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THE  
MICROSCOPIC CABINET

OF  
SELECT ANIMATED OBJECTS ;

WITH A DESCRIPTION OF THE  
JEWEL AND DOUBLET MICROSCOPE,  
TEST OBJECTS, &c.

---

TO WHICH ARE SUBJOINED,  
MEMOIRS ON THE VERIFICATION  
OF  
MICROSCOPIC PHENOMENA,  
AND AN  
EXACT METHOD OF APPRECIATING THE QUALITY OF MICROSCOPES AND  
ENGISCOPIES.—BY C. R. GORING, M.D.

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*Illustrated, from Original Drawings, by Thirteen coloured Plates and numerous  
Engravings on Wood.*

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BY ANDREW PRITCHARD.

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LONDON :  
WHITTAKER, TREACHER, AND ARNOT, AVE-MARIA-LANE.

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1832.

RECENTLY PUBLISHED, BY THE SAME,

In royal 8vo. price 10s. boards,

# MICROSCOPIC ILLUSTRATIONS

OF

A FEW NEW, POPULAR, AND DIVERTING

LIVING OBJECTS ;

WITH THEIR NATURAL HISTORY, &c.

CONJOINED WITH

DESCRIPTIONS OF THE LATEST IMPROVEMENTS IN THE  
NEW MICROSCOPES ;

THE BEST METHODS OF CONSTRUCTING THEIR MOUNTINGS,  
APPARATUS, &c.

AND

INSTRUCTIONS FOR USING THEM.

*Illustrated by highly-finished coloured Engravings, from Magnified Drawings of the  
Actual Living Subjects.*

---

BY C. R. GORING, M.D. & ANDREW PRITCHARD,

HON. MEM. SOC. ARTS, EDIN. &c.

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THE FOLLOWING OPINIONS OF THIS WORK ARE SELECTED  
FROM THE PUBLIC JOURNALS.

“ Impressed as we are with the high importance of this branch of science, and with the great value of the improvements which these gentlemen have introduced, we looked forward with the most sanguine expectations \* \* and have now now no hesitation in stating it as our opinion, that Dr. G. and Mr. P. have both accomplished their difficult tasks with the greatest success. The coloured engravings are executed in such a masterly manner that they will themselves bear to be seen by the microscope.”

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TO HIS GRACE THE  
DUKE OF BUCKINGHAM & CHANDOS,

LORD LIEUTENANT and CUST. ROT. of the COUNTY of BUCKS,

&c. &c. &c.

A ZEALOUS CULTIVATOR OF SCIENCE, AND MAGNIFICENT  
PATRON OF THE FINE ARTS,

THIS WORK

ON

MICROSCOPIC SCIENCE,

IS,

WITH HIS GRACE'S KIND PERMISSION,

RESPECTFULLY DEDICATED,

BY THE

AUTHOR.



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## P R E F A C E.

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THE study of the works of the Creator can need no apology ; of whatever class or dimension, they evince the same infinite power and wisdom in their production. Some portions, it is true, present greater diversities in their forms, and enable us to penetrate deeper into their structure and organization, than others—displaying more beauty in their forms and colouring—more delicacy—and a higher degree of finishing. In these respects, the specimens selected for this work are not exceeded by any.

While almost every part of nature has within the last few years been explored, and our knowledge augmented, the living objects described in this work, have been nearly overlooked by naturalists, and such representations as we possess of them are delineated in the most incorrect and grotesque manner that can well be conceived ; for these reasons the Author has presumed to call the attention of the public to this interesting branch of natural history.

The first thirteen chapters are devoted to

the description of the Aquatic Larvæ of Insects, Crustacea, and Animalcules. The reader must consider them merely as popular outlines of their general characters, chiefly collected from the Author's own observations. This was considered preferable to a scientific display of terms, or a lengthened history, which many persons might not be disposed to follow. To each of these classes are prefixed, for the information of the general reader, a few cursory remarks on their arrangement, &c.

The descriptions of the Living Objects are followed by that of the Jewelled Microscopes. This chapter is succeeded by an account of a Microscope which has been found, from actual experience, to be well suited for all general purposes\*: its construction is simple, it is easily managed, and with ordinary care is not liable to derangement.

The importance of certain objects in determining the qualities of Microscopes and Engiscopes † is now duly acknowledged, and as no complete account of these *Tests* at present exists, it is hoped that a full description of them

\* It is proper to notice that the coloured drawings in this work were made under a microscope, not an engiscope, which is a sufficient guarantee of what may be done with that instrument.

† See definition of this term, page 102.

will be found useful: but to render the subject complete in a scientific view, Dr. Goring has given a Memoir on an *Exact Method* of ascertaining the Quality of Microscopes and En-giscopes. Of this method, which has hitherto been a secret known only to very few persons, its value may be somewhat appreciated when it is stated that no perfect achromatic microscope has been produced without it; and although they have been known to the public some time, and profound mathematicians have assiduously employed their talents in the investigation of the conditions necessary for obtaining *achromatism* and *aplanatism*, yet no *perfect* instrument has been produced excepting by the means given in this memoir\*. The other memoir by Dr. Goring, "On the Verification of Microscopic Phenomena," contains the sum and substance of microscopic science: it is condensed into short aphorisms, but I think will be found on attentive perusal to contain all that is essential to a practical knowledge of the subject.

In the concluding chapter much useful information of a minor kind is given, which it is presumed will be found highly valuable to the student, as it is the result of practical experience.

It will be seen by reference to the title-page

\* The value of this memoir in my opinion is augmented when we consider that *effective* achromatic object-glasses for microscopes owe their existence to Dr. Goring.

that this work is written by two individuals, and that the papers of each are distinct and unconnected with each other. On this account it is possible that some slight repetitions will occur, and perhaps trifling discrepancies; but it was thought that the most effectual way of giving the public the benefit of the experience and knowledge of both (such as it is) would be to express these opinions candidly and sincerely, without comparing notes with each other.

The drawings, and most of the manuscript, have been ready for publication some time, and it was intended to appear soon after the "Microscopic Illustrations\*," had not the avocations of the Author prevented him: this delay was also increased by a consideration of the little encouragement bestowed upon such works, necessarily of an expensive description; for in the present forlorn state of scientific literature it is rare that the author gets "a return of his outlay," and indeed very often loses one half, the demand for illustrated scientific books being less than for that of any other class: it is therefore in vain for an author to expect pecuniary remuneration for his time and labour. All that is desired for this work is

\* Till the publication of that work and the writings of Dr. Goring, nothing of practical importance had appeared for the last half century, except some papers by Sir D. Brewster; it is therefore but just to infer, that the great attention now bestowed upon the microscope by scientific men, is occasioned through them, or at least in part.

that it may receive sufficient patronage to return its expenses. Should this be the case, and it have the effect of directing the attention of the public to this department of science, in an equivalent proportion to the former work, it is probable that the Author may again trespass on its indulgence by a further publication, with a view of comprehending every thing worthy of being recorded which modern discoveries and improvements in Microscopes and Microscopic Science may afford, so that it may, with the present work and the “*Microscopic Illustrations,*” complete the subject.

In conclusion the Author requests some indulgence for any “*want of finish*” in his writings, his avocations not permitting him to devote the attention he could wish in their execution. The work being chiefly the result of observation and experience, he is induced to believe the public will grant this favour, there being so few *real practical* works on scientific subjects—in confirmation of which it may be sufficient to mention that England does not at the present time possess any *regular practical* treatise on Optical Instruments, although she derives so many important advantages from them.

PICKET-STREET, STRAND,

*April* 1832.

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THE following four chapters are descriptions of insects in the larva or pupa state. To those who are unacquainted with these subjects it may not be amiss to give a brief outline of their general characters, though it must be borne in mind, in the perusal of this work, that it is not intended to treat the subjects on natural history technically, but familiarly.

The term insect has been greatly restricted by modern naturalists. Many groups, which Linnæus and others included under that name, have been separated from them, as spiders (*Arachnoidea*); crustacea; mites; (*Acari*); and centipedes (*Myriapoda* \*); which were included among the apterous insects. This rejection has been made from a more accurate examination of their internal organization, and the word insect is now confined to animals whose respiration is performed by two tracheæ, or air-pipes, which run parallel to each other, the whole length of the body occasionally sending off ramifications. These receive and emit the air through apertures (*stigmata*), placed at intervals along the sides, &c. As air-vessels pervade the body, a complete circulation of a vital fluid is not required, its æration being effected by air carried to it, and is not, as in the larger animals (*vertebrata*),

\* These are still included (but in a distinct order) by Cuvier.

collected into one great vessel, and then subjected to its action.

The nervous system is composed of two cords, united at certain distances, where an enlargement (*ganglion*) occurs, which sends off various branches to the surrounding parts. The head in insects is distinctly separated from the body, and is furnished with two antennæ, or horns. They have six articulated thoracic feet, and all of them, except the orders *Thysanura* and *Anoplura* \*, of Dr. Leach, undergo certain changes or metamorphoses (more or less complete) before they arrive at their final or perfect state, in which alone they are capable of propagation. In the first state they are called Larvæ, worms or caterpillars; the second, pupæ or crysalides, in which they are mostly inactive; and the last is the imago, or perfect insect. Their distinctive characters in this latter condition are the basis on which entomologists have classified them into orders, sections, families, genera, and species. The most minute differences have been recorded of the perfect insect; but, in the first or larva state, the descriptions are so meagre, especially of the aquatic, that, in many instances, it is impossible to ascertain the precise species to which they belong. This, however, is of little import in the view here taken of them.

\* The order *Parasita* of Cuvier and Latreille.

## CHAPTER I.

*Larva of a small Species of Dytiscus, popularly called the Crocodile.*

THE appellation of crocodile to this curious larva has arisen from its general resemblance in colour and form to that terrific amphibious animal; the sudden springs and starts which it makes assimilate it also in manners. The scientific name of the genus to which this aquatic beetle belongs is *Dytiscus*, a term derived from their habits; all the species in their perfect state being observed to dive or plunge into their watery element when approached.

The eggs from which these larvæ are produced may be found, during the spring and summer, adhering to aquatic plants, and to confervæ growing near the surface of the water. They are enclosed in a species of bag or cocoon, rather smaller than the common pea, of a dusky white colour, and are prevented from floating away with the current by a slender filament, which attaches them to the herbage. If a few of these eggs are deposited in a vessel of water, and exposed to the sun, in favourable weather, they will be hatched

in a few days. When the young first make their appearance they are of a dark colour, and remarkable active. At this period, if about half a dozen be put into an aquatic live-box, with a sprig of moss, as directed in the concluding chapter, they will afford an interesting spectacle under the microscope. When a few days old, they shed their skin, and, during the operation, which occupies some time, they are almost colourless, especially about the head; their activity forsakes them, and they abstain from food. As they recover, they gradually assume their variegated tints. If they are now supplied with one or two small blood-worms (larvæ of the *chironomus plumosus*) and placed under the microscope, an alternating motion of the glottis will be perceived, and, as the digestion of the coloured fluids of the worm proceeds, the alimentary canal, the different vessels, and their ramifications, will acquire distinct colours, forming a strong contrast with the transparent integuments surrounding them.

The difficulty of distinguishing between the ova of different species of aquatic insects, and the trouble of discovering them, by reason of their close adherence to the water-plants, render it advisable to collect the larvæ rather than the eggs, when desired merely as a microscopic object. For this purpose, the vegetation growing at the bottom and sides of ponds, marshes, and slowly-running brooks, should be carefully collected and laid on the banks, or, which is preferable, on a white cloth spread to receive it, and then carefully examined. They often creep into small crevices and holes in the roots and branches, to avoid discovery.

At other times they will remain motionless on a part of the plant of their own colour, and thus endeavour to evade detection. As they move with great rapidity when disturbed, they must be taken up quickly with a feather, or the net-spoon (see concluding Chapter), and put into a reservoir.

The disposition of these carnivorous larvæ is fierce and cruel; hence, if they are inadvertently placed in a vessel with other aquatic insects, the collector will find, to his regret, the latter either destroyed or injured.

The magnified view of this larvæ, represented in plate 1, was taken soon after it had cast its first exuvia or skin, a time at which its vessels and internal organization are, on account of the thinness and transparency of its recently-developed skin, more distinctly perceptible than at any other period of this creature's existence. Its pre-eminent qualities as a microscopic object are now exhibited in the greatest perfection, its anatomical structure is more delicate and beautiful than in any other larva of the Coleoptera order, and, although its weapons of attack are not so formidable in their appearance as in some larger species, yet the distinct manner in which its internal functions are displayed, more than counterbalance this trifling inferiority.

Before entering on a description of the drawing, I should remark, that no figure of this species has

appeared in print, at least in the state here given\*. All its internal structure, as exhibited in the living subject, is delineated with the utmost fidelity; and so minutely are the details preserved, that a magnifier is necessary to show them.

