polished surfaces of both these qualities of dense glass speedily became tarnished by exposure to the air; and thus the

dense flint concave could only be employed in a triple combination, that is, when cemented between two lenses of crown-glass: this form of front was kept a trade secret, and was not published in any work treating of the optics of the microscope. The front incident surface of the flint of the middle pair was made concave in order to reduce the depth of the contact; and for this reason only, as that surface has but little influence in correcting the oblique pencils, or in producing flatness of field, and may be a plane with an equally good or better result. "Eighths" of this form with angles of  $80^\circ$  were made, and remained unaltered till the year 1850, when larger apertures were called for, and Mr. Lister introduced the triple back lens.

The necessity for this will be seen by the diagram in fig. 18, which shows that the contact-surfaces of the back achromatic are too deep, thus giving great thickness to the lens and limiting its diameter; dense flint would have remedied this to some extent; but its liability to tarnish rendered its use in a pair objectionable. The highest density at this time known, quite free from this defect, was 3.686. By means of the triple back, the final corrections were rendered less abrupt, a greater portion of the marginal rays could be collected, and the aperture of an "eighth" was at once brought up to  $130^\circ$  or more.

At this time the author (Mr. Wenham) had been making some experiments in the construction of an object-glass in the form of fig. 18. Mr. Lister having favoured his "eighth" with an examination, was good enough to communicate his late improvement of the triple back. No time was lost in giving this a trial, the result of which proved that excessive negative aberration or over-correction could readily be commanded with lenses of shallow-contact curves. During these trials all chromatic correction was obtained by alterations in the triple back; for it was found that the colour-correction could not be controlled by a change in the concave surface of the triple front, as the negative power of the flint here appeared to be feeble, requiring a great difference in radius to give a trifling result. For this reason the front concaves were formed of very dense and highly dispersive flint; the cause of this was analysed by a large diagram, with the passage of the rays projected through the combination, starting from the longest conjugate focus at the back. This proved that the rays from that focus passed through the concave flint of the front nearly as a radius from its centre, or in such a direction that its negative influence was almost neutralised. It is well known that a lens may be achromatic for parallel rays, and under-corrected for divergent ones. The utmost extent of this condition was apparent in the object-glass under consideration.

This led the author to the idea of the single front lens of crown-glass, which gave a fine result at the first attempt, as the back combinations to which it was applied happened to have a suitable excess of

negative or over-correction existing in the triple back alone, the middle being neutral or nearly achromatic. Still there was a defect remaining as positive spherical aberration; and this was afterwards cured by giving additional thickness to the front lens, which is now recognised as a most essential element of correction. In a "fifteenth," for instance, a difference of thickness of only  $\cdot 002$  of an inch will determine the quality between a good and indifferent glass. Fig. 20 represents a front lens suitable for bringing the back rays to a focus. The dotted lines indicate the effect of this difference, showing that with a lens of less thickness the marginal rays fall within the central, producing positive aberration as the result.

The single front introduced by the author (Mr. Wenham) is now used by every maker: for several years he could not induce opticians to change their system, though challenged by a series of high powers constructed on this formula for the purpose of proving its superiority. Fig. 19 represents the curves of the first successful "eighth" on this system, having an aperture of  $130^\circ$ , enlarged ten times. On tracing the passage of the marginal rays through the combination, it will be seen that, though the successive refractions are nearly equalised, the contact-surfaces of the middle pair are somewhat deep, though no over-correction existed or was needed here, for this would have required a shorter radius still (the density of the flint in this was  $3\cdot686$ ). If this pair of lenses was not cemented with Canada balsam, total reflection would take place near the circumference of the contact flint surface, cutting off the marginal rays at *a*, and limiting the aperture. It might be argued that practically this would be no disadvantage, as these surfaces are united with Canada balsam, whose refraction is higher than the crown; so that the rays in this case must proceed with very little deviation. But incidences beyond the angle of total reflection may be considered detrimental, as they imply excessive depth of curvature; this can be discovered by looking through the front of an object-glass held close to the eye, any air-films in the balsam near the edge of the lens appearing as opaque black spots.

At the commencement of the year 1873, the author caused a few object-glasses to be made, with a middle of the form of fig. 21, the performance of which was very satisfactory. In this the extreme rays pass at more favourable incidences, and within the angle of total reflection. The upper lens is of dense flint.

When the experiments on the single front were concluded, and the remarkable corrective power of the triple back in conjunction therewith had been proved, the next attempt was to make the middle also a single lens, leaving the entire colour correction to be performed by the one bi-concave flint in the back. After numerous trials it was found that though something like over-correction or negative aberration could be

obtained with the back, in the degree requisite for balancing the under-correction of the single middle and front when set at the prescribed distance of the aplanatic focus, yet by trial on the mercury globule all the results invariably displayed two separated colour-rings; these could not be combined by alteration in the radius of the lenses. By projecting the blue or red, or visible rays of greatest and least refrangibility through the system, the cause became apparent. The left-hand section of this object-glass is shown in fig. 22. The rays from the focus are slightly divided by the first front surface. On emerging from the back the separation is increased; the red ray ( $r$ ) is outwards, and the more refrangible or blue ray ( $b$ ) inwards. Next, the divergence of these two rays is extended by the middle single lens. The following crown lens extends the angle of divergence so far that the flint lens of the back triple cannot recombine them; and they emerge at two distinct zones, shown by the practical test of the "artificial star" or light-spot reflected from a mercury globule, viewed within and without the focus.

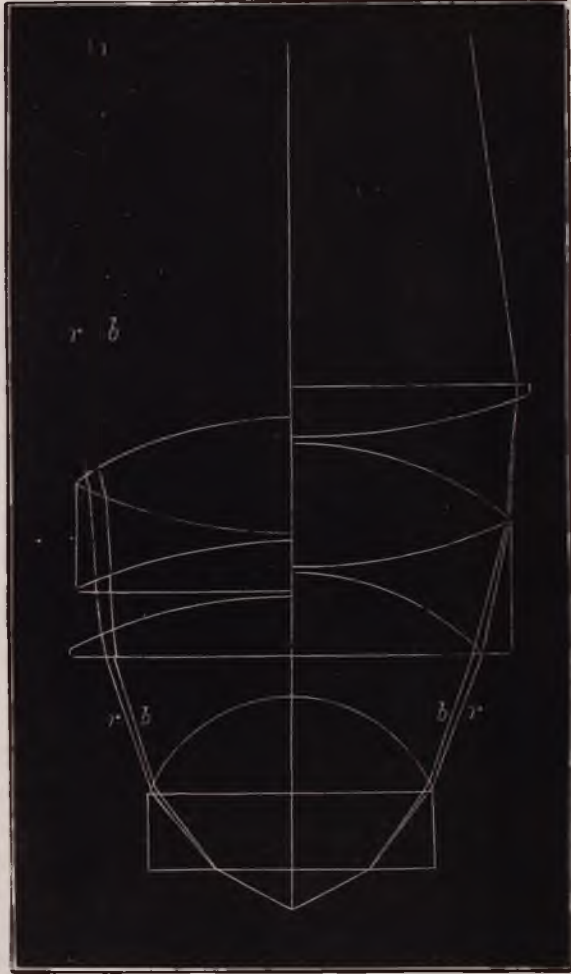
It might be supposed that these rays at their final emergence can be so refracted as to project the blue outwards. A crossing-point would then occur at a fixed conjugate focus in the body of the microscope, at which all rays would be combined, and if this focus was adjusted to that of the eyepiece, achromatism and final correction would be the result. But to meet the various conditions occurring in the use of the microscope, the conjugate focus constantly alters in position, this being affected by every change of eyepiece, length of tube, or adjustment for thickness of cover; therefore a correction for a fixed point cannot be maintained. Achromatism in the microscope object-glass, like that of other perfectly corrected optical combinations, must be the reunion of the rays of the spectrum close to the final emergent surface of the system. The remedy suggested by these experiments appeared to be in a transposition, that is, in placing the over-corrected triple in the middle of the entire object-glass; this would at once cause a convergence of the blue and red rays. A single lens of longer focus at the back would then bring these rays parallel at the point of final emergence.

By projection in a diagram, this condition was apparently realized. The dispersive power of the flint (density 3.686) was taken by the refractive index 1.76 of line H in the blue ray of the spectrum, and 1.70 of the line B in the red ray. The refraction of the corresponding rays in the crown (density 2.44) was 1.53 H and 1.51 B. With these indices the rays are traced in fig. 22. The radii in the right-hand half section are these of an "eighth" of the new form drawn about 15 times the size of the original. The single front is of the usual form, as this is much alike in all cases. The radius or focus of the single plano-convex back is about four and a half times that of the front, and the focus of



the middle (triple) three times. The passage of the blue and red rays at the extreme of the pencil is shown in contrast with the preceding, the separation from the same front being alike.

Fig. 22.



