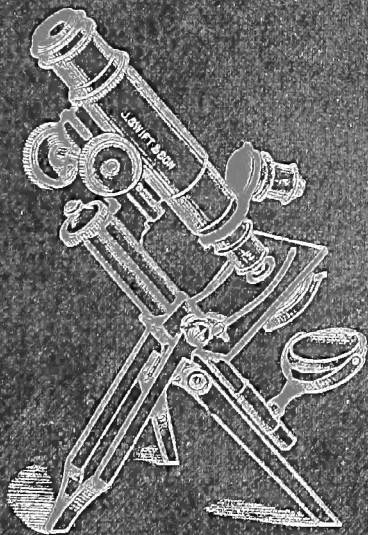


HOW · TO · USE · THE
MICROSCOPE

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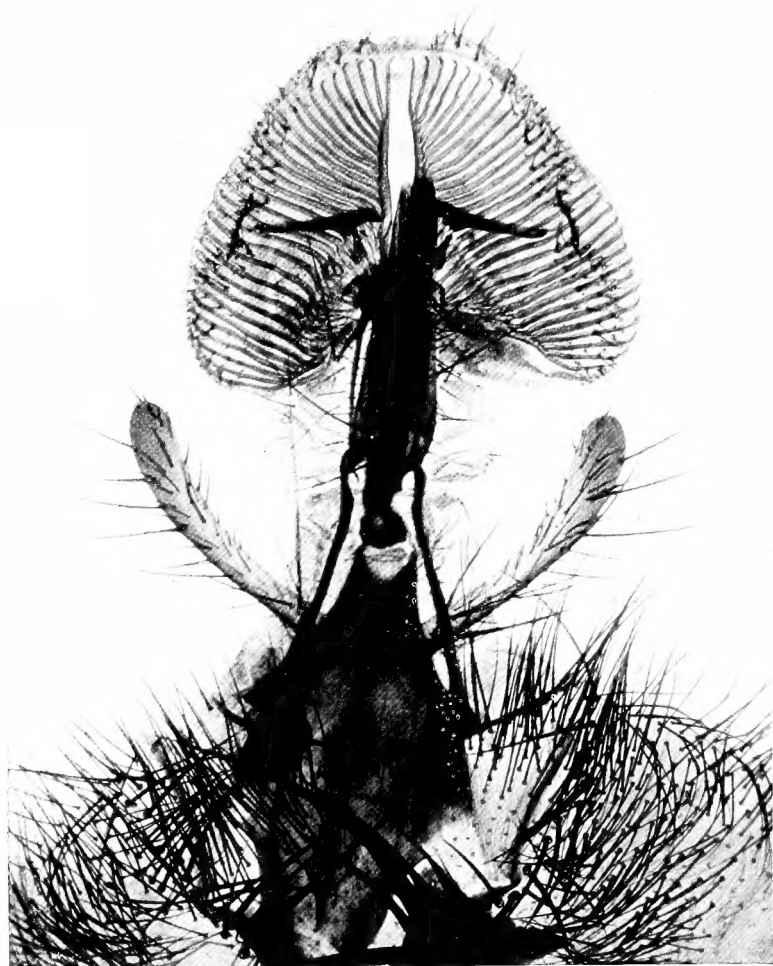
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Proboscis (Tongue) of Blow-Fly (*Musca vomitoria*). × 40

HOW TO USE THE MICROSCOPE

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PREFACE

IN writing this little book I have endeavoured to cater for the beginner who has practically no knowledge of the microscope ; it is a guide for the novice, and I have not presumed to offer advice to the expert microscopist. The instruments described are all relatively inexpensive.

The photographs which are reproduced are my own work, and were obtained by the method described in the concluding chapter.

I am much indebted to Messrs. W. Watson and Sons, Ltd., R. and J. Beck, Ltd., James Swift and Son, and A. Williams and Co., for loan of blocks which appear in the text. I have also to acknowledge Messrs. Watsons' kindness in lending me the exquisitely mounted slides of which photographs are reproduced on Plates 16 and 17.

CHARLES A. HALL.

MEIKLERIGGS,
PAISLEY, 1912.

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House-Fly (*Musca domestica*), with extended Proboscis. × 6

HOW TO USE THE MICROSCOPE

CHAPTER I

THE SIMPLE MICROSCOPE

SOME time ago I handed a pocket lens to a working man of average intelligence, and induced him to examine several common objects with its aid. He was astounded and delighted with what he was able to see. He declared that he had never seen so many wonderful and beautiful things in his life; and it was not long before he bought a cheap lens for himself, which he now has in regular use. It may be said that his lens has introduced him to a new world, in that it provides a means for him to see in beautiful detail many things which cannot be so seen with the unaided eye. I was surprised to learn that this man had never used a magnifying glass until I lent him mine. I am so accustomed to the use of my pocket lens that I found it difficult to realize what is undoubtedly true—that an enormous number of civilized persons, who have received some elements of education, are in the position of my working-man friend; they hardly know the use of a simple magnifying glass, and the compound microscope is entirely beyond their ken.

Presumably a purchaser of this little book will not be in the position indicated, and in writing I propose to assume a slight knowledge of my subject

on the part of the reader. But I shall treat him as one knowing but the barest facts, yet desiring to have a more practical knowledge of microscopy. In point, I write for the beginner who wishes to know how to begin and how to proceed, in a simple and relatively inexpensive way.

The word "microscope" is derived from two Greek words (*mikros*, little; *skopein*, to look at), and a microscope is an instrument which presents to the eye a magnified image of the object examined. The simplest form of microscope is an ordinary magnifying lens, whether in the form of a reading-glass or a pocket magnifier; while a compound microscope is an instrument provided with at least two lenses, one of which is called the "objective," and the other the "eye-piece." The objective and eye-piece are fixed in the opposite ends of a tube, and the object is placed in focus under the objective, which forms an image of a certain magnification; this image is again magnified by the eye-piece. The final magnification depends upon the power of the objective, the power of the eye-piece, and the length of the tube. Taking an objective which magnifies 15 diameters, an eye-piece magnifying 5 diameters, and having a tube of standard length—10 inches—we have a final magnification of $15 \times 5 = 75$ diameters.

Beginners are cautioned against statements issued by vendors of cheap lenses as to their magnifying powers. A microscope may be advertised as capable of magnifying thousands of times. Those "times" are the square of the standard diameters. Thus 2,500 times is really the square of 50 diameters



Tongue of Drone-Fly (*Eristalis tenax*). × 40

—*i.e.*, 50×50 . A million times is 1,000 diameters multiplied by 1,000. This magnification is very great, and involves the use of expensive objectives and the most careful manipulation. For the sake of brevity, magnification is represented by the multiplication sign and the number of diameters : thus $\times 50 = 50$ diameters. .

No matter how impecunious a student may be, he need not be deprived of a lens. Here are two ways in which he may extemporize one at practically no cost. In the first place he may insert a drop of water in a hole in a black card pierced with a red-hot needle. The drop of water will form a lens of some magnifying power. Such a lens, of course, is only a temporary expedient. The second way is to make a small circular hole in a black card, and pour into it a drop of warmed Canada balsam, which on cooling will set hard and form a lens.

Such expedients cannot, however, be taken too seriously ; they can be regarded as curious and experimental, and need be resorted to only as such when we consider that lenses of permanent value can be purchased for a few pence. For a modest sixpence almost any optician will supply a fair magnifying glass in a folding metal mount, suitable for carriage in the waistcoat pocket. This will do good work, and is very suitable for young nature students ; and it need not be disdained by the experienced field-naturalist. It is really remarkable how much is revealed by so simple and inexpensive a tool.

The uses to which a pocket lens may be put are manifold ; they extend to every department of

4 HOW TO USE THE MICROSCOPE

natural history. The rock-pool on the seashore yields abundance of living creatures which may be studied with the naked eye, but it also contains objects of the most interesting nature and habits which the pocket lens enables us to observe. It extends the field of observation in every direction. Some flowers are so small that their parts can be barely distinguished without the aid of the lens, and it is indispensable to the botanist who means business. The entomologist uses it in the examination of insect parts and in other respects ; he also finds it indispensable. The geologist needs it in



FIG. 1.—SIMPLE POCKET MAGNIFIER.

his study of soils, rocks, minerals, and fossils ; the general zoologist must never be without it.

The lens has an æsthetic as well as a scientific value ; it stimulates our sense of the wonderful and beautiful ; it ministers to poetry. He must indeed be dull of soul who is not stirred by the exquisite coloration and symmetry of an insignificant flower as it appears in a magnified image.

Pocket lenses are purchasable in several forms. Cheap single glasses may be had in metal, ebonite, vulcanite, or tortoiseshell mounts. For two or three shillings a mount can be obtained, including three lenses, which may be used separately or in combination. The ordinary watchmaker's glass is

sometimes useful, as it can be held to the eye while the hands are left free to manipulate the object. The Coddington lens used to be held in high esteem ; it is a thick, double-convex glass grooved about the middle, the groove being blackened and acting as a diaphragm. It gives fair magnifying power, but has some imperfections ; thus, it does not yield a sufficiently large and flat field, and the working distance between lens and object is too short. It has to be remembered that working distance lessens with increase of power, and that the shorter this

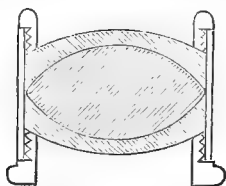


FIG. 2.—APLANATIC MAGNIFIER, SHOWING ARRANGEMENT OF LENSES.

distance is, the less is the size of field and the degree of illumination of the object. Lenses of the Coddington pattern cost from 4s. 6d. to about 9s. For splendid definition, size, and flatness of field, and good working distance, the Aplanatic or Platyscopic lenses are the best in the market. They consist of three lenses cemented together, and are to be had of different powers and in various mountings to suit the purchaser's requirements. Mr. John Browning, 146, Strand, London, supplies in pocket mounts with powers ranging from 10 to 30 diameters ; Messrs. W. Watson and Sons, Ltd., 313, High Holborn, W.C., supply in three patterns of mounting,

one being suitable for fitting into a dissecting microscope, the second for the pocket, and the third being a combination mount, which can be used either for the pocket or as a dissecting lens. With this firm's lenses the magnifying power ranges from 6 to 20 diameters, and the price in nickelled pocket mounts for any power is 12s. 6d. Aplanatic magnifiers are made by all the leading manufacturers. If the price is not too serious a consideration, I should certainly advise the reader who desires the best available pocket lens to purchase an Aplanatic by a good maker.

A pocket magnifier of any type permits the obvious advantage of great freedom in its use. It can be held at any angle, and be used anywhere where there is a sufficient light. The fullest advantage can be taken of such light as is available, and the lens is compact and portable. Carried in a vest pocket, it is at hand in any emergency. Of course, it cannot give the magnification of a compound microscope, but a good worker will always use it in preliminary observations of objects which are to be prepared, wholly or in part, for examination under higher powers.

Pocket magnifiers are of sufficient power for purposes of dissection of various objects. The magnification they give is usually sufficient to enable the student to make clean and satisfactory dissections of flowers, insects, and other objects too numerous to detail. But to make dissections both hands must be free, and to secure this freedom the lens must be fixed in some kind of a stand ; so fixed, it becomes a dissecting microscope.



Fore-leg of Male Water-Beetle (*Dytiscus marginalis*). $\times 20$

Now, a dissecting microscope need not be elaborate or costly ; indeed, the student may extemporize one at any moment. All that is required is a block of wood, say 6 inches square by an inch or an inch and a half thick, for the foot ; a straight, stout piece of wire about 6 or 8 inches long for the upright ; a cork ; and another piece of thinner but stiff wire for the arm. The stout wire is to be fixed firmly in the block of wood, so as to be perpendicular to it. The wire for the arm is at one end bent at a right angle ; the other end is twisted securely round the cork. The bent end is slightly sharpened with a file, so that it may be inserted in a hole bored through the handle of a pocket lens. A hole must be bored through the centre of the cork, which can now be made to slide up or down the upright wire, in order that the lens, held by the arm parallel to the foot-board, may be accurately focussed. The object, fixed on a piece of sheet cork pinned to the wooden foot or otherwise secured, according to its nature, can now be examined through the lens, and the hands are free to use the dissecting tools, of which more anon. If greater illumination of the object is desired, light from a lamp may be concentrated upon it by means of a bull's-eye condenser, or be reflected upon it by a carefully arranged mirror.

An ingenious worker will easily improve upon a dissecting microscope of such a rough-and-ready order. For instance, it will be discovered that light transmitted through the object will prove advantageous in some dissections. In Fig. 3 we have an illustration of an excellent dissecting microscope

8 HOW TO USE THE MICROSCOPE

supplied by Messrs. Watson. This instrument is made of mahogany; the slope of the sides affords convenient support to the hands; the removable stage, $4\frac{1}{2}$ inches square, is of glass; the arm for carrying the lens is raised or lowered by a spiral rack-and-pinion adjustment; and light is transmitted through the glass stage by means of the mirror beneath. The cost, without lenses, is £2. With a sliding bar instead of rack-work, the cost is reduced to £1 5s. But the worker who does not feel able to afford such an instrument need not on

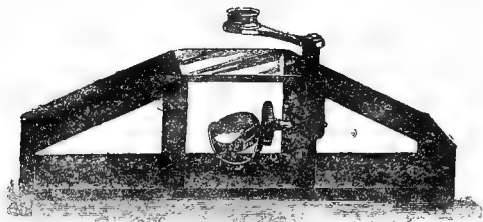


FIG. 3.—WATSON'S "LABORATORY" DISSECTING MICROSCOPE.

that account go without one that will yield satisfactory results. A piece of glass let into a suitable opening in the side of a cigar-box will form a stage; a mirror fixed at an angle of 45 degrees below it will reflect light through a sufficiently transparent object placed on the stage; and the arm holding the lens may be made to slide, for focussing purposes, on a suitable upright. Nor is there any reason why a mirror should not be fixed on a moving fitting, so that it may be made to reflect light through the stage at various angles.

It should be added that cheaper dissecting micro-



Antenna of Cockchafer (*Melolontha vulgaris*). × 15

scopes than that illustrated in Fig. 3 are obtainable in some variety of forms from various makers. Messrs. Watson supply one (see Fig. 4) at the low price of 5s. This has a simple metal base, 4 inches by $3\frac{1}{8}$ inches, on which a piece of matt opal glass, $2\frac{7}{8}$ inches by $2\frac{3}{4}$ inches, fits in grooves. The arm for holding the magnifier slides on the upright cylindrical rod. The price mentioned is for the stand only ; a single magnifier of about 9-diameter power is supplied for this instrument for an extra 2s. 6d.

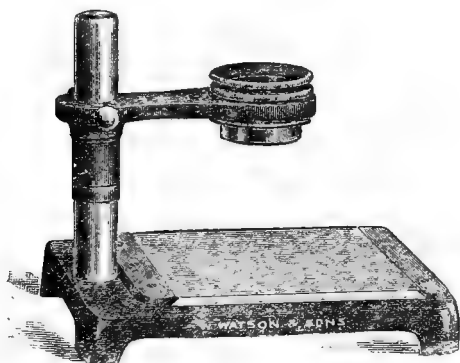


FIG. 4.—CHEAPER FORM OF DISSECTING MICROSCOPE.