This larva is armed with a pair of bent forceps or mandibles, as shewn in the engraving; they move horizontally, and are long enough to cross each other when closed; they are of a bright chesnut colour, assuming a deeper hue towards the points, which are hard and sharp †. With these weapons it seizes its prey, and, having brought it towards the mouth, it commences the operation of exhausting the juices from that portion within its grasp, having previously made an incision with the mandibles. This larva does not kill its victim before eating it, unless compelled by the superior strength of its prey, but, taking hold of any part indiscriminately, it devours that portion while the animal is alive. Having so done, if its victim be the larva of a gnat, or other soft animal, it turns it round, and thus brings a fresh portion within its grasp,—alternately opening and closing each mandible, till the whole is consumed, except the skin. If

\* In vol. 4, plate 31, of Reaumur's *Memoirs of Insects*, is represented a larva of a *Dytiscus*, something like this, but devoid of any internal display. Also Moses Harris has a figure, in plate 26 of his *Work on Insects*, of a species apparently not very remote from this.

† In some of the larger species, according to Swammerdam, the mandibles are perforated by an oblong hole, or slit, by which they imbibe the juices of their prey.

the prey is a strong crustaceous animal, it seizes it, and either holds it for some time stationary, till it is exhausted, or nips off, at successive grasps, all its limbs, turns it upon its back, and imbibes its contents. The fore part of the head is finely serrated, as shewn in the drawing; but, whether these processes perform the office of teeth, I am unable to determine. The palpi, or feelers, situated about the mouth, are flexible, and composed of four articulations, as shewn at *a*; they are very transparent, especially about the joints. The eyes are disposed in two clusters of six each; in some specimens they are placed at equal distances from each other, forming a circle; while, in others, three or four are blended in one group, and the rest a little separated. The head, when viewed laterally, is flat, and slightly tapering, and is so transparent in the infant larva, that the palpi are seen through it. It is connected with the first segment or prothorax by flexible muscles, which allow it to turn horizontally or vertically; the latter, however, is the most usual motion. In the thorax or corselet, composed of the three anterior segments, are placed the ganglia, or nervous cords, terminated by three loops. They are very perceptible in the young larva, as may be seen in the drawing, and are of a brighter colour than the other parts. The two large vessels, or tracheæ, originating in the head, here attain their greatest development, and proceed along the succeeding annuli forming the abdomen, to the other extremity, where they unite and terminate. During the progress of these air tubes they send off numerous ramified branches, as displayed in the engraving. The inner

pair of vessels commence at the ganglia, and lose themselves in the third segment from the tail. In the penultimate annulus is situated the pulsatory organ, which by some Zootomists is considered to be the true heart of insects, but, from the examination of Cuvier and others, it appears to have no communication with the main vessels of the insect, and hence cannot be an organ for circulation. It is termed by him the "dorsal vessel," and its function, according to Marcel de Serres, is the secretion of fat, which is afterwards elaborated in the adipose tissue that envelopes it.

To the under-side of the thorax are attached six transparent crustaceous legs, margined with fine bristles, placed at short intervals, and having strong spines at their articulations. They are also terminated by strong ciliated claws, and a delicate ramified vessel runs through their whole length; the tail is composed of two processes or spines, having several smaller ones branching from them. When one of the larger spines is destroyed, I have observed it to be replaced by another, which, however, seldom attains the size of the former.

These larvæ feed on almost every other kind, and, in their turn, are devoured by the larger water-beetles, (*dytiscus marginalis* and *semistriatus*.) Their favourite food is the larvæ of the ephemera \* and gnat. On the other hand, even when kept without food, they refuse monoculi, preferring to feed on each other.

\* An elegant species of this larva is figured in the "Microscopic Illustrations."

From this propensity, if confined in separate vessels for a few days, and afterwards put together, the most fierce and obstinate combats ensue. In these engagements the little animals display all the courage, skill, and caution of two well-trained pugilists, turning about with extended jaws, till a fit opportunity occurs for attack. Their courage is such, that I have seen a small one seize another twice its size, and hold it for several seconds. When, however, they are of equal size, and exceedingly pressed by hunger, the contest will be continued for several minutes, and, to the lovers of such sports, will be found not inferior to any, and, when viewed on the screen of a solar microscope, several spectators can witness it at the same time, and make their observations and remarks as the battle proceeds.

They move with great rapidity, both in running and swimming, and in the latter they are assisted by their tails. In rising, which they do occasionally for the purpose of respiration, they seem to beat the water, and sometimes hold their tail above its surface, to admit fresh portions of air into the tracheæ, by the stigmata or orifices near that part. In warm weather they creep up the stalks of plants, and remain near the surface of the water, delighted to bask in the genial rays of the sun, while in cold weather they retire to the bottom, concealing themselves in the mud, where they remain in an almost torpid state.

As they advance to their full size their motions become sluggish, and if at this time they should be in-

fested, as is very common, with the clustered Bell-polype (*Vorticella Convolaria*,) these parasitical animalcules will rapidly increase in number, to the great annoyance of the larvæ. In a similar manner, when the larvæ are kept in vessels too small to permit them to take sufficient exercise, the Bell-polype become so numerous as to occasion disease. As a microscopic object, however, these parasites add materially to the interesting characters which it displays. Their appearance to the unassisted eye, resembles a species of down, or mildew, surrounding the animal. If touched with the point of a feather, the mass becomes whiter and diminishes in magnitude. The cause of this change is readily discovered under the microscope. In the first instance, the parasites were extended at the extremity of the filament that attaches them to the animal, and consequently dispersed over an extensive surface; in the latter case, they approach the animal by bending or coiling the connecting filament, and thus reducing the size of the mass.

Our knowledge of the transformation of these aquatic coleoptera is very limited; Ræsel and Swammerdam are the only naturalists that have left any record of their change; and even their accounts are partly conjectural. They state, that the larvæ when mature, bury themselves in an oval cavity formed in the earth on the sides of their natal ponds or marshes, and there undergo their first change into a chrysalis, and after remaining a proper time in this quiescent state, emerge from the earth a perfect beetle. The appearance of the complete insect has no resemblance to that of the larva;

indeed, so different are they in the two states, that not only have casual observers been deceived, but Dr. Shaw informs us, that even the early writers on Entomology have classed the larvæ with fresh water shrimps, under the name of *Squillæ aquaticæ*.

The body of the perfect insect is short, and furnished with wings, covered by shelly cases (*elytra*.) It has two compound eyes, and is amphibious; it, however, seldom takes flight or leaves the water in the day-time. The feet, which are long, have the tarsi composed of five articulations. The four anterior feet of the males in the larger species (*marginalis*,) are furnished with spongy cups. They swim with great rapidity by the assistance of the hinder legs, and being sharp-sighted, pursue every aquatic insect within their reach.

Modern entomologists have divided these pentameorous insects into several sub-genera, and enumerated various species in the *perfect* state, the systematic distinctions of which it is not the province of this work to describe. The difference between the smaller species (which are numerous,) in the larva state, is unknown. I am inclined to believe that this subject is the *Dytiscus minutus* of Linné, or the *Laccophilus minutus* of Dr. Leach.

## CHAPTER II.

*Larva of a Species of small Gnat or Tipula, hitherto undescribed.*

THIS creature presents a peculiarity in structure, which distinguishes it from any other with which I am acquainted. Its singularity consists in its very distinct division into annuli, and in its strong corded appearance, which, together with its beautiful star-like tail, small dark eyes, perviosity to light and elegant evolutions, render it a choice subject for microscopic examination.

These larvæ are generally met with in ponds and ditches, in which there is an abundance of healthy vegetation, creeping among the stalks of aquatic plants, but particularly in clear waters covered with duck-weed.

In collecting them, a quantity of the herbage should be taken with a cloth-net, or bason, and put into a deep vessel of water. In a few minutes they will disentangle themselves from the plants, and may

then be removed to a convenient reservoir, or they may be separated from aquatic plants without an additional vessel, by spreading the plants on a white cloth, placed in the sun. In a few seconds they will creep out, and may be taken up on the point of a feather. Of these two methods the first is the best; for, unless great care be taken in removing them with the feather in the latter method, their delicate bodies will be injured. When it is desirable to preserve them alive for some time, a portion of the plant must be kept along with them: this will furnish them with food, as there is generally an abundance of animalcules about their roots.

They may be caught at most seasons of the year, but in severe cold weather, they descend to the bottom of the water, and remain inactive.

Plate 2 exhibits a magnified view of one of these larva in a position that it frequently assumes, and also one of its natural size. When recently taken, in a healthy state, it exhibits the colours shewn in the drawing, which, however, it gradually loses, if kept in a small vessel. It is composed of twelve segments; the first is connected to the head, by a ring or neck, shorter than the annuli. When the larva turns its head sideways this intermediate link enfolds itself within the first segment, without disturbing its position. The skin of this animal is covered with a series of longitudinal stripes or cords, as shewn in the engraving. From this structure it happens, that, when the larva twists or turns part of its body, the segments

in those places become less transparent, the longitudinal lines assuming a spiral direction, and presenting the appearance of a many-threaded screw, while the under and upper ones, crossing each other, stop a portion of the light. On reassuming its straight position, its transparency is instantly restored. These alternately opaque and pellucid appearances seem, at first glance, to arise from a power in the creature to change its colour, but explained as above, which may be verified by means of a strong magnifier, the mystery vanishes, and we see how admirably Nature has adapted its structure for the purposes intended; for, were it not for these longitudinal cords, in turning or twisting, a considerable pressure, and consequent injury, would have been sustained by its internal parts.

The head is furnished with two pair of eyes; the anterior ones, which are situated near the mouth, are smaller than the others. The two large vessels, running the whole length of the larva, have their origin in the head, and the ramification commences near the eyes. Throughout the animal a peristaltic motion is perceptible; its interior appears to be one large canal, having the vessels running along each side of it; the tail consists of nine strong bristles, each tapering to a point; they are transparent, and, when viewed under a deep magnifier, appear like hollow tubes, without striæ or markings of any kind. The animal has the power of closing all these bristles into a bundle, and, from the instantaneous manner in which this is accomplished, casual observers have supposed them sheathed within the last segment of the body.

As general microscopic objects, few will be found to afford more amusement ; placed in an aquatic live-box, with a sprig of moss or confervæ, they form an entertaining spectacle, entwining themselves among the moss, and darting about in various directions, withdrawing and spreading out the tail, &c. If put in the same aquatic slider with the larva of a dytiscus, the latter may be seen in pursuit of them, and destroying all within its reach.

They seldom require more amplification than that of a single lens of a quarter of an inch focus (viz. forty times linear measure.) If the instrument is a compound one, or engiscope, and a sprig of moss is employed, it must be fixed in an *inverted* position, by a little cement or sealing-wax in the aquatic slider, in order to appear erect through that instrument.

I am not aware of any account of the transformation of this insect in print ; indeed, some consider it as a species of nais, which does not undergo any metamorphosis. From my own observations, I find the larvæ change to pupæ in the month of May. In this state it is shorter than in the former, and has some resemblance to the pupa of the Tipulidan gnat (*Corethra plumicornis*), figured in the Microscopic Illustrations. It is, however, devoid of its membraneous tail, and differs also about the head. When about to change, they fix themselves in the crevices of some floating body, to assist them in casting their exuvæ. The pupæ are rather inactive, and float near the surface of the water, with their head erect. Immedi-

ately after the transformation they are of a pale colour, but in a few days they become of a deep brown, and exhibit a row of spiraculæ, or breathing holes, along each side. In this state they may be preserved between glass and talc, as also the larvæ, and the skins which they shed. The latter are extremely diaphanous, and the former furnish excellent substitutes when living specimens cannot be procured.

## CHAPTER III.

*The Larva and Pupa of a beautiful Species of  
Libellula or Dragon Fly.*

*Libellula grandis.*—*Linné.*

*Æshna grandis.*—*Fabr. & Leach.*

AMONG the numerous species of the family Libellulidæ, the larva and pupa of that which forms the subject of these remarks, stand pre-eminent as objects for microscopic examination, both for the elegance of their form, and the variety and brilliancy of the tints which adorn them ; while the possession of a sufficient transparency to exhibit a portion of their internal organization, and a distinct view of the ramifications of the air-vessels (*tracheæ*), which pervade the delicately margined appendages of their tail, together with the peculiar structure of their weapons and manducatory organs, render them curious and highly interesting examples of the diversified contrivances that nature displays in the insect creation.

The eggs are deposited in the water by the parent fly, who, hovering over a selected spot, immerses the lower extremity of her body, and deposits, at intervals, a single egg. These eggs, when examined by

a microscope, appear of an oblong form, having the fore part terminated in a point of a blackish colour\*. The young, when they first emerge from the ova, are very small, indeed almost imperceptible. In a few days they grow to the length of the tenth of an inch, and cast their exuviæ the first time. I have taken them of this size, in the months of June and July, sporting in ponds containing healthy aquatic plants. If these creatures be examined at this period, their heads will be found much larger, in proportion to the body, than at a more advanced stage of their growth. Indeed, by unassisted vision, they now appear like dark specks, having a tail attached to them. They grow rapidly if well supplied with food, and, when about two-tenths of an inch long, begin to exhibit all the courage and ferocity of the mature larva, attacking, with extended jaws, beings ten times their own size, and, when incommoded, even destroying those of their own species.