The inner and outer, or blue and red rays, after passing the first surface of the triple middle, meet the concaves of the flint, which refract the blue rays to a greater extent than the red, and cause them to converge (instead of diverging, as in the opposing half diagram), so that at their exit from the triple they meet and would cross, effecting what is known as "over-correction;" but this is so balanced and readjusted by the single back of crown-glass that the rays are finally united, and emerge in a state of parallelism. This form of object-glass is suitable for the high powers, or such as have a cover adjustment, viz., from the

“ $\frac{1}{2}$ -inch” upwards; perfect colour-correction is equally to be obtained in all of them.

It may be asked by some who have devoted their attention to the higher branches of optical mathematics, why the above result should have been worked out entirely by diagrams. But it has been found such a difficult task to calculate the passage of the two rays of greatest and least refrangibility through a combination having sixteen surfaces of glass of three different densities and refractions, that even first-class mathematicians have hitherto shrunk from the attempt.

Diagrams, however, are surprisingly accurate in their capability of indicating causes and results in the microscope and object-glass; for these lenses are minute, with deep curves and abrupt refractions; so that if the projection is worked out some fifty times the size of the original, small errors can be detected. The work should be commenced at the back from a long conjugate focus, which not being a constant distance, may be taken as very near to parallelism. The high powers all have the means of correction within this distance, and perform better with a long posterior focus than with a very short one. The relative indices for the two or more rays should be marked on a large pair of proportional compasses, the long limb representing the sine of the angle of incidence, and the short one that of refraction. Both the sines ought to be set off in a diagram behind, and neither of them in front of the ray in course of projection; this leaves the way clear, with the least confusion of lines.

At the same time a second or counterpart diagram should be at hand, to which the rays only are transferred as soon as their direction is ascertained; with these precautions a mistake is scarcely possible.

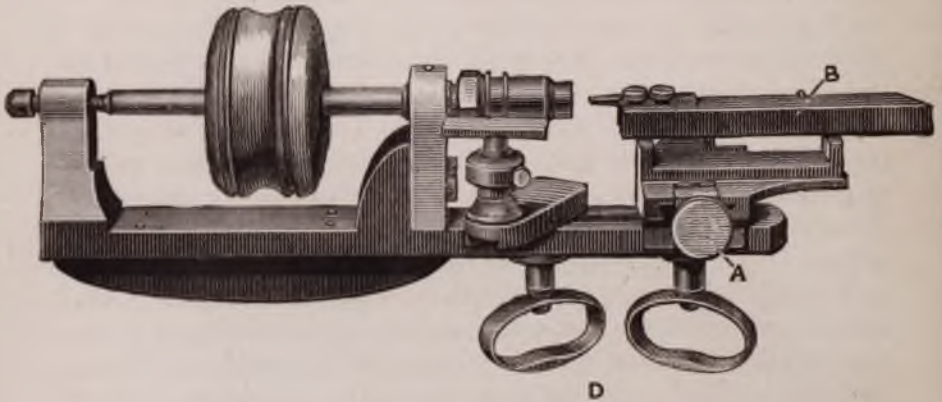
Now it is hoped that some improvements may be effected by this investigation, on account of the simplicity attained in the combination, in which we have two single lenses of crown, whose foci bear a definite proportion to each other; while all the corrections are performed by one concave of dense flint, the acting condition of which is not altered by the influence of any other concaves acting in the combination, and hitherto taking a share of the duty. This one flint is now to be considered singly as the heart and centre of the system in reference to the correction of the rays entering and leaving.

This memoir is of necessity incomplete, for want of definite information concerning the optical properties of various kinds of glass. Nothing of importance has been published since Fraunhofer's Table, containing the refractive indices for each of the seven primary colour-lines of the spectrum for ten kinds of glass. Great advance has been effected since that date in the manufacture of optical glass, a most complete collection of which, of every variety, has been made by the Messrs. Ross, up to the present date. Selected specimens from this will

be worked into prisms, and the relative spectra mapped out by the Fraunhofer lines, leading, it is hoped, to the discovery of a combination of crown and flint glass which shall be free from secondary spectrum or absolutely achromatic ("Proc. Royal Soc.," No. 141, 1873).

**405. Note on Mounting Lenses by Mr. Swift.**—The tool best suited for mounting the lenses in their cells is shown in the accompanying engraving; this can be worked with a drill bow, or can be made to act

Fig. 23.



Lathe as arranged for working.

with the foot, in the way of an ordinary lathe, which is preferable, as it leaves both hands at liberty for manipulating with the slide-rest carrying the cutter. The slide-rest, as will be perceived by the engraving, is of a very simple construction; the two milled-heads, marked AA, are for the purpose of adjusting the cutter to the diameter of a cell required to receive the lenses. These screws act in opposite directions upon a dove-tail slide, moving at right angles to the mandril of the lathe. B is

a bar of metal, about 6 inches long, upon which the cutter is fixed. This bar is planed out  $\Lambda$  shape, and bears upon two supports of similar form. By this means a sliding motion is obtained, in a direct line with the axis of the mandril, upon which the object-cell is screwed. By moving the milled-head screw in fig. 24, the point of which bears against a stop, any depth of cut required for the combinations can be obtained. The bar B, fig. 23, when in use, must be held firmly on its



The opposite side of the right part of the lathe represented in Fig. 23, under a, and showing the set-screw referred to in the text.

fitting, and pushed along until the cut ceases by the point of the milled-head screw coming in contact with the stop before mentioned. Thus,

the required depth of the cell can easily be obtained. It is best, before proceeding to mount the combinations in their cells, to see that the mount takes a good bearing against the chuck in which it is screwed. If this precaution is not taken it often happens, after the objective is nearly finished, that the lenses first mounted are found to run untrue, owing to the main screw of the mount taking a fresh bearing by the continued screwing and unscrewing it off and on the lathe. It will be seen that a T-rest, D, is used in addition to the slide rest. This is handy for making chucks for turning out the back of the cells, &c. A rib is seen under the frame or base of the lathe by which it is held in the vice. If worked by the foot, a wheel treadle can be easily fixed underneath the board to which the vice is bolted.

The two following sections have been also furnished by Mr. Swift.

**406. Formula for a Quarter-Inch Objective of Eighty-Five Degrees of Aperture, the Curves of which are given in Radius.**—1. Back triple combination. Curve of back surface of crown lens,  $\cdot 525$ . Contact surface,  $\cdot 225$ . Contact surface of lower crown lens,  $1\cdot 500$ . Incident surface,  $\cdot 59$ . Working diameter of back crown,  $\cdot 325$ . Incident crown working diameter,  $\cdot 34$ . These lenses must be worked up to a sharp edge at the above diameters, for the purpose of getting the requisite thickness of the lenses, which, in all optical combinations of this description, is the only method by which it can be readily effected without the necessity of dismounting the lens from the lathe or stick on which it is ground, to gauge its thickness by means of a master-gauge. The finished diameter of these lenses is  $\cdot 315$ . Thickness of edge of flint at this diameter,  $\cdot 080$ . The middle combination of this objective is composed of two lenses,—a double convex crown of  $\cdot 225$ , of equal curves, and a plano-concave flint. These, as a matter of course, like the back combination, are cemented together. The working diameter of the crown lens is  $\cdot 27$ , when worked to a sharp edge, as before described, the finished diameter being  $\cdot 26$ . Thickness of edge of flint, when reduced to the finished diameter, must be  $\cdot 070$ . The front glass is a plano-convex crown lens of  $\cdot 115$  radius, which is worked to a half sphere; its diameter, therefore, being equal to double its radius. The combinations of this objective, together with the front lens, are set in their cells against shoulders, which renders the setting or centering of the lenses, after a little practice, a very easy operation. The cell, carrying the front lens for convenience of adjustment, is best screwed to a piece of triplet-drawn tube, which can be made to fit over the cylindrical part to which the back and middle cells are screwed. By this contrivance, the proper point of adjustment on mercury can be readily obtained, by shortening the plain end of the tube fitting until the diffraction rings become equal on both sides of the focus of the objective. The curves of this objective are computed to suit a density of flint  $3\cdot 9646$ , crown

2·540. This flint and crown glass is made by Messrs. Chance, of Birmingham, and can be obtained from their agents, Messrs. Claudet and Houghton, High Holborn, or of Mr. Jackson, Glass Warehouse, Oxford Street, who will supply it by order, in sheets of suitable thickness, thus saving the necessity and expense of slitting.

**407. Formula for One-inch Objective of Twenty-five Degrees of Aperture, the Curves of which are given in Radius.**—The posterior or back of this objective is composed of a triple combination. The front or anterior is a plano-convex crown lens and a meniscus flint. The curve of the back surface of the posterior crown lens is  $\cdot76$ . The curve of the next two surfaces is  $\cdot525$ . Contact surface of incident crown  $3\cdot25$ . Incident or outside surface,  $2\cdot5$ . The back surface of the posterior crown should be worked  $8\text{-}10$ ths of an inch in diameter, to insure accuracy of figure. Previous to grinding the contact surface of this lens, the diameter must be reduced to  $\cdot615$ , then worked to a sharp edge, which will give the thickness required for this lens. The working diameter of the incident plate is  $9\text{-}10$ ths. This, as a matter of course, will be ground to a sharp edge, as before described, for the purpose of getting the required thickness. The best method for an amateur to adopt would be to work the lens on a hard pitch pallet one inch or less in length. The lens is not so liable to tilt in working in the tool as it would be if the ordinary length of stick employed for this purpose were used. This method also applies to the shallow surface of the flint. Diameter of the posterior lenses when finished is  $5\text{-}10$ ths; thickness of edge of flint at this diameter will be  $1\text{-}10$ th of an inch. Back surface of anterior flint is  $\cdot41$ . Next two, or contact surfaces,  $\cdot21$ . Working diameter of front crown,  $4\text{-}10$ ths. Finished diameter  $\cdot38$ . Thickness of anterior flint, at the finished diameter, measuring from back surface to front edge,  $\cdot125$ . Separation between the lenses is  $7\text{-}10$ ths. Density of flint,  $3\cdot64$ . Density of crown,  $2\cdot540$ .

