IX

THE WONDERS OF MICROSCOPY

THE use of a lens for magnifying purposes is ancient, but the first "compound microscope" was probably made in 1590 by a Dutchman, Zacharias Jansen, whose invention was followed up by Galileo a few years later. But it did not become an effective instrument till towards the middle of the eighteenth century. In a "simple" microscope we look at the object directly through a lens or through several lenses. This kind of instrument is often used for microscopic dissection. But in the "compound" microscope we look through an eye-lens or ocular at an inverted image of the object formed inside the tube of the instrument by an object-lens or objective. In all ordinary microscopes there are two lenses in the eye-piece and three lenses in the objective, and all sorts of ingenious devices have been invented for making the most of the magnifying power without losing clearness and definition.

An Invisible World of Life.

In the early days of microscopy the instrument was to a large extent a scientific toy. The observers magnified objects and often drew them very beautifully, but without making them more intelligible. There is not much gain in seeing a minute object loom large unless we understand it better. This was a necessary stage. Soon, however, great steps were taken, and one of these may be called *the discovery of the invisible world of life.* The pioneer explorer was surely the Dutch observer Leeuwenhoek (1632–1723), who discovered minute creatures like the Rotifers or Wheel-Animalcules which are com-

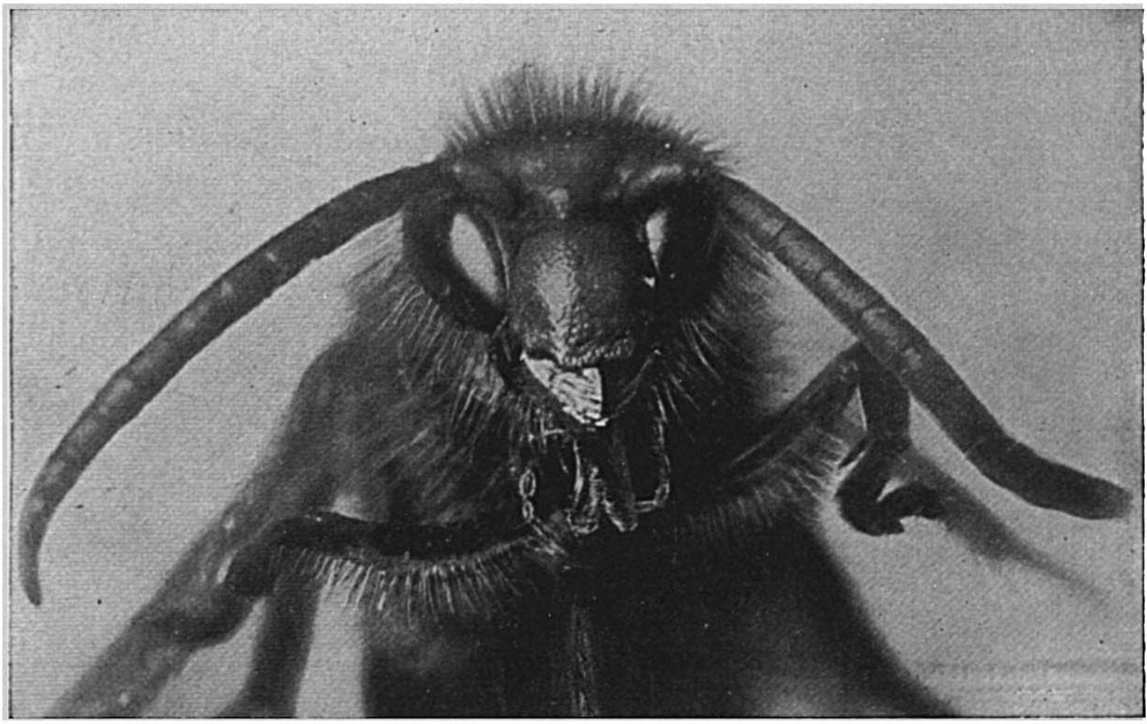


Photo: J. J. Ward.

FULL-FACE PORTRAIT OF THE COMMON WASP.

The large compound eyes are well seen, and above these are the feelers or antennæ. Protruding underneath the front of the head are some of the biting mouth-parts, and the first pair of legs are also seen. Note also the numerous setæ or bristles.

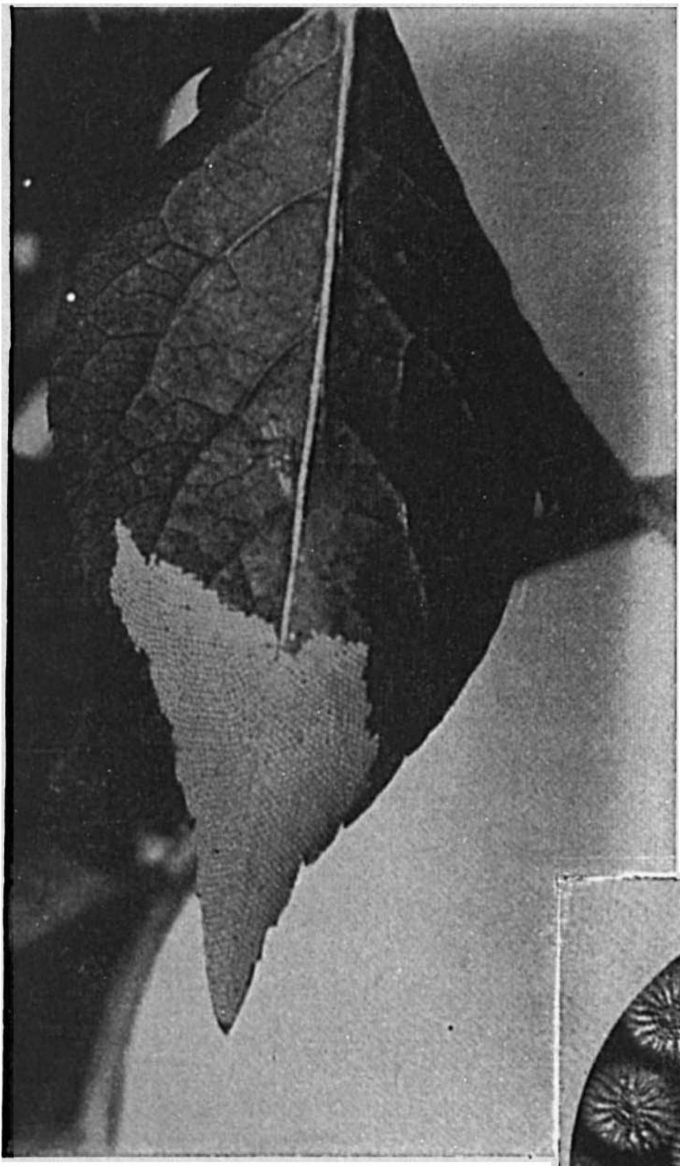


Photo: J. J. Ward.

EGGS OF THE BROAD-BORDERED UNDERWING MOTH, CROWDED TOGETHER ON THE UNDERSIDE OF THE LEAF.

There are about 1,300 eggs, all deposited in one evening. In another photograph a few of the eggs are shown much enlarged.

mon in ponds, and the Infusorians which abound wherever vegetable matter rots away in water. He made numerous microscopes, and though they had neither tube nor mirror, they were sufficient to enable him to demonstrate his animalcules before the Royal Society of London, the Fellows signing an affidavit that they had seen the little creatures. It was Leeuwenhoek also who (in 1687) discovered bacteria, the very minute organisms which cause all putrefaction, are responsible for bringing about many diseases, and are yet of immense service to many living creatures.

It was not till long afterwards that Pasteur and others demonstrated the importance of bacteria, but it was a great event in the history of science when Leeuwenhoek first proved their presence. It was literally the discovery of a new world with a teeming population, with incalculable powers for good and evil. It must have been a seed in the human mind, this idea of an intense activity going on all unseen until men stuck lenses of glass in front of their own.

Another great event, though its importance was not recognised till afterwards, was *the discovery of the male elements* or spermatozoa of animals, which fertilise the egg-cells so that these may begin to develop. This discovery was probably due (1677) to a medical student in Leyden, Louis de Hamen, who showed them to

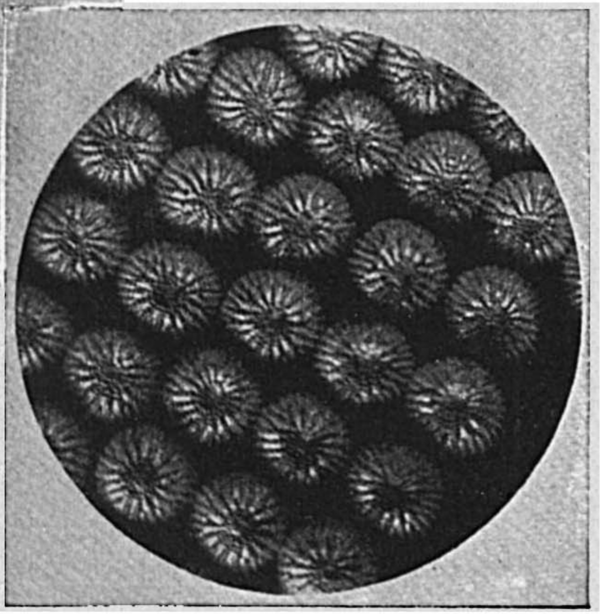


Photo: J. J. Ward.

EGGS OF THE BROAD-BORDERED UNDERWING MOTH.