The ramifications of the two large vessels (*Tracheæ*), running along the back, are now distinctly developed in the head, and a larger branch to each eye. These vessels are double, and each separates into two at the commencement of the second segment or *mesothorax*, but they afterwards unite a little lower down, first sending out a branch to each of the middle pair of legs, which have their insertion in this segment. The first pair of wings subsequently emanate from this part, which may account for the division of these ves-

\* Swammerdam's Book of Nature, p. 98.

sels. The re-united vessels proceed onward to the posterior extremity of the body, and then beautifully ramify over the three membraneous appendages of the tail, each appendage being furnished with a branch from *both* the tracheæ. The larva of the ephemera marginata have a series of smaller leaf-like appendages, on each side of the body (see Microscopic Illustrations, figure 7), which are considered to perform the office of gills. It is therefore exceedingly probable that these tails of the libellula, which are similar in appearance, perform the same office, although they do not exhibit that vibratory motion which is produced by the ephemera.

In the infant larva these caudal appendages are not developed, but consist of three tubular spines, with smaller ones proceeding from them. The first and second exuvia which it sheds exhibits the structure of these spines very distinctly, and, from its transparency, allows of considerable amplification.

The larvæ of the libellula depressa, and some other species, are devoid of these leaf-like appendages. They possess a curious hydraulic apparatus, which *Reaumur* \* informs us they employ for propelling themselves, and also for respiration. This apparatus, which forms the cavity of the lower part of the abdomen, it can dilate or contract at pleasure. When closed by the muscular action of the larva, the water with which it was previously filled is expelled, and,

\* Reaumur Mem. Insects, Vol. VI.

by its action against the stationary fluid, the creature is urged forward ; when again dilated, a fresh portion of water is admitted, and the *pumping* is repeated, at the will of the creature. The anatomy of these parts, by which the air is absorbed for the purpose of respiration, is briefly described by Kirby and Spence, in Vol. IV. p. 67, of their Introduction.



The young larvæ of the *Libellula grandis* swim with great activity, inflecting the body laterally as they advance, and assuming the position exhibited in the annexed sketch, the third pair of legs being brought near the body by the resistance of the water.

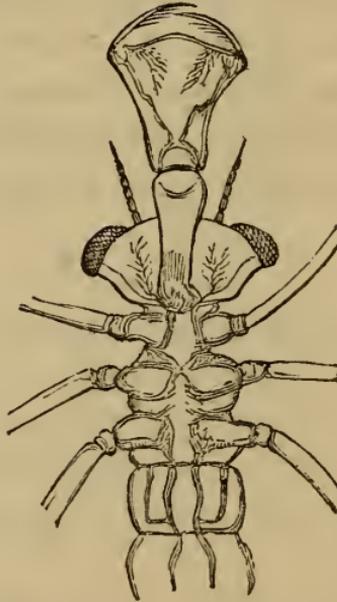
This larva, which is here represented magnified, is about two-tenths of an inch long; its antennæ are straight and stiff, and the eyes are much smaller in proportion to the size of the head than at a later period of its existence. As it increases in magnitude, the wings are gradually developed, and it is then termed the *pupa*. In proportion as it approaches its transmutation into the perfect fly, it becomes sluggish in its motions, and often remains stationary on the stalks of plants, with its head directed downwards, eluding observation, from its colour approximating to that of the plant on which it rests. At this period it evinces much cunning in the gratification of its predaceous appetite, which ceases a short time previous to its change.

During its growth it casts its skin several times. These exuviæ are beautiful objects for the microscope, as they are quite transparent, and exhibit the prominencies, depressions, and markings of every member, being, in fact, a perfect mould of the creature.

The magnified representation of this libellula, given in Plate 3, was taken just before its transformation to the perfect fly. This period was selected as the brilliant colours which adorn it had attained their maximum of intensity, and the immature wings, with their envelope, were most perceptible. It measured eight-tenths of an inch in length from the tip of the antennæ to the end of the tail. As the details are accurately preserved in the engraving, it would be superfluous to recapitulate the form and number of its members, when a more accurate idea can be obtained

by inspection, observing, that, as the drawing is a side view, the broad figure of the head (see the sketch) is foreshortened.

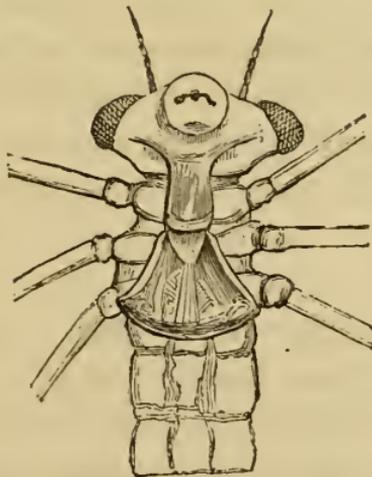
As the most curious part about these larvæ, at least as regards their external organization, cannot be well shewn in the drawing, it is requisite to describe it here, for the illustration of which I have made two sketches of the different parts.



The mouth is situated on the inferior surface of the head, and is concealed from view by a peculiar piece of apparatus, denominated by naturalists the *mask*; it is composed of several pieces, and its structure varies in different species: in the present one it consists of two corneous plates, terminated by a pair of forceps. The form of these plates, extended outwards, is shewn in the annexed figure, which represents a magnified *nether-view* of the head and thorax, and the first two integuments of the abdomen.

The first piece of this manducatory instrument is attached to the head, near the prothorax, by a strong joint; this plate, in its natural position, is thrown back, and covered by the second plate, to which it is attached by a joint; it is convex, externally, but concave next the mouth, whereby the juices of its prey are more easily conducted to it.

In the following view the parts are thrown back, to show the mouth and internal structure of the plates; the forceps, which terminates the second plate lying upon it, are not very distinctly seen. It must be remembered, however, that this position is never assumed by the animal.



In the *libellula depressa*, instead of a pair of forcipated jaws attached to the extremity of the second plate, there is a pair of triangular plates, each piece or plate being attached by one of its angles, and forming a joint, which, when closed, permits the op-

posite sides of the triangles to meet, and, being dentated along the sides in contact, they fit into each other.

The use of this curious organ is for seizing their prey, a purpose which they effect with much caution, stealing upon it till it is completely within their devouring grasp, then seizing it with their fangs, and, bringing it to their mouth, they speedily devour it. They are very courageous. I have sometimes seen them, when pressed by hunger, attack larvæ of the *Dytisci* of nearly double their own size. If kept in a glass jar without food, they will devour each other, first destroying the tails. The ravages they commit on their less offensive neighbours would soon exterminate many genera, if they were as prolific as they are voracious. The all-wise Creator has limited the increase of these carnassial insects, the perfect fly only laying about two dozen eggs, while the number produced by some herbaceous tribes amount to as many thousand.

The colour of these larvæ when young is ferruginous, with markings, at intervals, of a deeper brown. As they increase in size, the wings make their appearance, and the head begins to assume a brilliant variegated transparent green; after this, the body gradually exhibits the same hue, as shewn in the drawing. The ramifications in the tail, and the two vessels running along the body, assume the rich warm colouring there shewn—an effect which is greatly assisted by being contrasted with the transparency of the sur-

rounding parts. From the splendour of these tints, and their carnivorous habits, they have obtained the name of *King-fishers*.

The eyes of these creatures are very prominent, both in the larva and final state; and from their size and curious structure, afford excellent objects for microscopic examination. In the perfect insect they have been a fruitful object of study to naturalists. They are immoveably fixed on each side of the head, and are compound, each consisting of numerous distinct smaller ones. They are externally convex, and it has been observed by Latreille, that the eyes of insects in general, are "by so much the more convex as the insect is more carnassial." Under a low magnifier the surface appears reticulated, which on minute examination, is found to arise from hexagonal cells; each forming a separate eye. Lceuwenhoek states, that he has counted twelve thousand in one individual. The cornea consists of lenses possessing all the properties of those made of the usual transparent media, forming an image of bodies in the same manner, and capable of being employed as magnifiers. These interesting facts may be observed, by placing any object under the eye of the insect, and viewing it in a microscope, when each of the minute lenses of the eye will form an inverted image of the object employed. By separating one of these lenses and forming an inverted telescope with it, using a magnifier of low power as an eye glass, and the eye of the insect as the object-glass, and adjusting their distance, a distinct view of objects at a moderate distance may be readily obtained. In this way,

the focus of the eye may be found, as in the case of common lenses; if we know the exact power of the eye-glass:—for example, if this magnifier is the one-twentieth of an inch, and on looking through this inverted telescope at the window bars, you find (*keeping both eyes open*) that three of the squares of glass are exactly equal in length and breadth to one seen by the other eye at the same time without the telescope, the two images being brought apparently to overlap each other, the focal length of the eye under examination, will be one-third of the eye-glass, or one-sixtieth of an inch. I regret that I have not measured the focal length of the eye we have been describing, but in the common house fly (*musca domestica*), the lenses are each about the one hundredth of an inch focus. In preparing the compound eyes of insects, it is requisite to soak them for some days in water, to render them supple, and then to wash out the black pulp (*rete mucosum*), with a camel's hair pencil, when they may be mounted between slips of glass, or in ivory sliders, unless it be intended to measure the exact focus, when all pressure must be avoided\*.

To give a description of all the minute parts of this larva that would interest a true lover of nature, would

\* It appears, from some recent dissections of compound eyes, that the plates which compose the cornea are distinct lenses, each capable of forming an image; a tube is placed behind them, and *another lens* at the opposite end. A favourable example of this construction is the pedunculated eye of the Craw-fish and Lobster. It is difficult to find a subject more interesting for microscopic investigation than the dissections of compound eyes.

occupy a volume. I cannot, however, omit to notice the singular structure of the bristles which adorn their feet. They are branched, or serrated, like those on the bodies of certain flies (*syrphi*), and plants, a beautiful example of which is afforded on the petals of the flower of the scarlet chick-weed. In the libellula their form is constantly the same in similar parts; hence, we may infer, they perform a specific office. Thus those about the joint, at *a*, Plate 3, are strong tridents without any serratures or spines; while those which border the next joint, *b*, are formed in the curious manner shewn in the annexed figure, which is a highly magnified view.



The trident hairs lie on the inferior side of the foot, and in the dry limb are barely perceptible, from its opacity; as, however, in casting the exuvia, these insects also throw off the covering of these hairs, they are exhibited in them with great effect.

The transformation of the pupa to the perfect fly, is accomplished in the short space of a few minutes, and is an occurrence that is seldom observed. At the period of the change, it crawls out of the water, and fixes itself by its claws to some adjacent plant, and after remaining a few seconds it becomes dry, and the skin along the back separates, allowing the head and legs and part of the body of the perfect insect, to be protruded, while the empty skin of the feet remains firmly fixed to the plant; it now remains stationary for a short time longer, while the wings expand and unfold themselves; the remaining parts are then liberated, and when sufficiently extended and dry, the perfect fly soars into the atmosphere.

This fly has four reticulated wings, and is equally predaceous with its larva, feeding on butterflies and other insects. They may be taken in June and July on plants on the banks of ponds:—they are vulgarly called horse-stingers, though entirely destitute of a sting. The French give them the name of *Demoiselles*; surely our neighbours are too gallant to name them thus from the very amiable habits they exhibit in wantonly destroying every inoffensive insect they meet. In courtesy we must suppose it is from the elegance of their form, and the brilliant colours which adorn them.

## CHAPTER IV.

*The Larva of a Small Notonecta or Boat-fly.*

*Notonecta minutissima.*—*Linne.*

*Plea minutissima.*—*Leach.*

THE rich transparent and brilliant colouring of these insects both in the larva and perfect state, when they have newly cast their skins, the agility of their movements, and the peculiarity of their habits, excite an interest inferior to none in this department of animated nature.

These insects swim on their backs, whence they derive their name. At first sight their appearance is not unlike that of a boat; the hinder feet, which are adapted for swimming, are formed like feathered oars; and are used by them with much facility and elegance. They are constantly on the alert, and dive to the bottom of the water on the slightest alarm.

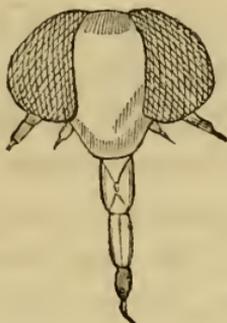
During the spring, they are found in ponds and rivulets, and may frequently be seen in droves descending to the bottom, on the approach of a specta-

tor. They may be taken in a hand net, though not without considerable adroitness, unless by accident. About the months of September and October, they arrive at their perfect state, when their colouring is much heightened. At this period their eggs may be discovered in the water, adhering to stones; they are small, and have a gelatinous appearance. During their progress to maturity, they shed their skin several times, and are then quite colourless, except the eyes, which are light crimson; they afterwards gradually assume their proper colouring, and the abdomen undergoes all the variations of tint from a pale yellow to a rich carmine.

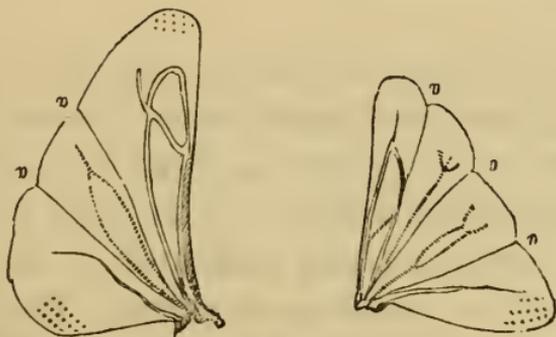
The body is of a "squarish oval" form, as represented in the magnified view of its under side, in Plate 4, Figure 1. The head is narrow and furnished with two prominent reticulated eyes of a deep crimson colour approaching to black. It has three pair of feet; the first pair is short, and thickly beset with hair, and their articulations equally distant. From their colour, and the position they assume, they often elude the sight. The second pair of feet, in swimming, are usually laid downwards, as shewn in the drawing. The hinder pair, or swimmers, are the strongest; they are ciliated along their margin, and terminated by large claws.