TABLES  
FOR PRACTISING THE USE  
OF THE MICROSCOPE  
AND  
MICROSCOPICAL MANIPULATION.

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All who desire to become practically familiar with the use of the microscope, and to learn how to observe, are strongly recommended to submit to the routine which a conscientious performance of the experiments given in the following Tables necessarily involves. The author is fully persuaded that the patient prosecution of the course recommended will enable the student to obtain a practical acquaintance with the elements of microscopical enquiry, which it would not be possible for him to acquire so readily by reading, or indeed by any other plan. Each table will require from two to three hours.

## TABLE I.

ARRANGEMENT OF THE INSTRUMENT FOR OBSERVATION.—DRAWING AND MEASURING OBJECTS.

1. Arrange the microscope for examining objects by transmitted light.—§ 34, p. 29, pl. XIII, fig. 1, p. 22.
2. Examine the objects upon the slide\* with the inch, and afterwards with the quarter of an inch object-glass, using first the shallow, and afterwards the deep eye-piece.—§§ 4, 5, 6, p. 7, pl. I, figs. 3, 4, 7.
3. Arrange the mirror in such a manner that the rays of light may pass through the object in a direct course or obliquely.—§ 10, p. 11, pl. VI, fig. 6, p. 14.
4. Examine the same object under the quarter of an inch object-glass with the achromatic condenser, and afterwards without the use of this instrument.—§ 37, p. 30, pl. XV, fig. 2, p. 26.
5. Draw upon paper some of the objects† on the slide.—§ 41, p. 31.
  - a. Judging of the size of the paper by the eye alone.
  - b. By placing the paper on a level with the stage.
  - c. By measuring with a pair of compasses, p. 355.
  - d. With the aid of the neutral tint-glass reflector.—§ 44, pl. XVII, fig. 4, p. 34.
6. Ascertain the diameter of the objects upon the slide‡ using the inch object-glass and stage micrometer divided to 100ths of an inch, with the aid of the neutral tint-glass reflector.—§ 44, p. 33, §§ 62, 64, p. 43, pl. XVII, figs. 7, 8; pl. XV, fig. 4, p. 26.
7. What are the magnifying powers of the two French and English object-glasses on the table? ||—§ 63, p. 44.
  - a. With the shallow eye-piece.
  - b. With the deep eye-piece.
8. Measure the angles of the crystals¶ upon the slide.—§ 266, p. 218; pl. LVI, figs. 6, 7, 8, p. 218.

\* Scales from the wing of a butterfly.

† Tracheæ from a caterpillar.

‡ Fragments of human hair.

|| French quarter and one inch.—English quarter and one inch.

¶ Crystals of cholesterine.

## TABLE II.

EXAMINATION OF OBJECTS BY DIRECT OR REFLECTED LIGHT,  
TRANSMITTED LIGHT, AND POLARISED LIGHT.

9. Examine the objects upon the slide\* and carefully note the different appearances produced by examining them :—
1. *By reflected light* as opaque objects employing
    - a. The bull's-eye condenser.—§ 27, pl. XVI, figs. 2, 4, p. 28.
    - b. The Lieberkuhn and a stop.—§ 30, pl. XV, fig. 1, p. 26.
  2. *By transmitted light*, employing
    - a. Direct rays.
    - b. Oblique rays.—Pl. XIII, fig. 1, p. 22.
  3. *By polarised light*.
    - a. Employing the polariser and analyser only.—§ 23, pl. XVII, figs. 1, 2, p. 34.
    - b. After placing beneath the object a plate of selenite.
10. Examine some of the same crystals in different media, as described in §§ 136 to 143, pl. XXIII, p. 80.
- a. In air.—§ 141, p. 86.
  - b. In water.—§ 142.
  - c. In turpentine, oil, or Canada balsam.—§ 143.
11. Examine the different appearance of the globules of potato-starch, and pollen grains from different plants in air, water, and Canada balsam.
12. Examine some minute globules of mercury illuminated by reflected light, under a half-inch object-glass.
13. Notice the microscopical characters of air-bubbles and oil-globules† and examine them by reflected and by transmitted light.—§ 137, pl. XXIII, figs. 10, 11, 12, 13, 14, p. 80.
14. Follow the directions given in pp. 81, 82, 83, for the examination of common objects.

\* Spherical crystals of carbonate of lime or starch globules.

† Small air-bubbles can be obtained by shaking a little gum-water in a bottle. A drop may then be placed upon a glass slide. *Milk* affords oil-globules in abundance.



## TABLE III.

## ON MAKING CELLS FOR PRESERVING MICROSCOPICAL SPECIMENS.

15. Make a paper cell and attach it to the glass slide.—§ 114, p. 70.
16. Make a thin cell with the aid of marine glue, and another with tinfoil.—§§ 117, 118, p. 70.
17. Make some square thin cells of Brunswick black, and some circular cells with the aid of Mr. Shadbolt's apparatus.—§ 116, p. 70, pl. XX, fig. 5, p. 54.
18. Cut some squares of thin glass, with the writing diamond.—§ 119, p. 71.
19. Cut some circular pieces of thin glass, using the brass circles.—§ 119, p. 71, pl. XX, figs. 6, 8, 9, p. 54.
20. Make some thin glass cells in the manner directed in §§ 124, 125, p. 72, pl. XXI, fig. 3, p. 76, and when complete, grind the upper surface upon the emery slab, fig. 6.
21. Cut with the glazier's diamond some slips of glass, three inches by one inch, for slides.—§ 119, p. 71, pl. XX, fig. 6, p. 54.
22. Make a cell of thick glass in the manner described in §§ 127, 128, p. 74, pl. XXI, figs. 5 to 9, p. 76. Pl. XXII, figs. 3, 4, p. 78.
23. Make a deep cell of gutta-percha. The gutta-percha must be softened in hot water and then moulded upon some object the size of the required cell.—§ 131, p. 75.

## TABLE IV.

ON MAKING MINUTE DISSECTIONS.—CUTTING THIN SECTIONS OF  
TISSUES FOR MICROSCOPICAL EXAMINATION.

24. Trace the nerves in the portion of tissue on the table.\* Pin it out on a loaded cork, and dissect it beneath the surface of water with the aid of a strong light condensed upon it by the large bull's-eye condenser in the manner directed in § 144, p. 91, pl. XXII, figs. 4, 5, p. 78.
25. Cut some very thin sections of the different soft tissues upon the table.†—§ 147, p. 92.
- a. Using the scissors.—Pl. XIX, figs. 5, 6, 7.
  - b. Using the double-edged knife.—Pl. XVIII, figs. 8, 9, 10.
  - c. Using Valentin's knife.—Pl. XIX, figs. 1, 2.
- All these instruments must be well wetted before the section is removed.—§ 147.
26. Place some small pieces of tissue in the compressorium and dissect them under the microscope in the manner described in § 149, p. 96, pl. XXV, figs. 3, 4, p. 92.
27. Make some thin sections of wood with the aid of the simple section cutter alluded to in § 156, p. 99, pl. XXV, fig. 6, p. 92.
28. Place some of the sections of pith or bone in thin cells, cover them with thin glass, and then let them be preserved as dry objects.—§§ 141, 152, pp. 86, 97.
29. Ascertain the effect of the different preservative solutions upon the appearance of the sections in the microscope.—§§ 99 to 113, p. 64. Place some of the sections which have been allowed to soak for half-an-hour in the fluid in which they are to be preserved in thin glass cells, and apply the thin glass cover, observing the precautions detailed in pp. 82, 136. Remove the fluid outside (with the help of blotting paper), and anoint the edge with Brunswick black, which must be applied with a small brush.
30. Make a thin section of the injected tissue on the table and preserve it in glycerine, or in gelatine and glycerine.—§§ 100, 105, 106, p. 64. Dry another section and mount it in Canada balsam.—§ 143, p. 88.

For directions for the preparation and examination of various tissues, *see* pp. 138 to 151.

\* The skin or muscular tissue of any small animal, a part of a frog.

† A piece of tendon, cartilage, kidney, and liver of a sheep. These may be easily obtained of the butcher.

## TABLE V.

KIDNEY.—MUSCULAR FIBRE.—PIG'S SKIN.—PITH.—WOOD.—SPIRAL  
VESSELS.—VALLISNERIA.

31. Make thin sections of the sheep's kidney upon the table, and after washing them, subject them to examination with the inch, and afterwards with the quarter. Some may be examined in water and others in glycerine, one section should be mounted in the mixture of gelatine and glycerine.—§ 106, p. 67. Observe the different characters of the tubes in the central and in the cortical portions of the organ, and endeavour to make out the following structures:—*Epithelium, basement membrane of the tubes, Malpighian bodies, and capillary vessels lying between the tubes*, p. 162. The arrangement of the vessels may be satisfactorily demonstrated in an injected specimen.—Table VII.
32. Take a very small fragment of the muscular fibre of the skate or eel, and after tearing it up with needles, moisten it with water, and cover it with thin glass. Endeavour to find elementary fibres in which the tube of *sarcolemma* remains entire while the *sarcous* tissue within is ruptured.—§§ 219, 224, p. 142, pl. XXXIV, fig. 3, p. 146.
33. The portion of pig's skin on the table has been allowed to dry by exposure to the air. Thin transverse sections are to be removed with a sharp knife, and subsequently moistened with water. In this manner a very thin section may be obtained, which soon regains its normal appearance. It may be mounted in any of the preservative fluids before alluded to.—§ 150, p. 97.
34. Cut thin sections of the cornea and sclerotic of the eye which have been allowed to dry after having been pinned out on a board; soak them in a drop of water for twenty minutes or more, and examine them first with an inch object-glass and afterwards with a quarter.—§ 150, p. 97.
35. Cut a thin section of the pith of the rush and examine it as a dry object; afterwards place it in fluid. Observe the air within many of the cells.
36. Demonstrate the circulation in the cells of *vallisneria spiralis*.—§ 263, p. 198, pl. XLVI, figs. 6, 7.
37. Wash some pieces of the sea-weed in plain water, and preserve some of them in glycerine, and others in a solution of chloride of calcium, p. 68.

## TABLE VI.

MAKING THIN SECTIONS OF BONE AND HAIR, AND MOUNTING THEM IN CANADA BALSAM.—MOUNTING DIFFERENT PARTS OF INSECTS.—SEPARATION OF DEPOSITS FROM FLUIDS.

38. Cut some thin sections of dry bone with the saw and grind them to the required degree of tenuity, by rubbing upon a fine oil stone, or between the hones. Water, but not oil, is to be used.—§ 152, p. 97; § 218, p. 141.
39. Upon microscopical examination they will be found covered with numerous scratches, which must be removed by rubbing the sections upon a dry hone, and afterwards upon a piece of good plate-glass.—§ 152, p. 97.
40. When the sections of bone are sufficiently smooth, mount one of them at once in balsam, and treat another section with turpentine before immersing it in the balsam. Compare the different microscopical characters of these two specimens, p. 89.
41. Cut some thin transverse and longitudinal sections of hair, according to the directions given, and examine them under the quarter of an inch object-glass. These may be washed in water and mounted in Canada balsam.—§ 155, p. 98.
42. After drying several portions of the insects in a capsule over the water-bath (claws, antennæ, wings, eyes, spiracles), moisten them with turpentine and mount them in Canada balsam.—§§ 143, 244, 245, 246, pp. 167, 168.
43. After the deposit suspended in the fluid in the conical glass has subsided,\* a portion is to be removed with the pipette and placed in a cell, or in the animalcule cage, for examination.—§ 159, p. 100, pl. XXVI, fig. 3.
44. The fluid may then be allowed to evaporate spontaneously or by placing the slide under a bell-jar over sulphuric acid, pl. XXIV, fig. 5, p. 88, and the residue mounted in Canada balsam.
45. Subject to examination, under a quarter of an inch object-glass, some of the infusoria and other organisms, in the specimen of the water on the table.†—p. 186.

\* Small marine shells, sand, &c.

† Water containing a few small pieces of animal and vegetable matter about the size of a pin's head, which had been kept in a warm light place for several days.

## TABLE VII.

OF INJECTING WITH OPAQUE AND TRANSPARENT MATERIAL.—PRUSSIAN  
BLUE FLUID FOR INJECTION.

46. Arrange the injecting apparatus conveniently (§ 165, p. 102) and proceed to inject the artery supplying the eye-ball of the ox's eye on the table, with size and chromate of lead.—§§ 167, 171, p. 105 ; § 186, p. 14.
47. *Eye*.—Introduce the pipe into the vessel running close to the large optic nerve, and tie it carefully, observing the precautions detailed in p. 115. The eye must be allowed to remain in warm water until warm through, and the injecting material prepared in the manner described ; it is to be mixed with melted size and strained immediately before use. When the injection is complete the eye is to be placed in cold water. Should it become very much distended by the accumulation of the injection within it, a puncture may be made in the cornea, which will permit the escape of the aqueous humour, and then the vessels may be more completely injected.—§ 186, p. 114.
48. Prepare some Prussian blue injection fluid.—§ 178, p. 109. The fluid should contain no visible deposit. Prepare some finer injecting fluid, according to the directions given in p. 363, and inject.
49. *Frog*.—Insert an injecting pipe into the aorta of the frog in the manner described in § 186, and slowly inject the fluid. Another frog is to be injected with the finer injecting fluid, p. 363.
50. The specimens having been completely injected portions may be submitted to microscopical examination.—§ 212, p. 136.
51. The globe of the eye may be opened and portions of the following tissues removed with scissors :—*ciliary processes* situated behind the iris, the *retina* (the most internal of the membranes within the globe), the *choroid* (external to the delicate retina). These, after having been carefully washed in water, may be submitted to examination in fluid with the inch object-glass.
- The ciliary processes and the choroid require to be well washed in order to remove the black pigment with which they are covered.
52. Portions of the lung and intestines of the frog may be removed, and after being well washed, may be submitted to examination. These are to be examined by transmitted light, and may be placed in glycerine. The inch object-glass should be employed in the first instance, and afterwards the quarter.

## TABLE VIII.

ON PREPARING AND MOUNTING MINERALOGICAL SPECIMENS FOR  
MICROSCOPIC EXAMINATION. BY MR. F. RUTLEY.

53. Grind down and mount a thin section of marble (ordinary marble, such as is used for chimney-pieces), § 267, pp. 212, 215.\*
54. Examine by trans. light and by refl. light, and note cleavage planes.
55. Examine it by polarised light, p. 220, and note the twinning bands.
56. Grind down and mount a section of basalt containing felspar crystals, visible to the naked eye, and examine it by transmitted light. The dark crystals or patches may be magnetite, titaniferous iron, pyrites, or pseudomorphs after felspars, augite, olivine, &c., p. 233.
57. Examine by transmitted light, during the revolution of a Nicol's prism, beneath the stage, no analyser being used. Note the dichroism of any hornblende that may be present, or that of any crystals or plates of magnesian mica, if cut transversely to the crystallographic axis. Note, also, the general absence of dichroism in the augite, and if any good transverse sections of crystals of that mineral be present, measure the angles of the prism, either by means of a goniometer or by the camera and a protractor. Note the rough surfaces of any olivine crystals and their rounded angles.
58. Adjust the analyser and observe the twin banding in the felspar crystals (Plagioclase). Note whether any of the augite or olivine crystals, p. 227, exhibit a pieced structure, by polarised light; if so, they are probably pseudomorphs. If they be of serpentine, observe the neutral tints in which they polarise.
59. Examine a smoothly-ground chip of the same rock to ascertain the nature of the opaque matter. For this purpose, a bull's-eye condenser or a silver reflector may be used; if the surfaces look brassy and tolerably bright, pyrites, or copper pyrites is probably present. Test the substance by isolating a small fragment of it, and examining it before the blow-pipe.
60. Scrape out a little of the supposed serpentine from the rock and examine it for magnesia.
61. If magnetite be suspected, hold a chip of the rock near a magnetic needle, keeping a sheet of paper between it and the mouth and nose, so that the breath may not cause any deflection.
62. Note the forms of the sections of magnetite, which vary with the directions in which they have been cut through the crystal.

\* During the grinding of the sections they should be frequently washed and examined with a lens. The different forms of any imbedded crystals should be carefully noted, the hardness of doubtful minerals tested with the point of a knife and reagents applied if necessary. The facilities offered for the application of such simple tests is one of the great advantages which the student derives from preparing his own sections.

## TABLE IX.

ON EXAMINING AND MOUNTING MINERALS FOR THE MICROSCOPE.  
BY MR. F. RUTLEY.

63. Grind and mount a section of granite. Observe the strong chromatic polarisation of the quartz, and the darkness which ensues in a transverse section of a quartz crystal when the Nicols are crossed. Note, also, the twinning of the felspars, the orthoclase presenting only two twin lamellæ (Carlsbad type), while any plagioclase crystals which may be present show numerous bands.
64. Examine the quartz under a quarter inch objective, to ascertain the presence or absence of minute cavities, and note their nature, and, if containing fluid, the relative size of the cavity, as compared with that of the bubble, § 272, p. 235.
65. Grind and mount a section of hornblende schist, syenite, or diorite, and examine it under the microscope during the rapid revolution of the polarising prism only, and note the strong dichroism of the hornblende. If any good transverse sections of hornblende crystals occur, measure the angles of the prism and compare with the measurements of the augite in the basalt already examined. Also measure the angle of intersection of the corresponding cleavages and compare them with that of the augite.
66. Grind and mount a section of pitchstone, and make a drawing showing some of the included crystals and microliths, p. 233. After making the outline, by means of the camera, remove the preparation and replace it by a Maltwood's or other finder. Note the spot indicated by the finder on the margin of the drawing. Remove the finder and shift the stage (if a mechanical one).—§ 67, p. 47.
67. Replace the finder; verify the correct spot. Replace the preparation and complete the drawing, filling in the detail without the assistance of the camera.
68. Grind and mount a section of phonolite. Note how the transverse sections of the nepheline crystals become dark when seen between crossed Nicols, while sections of the same mineral, cut in a different direction, do not. Compare the sections of nepheline with sections of apatite which may be found in slices of such rocks as granite, syenite, diorite, basalt, &c.
69. Grind and mount a section of felstone, and examine it by ordinary, transmitted, and then by polarised light.
70. Prepare a section of minette (Mica Trap) and compare it with the preceding section.
71. Compare sections of quartz, porphyry, and granite with the two preceding sections, p. 231.

72. From the foregoing observations make a tabulated list of the rocks examined, and of the minerals which any two or more of them contain in common, writing opposite the name of each mineral its chemical composition, and the crystallographic system to which it belongs.\*

## TABLE X.

### OF THE USE OF CHEMICAL REAGENTS IN MICROSCOPICAL INVESTIGATION.

73. Test the powder on the glass slide for the presence of carbonate, (chalk), using the precautions detailed in § 309, p. 261.
74. Each of the solutions† is to be diluted and separately tested for sulphates, phosphates, and chlorides.—§ 309, p. 261.
75. Make some crystals of common salt.  
*a.* By evaporating a solution rapidly to dryness on a glass slide.  
*b.* By allowing the solution to evaporate slowly until crystals form, when a thin glass cover may be applied and the crystals subjected to microscopical examination.—§ 314, p. 264, pl. LVIII, fig. 8, p. 218.
76. Fill one of the little bottles with capillary orifices with acetic acid.—§ 307, p. 260.
77. Examine some of the white fibrous tissue‡ under a quarter, before and after the addition of a drop of acetic acid.—§ 297, p. 254.
78. Ascertain the effect of a solution of caustic soda§ upon the cells on the slide.—§ 301, p. 257.
79. Describe the microscopical characters of the structures upon the glass slide,|| and sketch roughly their most important characters.—§ 57, p. 39.
80. What is the nature of the substances forming the deposit in the glass?¶

\* The above scheme for the preliminary examination of minerals and rocks under the microscope, may be of use to the beginner if carefully followed out. It must, however, be considered merely as a rough sketch, and as his studies progress he will have to familiarise himself with many minerals and rocks which are not mentioned here, and with other methods of research. In Tables VIII, IX, only the most salient microscopic features are considered. Methods for ascertaining the precise nature, even of the *common* rock-forming minerals, must be sought in books specially devoted to the subject.

† Sulphate of soda, phosphates of lime, and ammonia and magnesia, and common salt dissolved in water to which a few drops of nitric acid have been added.

‡ The white tendon of a muscle of any small animal, as a mouse, &c. § Cuticle.

|| Eye and proboscis of fly.

¶ Potato-starch, blanket-hair, feathers.



## EXERCISES FOR MORE ADVANCED STUDENTS.

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The foregoing tables contain exercises for commencing students, but any one who has been through them will be able to practise different branches of special inquiry not included if he refers to the different parts of the work in which these special matters are treated of :

On staining tissues, *see* § **196**, p. 123.

On collecting and dredging, *see* § **254**, p. 175.

On keeping the lower animals in aquaria and vivaria, *see* § **255**, p. 182.

On examining the lower animals during life, *see* § **255**, p. 186.

On demonstrating the contractility of muscle and ciliary movements, *see* § **258**, p. 189, § **261**, p. 193.

On demonstrating vegetable tissues and the circulation in the cells of certain plants, *see* § **263**, p. 198.

On the movements of living beings, and on vital movements, *see* p. 201 to p. 206.

Of the microscopic structure of iron and steel, *see* § **273**, p. 236.

On preparing fossils for microscopical examination, *see* § **274**, p. 237.

On making and recording microscopical observations, and of the fallacies to be guarded against, *see* § **277** to § **280**, p. 239.

On spectrum analysis, *see* § **318** to § **322**, p. 269.

On taking photographs of microscopic objects, *see* part V, from p. 284 to p. 342.

On using the highest magnifying powers, *see* § **355** to § **363**, p. 344.

On preparing specimens for examination under the highest powers, *see* p. 366.

For new views concerning the structure and mode of growth of tissues, *see* p. 381.

For new views concerning the nature of life, *see* § **387**, p. 397.

For new views on the structure and action of a nervous apparatus, *see* p. 406.

## APPARATUS REQUIRED IN MICROSCOPICAL INVESTIGATION.

### I.—The Microscope.

#### NECESSARY.

1. *Microscope* with large stage, firm tripod stand, coarse and fine adjustments, double mirror, and arrangement for inclining body; generally termed the *Student's Microscope*.—§ 15, p. 13, pls. II, III, IV.

The student's microscope with two powers and bull's-eye condenser costs from five to ten guineas.

2. Pocket Clinical or Field Microscope, in case, with pipettes, test-tubes, &c.—§ 20, pl. X, p. 20.
3. *Object-glasses*.—1. *The inch*, magnifying from 30 to 40 *diameters*, the glasses of which can be removed one by one, so that lower powers can be obtained.  
2. *The quarter* of an inch magnifying about 200 *diameters*. These glasses should *define well*, the field should be *perfectly flat* and free from *coloured fringes*, and they should admit a sufficient amount of light.—§ 6, p. 8, pl. 1, figs. 7, 8, p. 6.

#### ADVANTAGEOUS.

*Large microscope* provided with movable stage and all the modern improvements.—§ 16, p. 13, pl. VII, p. 16.

With two powers, this instrument costs from twenty to thirty guineas.

*Binocular microscope*.—§ 17, p. 8, pl. V.

*Two-inch object-glass*.—§ 6, p. 8.

*Eighth of an inch*.

*Twelfth of an inch*.

*Twenty-fifth*.

### II.—Accessory Apparatus.

4. *Diaphragm plate*.—§ 14, p. 12, § 36, p. 30, pl. I, fig. 9, p. 6.
  5. *Bull's-eye condenser*.—§ 27, p. 26, pl. XVI, figs. 2, 4, p. 28.
  6. *Universal condenser*.
- Gillett's achromatic condenser*.—§ 39, p. 30.
- Polariscope*.—§ 23, p. 22, pl. XVI, figs. 1, 2, p. 34.
- Spot glass*.—§ 33, p. 28, pl. XV, fig. 3, p. 26.

*For Artificial Illumination.*

## NECESSARY.

7. Small paraffin lamp.—§ 25, p. 25, pl. XIV, fig. 2, p. 24.

## ADVANTAGEOUS.

- Smith and Beck's camphine lamp, or Mr. Highley's gas lamp.—§ 26, p. 25, pl. XIV, fig. 4, p. 24.  
Bockett lamp, pl. XIV, fig. 3, p. 24.

**III.—Apparatus for Drawing Objects.**

8. *Neutral tint glass reflector.*—§ 44, p. 33, pl. XVII, fig. 4, p. 34.  
9. Common hard pencils, steel pens, Indian ink, fine Bristol board, smooth white paper.

**IV.—Apparatus for Measuring Objects and for Ascertaining the Magnifying Power of the Object-Glasses.**—§§ 58 to 66, p. 41.

10. *Stage micrometers*, divided into 100ths and 1,000ths of an English inch.—§ 60, p. 42.  
*Neutral tint glass reflector.*—§ 44, p. 33, pl. XVII, fig. 4, p. 34.  
Nobert's lines, which may be used also as *test objects.*—§ 61, p. 42.  
Maltwood's finder, or the arrangement described in p. 42.

**V.—Instruments and Apparatus for General Purposes.**

11. *Wire retort stand.*—§ 70, p. 49, pl. XVIII, fig. 2, p. 48. *Water bath.*—§ 73, pl. XVIII, fig. 6, p. 48.  
12. *Tripod wire stands.*—§ 71, pl. XVIII, figs. 4, 5.  
13. *Spirit lamp.*—§ 69, pl. XVIII, fig. 3.  
14. *Evaporating basins.*  
15. *Watch glasses.*—§ 85, p. 54.  
16. *Thin glass.*—§ 84, p. 53.  
17. *Plate-glass slides.*—§ 83, p. 53.

**VI.—Instruments for Making Dissections and for Cutting Thin Sections of Soft Tissues.**

18. *Common scalpels.*—§ 74, p. 50. *Valentin's knife.*—§ 77, p. 51, pl. XIX, figs. 1, 2, p. 52.  
18a. *Double-edged scalpel.*—§ 75, pl. XVIII, figs. 8, 9, 10, p. 48. *Spring scissors.*—§ 79, p. 51, pl. XIX, fig. 6, p. 52.

## NECESSARY.

19. *Scissors*.—Ordinary form and two small pair, one with curved blades.—§ 79, p. 51, pl. XIX, figs. 5, 6, 7, p. 52.
20. *Needles* mounted in handles.—§ 80, fig. 3, p. 52.
- 20a. *Needles flattened* near the points.—§ 80, p. 52, fig. 3.
21. *Forceps*.—One pair of ordinary dissecting forceps, and one pair with curved blades.—§ 81, p. 52, pl. XIX, figs. 8, 9, p. 52.

## ADVANTAGEOUS.

- Compressorium*.—§ 149, p. 96, pl. XXV, figs. 3, 4, p. 92.
- Section cutter*, p. 92.
- Freezing apparatus*, p. 94.

*For Dissecting under Water.*

22. *Glass dishes* of various sizes from an inch to two inches in depth.—§ 144, p. 91.
23. *Loaded corks*.—§ 145, p. 91, pl. XXV, fig. 2, p. 92.
24. *Fine pins* and *thin silver wire*.
25. *Tablets* of wax and gutta-percha.—§ 146, p. 92.
- Large Bull's-eye Condenser*, for condensing a strong light upon the object.—§ 145, p. 91, pl. XXV, fig. 1, p. 92.

*For Cutting Thin Sections of Hard Tissues.*

26. *Saw* with fine teeth, for cutting thin sections of bone.—§ 152, p. 97, pl. XXV, fig. 8, p. 92.
27. *Hones* for grinding the sections thinner and polishing them.—§ 152, p. 97.
28. *Strong knife* for cutting thin sections of horn, &c.—§ 155, p. 98, pl. XIX, fig. 4, p. 52.
- Section cutter* for cutting thin sections of wood.—§ 156, p. 99, pl. XXV, fig. 6, p. 92.

## VII.—Cements.

29. *Brunswick black*, containing a few drops of a solution of India-rubber in coal naphtha.—§ 91, p. 55.
- 29a. *Bell's cement*.—§ 90, p. 55.
30. *Marine glue*.—§ 92, p. 55.
31. *Gum water*.—§ 97, p. 58.
32. *Gum* thickened with *starch* or *whiting*.—§ 97, p. 58.
33. *French cement*, composed of lime and India-rubber.—§ 98, p. 58.
- Gold size*.—§ 87, p. 54.
- Solution of Shell-lac*.—§ 89, p. 55.

## NECESSARY.

34. *Spirit and water.*—§ 99, p. 64.  
 35. *Glycerine.*—§ 100, p. 64.

## ADVANTAGEOUS.

- Gelatine and Glycerine.*—  
 § 106, p. 67.

## VIII.—Preservative.

36. *Solution of naphtha and creosote.*—§ 102, p. 66. *Gum and glycerine.*—  
 § 107, p. 69.  
 37. *Chromic acid.*—§ 104, p. 67.  
 38. *Turpentine.*  
 39. *Canada balsam.*—§ 94, p. 56.

## IX.—Apparatus Required for Making Cells and for Cutting and Grinding Glass.

40. *Brass plate* for heating slides to which marine glue is to be applied.—§ 72, p. 50, pl. XIV, fig. 4, p. 24. *Cements* before enumerated.—§§ 87 to 98. *Shadbol's apparatus.*—  
 § 116, p. 70, pl. XX, fig. 5, p. 54.  
 41. *Small brush* made of bristles.  
 42. *Tinfoil* of different degrees of thickness.—§ 118, p. 71.  
 43. *Writing Diamond.*—§ 119, p. 71, pl. XX, fig. 8, p. 54. *Brass rings* for cutting circles of thin glass.—  
 § 119, p. 71, pl. XX, fig. 9, p. 54.  
 44. *Glazier's diamond.*—§ 119, pl. XX, fig. 6, p. 54.  
 45. *Flat stone or pewter plate* for grinding glass.—§ 120, p. 71. *Wooden forceps* for holding glass slides.—§ 82, p. 52.  
 46. *Emery powder.*  
 47. *Old knife* and small chisel for cleaning off superfluous glue.—§ 123, p. 72, pl. XX, fig. 7, p. 54.  
 48. *Solution of potash* (liquor potassæ.)  
 49. *Sections of glass tubes* and of thick square vessels of various sizes, for making cells for the preservation of injections.—§ 127, p. 74, pl. XXI, figs. 5 to 9, p. 76. *Shallow concave glass cells.*  
*Moulded glass cells.*—  
 § 130, p. 75.

## X.—Apparatus for Preserving Objects in Air, Fluid, and Canada Balsam.

50. *Cells* of various sizes, before enumerated.—§ 126, p. 73, pl. XXI, fig. 4, p. 76. *Brunswick black.*  
*Gum thickened with whiting.*—§ 97. *Apparatus* for pressing down the thin glass cover while the cement is drying.—§ 96, p. 57, pl. XV, figs. 3, 4, 10, p. 54.

## NECESSARY.

## ADVANTAGEOUS.

51. *Thin glass* cut of the requisite size.
- 51a. *Preservative solutions*.—§§ 99 to 113, p. 64. Live cells for keeping bodies alive.
52. *Watch glasses* to soak sections in the preservative fluids.—§ 85, p. 54. *Bell jar* with vessel for *sulphuric acid*.—Pl. XXIV, fig. 5, p. 88.
53. *Glass shades* to protect recently mounted preparations from dust.—§ 86, p. 54, pl. XX, fig. 1, p. 54. *Air pump* to remove air bubbles from the interstices of a tissue.—§ 143, p. 88, pl. XXV, fig. 5, p. 92.
54. *Brass plate*.—§ 72, p. 50, pl. XIV, fig. 4, p. 24. *Canada balsam*.—§ 94, p. 56. *Needles* to remove air bubbles.

**XI.—Apparatus Required for the Separation of Deposits from Fluids and for their Preservation.**

55. *Conical glasses*.—§ 157, p. 99, pl. XXVI, fig. 3, p. 100. *Glass troughs* for *Zoo-phytes*.—§ 133, p. 76.
56. *Pipettes*.—§ 158, p. 100, pl. XXVI, fig. 2, p. 100.
57. *Wash-bottle*.—§ 163, p. 101, pl. XXVI, fig. 5, p. 100.
58. *Cells for examining infusoria*.—pl. VIII, fig. 8, p. 18.
59. *Animalcule cage*.—§ 134, p. 76, pl. XXII, fig. 7, p. 78.

**XII.—Instruments and Apparatus Required for Making Injections.**

60. *Injecting syringe*, holding from half an ounce to an ounce.—§ 165, p. 102, pl. XXVII, figs. 4, 5, p. 104.
61. *Pipes* of various sizes.—§ 165, pl. XXVII, figs. 10, 11.
62. *Corks* for stopping the pipes.—§ 165, pl. XXVII, fig. 3. *Stop corks*.—§ 165, p. 102, pl. XXVII, fig. 9, p. 104.
63. *Needle* for passing the thread round the vessel.—§ 165, pl. XXVII, fig. 12.
64. Thread of different degrees of thickness.
- 64a. Bull's nose forceps for stopping vessels. *Apparatus* for injecting by mercurial pressure, p. 104.

*For Making Opaque Injections.*

## NECESSARY.

65. *Size or Gelatine*.—§ 168, p. 105.  
 66. *Vermilion*.—§ 170, p. 105.  
 67. *Bichromate of potash and acetate of lead* for making solutions for precipitating yellow *chromate of lead*.—§ 171, p. 105.  
 68. *Carbonate of soda and acetate of lead* for making solutions for precipitating *carbonate of lead*.—§ 171, p. 105.

## ADVANTAGEOUS.

*Injecting can*, made of copper.—§ 166, p. 103, pl. XXVII, fig. 6, p. 104.

*For Making Transparent Injections.*

69. *Ferrocyanide of potassium*. “*Muriated tincture of iron*.” *Glycerine and Spirits of wine* for preparing the *Prussian blue injecting fluid*.—§ 178, p. 109. *Carminé*.—§ 180, p. 111.

## XIII.—Of Staining Tissues.

70. *Carminé fluid* for colouring the bioplasm of tissues.—§ 190, p. 125.

## XIV.—Chemical Analysis in Microscopical Investigation.

71. *Platinum foil*. *Small platinum capsule*.  
 72. *Test tubes and rack*.—Pl. LXI, fig. 5, p. 262.  
 73. *Small tubes* about an inch or an inch and a half in length. *Small flasks*.  
*Platinum wire*.  
 74. *Stirring rods*.  
 75. *Evaporating basins*.—Pl. XVIII, fig. 6, p. 48.  
*Watch glasses*.—§ 85, p. 54.  
 76. *Small glass bottles with capillary orifices*.—§ 307, p. 260, pl. LXI, figs. 1 to 4, p. 262.  
 77. *Wire triangles, tripods*.—§ 71, p. 50, pl. XVIII, figs. 4, 5, p. 48.  
 78. *Small retort stand*.—§ 70, p. 49, pl. XVIII, fig. 2, p. 48.

## Reagents :—

79. *Alcohol*.—§ 289, p. 253.  
 80. *Ether*. *Chloroform*.—§ 290, p. 253.  
 81. *Nitric acid*.—§ 292, p. 254.  
 82. *Sulphuric acid*.—§ 293, p. 254.

83. *Acetic acid*.—§ 295, p. 254.  
 84. *Hydrochloric acid*.—§ 294, p. 254.  
 85. *Ammonia*.—§ 300, p. 257.  
 86. *Solution of potash*.—§ 298, p. 256.  
 87. *Solution of soda*.—§ 299, p. 257.  
 88. *Nitrate of silver*.—§ 303, p. 258.  
 89. *Nitrate of barytes*.—§ 302, p. 258.  
 90. *Oxalate of ammonia*.—§ 304, p. 258.  
 91. *Iodine solution*.—§ 305, p. 258.  
 92. *Test papers*.

**XV.—Cabinet for Preserving Microscopic Specimens.**

93. *Drawers* arranged so that the specimens may be *perfectly flat*.—§ 276, p. 239.  
 94. *Boxes with trays* for containing specimens, pp. 276, 239.

The apparatus required for mineralogical investigation is described in p. 207, *et seq.* The instruments and apparatus required in micro-spectroscopic work will be found in sections 318, 319, pp. 269-283.

Other instruments for special minute research are referred to in other parts of the volume, and will be easily found if the index be consulted. A list of the makers of microscopes, and of instruments and apparatus required by the microscopist, and the preparers of microscopic objects, will be found at the end of this work, after the index.



WORKS ON THE MICROSCOPE, NATURAL HISTORY,  
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A full list of foreign as well as British works in every department of natural history is published by Mr. Weston, of Essex Street, who will forward catalogue to anyone sending a penny stamp.

#### ON THE MICRO-SPECTROSCOPE.

Several works on this subject will be found enumerated on page 283.

#### WORKS AND MEMOIRS ON PHOTOGRAPHY AS APPLIED TO THE MICROSCOPE.

For the following list of memoirs and works on photography in connection with the microscope I am indebted to the kindness of Dr. A. Clifford Mercer, who has spent much time in verifying nearly all the references. The list is very accurate, and will probably be found of great use by those who intend to work in this department.

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## APPENDIX.

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**408. New Microscope of Low Power.**—Mr. Browning has lately designed an excellent little instrument for general investigation with low powers, which is known as *Browning's New Miniature Microscope*. The instrument is of the size of the engraving on p. 496. The price in nickel silver is 3*l.* 17*s.* 6*d.* There are two achromatic powers: one magnifying 15, the other 35 diameters. Objects may be viewed by reflected or by transmitted light. The instrument is admirably suited for botanical and entomological investigations, and objects in the ordinary microscopic slides may be examined by its aid.

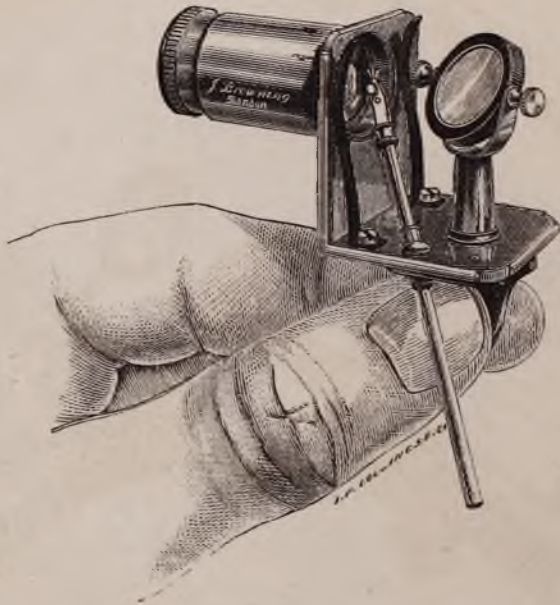
**409. New cheap Microscopes.**—The instruments figured in pl. XCIX. have been recently made by Mr. Crouch, and are excellent students' microscopes. A good instrument for those who work at animal tissues is represented in pl. XCIX, fig. 1. Fig. 2 is the student's binocular, while a very cheap school microscope is shown in fig. 3. In the last there are two lenses, an inch, and a half inch, and a condenser for opaque objects; the whole, fitted in a case, costing only 2*l.* 10*s.* With an extra eye-piece, spot lens, polariscope, and other apparatus, this microscope costs 5*l.*

**410. New cheap Object-glasses for the Microscope.**—Besides the cheap lenses referred to in the text, some very good ones have been recently made by Mr. Swift according to a new formula, and are sold at about the same prices as the foreign objectives. The three-inch and two-inch cost 17*s.*, the quarter 26*s.*, and the one-eighth 50*s.*

**411. New Oil-immersion Lenses.**—In examining objects under high powers, it is necessary to adjust the object-glass very accurately, or the definition will be defective. And as the adjustment varies according to the thickness of the covering-glass, it is sometimes a very troublesome operation to adjust and readjust the objective for the examination of several different preparations one after the other. It is, indeed, in practice frequently difficult to decide the exact degree of rotation of the adjustment collar which actually gives us the clearest definition.

The distance between the lower surface of the object-glass and an object when in focus varies according to the thickness of the covering glass, which distance is made up partly of a stratum of air and partly of the covering-glass. It is the great difference between the refractive index of the air and that of the glass which renders adjustment necessary

for clear definition. Now if, as has been well remarked by Mr. J. W. Stephenson, some fluid substance, the refractive and dispersive properties of which are the same as those of the covering-glass, could be substituted for the air in the intervening space, *correction would be no longer required*—a sort of liquid glass being interposed between the objective and the cover, it matters not whether the covering-glass be thick or thin, for the object would be defined with equal distinctness. Mr. Stephenson suggested the desirability of obtaining a new objective on this principle to Professor Abbe, of Jena. Very soon afterwards a glass was constructed according to Professor Abbe's recommendations by



Mr. Zeiss. After trying a number of oils and other substances, Professor Abbe found that oil of cedar-wood (made by Shimmel and Co., Leipzig and New York), although not identical with crown glass, answered well. But the same authority is of opinion that even a better medium may yet be discovered.

As far back as 1844, Amici suggested that, in preference to water, glycerine and oil of aniseed, or the latter alone, should intervene between, and thus connect the covering-glass of the object and the lens.\* Mr. Wenham, also, in 1870, drew attention to the importance of "homogeneous immersion," and remarked that, if a medium of the same refractive power as the glass were employed, it would give better results than water; but Mr. Stephenson was the first to announce that important practical results had actually been obtained by this method, with an

\* Ch. Robin, "Traité du Microscope." Paris, 1871. Page 191.

NEW CHEAP MICROSCOPES BY MR. CROUCH.



Biological Microscope.

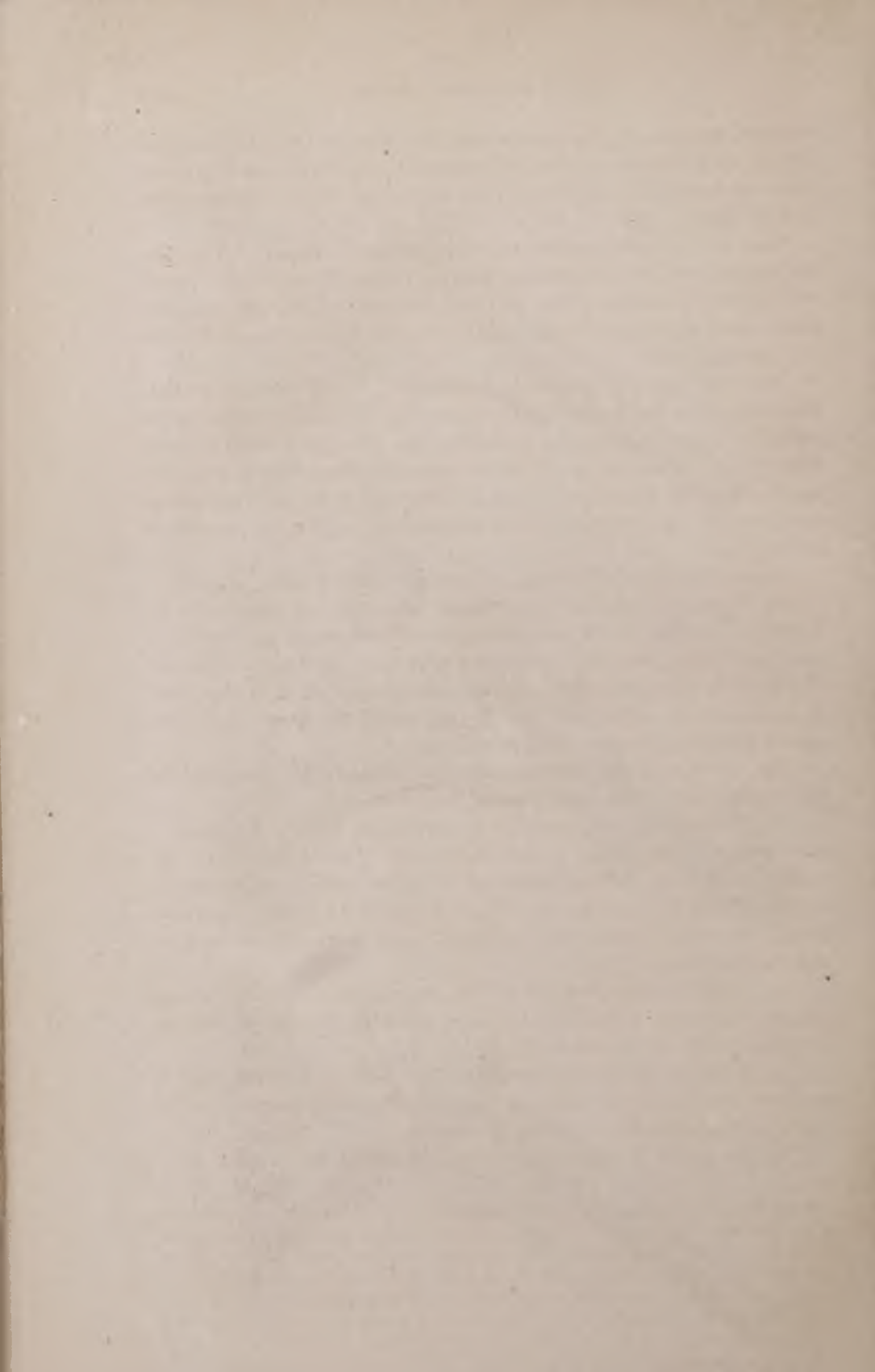


Student's Binocular Microscope.



School Microscope





immense increase of angular aperture, in a paper "On a Large-angled Immersion Objective without Adjustment Collar; with some observations on numerical Aperture," read before the Royal Microscopical Society, April 3, 1878.

One of the leading points of Professor Abbe's theory of 1874 was his explanation of the important bearing which the *diffraction pencils* have on the formation of the microscopic image, so that the resolving power of an object-glass is dependent upon the diffraction pencils that are taken up by it.

This fact was not previously known, and in the absence of that knowledge, it is not surprising that those who suggested the use of oil instead of water abandoned it in practice, not thinking it worth while to follow it up. The use of oil as an immersion fluid would obviously have seemed at that time to be a *disadvantage*, as far as aperture was concerned, in consequence of the diminution of *angle* which was necessarily caused.

When, however, the bearing of Professor Abbe's theory was appreciated, it was seen that an object-glass, acting in oil, might take up diffraction pencils which one of larger *angle*, acting in air, could not reach, and hence, although the *angle* was reduced by the use of oil, yet that the diffraction pencils belonging to an *aperture* of more than  $180^\circ$  in air, would be compressed (so to say) within the lesser *angle*, and greatly increased *aperture* could be utilised.

The qualities of the new oil-immersion objective are described by Mr. Stephenson, in the above memoir, as follows:—

"1. There being no aberration to correct for varying thickness of cover-glasses, there is no collar adjustment. For thick covers, say 0.008 to 0.009, the ordinary length of 10 inches gives the most perfect definition; for thin covers, say 0.004, a length of 12 inches is perhaps better. But the difference is so *very* slight that it is scarcely necessary to use the draw-tube.

"2. It has a balsam angle of  $113^\circ = 1.25$  numerical aperture,\* which renders it extremely sensitive in focussing, and also indicates the highest resolving power hitherto attained.

"3. It has a large working distance. The distance between front of lens and object is 0.02, which gives a working distance of 0.012 for 0.008 cover-glass, 0.016 for 0.004, and so on.

"4. Its power is rather more than one-ninth, and having com-

\* Briefly stated, "numerical aperture" is equal to *the product of the refractive index of the medium in front of the objective, multiplied into the sine of the semi-angular aperture* =  $n \sin. w$ . This definition of "numerical aperture" offers at once a means by which all objectives, whether dry, water, or oil immersion, can be directly compared. It is based on the theory whence Professors Abbe and Helmholtz deduced the limit of visibility. The angle of the oil-immersion lens described by Mr. Stephenson

ponent lenses throughout the combination, larger than in other objectives of the same power, it transmits more light, the latter quality being enhanced by a diminution in the reflection of the peripheral rays.

“5. It bears very deep eye-pieces and has a flat field.

“Lastly. An essential condition to its *perfect* performance is that if the object be dry, it must be mounted on, or nearly touch, the cover, or if not a dry object, that it be mounted in some medium having approximately the same refractive index as the oil, such as Canada balsam, &c.

“The special advantage of this objective for petrographic work is that the oil used, having very nearly the refractive index of the objects to be examined, renders cover-glasses and highly polished surfaces unnecessary; the minerals, if sufficiently translucent, can be observed through a considerable depth, say 1-50th of an inch, and, on the assumption of identity of index, every plane, from the surface downwards, will have the same perfect correction.

“To a certain extent, the latter observation applies to all transparent objects mounted in balsam, as the thickness of the balsam above the object may be looked upon as equivalent to a thicker cover, and the penetration must therefore be considerable, although the latter quality will be still greater in the smaller-angled objectives constructed on the same principle, which will hereafter be made.”

Professor Abbe, writing to Mr. Stephenson, on the objective, says:—  
“The advantage of the greater aperture is shown in a most striking manner on *Pleurosigma angulatum*, when observed by very oblique light. This diatom mounted dry with the frustules adhering to the cover is seen in quite a new aspect; by causing the pencil of light to fall at right angles to the axis of the valve (or more generally parallel to any of the three ordinary lines). It then presents at the portion adhering to the thin glass cover white rectangular fields, separated by dark broad beams, alternating from row to row, paler lines crossing the white space between the black bands which are thus joined; the ratio of the length of the rectangular division comprised between the dark bands being to the width as 2 :  $\sqrt{3}$ .”

The Stephenson system of homogeneous immersion has been further improved and developed by Professor Abbe,\* of Jena, and in a memoir read before the Royal Microscopical Society, on March 12, 1879, he describes the construction of a new objective for oil-immersion. *See*

being  $113^\circ$ , gives a semi-angular aperture of  $56\frac{1}{2}^\circ$ , of which the sine is 0.839, which, multiplied by 1.50, the refractive index of the oil, gives a “numerical aperture” of 1.25; hence we see that we have in it a resolving power exceeding the possible limit of a dry lens ( $\sin. 90 = 1$ ) by no less than 25 per cent.

\* Ueber Stephenson's system der homogenen Immersion bei Mikroskop-Objectiven. —Jena, 1879.

"Journal of the Royal Microscopical Society," for 1879, vol. II, page 256. The oil-immersion lenses have a resolving power some 50 per cent. higher than dry lenses.

In a note to me, dated June 5, 1879, Mr. Stephenson sums up the chief advantages of the system of "Homogeneous Immersion" in the following words:—

"It enables the optician to produce objectives the equivalent angles of aperture of which greatly exceed the ideal maximum of  $180^\circ$  in air. As the resolving power of every objective is exactly proportional to the sine of half the angle multiplied by the refractive index of the immersion or separating medium employed, we have, for the *same* geometrical angles, resolving powers proportional to 1, 1.33, and 1.50 in the several cases of air, water, and oil. Hence we see that, *cæteris paribus*, the resolving power of an oil-immersion is 50 per cent. greater than that of a dry lens in air, and already 40 per cent. beyond even the ideal maximum of a dry lens has been obtained.

"2. The correction for spherical aberration is much facilitated.

"3. The tiresome correction with the adjustment collar of the objective is entirely done away with.

"4. Objects mounted in balsam, when in focus, are in the best possible correction irrespective of quantity of balsam or thickness of cover. This point I have noticed in my paper on the subject last year, as also the great advantage it possesses in its great penetrative power in the examination of minerals.

"Lastly, there is also the obvious advantage of saving the light lost by reflection, which is very great, in all dry objectives of large aperture, and the front lenses being much larger there is necessarily greater working distance with the same angle.

"Professor Abbe says, in his paper, that probably 1.35 would be the extreme limit, but, as before stated, 1.40 (equal to a balsam angle of  $137^\circ 48'$ ) has already been attained out of the *possible* 1.50, or rather out of the theoretical maximum of 1.50."

**412. New Objective by Professor Abbe.**—At the last meeting of the Royal Microscopical Society for the session 1878-9, on June 11th, Professor Abbe showed an objective, for oil-immersion, made according to a new formula. For a description, the reader is referred to Professor Abbe's paper, published in the Society's Journal.

**413. Mineralogical Microscope.**—An excellent student's microscope for mineralogical work, with large rotating stage, convenient arrangement for polariscope and other pieces of apparatus, has been lately designed by Mr. Frank Rutley, of the Geological Survey, and may be obtained of Mr. Watkins, Pall Mall. Mr. Swift also makes a student's mineralogical microscope.

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 ERRATA, &c.

Page 429, for 1-1,000,000th read 1-100,000th.

Page 137, fourth line from the bottom, for Parker read Parkes.

The following note should have been inserted on p. 15:—

“On a binocular microscope for high powers,” by F. H. Wenham. “Trans. of the Microscopical Society.” New Series. Vol. xiv. 1866. P. 103.

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