The worker requires a few dissecting tools. Complete sets vary in cost from half a guinea to over a sovereign. A scalpel, a pair of scissors, a pair of forceps, and three or four needles set in handles, are really necessary. The beginner who has to study cost may be able to make a sharp pocket-knife do in place of the scalpel, which costs at least 1s. 6d. The scissors, to be good, will cost 2s. 6d. The forceps supplied with cheap compound microscopes

are not always of best quality, and for dissecting purposes a good straight and true pair costs 1s. 6d. A curved pair will also be very useful—cost, about 2s. 6d. The needles, mounted in plain cedar handles, are only 2d. each. A curved pair of scissors can be added to the stock of tools when needed; they cost at least 3s. 6d. These tools should be kept thoroughly clean and free from rust; the knife or scalpel will require sharpening to a smooth, keen edge on a hone from time to time. Good clean work cannot be done with dull or dirty tools.

The needles required are easily prepared at home. All that needs to be done is to fix needles of different sizes in wooden handles. The hafts of worn-out camel-hair brushes serve well. They should be bound at the end in which the needles are to be inserted with strong waxed thread. The eyes of the needles must be broken off, and after a small bore has been made with a needle-point in the wooden hafts each needle can be forced into a secure position by means of a pair of small pliers.

In order to deal with some parts of an object, curved or bent needles may be necessary. The desired curvature is easily effected by heating the needle in the flame of a spirit lamp, and bending it while red-hot. The heat, of course, takes the hardness out of the steel, but this is quickly renewed by raising it once more to a red heat, and plunging it quickly into water. In the absence of a spirit lamp, the needles may be heated in a candle or gas flame, but such flames blacken them with soot, which will have to be carefully wiped off.

The student will also find use for a few camel-

hair brushes and some glass dipping tubes. The latter are used for removing superfluous liquids, washing delicate tissues, and transferring tiny organisms from the water in which they are stored to the stage of the microscope. The glass tubes supplied for filling stylographic and fountain pens make good dipping tubes, but for some work the narrow apertures need to be enlarged. Dealers supply tubes of various apertures, some straight and others curved, for about 3d. each ; but I prefer to prepare my own. The method is simple and requires little skill. Glass tubing as used by chemists is to be bought cheaply enough ; it costs about 1s. 2d. per pound. Two or three pennyworths in 12 or 14 inch lengths will be an ample supply. A piece, say, 12 inches long is heated at the middle to a red heat in a gas or spirit flame, and the ends drawn apart gradually and carefully. The tube should be twirled while in the flame. Naturally, when the glass is softened by heat, and the ends of the tube are pulled apart, the softened portion becomes elongated and narrowed. When this is done and the glass is cooled, a scratch with a fine file makes it easy to break the tube evenly in the centre, and two dipping tubes are now made. The rough edges caused by the breakage are smoothed and rounded by heating in the flame. Tubes may thus be narrowed to any desired aperture, and they may also be bent or curved as required.

The filling of a dipping tube is a simple matter. Press a finger over the wide end so as to close it effectually, plunge the other end in water, remove the finger, and water will rush into the tube. Re-

place the finger and remove the tube ; the water will stay in it so long as the finger is held in position. The contained fluid can now be deposited where it is required by removing the finger. Tiny living objects contained in water are easily caught and transferred to the stage by this method, which is thus particularly valuable in dealing with pond-life. The indiarubber teat on fountain pen ink-fillers acts by suction, and delicate tissues can be washed by ejecting water from the tube on to the object by pressure of the teat ; but a glass syringe acts more satisfactorily, and is not expensive.

Many volumes might be filled with directions for dissecting, and it would be altogether beyond the scope of this little book to go into details. The student usually takes up a special line of investigation, in which he will have textbooks for guidance. He must know what he is doing, and study the anatomy of his objects. His procedure in different lines of investigation will necessarily be greatly varied. If my reader is totally unacquainted with dissecting, and yet desires to make some progress in the art, he cannot do better than commence with a flower, some parts of which he can handle without a lens. Let him consult an elementary book on botany, and as he removes each part of the flower lay it out carefully on a card, writing its name beneath it, arranging sepals, petals, stamens, and pistil in order. The lens will be requisitioned when stamens with their antlers call for attention, and also when the pistil with its stigma, ovary, and ovules are to be examined. Pollen grains, sections of ovaries, and ovules and other details, will need

to be prepared for examination under the higher power of a compound microscope.

From such simple dissection he may proceed by easy stages to more elaborate work, not only in botanical study, but in other lines. For example, a beetle is a good subject for the beginner. Let it be pinned on to a flat piece of cork, say 2 inches square, weighted with lead. Preliminary dissection of wing-cases, wings, legs, antennæ, etc., should be effected in air under the lens ; but when the internal anatomy is to be dealt with, the object, secured to the weighted cork, should be sunk in a vessel of liquid. If the dissection can be proceeded with quickly, water will do ; but if the object is to remain long in liquid, a 4 per cent. solution of formalin will serve. The various organs and tissues require delicate handling ; scalpel, needles, forceps, syringe, and camel-hair brush will be brought into use. The viscera can be more readily separated in fluid than in air, and their details are more apparent in that medium. Each part as separated comes in for examination under the compound microscope, and, if desirable, can be mounted on a glass slip as a permanent object. Mounting will be discussed in a later chapter.

Watch-glasses are often used to contain objects in fluid during dissection. In cases in which larger vessels are required, small photographic developing dishes, plain, shallow salt-cellars, porcelain ointment boxes, or other vessels at hand, may suggest themselves. Square slabs of glass with deep concave cells and cover glasses are sold for the purpose at low cost.

CHAPTER II

THE COMPOUND MICROSCOPE

VALUABLE as is the simple lens either for use in pocket form or as a dissecting microscope, it has distinct limitations, especially in magnifying power. The microscopist cannot dispense with it, for obvious reasons, but when it is necessary to make detailed examinations of minute organisms and structures a compound microscope must be used.

The beginner will be able to gain a distinct idea of the structure of a comparatively inexpensive instrument from the accompanying illustration (Fig. 5). The body tube (1), with the foot (5), stage (7), and all the appurtenances thereof, comprise the "stand," which is a convenient structure for the carriage of the lenses and the holding and lighting of the object. The distance between the eye-piece (13) and the objective, which fits into a female thread (12) at the stage end of the tube, is increased by sliding out the draw-tube (2). Rough focussing is accomplished by means of the milled heads (3), by turning which the body tube is raised or lowered. Fine focussing is managed by the milled head (4) controlling the fine adjustment. The axis joint (6) permits the worker to incline the body of the instrument, along with the stage and

mirror, at a convenient angle, even to the horizontal. The object, suitably confined or mounted, is placed

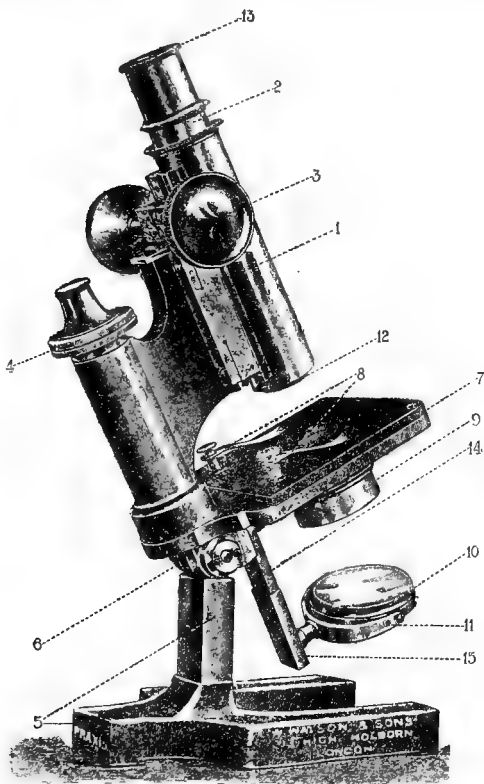


FIG. 5.—WATSON'S "PRAXIS" MICROSCOPE.

For description of numbered parts, see text.

on the stage (7), and the glass slip or containing vessel is held in position by the stage springs (8). The object is illuminated by light reflected by the

mirror (10), which, in its gimbal (11), is inclined at any angle. Beneath the stage is a substage collar (9), into which a light condenser, a spot lens, or polariscope, may be slipped. The stage, it will be noted, has a circular opening, in order that light may reach the object from beneath.

The stand figured embodies all the essential features of a compound microscope. More elaborate stands in great variety, providing numerous conveniences, are obtainable at considerable cost, but the less costly stand described is equal to all the demands that an amateur worker is likely to make upon it.

A handy youth, possessed of more ingenuity than cash, and desiring to have a microscope, need experience little difficulty in making one for himself. When the author was a boy he made one with which he did a good deal of work, and from which he extracted much pleasure. Of course, it had many faults, but it served when money for a good instrument was not available. The body tube was made by rolling glued black paper round a portion of a broom-stick. When the glue had set, the tube was removed from the stick and cut to a 10-inch length. I had two objectives, one consisting of a small double convex lens set in a home-made tube 1 inch long, and made to slip in the body tube; and the other of two double convex lenses, fixed one at each end of an inch tube, slipping into the body in similar fashion. In each objective there was a limiting diaphragm in the form of a metal "washer" with an aperture of about $\frac{1}{4}$ inch. The diaphragms served to cut off objectionable light rays, and thus



(1) Human Flea, Female. $\times 24$

(2) Human Flea (*Pulex irritans*), Male. $\times 24$

improved definition. Lenses and diaphragms were held in position by cardboard collars (blackened) glued inside the little tubes. The one eye-piece I made consisted of a tube made to slip into the opposite end of the body ; it was about 2 inches long, and contained two plano-convex lenses, one at each end, with their convex faces turned downwards. It also had a diaphragm, with a $\frac{3}{4}$ -inch aperture, placed in the tube midway between the lenses. The end of the eye-piece nearest the eye was capped with the rim sawn off a cotton-reel, its aperture being enlarged to $\frac{3}{8}$ inch.

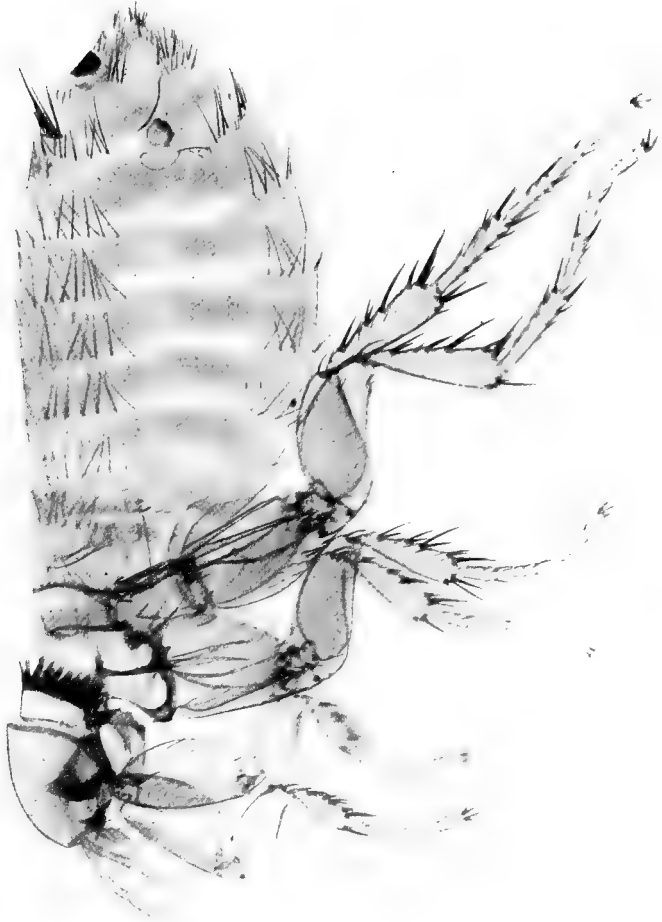
The body tube was made to slide in another short tube for focussing purposes, and the rest of the stand, including the stage, was of wood, the stage being worked out of a cigar-box lid. The stage springs for holding the mounted objects in position were pieces of watch-springs. The mirror was a circular one, with plane surface, which, I think, cost 2d., and was suitably fixed below the stage.

A double convex lens, it should be explained, is one that bulges on both sides ; a plano-convex lens bulges on one side and is flat on the other. My objective lenses cost me nothing, as they were obtained from an old triple pocket magnifier with broken mount which was discovered in the house. My eye-piece lenses were got from an optician out of old stock at about a shilling. I understand that Messrs. J. Lancaster and Sons, Ltd., Birmingham, supply a set of lenses and accessories for use of amateur microscope-makers.

While such a home-made microscope can be made use of when a better instrument is not available,

it has limited power, and one particularly objectionable fault: its lens are not achromatic, or colour-corrected. In consequence, objects viewed through it tend to appear surrounded with a rainbow halo inimical to critical work. The same fault is very evident in the little compound microscopes sold by opticians for a few shillings. These cheap instruments usually have two or three non-achromatic "powers," which screw into each other, low magnification being secured by use of one power, and higher by screwing on one or two more. They are too lightly made for steadiness, and give little stage room for manipulation of objects. For the price at which they are sold one could hardly expect anything better, but no serious worker would consider them for a moment. For good work a reliable instrument must be purchased, and, taking everything into consideration, a satisfactory microscope may be obtained for a moderate figure, as we shall now see.

The intending purchaser of a microscope should make the stand his first consideration, taking care that it is firm on its foot, that its coarse and fine adjustments work evenly and without jerkiness, and that the working distance between the nose of the body tube and stage is sufficient to allow of the use of low-power objectives. The mirror should be double, having a plane surface for low-power illumination and a concave surface for high-power work. A substage fitting is also a valuable adjunct. Having secured a good stand, objectives, eye-pieces, and other accessories can be added according to need and available cash.