The rostrum, or beak, is hard and pointed. In some of the larger species it has sufficient strength to effect a severe puncture and wound. As this part is foreshortened in the drawing, I have here given a

sketch of the head and rostrum of the notonecta *glauca* magnified. Its covering is of a strong corneous texture; it has a channel down the middle, and is terminated by a strong hard point; the eyes are prominent and compound.



The wings of the perfect insect are delicate and transparent; they are folded under the wing cases, which overlap each other along the anterior margin; they are variegated in some species, and striated in others. The folds of the wings are shewn at *a*, in the following figures; the larger one is the wing of the *glauca*, and the smaller one the notonecta *striata*, both magnified.



The body of this insect is fringed with long hair,

and on each side, and down the middle of the abdomen, are disposed thick rows of the same. In the larger species they are very perceptible; their office appears to be that of buoying the insect on the surface of the water without requiring any muscular exertion, which is performed in this manner:—The insect rises to the surface, and elevates the inferior extremity of the body; then lifting up the side rows of hair, it permits a portion of air to enter the channel which they previously occupied, and there retains it. When it wishes to sink, I observe that it strokes down the fringe with the feet, and thus liberates the air, by which means, their bodies becoming specifically heavier, they descend. The contemplation of contrivances such as this, so admirably calculated to effect their intended end, must surely elicit the highest admiration of the works of the Creator, even from the most obtuse and thoughtless. Many fish possess an air-vessel, which, through the aid of proper muscles, they have the power of compressing or dilating, to facilitate their ascent and descent. In these insects the same purpose is effected by the simple law of capillary attraction only.

Both in the larva and perfect state this insect feeds on the eggs and small aquatic larva of insects, and the thoughtless victim is often captured in descending to the bottom of its element, by the wary position in which its destroyer places itself, with its rostrum upwards, ready to commence an attack. The eggs are their favourite food; these they devour with avidity,

as soon as they are emitted by the parent, even before they reach the bottom of the water.

The species belonging to this family (*Notonectidæ*) are numerous, and most of them are inferior in interest, as microscopic objects, to the one here figured. Dr. Leach has separated them into four genera, viz. the *Notonecta* (proper), *Plea*, *Sigara*, and *Corixa*, which it would be out of place, in a work devoted to the microscope, more than to name. His paper, which displays much erudite knowledge of systematic arrangement, may be consulted in the twelfth volume of the *Transactions of the Linnæan Society*.

THE two succeeding chapters are devoted to that minute class of living beings denominated *animalcules*. This term admits of great latitude. It is not confined to that numerous tribe of aquatic animals which are wholly invisible to unassisted vision, but is applied to all whose members require the aid of a microscope to render them manifest. Some have preferred the term *infusoria*, they being always found in infusions of vegetable or other organized matter, and have defined them as mere active gelatinous matter, devoid of any muscular, digestive, or nervous system. A careful examination, however, under a good instrument, will show that all of them are possessed of digestive organs, and many, especially some species of the vorticella, are highly organized. At the same time, it cannot be denied that some functions, which in the larger animals require distinct organs for their performance, may in these be effected, by a peculiar conformation of the integuments which envelope them, their surface being so very great compared with the quantity of matter they contain.

Otho. Fred. Müller, the Danish naturalist, was the first who arranged the infusory animalcules. His

classification and descriptions are accompanied by drawings of each species, which render his work, even at the present day, the most valuable we possess, although his arrangement has been extended and improved by succeeding writers. The basis of his division is, their external characters, and the structure of their envelope\*.

Since the year 1786, the date of Müller's work, very few facts have been added to this part of natural history. The great advance to perfection, which the microscope has recently made, and the confidence that, under proper management, may be reposed in it, seem to warrant the expectation of a great accession to our knowledge of these curious animated atoms, important from their immense numbers and universal occurrence. Dr. Ehrenburgh, of Berlin, has conducted a series of observations on them under one of these microscopes, and the result of his labours proves, beyond scepticism, the value of these improvements. He has also formed a more natural arrangement of them according to their organization, under the term *Phytozoa*, excluding, however, among others,

\* The following are the genera of Müller.—Without external organs—*Monas* (a mere point); *Proteus* (changeable); *Volvox* (spherical); *Enchelis* (cylindrical); *Vibrio* (worm like).—Membraneous—*Cyclidium* (oval); *Paramæcium* (oblong); *Kolpoda* (sinuous); *Gonium* (angular); *Bursaria* (hollow).—Having external organs—*Cercaria* (with a tail); *Leucophra* (ciliated all over); *Vorticella* (the mouth ciliated); *Trichoda* (with hair); *Kerona* (with horns); *Himantopus* (with a tuft of hair); and *Brachionus*, having the apex ciliated and the body covered by a shell.

the eels in paste\* and vinegar (*vibrio anguillula glutinis et aceti*), as more complex organized animals. The two grand divisions of his Phytozoa are the *Polygastrica* and the *Rotatoria*. In the former he includes the more simple animals, as the *monas-termo*, *vorticella cineta*, *convolaria*, *digitalis*, *versatilis*, *Cyclidium glaucoma*, *Proteus diff.* *Trichoda sol*, *Enchelys pupa*, &c. &c., whose digestive organs are composed of sacs or stomachs, branching from a slender tube or intestinal canal. These sacs or cavities, in some species, amount to nearly 200; the greatest number is in the *Paramœcium crysalis*. No vascular or nervous system has been discovered in them. The structure of the second class, or *Rotatoria*, is much more complicated. They have only one stomach or alimentary canal, and their mouth is furnished with rotatory organs, as the *Vorticella senta*, *Cercaria poduria*, *Trichoda lon.*, &c. Both of these classes may be formed into two parallel groups, which differ only in their external covering, the one being membranous (the *Nuda*), and the other having a shelly or crustaceous envelope (the *Loricata* †.)

\* These were long ago separated from the infusory animalcules, as *intestinal* worms, the former being supposed destitute of alimentary organs.

† An interesting abstract of the Phytozoa, by Dr. Gairdner, will be found in the *Edin. New Phil. Journal*, vol. xi. p. 209, and vol. xii. p. 78. The original papers are in the *Berlin Transactions*.

## CHAPTER V.

*The Animalcules, or Eels, in Paste.*

*Vibrio anguillula glutinis.*—*Müller.*

THE animals described in the preceding chapters emanate from parents, and although our knowledge in some cases is very limited, yet no doubt is entertained of that fact. With the present subject it is far otherwise; for, although we can procure this animalcule at any period of the year, yet we are unable satisfactorily to determine its primal production; indeed, it is one of those subjects which to the present day seem to favour the opinion of equivocal or spontaneous generation—an opinion utterly repugnant to sound reason.

If we take some fresh flour paste, and examine it under a microscope, no appearance of life will be observed, nor, indeed, do we expect it, for having subjected its ingredients to a much greater degree of heat in boiling, than that at which life can be supported, we should rather be surprised if we found any

living beings. If, however, this paste be kept a few days, and then examined, we find its surface crowded with living matter. This might be imagined to arise from some creature depositing its eggs in it during its exposure to the air ; but some doubt is cast upon this supposition, by the eels being produced even when the paste is covered ; and secondly, that these animals are *viviparous*. These speculations have naturally excited the attention of philosophers, and Mr. Adams has observed that these eels “ have been more distinguished than most other animalcules, as well on account of the various speculations and theories to which they have given rise, as their many curious properties.” And hence most writers on the microscope have given us magnified figures of them. However, as they have omitted to give any distinct representation of their structure\*, a portraiture of them will not, I think, prove unacceptable.

Figure 2, plate 4, is a magnified view of a mature animalcule, whose real size is shewn in the small circle below it ; *a* is the mouth ; the light-brown balls, *c c c*, are particles of matter found along with them. If we suppose this full-grown eel bisected, several living young, with the other bodies, will be protruded. The remainder of the group there represented is the result of such an experiment, and are all amplified to the same degree as the parent.

\* No coloured figures of it have been published in this country, except one with a slight blue tint, in G. Shaw's *Naturalist's Miscellany*, plate 431. His figures are pointed at both ends, and devoid of organization.

The infant animalcules present a similar appearance under the microscope to the premature young shewn in the engraving, no internal organization being perceptible. At this period, their serpentine motions among each other, and their transparency, are the only characters exhibited. As they advance in growth, the alimentary canal becomes apparent, and then the embryo young, coiled around it within the animal, as shewn in the engraving. They are very prolific, as upwards of one hundred young ones may be counted in a single individual.

The head (*a*) is merely an elongation of the body, and no external markings or wrinkles have been discovered on its surface. In Mr. Baker's figure, he has introduced eyes; but these organs have hitherto eluded my notice. I have sometimes seen a dark spot in that part of the head, but it has afterwards passed into the alimentary canal, and was probably a portion of its food. The mouth and glottis are very distinct, and it may be observed under the microscope feeding on the paste. From the rapid and unremitting motion of these creatures, the forms of their various parts are best seen when the animals are wounded, or the fluid is nearly evaporated. The alimentary canal is one continued slender tube, running nearly the whole length of the animalcule. It is more opaque than the other parts, from the food which it contains, and it terminates near the tail. It has a peristaltic motion, and the young which are coiled around it are each enclosed in a delicate transparent tissue.

These animalcules may be procured at any season of the year, and will afford us a constant source of amusement. The little trouble and attention required for their preservation, render them highly valuable as microscopic objects, all that is necessary for their support being a little fresh thick paste about once a month.

The paste proper for procuring these animalcules is made with flour and water *only*—that of the shops, containing resin and other matters, is unfit for the purpose. It must be made very thick, and boiled; when cold, it should be well beaten, and stirred with a wooden spatula, which must be repeated every day, to prevent mildew on its surface, previously examining a portion with a magnifier, to ascertain if it contains any eels. If the weather be warm, a few days will be sufficient to produce them. When they are once obtained, their motion on the surface of the paste will prevent any cryptogameous growth, and it therefore requires no further attention. In like manner it will prevent its freezing in winter. If the paste is too thin, they will creep up the sides. In this case, a portion of very thick paste must be added, to preserve them. When it is desirable to give them a fresh supply of food, it must not be put upon them; but they must be placed upon it.

To prepare them for the microscope, take a few drops of clean water, and put a small portion of the paste containing the eels into it. After it has stood a minute or two, the eels may be taken out and placed

under the microscope, freed from a considerable portion of foreign matter.

It is advisable to have the sliders for containing these objects thin, so as to impede as little light as possible; and they should be laid flat till the instant they are wanted, as the eels always sink to the bottom of the water.

As they are devoured by many of the aquatic larvæ, a few of them may be put into the slider along with the latter, which will add much to the interest of the spectacle.

## CHAPTER VI.

*The Wheel Animalcule.*

Vorticella Rotatoria.—Müller.

THROUGHOUT the entire range of the animal kingdom, there is no portion the contemplation of which calls into more active exercise the powers of the imagination, and produces in every uncontaminated mind higher feelings of admiration and delight, than that which comprehends those animated beings, the evidence of whose existence is not attainable by our unassisted organs of vision. Animals endowed with freedom of action, capable of selecting such situations as are most conducive to their well-being, possessing appropriate organs for procuring the food they affect, and evincing an instinct not inferior to many of the higher animals, contained in a portion of space too minute to be discerned by our visual organs, furnish sublime and striking examples of creative wisdom and power that must have remained for ever concealed from our view but for the invention of the microscope.

The peculiar nature and curious forms assumed at pleasure by the singular creature that forms the

subject of this chapter, have procured it the notice of most writers on the microscope; it may therefore need some apology for its introduction in this work. All, however, that it appears necessary to state, is, that the figures given of it by preceding authors are in many particulars devoid of accuracy, and their description of some of its functions so mistaken, that the Doctor's drawings may be taken as a fair example of our advancement in these pursuits, while at the same time it is an object the study of which is always pleasing and delightful.

The wheel animalcule is met with in vegetable infusions, especially in that of hay; "in the red sediment left by rain-water passing over leaden gutters\*," immersing it in clean water, in ditches surrounded by vegetation, and not communicating with sewers, and in shallow ponds. They are found most abundant about farm-yards, in collections of stagnant water, covered with weed and *confervæ*, and are at their greatest perfection during June, July, and August. They are very fond of sunshine, and on a cloudy day are seldom to be taken, as they descend to the bottom of the water, and conceal themselves in the mud, or among the roots of aquatic plants. After a few days of fine hot weather, the pools in which they reside being partially evaporated, they become so numerous as to colour the water. They now attain their full size, and the richness and intensity of their colouring are at their maximum; the

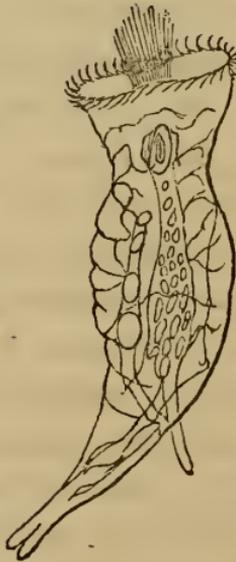
\* Baker's Employment, p. 270.

latter, however, they lose in a few days, if confined in a small vessel. Some specimens which I measured in this state, taken about the middle of June, were full *one-thirtieth* of an inch in length, while the largest bred in artificial infusions seldom exceed half that size. They were very numerous; a single drop of the water taken up on the head of our feeding-pin (see concluding chapter) contained about thirty animalcules. They may be preserved alive for a considerable time, if occasionally supplied with a little hay. Some of those from which the drawings about to be described were taken, have been kept five years in a glass vase; their descendants, however, are much smaller, and have become perfectly colourless and pellucid.