Each egg has a shell of the substance called chitin, which covers the living skin of all insects. The egg-shell is secreted in the oviduct of the female insect. Its outer surface is very beautifully sculptured, but the significance of the pattern is unknown. It looks as if the beauty of many organic structures is like that of snow crystals—an expression of the way in which the dance of molecules sinks into relative rest.

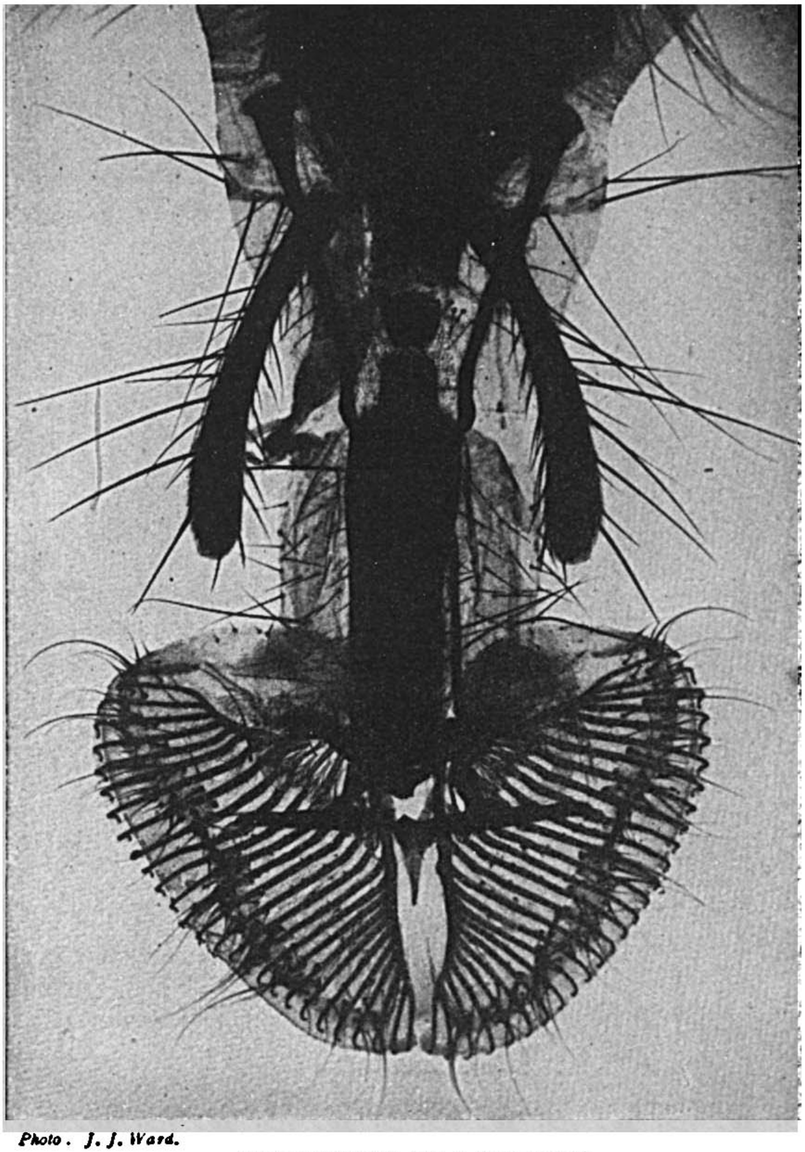


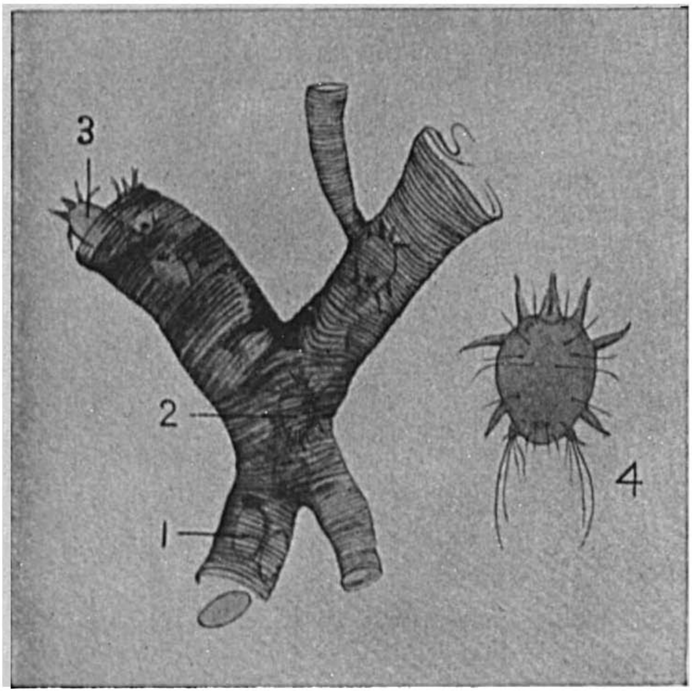
Photo. J. J. Ward.

THE PROBOSCIS OF A HOUSE-FLY.

It is a tubular structure ending in two broad pads, traversed by numerous small canals by which saliva from the mouth can be passed out on the surface of the pads. This juice dissolves solid substances like sugar, and the result is sucked up the proboscis. Two unjointed sensitive palps are also shown. When not in use the proboscis is drawn into a hollow beneath the fly's head.

Leeuwenhoek, but it was not till more than a hundred years later that the meaning of these sperm-cells was recognised. And it is interesting to remember that it was not till 1843 that another medical student, Martin Barry, in Edinburgh, observed for the first time in the rabbit the fertilisation of the mammalian ovum by the spermatozoon. In modern times an extraordinary intensity of research has been focused on the usually microscopic egg-cell and the always microscopic sperm-cell. In the union of these an individual animal has its beginning, and it is interesting to trace this modern study, so important in connection with heredity, back and back to the Leyden student's first glimpse of spermatozoa.

But we must not lose the wood in the trees: one of the real wonders of microscopy, rising high above any mere curiosity collecting, is the discovery of a world of invisible life. There are the bacteria, which may be regarded as the simplest of living creatures; there are the yeasts and the simple moulds; there are the single-celled green plants which play so important a rôle in the economy of the sea by providing food for humble animals like water-fleas. There are the one-celled animals or Protozoa, such as the chalk-forming Foraminifera, the Infusorians which often serve as middlemen between the products of bacterial putrefaction and some higher incarnation in crustacean or worm, and the death-bringing organisms of malaria and sleeping-sickness. There are also many-celled animals of microscopic dimensions, such as the wheel-animalcules of the pond and the minute crustaceans which play so important a part in the circulation of matter by feeding on the microscopic Algæ and Infusorians in the water and being themselves devoured by fishes. There are also the invisible early stages of many important parasites, whose life-history would have remained quite obscure if naturalists had been without microscopes. It seems hardly too much to say that the system of animate nature would be uncomfortably magical if the microscope had not enabled us to detect the missing links in many a chain of events. The liver-fluke which often destroys the farmer's sheep is a relatively large animal—about an inch long—but it starts its life as a microscopic egg which develops into a microscopic larva that enters a water-snail, and has a remarkable history there. The tapeworm, with which man becomes infected by eating bad beef imperfectly cooked, may be several yards in length, but it began as a microscopic egg which was swallowed by a bullock and hatched into a microscopic boring larva, which eventually became the beef-bladderworm. In hundreds of cases the microscope reveals the life-history. In the course of a few years a very serious bee-pest, known as Isle of Wight disease, has spread throughout Britain, causing havoc among the hives, and greatly discouraging a lucrative and wholesome industry. The nature and meaning of this disease remained baffling until strenuous and patient microscopic work by Rennie and White demonstrated that the plague was bound up with the presence of an extremely minute mite in the anterior breathing-tubes of the bee. And when the cause of a disease is discovered, it is not usually long before investigation also reveals a cure.



"ISLE OF WIGHT DISEASE" HAS SPREAD ALL OVER BRITAIN, CAUSING THE RUIN OF THOUSANDS OF BEEHIVES.

It is associated with the presence of a very minute mite (*Tarsonemus woodi*) in certain air-tubes or tracheæ of the bee. The figure shows an enlargement of a branching air-tube with a mite's egg (1), an immature female (2), a mature female (3) struggling out. In Fig. 4 is shown a mature mite still more enlarged; note the four pairs of walking legs with bristles and two pairs of piercing and sucking mouth parts. The mite feeds on the bee's blood, and as the numbers increase the infected air-tubes become blocked. This means that certain muscles, e.g. those of flight, are bereft of their normal supply of oxygen and naturally go out of gear. The bees are unable to fly, and crawl about helplessly in front of the hive.

Intricacy of Architecture in Small Animals.