Female Flea from Rat. $\times 40$

I calculate that many of my readers will be naturalists, and anxious to know of an instrument which will serve them in the general purposes of nature study. To such I can recommend confidently "The Naturalist's Microscope," made by Messrs. W. Watson and Sons, Ltd., London, illustrated in Fig. 6. This tool is well made in every detail. It has good rack-and-pinion coarse adjustment, an inclining joint, and the mirror and stage are re-

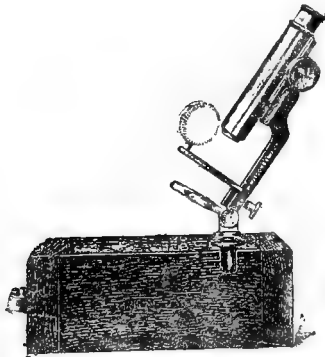


FIG. 6.—WATSON'S "NATURALIST'S" MICROSCOPE.

movable. The mirror can be used below the stage for transmitting light through the object, or fixed on the stage to reflect light on to the object, if it be opaque. The base is formed either by the case in which the instrument is supplied or by the bench on which it is used. A socket in the side of the case holds the stand firmly, and a socket is supplied as a bench fitting. The stand alone, with bench socket, costs only £1. A strong case costs an extra 7s. 6d. One eye-piece and a 2-inch objective,

magnification 28 diameters, run the cost up to £2. Or, instead of the 2-inch objective, a combining object glass, giving with eye-piece 30 to 60 diameter power, is supplied, making the price £2 3s. 6d. Other eye-pieces and objectives can be added as desired. The instrument is compact in its case, and is easily carried, making it suitable for conveyance on a holiday. It is adapted for a great variety of uses.

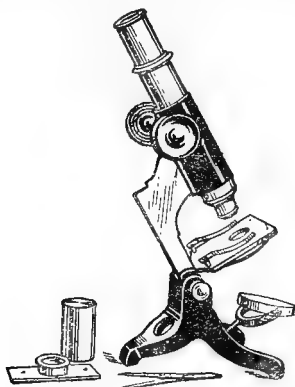


FIG. 7.—WILLIAMS' "WONDER" MICROSCOPE.

Messrs. A. Williams and Co., Wood Green, London, make a speciality of their "Wonder" microscope. This has a lightly made but firm stand (see Fig. 7), with rack-and-pinion coarse adjustment, operated by two milled heads. It is remarkably cheap and yet efficient. Supplied in neat polished mahogany case, together with one objective, an eye-piece, brass forceps, and a live cage, it costs £2 7s. 6d. The same firm make a series of achromatic objectives, which sell at 10s. 6d. each.

Mr. C. Baker, London, advertises a nature-study microscope, with one eye-piece and a combining objective giving magnification $\times 60$, $\times 120$, and $\times 240$ for £2 5s. The joint of this instrument^{es} is not inclinable.

The "Star" (Fig. 8), made by Messrs. R. and J. Beck, Ltd., London, is also an efficient yet inexpensive tool, worthy of favourable consideration by



FIG. 8.—BECK'S "STAR" MICROSCOPE.

beginners. The cost, with one eye-piece and a 1-inch objective, is about £3. The "London" model, made by the same firm, is sound in every respect, but it is more costly than the "Star." It can be had in a comparatively simple form, or in increasing degrees of elaboration. One form, having inclining joint, coarse and fine adjustments, vulcanite-faced stage, draw-tube with millimetre scale, double mirror, iris diaphragm, and substage collar, for stand in case, is listed at £3 5s. 6d. With the addi-

tion of one eye-piece and two objectives, giving power from $\times 59$ to $\times 270$, the price is £5 3s. 6d.

I consider Messrs. Watson's "Praxis" microscope (Fig. 5) to be one of the cheapest on the market. It is sound in construction, good in all its details. It is conspicuous for compactness, lightness, and portability, combined with complete steadiness and entire absence of vibration. For the stand only, fitted with coarse and fine adjustments, plane and concave mirrors, condenser fitting, draw-tubes, and ebonite covered stage, the list price is £3 15s. Possessing such a stand, the beginner can add eye-pieces, objectives, and accessories as needed, and may consider himself the owner of an instrument which will do excellent service and bear hard usage. I also recommend the "Fram" stand (Fig. 9), made by the same enterprising firm; it is a high-class instrument, marketed at the low figure of £4. I find it particularly suitable for photo-micrography; indeed, it was used in the production of the photographs illustrating this volume.

The "Portable Clinical and Field Microscope," made by Messrs. James Swift and Son, London, is held in high regard by many naturalists, particularly as it can be packed very compactly in a leather case, and is thus easily portable. This instrument is strong in build. It has a draw-tube with millimetre scale, mirror, and substage fitting. The stand with one eye-piece, in leather case, with accommodation for two objectives, etc., is listed at £5 (see Fig. 10).

The instruments mentioned above are a few selected out of many that are on the market. I



Head of Male Mosquito (*Culex fuscatus*), from India. × 34

have called attention to them, first, because they are inexpensive, and, secondly, because I have handled them and can speak of them with confi-

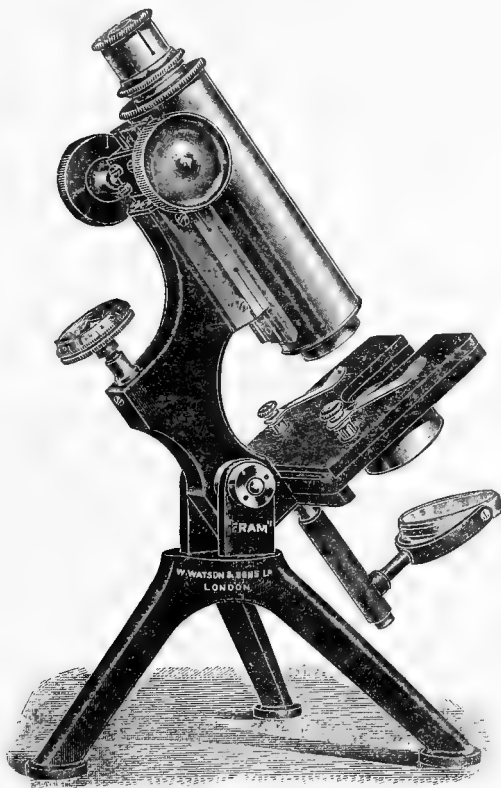


FIG. 9.—WATSON'S "FRAM" MICROSCOPE.

dence. The intending purchaser should, however, consult the catalogues of various makers before selecting an instrument. He will soon discover

that, if he is disposed to do so, he can spend much more money on a stand than I have indicated.

Having secured a satisfactory stand, the beginner will proceed to select objectives, which, after all,

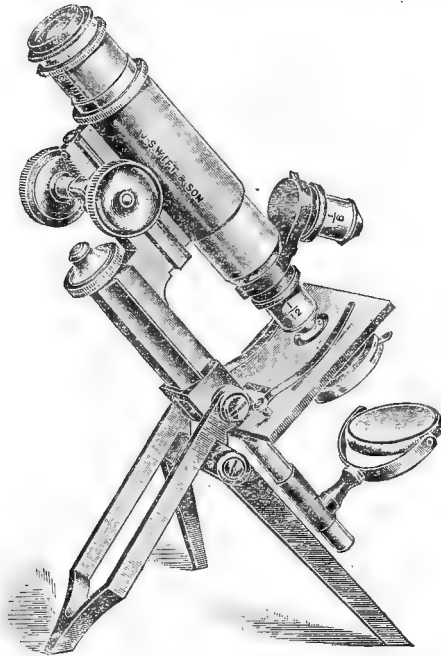
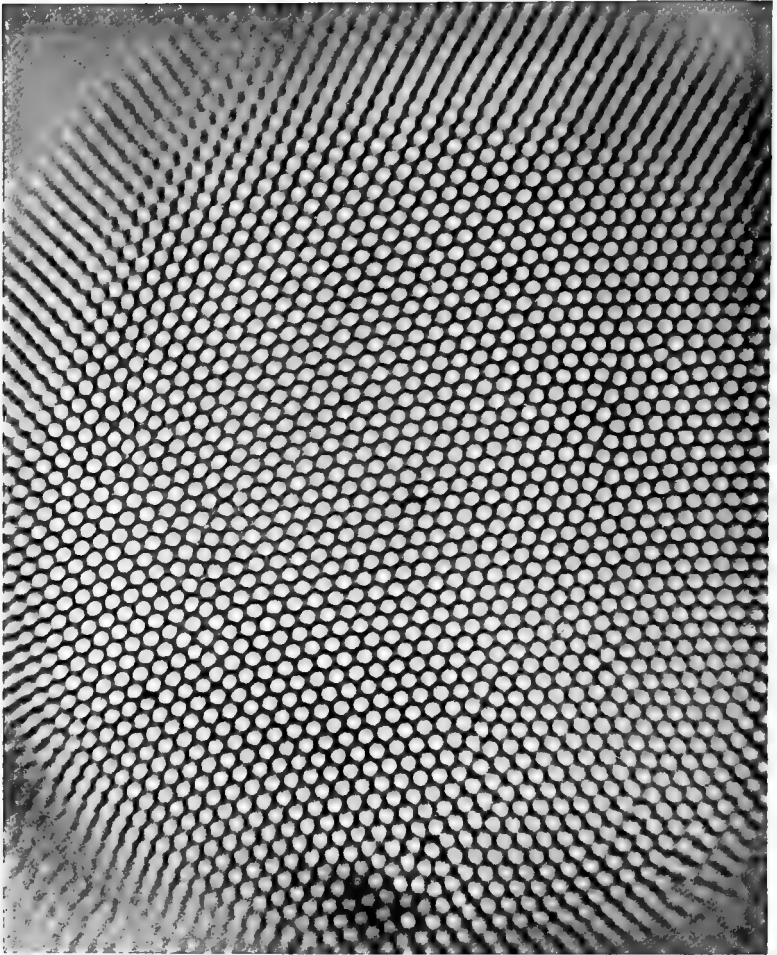


FIG. 10.—SWIFT'S "PORTABLE CLINICAL AND FIELD"
MICROSCOPE.

perform the most important function of a microscope. The number of objectives on the market is legion, and I shall not venture to comment on the various kinds and makes, nor shall I load valuable space with an attempt to elucidate the principles



Cornea of Eye of Beetle, showing Multiple Lenses. $\times 80$

on which they are made. But I counsel the purchaser to consider only such objectives as are made by firms of standing reputation, and in making his choice to obtain, if possible, the advice of a practical microscopist. Objectives of ancient date, offered second-hand, even if made by reputable makers, should be carefully tested. Indeed, any but recently made glasses should be regarded with suspicion.

Achromatism, already spoken of, may be taken for granted in all good class objectives. Other points to be considered are definition, whereby a sharp line in an object is rendered in a sharp image by the objective; the power of penetration, giving depth of focus; flatness of field; and working distance between objective and object. Of course, the higher the power of the object glass, the less is the working distance. Roughly speaking, objectives are rated according to their working distances; thus a $\frac{1}{4}$ -inch glass is more powerful than a 1-inch glass, and the distance between the under side of the lens and the object is greater, when focussing has been done, in the case of the 1-inch than in that of the $\frac{1}{4}$ -inch. But because an objective is classed as a $\frac{1}{4}$ -inch or 1-inch, it does not follow that its working distance is exactly $\frac{1}{4}$ inch or 1 inch; it will probably be considerably less.

As to what "powers" the beginner needs, this depends upon the kind of work he proposes to do. If he is simply going to amuse himself and his friends in a desultory fashion, a $\frac{1}{2}$ -inch objective might serve him as well as any other—perhaps better, because he will find it easy to focus and illuminate.

But if he is going to prosecute a serious course of study, he must take into consideration the magnification he is likely to require in his particular line. In general nature study I find myself using a 3-inch objective most constantly, and a $1\frac{1}{2}$ -inch is next in frequency of use ; in that particular line it is only occasionally that I use a $\frac{1}{4}$ -inch. In my geological work I seldom use a higher power than $1\frac{1}{2}$ -inch ; while in botanical study I use my $1\frac{1}{2}$ -inch, 1-inch, and $\frac{1}{4}$ -inch with much frequency. For bacteriological investigation considerable power is needed ; a $\frac{1}{8}$ -inch is certainly required, and a $\frac{1}{1\frac{1}{2}}$ -inch oil immersion objective is often imperative. But bacteriology is highly specialized work, and oil immersion object glasses are for expert workers, for whose benefit this simple little work is *not* being written.

In brief, my own experience, which I believe is general, points to the most regular use of low powers, and I think I am justified in advising the beginner who can see his way to buying only one objective with his stand to get a 1-inch. If he proposes to buy two, let him get a 1-inch and a $\frac{1}{4}$ -inch ; and if he is to have three, let him add to his $\frac{1}{4}$ -inch and 1-inch a 2-inch or 3-inch glass.

Eye-pieces, or oculars, are the next consideration, and it has already been stated that the eye-piece magnifies the image formed by the objective, and its magnification depends upon power and tube-length. The eye-piece must, of course, be thoroughly good and able to magnify, but it must always be remembered that its function is simply to magnify and present to the eye an *image*. If through in-

feriority of the objective the image formed by it is poor, a powerful ocular will but magnify and accentuate its defects. In point, it is to the objective that we must turn for definition and detail. Thus an objective magnifying $\times 10$ and an eye-piece of similar power will give at a 10-inch tube-length magnification of 100 diameters, but the detail of the object will be more defined if the power of the objective be $\times 20$ and the ocular $\times 5$, although the final magnification in both cases is $\times 100$. The worker's rule, then, should be to use an objective sufficiently good and powerful to bring out a detailed and well-defined image of the object, and an ocular which will present that image to the eye in a satisfactory manner. Personally, I have little use for high-power oculars. I use three with some regularity; my No. 2, magnifying $\times 6$, is in most common use; next comes No. 3, $\times 8$; and last No. 1, $\times 5$. These three eye-pieces in superior mounts cost 10s. 6d. each; they are to be got in the student's pattern for 5s. each.

Messrs. Watson make a series of "Parachromatic" objectives which have many excellencies, and have the recommendation of being relatively inexpensive. The $\frac{1}{4}$ -inch in this series costs £1 5s.; the 1-inch, £1; and the $1\frac{1}{2}$ -, 2-, and 3-inch, £1 2s. each. Combined with their No. 2 Huyghenian eye-piece, these objectives, calculating a $7\frac{7}{8}$ -inch tube-length, give the following total magnifications:

3 in. Parachromatic Objective and No. 2 Ocular	= \times 16
2 " " " "	= \times 29
$1\frac{1}{2}$ " " " "	= \times 36
1 " " " "	= \times 50
$\frac{1}{4}$ " " " "	= \times 209

Greater extension of the tube will give higher magnifications, but not better definition. Thus, with the same eye-piece, a larger image may be obtained by increasing the tube-length.

These figures give the reader a rough idea of magnifications which are obtained in a similar combination of objectives and eye-piece by other makers; but when accurate measurements are desired, they must be obtained by use of a micrometer scale, described on p. 43.

Furnished with a good stand, an eye-piece, and an objective, the beginner is equipped for work. The range of observation is increased by additional objectives and oculars, and there are other accessories, some of which are yet to be mentioned, which are valuable additions to the microscopist's equipment.

CHAPTER III

HOW TO USE THE COMPOUND MICROSCOPE

A MICROSCOPE is a delicately constructed instrument, and needs handling with care. When not in use it should be kept in its case or under a glass cover, so that dust may not settle upon it. The lacquered parts ought not to be polished with any polishing material, nor should they be touched by fingers wet with spirits of any kind. Chemical reagents applied to objects under examination, if allowed to run on to the stage, may cause corrosion. Except when absolutely necessary, the lenses of which oculars and objectives are composed ought not to be removed from their position, lest dust should lodge between them. Dust on exposed surfaces of lenses, or if by any chance lodged on their inner faces, can be removed by gentle cleaning with very soft cloth moistened with methylated spirit. Care must be taken lest lenses are scratched by attempting to clean them with rough, coarse cloth or by other rough usage.