The minuteness of these creatures renders it necessary to employ a magnifier to discover them. The best method to collect them is to take up a little of the water we wish to examine with a ladle, and pour it into a wide-mouthed glass phial, and examine it with a hand microscope. As they soon attach themselves to the sides of the bottle, they are easily detected. In this way fresh portions from different waters must be successively examined, till a sufficient number is procured. For observation under the microscope they are best applied to the stage glass by the feeding-pin above referred to, covering the surface of the glass with a plate of mica, to prevent evaporation, and to render the surface plane, or they may be put into an aquatic live-box.

The most usual form which these animalcules assume is that shewn in plate 5, figures 1 and 2. The first figure represents a full-grown specimen, the second the same when young. Taking the average length of the mature vorticella at one-fortieth of an inch, the superficial amplification of the drawings will be 25,600 times, or 160 in length. It is under the form of figures 1 and 2 that it exhibits those curious rotatory organs from which its name is derived. When these wheels are protruded, the breadth of the head is equal to that of the body; but when the animal assumes the form shown in figures 3 and 4 of plate 6 (which are magnified in the same proportion as those in plate 5), it is much narrower. These two wheel-like organs (*h h*, figure 1,) are situated at the extremity of the head, and their precise form, which appears conical, is difficult to observe, owing to their delicate structure and transparency, which render their shape confused when seen by transmitted light. Each of these wheels is surrounded by a row of fimbrellæ or cogs, which are apparently in a constant rotation, occasioning a current towards the vortex or opening between the wheels, as shown by the arrows and particles of matter. By this means the aliment is brought to the mouth, which is situated below the neck at the commencement of the body, as shown at *b*. The jaws move laterally, and from their constant motion (which, however, is only when the wheels are in action) have been improperly described by some authors as the heart.

This animalcule is capable of changing the direction of the rotation of the wheels, which it does occasionally, or it can withdraw the whole of this machinery in an instant, the head then assuming the form shown in figure 3, and is terminated by a straight cluster of fimbrellæ, which do not revolve. It is probable that these are a distinct set from those shown in figure 1, as in an allied species (*vorticella senta*), I have seen the two sets at once, as exhibited in the annexed sketch.



The straight fimbrellæ appear to answer the office of feelers; they are mostly protruded when it changes its situation, and is in search of food. Detrochet and Cuvier are of opinion that the fimbrellæ of the deflected wheels are respiratory organs, though it is evident that one of their uses is to draw food towards them by the current they produce.

A favourite speculation among philosophers is whether the wheel of this animalcule actually revolves, or whether it is a visual illusion. I am inclined to believe it is the latter. Dr. Ehrenburgh informs us, that in the vorticella senta the fimbrellæ are attached to several globular bodies, which are connected to the inside of the animal by slender filaments. These balls being set around the vortex or orifice, it is easy to conceive, that, by revolving about their own axes, they will produce a current, each filament being twisted during the rotation.

Near the manducatory organ (*b*) is an opening, through which any foreign matter, carried to them by the current, is thrown out without impeding the action of the wheels, while that portion proper for nourishment passes into the alimentary canal. This canal (*f*) is a membraneous tube, enclosed within the integuments of the body; it is easily distinguished by the glassy appearance of the latter, while the coloured aliment it contains also heightens the contrast.

The ovarium, which contains the eggs (*d*), is another canal, running along each side of the former. It is pellucid, as are often the eggs which it contains. It terminates at *e*, where the refuse of the aliment is discharged. The form of the eggs is oval; several of them are shewn among the green matter at the bottom of the drawings. They are sometimes of a pink colour, at others of a deep golden yellow, with their surface beautifully granulated. They are deposited in rows by the parent, and may often be seen ad-

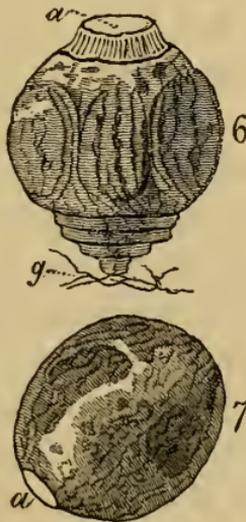
hering to the sides of the vessels in which they are kept. The best method to observe them is to place the bottle on a stand, as shewn in figure 2, plate 11.

The posterior extremity of the body is colourless, and furnished with two pair of retractile feet; it is also cleft at the end. By the assistance of these appendages it attaches itself, as shewn in figure 1, at *e*, and thus preserves a steady position, while the wheel-like organs are in motion. Sometimes it attaches itself like a common leach (*Hirudo medicinalis*), and moves from one spot to another, alternately fixing by the head and tail, and bending itself, as shewn in figure 3, plate 6.

Having described all the prominent features of this creature, except the curious organ (*i*), situated at the opposite side of the opening (*b*), and shewn in figures 3, 4, and 5, the use of which is not ascertained, though not improbably a sexual distinction, it remains to notice the manner in which the joints, *fff*, are formed, and the beautiful decussation of its muscles. These are very distinct in the full-grown colourless specimens; and although this is the smallest creature in which they have hitherto been observed, yet a moderate amplification (from 100 to 200 times, linear measure,) is sufficient; it is essential, however, that the magnifier be tolerably free from aberration. These muscles are disposed in an oblique direction from head to tail; they possess great latitude of motion, and are held in their proper situation by others, which cross them nearly at right angles. Their appearance,

though smaller, is not unlike those exhibited in the beautiful larva of a species of tipulidan gnat, described in the "Microscopic Illustrations," chapter 1.

The joints *c c c c*, in the various figures, are formed at the will of the animalcule; they do not appear to be confined in number or situation; the integuments (*c*), where a joint is produced, are drawn within the parts above, and slide out like the tubes of a telescope, when the joint disappears. It is this power that enables it to assume the form of a sphere, the head and tail being drawn within the body. This is shewn as nearly accomplished in figure 6, the toes (*g*), however, being still attached to a stem. In figure 7, it is entirely withdrawn, and forms a ball, in which state it moves about spontaneously, and exhibits only the vortex (*a*), which is also seen in figure 6.



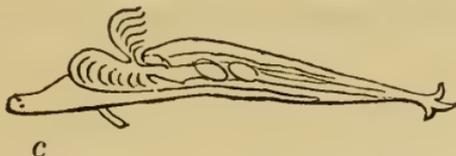
The folds and external markings which present themselves in these forms exhibit the manner in

which the body has contracted, and require attention to develop them. It is while in the form, figure 7, that they remain torpid. So great is their tenacity for life, that Leeuwenhoek states, and it is confirmed by Baker, that, having kept some of the sediment containing them, found in leaden gutters "as dry as clay," for twenty-one months, when infused in water, multitudes soon appeared, unfolding themselves, and putting out their wheel-like organs in search of food. These creatures feed on small animalcules and vegetable matter, some of which is seen approaching it in the direction of the arrows, figure 1. In preserving them, care must be taken that the decomposed vegetation does not accumulate, and a little fresh water must be added occasionally, preferring rain-water\*. A stem or two of new hay may be added from time to time, and the old removed. The water fleas (*Daphnia pulex*. *Mull.*) and the Cyclops Quadricornis, devour them with avidity, and must therefore be excluded from the vessel in which they are kept.

The species of vorticella are very numerous. Müller enumerates seventy-five; nor are the varieties of the species I have described less abundant. In that figured by the above distinguished naturalist, as shewn in the annexed copy from his, the rotatory organs are disposed on the back, more like wings; and the head, which is extended, has two dark spots, like eyes. These may be observed in some specimens, but

\* The rain-water in cities contains so much soot, which it has collected in the atmosphere, that it is unfit for this purpose.

never when the wheels are extended: that they are visual organs, appears dubious; though, from the sagacity which these creatures display, I should infer, that they are not destitute of sight. The horn (*c*) is also shewn in this figure, and called by him *spiculum collare*.



Naturalists do not agree in the rank assigned to these creatures in the scale of vitality; some elevate them little above the monads, or lowest of the infusoria, the tentacula of the rotatory organs being less developed than in the Polype (chapter 7), whose arms are retractile, and more nearly approximating to members. Yet this superiority cannot be acceded to, inasmuch as these vorticellæ possess a perfect alimentary canal, or stomach, inclosed in an external envelope, forming the body, and are furnished with two apertures, while the polypi regurgitate at the same aperture at which the food was admitted, and the interior of the surface of the body, performs the office of a digestive organ. These, and their mode of reproduction by eggs\*, elevate them far above the polype, which are produced, like vegetables, by shoots, and, indeed, give them a very elevated station among the Acrita. Those who are desirous of pursuing these

\* In some species the young is visible in the ovum before it is excluded.

inquiries, may consult the works of Cuvier, Lamarck, Dutrochet, and Leclerc, among the continental authors. In England, I regret to say, the little patronage hitherto bestowed on these subjects, does not enable me to mention any but a tract by Macleay.

## CHAPTER VII.

*On the Green and Brown Polype.*

*Hydra viridis et grisea.*—*Linne*.

THE remarkable simplicity in the organization of this creature, its limited functions and singular method of reproduction, form a striking contrast to the grand and beautiful machinery exhibited in the structure of the superior grades of the vertebrated animals. The perfect developement of their nervous system; the intricacy of construction in their apparatus for producing a double circulation, for the assimilation of their food, and the elimination of their old and useless parts, are among the principal means by which they perform those internal functions of which the polype is either wholly destitute, or performs in the most simple manner.

The interest attached to these creatures, from the station they hold among organized matter, apparently partaking in many respects both of the vegetable and the animal nature, is abundantly attested by the voluminous descriptions of them that have appeared

since their discovery by Antony van Leeuwenhoek in 1703, and the investigation of their structure by Mr. Trembley, in 1740. Mr. Baker has devoted a moderate octavo volume to it; I have therefore fewer novelties to offer. My principal object is to present a more accurate and complete graphic representation of them. In so doing, it may be remarked, that the figures of this animal that are already before the public have a closer resemblance to it than is generally observable in portraitures of living microscopic subjects, and shows the verity of Dr. Goring's remarks on the difficulties of making drawings from living animals \*. This creature being more quiescent in its habits, and simpler in its structure than any other with which I am acquainted, may account for its being more accurately delineated.

Plate 7 exhibits a magnified view of a group of polype in different states of contraction, with their prey within them; the small circle shows them of the real size.

The polype is composed of a granulated gelatinous tube, gradually tapering from the superior to the inferior extremity. The former or mouth is surrounded by a number of *tentacula* or feelers (*a*) arranged like rays around a centre. They are formed of a similar substance to the body, and like it are tubular. The number of these feelers, or arms, varies in different specimens from six to thirteen.

\* See "Microscopic Illustrations," page 3.

The mouth (see *b*, figure 2, &c.) assumes different appearances as it is more or less contracted. It is not furnished with any appendages for mastication, and its form is sometimes that of a conical or truncated papilla, at others it is hollow; and has an aperture in the centre capable of great enlargement, for the reception of its prey, as shown in figure 4.

The tail (*c*) which forms the posterior extremity of the body, is slightly dilated for increasing the surface of attachment. Although it appears perforated, nothing is observed to pass, the refuse of the aliment being regurgitated. It seems only designed for attachment, and to assist the animal in changing its place.

The whole internal surface of this animal performs the office of a stomach, or digestive organ. The food, when it consists of small pieces, and the nutritive juices when large, are observed to move along the arms and body by the contraction and dilatation of the animal, like the peristaltic motion in animals which have a separate digestive cavity. No circulating or radiating system is therefore necessary for conveying the nutritive portion of the food to the different parts of the creature, each portion performing that office for itself. The small granulated bodies diffused throughout the substance of the animal, are probably the glands, by which the assimilation of the food is effected,—an opinion which is strengthened by the fact that the colour of these granular bodies approxi-

mates to that of the food, while the other parts of the animal are colourless.

No nervous or respiratory organs have been discovered in these creatures; indeed, I conceive the latter function, if necessary in animals of this kind, may be amply performed by absorption at the surface of the animal itself, as this surface is vastly greater in proportion to the mass of the animal, than are the lungs compared with the body of the higher orders of animals.

They move about from place to place by alternately fixing themselves by the head and tail; they can descend or ascend in the water at pleasure; they also move along the surface of the water, and suspend themselves thereon either by the arms or tail.

They feed on small crustacea, worms, and larvæ, but they do not refuse small pieces of raw meat, with which it is requisite to supply them, when there is a dearth of other food.