Long before there was any microscope the use of the scalpel, helped sometimes by the simple lens, had revealed the intricacies of the body in man and in animals. We may save ourselves from exaggerating modern achievements by recalling how much Aristotle (384–322 B.C.) knew of animal structure. He dissected many a creature, such as the sea-urchin; he saw the beating of the tiny heart of the unhatched chick; he described how the embryo of the smooth dog-fish is bound to the wall of its mother's

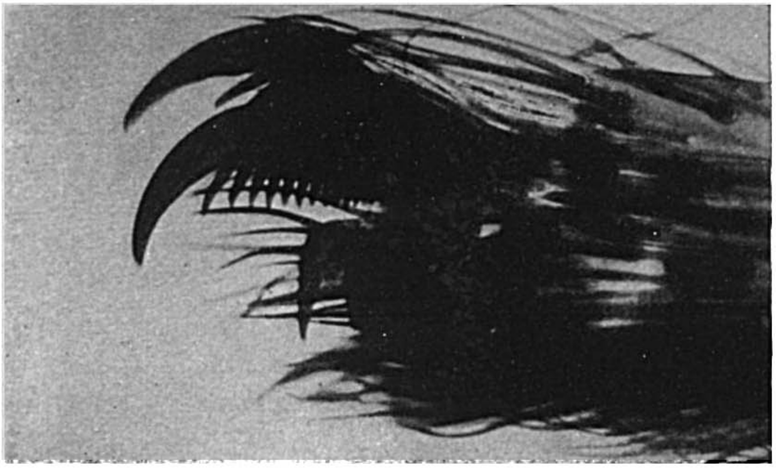


Photo: J. J. Ward.

FOOT OF SPIDER, SHOWING COMBED CLAWS AND CUTTING-HOOK BELOW.

When the spider runs up a wall or creeps along a ceiling, it is gripping the roughnesses on the surface by means of these combed claws. There is mention in the Scriptures of the spider "laying hold with her hands"; but some scholars say that the Hebrew word really refers to the wall-lizard called the Gecko, which has toes with adhesive surfaces. A spider cannot climb up a quartz fibre, for its claws will not grip the smooth surface.

oviduct, and much more besides. And Aristotle had his successors, few and far between, who kept up the anatomising tradition, long before there was any microscope. But what the early microscopists did was to reveal the fact that the multitude of minute creatures which it was hopeless to try to dissect had an intricacy of structure comparable to that in larger and higher animals. One of the pioneers in this exploration was the Italian, Marcello Malpighi (1628–1694), who described the internal architecture of the silkworm as animal had never been described before. He worked so hard that he threw himself into a fever and set up inflammation in his eyes. "Nevertheless, in performing these researches so many marvels of nature were spread before my eyes that I experienced an internal pleasure that my pen could not describe." He discovered, for instance, the delicate branching air-tubes (or tracheæ) which carry air to every hole and corner of the insect's body; and it is plain from this instance that he discovered internal structures which made the insect at once more intelligible. This sort of discovery (we still call the excretory organs of insects Malpighian tubes) was characteristic of the man, and characteristic of a kind of investigation which continues untiringly to the present day. It makes for a realisation of the unity of organic nature to disclose in creatures which will pass through the eye of a needle the presence of organs comparable to those in man himself. Much of Malpighi's work was done with a simple lens, but he had also his microscope with two lenses, and in any case his name may be associated with the great discovery that as far as intricacy of structure goes, size does not count for much.

It is a very striking experience to observe a

Photo: J. J. Ward.

FOOT OF A WINGLESS FLY, *MELOPHAGUS OVINUS*, OFTEN, BUT BADLY, NAMED THE SHEEP-TICK.

For a tick is not an insect at all. The "ked," as it is popularly called, has a compressed body about a quarter of an inch long. It has piercing mouth-parts and sucks blood from the sheep. Very striking are the two curved claws at the tip of the foot, well suited for holding up to the fleece. Part of the body, with short hairs, is also shown. The "keds" usually pass from one sheep to another by contact.

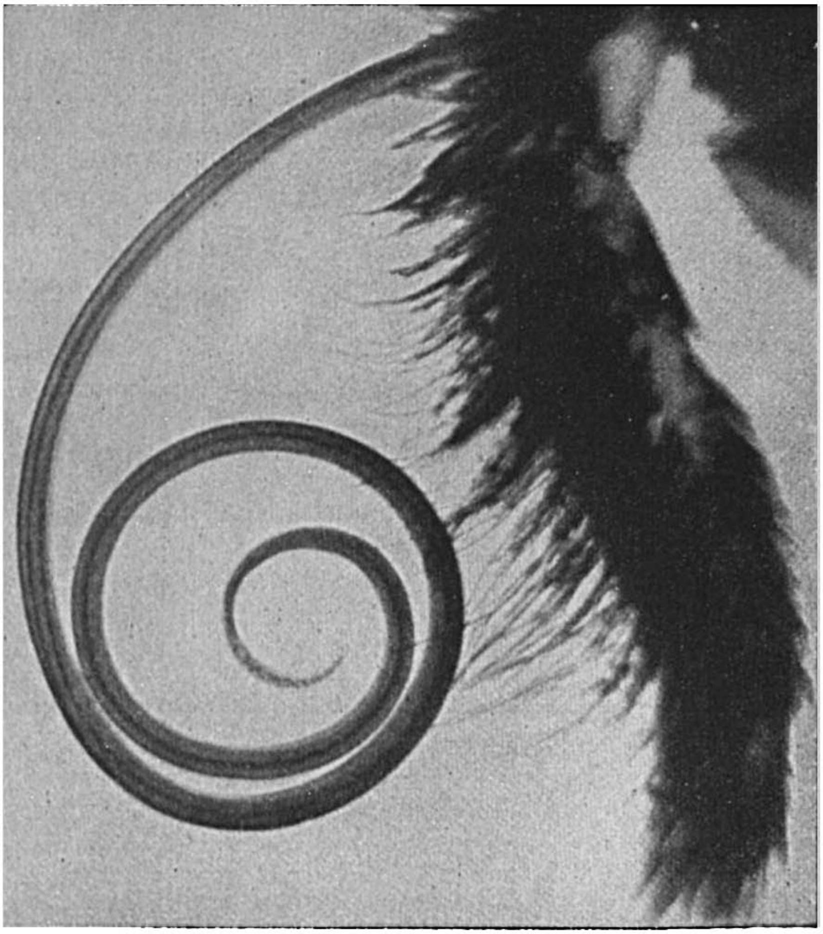


Photo: J. J. Ward.

COILED PROBOSCIS OF A BUTTERFLY.

It is a paired structure, but only one-half of the tube is shown. It is used for sucking up nectar from flowers, the suction being due to a muscular pump inside the insect's head. In some of the Hawk Moths the proboscis may be 10 inches long. Rising from near the base of the proboscis there are two palps covered with sensitive hairs, as the photograph shows. The caterpillar or larva of the butterfly has biting mouth-parts in great contrast to the suctorial parts of the adult.

minute animal like the Rotifer Hydatina, no more than a pin-prick in size, and to find that it has a food-canal, a chewing apparatus, a nerve-centre, various muscles, a delicate kidney-tube, and so on. Yet it is such a pigmy when all is said. There are little beetles (Trichopterygids), well represented in Britain, which are sometimes only one-hundredth of an inch in length—practically invisible. Yet within that small compass there is the same kind of intricacy that is found in a Goliath Beetle—brain and nerves, muscles and food-canal, air-tubes and kidney-tubes, blood and germ-cells. He would be a bold man who says he quite understands how there is all this intricacy within bulk so small. But this we venture to call the second wonder of microscopy, that *great intricacy of structure may occur in a microscopically minute living body*.

Intricacy of Vital Architecture.

We have singled out the name of Malpighi in Italy as a pioneer in the exploration of the structure of minute animals, but we might have taken with equal justice Swammerdam in Holland, whose precision of minutiose observation has rarely been equalled. He is memorable not only for his anatomy of small creatures, but, like Malpighi, for his minute anatomy of larger ones, and here we might also include the early British microscopists, Hooke and Grew. For this was another line of advance, to disclose the intricacy of vital architecture that lay beyond the limits of scalpel and simple lens. Thus it was a great step when Swammerdam discovered in 1658 the blood corpuscles of the frog; when Malpighi demonstrated the air-cells in the lung where the gaseous interchange takes place between blood and air; when Leeuwenhoek completed Harvey's theory of the circulation of the blood by demonstrating in 1680 the capillary connection between arteries and veins. Speaking of the tail of the tadpole, he said, "A sight presented itself more delightful than any mine eyes had ever beheld; for here I discovered more than fifty circulations of the blood in different places, while the animal lay quiet in the water, and I could bring it before my microscope to my wish. For I saw not only that in many places the blood was conveyed through exceedingly minute vessels, from the middle of the tail toward the edges, but that each of the vessels had a curve or turning, and carried the blood back toward the middle of the tail, in order to be again conveyed to the heart." Such was the momentous observation of the fact that the arteries leading *from* the heart, and the veins leading *back to* the heart are bound into one system by the intermediation of the capillaries.

This is an easy illustration of the kind of service microscopy has never ceased to render—making vital activity more intelligible by revealing the intricacy of structure. For it is in a study of the structure that we get a better understanding of the ways and means of life. It is not the whole story of the workshop to know the furnishings and the tools, but it is an essential part of the story. We hastily draw away our finger from a hot plate—a reflex action—it is only with the help of the microscope that the physiologist can tell how the message travels by sensory nerve-cells to intermediary nerve-cells and thence to motor nerve-cells which command the muscles to move. Our mouth waters at the sight of palatable food: it is only by help of the microscope that the physiologist is able to trace the message from eye to salivary glands, and to show how in the cells or unit-corpuscles of these glands there is a preparation of secretion which is discharged when the trigger is pulled by a nervous command. The study of vital activity requires experiment and chemical analysis, but it cannot dispense with the microscope. So we venture to say that a third wonder of microscopy is the revelation of *the intricacy of minute structure.*

The Stones and Mortar of the House of Life.