To use the microscope the eye-piece is slipped into the tube at 13 (Fig. 5), and the objective is screwed into the thread at the stage end of the body tube at 12. The object, suitably mounted on a 3-inch by 1-inch glass slip, and covered with a

thin cover-glass, or otherwise held in position, is placed on the stage (7) and secured in the field of vision by the stage springs (8). The instrument is placed in a suitable position in relation to the source of light, and light is reflected through it by the mirror (10). To secure good and even lighting, the sliding mirror fitting (15) may need to be raised or lowered on the tail-piece (14). The mirror has two surfaces, one concave, and the other plane. The concave surface is used with high-power objectives, and the plane with low-power.

We are now ready for focussing, which must be done with care. Rash and hasty raising and lowering of the body tube may lead to disaster to both object and object glass. Let us suppose that we are using a 1-inch objective. Making use of the milled heads (3) controlling the coarse adjustment, we lower the nose of the objective until it is within about $\frac{3}{8}$ inch of the object. Placing the eye to the ocular, we slowly raise the tube until we see a clearly defined image of the object. Using a 1-inch objective, it is probable that we shall be able to focus sufficiently accurately with the coarse adjustment alone, but with higher powers we first roughly focus with the coarse adjustment, and do the final focussing with the fine adjustment (4). Let it be a rule always to *raise* the tube in the first focussing. If it be lowered towards the object while the eye is at the ocular, the novice will very likely lower too far and break the object, perhaps doing other damage as well. A high-power objective will need, in the first instance, to almost touch the cover-glass, from which position it must be raised very gradually.

If, after raising the objective to its proper limits, the object does not appear, it will be because it is not properly centred in the field. The "finding" of an object with lower powers is simple enough ; it becomes more difficult with high powers, whose aperture is very small. The beginner should practise focussing first with a low power, and when expert with it proceed to the use of high power. It is also advisable to practise with a permanently mounted object, which any dealer will supply.

The subject of the source of illumination needs a little consideration. Some workers use daylight, but the beginner is warned against using direct sunlight, a proceeding which might lead to damage to the objective as well as to a mounted object. If daylight be used, it should preferably come through a window facing north. But there are two distinct disadvantages in the use of daylight : in the first place, it is a variable quantity ; and, in the second, it illuminates the workroom as well as the object. Work is always done at its best when the worker is practically in darkness and only the object is illuminated. However, with low powers daylight does not present any difficulties.

But it is generally more convenient to work by artificial light, and it is really the more satisfactory. I sometimes use electric light, but find that the greatest satisfaction is got from a small paraffin lamp taking a $\frac{1}{2}$ -inch flat wick. Elaborate microscope lamps with many conveniences are advertised by dealers, but a glass lamp, which need cost no more than 1s., will meet all the requirements of a beginner. The flame is made whiter by placing a

piece of camphor in the oil. The light from the lamp is concentrated by placing a cylinder of white cardboard over it. This cylinder must, of course, be open at the top for the escape of heat, and have air-holes at the bottom; in addition, a suitable opening through which light can proceed from the flame to the mirror is needed in the side. A metal reflector is not advantageous.

The lamp should be placed about a foot from the mirror, and when low powers are used the *flat* of the flame is turned to the mirror; but with the $\frac{1}{4}$ -inch and higher powers the edge gives more satisfactory results.

Most microscopes are fitted with diaphragms beneath the stage. In the older stands they usually consist of rotating discs of metal pierced with holes of varying diameters. In more modern stands they take the "Iris" form, which can be regulated to any aperture. The diaphragm is used to moderate illumination of the object by cutting off unnecessary rays of light. The worker will soon learn to use the diaphragm with judgment, taking care to use only such light as is necessary. His concern will be to concentrate an even light upon the object, and to avoid dazzling his eye with a flood of light extended beyond the object for which there is no practical use. When objects are so dazzlingly illuminated that the eye is rendered uncomfortable, the light is easily toned by placing a slip of blue-tinted glass under the object.

Up to the present point I have had in mind only such objects as can be examined by transmitted light, and these will be found in the majority. But



Spiny Spider (*Gasteracantha cancriiformis*), from Trinidad. × 6

when we have to deal with opaque substances we usually do away with mirror illumination, and arrange for them to be lighted by other means. Suppose we wish to examine a portion of the wing of a butterfly, so as to observe the shape, colour, and arrangement of its covering scales. The object is placed on a glass slip, and covered with a cover-glass or another glass slip, and put in position on the stage. We attempt to illuminate it by light reflected by the substage mirror, but find that, although possibly a very little light gets through the object, it is not sufficient or satisfactory. To get the best results, we must throw light on to the object from above, and not attempt to pass any through it. In Messrs. Watson's "Naturalist's" microscope, the substage mirror can be removed from its ordinary position and placed in a socket on the stage, so that it may reflect light on to the object. But the commonest method of illuminating opaque objects is by means of a bull's-eye condenser (Fig. 11)—an accessory which is often supplied with a microscopist's outfit, and which can be obtained in various sizes and mountings from 7s. 6d. upwards. A necessary feature of the mounting is that it should allow the lens to be turned in every possible direction.

The bull's-eye condenser is a plano-convex lens of crown-glass. Its convex surface is nearly hemispherical. In using it for illumination of opaque objects, the lamp should be raised as high above the level of the stage as it can be without being so situated that the objective will cause a shadow on the object. The light should be about 10 inches

from the stage. The bull's-eye is placed with its plane surface towards the flame, between it and the object, and at such a distance that the latter is

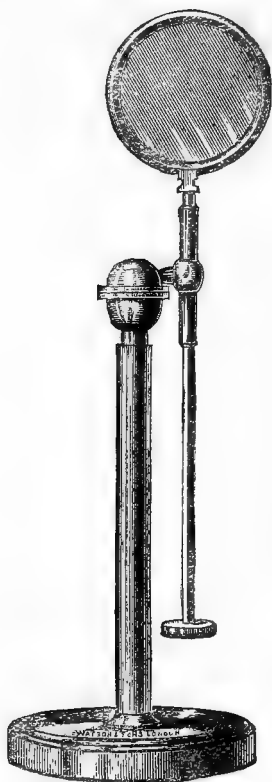


FIG. 11.—BULL'S-EYE CONDENSER.

illuminated by a small image of light focussed upon it.

It is usually stated that a large bull's-eye is better

than a small one, but the difference is not very great so far as actual results are concerned. The illumination given by this accessory is necessarily one-sided, and gives rise to severe contrasts of light and shade. If more even lighting is necessary, it can be secured



FIG. 12.—SILVER SIDE REFLECTOR.

by using a silver side reflector (Fig. 12). This is supplied in a mount with a stem for fitting into the stage or body of the microscope, and ball-joints allowing the reflector to be adjusted, hollow surface inwards, by the side of the object. The lamp is placed on one side, on a level with and opposite to

the reflector, and light rays collected by the reflector are focussed by it on to the object. Or the light is further strengthened by centring the bull's-eye in line with lamp and reflector, and throwing parallel rays on to the latter.

It is useful to practise the parallelization of light by means of the bull's-eye. This result is obtained when an image of the light-flame is formed on the wall of the room about 10 feet distant. This image secured, note distance of lens from the flame, and at that distance an approximately parallel beam of light will always be obtained. A parallel beam from the bull's-eye thrown on to the mirror below the stage will often be of great value in illuminating transparent objects, and it is also useful, thrown directly on to the object, in the practice of photomicrography.

The student will find it necessary to take care of his eyes, and he will be enabled to do so by toning the field with tinted glass, as already mentioned (p. 32), and also by accustoming himself to use either eye with ease. In using the microscope, the eye should always be placed close to the ocular, but it must not be pressed upon it.

The owner of a good microscope, howsoever generously he be disposed, is well advised not to allow any but expert persons to use his instrument.

CHAPTER IV

SOME ACCESSORIES AND THEIR USES

LET the worker of limited means distinctly understand that excellent work is assured by the thoughtful use of the equipment already described. Further expenditure on accessories is not imperative, but it may be deemed desirable. I now proceed to describe a few accessories out of the hundred and one advertised that will materially assist the student in his observations.

We shall first consider a most valuable illuminating accessory, particularly in its use with high powers—the Substage Condenser. As its name implies, it is used to condense or concentrate light upon the object to a greater extent than can be secured by a mirror alone. Condensers are supplied in mounts which slide into the understage collar (see Fig. 5, 9), or can be centred in the focussing substage fitted to higher-priced microscopes. The commonest form is known as the Abbe Illuminator, which costs from about 17s. 6d. upwards, according to additional conveniences. The better forms are distinguished by larger lenses, the inclusion of an iris diaphragm, and a carrier for the stops used to obtain dark-ground illumination.

In use, the condenser is first slipped into the

under-stage collar until the outside surface of the top lens is flush with the surface of the stage and in touch with the under side of the object. The lamp is placed 4 or 5 inches from the mirror, the *plane* side of which is used, and light is directed through the condenser. Then the object is focussed with the objective in the usual way. With the iris diaphragm nearly closed, the condenser is gradually moved downwards in the under-stage collar until the flame of the lamp is imaged in the field as a central streak of light between dark margins. The dia-

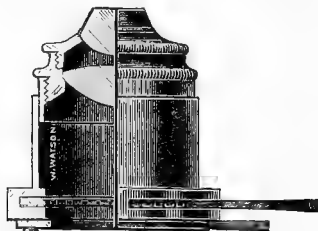


FIG. 13.—ABBE CONDENSER MOUNTED FOR UNDER-STAGE.

phragm is finally adjusted to the most suitable aperture. The *edge* of the flame is turned towards the mirror.

With the condenser thus used, the centre of the field is critically and brightly illuminated, enabling the worker to get the best possible results with medium and high-power objectives, which invariably give their best definition at one point of the field only, and it is that point, in the centre, upon which light is concentrated. If it is desired to light the whole field, the *flat* of the flame may be turned to the mirror, or rays from the flame can be parallelized

by interposing a bull's-eye between the flame and the mirror.

It is not usually considered necessary to use a condenser with objectives of lower power than $\frac{1}{2}$ -inch, but if it is desired to use it with such, the top lens of the condenser will need to be removed so as to secure a larger field of illumination. The worker should also note that any lens of proper size and suitable focus fitted into the under-stage collar will act as a condenser and improve the image.

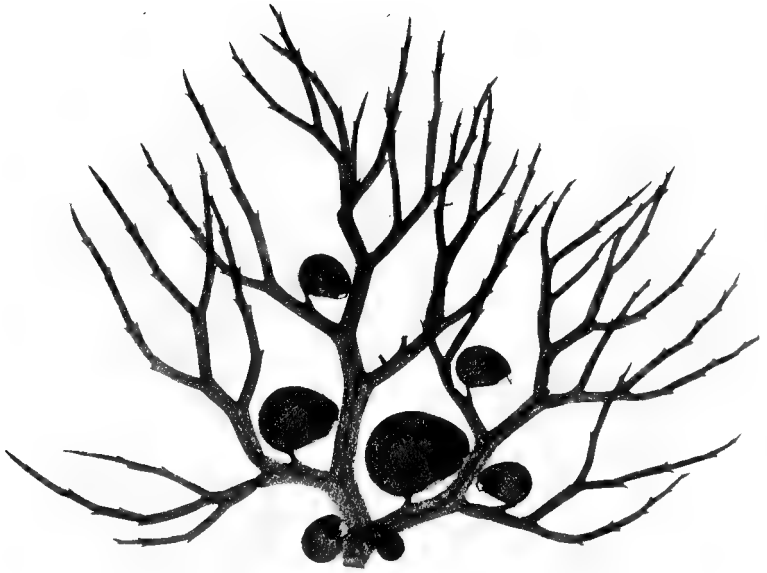
Certain objects of a highly transparent character are examined to the greatest advantage with what is known as dark-ground illumination, by means of which the object is beautifully lighted and at the same time thrown up clearly against a black background. Condensers are usually fitted with a carrier into which "stops" of blackened metal can be inserted. The carrier is swung out, a suitable stop inserted, and swung back into position. The circular stop is thus placed below the centre of the back lens of the condenser, cutting off the central rays of light which would ordinarily enter the objective. The black background is thus obtained, and when an object is placed in the field the rays, which would not in the usual course enter the objective, are caught by the object and diffracted, so that the latter is exquisitely illuminated. Many creatures coming under the term "pond-life" are seen in remarkable beauty by this method of lighting; the same may be said of some marine zoophytes and radiolarians, foraminifera and diatoms, also hairs of plants.

Until condensers with carriers for stops for dark-

ground illumination came into vogue, what is called a "spot lens" was used for this purpose. It was a lens with a central black circle, fitted in a sliding mount in a collar, which could be slipped into the under-stage and focussed. Spot lenses are not used so frequently as they were, because they are practically included in a condenser; but they are still available, and, having a long focus, are often exceedingly useful for illuminating zoophytes in troughs which are beyond the focus of an ordinary condenser.

On occasion, a spot lens can be extemporized by sticking a circle of black paper on the flat surface of a bull's-eye. This lens is placed plane surface to the mirror, under the stage, at a suitable distance beneath the object. I have also read somewhere about an ingenious individual who made a rough spot lens out of a bull's-eye taken from an electric pocket lamp. The lens, with black paper disc affixed on its plane surface, was fixed into a circular aperture in a small slab of cork, the highest point of the convex surface being barely flush with the surface of the slab. This device was used *on* the stage of the microscope, the object being laid above the extemporized lens.

The Polariscopes is an accessory I should not care to dispense with. It consists of two Nicol prisms of Iceland spar suitably mounted; one prism, known as the "polarizer," is mounted so that it can be slipped into the under-stage collar and rotated by means of a milled head, and the other is mounted so that it can be either screwed on to the nose of the body tube above the objective, or fixed above the eye-



Portion of the Carnivorous Plant Bladderwort
(*Utricularia vulgaris*). × 7

The leaves grow in water and bear little bladders
which are traps for minute animalculæ.

piece. The second prism is called the "analyzer." Very often the analyzer is made to rotate instead of the polarizer. Lighting is effected by the mirror. The polariscope splits light in such a way that certain



FIG. 14.—POLARIZER.

objects illuminated by it display most wonderful colour effects, which are varied as the rotating prism is turned. Films of selenite interposed between the polarizer and the object produce variations of tints and colour backgrounds. The



FIG. 15.—ANALYZER.

polariscope is commonly used in examining rock sections, crystals, starches, etc., and it is valuable in such examinations because of the remarkable way in which it reveals structure. The modern

geologist makes much use of this delightful and valuable accessory. For the best and most highly finished polarizing apparatus a good deal of money can be paid, but the ordinary worker will find the less expensive forms quite satisfactory. Messrs. Watson supply complete apparatus, with a selenite film, for 17s. 6d., while Messrs. Williams and Co., the makers of the "Wonder" microscope, list quite a good polarizing outfit for 15s.