When in search of prey they stretch out their arms and body to the utmost, and spread the former in various directions, thus presenting a large surface to entrap it. Figure 1 shews a green polype extended for this purpose. As soon as an animal comes within their range, they entwine their arms about it, and afterwards, by contracting them, bring it to the mouth and devour it. It sometimes happens that the

velocity with which their prey is moving prevents the polype from securing its victim. In such cases I have observed the little animal, after the attack, sink in the water apparently lifeless, and remain so for a few seconds before it resumed its wonted activity. From this singular fact, I am induced to imagine that the polype possess the power of giving minute electric shocks, similar to some fish and insects; for in no other way can I account for the momentary torpor of such active little animals as the water-fleas (*Daphnia Pulex*) and the Cyclops, after coming within its reach; and this is the more probable, as their prey, even when it consists of worms (whose tenacity for life is well known), is instantly deprived of life, and no weapons of any kind can be discovered.

When they have devoured their food, they generally contract themselves, as represented in the drawing, figure 2, and partially contracted at *e*, figure 3. They are very sluggish during the process of digestion, and the nutritive fluid is dispersed over the whole internal surface, both of the body and arms, imparting to them a coloured appearance.

The young are produced by shoots growing out of different parts of the body of the parent, as shown in figures 1 and 3. They do not possess any sexual distinctions, and the power of reproduction is not confined to any particular part of the animal. When the creature is well fed, and the weather warm, it is very prolific, three or four germinating at the same time from a single individual, and others again

sprouting out of these while attached to the parent. When a young one is about to be produced, that part of the animal from which it is to emanate increases in size, and projects, as shown at *d*, figure 1. After it has increased sufficiently, the head is protruded, and the tentacula issue forth. The young one then supplies itself with food in the same manner as the parent (see *e*, figure 3). Until nearly matured and thrown off, there is an internal communication between the parent and the young, and they seem to possess a sensation common to both, for, if one be disturbed and contract, the other immediately does the same.

In the autumn it is said to produce eggs at the sides, in the same manner as the young are formed in summer. This I have not been able to verify, as all the polype that I have kept propagate in the way first described.

The most remarkable fact relative to these creatures, is, that they can be cut asunder, and each part will reproduce the deficient parts, and form a perfect animal. The best account I have seen of experiments on this subject is given by Baker in his "*Natural History of the Polype*," before alluded to. His results, however, have been discredited by several intelligent observers; I have therefore made some experiments on them myself, and find them agree with his statements in every material point: a description of the details of one may not be uninteresting.

On the 22nd of August I selected a brown polype out of a glass vase containing a good supply of them, none of which had more than seven arms. The individual selected was then laid on a plate of glass, with a drop of clean water. Having provided myself with a good Whitechapel needle, and ground the pointed end so as to form a cutting edge, I severed the polype obliquely, the *superior* part comprising the greater portion of the head and four arms; the *inferior* part being the tail, and the remainder of the head with two arms. These pieces were then put into a four-ounce phial of water, with a few small crustacea (*Daphnia and Cyclops*), where they sunk to the bottom apparently lifeless. Three hours after the operation I examined them (without disturbing the vessel), and found them in the same inert state. Twelve hours after this, I found the inferior piece attached to the side of the phial by its tail, with its arms extended in quest of food, the superior one still remaining at the bottom, but with its arms extended like the other. On the 24th, a new tail was completed to the superior portion of the polype, and the rudiments of additional arms were developed in both; they appeared in good health. The third day the new arms were nearly of the same size as the others, and in less than a week each polype had a young one shooting from it.

The most curious circumstance connected with this experiment, was, that the two new polype had each *ten arms*, while that from which they were produced,

as well as those that were in the same vessel, had only six or seven.

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It may not be inapposite to append here a few remarks on the proper method of preserving polypi.

They thrive best in a large vessel. A glass cylindrical jar, holding about three quarts, will answer the purpose very well; I have kept them for several months in a vessel of this description.

Although they do not seem to possess any visual organs, yet they appear sensible to light, and prefer that side which is most illuminated.

A fresh supply of water must be given them occasionally. If it cannot be procured from the pond from which they were taken, river-water should be substituted, always keeping a *small* quantity of *live* vegetation with them. The common duck-weed will answer this purpose; but not so well as most other aquatic plants, as it is so rapidly decomposed in hot weather.

Before changing the water, the polype must be removed by a feather into a goblet of the same water, in order that the sides of the glass may be well cleansed from the dirt and spontaneous confervæ which adhere to it; for, if these are permitted to

accumulate, the creatures will not thrive, although a due supply of food and fresh water be afforded them.

Small larvæ, crustacea, or worms, must be supplied them, or in the absence of these small snails (*Helix Planata*), or pieces of raw meat cut very small, and carefully dropped into the water over the place where they are situated, that it may fall within their reach.

In cold weather they must not be exposed too near the window, as they are very tender, and become torpid.

## CHAPTER VIII.

*The Lurco, or Glutton—a diaphanous Species of Nais.*

**THIS** delicate subject appears hitherto to have eluded the notice of naturalists; at least, I have been unable to find any figure of it, and therefore am obliged to content myself with the above cognomen, which will be found not inappropriate.

Its transparency exhibiting its internal conformation, added to its sloth and gluttonous propensities, are its pre-eminant features as a microscopic object, while its perviosity to light enables us to perceive the action of every muscular fibre. The curious structure of its stomach, or rather series of stomachs, is particularly worthy of notice; their contraction and dilatation, with their prey moving alive within them, as seen under the microscope, give to this object that intense interest, and produce that high gratification, for which we might seek in vain without the aid of that instrument.

The Lurco is generally found, during the spring and summer, among masses of partially decomposed plants. I first met with it in a trench of clear rain-water, that had drained from a field of recently-mown grass. It was a hot day in June, and during sunshine. In such weather they come to the surface, but, when the atmosphere is cloudy, they remain on the sediment at the bottom of the trench or pond—a circumstance which renders them difficult to be procured. When found at the bottom, they congregate in clusters, and, to the unassisted eye, resemble short filaments of vegetable matter, interwoven with each other. As their motions are slow, they may easily be mistaken for a mass of decayed weed. They may be preserved alive for several months in a glass vase, where their habits can be observed without disturbing them, and, when plentifully supplied with food, they rapidly increase in numbers and size. They do not undergo any transmutation. Those I caught in June were about two-tenths of an inch when extended, and about half that length in a contracted state. The vase in which they were kept held about three quarts, and was well supplied with small monocoli (*Daphnia* and *Lyncei* MULLER.) In October, four months after they were caught, they had become exceedingly numerous, and they congregated together in large masses, and many of them measured six-tenths of an inch when extended. Several of the larger ones, when examined under a microscope, had numerous small diaphanous globular bodies, of various sizes, irregularly disposed around the second and succeeding

stomachs. They gave the object a very peculiar and interesting appearance, and as they did not appear in the young specimens, one of which is shewn at figure 1, plate 8, it was natural to mistake them for the ova; though it appears that all the species of the nais propagate by division; hence it is highly probable that these globular bodies are glands, secreting the nourishment imbibed from the contents of the stomachs.

The general aspect of this creature is not unlike a worm, and, like it, there is no division or neck between the body and the head. The mouth (*a*) is furnished with a row of fimbrella, which appear to possess tactual feeling; its shape, when open, is that of a pear, the radial muscular fibres, which are distinctly perceptible, being stronger at the inferior side. By the contraction and dilatation of these fibres, the pharynx is opened or closed. It has no feet, but small fasciculi of delicate hairs, or seti, at various distances, along its inferior side, and a larger cluster under the mouth. The œsophagus (*b*), connecting the cavity of the mouth with the first stomach, is capable of great and instantaneous expansion, and is never completely closed, for its prey, which it always swallows alive, may be observed moving about in the first cavity, and endeavouring to make its escape through the contracted opening. All the digestive cavities or stomachs are preserved in their proper situation by a transparent muscular annulus between each of them. These diaphragms possess considerable contractile power, and are attached by their outer circumference to the mus-

cular stratum, under the skin of the animal, while their inner margin surrounds the contracted parts of the alimentary canal, and is fastened to it. The fibres of these muscular plates diverge like rays, analagous to those in the iris of the human eye, and vary the aperture of the stomach, like the pupil of the eye, in the latter case. At *b*, is situated a pulsatory organ, which terminates in two nervous lobes; these are scarcely discernible in the young specimens, and are not represented in the drawing.

The digestive power of the stomachs must be very considerable, as the food which they prefer is crustaceous. They will often devour monocoli greater in diameter than their own bodies, and that with a degree of rapidity and insatiability not inferior to the *Boa Constrictor*, with whose manner they assimilate. It moves its head with a sluggish motion, and, when filled to repletion, is altogether inactive. The mouth is not possessed of any organs for mastication, nor has it any weapons of defence. So great is the voracity of this creature, that I have seen a middle-sized one devour seven Lyncei (similar to those shewn at figure 3, in the same plate,) in half an hour. Five of these were moving about in the first cavity, at the end of that time; the other two, having passed into the second, had become exhausted. In the drawing (plate 8, figure 1,) at *c c*, are seen three of their prey, and the refuse of others at *d*.

The slow motion of this creature admirably adapts it

for inspection under the microscope, where the motion of an object is always augmented in the same ratio as the magnifying power of the instrument. An amplification, equivalent to a lens of about a quarter of an inch focal length, is amply sufficient to give a general view of its organization. Its management in the Solar microscope requires considerable tact and address, on account of its delicacy, as the heat of the sun soon kills it, and separates its parts in a few seconds, if brought too near the focal point of the illuminator. They are rather scarce objects, but, with care, may be preserved alive for a considerable time.

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THE specimens described in the five following chapters have been separated, by modern naturalists, from the apterous insects, and now form a distinct class, under the name Crustacea, as their internal organization and respiration is performed in a manner distinct from that of insects. In the Crustacea this function is accomplished somewhat analagously to that in fish, by a species of gills called *branchæ*. The form of these organs varies in different tribes; in some they are like feet, and are so called by Müller; in others, they are plates, disposed between the proper feet. They are divided into two large groups—ENTOMOSTRACEA and MALACOSTRACEA. The animals of the first are generally small, their legs are branchial; the mandibles are either wanting or simple. Müller's work is the only one with which I am acquainted that possesses original figures of them; he has enumerated a great number of species, and his representations are good, though the details are not distinct. We do not possess any work in this country exclusively devoted to them.

The sub-class Malacostracea, includes lobsters, crabs, shrimps, &c. Chapter 13 is devoted to a small specimen of this group. Dr. Leach has displayed profound knowledge and judgment in the scientific classification of them, and a very able paper of his may be found in Dr. Brewster's Encyclopedia, and another on the same subject in the 11th volume of the Linnæan Transactions.

The following is Müller's arrangement of the Entomostracea :—

CLASS I.—MONOCULI, animals having only one eye.

\* The body covered by a single shell.

*Amydone*, 4 feet.

*Nauplius*, 6 feet.

\*\* The body enclosed in a bivalve shell.\*

*Cypris*, 4 feet.

*Cythere*, 8 feet.

*Daphnia*, † 8 to 12 feet. (*branchæ*.)

\*\*\* The animal enclosed in a crustaceous covering composed of plates.

*Cyclops*, 8 feet, antennæ.

*Polyphemus*, 8 feet, no antennæ.

CLASS II.—Binoculi, having two eyes.

\* Body covered with only one shell.

*Argulus* : oculi inferi.

*Caligus* : oculi marginalis.

*Limulus* : oculi superi.

\*\* Body covered with a bivalve shell.

*Lynceus*, eyes lateral.

\* Not unlike the muscle, and other bivalve shell-fish, in miniature.

† These are commonly called water-fleas.

## CHAPTER IX.

*The Satyr.**Amygone Satyra.*—Müller.

IF a contemplation of the variety of forms in the animal creation will produce pleasure, and excite our admiration of the boundless powers of their Creator, there is no class of beings so various in their external or internal forms and structure as those whose details are developed by the aid of the microscope. Larger animals in general possess the same number of members, varied only in proportion and situation, while the minute ones not only possess these variations in every possible degree, but the number of their members and their organization are varied in a thousand different ways.

The subject of this chapter illustrates the general characters of the univalve Entomostracea, of which there are several species. Its curious form, and the disposition of its members, give it a novel and interesting aspect. The magnified view of the inferior side, given in Plate 8, figure 2, exhibits a full-grown

Satyr, as it is commonly seen on the side of a vessel of water in an upright position.

The real length of the specimen represented in the drawing, was the *one-hundredth of an inch*. In the infant state they are much smaller, and their great transparency at this period renders them highly valuable for the microscope.

These creatures I have found most abundant in the spring, during the months of March and April. They may be taken in shallow pools of clear water, near the surface, among thriving aquatic weeds and plants, by means of a bason or cloth net. When the water is putrescent, or the vegetation in a state of decomposition, it will be useless to search for them. I am not aware that this creature undergoes any transmutation, though it is asserted that some of the smaller crustacea do: as its growth advances its members alter their proportions, and the ovaria, which are barely discernible in the infant state, become a prominent feature, as shown at *d*.

The back of this creature is covered with a delicate transparent shell, while the inferior side is unprotected and membranous. Its appearance, when viewed in profile, much resembles that of the tortoise, and the under view shown in the drawing is not unlike the form of a horse-shoe. Attached to the lower part, and radiating as from a centre, are four legs and two antennæ. In the middle, between the two latter, is posited the mouth and a single eye (*a*);

the latter is of a deep black colour, surrounded by a quadrangular crimson socket. The two antennæ (*b*) consist of four joints each; their ends are furnished with bristles. The legs (*c c*) are separated at their second joint, and terminated by strong claws. The peristaltic play of the alimentary canal may be observed in the dark parts running along the middle. On each side of this vessel are situated the ovaria (*d*), which are very dark when mature. The tail (*e*) consists of two processes, each terminated by strong spines.