It is a long and tangled story which tells of the gradual discovery of the cells or unit-areas of which all but the simplest living creatures are built up, and of the living matter or protoplasm which these cells contain or portion off. The genius of the short-lived French anatomist Bichât had analysed a living body into a web of tissues—nervous, muscular, glandular, connective, and epithelial. But to Schwann and Schleiden, Virchow and Goodsir, is due the credit of a further advance—the Cell-Theory—certainly one of the triumphs of microscopes with brains behind them. The Cell-Theory or Cell-Doctrine states three facts: (1) that all plants and animals have a cellular structure (being either single cells or combinations of

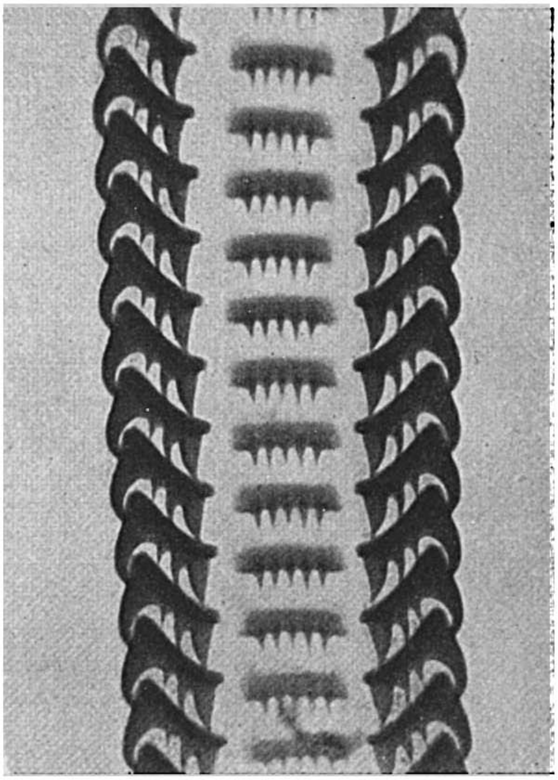


Photo: J. J. Ward.

RASPING RIBBON OR FILE, BADLY CALLED THE PALATE, IN THE MOUTH OF THE WHELK.

By means of this toothed flexible file the whelk can bore a hole through the skin, or even through the shell, of an animal on which it preys.

numerous cells); (2) that every living creature, reproduced in the ordinary way, begins its life as a single cell, and, if it does not remain at that humble level, proceeds to build up a body by the division and re-division of cells which eventually form tissues and organs; and (3) that the activities of a many-celled organism are the co-ordinated summation of the activities of the component cells. "Every animal," Virchow said, "appears as a sum of vital units." Not that we are to think of an ordinary animal as a colony of cells, as a mob is a collection of angry men, or even as a battalion is a co-ordination of disciplined soldiers. It is nearer the truth to think of the fertilised egg-cell—a *potential organism*, when we come to think of it—dividing and re-dividing into cells so that the unified business of life may be more effectively carried on by division of labour. As one of the greatest of botanists said: It is not that the cells form the plant; it is rather that the plant makes the cells.

JOHN GOODSIR, 1814-1867, PROFESSOR OF ANATOMY IN THE UNIVERSITY OF EDINBURGH.

A remarkable pioneer who had an important share, along with Schwann, Schleiden, and Virchow, in establishing the Cell-Theory—one of the foundation-stones of Biology.

The Microcosm of the Cell.

With a few exceptions, notably Aristotle, the early naturalists were content to study the outsides of animals; then came the study of internal organs, like hearts and lungs; Bichât marks the deeper penetration to the tissues that make up the organs; then came the recognition of the cells that compose the tissues; finally there was the recognition of protoplasm—which Huxley called "the physical basis of life." It may be useful to place the different levels of study in a clear scheme (see illustration opposite).

ORGANISM

ORGANS

TISSUES

CELLS

PROTOPLASM

A living creature or *organism* is usually built up of *organs*, such as heart and kidneys; the organs are composed of *tissues*, like muscular and nervous, glandular and connective tissue; the tissues, e.g. a piece of flesh, are built up of microscopic unit-corpuscles or *cells* of various kinds; and the cells consist largely of living matter or *protoplasm*.

The old picture of a cell was that of a little drop of living matter with a kernel or nucleus, and sometimes with an enclosing wall. But the revelations of the microscope have made this picture obsolete. We have to think of a more or less unified minute area of great chemical diversity, with complex particles and unmixing droplets restlessly moving in a fluid. In the centre of this whirlpool, with its flotsam of reserve-products and waste-products, there floats the nucleus, a little world in itself. Inside its membrane, through which materials are ever permeating out and in, there are readily stainable nuclear bodies or "chromosomes," usually a definite number for each species. And each "chromosome" is built up of bead-like "microsomes" strung on a transparent ribbon. It

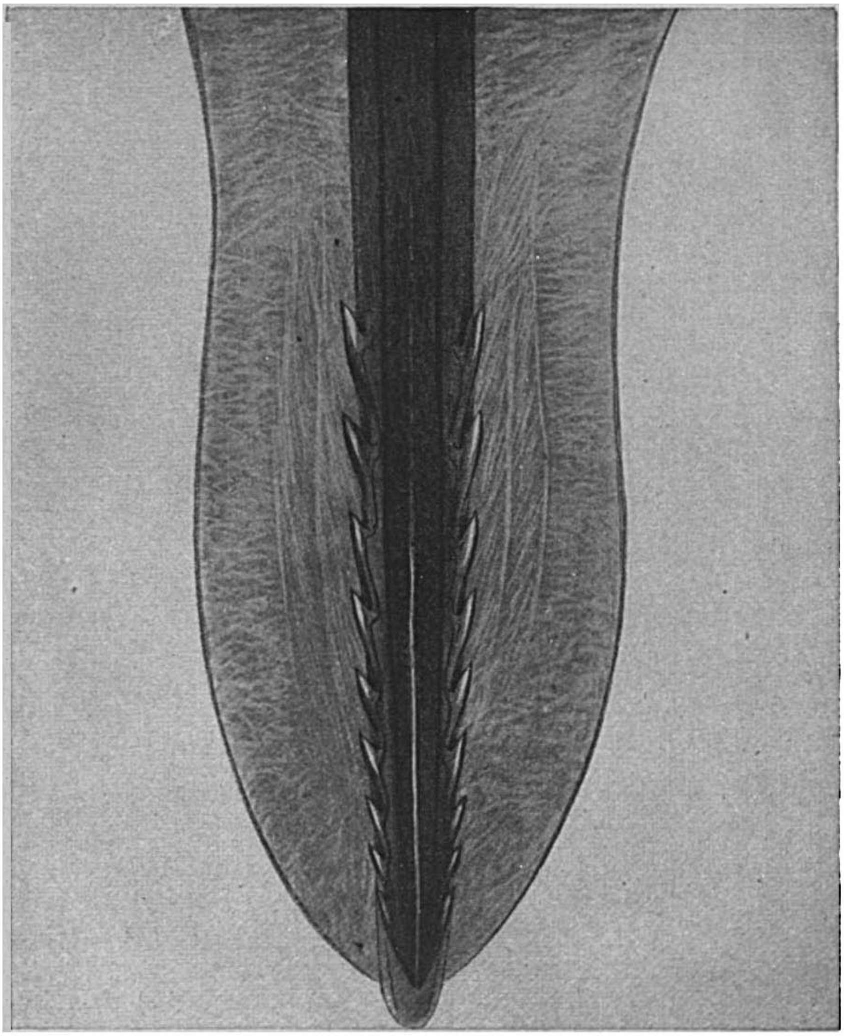


Photo: James's Press Agency.

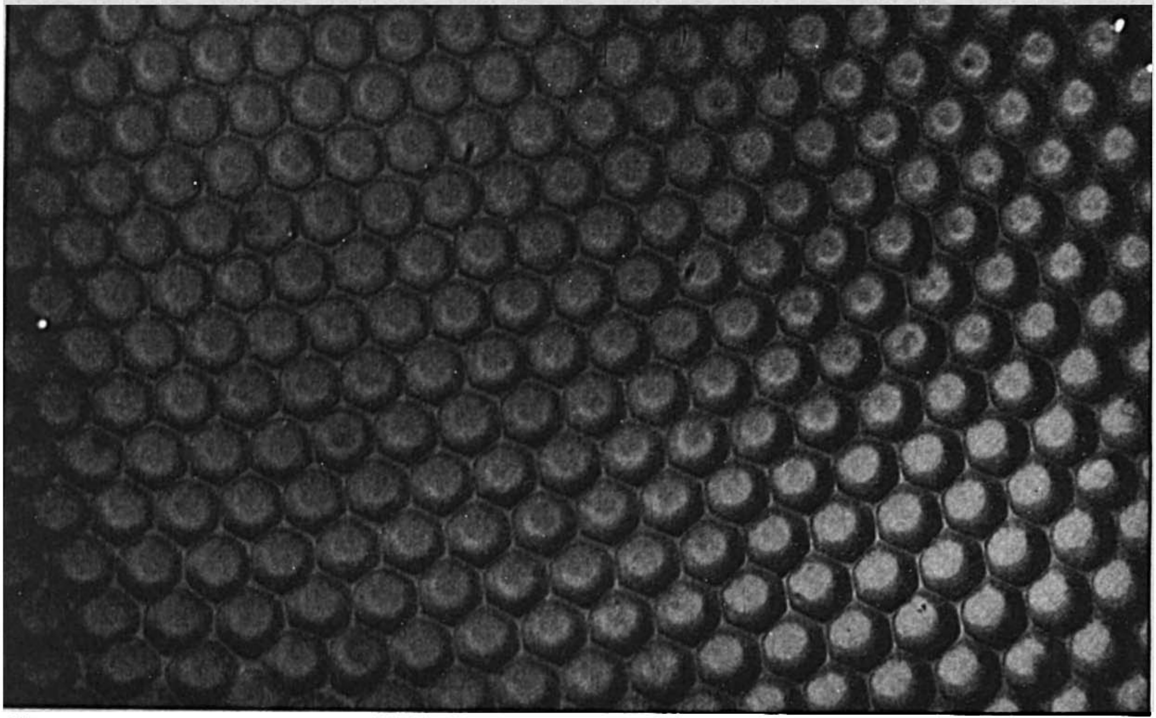
STING OF THE HONEY-BEE.

In the middle there is a deeply grooved "guide," pointed and barbed at the tip. Working in a concavity on each side of the "guide," is a slender lancet or "dart," with recurved barbs at the tip. There are beadings which keep the darts sliding smoothly along the guide. The tips of the darts can be protruded beyond the end of the guide. Enclosing the three dark-coloured piercing structures there are two fleshy "sting-palps," shown in lighter colour in the figure, which includes only the *terminal* part of the sting. When the bee strikes, the secretion of the poison-gland is forced down between the darts and the guide.

begins to make one's head reel—cell, nucleus, chromosomes, microsomes! But it is all fact.

Inside the nucleus there may be a nucleolus or more than one, and outside the nucleus there is a minute body called the centrosome, which plays an important part in the division of the cell. This is not nearly all, but it is enough to suggest *how complex is the microcosm of the cell.* Inside each of man's cells there are about two dozen chromosomes, and one of the authorities on cell-lore speaks of each chromosome having the corporate individuality of a regiment, the really indivisible living units being the beads or microsomes—which correspond to the men! And to this must of course be added the fact that we have many millions of these cells in our body. Indeed, we are fearfully and wonderfully made!

Every many-celled creature, which reproduces in the ordinary way, starts on the journey of life as a single cell—the fertilised ovum. As we have made clear in a previous article, the usually microscopic fertilised egg-cell contains, in some way that we cannot picture, the initia-



SURFACE VIEW OF THE COMPOUND EYE OF A FLY, SHOWING SOME OF THE THOUSANDS OF CORNEAL FACETS. Corresponding to each facet is a complete " eye-element," including a double lens and a percipient retina or retinule.

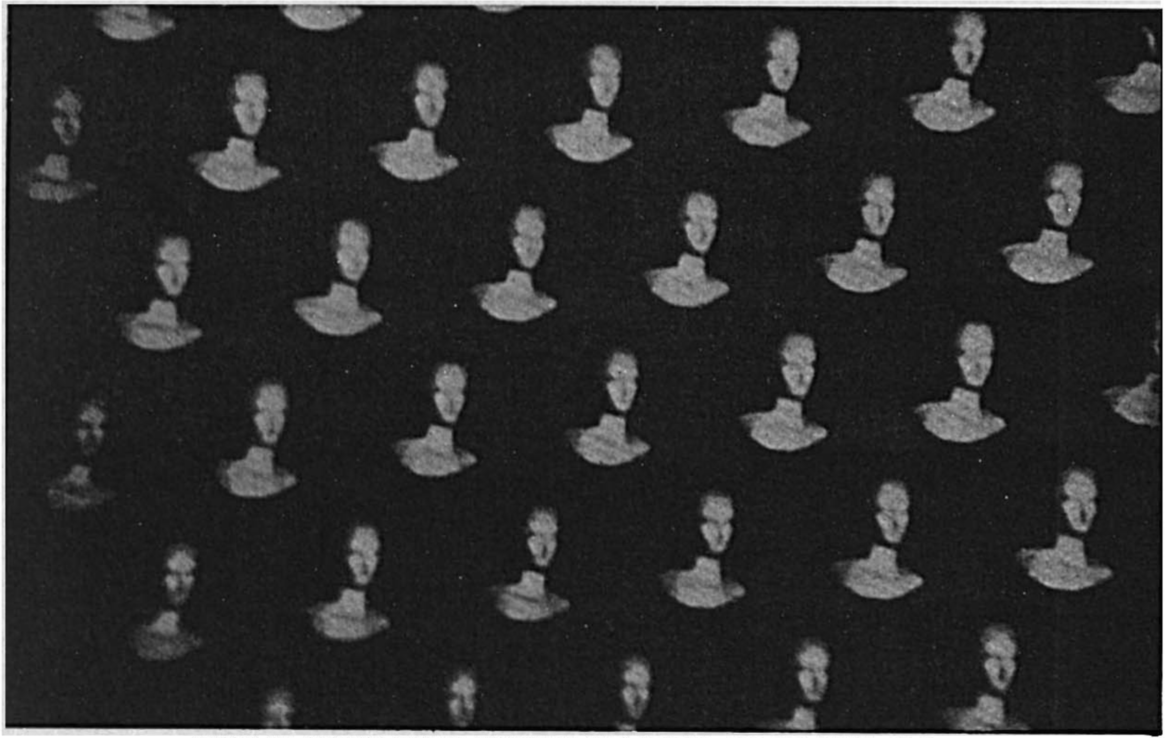


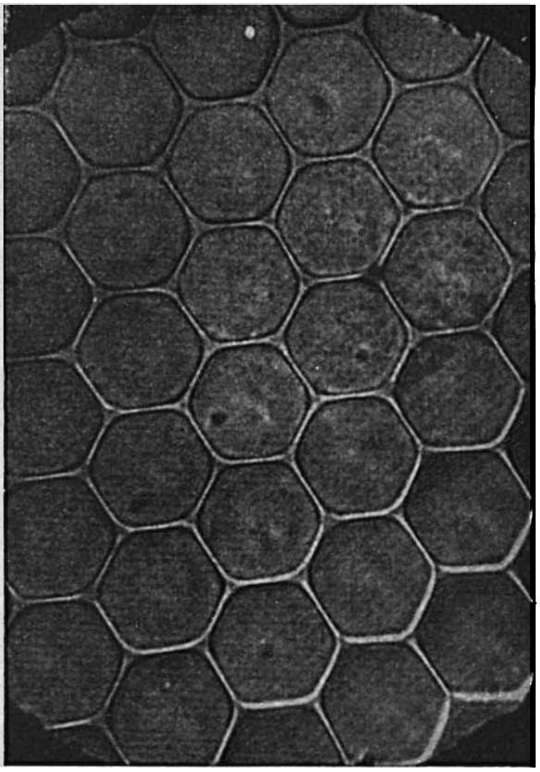
PHOTO OF STATUE TAKEN THROUGH THE LENSES OF THE FLY'S CORNEA.

A multitude of images has been formed, one image through each of the thousands of lenses. The photo-micrographs of the fly's eye were taken by means of Davidson's " Davon " Patent Super-Microscope, in which an achromatic combination called a " collector " is placed behind the objective in the microscope. This projects an " air " image of the object under examination beyond it, and this " air " image is magnified by another objective and eyepiece acting as a compound eyepiece. The result is that higher magnification can be employed on any given objective than is usually employed and without loss of resolution.

tives or "factors" for the hereditary characters of the living creature in question. But the microscope has begun to reveal the little world within the egg-cell, and it has been found possible to map out the way in which the factors for certain characters are disposed in the chromosomes. Thus in the case of the egg of the fruit-fly called Drosophila, it is possible to say that the hereditary or germinal factor for, say, red eye or grey wing, lies at such and such a level in one of the four chromosomes. *It would be difficult to find a wonder of microscopy greater than this.*

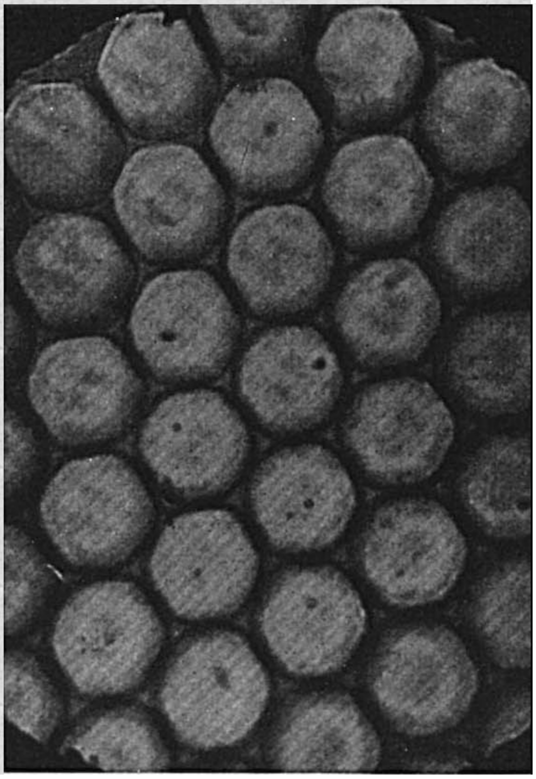
The Beginning of the Individual.

Yet this is but an instance of what goes on at a level of visibility which only the microscope can reach. We know much in regard to the permutations and combinations which take place when the germ-cell is ripening—shufflings of the hereditary cards which throw some light on the origin of new departures. We know something of the manner in which the paternal and maternal hereditary contributions behave in relation to one another when and after fertilisation takes place. We know much in regard to the sequence of events in individual development, wherein the obviously complex emerges from the apparently simple, and the implicit inheritance becomes an explicit individual. In the seventeenth century, William Harvey, the discoverer of the circulation of the blood, wrote in regard to development: "Although it be a known thing subscribed by all, that the fœtus assumes its original and birth from the male and female, and consequently that the egge is produced by the cock and henne, and the chicken out of the egge, yet neither the schools of physicians nor Aristotle's discerning brain have disclosed the manner how the cock and its seed doth mint and coine the chicken out of the egge." But although we do not understand to-day how the factors of an inheritance are condensed into the dimensions of a pin-prick; or how the fertilised egg-cell segments into two, and cleavage after cleavage continues, with associated division of



SURFACE VIEW OF THE COMPOUND EYE OF A FLY, SHOWING THE NUMEROUS HEXAGONAL FACETS ON THE TRANSPARENT CORNEA.

To the inside of the facet there is an outer or corneal lens, inside that a crystalline cone or inner lens, and inside that again a percipient rod.



SURFACE VIEW OF THE SAME EYE, SHOWING THE CORNEAL OR OUTER LENSES FITTING AGAINST THE HEXAGONAL FACETS OR FRAMES.

In the house-fly there are about 4,000 facets, corneal lenses, crystalline cones, and sensitive rods.

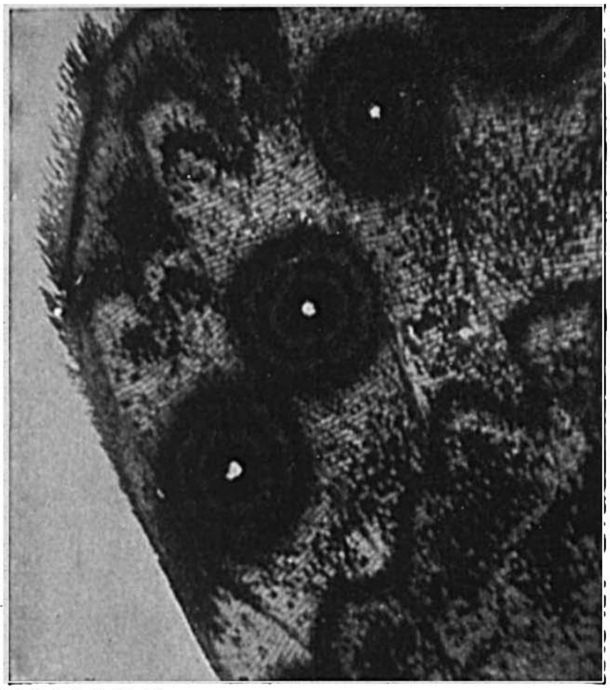


Photo: J. J. Ward.

PART OF THE WING OF A WALL-BUTTERFLY.

Showing how the numerous scales build up its design, not only covering the general surface like the slates on a roof, but arranged in wavy bands and concentric zones. Each microscopic scale is finely striated longitudinally, and the light falling on these undergoes "interference." This gives the metallic iridescence to the wings of many butterflies, greatly enhancing the coloration due to pigment.

labour, until an embryo is built up; we *do* know why it is that like tends to beget like, why certain hereditary characters are distributed in a particular way among the offspring. And we also know the successive steps by which the process of development is accomplished. It is this kind of knowledge, we think, which must be regarded as *the crowning wonder of microscopy.* These fundamental questions of heredity and development will be discussed in a separate article, but the point here is that the scientific study of inheritance can as little dispense with microscopy as with breeding experiments and statistics. All three are *essential.*

Manifold Uses of the Microscope.

Everyone knows that finger-prints are sometimes of critical importance in the identification of a criminal. The details of the pattern of the ridges on the fingers vary from man to man; they are *individual.* Therefore, if a good impression is available on some surface which has been handled in the course of a burglary, let us say, it can be compared with the collection in the album of criminals finger-prints, and identification may follow. The microscope has even subtler use in *the detection of crime.* If splashes of blood on the clothes of a suspected murderer are declared by him to be due to the blood of a rabbit which he killed, it is usually possible to test the truth of his statement *microscopically.* For the dimensions of the very minute red blood corpuscles differ in different mammals, and the *circular* shape in all mammals (except camels) can be distinguished at a glance from the *elliptical* shape in all the other backboned animals. Moreover, the red blood pigment of hæmoglobin can be easily made to assume a crystalline form, and it is a very remarkable fact that the blood-crystals of the horse can be distinguished microscopically from those of the ass, and even those of the domestic dog from those of the wild Australian dingo. Poisons that crystallise may also be detected by means of the microscope.

The use of the microscope in *medicine* may be illustrated in reference to the blood. For it is often possible by microscopically

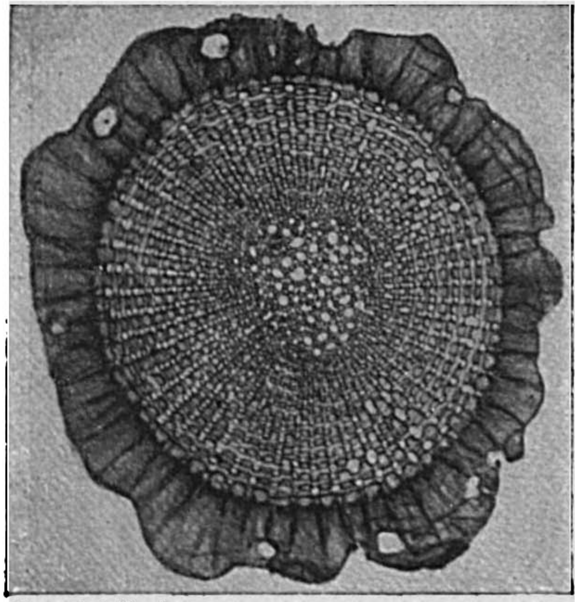
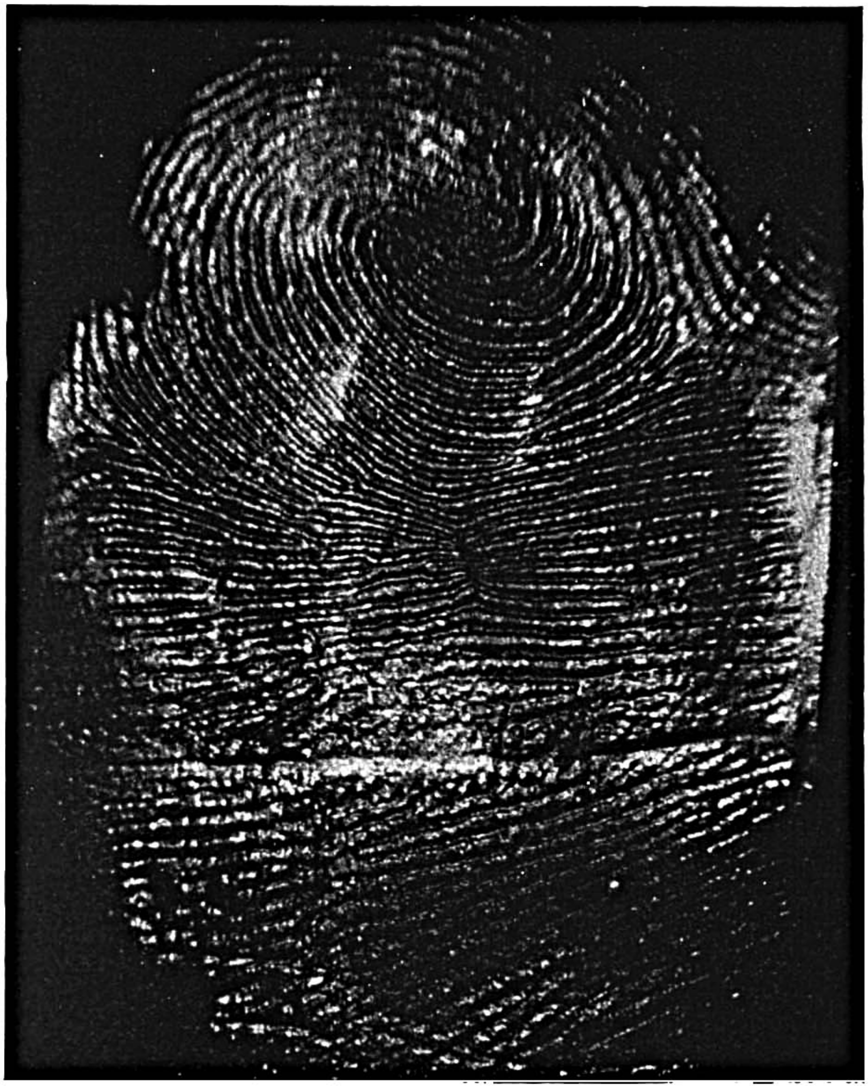


Photo: J. J. Ward.

CROSS-SECTION OF THE SPINE OF A SEA-URCHIN (*CIDARIS METULARIA*), MAGNIFIED SEVERAL DIAMETERS.

The remarkable feature is the beautiful zoned structure. The spine is a delicate needle to start with, but around this there is a periodic deposition of lime from the skin, one concentric zone after another. It is probable that this kind of architecture gives the spine great stability, but it is primarily an expression of rhythmic orderly growth. It shows that the quality of beauty is not confined to the outsides of animals.



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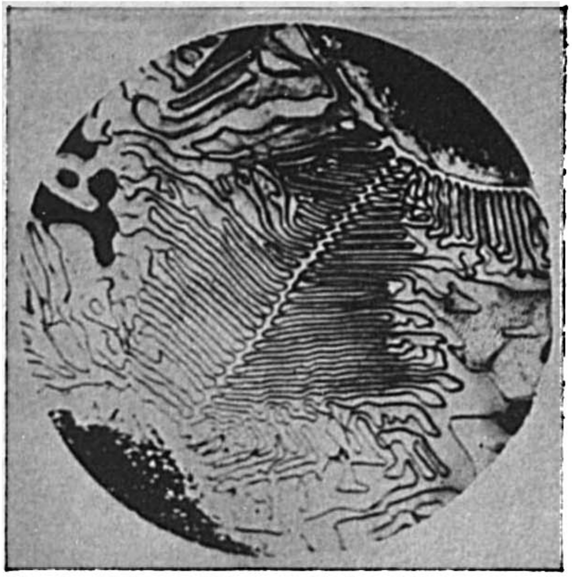
THUMB-PRINT IN WAX.

The skin is marked by numerous ridges and intervening valleys, which have individual peculiarities of pattern, even in the same family. This illustrates inborn variability. The individuality of the pattern is so marked that the prints are used as sure means of identification.

examining a film of blood, spread on a slide, to tell what is wrong with the patient. Microscopic parasites may be detected, like those of malaria; methods of counting the red blood corpuscles (man has trillions !) may show that they are far below the proper number; and a change in the normal shape of the hæmoglobin crystals may show that something is amiss. It is unnecessary to dwell on the medical importance of the microscope in determining the presence or absence of certain kinds of microbes and higher parasites in the blood or food-canal of the patient. Along with this physiological utilisation of the microscope we may take its use in testing drinking water, which is liable to be fouled by the presence of bacteria and various minute animals. Also of great importance is the microscopic study of milk, for this fluid is peculiarly liable to contamination, and is very suitable for the growth of various kinds of disease germs.

For *the detection of adulteration* the microscope is also invaluable. The starch grains of different plants, such as potato, wheat, rice, maize, are readily distinguished from one another, and a microscopic examination may immediately prove that a commodity sold under a particular name, e.g. as arrowroot, is not what it professes to be. If a sample of so-called "honey" contains no pollen-grains, but a great many starch-grains, we may be sure that the busy bee was not the chief agent in its production. In short, the microscope is a valuable detective of dishonesty. But a use of the microscope more important and more pleasant to think of is in metallurgy, where its utilisation to detect the structural features of the stable and the transient in various metallurgical combinations, such as different kinds of steel, has been of inestimable importance.



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A PIECE OF HIGH-SPEED STEEL SEEN UNDER THE HIGH MAGNIFICATION OF 1,500 DIAMETERS.

Note the marked lines of flow.

A farmer can always make good use of a lens in examining samples of seeds, or in identifying particular kinds of injurious insects, or in detecting the beginnings of "rusts" and "mildews" on his crops. But the expert agriculturist must of course go much further, especially in warm countries, where the microscope is necessary for the study of the insidious Fungi which are always ready to find a weak spot in the plants' defences—in all sorts of plantations from coffee to rubber.

Photo: J. J. Ward.

SCALE FROM A GOLD-FISH.

Showing the rings of growth by which the age of the fish can be reckoned. Starting from a little speck, the scale has line upon line added to it. Periods of rapid growth alternate with periods of slow growth; or the growth in summer may be different in character from the growth in winter; and thus alternate zones are established. Just as we can tell the age of a tree by counting the summer and autumn rings on the cut stem, so, after getting some secure data, we can tell the age of the fish. It keeps its diary on its scales.

The Ultra-Microscope.

Early in the twentieth century an ingenious method was described by Siedentopf and Zsigmondy, which is often briefly referred to as the *ultra-microscope.* Everyone knows from personal observation that a strong beam of sunlight entering a darkened room reveals a multitude of dust particles, which are not seen at all in ordinary light. The same multitude of particles is often seen in the track of a strong beam from a "magic lantern" in a darkened room. These dancing particles, whose abundance we scarcely suspected, become visible because they are so strongly illumined; there is a diffraction of rays from their surface, and they look much bigger than they really are.

In 1899 Lord Rayleigh pointed out that a particle too small to be seen by the highest power of the microscope under ordinary conditions might be made visible if it received sufficiently intense illumination; and the ultra-microscope took advantage of this idea. It occurred to Siedentopf and Zsigmondy that if the particles in a solution could be strongly illumined by a beam coming in, so to speak, sideways, then particles ordinarily invisible might stand out. Their diffraction-images, at any rate, would be seen. In ordinary microscopic conditions the beam of light is thrown by the mirror, usually through a sub-stage condenser, directly through the solution or thin transparent section, up into the tube of the microscope, where an image is formed, to be re-formed by the eyepiece. In the ultra-microscope for examining solutions the beam of light is projected *horizontally* into the solution and examined from above. The result is that particles ordinarily invisible are seen in a vigorous dance, the so-called Brownian movement. This dance is due to the particles being bombarded by the moving molecules of the fluid in which they are suspended. By accessory devices it becomes possible, in the use of the ultra-microscope, to count the number of particles in a solution and to measure the mass of each. This has formed the basis of exceedingly interesting conclusions which are unfortunately beyond our scope in this article.

A reference should be added, however, to another method called "dark-ground illumination" which makes structures visible which are

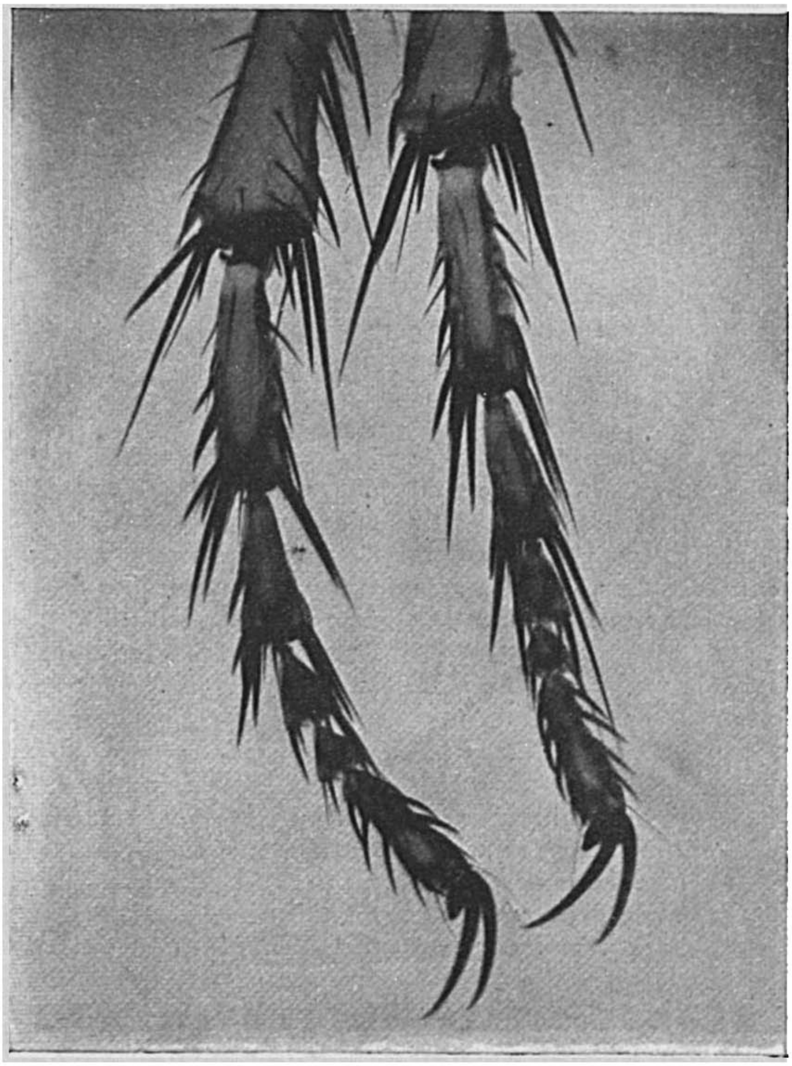

Photo: J. J. Ward.

FEET OF THE JUMPING-LEGS OF THE COMMON FLEA.

The powerful muscles which give the flea its familiar power of leaping are mainly in the uppermost part of the leg, which is not shown here; but there are minor muscles continued to the very tip of the legs, to the base of the terminal claws. Note the numerous bristles or setæ on the leg.

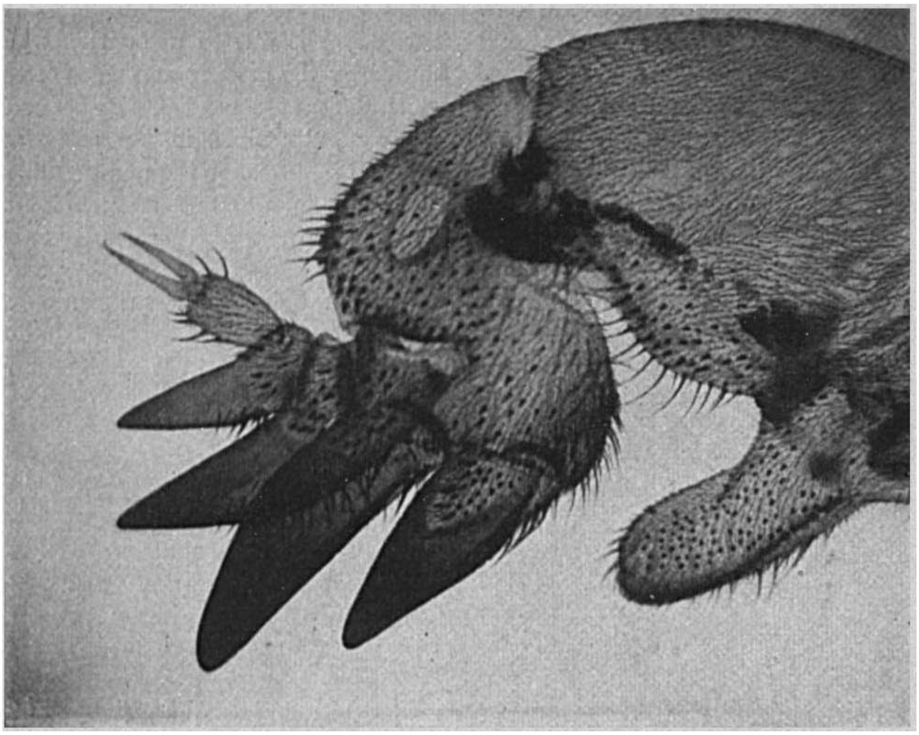

Photo: J. J. Ward.

ONE OF THE FORE-LEGS OF THE MOLE CRICKET (GRYLLOTALPA).

Showing very strong digging blades, reminding one of the mole's claws. Small forceps are also seen, and an oval mark on the "knee" is a sense-organ sometimes regarded as an "ear." The Mole Cricket is nearly related to crickets and grasshoppers and is a very powerful burrower.

invisible in ordinary conditions of microscopic work. Professor Bayliss writes: "The central rays of the illuminating beam are cut out by means of a stop, and the peripheral rays are reflected by a parabolic surface so as to meet in a point in the object under examination; they cross at such an angle as to pass outside the field of the objective in use, which only picks up the light refracted, or diffracted, from structures in the preparation." The dark-ground illumination brings out features which are invisible in the ordinary direct illumination.

The essential parts of a microscope are, as we have seen, (1) the objective for obtaining the first magnified image of the object; (2) the ocular for further enlarging that image and transmitting it to the observer's eye; and (3) the sub-stage condenser for illuminating the object with a cone of light. Now, in modern times, there have been numerous detailed improvements in these parts, e.g. in the quality of the glass used in making the lenses; and a present-day microscope is certainly a very perfect instrument. Indeed, unless some new idea is discovered, such as those behind the ultra-microscope and dark-ground illumination, it does not seem likely that great advances in technical microscopy can be made. The reason for this statement is to be found in the optical limitations of the instrument. The use of the microscope is not mainly magnification but *resolution*. "By resolution," says Mr. J. E. Barnard, "is meant the power the objective has of separating and forming correct images of fine detail." Unless we see more of the intimate structure, the magnification in itself does not greatly avail. It does not help us to understand the thing better. Now there are two factors that determine this "resolving" power of the microscope. The first is what is called the "numerical aperture" of the lens, which means, in a general way, the number of divergent rays of light that the curvature of the lens will allow to impinge upon it. Lenses of high magnifying power are so small that they admit only a very small beam of light. Thus what is gained

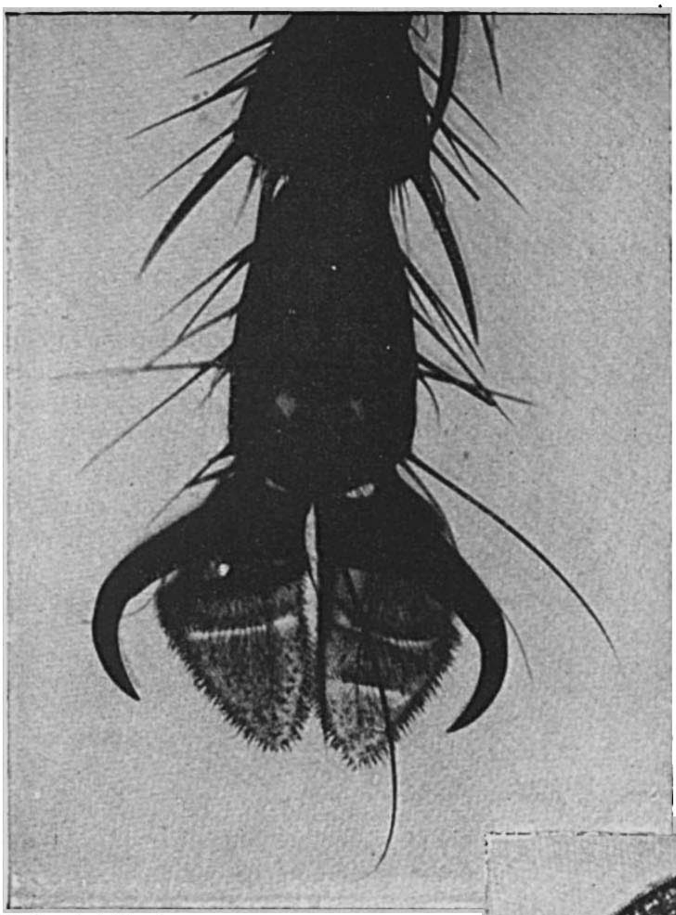

Photo: J. J. Ward.

FOOT OF A HOUSE-FLY.

Showing two claws for gripping minute roughnesses and, between the claws, a double pad or cushion which is used in climbing up a smooth surface like a window-pane. The probability is that a moist secretion from the pad helps the adhesion. There is also very close apposition of the cushion to the smooth surface, and some say a partial vacuum is formed. But we are not quite sure how a fly runs up a window-pane—one of the most familiar sights in the world.

in magnifying power may be lost because of deficient illumination. A pretty device to increase the income of light in these high-power lenses was the "immersion lens," made of such a curvature that when the lens was focussed down into a drop of oil, or some other liquid, placed over the object on the slide, it received light from all sides. The drop into which the lens is focussed down or "immersed" greatly increases the illumination of a lens with high magnifying power. This method has enhanced the value of the microscope as an instrument that analyses structure, or, in other words, that discloses the intimate architecture of things. But the main point is that the "numerical aperture" of even the oil-immersion objective has at the present time reached its practical limit.

Yet there is a second factor, and that is the wave-length of the light-rays that impinge from the mirror and condenser on the object on the slide. But here again there is a limit, for, as Professor Bayliss tersely puts it: "Any object smaller than half the wave length of the light by which it is illuminated cannot be seen in its true form and size owing to diffraction. Hereby is set a limit to microscopic observation." These are difficult matters, but the important point is that there are practical limits to what the microscope can do in the way of magnification and "resolution."

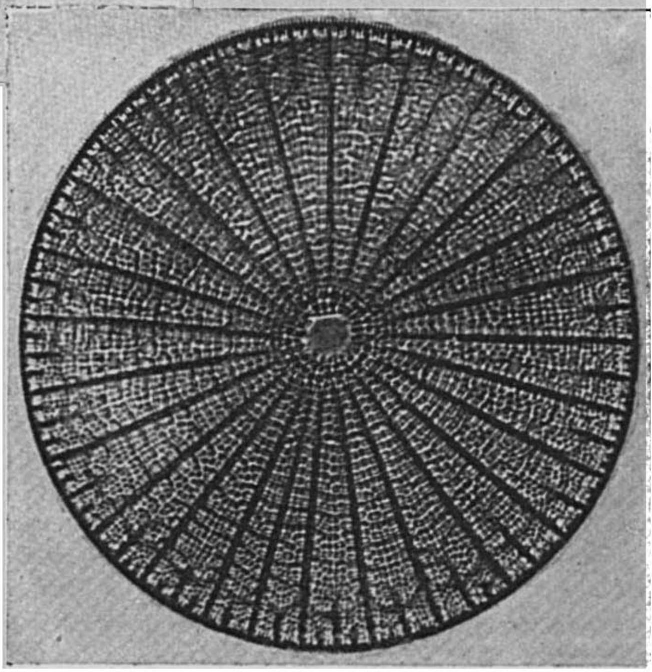

Photo: J. J. Ward.

THE BEAUTIFUL PATTERN ON THE MICROSCOPIC FLINTY SHELL OF A DIATOM (*ARACHNOIDISCUS EHRENBERGI*), A KIND OF UNICELLULAR PLANT.

Two hundred of these cells placed side by side would scarcely extend one inch. It is not known that there is any utility in these beautiful markings. They are expressions of rhythmic orderly growth.

But Mr. J. E. Barnard has recently made an interesting step forward by using an illuminant such as a mercury vapour lamp, which is rich in blue and violet radiations. It may also be practicable to utilise invisible radiations in the ultra-violet, which would further increase the microscope's resolving power. As things are at present, the limit of useful magnification is somewhere about 800 diameters.

We cannot close this article without referring to a very different subject—namely, the extraordinary beauty of many microscopic objects. There are endless "beauty feasts" to be found in the architecture of the shells of diatoms, Foraminifera, and Radiolarians; in the structure of the outside of pollen-grains and butterflies' eggs; in the zoned internal structure of the stems of plants and the spines of sea-urchins; in the sculpturing of the scales on butterflies' wings and the multitudinous hexagons of their eyes; in the strange hairs on many a leaf and the elegant branching of zoophytes; in the intricate section of a rock and the variety of snow crystals. Of microscopic beauty there is no end.

Beauty of Microscopic Structure.

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