The earnest worker naturally wishes to preserve records of his observations, not only in the way of written notes, but also by means of drawings. A person possessing drawing accomplishments may feel able to draw objects without assistance, but all microscopists are not good draughtsmen, and the majority are glad to avail themselves of some form of Camera Lucida—a device whereby images of objects are apparently projected on to paper so that they may be fairly easily outlined with a pencil.

The least expensive form of drawing apparatus is Beale's Neutral Tint Camera, consisting of a thin plate of neutral tint glass mounted at an angle of 45 degrees. It costs 5s. or 6s. The brass tube to which the glass is fixed is slipped on to the eye-piece, or body tube, after the eye-piece cap has been removed. The microscope is inclined horizontally, and raised on a box or book so that the central axis of the tube is distant 10 inches from the table. The drawing paper is placed flat on the table below the eye-piece. The observer's eye is directed on to the neutral glass, which reflects the image of the object upwards. But although the image is really reflected to the eye, it appears to be thrown on to the paper,

where it can be drawn, preferably with a hard pencil. The novice will probably experience a little difficulty in his first use of the camera lucida, but he will gain the knack of it with practice. It is necessary to keep one-half of the pupil of the eye looking upon the edge of the camera, and the other half at the pencil and paper. Light also must be carefully adjusted, as much depends upon the brightness of the image appearing on the paper in relation to that of the paper and pencil.

To ascertain the degree of magnification of an object by the microscope in a sufficiently exact manner, a Stage Micrometer is needed. This accessory is a glass slide ruled with a line, divided into spaces either $\frac{1}{100}$ or $\frac{1}{1000}$ inch wide, or possibly marked in fractions of a millimetre. It is used thus: The microscope is arranged for drawing with the camera lucida attached as usual, care being taken that the distance of 10 inches between tube and paper is maintained. The object is focussed, and the dimensions of the image marked on the paper. Then the stage micrometer is substituted for the object, and the image of its divisions seen on the paper gives an indication of magnification, as well as of the actual size of the object. Such a ruled glass micrometer costs 5s.

A Live Cage is used for holding small living objects in position, and if properly handled will hold many live creatures in position without destroying them. This accessory is particularly useful in examining pond life, such as water-fleas, cyclops, and water-mites. It consists of a brass plate, with a circular aperture crowned by a short brass tube, holding a

disc of stout glass. This tube is capped with a sliding cap in which is a thin cover-glass. The object is placed dry, or more generally in a little water, on the thick glass disc, and then the cap is gently lowered upon it so that it is held between the two glasses. Both glasses ought to be carefully cleaned before and after use. Live cages vary in

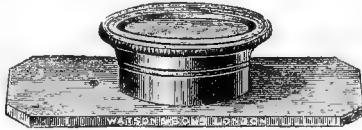


FIG. 16.—LIVE CAGE.

price according to quality and size ; they are listed as low as 2s. 6d. (see Fig. 16).

Stage forceps (Fig. 17) are sometimes convenient for holding insects and other unmounted objects during examination. They are provided with a fitting which slips into a convenient hole on the

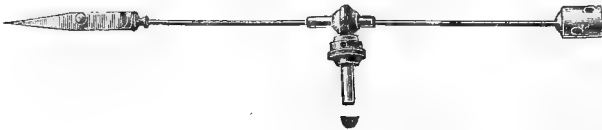


FIG. 17.—STAGE FORCEPS.

stage, or limb, of the microscope, and they are so constructed that the object can easily be brought into the field. The cheapest forms consist of forceps in suitable mounts ; better kinds have forceps and a brass well, containing cork, into which pins holding the object can be thrust. One of the latter costs 5s. or 6s.

CHAPTER V

SOME COMMON OBJECTS

I PROPOSE in this chapter to direct attention to some common objects which are especially worthy of examination. Space is not sufficient for me to deal exhaustively with any that I mention, nor can I attempt to cover the whole ground open to the microscopist. His field is practically unlimited, and objects are legion in any special line of investigation. I must rest satisfied with giving the novice a slight indication of the ground that may be covered. The worker has the whole realm of Nature to draw upon, and can find inexhaustible treasure in each of the three great kingdoms—mineral, vegetable, and animal. As regards the last two kingdoms, the microscopist finds difficulty in drawing a distinguishing line between them. There are numerous minute organisms which are said to be plants that behave like animals.

Let us suppose that a novice has just received a microscope, that it is a cold winter evening, and, while it is out of the question to go out of doors in search of objects, the enthusiast is eager to try his instrument. What can he examine? There is no need to go beyond his own person for material. Let him pluck a single hair from his head, place it

between two glass slips on the stage of the microscope, and examine it with a 1-inch or $\frac{1}{2}$ -inch objective, taking note of the line of cells of which it is composed, and also of its root structure. Perhaps there is a cat and also a dog in the house ; hairs from both these animals may be examined, and their structure compared with that of the human hair. Feathers from a pet canary, or extracted from a pillow, make good objects. Perhaps the dog is troubled by fleas ; at any rate, it is worth while engaging in a flea hunt in order to secure one or two of these lively blood-suckers for examination. The live cage comes in handy for holding such active creatures in position. But they are seen to best advantage after being killed and prepared. Then "lively" cheese presents possibilities in the way of cheese-mites, which look so disgusting and formidable, under even a low power, that the observer's appetite for cheese is likely to be spoiled. Table and window plants yield abundance of material in all their parts, and the same may be said of ordinary vegetables and fruits.

This first evening of desultory examinations ought to be followed by periods of more serious work. There are far too many owners of microscopes who regard their instruments rather as interesting toys and a source of amusement than as a means of real intellectual culture. Possibly one reason for this attitude is lack of scientific training and the need of guidance in observation. But if a novice lacks training he need not be deterred from serious investigation, for scientific method can be acquired provided the worker puts real effort into his work, is

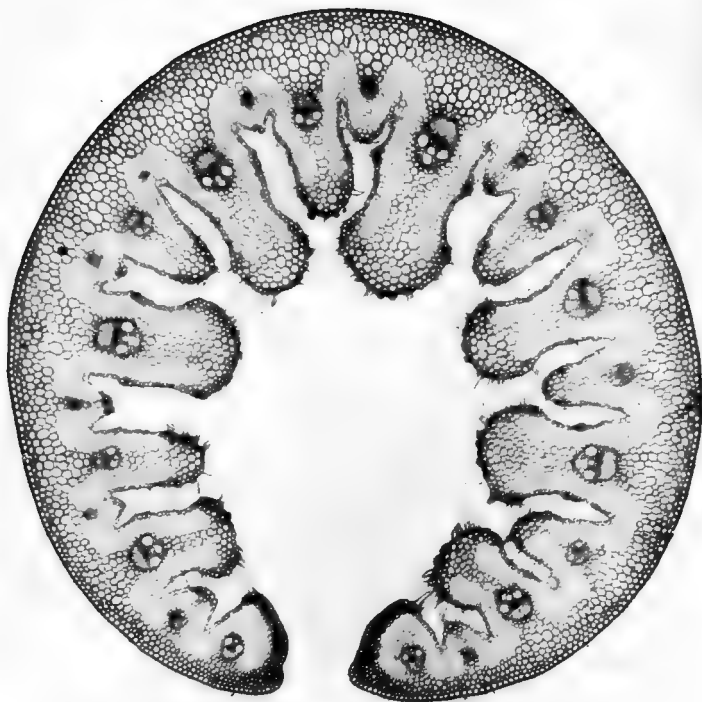
willing to study helpful books, and benefit by the instruction of others. While I do not suggest that any microscopist should abstain from general observations, I certainly advocate the taking up of a special line of study which will lead to intellectual development and expertness in manipulation.

As a slight indication of scientific method I will allude briefly to botanical study. Presuming that the reader is disposed to specialize in this line, how is he to proceed? If his knowledge of botany is vague or nil, he must first study an elementary primer, so as to get the general "hang" of the subject. Elizabeth Healey's "First Book of Botany" will serve as an introduction, and I can also recommend "Botany" by J. Reynolds Green in Dent's Scientific Primers series. My own "Wild Flowers and their Wonderful Ways" might also be mentioned. These three books are very inexpensive. After digesting the contents of a primer, a more ambitious work should be studied, and at this stage no better book could be read than D. H. Scott's "Structural Botany." This book will prove a good theoretical guide, and by the time the worker is familiar with its contents he will be prepared to benefit by the instruction and guidance in practical investigation afforded by Bower and Gwynne-Vaughan's "Practical Botany for Beginners." This book is packed with directions relating to the use of the microscope in botanical study, and in terse language outlines numerous experiments. With such a book for a guide the worker will be able to proceed from step to step in microscopic investigation, and will have the satisfaction, not only of seeing

many things that would escape the desultory observer, but also of understanding the meaning of what he sees.

Very probably the reader, while desiring to do serious work, has no special inclination to any particular study, and in a way feels lost or bewildered amidst the innumerable possibilities of Nature. What is to be done under such circumstances? All I can advise is that he take a walk, and bring home the first object that attracts his attention, whether it be mineral, vegetable, or animal. Let that object be studied in all its aspects, and be allowed to form a centre, or starting-point. If it be studied intelligently it will lead to innumerable inquiries, and be a means of accumulation of much knowledge. For a single object from Nature has vast relations; it is interesting in itself and in its relations to other things. How did it come into being? Of what is it composed? What is its use? How is it affected by its environment? What effect does it have on its surroundings? These are samples of many inquiries to be made, and the use of the microscope will assist us to a number of conclusions.

The other day I was searching for molluscs among some stinging-nettles, and in the eagerness of my quest got stung. Writing the foregoing lines brings the irritating little experience to mind. Suppose a reader goes out and is stung by a nettle. Why should he not take his revenge, and turn his experience to account by making the stinging hairs of the nettle the subject of microscopic investigation? And this little study may suggest a very instructive

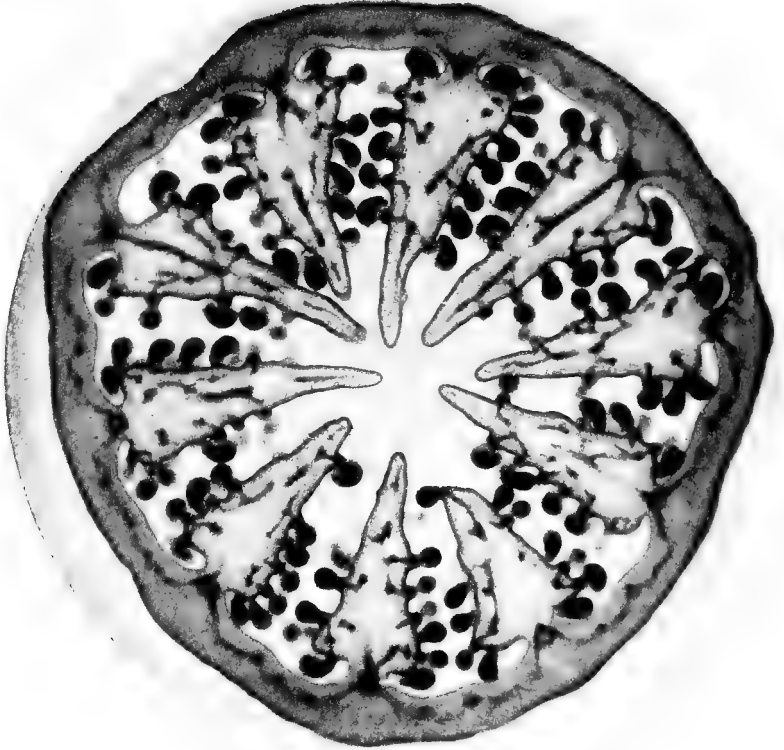


Transverse Section of Marram Grass (*Psamma arenaria*). × 55

course—the general study of plant-hairs, which is a very fruitful subject.

Putting on a glove, or otherwise protecting the hand, we secure and take home a plant of the stinging-nettle. We first examine it with the pocket lens, which shows that the stinging hairs are scattered over stem and leaves. But we desire to observe the structure of these interesting hairs, and to do this must use the compound microscope. With a sharp knife we cut away a very thin portion of the cuticle or “skin” of the stem, with hairs attached. This portion is placed between two glass slips, and examined with a 1-inch objective. If the object is properly manipulated we can now see that each hair is really a flinty needle channelled through its centre, and having at its apex a tiny ball of flint closing the tube. At the base is a poison sac, or bag, containing the irritating fluid. We soon gather that the sting we feel is due to this fluid being forced into our skin through the centre of the needle. In touching these stinging hairs as they are on the living plants we break away the little ball closing the tube at the apex, and the slight pressure of the touch is sufficient to enable the fluid to be forced up the channel into the skin, which is already penetrated by the sharp needle. The sting of the nettle is a natural hypodermic syringe. We may prove the flinty character of the hair by placing it upon a small piece of platinum, and burning it over a spirit lamp. The heat will destroy all organic matter, but leave the flinty needle intact.

The study of plant-hairs can readily be extended and become thoroughly fascinating. Without call-



Transverse Section of Ovary of Poppy, showing
Unfertilized Ovules. $\times 6$

its contents. You will note the cell wall, which surrounds and encloses the contents, a film of protoplasm forming an inner lining to the cell wall, and what may seem to be an empty cavity in the centre of the cell, which is really filled with sap, and is called the "vacuole." Pale green chloroplasts with chlorophyll grains, which are the green colouring material of plants, will be seen among the cell contents.

Probably the contents enumerated will be all that can be detected up to this point. To make observation easier we proceed to stain the hairs with iodine solution. This solution is prepared by taking 10 grains of iodine, 5 grains of potassium iodide, and making a clear solution in distilled water, about 2 ounces. To stain the hairs, place drop after drop of iodine solution on the slide at one edge of the cover-glass, but do not allow any of it to flow on top of the cover. Then hold a small piece of blotting paper to the opposite edge of the cover. The blotting paper will soak up the water in which the hairs are mounted, and the iodine solution will be drawn into its place. When the stain has thoroughly permeated the hairs they are ready for further microscopic examination. We are now able to observe the cell and its contents with greater clearness. The cell wall is barely, if at all, stained. The stain will have so affected the protoplasm that it is coloured yellow or nearly brown. The little chlorophyll bodies will have assumed a dingy purplish colour. But *the* point of interest is the appearance of a tiny oval body within the film of protoplasm. This body is the nucleus, which will be more deeply

stained than the protoplasm, and if we look exceedingly carefully, it is highly probable that we shall discover within the nucleus a minute, deeply stained, granular body, called the "nucleolus." Reference to a botanical treatise will enable us to appreciate the functions of these two bodies, and the wonders we are able to see.

The iodine solution is not only a stain, it is also a reagent, and the serious worker will find many uses for it. It is very commonly used to demonstrate the presence or absence of starch. If starch is present iodine will stain it blue. A potato is packed with starch grains, which make interesting objects. If a potato be cut, and its freshly cut surface be scraped with a knife, a very small quantity of the scrapings will yield abundance of starch grains for microscopic purposes. Mount some of the scrapings in water, and treat with iodine in manner already described in regard to hairs of *Primula*. The grains will be stained blue.

But to make an even more satisfactory examination, a very thin section sliced from a potato with a razor (which should be moistened with water) should be mounted and examined with a $\frac{1}{4}$ -inch or $\frac{1}{8}$ -inch power. The grains can thus be seen packed in their cells, and protoplasm, very small in quantity, will also appear. The grains of potato starch are somewhat oval, and are bright in appearance. At or near one end of each grain there is a spot known as the "hilum," and each grain is built up in several layers or stratifications.

It is interesting to compare various kinds of starch grains, and the ability to distinguish the

different varieties may be a valuable practical acquirement. Starch is obtainable from most vegetable substances, but the grains obtained from wheat, rye, barley, oats, etc., are probably the most common forms favoured by the microscopist. If the worker possesses a polariscope (p. 40) he should certainly examine properly mounted starches under polarized light.

Probably the most fascinating line of study for the beginner is the observation of the exceedingly numerous minute life-forms, both vegetable and animal, which are to be found in fresh-water ponds



FIG. 18.—NET FOR COLLECTION OF POND-LIFE.

and salt-water rock-pools. To secure the requisite material some collecting apparatus is needed, but this need not be elaborate or expensive. Many a time I have caught abundance of material with a wide-mouthed glass jar which I attached to a string and threw into a pond, drawing it quickly back to me through the water, or allowing it to drag over the mud. But a fine muslin net attached to a wire ring, about 6 or 8 inches in diameter, fastened to the end of a walking-stick, is more satisfactory, particularly if the net is made to the shape of a cone in the apex of which a small round bottle is fastened. The bottle ought not to be too narrow in the mouth.

If one can be got with a mouth about 1 inch in diameter, and about 4 inches long over all, so much the better. This net is used for capturing free-swimming life-forms. It is plunged into the water and swept about in different directions, and in due time raised above the surface to allow superfluous water to escape through the muslin. If carefully handled the captured creatures will be forced into the bottle, from which they are to be transferred to store bottles or tubes for examination at home. I find the tubes in which tabloid drugs and photographic chemicals are sold particularly useful. On arrival home the living material should be placed in glass vessels, such as wineglasses or tumblers, with a sufficiency of water, and some small aquatic plants, which will oxygenate the water, and so prolong the life of its inhabitants. Many aquatic plants make beautiful and instructive objects, and it must not be forgotten that a number of interesting creatures attach themselves to their leaves and stems. For more detailed guidance in the collection of these life-forms, I cannot do better than refer the reader to an inexpensive book, "Ponds and Rock-Pools," by Henry Scherren, F.Z.S.

The limits of this volume render it impracticable for the writer to give the reader anything like a complete and detailed account of the living material contained either in a pond or rock-pool. He must satisfy himself with brief mention of a few life-forms.

Among the vegetable life of the pond may be found various forms of Algæ, some of which grow in threadlike lengths, each thread being composed of



Transverse Section of Large Intestine (Human). showing
Solitary Gland. $\times 6$

a single line of cells growing end to end. *Zygnema* is one form and *Spirogyra* another. The latter is very common ; in slow-running streams it is often seen hanging from weeds in long streamers, while in stagnant waters it grows independently in scum-like masses. It is also common in roadside drinking-troughs. The threads are exceedingly fine, and should be examined in water on a glass slip with thin cover, with an objective of not less than $\frac{1}{4}$ -inch power. Two or three pieces of a filament are sufficient. Each cell is characterized by the spiral chloroplasts, which are bright green in colour. Treat the object with iodine solution ; the cell contents will be stained, and the nucleus and nucleolus will appear, while the protoplasm will assume a yellow colour.

By carefully examining selections from a mass of *Spirogyra*, the worker may chance to find two filaments in conjugation. Two threads come together, and some of their cells put out tiny processes by which the threads become united. Such filaments lose their usual appearance ; the chloroplasts lose their spiral form ; the cell walls are being absorbed, and a way is being made for the contents of the cells of one thread to pass into the cells of the other. In due course the blended cell contents will form spores, from which new plants will develop.

The cells in the leaves of the Canadian waterweed (*Elodea*) exhibit remarkable movements of their protoplasm, a movement described as circulation. The same phenomenon is displayed in a more or less clear manner by the Frogbit (*Hydrocharis*) and *Vallisneria spiralis*. To observe this movement

a high power must be used. These three plants are commonly cultivated in aquaria.

The "revolving globes" of *Volvox globator* are among the greatest marvels of pond-life. A full-grown globe will be about $\frac{1}{20}$ inch in diameter. If

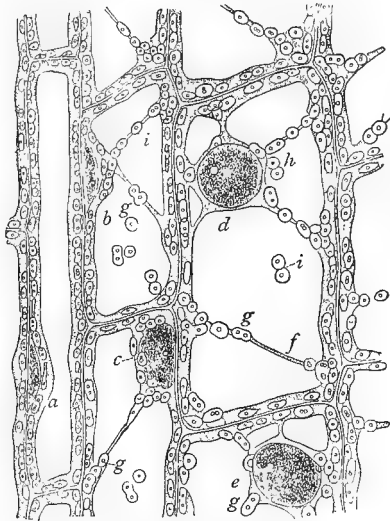
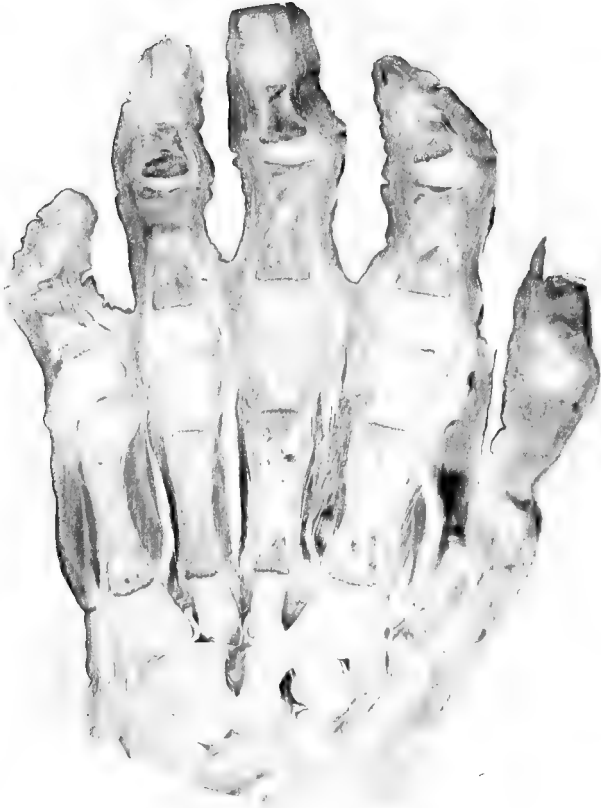


FIG. 19.—A FEW CELLS FROM THE LEAF OF THE AMERICAN WATER-WEED.

a, b, c, d, e, Nuclei of the various cells; *j*, a strand of protoplasm crossing the cell-cavity; *g, h, i*, chlorophyll granules, some of which are dividing. The small bodies inside the chlorophyll granules are starch. (After Kny.) Magnified several hundred times.

we have been fortunate in our pond-hunting, we may see a number of these tiny marvels revolving freely in a rather majestic fashion in one of our store tubes. Let one or two be transferred to a glass slip, with a concavity in the centre (such slips are bought from dealers at about 2d. each). The



Section of Hand of Human Embryo. $\times 6$

little creatures must have a drop or so of water in which to move, and be covered with a thin cover-glass. We examine them with a 1-inch or $\frac{1}{2}$ -inch objective. Now it can be seen that each globe consists of a sphere of united cells, and that from each cell two lashes project. The lashes of all the cells, acting in unison, propel the globe in its aquatic revolutions. But the sphere also encloses other smaller globes, miniature editions of itself, and if the parent sphere be burst, the enclosed ones are set free, and behave like their parents. In fact, the parent spheres do burst in the natural course of things, and set their young free to grow and repeat the story. This is the method of reproduction. Some observers declare that these globes are animals; others claim them as vegetable; and the latter are in the majority.

It behoves me to refer to another variety of vegetable life common in the pond and other situations, having considerable power of movement: I mean the Diatoms. They may be found in great numbers forming a green or reddish scum on mud or pond bottoms, and even in old cart ruts in which water has stood for some time; they are also found attached to seaweeds, and in numerous other places. When pond-hunting, the student should secure scrapings from the surface of the mud. Such scrapings are almost sure to contain diatoms. A minute portion of the material gathered placed on a glass slip in a very little water is sufficient for examination at one time. Diatoms are minute, one-celled plants enclosed in a shell of flinty material known as the "cell wall." The shell is two-valved,

one valve fitting over the other like a lid on a pill-box. A slimy secretion covers the exterior of the cell wall, and this enables the little plant to slip easily over the surface of the mud. It is exceedingly interesting to see diatoms gliding quite majestically on the glass slip under the microscope. The cell walls are covered with wonderful markings. Live diatoms are coloured with chlorophyll, the usual colouring matter of green plants. But diatoms are also found in fossil forms, from which the colouring matter has, of course, disappeared. There is a vast variety of living and fossil species, and some microscopists devote their whole attention to their study. Preliminary examinations of diatoms should be made with a fairly low power— $\frac{2}{3}$ inch or $\frac{1}{2}$ inch—but to see them in fuller detail a $\frac{1}{4}$ -inch or $\frac{1}{8}$ -inch objective must be used. They vary considerably in size.

Other single-celled plants, called "Desmids," may be taken from ponds, especially such as have green-looking water, either with the net or scraped from the bottom. These tiny plants exhibit interesting protoplasmic activity within their cell walls. But I must pass rapidly to a brief consideration of a few forms of distinctly animal life common in the pond.

In sweeping the water with our net, we are fairly sure to capture a quantity of Water-Fleas, which we shall see swimming in the bottle in a jerky fashion. By means of a dipping tube (p. 11) we transfer one of these lively creatures to the live cage, and examine it with a low power. We find that the animal, which is hardly more than $\frac{1}{16}$ inch long, is quite highly organized. It has a small head, with

branched, feathery antennæ, a compound eye, two mandibles and jaws, and a big lower body in which we can see the heart beating, and the digestive apparatus. In a female specimen we may detect eggs filling a space towards the back. The Water-Flea is really not a flea ; it is a crustacean, allied to

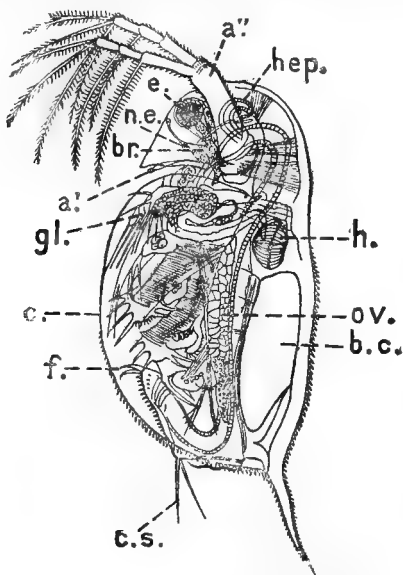


FIG. 20.—FEMALE WATER-FLEA (*DAPHNIA PULEX*).

a', antennule ; *a''*, antenna ; *bc*, brood-chamber ; *br*, brain ; *e*, eye ; *f*, furca ; *gl*, maxillary gland ; *h*, heart ; *ov*, ovary.

the crab and the multitude of creatures of that "ilk." There are several species. Fig. 20 represents *Daphnia pulex*, the Common Water-Flea.

In the same haul we shall probably find another crustacean of microscopic proportions—the Cyclops, noted for its single eye in the centre of the head, and

thus named after the mythical giant. The body is pear-shaped, having a flattened head and a tapering tail. There are two pairs of antennæ, and five pairs of short legs, by means of which the little crustacean jerks itself through the water. The females greatly exceed the males in number, and are easily known

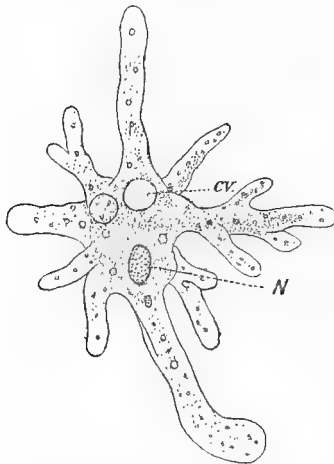


FIG. 21.—AMŒBA PROTEUS.

CV, contractile vacuole ; *N*, nucleus.

by the egg bags which hang on either side of the lower part of the body.

Other kinds of minute crustaceans live in fresh water, but we must pass them over in order to give a few other life-forms brief notice. Among them we must include the Amœba, the simplest organism of which we have any knowledge. This creature is plentiful among mud and decaying vegetation found in ponds. It is exceedingly small, seldom reaching

$\frac{1}{90}$ inch in diameter. It is a mass of protoplasm of no definite shape, but capable of assuming many forms. So simple is the amœba that it has no members or organs, yet it can push out processes from its substance which serve the purposes of hands and feet. In the absence of digestive organs it wraps itself round its prey and absorbs its substance. Without true hands or legs it can swim or walk, without stomach it can digest, and without nerves it can respond to stimuli. The amœba reproduces itself by *fission*—that is, it divides into two halves, and each half becomes a whole. Examine in water on a glass slide, first with a $\frac{1}{2}$ inch or $\frac{2}{3}$ -inch objective, afterwards with a higher power.

Then there are a number of Polyzoons, which are rightly regarded as the most lovely objects a microscopist can examine. As a type of this order we will take the "Bell-Flower Animal," or "Plumed Polyp" (*Lophopus crystallinus*). This occurs in ditches and ponds, attached to roots of trees and aquatic plants. The tiny polyps live in colonies of ten to fifteen, held together in a mass of mucilaginous substance, which out of water is slimy and shapeless, but in water somewhat resembles a wine-glass turned mouth upwards. The mass, expanded in water, may measure about $\frac{1}{2}$ inch in length; it is highly transparent. The polyps occupying this habitation are exceedingly beautiful. When at rest or alarmed they keep within their transparent habitation, but when actively feeding they extend a lovely waving crown of tentacles into the water, in which they create a vortex as a means of drawing

food to their mouths. There are several details in the anatomy of *Lophopus* worthy of careful observation, and the characteristics of this species should be compared with those of other polyzoa, both fresh-water and marine. A low power is sufficient for this object, and with dark-ground illumination it is seen in all its glory.

The various species of Rotifers (literally, "wheel-bearers") which are to be found in a pond, some

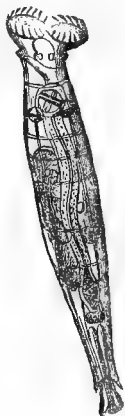


FIG. 22.—COMMON ROTIFER (*ROTIFER VULGARIS*).

attached to vegetation, others free-swimming, also call for the student's attention. Fig. 22 represents the common rotifer. Note the sucker-like foot, the transparent body in which the internal organs are displayed, and the two discs at the head. These discs are edged with cilia or fine lashes, which wave in unison in such a manner as to make it seem as if the discs are rotating like wheels. It was this appearance that led early observers to call these

creatures "wheel-bearers." In reality the discs do not rotate, and the object of the movement of the cilia is the creation of a vortex for capture of prey. When at rest, or feeding, the common rotifer attaches itself to some water-plant. It can travel by looping its body somewhat after the manner of a caterpillar, using its foot and proboscis in place of legs.

Perhaps the most remarkable rotifer is *Melicerta ringens*, which, although only about $\frac{1}{25}$ inch in length, succeeds in making tiny pellets, and building them into the form of a tube for its occupancy. When alarmed the rotifer retires into its tube, but in feeding it extends itself, and feeds in true rotifer fashion.

Every opportunity for collecting material from the seashore should be taken advantage of. The reader will find some valuable assistance in this work by consulting "Ponds and Rock-Pools" already referred to, and also "Life by the Seashore," by Dr. Newbiggin. Rock-pools teem with minute life-forms, and in the clean white sand found in the ripples of the beach, at high and low water marks, an abundance of Foraminifera ought to be discovered. Foraminifera (literally, "hole-bearers") are minute amoeba-like creatures which occupy tiny shells formed from lime extracted from sea water. These shells are punctured with small pores, through which the animal protrudes wisps from its body, as a means of swimming and catching prey. It is usually the shells of these creatures that we find on the beach. But the shells are very small, and while we may detect some of them with a pocket lens, the

material containing them is best sorted and examined at home. Foraminifera also occur as fossils in limestone and chalk deposits.

Allied to the foraminifera are the Radiolarians, which live in the plankton on the surface of the sea. They differ from the foraminifera in that their many-formed shells are composed of siliceous or flinty material. They, too, are punctured, but with larger holes. They are also obtained in fossil forms, and are much prized by microscopists on account of the beautiful appearance they present under dark-ground illumination.

The Corallines commonly found attached to seaweed and other substances are exceedingly interesting *live* objects. As a type, we consider the Knotted Thread Coralline (*Obelia geniculata*) which occurs on seaweed near low-water mark. The stem extends to about 1 inch, and is sometimes branched; it is easily recognized by its zigzag form. Examined in a glass trough, in sea water, under a low power, we see that the coral-like stem gives off a series of cups, each one of which is occupied by an animal armed with tentacles. It is interesting to note that in summer these "zooids," as they are named, give rise to tiny medusoids, or swimming bells, which produce eggs from which new colonies of *Obelia* develop. This species of coralline is phosphorescent.

The serious worker will not satisfy his mind by passing lightly from the examination of one object to another. On the reverse, he will seek to know the life-stories of the creatures he observes, to understand their anatomy and physiology, and to be able to classify them in scientific fashion.



Marine Worm (*Serpula vermicularis*), showing Gills and
Operculum. × 6

Photo from slide kindly lent by Messrs. W. Watson and Sons, Ltd.

Without venturing into other fields in quest of common objects, I shall conclude this chapter by a short reference to the microscopic possibilities of the Insect World. These are, indeed, vast ; practically unlimited. Eggs and larvæ, external members and internal organs, curious adaptations of members to conditions of life ; these provide boundless wealth of material. Each species of insect has distinct peculiarities. The student will find it advisable to take up a special line in this great field, following it up systematically. If he takes the Lepidoptera, or scale-winged insects, as his special study, he will investigate and compare their salient features. More than this, he should make comparisons between, say, the legs, antennæ, and mouth organs of this class with those of other insect classes. All along the question, What is the *use* ? should be asked. Why do certain insects have specially developed organs, and how are they advantaged thereby ?

As an example of the study of a single species in all its salient features, let us consider the Common House-Fly, which belongs to the diptera, or two-winged insect class. We start with the eggs which are found on decaying vegetable or animal matter. These eggs are beautiful objects, particularly as seen under dark-ground lighting. They should be compared with eggs of other kinds of diptera. The larvæ hatched from the eggs should also be examined, not only as to their external form and members, but also as to their internal organs. They are hatched from the eggs about a couple of days after they are laid ; they feed on refuse for about six days, then change into the pupa stage. The perfect insects

appear after some seven days in the chrysalis condition. The perfect fly provides several interesting features. There is its internal system, which must be carefully dissected ; and, externally, we have the large eyes formed of a great number of facets or lenses, the antennæ, the exceedingly wonderful proboscis, and the spiracles, or air-openings, part of the breathing system, in the body skin. Then we have to consider the wings, and the legs, which are covered with hairs and terminate in a pair of claws and foot-pads, the latter enabling the fly to walk easily upside down on the ceiling, or climb up the window-pane. There are other details to be examined. I have mentioned the foregoing as a rough outline, and a general suggestion of the course which a worker may follow.



Portion of Knotted Thread Coralline (*Obelia geniculata*). $\times 20$

Photo from slide kindly lent by Messrs. W. Watson and Sons, Ltd.

CHAPTER VI

THE PREPARATION AND MOUNTING OF PERMANENT OBJECTS

THE worker will find it desirable to prepare and mount objects so that they may be permanently preserved for future examination. This work has become a fine art, indeed, a science; and literature relating to it is voluminous. I shall not burden the reader with a bewildering mass of details, but confine myself to the description of some simple methods, by following which the student will gain the knack of the work, and be prepared to follow more elaborate methods as occasion demands. The directions I proceed to give will be all that are necessary for the guidance of the beginner.

The mounting of opaque objects is a comparatively simple matter. The following articles are necessary :

1. A supply of 3-inch by 1-inch glass slips. These cost from 2d. to 6d. a dozen, according to quality. It pays to use the best.

2. Some thin cover-glasses; circles from $\frac{5}{8}$ to $\frac{7}{8}$ inch diameter, and a few squares will be useful. An assortment can be had at the rate of about 1s. per $\frac{1}{4}$ ounce.

3. A turntable (Fig. 23). This consists of a small block of wood on which is mounted a revolving

disc of metal controlled by a milled head beneath. The glass slip is held in position on the table by a pair of spring clips. Cost of turntable is about 6s.

4. Two or three small camel-hair or sable pencils. Sables are certainly the best.

5. A pair of forceps (see p. 9).

6. A bottle of best gold-size, 6d. or 1s.

7. A bottle of Club Black enamel, 6d. Or ordinary Brunswick black will serve.

8. A glass spirit-lamp as used in chemical laboratories.

These requisites, and all others that are likely to

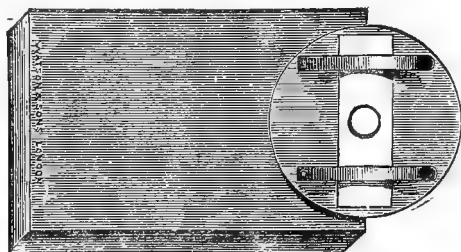


FIG. 23.—TURNTABLE.

be needed in mounting, are obtainable from dealers in microscopic sundries.

The worker should first practise cell-making. In this operation a clean glass slip is centred on the turntable, and a thin ring of gold-size is made on the slip. To make this, a small quantity of gold-size of the right consistency is taken on the tip of a sable pencil and run on to the slip as it is rotated on the turntable. The ring must be even, of regular width and thickness, and its diameter must admit of the cover-glass, which is to be used, so covering

it that a narrow margin of the ring extends beyond it. For very thin objects only one ring will be necessary, and as soon as it is made the slip should be set aside to dry in a dust-proof place. If thicker objects have to be provided for, the cell can be deepened by superimposing two or three more rings of gold-size, but each layer must be allowed to dry before another is added.

Suppose we desire to mount a portion of a butterfly's wing. Taking a prepared cell of requisite depth, we cut the object so that it will fit inside the cell without moving. If cut square it can be held in position by the corners where they touch the ring. Then, object in place, we put the slide on the turntable and run a thin layer of gold-size on the surface of the cell, and set it aside to dry until it becomes "tacky." When this condition is reached, we clean a cover-circle, lay it gently and evenly on the cell, and, using gentle pressure, see that it adheres all round its edge. We seal and finish the cell with a ring of Club Black enamel, label the slide, and, when the enamel is set, put it away until required for use.

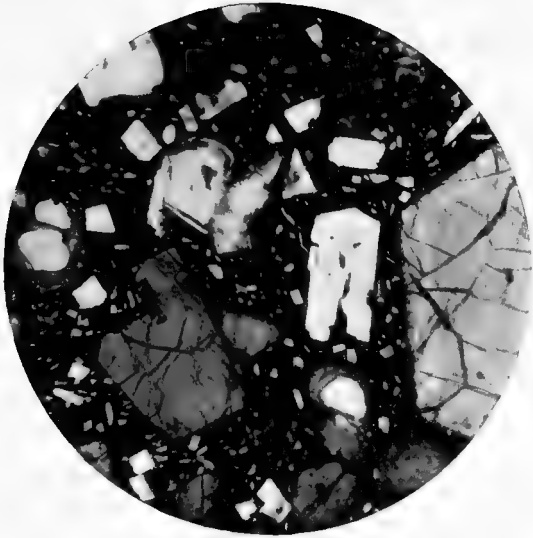
The worker must take care that the object, the glass slip, and the cover-glass, are perfectly dry, and even that the gold-size is hard, with the exception of the tacky top layer, before the object is enclosed. Failing this, the slide will be ruined. Cover slips should be lifted with the forceps and passed two or three times through the flame of the spirit lamp in order that moisture may be driven away, and if there is suspicion of moisture on the slip or in the object, they ought to be dried with gentle warmth.

Deeper cells are conveniently made with vulcanite rings supplied at small cost by the dealers ; or with rings of paper dipped in melted paraffin wax and allowed to dry. These rings are attached to the centre of the glass slip with a layer of gold-size ; they must stick firmly and be in perfect contact with the glass.

Slips and cover-glasses must be thoroughly clean. The former should be washed in soap and water, and dried with a piece of soft linen ; the latter are very fragile, and require careful handling ; they, too, should be washed and dried, and then receive a final polish with chamois leather. With a little practice the worker will be able to handle them without breakage.

Some opaque objects require securing in position in their cells with a tiny drop of gum. This, of course, is placed where it will not interfere with observation of the object, and must be thoroughly dry before the cover-glass is affixed. Wing scales of lepidoptera and pollen grains from flowers are commonly secured by a film of thin gum on the cell bottom. The gum is laid on the glass, and allowed to dry ; then it is made sufficiently moist by breathing upon it. The objects are placed on the film, and when all is thoroughly dry the cell is covered and sealed. Or the film of gum may be laid on the cover-glass and the objects secured on it instead of the bottom of the cell. Many objects are secured without adhesive material : placed in a shallow cell, the pressure of the cover glass is sufficient to keep them from moving.

It used to be the custom to mount opaque objects



- (1) Under Ordinary Illumination
(2) Under Polarized Light

in opaque cells which were made by blackening the cell bottoms ; but this custom is now abandoned. If objects need a black background it can be supplied by placing a slip covered with dead-black paper under the slide on the stage of the microscope.

The foregoing instructions apply only to opaque objects that can be mounted dry ; some need to be mounted in fluids. But such work is not likely to be tackled by the beginner.

It ought to be mentioned that all objects for the microscope should be reduced to the smallest possible proportions. I remember an individual who put a chunk of cheese under his microscope in order to



FIG. 24.—BALSAM BOTTLE, WITH DIPPING-ROD.

examine cheese mites, and wondered that he was defeated in his purpose. A thick mass of pollen grains in a cell is useless ; a few grains spread over the cell bottom are all that is necessary. It is also desirable that objects be mounted as flat as possible, so that they appear in one plane.

The next step is to mount transparent objects, which are to be examined by transmitted light, in Canada balsam. For this work we shall require :

1. A stock of Canada balsam dissolved in benzole. A 1s. bottle will suffice to begin with.
2. A balsam bottle. This is a wide-mouthed bottle with a glass cover cap (Fig. 24).

3. A short piece of solid glass rod for manipulating the balsam.

4. A mounting table, consisting of a plate of brass, usually about 4 inches by 3 inches, with four legs a few inches high. This is used for heating slides laid upon it. The heat is derived from a spirit lamp placed beneath the table. A small brass plate, resting upon a home-made wire support, will serve.

5. A supply of methylated spirit and turpentine.

In drawing up this list of requisites I am assuming that the worker already possesses slips, cover-glasses, spirit lamp, and other necessities mentioned in connection with opaque mounting, and I omit details of reagents required in the preparation of objects ; these will be mentioned in due course.

Now, let it be understood that Canada balsam is a resinous substance with which water is incompatible—that is to say, balsam and water will not blend. Therefore any object to be mounted in balsam must be dehydrated : have every trace of water extracted from it. Dehydration is effected by soaking the object in methylated spirit. Another point to be remembered is that before mounting an object in balsam it must always have a final soaking in turpentine, which blends with balsam and enables it to permeate the object if it be permeable.

If the worker desires to practise mounting in balsam without going through the necessary stages in the preparation of objects, he cannot do better than communicate with Mr. R. G. Mason, 78, Fox-bourne Road, Upper Tooting, S.W., who supplies prepared objects at a very cheap figure. All that



Section of Arran Pitchstone, showing Microliths. $\times 20$

has to be done with these objects is to first soak them in turpentine, and then proceed to mount.

The mounting is accomplished thus : First clean a glass slip and a suitable cover-glass. Lay the slip on the mounting-table, which must be heated with the spirit lamp. The slip will be warm enough when the heat is no more intense than can be borne when the finger rests upon it. Then a couple of drops, more or less, of balsam are dropped from the point of the glass rod exactly in the centre of the slip. The object is taken out of the turpentine by means of a needle, the forceps, or a proper section lifter (costing about 6d. at the dealer's), placed in the balsam, and worked well into it. Now we make an examination with a pocket lens to make sure that the object is properly in the centre, and that no air-bubbles cling to it. All being satisfactory, we pick up the cover-glass with the forceps, warm it in the spirit flame, and lower it on to the balsam, and apply gentle, even pressure. It is often advisable at this stage to apply a spring clip to the mount, and to allow it to remain in the clip for some hours. Suitable clips cost about 1s. 6d. a dozen. Sufficient balsam must be used to fill the entire space under the cover. Any overplus can be cleaned off with methylated spirit after the balsam has set. Balsam mounts do not need ringing with enamel, although the worker may ring them if he likes and thinks the appearance is improved by so doing ; and it will be noted that ordinary balsam mounts do not require cells. Air-bubbles sometimes present difficulties ; if they are not involved in the object they are a negligible

quantity ; but if they are mixed up with the object it may be necessary to heat the slide on the table until the balsam boils, and at that stage apply gentle pressure on the cover. Such a proceeding, however, requires great care ; with some objects it would be disastrous.

Another method is to first embed the object in balsam on the cover-glass, set aside for twelve hours under cover to keep dust off, then apply a fresh drop of balsam, and finally lay the cover with attached object on a previously warmed slip, taking care to avoid bubbles, and seeing that the cover is evenly laid and centred.

Many writers advise gradual lowering of the cover-glass from one edge with the aid of a needle, but my own experience points to placing the cover horizontally on to the balsam right off as the better method. Let the reader understand that in this work, as in all else, " Practice makes perfect " ; he will improve his results with experience, and the best remedy I can offer for difficulties that crop up by the way is a blend of common sense with patience.

However convenient it may be to practise mounting bought objects already prepared, it is surely more satisfactory to do one's own preparing. Of course the work of preparation varies with the nature of the objects, but, by way of example, let us suppose that we desire to mount a specimen of the common flea. First we kill our object by immersing it in methylated spirit, and we keep it in the spirit until we are ready to go on with our work. Being ready to proceed, we soak the object in two

or three changes of water, so as to get rid of the spirit. Having previously prepared a 10 per cent. solution of caustic potash, we pour a few drops into a watch-glass, or any suitable receptacle (an egg-cup will serve), and let the flea soak in it for a few hours. The soaking of the object in this solution must continue until the internal organs have dissolved and can be removed with gentle pressure of a camel-hair brush ; but before we attempt to remove them the object must have further soakings in several changes of water to get rid of the potash. Having cleaned the object, we now transfer it to a glass slip, arrange it with a brush or needle, and put slip with object on it in methylated spirit, which has a hardening effect. After a few hours in spirit, we transfer the object to turpentine, in which it must remain until it is thoroughly permeated and transparent. Then we mount in balsam in the usual way. In some instances it is wise to soak the object in clove oil, which clears it of spirit, before transferring to turpentine.

Larger insects require longer soaking in the potash solution, and to rid them of their dissolved internal organs it may be necessary to pierce the skin with the point of a needle to make an exit ; and after the object has been arranged on a slip, it is generally best to cover it with another slip, putting a piece of paper or card between the slips at either end to prevent undue pressure, and tying all tightly with string before placing in methylated spirit to dehydrate and harden.

Parts of insects, such as legs and wings, in some cases do not need to be treated with the potash

solution. After a soaking in methylated spirit, and then turpentine, they can be mounted.

In order to examine the structure of certain materials, it is frequently necessary to cut thin sections, and give them treatment before mounting. The novice will hardly venture into the higher branches of section-making, but practice with vegetable objects will pave the way for more advanced work. I shall therefore give a few instructions for making and preparing thin sections



FIG. 25.—MICROTOME FOR BOTANICAL SECTIONS.

of the stems of plants. Such may be cut with a razor, the stem being held between the finger and thumb of the left hand. The finger is held so that the blade of the razor rests upon it, while the stem to be dealt with is supported against a piece of pith or carrot placed between it and the thumb. The section is made with a diagonal cut of the razor. Some workers become very expert in hand-cutting, but I prefer to use a *microtome*. The least expensive form of microtome, which is quite good for botanical work, is represented in Fig. 25; it costs 5s., and consists of a tube surmounted by a round flange

or table. The material to be cut is fixed in the tube either by suitable wedges or by being embedded in wax. The screw is used to raise the material above the table, so that by drawing the razor resting on it through the object a thin section is made. The first cut, or the second, will level the object, then a slight turn of the screw will raise it sufficiently for the cutting of a suitable section. Before each cut the razor should be well wetted with dilute methylated spirit, and it should be kept very sharp. Paraffin wax is generally used for embedding. It must be melted by placing it in a suitable jar and holding it in boiling water, taking care that no water gets into the jar. The stem to be cut is first dipped into the melted wax, so as to be thinly coated with it; then it is held in position in the microtome tube while sufficient wax is run in about it. As the wax shrinks on cooling, plenty should be used.

Very woody stems need to be softened by long soaking in water before satisfactory sections can be made of them, and if they are resinous they should also be treated with alcohol, which will dissolve out the resins. In some cases woody stems require to be boiled in water for a lengthy period. Indeed, most stems to be sectioned are improved by a day or two in methylated spirit for removal of resins, and afterwards a few days in water to remove gums.

It is usual to stain vegetable sections, not merely to give them an attractive appearance, but to render details of structure distinct.

Prior to staining, the sections may need to be thoroughly bleached. Bleaching fluid is made by

taking two vessels (such as tumblers or jugs) and dissolving 1 ounce of chloride of lime in 10 ounces of water in one, and 2 ounces of washing soda in 10 ounces of water in the other. Then the two solutions are mixed and shaken. After standing to settle for a day or so, the clear fluid is filtered and bottled. Sections to be bleached are given a good soaking in water, and then immersed in bleaching fluid for an hour or more. Bleaching may take several hours, but the sections should be carefully watched while undergoing this process. When bleaching is complete, the sections are washed in several changes of water in order that no trace of chlorine or soda may remain about them.

The worker has a number of stains from which he may choose, but for his first efforts I would advise him to avoid all others in favour of hæmatoxylin, which is prepared from logwood. It will simplify matters if an aqueous solution of hæmatoxylin be purchased at the dealer's. To stain, fill a watch-glass with distilled water, and add 10 to 20 drops of the hæmatoxylin solution; soak the section in this stain for a period which may vary from ten minutes to half an hour. When sufficiently stained, wash the section first in distilled water and afterwards in tap water. Dehydrate with two changes of methylated spirit, clear by ten minutes' immersion in clove oil, transfer to turpentine, and mount in balsam and benzole. If the section is too deeply stained, the colour may be reduced by soaking for five or ten minutes in a $\frac{1}{2}$ per cent. solution of acetic acid (glacial) in distilled water.

Glycerine jelly is an excellent mounting medium

for botanical objects, and is often preferred before balsam, as its use is simpler. It has been noted that objects to be mounted in Canada balsam must be completely dehydrated; but the worker who favours the use of glycerine jelly must bear in mind that objects mounted in it must have a previous soaking in water or some watery solution. This medium is readily prepared at home, but the beginner had better buy a small quantity from a dealer.

Suppose we wish to mount some stinging hairs of the nettle (p. 48) in glycerine jelly. We first cut a short strip, bearing two or three hairs, from the cuticle of the plant. We give this a good soaking in water which has lately been boiled and allowed to cool. Water which has been boiled is freer from air than water fresh from the tap, and soaking in water frees the objects from air-bubbles. Then we transfer to a 1 in 3 mixture of glycerine and water, and allow the object to soak in it for some time before proceeding to mount. In mounting, we place a clean glass slip on the mounting table, transfer the object to the centre of the slip, soak off excess of fluid with blotting-paper, place a sufficient quantity of glycerine jelly on the object, light the spirit lamp, and heat the table. As soon as the jelly melts, which will be in a minute or so, the lamp must be removed. Skim off air-bubbles, and carefully lower a clean cover-glass over the object, pressing it gently into position. After the slide has set—say in eight or nine hours—excess of jelly is removed with a knife-blade, and the slide carefully cleaned with water and soft rag.

The microscope is now extensively used by geologists and mineralogists in the study of rocks and minerals, and that delightful accessory, the polariscope (p. 40) is especially valuable to such workers, because it shows structure in a remarkable degree. But rock sections are also interesting to the general microscopist, and in closing this chapter I shall give a few hints as to a simple method whereby thin sections of rocks suitable for microscopic examination can be prepared. These sections are usually made with the aid of a cutting, grinding, and polishing machine, but they may be prepared quite satisfactorily by hand if the worker is prepared to render time and patience to the work.

Secure a flat flake of the rock to be ground and reduce it to about 1 inch square. Grind one face of it smooth on a plate of zinc, using coarse emery-powder and water for grinding purposes. Take a glass slip, or, better, a fairly thick square of glass, and fasten the polished surface to it by means of old dried Canada balsam, which must, of course, be heated. Set aside to cool and harden. Then grind the other face with emery and water on the zinc plate until the section is moderately thin. The final grinding is then to be done on plate-glass, using very fine emery powder and water. The section must be made as thin as possible; it should be reduced to a small fraction of an inch in thickness. When sufficiently reduced, wash in water, dry, heat over a spirit lamp, and when the balsam is melted push the section off the glass by means of a knife-point or needle into turpentine. Let it remain in the turpentine until cleared of balsam; then give



Section of Fossil Wood from Coal, Oldbury,
Shropshire. $\times 30$

it a soaking in clean turpentine and mount in Canada balsam on a 3×1 inch glass slip in the ordinary manner.

This method applies to hard rocks. Rocks which are friable, soft and loose in texture, such as coal, need to be bound by some medium, lest they break up in grinding. They may be prepared for grinding as follows : Cut thin plates with a fine saw and soak them for some hours in benzole. The benzole must soak into the texture of the material. Then soak in balsam and benzole until thoroughly penetrated by the balsam. Place the section on a 3×1 inch slip, and cover with balsam ; set aside in a dust-proof place until the benzole has evaporated. Then place the slip on the mounting-table, light the spirit lamp, and bake until the balsam is thoroughly hard. The section is now ready for grinding until thin enough on a hone of water-of-Ayr stone. After grinding, wash in water, dry, cover with balsam and benzole, and place a cover-glass over all in the usual way. It will be noticed that in this instance the section is not removed from the glass slip after once being attached thereto.

CHAPTER VII

SIMPLE PHOTO-MICROGRAPHY

THE average person seems to be under the impression that the photography of microscopic objects is a complicated business, involving great skill and the use of elaborate and costly apparatus. It is quite true that photo-micrography in some of its branches can be undertaken only by a skilled worker prepared to spend some money; but, generally speaking, the individual who knows how to use a microscope, and has a working knowledge of photography, can produce good photo-micrographs with simple apparatus and at little expense. Low-power photo-micrography is comparatively easy; the process becomes more difficult in operation with the use of increasing powers, which involve greater care in focussing and illumination. The photography of live objects is fraught with many difficulties, the chief among them being that of exposure, which must be very short if movement is not to be recorded—generally too short for any but special illumination. But low-power work in connection with fixed objects is the most common, and is certainly well within the reach of the ordinary amateur worker.

I assume that the reader who is anxious to secure

photographic records of objects is already acquainted with ordinary photographic procedure. If he has no experience in photography, he had better acquire some before tackling the process in connection with the microscope. Supposing that we possess a bellows camera, and know how to expose and develop a plate, how are we to apply the camera to the microscope? All that we need to do is to place microscope with object, camera (without lens), and source of light in line; focus and make an exposure. The essential requirements are thus stated in a few words, but in practice we have to pay much attention to detail if results are to be satisfactory.

The body of the microscope, in the method I describe, must be inclined horizontally, the lens of the camera must be removed, and the eye-piece end of the microscope tube is to be connected with the camera aperture. This connection needs to be perfectly light-tight, a condition which can be secured by means of a black velvet collar attached to the camera flange, and having elastic in a hem which will grip the microscope tube. Provision needs to be made so that camera and microscope are held steadily in line, and for this purpose a solid base-board about 5 feet long by 8 or 10 inches wide, fitted with strips of wood to hold the apparatus in position, will suffice. The ingenious worker will not need a detailed description of a base-board and its fittings; he will devise such arrangements as are required for the apparatus he possesses. The lamp must have a place on the baseboard, and be placed in line with the objective and the centre of the

focussing screen of the camera. The mirror of the microscope is not required, so it is turned aside ; and it may be as well to state that the camera lens is removed because the microscope is itself a lens.

In my own work I invariably use an eye-piece in the microscope ; by so doing I do not need a long extension of the camera bellows ; the bellows extension needed is much greater when the eye-piece is discarded.

Perfect illumination of the object is of the highest importance. Using a metal filament electric lamp enclosed in a box whitened inside, with a 3×1 -inch aperture for escape of light, and diffusing the light with a slip of ground glass, I have obtained good results without any substage accessory when working with very low powers. But when an ordinary oil lamp is used, I have no hesitation in saying that, with all powers, some accessory is required. With objectives 1 inch and lower, the light can be parallelized with a bull's-eye condenser (p. 33), in which event light, condenser, object, and microscope must be in perfect line. It is not wise to use more rays than are really required, and the diaphragm is needed to cut off unnecessary ones. With objectives higher than 1 inch a substage condenser is necessary for critical illumination.

To take a photograph, we first put the object in position on the microscope stage and focus it roughly. Then we connect microscope tube and camera, seeing that they are in perfect line. Having arranged the light, we focus the image projected on the focussing screen of the camera. If the image is not large enough to fill the screen, we extend the

bellows and re-focus until the size is satisfactory. Then we insert the dark slide and make the exposure, which will, of course, vary according to the degree of illumination and of the nature of the object. The light can be cut off as required by placing a card between the object and the objective.

Artificial light is best for photo-micrography, it being less variable than daylight. The worker will discover the exposure required by experimentation. Some writers on the subject recommend slow plates. I find fairly rapid orthochromatic plates work well, and I generally use Imperial "Non-Filter," because they provide a moderately rapid orthochromatic plate plus a light filter—a particularly valuable feature in photo-micrographic work. There must not be the slightest vibration of the apparatus during exposure, and the worker will help to avoid this by keeping quite still at the critical moment.

It very often happens that a photograph is desired of some object which requires only small magnification, but which is of such a nature that an ordinary microscopic objective will not cover it or provide sufficient depth of focus. I have more than once met this difficulty by using the ordinary camera lens and photographing the object through a large reading-glass. But results so obtained are not of the most satisfactory kind; the image is apt to be distorted. Several manufacturing opticians have faced this problem, and now lenses are to be obtained which work at a wide aperture and have great covering properties at short distance from the object, and considerable depth of focus. They are practically short-focus photographic lenses mounted

in a microscopic fitting ; they take the place of a micro-objective, and are used without an eye-piece. With long extension of bellows, they give magnification of several diameters. These lenses have hitherto been rather costly, but Messrs. Aldis Brothers, Sparkhill, Birmingham, have recently put one on the market at the remarkably low figure of £1 10s. 6d. It is known as the "Aldis Anastigmat for Photo-micrography." I have tested this lens and find it excellent.

APPENDIX

THE worker desirous of securing more advanced guidance than is to be found in the simple instructions given on the foregoing pages will be well advised to consult any of the following books :

The Microscope and its Revelations, by W. B. Carpenter. Edited by Dr. Dallinger. Churchill. 28s. This is the standard work.

A Popular Handbook to the Microscope, by Lewis Wright. Religious Tract Society. 2s. 6d.

Modern Microscopy, by Cross and Cole. Fourth Edition, 1912. Baillière, Tindall and Cox. 6s.

Elementary Microscopy, by F. Shillington-Scales, 1905. Baillière, Tindall and Cox. 3s. 6d.

Practical Microscopy, by George E. Davis. Allen and Co., 1889. 7s. 6d.

Practical Photo-Micrography, by A. Pringle. Iliffe. 3s. 6d.

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