In swimming it makes sudden starts or jerks, and moves its feet with great celerity; at other times it creeps along the sides of the vessel.

Müller has described \* five other species of the *Amymone*, some of which closely resemble the genus *Nauplius*, excepting that all the species of the latter have six feet. Joblet gave the name of *Satyr* to this creature, from its likeness to a face, and Baker has continued it, thinking it not inappropriate; the two ovaria (*d*) “forming the eyes, and the dark alimentary canal between them,” (which he has represented like a wine decanter inverted,) “answering to the nose, and the tail forming a piqued beard.” This idea must have been formed when viewing it *inverted*, as in a compound microscope or engiscope.

\* See *Entomostraca seu insecto testacea*, 1785.

## CHAPTER X.

*The round Lynceus.*

Lynceus Sphericus.—Müller.

Monoculus Minutus.—Linné.

THIS creature is generally known by the name of the small Monoculus, though a very slight examination will convince us of the impropriety of this appellation, as its two eyes may be very distinctly seen. Müller, from whom I borrow the name at the head of this chapter, has with more propriety classed it with his Binoculi.

The shells of the Monoculi, as well as that of the present subject, are beautifully marked with reticulations of various forms, and present under the microscope diversities in structure highly worthy of investigation. The Mosaic appearance of the shell of this Lynceus closely resembles the joints in masonry or brick-work. In the *Monoculus vulgaris* (*Daphnia pulex*, MUL.) the shell is covered with diamond-shaped reticulations, while in other species it is divided into hexagons and other angular figures.

The shell, which is perfectly transparent, consists of a single piece, no hinge or joint being perceptible; it, notwithstanding, possesses sufficient elasticity to permit the animal to open it at pleasure, in a manner similar to the common muscle (*Mytilus edulis*). The two edges of the opening are seen in the drawing near *c*, Plate 8, figure 3, which represents a magnified side view of this creature. The two eyes (*a*) are of different magnitudes, and their black colour forms a striking contrast to the surrounding parts. They are embedded in the shell, and consequently protected by it. The rostrum, or beak (*b*,) is pointed, and partakes of the general convexity of the shell. Beneath this is situated another process, similar in appearance, but shorter; at its extremity are three setaceous bristles, which probably perform the office of palpi; below these are situated the two antennæ (*c*,) each terminated by similar bristles, but longer. The false feet, or *brancheæ*, are four in number, and disposed in a single row within the shell; they are hirsulate, and terminate like the antennæ. When in motion they cause the animal to revolve, which it can accelerate by the action of the process (*d*,) against the water. At other times the false feet appear to assist the animal in creeping along the stalks of plants, to which they attach themselves by closing their shell. In cold weather clusters of them may be observed around the stalks of aquatic plants, giving them the appearance of ice-plants.

The process (*d*,) is ciliated along its posterior margin, and armed with two strong claws, and the curious

trident appendage at the base is attached to it. The ovaria are of a greenish blue colour, and their surface resembles the form of the mulberry. The convolution of the alimentary canal, with the food within it, are clearly perceived from one extremity to the other. The most remarkable organ, and one that has hitherto escaped notice, is the small oval body behind the head ; it has a quick pulsatory motion.

The Lyncei feed on animalcules \*, and in their turn are preyed upon by aquatic larvæ and water-beetles. They are the choice food of the Lurco, a magnified view of which, with some of them within its stomach, is shown in figure 1 of the same plate. They are seldom met with in autumn, being the earliest to appear and disappear in the season. They inhabit the shallow parts of ponds, and collections of rain-water. The young play near their parent, and at the approach of danger swim for protection within the shell of the mother, which she, conscious of their feebleness, immediately closes.

\* I have sometimes observed them feeding on vegetable matter.

## CHAPTER XI.

*The Four-horned Cyclops, or small Water Flea.*

Cyclops Quadricornis.—*Müller.*

Monoculus Quadricornis.—*Linné.*

Pediculus Aquaticus.—*Baker.*

THE Author of Nature, to whom all things are alike easy of execution, as if intending to teach man a lesson of humility, and that no part of creation, however minute, is beneath his consideration, has conferred on those animals, that are barely perceptible to our unassisted vision, more elegance and variety of form, more richness in their colouring, and more beauty and exquisite finishing, than on the whale or the elephant, which mainly excite our admiration by the magnitude of the mass of living matter they present to us.

The little crustaceous animals which form the subject of this chapter, may be found at all seasons of the year near the surface of the water; they are, however, most abundant in July and August. I have collected great numbers of them on a warm day, in the latter month, with a small cloth-net, immersing it about an inch below the surface. They are mostly colourless, in

ponds covered with herbage, but in small collections of rain-water, on a loamy soil, they are of a fine rich colour; they are never very numerous in waters frequented by the common water-flea (*Daphnia pulex*), though frequently met with in neighbouring pools.

In Plate 9, figure 1, is a drawing of this Cyclops of its real size, and figure 2 of the same plate is a magnified representation of it.

The body of this creature is covered with crustaceous or shelly plates, which overlap each other, and admit both of a lateral and vertical motion between them. Their ends do not meet on the under side, but have sufficient space between them for the insertion and play of the organs of respiration, (*a*). The rostrum, or beak, is short and pointed; it is a prolongation of the first segment or convex plate, which, terminating obtusely, forms the head. A little above the beak is embedded beneath the shell a single eye of a dark crimson colour, nearly approaching to blackness. The true form of this organ is difficult to determine. Mr. Baker gives it the shape of two kidney-beans placed parallel to each other, and united at their lower extremities. When viewed laterally it appears round, while in some other positions it is square.

On each side of the eye are inserted the antennæ; the superior pair is longer than the inferior ones. They are composed of numerous articulations, from each of which proceed two or more setaceous bristles.

In some species the form of these organs distinguishes the sexes, as in the *Cyclops rubens*, the males having their right antennæ enlarged, forming a bulb about the middle, as shown in figure 4 of the same plate.

These creatures move by sudden starts, though they creep along the stalks of plants, in which they appear assisted by the feet, or branchæ (*a.*) These members, however, are generally in motion, from which it is difficult to observe their precise form while the animal is alive. One of them on a larger scale is shown at figure 3. They are mostly pellucid, but occasionally of a greenish blue colour.

The ovaria consist of two bags, presenting a similar appearance to clusters of grapes, and being of considerable magnitude, compared with the size of the animal, they give it a novel and peculiar character. The eggs are of a globular figure, and enclosed in a transparent membrane, independent of their shelly ovarium. The centre of each egg is of a deep opaque colour, which in some specimens is green, in others red. Their number increases with the age of the parent, and when sufficiently matured, the embryo of the future animal may be perceived under a deep magnifier. I have distinctly seen the contour of the future *Cyclops* by the assistance of a lens of one-twentieth of an inch focus. At the termination of the alimentary canal the tail is separated into two portions, and the ends of these bicaudal processes are furnished with branched seti, which form a beautiful plumed

appendage. In the males, which are less numerous than the females, these bristles are not branched.

The alimentary canal, and its peristaltic motion in the pale specimens, is distinctly visible. Above this may be observed in the female the two conduits which lead the ova to their receptacle on each side of the tail.

The coloured markings on the shell of these creatures vary in different specimens, as also do the colours of the ovaria. The majority are pellucid, and do not possess the beauty of the bright variegated red specimens from which the drawing was taken. Some are of a bluish green, others are red, with the ovaria green.

## CHAPTER XII.

*The small Cyclops, or Vaulter.*

Cyclops Minutus.—Müller.

THE facility which these creatures display in transporting themselves through the watery element, combined with the elegant and graceful form they assume in effecting these motions, renders them highly amusing and interesting. The popular name of this little animal is derived from its motion, which is usually a succession of leaps.

They seem to possess great discernment and cunning, for, if approached, they remain motionless on the plant on which they reside, in the apparent hope that they may be overlooked; but when a fit opportunity occurs they suddenly inflect themselves, and spring away with a kind of vaulting leap.

They inhabit various species of confervæ, and may often be met with in great numbers on the stalks and underside of healthy duck-weed growing on the surface of water. They are most numerous in April

and May, and disappear as the heat of the season increases. They will not live in stagnant water containing much decomposed vegetation, and require therefore to be kept for observation in a large vessel of clean water. They are easily caught, after a shower of rain, on the under surface of the duck-weed, by taking a little out with a bason or cloth-net. When found, they appear busily engaged in search of prey, moving about with great activity, and examining every portion of the plant in the most scrutinizing manner. In this pursuit the body is not inflected, as exhibited in the magnified representation of it given in Plate 9, figure 5, but is kept in a straight crawling position. Their natural length is about the three-hundredth of an inch. In the drawing, which is the first published in this country, Dr. Goring has chosen the deflected position, as giving a more interesting view of the character of the animal.

These creatures undergo no transmutation, but as they advance in growth their different members become more developed, especially the bicaudal processes of the tail, which at first is scarcely discernible.

The construction of the shell is similar to that of the quadricornis, but it has a greater number of segments, and is more gracefully tapered. The eye is single, and embedded in the shell. The antennæ are not composed of so many articulations as in the quadricornis, and the inferior pair of palpi are more plumose at their extremities. The most prominent distinction between the two species (independent of

the difference in size, the present species being the smallest of the Cyclops), consists in this having a single branchial or respiratory organ under the rostrum; it has also ten legs, and the female carries a single cluster of eggs under the abdomen, somewhat resembling the wolf-spider. In some specimens which I have examined, the form of the respiratory organ was similar to that I have shown at figure 6. It is in constant motion, and produces a current in the water towards the animal.

The legs, five only of which are seen in the side view, figure 5, are so accurately depicted that verbal description would be superfluous. The setaceous bristles forming the tail are not so numerous as in the quadricornis, but conjoin with the body in producing the graceful figure it exhibits; while its intensely bright colour serves to heighten the delight and gratification experienced in an attentive examination of this interesting specimen of the minutæ of nature.

## CHAPTER XIII.

*A small Fresh-water Shrimp.**Gammarus grossi.*—*Leach.*

THIS creature belongs to the family *Gammaridæ* of Dr. Leach. In some respects it accords with the genus *Talitrus*, the first three joints of the superior antennæ being shorter than the inferior ones, while it agrees with the genus *Gammarus* in having bundles of spines at the joints above the tail.

They are often very abundant in ponds and rivulets during the spring, and in fine weather congregate among confervæ and water-plants. If kept a few days in a vessel of clean water, they become more transparent, and assume a more interesting appearance under the microscope. The body is curved, and compressed laterally; it consists of ten segments of a variegated cinerous colour, with fine touches of bright red. The dark alimentary canal is finely displayed when the creature is well fed, and a pulsatory motion is observable along the back. The head is broad, and has a cluster of small eyes embedded on each side.

These eyes are jet black, set in a dead-white socket. In the species at present under our notice, the cluster is circular, but in the *Gammarus locusta* they are arranged in a lunate form. The antennæ are four in number, and are inserted in pairs. The three basal articulations are larger than the others, which are short and numerous; their inferior side is studded with a row of fine bristles, which, ordinarily, appear single, but when viewed under a lens of one-tenth of an inch focus, are found to consist of clusters of three each, of unequal length. The legs are fourteen. In Plate 10, which represents a side view magnified, only seven are shown, the others being omitted, to prevent confusion. They are furnished at their insertion with laminated plates (coxæ), whose structure is worthy of examination, and requires a good microscope and careful management, to develope. They are transparent, having their inner surfaces covered with rows of bent spines, which, viewed in some positions, appear like lines; in others, like dots. The first four legs are monodactyle, and increase in magnitude towards their extremities; the next two pair are small and tapering, and the last six are the longest. They are all set with clusters of fine hair. The three pair of branchial organs, which succeed the legs, are in constant vibratory motion, and play between the lamelliform plates before described; they are furnished with fine bristles at their extremities, and along their sides: the latter are not shown in the drawing, nor are they easily detected in living specimens; I first observed them in the exuviæ. It is worthy of obser-

vation, that the function of respiration in these creatures is performed externally. The branchial organs playing between the plates bring fresh portions of water containing air, to be absorbed by their internal surfaces, answering the office of lungs in the vertebral animals.

The tail consists of two caudal processes terminated by spines; they are attached to the body by four intermediate segments, the first and third of which are furnished on the inferior side with a double appendage, as shown in the drawing.

These crustacea are very voracious, yet they can live for a considerable time without food. I put a few aquatic Moluscae and a Nais with it in the same vessel. It first endeavoured to avoid the rapid wriggling motion of the latter, fearful of getting its antennae entangled with it; but, after a few minutes had elapsed, the Nais became more quiet, when it seized it by means of its monodactyle legs, and devoured it in a few seconds, rejecting only the skin. The same evening I put about a dozen more specimens into the same vessel, and in the morning they were all devoured: the moluscae it would not feed on, though afterwards kept without other food.

They may be preserved alive during the winter, and bred in a large vessel of water. The eggs are numerous, of an oval figure, and at first quite transparent. In a short time the rudiments of the future

Gammarus are discernible near the centre of the egg, which then loses its transparency: they are hatched in the spring.

They usually swim in a curvilinear direction, and seldom in a straight line; they are exceedingly nimble; they often swim in pairs, and assist each other in casting their exuviæ. If well fed, they grow rapidly, measuring half an inch in length without the antennæ; when, however, they are about a quarter of this size, they are in the best condition for the microscope. The exuviæ may be kept between slips of glass, and afford very delicate and beautiful subjects under moderate amplification.

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I presume it will not be thought impertinent to append here a popular explanation of a few Optical Terms used in the following chapters on the Microscope, that readers unacquainted with this branch of science may be enabled the better to comprehend their import.

Microscopes may be formed into two grand divisions: first, those in which we look at the object *itself*, as single microscopes, doublets, and other compound magnifiers; and secondly, those instruments, in which we view a magnified *image* of the object, and not the object itself, commonly called *compound* microscopes; but, as the term *compound* is equally applicable to doublets, &c., they being composed of two lenses, and as the latter instruments operate on a principle distinct from the former, in this work, those which exhibit an *image* of the object are termed **ENGISCOPIES**\*, whether reflectors or refractors, and the others **MICROSCOPES**.

An Engiscope (compound microscope), consists of two parts, that which forms the image called the object end or *objective*, being those lenses or metals

\* See Microscopic Illustrations, p. 47.

next the object. The other part, that which magnifies this image, and enables us to view it, called the *eye-piece*, being those lenses or glasses next the eye. In looking through a common engiscope (compound microscope), the observer will probably notice rings of bright colours around the edge of the field of view, and also similar colours around the edges of the object he is viewing. These defects are caused by the decomposition of common white light, and are called *chromatic aberration or dispersion*. The first, viz. the colours around the field of view, are produced by the defects of the *eye-piece*, by which we view the image formed by the object-glass or metal; and the second, viz. those around the edges of the object we view, are produced by the defects of the object-glass itself: when an instrument is devoid of these defects, it is called **ACHROMATIC**. Again—if you look at the object as before through the instrument, you will observe its outline or edges are not sharp and distinct, but thick and confused: this is caused by the rays from any point in the object, which are spread over the surface of the object-glass, not being collected into a perfect point as they were on the object itself; this defect is called *spherical aberration*: when an instrument is free from it, it is called **APLANATIC** \*.

If an instrument has neither its chromatic or spherical aberration removed, it is said to be *uncorrected*. To conceal these defects, there is generally a small

\* As this term signifies freedom from *error*, it may not improperly include *achromatism*, and in this sense denotes a perfect instrument.

hole or *stop* put behind the object-glass, &c. This is injurious to the vision, as it prevents a large portion of light from entering the eye, and makes the objects appear dark, and, moreover, will not exhibit their structure: when this is the case, the instrument is said to want *angular aperture*, for ascertaining which see Dr. Goring's Memoirs\* .

\* For further information the reader is referred to the valuable little volume on Optics, in Lardner's Cyclopædia, by Dr. Brewster. See also my short treatise on Optical Instruments, Lib. Useful Knowledge, No. 13 and 21.

## CHAPTER XIV.

*On Jewelled Microscopes.*

NEARLY all the naturalists who have distinguished themselves by their discoveries with the microscope, have rejected the compound instrument, with its luxurious field of view, and attached themselves solely to the single instrument. The reason of this preference (previous to the recent introduction of the achromatics) was, that no compound had been constructed, which was *power for power equal* to the single in exploring the structure of objects. The great loss of light in the ordinary compounds, with the consequent absorption of all the delicate tints and colours of an object, make it appear like a coarse engraving in black and white. This, added to the great and sensible dispersion, which envelopes every object seen through them in a false prismatic halo \*, and utterly obliterates all its delicate markings and structure,

\* It might be supposed that the coloured fringes about the edges of an object would not lead a naturalist astray, yet in the best *coloured* illustrations we have of microscopic subjects, viz. Leder-müller's, the objects drawn under the compound have the prismatic colours produced by its chromatic dispersion represented in the plates.

renders this instrument almost useless for investigation.

When these defects were beginning to be remedied by the introduction of achromatic object-glasses, and Amician reflectors, *with large angles of aperture*, Dr. Goring, who directed the resources of the artists who executed these improvements, conceived the idea of substituting deep lenses of adamant for those of glass, as an advance towards perfection in the single microscope commensurate with that which he had originated in the compounds; for, single microscopes naturally aplanatic, or at least sufficiently so for practical purposes, possess an incontestible superiority over all others, and must be recognised as verging towards the ultimatum of perfection in magnifiers. The advantages obtained by the most improved engines resolve themselves into *the attainment of vision without aberration, and with considerable angles of aperture*; but against this must be set the never-to-be-forgotten fact, that they only show us *a picture of an object, instead of nature itself*. Now, a diamond lens exhibits the real object without any sensible aberration like that produced by single glass lenses; and the advantage of viewing an object by the interposition of but one magnifier, instead of looking at a picture of it with an eye-glass (as is the case in all compounds), must surely be appreciated by every person endowed with ordinary reason. It requires little knowledge of optics to be convinced that this simple unadulterated view of an object must enable us to penetrate farther into its real texture than we

can hope to do by any artificial arrangement whatever; it is like seeing an action performed, instead of a scenic representation of it.

The valuable properties of the diamond, for microscopic purposes, were first pointed out by Dr. Brewster in his admirable Treatise on new Philosophical Instruments, published in 1811, in which the following passages occur, though it seems the Doctor never contemplated the possibility of working this refractory substance into magnifiers.

“ In all minerals, in which a metal is the principal ingredient, those which have the greatest density have also the greatest faculty of producing colour, while in all the precious stones a high refracting power is attended with a low dispersive power,” p. 314; --- “ we cannot therefore expect any essential improvement in the single microscope, unless from the discovery of some transparent substance, which, like the diamond, combines a high refractive with a low dispersive power,” p. 403.

In the summer of 1824, Dr. Goring directed my attention to the above passages, of which I immediately saw the full force, and it was agreed that I should undertake to grind a diamond into a magnifier. For this purpose, Dr. Goring forwarded me a small brilliant diamond to begin upon, and it was proposed to give it the curves that in glass would produce a lens of a twentieth of an inch focus, with the proportion of the radii of their surfaces, as two to five.

This stone I ground with the proper curves, and polished the flatter side, contrary to the expectations of many, whose judgment in these matters was thought of much weight, who predicted that the crystalline structure of the diamond would not permit it to receive a spherical figure. When thus far advanced, fate decreed that I should lose the stone, and my only consolation was to discover afterwards, that had it been completed, its thickness, and enormous refractive power, would probably have caused the focus to fall within the substance of the stone.

Having, however, in this experiment proved the possibility of working lenses of adamant, I set about another, and selected a rose-cut diamond, in order to form it into a plano-convex lens, and thereby save a moiety of the labour.

In the progress of working this stone, the heat generated by friction in the course of the abrasion of the diamond was perpetually melting the cement (shell-lac), by which the flat side was affixed to the tool, and compelled me to seek some means by which it might be prevented. After several trials, I found that when a portion of finely-powdered pumice-stone was mixed with the shell-lac, the cement was much stronger, and less liable to melt than any other similar substance.

On the first of December, 1824, I had the pleasure of first looking through a diamond microscope, and it was doubtless the first time this precious gem

had been employed in making manifest the hidden secrets of nature. A few days after, I had polished it sufficiently to put it into the hands of Dr. Goring, who tried its performance on various objects, both as a single microscope, and as the objective of a compound. He states, in a letter addressed to me, dated third of January, 1825, that "it has shown the most difficult transparent objects I have submitted to it;" and again, "I can clearly perceive the amazing superiority it will possess when completely finished\*." I must, however, inform my readers, that we discovered in this state various flaws in the stone, in consequence of which we abandoned all thought of completing it.

In this condition the project remained for about a year, when I determined to resume my attempts, and having worked several stones into lenses, I at last succeeded in obtaining a perfect one. In the course of these labours, a new, though not unexpected defect, appeared in several lenses, which would have subverted the whole scheme, had not the first diamond lens been free from it.

These lenses, instead of giving a single image like the first, gave a double or triple one. This rendered them utterly useless as magnifiers, and made the defects of soft and hard parts in the same stone, and the

\* It ought to be mentioned that at that time the scales of the Podura were unknown as test-objects.

small cavities \* in others, of comparatively trifling consequence. The images exhibited in such lenses overlapped each other, but were never entirely separated, though the quantity of overlapping varied in different specimens †.

It was now evident that these defects arose from polarization, though this stone is described as “refracting single ‡.” I subsequently learnt, from Dr. Brewster, after I had overcome these obstacles, that this property of the Diamond had been observed by him, and an account of it given in the Edinburgh Philosophical Transactions §. On referring to his paper, it appears Dr. B. found that some stones “polarized in particular *parts*, while other *portions of the same stone were quite free from any trace of polarity,*” and thus perfectly adapted to our purpose, as had previously been demonstrated in the first diamond lens.

Notwithstanding these difficulties, and the conse-

\* These cavities, when broken into, fill with the oil and ground materials in polishing, and form black specks, by which their forms may be ascertained.

† Deep glass lenses, without any sort of polarization, will, with the light in a particular direction, and the object a little out of focus, *double the lines* on delicate tissues: this deception it is necessary to guard against, or we may reject a good lens. Similar appearances are also produced by defects in the illuminating mirror.

‡ Dr. Ure’s Dict. Chemistry, art. Diamond, 4th ed.

§ Vol. 8, p. 157, for 1817.

quent expense and labour they entailed on me before sufficiently experienced in working upon this refractory material with certainty, I have now the satisfaction of being able, by inspection *à priori*, to decide whether a diamond is fit for a magnifier or not, and have now executed two plano-convex magnifiers of adamant, whose structure is quite perfect for microscopic purposes. One of these is about the twentieth of an inch focus, and is now in the possession of his Grace the Duke of Buckingham; the other, in my hands, is the thirtieth of an inch focus, and has consequently amplification enough for most practical purposes.

Having devoted the preceding pages to the history of the formation of diamond lenses, before I enter into a detail of the advantages they possess, it will be apposite to say a few words on the formation of other jewels into lenses, as the valuable properties which direct us to select one as proper for microscopic uses are possessed, more or less, by all the precious stones.

It must be perceived, from what is stated above, that the chief impediment to the introduction of diamond microscopes is their vast expense; but, as their durability exceeds that of any other substance from which magnifiers can be formed, it is questionable whether in the end they are more costly than glass. Such being the case, my attention was next directed to obtain a substitute that might be procured at a cheaper original cost than the diamond. Taking this

view of the subject, it occurred to me that the sapphire, or ruby, might be employed with advantage, and at an outlay not much exceeding high powers of glass, which the result has verified.

In these pursuits, obstacles were presented, which, though inferior in magnitude to the former, were yet of entirely another character. These were the foulness and want of homogeneousness of the stones. Nor did my trials on others differ in the result. There was, however, this important difference between all these jewels and the adamant, viz. that we could afford to lose a few of the former, when defective; but, with the latter, it was too serious a concern. In my various trials on these stones, I sometimes discovered a partial polarity (which has not hitherto been noticed), which caused imperfect vision when an object was seen through one part of the lens, while another part of the same magnifier exhibited it beautifully distinct.

Having minutely detailed every defect to which jewelled microscopes are liable, it remains for me to state more particularly the manner in which they are formed into lenses, as many amateurs have busied themselves in these occupations.

Before grinding these stones into portions of a sphere, it is absolutely necessary to examine them carefully, and ascertain whether they have any of the imperfections above mentioned. If the stone you

propose working is a diamond, and not a *luske*\*, or table— (that is, flat on both sides), it should be ground and polished into that form, in order to examine it with a microscope; and also as to its powers of polarizing light. If it will bear these trials, it may be safely worked.

Dr. Brewster has ingeniously proposed to obviate the necessity of cutting the stone for trial, by immersing it in a fluid of the same refractive density as itself, the two surfaces of the fluid being made parallel by two plates of thin glass, or mica.

In the formation of sapphire lenses, such pieces must be selected as are free from veins, and they must be examined in the same manner as the diamond. As this stone has a double refraction, it must be so cut that the axis of the lens shall be coincident with the axis of double refraction.

Rubies may be arranged into four classes. The first, the spinelle, is the best in an optical point of view, from its superior refraction, but is the most difficult to work, the structure and cohesion of the crystal seldom permitting you to procure a perfect surface, small angular pieces continually separating. The second variety is of a deep red colour, and is, I think, not so proper to work upon as garnet, when it is desirable or necessary to operate upon a *coloured* substance. The third is pale, and nearly as soft as glass, and therefore not worth

\* This form is much used in ornamenting the dresses of the Oriental Ladies, but is not regularly brought to our markets.

working upon. The fourth is, in my opinion, the best; it is almost colourless, very hard, and takes a fine polish. It is often found in the rough, mixed with the sapphire, which in this state it closely resembles.

The garnet is more brittle than either of the former, which circumstance prevents its being worked into very thin lenses without great risk. Bright clean specimens must be selected, of an uniform colour throughout. Many of these stones have cavities and small dark specks in them; but, when they turn out sound, they make by far the best coloured magnifiers. