JOHN GEORGE WOOD

COMMON OBJECTS OF THE MICROSCOPE

John George Wood
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Содержание

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PREFACE TO THE SECOND EDITION

The task of revising and bringing up to date a work which has been the guide, philosopher, and friend of thousands of commencing microscopists has been, in the present case, one of no small difficulty. On the one hand, there was the natural desire to interfere as little as possible with the original work; and on the other, the necessity of rendering available, to some extent at least, the enormous advance in every department which has taken place in the thirty-six years which have elapsed since the work was first offered to the public. The reviser has done his best not only to fulfil these two objects, but to keep in view the original purpose of the book.

In the popular department of pond-life especially, about fifty new illustrations have been added, mostly from the reviser's own notebook sketches. The whole of the botanical part has been revised by one of our first English authorities, and, in short, no effort has been spared to make the work as accurate as its necessarily condensed form permits of. It is hoped, therefore, that it may be found not less useful than its predecessor by those for whom it is alone intended.

PREFACE TO THE FIRST EDITION

In my two previous handbooks, the "Common Objects" of the Sea-shore and Country, I could but slightly glance at the minute beings which swarm in every locality, or at the wonderful structures which are discovered by the Microscope within or upon the creatures therein described. Since that time a general demand has arisen for an elementary handbook upon the Microscope and its practical appliance to the study of nature, and in order to supply that want this little volume has been produced.

I must warn the reader that he is not to expect a work that will figure and describe every object which may be found on the sea-shore or in the fields, but merely one by which he will be enabled to guide himself in microscopical research, and avoid the loss of time and patience which is almost invariably the lot of the novice in these interesting studies. Upwards of four hundred objects have been figured, including many representatives of the animal, vegetable, and, mineral kingdoms, and among them the reader will find types sufficient for his early guidance.

Neither must he expect that any drawings can fully render the lovely structures which are revealed by the microscope. Their form can be given faithfully enough, and their colour can be indicated; but no pen, pencil, or brush, however skilfully wielded, can reproduce the soft, glowing radiance, the delicate pearly translucency, or the flashing effulgence of living and ever-changing light with which God wills to imbue even the smallest of His creatures, whose very existence has been hidden for countless ages from the inquisitive research of man, and whose wondrous beauty astonishes and delights the eye, and fills the heart with awe and adoration.

Owing to the many claims on my time, I left the selection of the objects to Mr. Tuffen West, who employed the greater part of a year in collecting specimens for the express purpose, and whose well-known fidelity and wide experience are the best guarantees that can be offered to the public. To him I also owe many thanks for his kind revision of the proof-sheets. My thanks are also due to Messrs. G. and H. Brady, who lent many beautiful objects, and to Messrs. Baker, the well-known opticians of Holborn, who liberally placed their whole stock of slides and instruments at my disposal.

CHAPTER I

Pleasures and Uses of Microscopy—Development of the Microscope—Extemporised Apparatus.

Within the last half-century the use of the microscope, not only as an instrument of scientific research, a tool in the hands of the investigator of the finer organisation of the world of nature, nor even as an adjunct to the apparatus of the chemist or the manufacturer, but as a means of innocent and instructive recreation, has become so firmly rooted amongst us that it seems hardly necessary to advocate its claims to attention on any of these grounds.

So wonderful is the information which it affords, so indispensable is it in many, if not in all, branches of scientific research, that not only would the lover of nature be deprived of one of his most valued sources of information and enjoyment, but some sciences would be brought absolutely to a standstill if by any conceivable means the microscope were to be withdrawn from their followers.

On the other hand, from every improvement in the construction of the latter, a corresponding enlargement and enlightenment of the fields reviewed by these sciences has taken place, and the beauty and interest of the revelations made by its means has attracted an ever-increasing host of earnest and intelligent volunteers, who have rendered yeoman service to the cause of knowledge.

Moreover, so vast is the scope of the instrument, that whilst discoveries in other fields of research are few and far between, comparatively speaking, in microscopic science they are of everyday occurrence, and the number of problems calling for solution by means of the instrument in question is so vast that even the humblest worker may be of the greatest assistance.

In the following pages we propose to carry out, as far as possible with reference to the microscope, the system followed in the "Common Objects of the Seashore and of the Country," and to treat in as simple a manner as may be of the marvellous structures which are found so profusely in our fields, woods, streams, shores, and gardens. Moreover, our observations will be restricted to an instrument of such a class as to be inexpensively purchased and easily handled, and to those pieces of supplementary apparatus which can be extemporised at small cost of money and ingenuity by the observer himself, or obtained of the opticians for a few shillings.

With the same view, the descriptions will be given in language as simple and as free from technicalities as possible, though it must be remembered that for many of the organisms and structures which we shall have to describe there are none but scientific names; and since, moreover, this little work is intended to furnish a stepping-stone between the very elements of microscopic science, and those higher developments of it which should be the aim of every worker, it would be unwise to attempt to invent commonplace appellations for the purpose of this book, and leave him to discover, when he came to consult works of reference in any particular subject, that his “simplified” knowledge had all to be unlearnt, and a new vocabulary acquired. Rather will it be our purpose to use correct terms, and explain them, as far as necessary, as we introduce them.

The commencing microscopist is strongly recommended, whilst not confining his interest entirely to one branch of research or observation, to adopt some one as his particular province.

The opportunities for discovery and original work, which are afforded by all alike, will be more readily appreciated and utilised by adopting such a plan than by a general and purposeless distribution of effort. To mention one or two. The student of the fascinating field of pond-life will find new organisms awaiting description by the hundred, and of the old ones, life-histories to make out; if he be attracted rather to the vegetable inhabitants of the same realm, the diatoms will furnish him with the opportunity of studying, and perhaps solving, the enigma of their spontaneous movement, and of watching their development. The smaller fungi, and indeed the larger ones too, will amply repay the closest and most laborious study of their habits of life and processes of development. Since the first edition of this work was published, the whole subject has been practically revolutionised, and more remains to be done than has yet been accomplished.

In short, there is scarcely an organism, even of those best known and most studied, which is so completely exhausted that persevering investigation would reveal nothing new concerning it.

There can be little doubt but that if any worker, with moderate instrumental means, but with an observant mind, were to set determinately to work at the study of the commonest weed or the most familiar insect, he, or she, would by patient labour accomplish work which would not only be of value to science, but would redound to the credit of the worker.

Something like finality appears to have been reached, at least for the present, in the development of the microscope; and whilst it is beyond the scope of this work to treat of the refined and costly apparatus which is essential to useful work in certain departments of research, the result has, on the whole, been highly favourable to the worker of moderate means and ambitions, since lenses are now accessible, at the cost of a few shillings, comparatively speaking, which could not have been purchased at all when this work first appeared. It is with such appliances that we have here to deal. The worker whose finances are restricted must be contented to extemporise for himself many pieces of apparatus, and will find pleasure and occupation in doing so. And let him remember, for his encouragement, that many such home-made appliances will fulfil their purpose quite as well as the imposing paraphernalia of glittering brass and glass which decorates the table of the wealthy amateur. It is not the man who possesses the best or most costly apparatus, but the one who best understands the use of that which he possesses, that will make the most successful microscopist. A good observer will discover, with only the aid of a pocket-magnifier, secrets of Nature which have escaped the notice of a whole army of dilettante microscopists, in spite of the advantages which, as regards instruments, the latter may enjoy.

It is for those who desire to be of the former class that this book is written, and in the course of the following pages instances will be given in which the exercise of a small amount of ingenuity and the expenditure of a few pence will be found equivalent to the purchase of costly and complicated apparatus.

An enormous amount of valuable work was done in the earliest days of microscopy, when the best apparatus available was a single lens, composed of the bead formed by fusing the drawn-out end of a rod of glass. Inserted into a plate of metal, or a piece of card, such a primitive instrument was capable of affording a large amount of information. Similar instruments are to be purchased for a few pence at the present day, and are not without their use for purposes of immediate examination of material. A very common form is a glass marble, ground flat on one side, and mounted in a tube. The material to be examined is placed upon the flat side, and is seen magnified to an extent inversely proportional to the diameter of the sphere of glass.

CHAPTER II

Elementary Principles of Optics—Simple Microscopes—Compound Microscope—Accessory Apparatus—Cover-glasses—Troughs—Condensers—Dissection—Dipping-tubes—Drawing—Measurement.

Before proceeding to deal with the microscope itself, it may be useful to give a short summary of the optical laws upon which its working depends.

To go into the minutiæ of the matter here would be out of place, but it will be found very helpful, especially in the matter of illumination, to acquire some knowledge of, and facility in applying, these elementary principles. We shall confine our remarks to convex lenses, as being the form to which all the combinations in the microscope may be ultimately reduced.

Every convex lens has one "principal" focus, and an infinite number of "conjugate" foci. The principal focus is the distance at which it brings together in one point the rays which fall upon it parallel to its axis, as shown in Fig. 1, in which *A* is the axis of the lens *L*, and the rays *RR* are brought together in the principal focus *P*. Thus a ready means of finding the focal length of any lens is to see at what distance it forms an image of the sun, or of any other distant object, upon a screen, such as a piece of smooth white cardboard. In the figure this distance will be *PL*.

Conversely, if the source of light be at *P*, a parallel beam of light will be emitted from the lens.

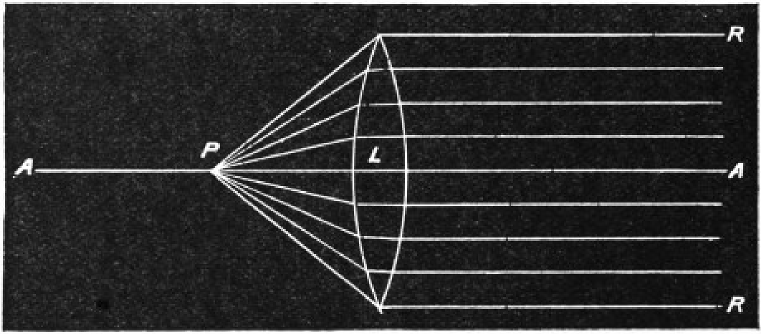

Fig. 1.

The focal length may, however, be found in another way. When an object is placed at a distance from a lens equal to twice the principal focal length of the latter, an image of the object is formed at the same distance upon the other side of the lens, inverted in position, but of the same dimensions as the original object. The object and image then occupy the equal conjugate foci of the lens, so that by causing them to assume these relative positions, and halving the distance at which either of them is from the lens, the focal length of the latter is known.

These points will be seen on reference to Fig. 2, in which *L* being the lens, and *P* the principal focus, as before, rays from the point *C* are brought together at the conjugate focus *C′*, at the same distance on the other side of *L*. In this case it manifestly does not matter whether the object be at one or the other of these points.

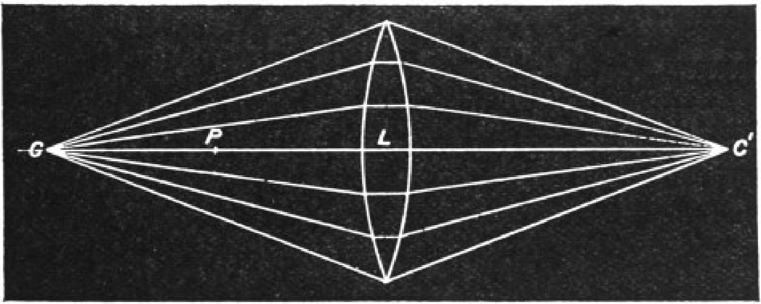

Fig. 2.

So far we have been dealing with points on the line of the axis of the lens. The facts mentioned apply equally, however, to rays entering the lens at an angle to the axis, only that in this case they diverge or converge, correspondingly, upon the other side. It is evident, from Fig. 1, that no image is formed of a point situated at the distance of the principal focus; but Fig. 3, which is really an extension of Fig. 2, shows how the rays passing along secondary axes form an inverted image of the same size as the object, when the latter is situated at twice the focal length of the lens from this last. To avoid confusion, the bounding lines only are shown, but similar lines might be drawn from each and every point of the object; and if the lines *ALA'*, *BL'B'* be supposed to be balanced at *L* and *L'* respectively, they will indicate the points at which the corresponding parts of the object and image will be situated along the lines *AB*, *B'A'* respectively. Moreover, rays pass from every part of the object to every part of the lens, so that we must imagine the cones *LAL'*, *LA'L'* to be filled with rays diverging on one side of the lens and converging on the other.

The image so formed is a “real” image,—that is to say, it can be thrown upon a screen.

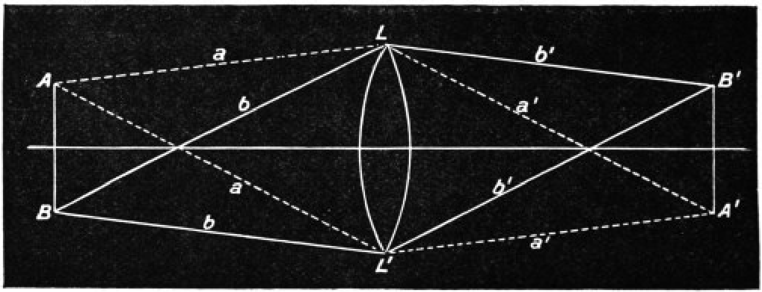

Fig. 3.

The microscopic image, on the other hand, is a virtual image, which can be viewed by the eye but cannot be thus projected, for it is formed by an object placed nearer to the lens than the principal focal length of the latter, so that the rays diverge, instead of converging, as they leave the lens, and the eye looks, as it were, back along the path in which the rays appear to travel, and so sees an enlarged image situated in the air, farther away than the object, as shown in Fig. 4. In this case, as the diagram shows, the image is upright, not inverted.

Images of the latter class are those formed by simple microscopes, of the kind described in the previous chapter. In the compound microscope the initial image, formed by the object-glass, is further magnified by another set of lenses, forming the eye-piece, by which the diverging rays of the virtual image are brought together to a focus at the eye-point; and when viewed directly, the eye sees an imaginary image, as in a simple microscope, whilst, when the rays are allowed to fall upon a screen, they form a real image of the object, larger or smaller, as the screen is farther from or nearer to the eye-point.

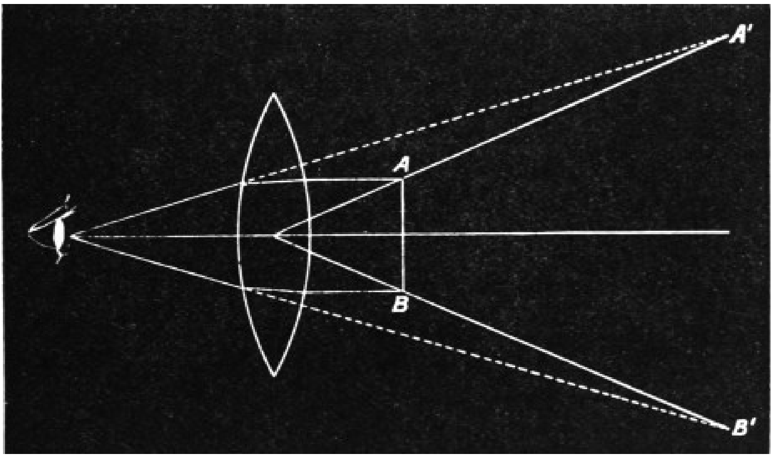

Fig. 4.

These remarks must suffice for our present purpose. Those who are sufficiently interested in the subject to desire to know more of the delicate corrections to which these broad principles are subjected in practice, that objectives may give images which are clear and free from colour, to say nothing of other faults, will do well to consult some such work as Lommel's *Optics*, in the International Science Series.

In following a work such as the present one, the simple microscope, in some form or other, will be found almost indispensable. It will be required for examining raw material, such as leaves or other parts of plants, for gatherings of life in fresh or salt water, for dissections. With such powers as those with which we shall have to deal, it will rarely happen that, for example, a bottle of water in which no life is visible will be worth the carrying-home; whilst, on the other hand, a few months' practice will render it not only possible, but easy, not only to recognise the presence, but to identify the genus, and often even the species, of the forms of life present. Moreover, these low powers, affording a general view of the object, allow the relation to each other of the details revealed by the power of the compound microscope to be much more easily grasped. A rough example may suffice to illustrate this. A penny is a sufficiently evident object to the naked eye, but it will require a sharp one to follow the details in Britannia's shield, whilst the minute scratches or the bloom upon the surface would be invisible in detail without optical aid. Conversely, however, it would be rash to conclude from an examination of a portion of the surface with the microscope alone that the portion in view was a sample of the whole surface. The more the surface is magnified, the less are the details grasped as a whole, and for this reason the observer is strongly recommended to make out all that he can of an object with a simple magnifier before resorting to the microscope.

For general purposes, the intending observer cannot do better than supply himself with a common pocket-magnifier, with one, two, or three lenses, preferably the last, as although the absolute performance is not so accurate, the very considerable range of power available by using the lenses singly, or in various combinations, is of great advantage. Such a magnifier may be obtained from Baker for about three-and-sixpence, or, with the addition of a powerful Coddington lens (Fig. 5) in the same mount, for nine shillings more. Aplanatic lenses, such as the one shown in section in Fig. 6, with a much flatter field of vision, but of one power only each, cost about fifteen shillings, and a simple stand, which adapts them for dissecting purposes, may be obtained of the same maker for half a crown, or may easily be extemporised from a cork sliding stiffly on an iron rod set in a heavy foot, the cork carrying a loop of wire terminating in a ring which carries the lens.

Fig. 5.

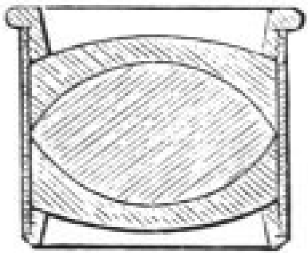

Fig. 6.

So much may suffice for the simple microscope. We pass on now to the consideration of the instrument which forms the subject of the present work, an instrument which, whilst moderate in price, is yet capable of doing a large amount of useful and valuable work in the hands of a careful owner, and of affording him a vast amount of pleasure and recreation, even if these be his only objects in the purchase, though it is difficult to understand that, an insight being once attained into the revelations effected by the instrument, without a desire being excited in any intelligent mind to pursue the subject as a study as well as a delightful relaxation. The microscope described, and adopted as his text by the author of this work, is still made, and has shared to a very considerable extent in the general improvement of optical apparatus which has taken place during the last thirty years. It is to be obtained from Baker, 244 High Holborn, and is provided with most of the apparatus which will be found indispensable by the beginner, costing, with a case in which to keep it, the modest sum of three guineas.

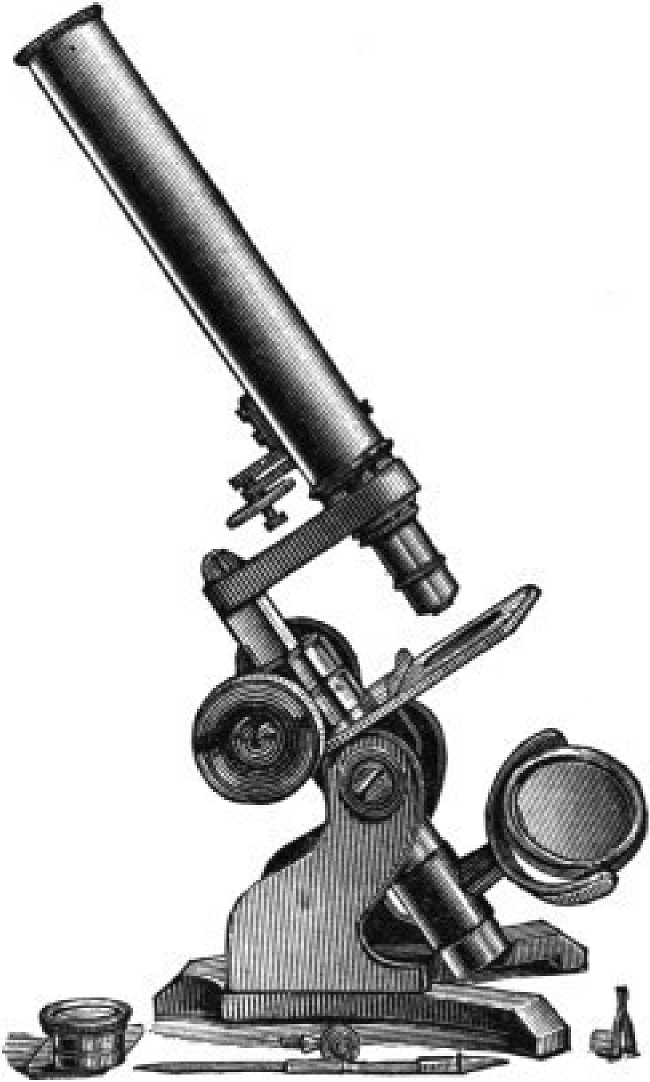

Fig. 7.

If this instrument represent the limit of the purchaser's power of purse, he may very well make it answer his purpose for a considerable time. The same instrument, however, with separate objectives of good quality, together with a bull's-eye condenser (an almost indispensable adjunct), a plane mirror in addition to a concave one, and a simple but efficient form of substage condenser, may be obtained for £5, 12s. 6d., and the extra outlay will be well repaid by the advantage in working which is gained by the possession of the additional apparatus.

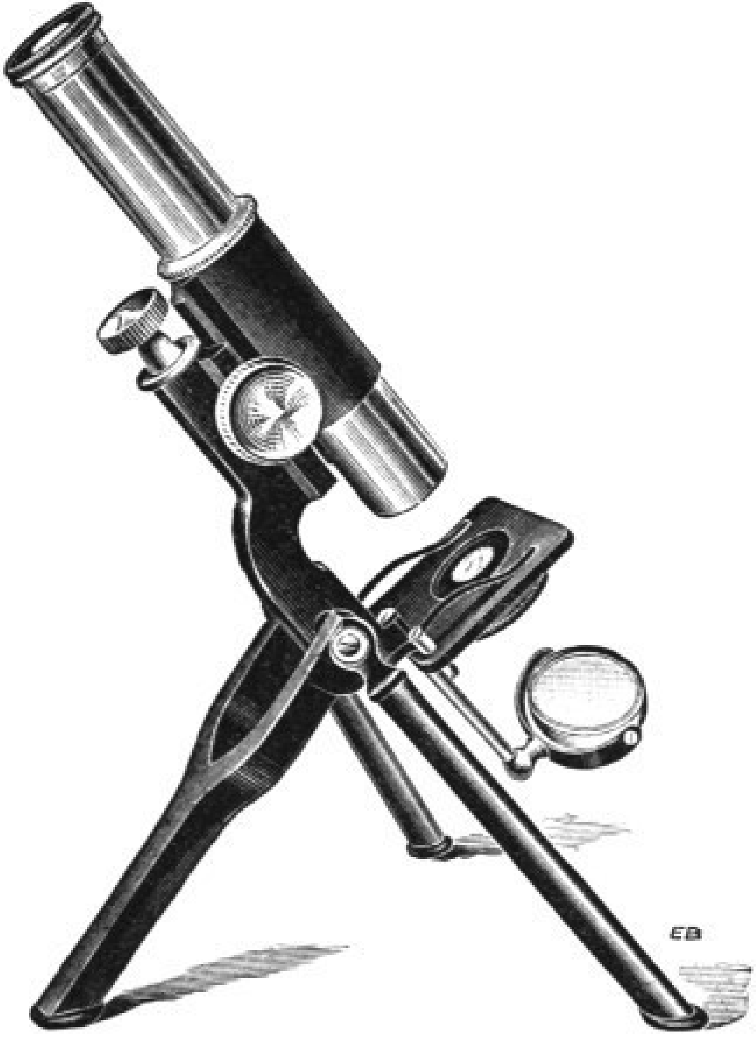
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Fig. 8.

A still better stand, and one which is good enough for almost any class of work, is that shown in Fig. 8, which is known as the “Portable” microscope. In this instrument the body is made up of two tubes, so that the length may be varied at will, and this gives a very considerable range of magnification without changing the object-glass, a great convenience in practice; whilst the legs fold up for convenience of carriage, so that the whole instrument, with all necessary appliances, may be readily packed in a corner of a portmanteau for transport to the country or seaside.

The objectives supplied with the simplest form of microscope above referred to are combinations of three powers in one, and the power is varied by using one, two, or three of these in combination. This form of objective is very good, as far as it goes, though it is impossible to correct such a combination with the accuracy which is possible in manufacturing one of a fixed focal length.

Perhaps the best thing for the beginner to do would be to purchase the combination first, and, later on, to dispose of it and buy separate objectives of, say, one-inch, half-inch, and quarter-inch focal lengths. It may be explained here, that when a lens is spoken of as having a certain focal length, it is meant that the magnification obtained by its use is the same, at a distance of ten inches from the eye, as would be obtained by using a simple sphere of glass of the same focal length at the same distance.

This, of course, is simply a matter of theory, for such lenses are never used actually.

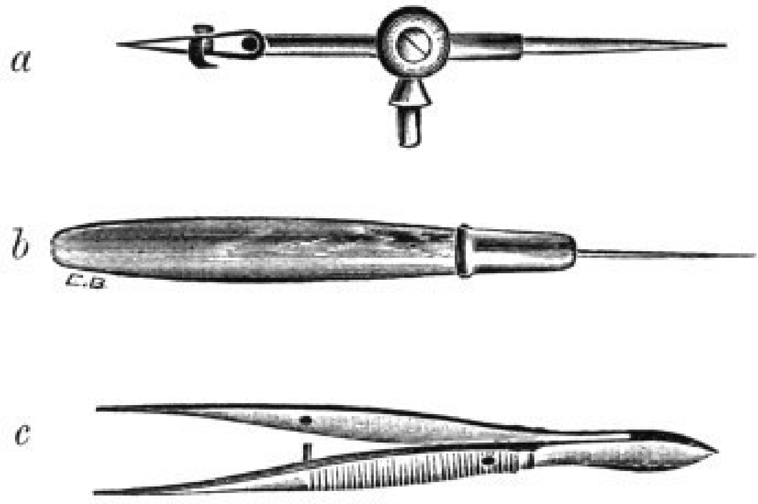

Fig. 9.

Of accessory apparatus, we may mention first the stage forceps (Fig. 9, *a*). These are made to fit into a hole upon the stage, so as to be capable of being turned about in any direction, with an object in their grasp, and for some purposes, especially such as the examination of a thin object, say the edge of a leaf, they are extremely useful.

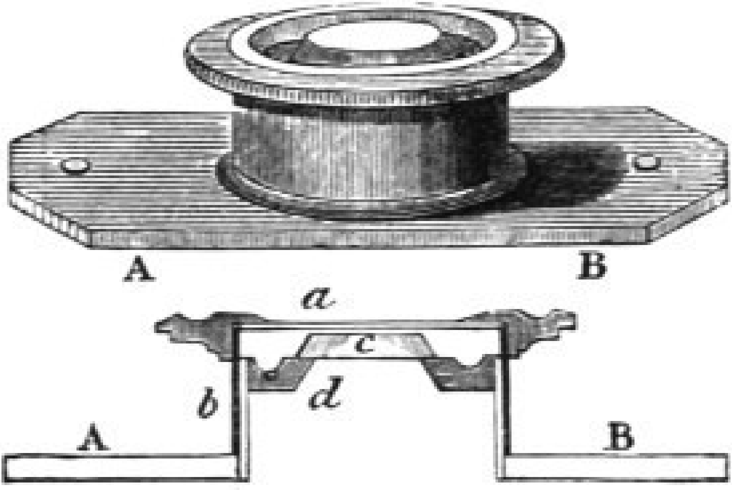

Fig. 10.

The live box, in which drops of water or portions of water-plants, or the like, may be examined, will be found of great service. By adjustment of the cap upon the cylinder, with proper attention to the thickness of the cover-glass in the cap, any required amount of pressure, from that merely sufficient to fix a restless object to an amount sufficient to crush a resistent tissue, may easily be applied, whilst the result of the operation is watched through the microscope. This proceeding is greatly facilitated if the cap of the live-box be slotted spirally, with a stud on the cylinder, so that a half-turn of the cap brings the glasses into contact. By this means the pressure may be adjusted with the greatest nicety.

In examining delicate objects, such as large infusoria, which invariably commit suicide when pressure is applied, a good plan is to restrict their movements by placing a few threads of cotton-wool, well pulled out, in the live-box with the drop of water.

A variety of instruments has been invented for the same purpose, of which Beck's parallel compressorium may be mentioned as the most efficient, though it is somewhat complicated, and consequently expensive, costing about twenty-five shillings.

A few glass slips and cover-glasses will also be required. The latter had better be those known as "No. 2," since the beginner will find it almost impossible to clean the thinner ones satisfactorily without a large percentage of fractures. The safest way is to boil the thin glass circles in dilute nitric acid (half acid, half water) for a few minutes, wash well in several waters, first tap-water and then distilled, and finally to place the covers in methylated spirit. When required for use, the spirit may be burnt off by applying a light, the cover-glass, held in a pair of forceps, being in no way injured by the process.

In addition to the glass slides, the observer will find it advisable to be provided with a few glass troughs, of various thicknesses, in which portions of water-plants, having organisms attached to them, may be examined. Confined in the live-box, many of the organisms ordinarily found under such circumstances can rarely be induced to unfold their beauties, whilst in the comparative freedom of the trough they do so readily. The troughs may be purchased, or may be made of any desired shape or size by cutting strips of glass of a thickness corresponding to the depth desired, cementing these to a glass slide somewhat larger than the ordinary one, and cementing over the frame so formed a piece of thin glass, No. 3; the best material to use as cement being marine glue of the best quality, or, failing this, Prout's elastic glue, which is much cheaper, but also less satisfactory. The glass surface must be made, in either case, sufficiently hot to ensure thorough adhesion of the cement, as the use of any solvent entails long waiting, and considerable risk of poisoning the organisms. A useful practical hint in the use of these troughs is that the corners, at the top, should be greased slightly, otherwise the water finds its way out by capillary attraction, to the detriment of the stage of the microscope.

Of optical accessories, the bull's-eye is almost the most valuable. So much may be effected by its means alone, in practised hands, that it is well worth the while of the beginner to master its use thoroughly, and the methods of doing so will be explained in the succeeding chapter.

The substage condenser, too, even in its most simple form, is an invaluable adjunct, even though it be only a hemisphere of glass, half an inch or so in diameter, mounted in a rough sliding jacket to fit underneath the stage. Such an instrument, properly fitted, will cost about fifteen shillings, but the ingenious worker will easily extemporise one for himself.

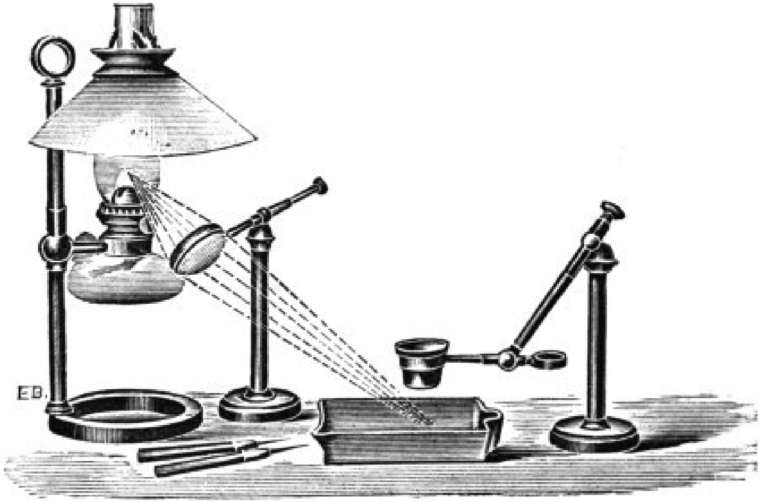

Fig. 11.

Many plants and animals require to be dissected to a certain extent before the details of their structure can be made out, and for this purpose the naked eye alone will rarely serve. The ordinary pocket magnifier, however, if mounted as described in a preceding chapter, will greatly facilitate matters, and the light may be focused upon the object by means of the bull's-eye condenser, as shown in Fig. 11. In the figure the latter is represented as used in conjunction with the lamp, but daylight is preferable if it be available, the strain upon the eyes being very much less than with artificial light. Two blocks of wood, about four inches high, will form convenient rests for the hands, a plate of glass being placed upon the blocks to support the dish, and a mirror being put in the interspace at an angle of 45° or so if required. A piece of black paper may be laid upon the mirror if reflected light alone is to be used.

As all delicate structures are dissected under fluid, a shallow dish is required. For this purpose nothing is better than one of the dishes used for developing photographic negatives. The bottom of the dish is occupied by a flat cork, to which a piece of flat lead is attached below, and the object having been pinned on to the cork in the required position, the fluid is carefully run in. This fluid will naturally vary according to the results desired to be obtained, but it must not be plain water, which so alters all cellular structures as to practically make them unrecognisable under the microscope. Nothing could be better than a 5 per cent. solution of formalin, were it not for the somewhat irritating odour of this fluid, since it at once fixes the cells and preserves the figure. For many purposes a solution of salt, in the proportion of a saltspoonful of the latter to a pint of water, will answer well for short dissections. For more prolonged ones, a mixture of spirit-and-water, one part of the former to two of the latter, answers well, especially for vegetable structures. When the dilution is first made, the fluid becomes milky, unless pure spirit be used, but with a little trouble the Revenue authorities may be induced to give permission for the use of pure methylated spirit, which answers every purpose. The trouble then is that not less than five gallons can be purchased, an *embarras de richesses* for the average microscopist, but, after all, the spirit is extremely cheap, and does not deteriorate by keeping.

When the dissection in either of these media is completed, spirit should be gradually added to bring the strength up to 50 per cent., in which the preparation may remain for a day or two, after which it is gradually brought into pure spirit, or into water again, according to the medium in which it is to be mounted.

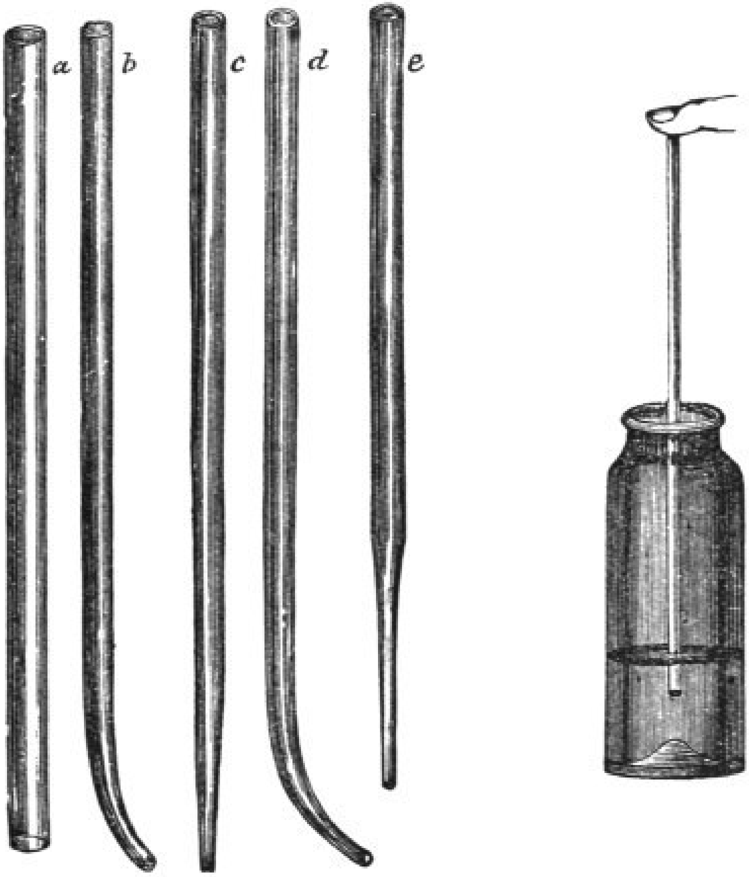

Fig. 12.

As to the tools required, they are neither numerous nor expensive. Fine-pointed but strong forceps (Fig. 9, *c*), curved and straight; a couple of pairs of scissors, one strong and straight, the other more delicate, and having curved blades, and a few needles of various thicknesses and curves, are the chief ones. The latter may be made by inserting ordinary needles, for three-fourths of their length, into sticks of straight-grained deal (ordinary firewood answers best), and thereafter bending them as required. A better plan, however, is to be provided with a few of the needle-holders shown in Fig. 9, *b*. These are very simple and inexpensive, and in them broken needles are readily replaced by others. Dipping-tubes, such as are shown in Fig. 12, will also be extremely useful for many purposes. These are very easily made by heating the centre of a piece of soft glass tubing of the required size, and, when it is quite red-hot, drawing the ends apart. The fine tube in the centre should now be divided by scratching it with a fine triangular file, and the scratch may of course be made at such a point as to afford a tube of the required fineness. The edges should be smoothed by holding them in the flame until they just run (not melt, or the tube will close). These tubes can often be made to supply the place of a glass syringe. They may be used either for sucking up fluid or for transferring it, placing the finger over the wide end, allowing the tube to fill by displacement of air, and then re-closing it with the finger. This last method is especially useful for transferring small objects from one receptacle to another. In speaking of the dissection of objects, it should have been mentioned that the microscope itself may, under careful handling, be made to serve very well, only, as the image is reversed, it is almost impossible to work without using a prism to re-erect the image. Such a prism is shown in Fig. 13. The microscope is placed vertically, and the observer, looking straight into the prism, sees all the parts of the image in their natural positions. This appliance is extremely useful for the purpose of selecting small objects, and arranging them on slides in any desired manner. A few words may be added as to the reproduction of the images of objects.

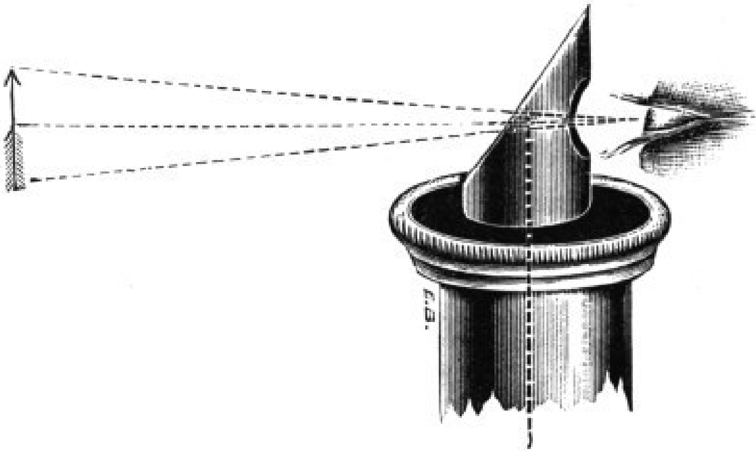

Fig. 13.

The beginner is strongly recommended to practise himself in this from the outset. Even a rough sketch is worth pages of description, especially if the magnification used be appended;

and even though the worker may be devoid of artistic talent, he will find that with practice he will acquire a very considerable amount of facility in giving truthful outlines at least of the objects which he views. Various aids have been devised for the purpose of assisting in the process. The simplest and cheapest of these consists of a cork cut so as to fit round the eye-piece. Into the cork are stuck two pins, at an angle of 45° to the plane of the cork, and, the microscope being placed horizontally, a thin cover-glass is placed upon the two pins, the light being arranged and the object focused after the microscope is inclined. On looking vertically down upon the cover-glass, a bright spot of light will be seen, and as the eye is brought down into close proximity with it the spot will expand and allow the observer to see the whole of the image without looking into the microscope. If a sheet of paper be now placed upon the table at the place occupied by the image so projected, the whole of the details will be clearly seen, as will also the point of a pencil placed upon the paper in the centre of the field of view; and, after a little practice, it will be found easy to trace round the chief details of the object. Two points require attention. The first is that if the light upon the paper be stronger than that in the apparent field of the microscope, the image will not be well seen, or if the paper be too feebly lighted, it will be difficult to keep the point of the pencil in view. The light from the microscope is thrown into the eye, and the view of the image upon the paper is the effect of a mental act, the eye looking out in the direction from which the rays appear to come. The paper has therefore to be illuminated independently, and half the battle lies in the adjustment of the relative brightness of image and paper. The second point is, that it is essential to fix one particular point in the image as the starting-point of the drawing, and this being first depicted, the image and drawing of this point must be kept always coincident, or the drawing will be distorted, since the smallest movement of the eye alters the relations of the whole. The reflector must be placed at an angle of 45°, or the field will be oval instead of circular. The simple form of apparatus just described has one drawback, inasmuch as the reflection is double, the front and back of the cover-glass both acting as reflectors. The image from the latter being much the more feeble of the two, care in illumination will do much to eliminate this difficulty; but there are various other forms in which the defect in question is got rid of. The present writer has worked with all of them, from the simple neutral tint reflector of Beale to the elaborate and costly apparatus of Zeiss, and, upon the whole, thinks that he prefers the cover-glass to them all.

A very simple plan, not so mechanical as the last-named, consists in the use of "drawing-squares," which are delicate lines ruled upon a piece of thin glass, and dropped into the eye-piece so that the lines rest upon the diaphragm of the eye-piece, and therefore are in focus at the same time as the object. By the use of these, in combination with paper similarly ruled, a diagram of any required size can be drawn with very great facility.

The squares, if compared with a micrometer, will furnish an exact standard of magnitude for each object-glass employed. The micrometer is a piece of thin glass upon which are ruled minute divisions of an inch or a millimeter. Suppose the micrometer to be placed under the microscope when the squares are in the eye-piece, and it be found that each division corresponds with one square of the latter, then, if the micrometric division be one one-hundredth of an inch, and the squares upon the paper measure one inch, it is clear that the drawing will represent the object magnified a hundred "diameters"; if two divisions of the micrometer correspond to three squares, the amplification will be a hundred and fifty diameters; if three divisions correspond to two squares, sixty-six diameters, and so on. If a draw-tube be used, it will be necessary to know the value of the squares at each inch of the length, if they are to be used for measuring magnification.

CHAPTER III

Examination of Objects—Principles of Illumination—Mirror and its Action—Substage Condenser—Use of Bull's-eye—Opaque Objects—Photography of Microscopic Objects.

So much depends upon a right method of employing the microscope, as regards both comfort and accuracy, that we propose to devote a little space to the consideration of the subject.

Let us first warn the intending observer against the use of powers higher than are required to bring out the details of the object. Mere magnification is of very little use: it increases the difficulties both of illumination and of manipulation, and, as already said, interferes with that grasp of the object which it is most desirable to obtain. Rather let the beginner lay himself out to get the very most he can out of his lowest powers, and he will find that, by so doing, he will be able far better to avail himself of the higher ones when their use is indispensable.

The essential means to this end is a mastery of the principles of illumination, which we now proceed to describe.

We suppose the microscope to be inclined at an angle of about 70° to the horizontal, with a low-power objective attached to it, a one-inch by preference. Opposite to the microscope, and about a foot away from it, is a lamp with the edge of the flame presented to the microscope, the concave mirror of which is so arranged as to receive the rays from the flame and direct them up the tube of the microscope. Upon the stage is placed a piece of ground-glass, and the mirror-arm is now to be moved up or down upon its support until the ground-glass receives the maximum of illumination, which it will do when the lamp-flame is at one conjugate focus of the mirror and the ground-glass at the other. The focus will not be an image of the flame, but a bar of light.

If an object be now placed upon the stage, instead of the ground-glass, and the objective focused upon it, it will, if the mirror be properly adjusted, be brilliantly illuminated.

It will be understood that every concave mirror has a focus, and converges the rays which fall upon it to this focus, behaving exactly like a convex lens. The principal focus of a concave mirror is its radius of curvature, and this is not difficult to determine. Place side by side a deep cardboard box and the lamp, so that the concave mirror may send the rays back, along a path only slightly inclined to that by which they reached it, to the bottom of the box. The lamp and box being equidistant from the mirror, it is evident that when the mirror forms an image of the former upon the latter equal to the flame in size, we have the equivalent of the equal conjugate foci shown in Fig. 2. Now move the box to the distance from the mirror which corresponds to the distance of the stage of the microscope from the mirror when the latter is in position upon the microscope, and then move the lamp to or fro until the mirror casts a sharp image of the flame upon the bottom of the box, which is not to be moved. The lamp distance so found will be the correct one for working with the concave mirror. The writer is led to lay special stress upon this matter, from the fact that he almost invariably finds that the mirror is arranged to be used for parallel rays, *i.e.* for daylight, and is therefore fixed far too close to the stage to be available for correct or advantageous working with the lamp, unless, indeed, the bull's-eye condenser be used, as hereinafter described, to parallelise the rays from the lamp.

Work done with the concave mirror can, however, under the most favourable conditions, only be looked upon as a *pis aller*. The advantages gained by the use of some substage condenser, even the most simple, in conjunction with the plane mirror, or even without any mirror at all, are so manifold that the beginner is strongly urged to provide himself with some form or other of it, and we now proceed to describe the way in which this should be used to produce the best effect.

To reduce the problem to its most simple elements, turn the mirror altogether out of the way, and place the microscope upon a block at such a height as shall be convenient for observation, and shall allow the rays from the lamp, placed in a line with it on the table, to shine directly into the tube of the microscope. Ascertain that this is so by removing both objective and eye-piece and looking down the tube, when the flame should be seen in the centre, edgewise. Now replace the eye-piece, and screw on to the tube the one-inch combination or objective. Place upon the stage an object, preferably a round diatom or an echinus-spine, and focus it as sharply as possible. Now place the substage condenser in its jacket, and slide it up and down until the image of the object is bisected by the image of the flame.

The centre of the object will now be brilliantly illuminated by rays travelling in the proper direction for yielding the best results. The object is situated at the common focus of the microscope and the condenser, and, whatever means of illumination be adopted, this is the result which should always be aimed at.

Satisfactory as this critical arrangement is, however, from a scientific point of view, it has its drawbacks from an artistic and æsthetic one. It is not pleasant, for most purposes, to have merely the centre of an object lighted up, and we have now to consider how the image of the edge of the flame may be so expanded as to fill the field without sacrificing more than a very small fraction of the accuracy of the arrangement just attained.

Referring to Fig. 1, we see that if we place the lamp at the principal focus of a lens, it will emit a bundle of parallel rays equal in diameter to the diameter of the lens. This is the key of the position. We cannot place the lamp at an infinite distance from the substage condenser, but we can supply the latter with rays approximately parallel, so that it shall bring them to a focus upon the object at very nearly its own principal focus. This we do by means of the bull's-eye condenser. Place the latter, with its flat side toward the edge of the flame, and at its principal focal distance (the method of determining which has already been described) from the latter, so that the bundle of parallel rays which issue from it may pass up to the substage condenser. On examining the object again, it will be found that, after slight adjustments of the position of the bull's-eye have been made, the object lies in the centre of an evenly and brilliantly lighted field.

It may be necessary to place the bull's-eye a little farther from or nearer to the lamp, or to move it a little to one side or the other, but when it is at the correct distance, and on the central line between the lamp and the substage condenser, at right angles to this line, the effects will be as described. It may help in securing this result if we mention that when the bull's-eye is too far from the lamp, the image of the flame is a spindle-shaped one; whilst, when the distance between the two is too short, *i.e.* less than the principal focal length of the lens, the field is crossed by a bar or light, the ends of which are joined by a ring, whilst on either side of the bar there is a semi-circular dark space.

We have hitherto supposed the objects viewed to be transparent, but there are many, of great interest, which are opaque, and call for other means of illumination. Of these there are several. The simplest and, in many ways, the best is to use the bull's-eye condenser to bring to a focus upon the object the rays of light from some source placed above the stage of the microscope. If light can be obtained from the sun itself, no lens will be needed to concentrate it; and indeed, if this were done, there would be considerable risk of burning the object. The light from a white cloud, however, with the help of the bull's-eye, answers admirably. At night-time an artificial source of light, the more intense and the more distant the better, is required. For most cases, and with powers not higher than one inch, a good paraffin lamp, placed about two feet away from the stage, and on one side of it, so as to be about a foot above the level of the object, will give all that is needed. Such a lamp is shown in Fig. 14. Low magnifications are, as a rule, all that is called for in this method.

Lieberkuhn's condensers are useful aids, but are somewhat expensive. They are concave mirrors, which are so adjusted to the objective that the latter and the reflector come into focus together, the light being sent in from below, or from one side.

One other method of illumination must be mentioned before leaving the topic, and this is the illumination of objects upon a "dark field." With suitable subjects, and when carefully managed, there is no method which gives more beautiful effects, and it has the great advantage of allowing the object to be brilliantly lighted, without the strain to the eyes which is involved in such lighting by the usual method of direct illumination.

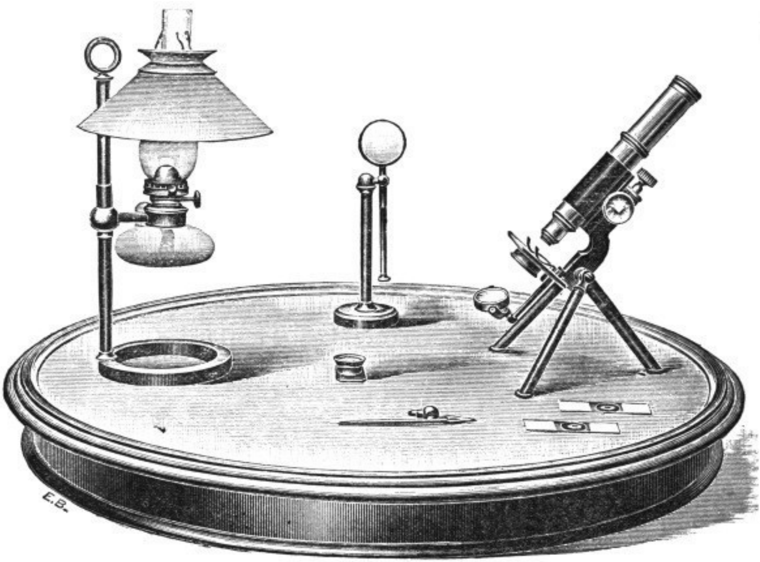

Fig. 14.

It consists essentially in allowing the light to fall upon the object from below, at such an angle that none of it can enter the objective directly. Thus the concave mirror, turned as far as possible to one side, and reflecting on to the object the rays from the lamp placed upon the opposite side, will give very fair results with low powers; this plan, however, is capable of but very limited application. Again, a disc of black paper may be stuck on to the middle of the bull's-eye, and the latter be placed below the stage between it and the mirror. In this case everything depends upon the size of the disc, which, if too small, will not give a black ground, and if too large will cut off all light from the object.

The best and only really satisfactory plan is to arrange the illumination with the substage condenser, as previously described, and then to place below the lens of the latter a central stop of a suitable size, which can only be determined by trial. When this has been done the object will be seen brilliantly illuminated upon a field of velvety blackness. Such stops are supplied with the condenser.

We have devoted a considerable portion of space to this question, since it is, of all others, the most important to a successful, satisfactory, and reliable manipulation of the microscope; but even now, only the main points of the subject have been touched upon, and the worker will find it necessary to supplement the information given by actual experiment. A few failures, rightly considered, will afford a great amount of information, but those who desire to go thoroughly into the matter are recommended to consult the present writer's *Guide to the Science of Photomicrography*, where it is treated at much greater length, as an essential part of the subject-matter of the book.

It may be added here, that no method of reproducing the images of objects is on the whole so satisfactory as the photographic one; and whilst a lengthened reference to the topic would be out of place in a work of the character of the present one, the one just mentioned will be found to contain all that is necessary to enable the beginner to produce results which, for faithfulness and beauty, far excel any drawing, whilst they have the additional advantage that they can, if required, be exhibited to hundreds simultaneously.

CHAPTER IV

Vegetable Cells and their Structure—Stellate Tissues—Secondary Deposit—Ducts and Vessels—Wood-Cells—Stomata, or Mouths of Plants—The Camera Lucida, and Mode of Using—Spiral and Ringed Vessels—Hairs of Plants—Resins, Scents, and Oils—Bark Cells.

We will now suppose the young observer to have obtained a microscope and learned the use of its various parts, and will proceed to work with it. As with one or two exceptions, which are only given for the purpose of further illustrating some curious structure, the whole of the objects figured in this work can be obtained without any difficulty, the best plan will be for the reader to procure the plants, insects, etc., from which the objects are taken, and follow the book with the microscope at hand. It is by far the best mode of obtaining a systematic knowledge of the matter, as the quantity of objects which can be placed under a microscope is so vast that, without some guide, the tyro flounders hopelessly in the sea of unknown mysteries, and often becomes so bewildered that he gives up the study in despair of ever gaining any true knowledge of it. I would therefore recommend the reader to work out the subjects which are here mentioned, and then to launch out for himself on the voyage of discovery. I speak from experience, having myself known the difficulties under which a young and inexperienced observer has to labour in so wide a field, without any guide to help him to set about his work in a systematic manner.

The objects that can be most easily obtained are those of a vegetable nature, as even in London there is not a square, an old wall, a greenhouse, a florist's window, or even a greengrocer's shop, that will not afford an exhaustless supply of microscopic employment. Even the humble vegetables that make their daily appearance on the dinner-table are highly interesting; and in a crumb of potato, a morsel of greens, or a fragment of carrot, the enthusiastic observer will find occupation for many hours.

Following the best examples, we will commence at the beginning, and see how the vegetable structure is built up of tiny particles, technically called "cells."

That the various portions of every vegetable should be referred to the simple cell is a matter of some surprise to one who has had no opportunity of examining the vegetable structure, and indeed it does seem more than remarkable that the tough, coarse bark, the hard wood, the soft pith, the green leaves, the delicate flowers, the almost invisible hairs, and the pulpy fruit, should all start from the same point, and owe their origin to the simple vegetable cell. This, however, is the case; and by means of a few objects chosen from different portions of the vegetable kingdom, we shall obtain some definite idea of this curious phenomenon.

I.

FIG.			
1.	Strawberry, cellular tissue	15.	Wood-cells, Elder
2.	Buttercup leaf, internal layer	16.	Glandular markings and resin, "Cedar" pencil
3.	Privet, Seed Coat, showing star-shaped cells	17.	Do. Yew
4.	Rush, Star-shaped cells	18.	Scalariform tissue, Stalk of Fern
5.	Mistletoe, cells with ringed fibre	19.	Dotted Duct, Willow
6.	Cells from interior of Lilac bud	20.	Do. Stalk of Wheat
7.	Bur-reed (*Sparganium*), square cells from leaf	21.	Wood-cell, Chrysanthemum
8.	Six-sided cells, from stem of Lily	22.	Do. Lime-tree
9.	Angular dotted cells, rind of Gourd	23.	Dotted Duct, Carrot
10.	Elongated ringed cells, anther of Narcissus	24.	Cone-bearing wood, Deal
11.	Irregular star-like tissue, pith of Bulrush	25.	Cells, outer coat, Gourd
12.	Six-sided cells, pith of elder	26.	Ducts, Elm
13.	Young cells from Wheat	27.	Cellular tissue, Stalk of Chickweed
14.	Do. rootlets of Wheat	28.	Holly-berry, outer coat


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I.

On Plate I. Fig. 1, may be seen three cells of a somewhat globular form, taken from the common strawberry. Any one wishing to examine these cells for himself may readily do so by cutting a very thin slice from the fruit, putting it on a slide, covering it with a piece of thin glass (which may be cheaply bought at the optician's, together with the glass slides on which the objects are laid), and placing it under a power of two hundred diameters. Should the slice be rather too thick, it may be placed in the live-box and well squeezed, when the cells will exhibit their forms very distinctly. In their primary form the cells seem to be spherical; but as in many cases they are pressed together, and in others are formed simply by the process of subdivision, the spherical form is not very often seen. The strawberry, being a soft and pulpy fruit, permits the cells to assume a tolerably regular form, and they consequently are more or less globular.

Where the cells are of nearly equal size, and are subjected to equal pressure in every direction, they force each other into twelve-sided figures, having the appearance under the microscope of flat six-sided forms. Fig. 8, in the same Plate, taken from the stem of a lily, is a good example of this form of cell, and many others may be found in various familiar objects.

We must here pause for a moment to define a cell before we proceed further.

The cell is a close sac or bag formed of a substance called from its function "cellulose," and containing certain semi-fluid contents as long as it retains its life. In the interior of the cell may generally be found a little dark spot, termed the "núcleus," and which may be seen in Fig. 1, to which we have already referred. The object of the nucleus is rather a bone of contention among the learned, but the best authorities on this subject consider it to be the vital centre of the cells, to and from which tends the circulation of the protoplasm, and which is intimately connected with the growth and reproduction of the cell. On looking a little more closely at the nucleus, we shall find it marked with several small light spots, which are termed "nucléoli."

On the same Plate (Fig. 2) is a pretty group of cells taken from the internal layer of the buttercup leaf, and chosen because they exhibit the series of tiny and brilliant green dots to which the colour of the leaf is due. The technical name for this substance is "chlorophyll," or "leaf-green," and it may always be found thus dotted in the leaves of different plants, the dots being very variable in size, number, and arrangement. A very fine object for the exhibition of this point is the leaf of *Anácharis*, the "Canadian timber-weed," to be found in almost every brook and river. It also shows admirably the circulation of the protoplasm in the cell.

In the centre of the same Plate (Fig. 12) is a group of cells from the pith of the elder-tree. This specimen is notable for the number of little "pits" which may be seen scattered across the walls of the cells, and which resemble holes when placed under the microscope. In order to test the truth of this appearance, the specimen was coloured blue by the action of iodine and dilute sulphuric acid, when it was found that the blue tint spread over the pits as well as the cell-walls, showing that the membrane is continuous over the pits.

Fig. 7 exhibits another form of cell, taken from the Spargánium, or bur-reed. These cells are tolerably equal in size, and have assumed a square shape. They are obtained from the lower part of the leaf. The reader who has any knowledge of entomology will not fail to observe the similarity in form between the six-sided and square cells of plants and the hexagonal and square facets of the compound eyes of insects and crustaceans. In a future page these will be separately described.

Sometimes the cells take most singular and unexpected shapes, several examples of which will be briefly noticed.

In certain loosely made tissues, such as are found in the rushes and similar plants, the walls of the cells grow very irregularly, so that they push out a number of arms which meet each other in every direction, and assume the peculiar form which is termed "stellate," or star-shaped tissue. Fig. 3 shows a specimen of stellate tissue taken from the seed-coat of the privet, and rather deeply coloured, exhibiting clearly the beautiful manner in which the arms of the various stars meet each other. A smaller group of stellate cells taken from the stem of a large rush, and exemplifying the peculiarities of the structure, are seen in Fig. 4.

The reader will at once see that this mode of formation leaves a vast number of interstices, and gives great strength with little expenditure of material. In water-plants, such as the reeds, this property is extremely valuable, as they must be greatly lighter than the water in which they live, and at the same time must be endowed with considerable strength in order to resist its pressure.

A less marked example of stellate tissue is given in Fig. 11, where the cells are extremely irregular, in their form, and do not coalesce throughout. This specimen is taken from the pithy part of a bulrush. There are very many other plants from which the stellate cells may be obtained, among which the orange affords very good examples, in the so-called "white" that lies under the yellow rind, a section of which may be made with a very sharp razor, and placed in the field of the microscope.

Looking toward the bottom of the Plate, and referring to Fig. 27, the reader will observe a series of nine elongated cells, placed end to end, and dotted profusely with chlorophyll. These are obtained from the stalk of the common chickweed. Another example of the elongated cell is seen in Fig. 14, which is a magnified representation of the rootlets of wheat. Here the cells will be seen set end to end, and each containing its nucleus. On the left hand of the rootlet (Fig. 13) is a group of cells taken from the lowest part of the stem of a wheat plant which had been watered with a solution of carmine, and had taken up a considerable amount of the colouring substance. Many experiments on this subject were made by the Rev. Lord S. G. Osborne, and may be seen at full length in the pages of the

Microscopical Journal, the subject being too large to receive proper treatment in the very limited space which can here be given to it. It must be added that later researches have caused the results here described to be gravely disputed.

Fig. 9 on the same Plate exhibits two notable peculiarities—the irregularity of the cells and the copiously pitted deposit with which they are covered. The irregularity of the cells is mostly produced by the way in which the multiplication takes place, namely, by division of the original cell into two or more new ones, so that each of these takes the shape which it assumed when a component part of the parent cell. In this case the cells are necessarily very irregular, and when they are compressed from all sides they form solid figures of many sides, which, when cut through, present a flat surface marked with a variety of irregular outlines. This specimen is taken from the rind of a gourd.

The "pitted" structure which is so well shown in this figure is caused by a layer of matter which is deposited in the cell and thickens its walls, and which is perforated with a number of very minute holes called "pits." This substance is called "secondary deposit." That these pits do not extend through the real cell-wall has already been shown in Fig. 12.

This secondary deposit assumes various forms. In some cases it is deposited in rings round the cell, and is clearly placed there for the purpose of strengthening the general structure. Such an example may be found in the mistletoe (Fig. 5), where the secondary deposit has formed itself into clear and bold rings that evidently give considerable strength to the delicate walls which they support. Fig. 10 shows another good instance of similar structure; differing from the preceding specimen in being much longer and containing a greater number of rings. This object is taken from an anther of the narcissus. Among the many plants from which similar objects may be obtained, the yew is perhaps one of the most prolific, as ringed wood-cells are abundant in its formation, and probably aid greatly in giving to the wood the strength and elasticity which have long made it so valuable in the manufacture of bows.

Before taking leave of the cells and their remarkable forms, we will just notice one example which has been drawn in Fig. 6. This is a congeries of cells, containing their nuclei, starting originally end to end, but swelling and dividing at the top. This is a very young group of cells (a young hair, in fact) from the inner part of a lilac bud, and is here introduced for the purpose of showing the great similarity of all vegetable cells in their earliest stages of existence.

Having now examined the principal forms of cells, we arrive at the "vessels," a term which is applied to those long and delicate tubes which are formed of a number of cells set end to end, their walls of separation being absorbed.

In Fig. 19 the reader will find a curious example of the "pitted vessel," so called from the multitude of little markings which cover its walls, and are arranged in a spiral order. Like the pits and rings already mentioned, the dots are composed of secondary deposit in the interior of the tube, and vary very greatly in number, function, and dimensions. This example is taken from the wood of the willow, and is remarkable for the extreme closeness with which the dots are packed together.

Immediately on the right hand of the preceding figure may be seen another example of a dotted vessel (Fig. 20), taken from a wheat stem. In this instance the cells are not nearly so long, but are wider than in the preceding example, and are marked in much the same way with a spiral series of dots. About the middle of the topmost cell is shown the short branch by which it communicates with the neighbouring vessel.

Fig. 23 exhibits a vessel taken from the common carrot, in which the secondary deposit is placed in such a manner as to resemble a net of irregular meshes wrapped tightly round the vessel. For this reason it is termed a "netted vessel." A very curious instance of these structures is given in Fig. 26, at the bottom of the Plate, where are represented two small vessels from the wood of the elm. One of them—that on the left hand—is wholly marked with spiral deposit, the turns being complete; while, in the other instance, the spiral is comparatively imperfect, and the cell-walls are marked with pits. If the reader would like to examine these structures more attentively, he will find plenty of them in many familiar garden vegetables, such as the common radish, which is very prolific in these interesting portions of vegetable nature.

There is another remarkable form in which this secondary deposit is sometimes arranged that is well worthy of our notice. An example of this structure is given in Fig. 18, taken from the stalk of the common fern or brake. It is also found in very great perfection in the vine. On inspecting the illustration, the reader will observe that the deposit is arranged in successive bars or steps, like those of a winding staircase. In allusion to the ladder-like appearance of this formation, it is called "scalariform" (Latin, *scala*, a ladder).

In the wood of the yew, to which allusion has already been made, there is a very peculiar structure, a series of pits found only in those trees that bear cones, and therefore termed the coniferous pitted structure. Fig. 16 is a section of a common cedar pencil, the wood, however, not being that of the true cedar, but of a species of fragrant Juniper. This specimen shows the peculiar formation which has just been mentioned.

Any piece of deal or pine will exhibit the same peculiarities in a very marked manner, as is seen in Fig. 24. A specimen may be readily obtained by making a very thin shaving with a sharp plane. In this example the deposit has taken a partially spiral form, and the numerous circular pits with which it is marked are only in single rows. In several other specimens of coniferous woods, such as the Araucaria, or Norfolk Island pine, there are two or three rows of pits.

A peculiarly elegant example of this spiral deposit may be seen in the wood of the common yew (Fig. 17). If an exceedingly thin section of this wood be made, the very remarkable appearance will be shown which is exhibited in the illustration. The deposit has not only assumed the perfectly spiral form, but there are two complete spirals, arranged at some little distance from each other, and producing a very pretty effect when seen through a good lens.

The pointed, elongated shape of the wood-cells is very well shown in the common elder-tree (see Fig. 15). In this instance the cells are without markings, but in general they are dotted like Fig. 21, an example cut from the woody part of the chrysanthemum stalk. This affords a very good instance of the wood-cell, as its length is considerable, and both ends are perfect in shape. On the right hand of the figure is a drawing of the wood-cell found in the lime-tree (Fig. 22), remarkable for the extremely delicate spiral markings with which it is adorned. In these wood-cells the secondary deposit is so plentiful that the original membranous character of the cell-walls is entirely lost, and they become elongated and nearly solid cases, having but a very small cavity in their centre. It is to this deposit that the hardness of wood is owing, and the reader will easily see the reason why the old wood is so much harder than the young and new shoots. In order to permit the passage of the fluids which maintain the life of the part, it is needful that the cell-wall be left thin and permeable in certain places, and this object is attained either by the "pits" described on page 43

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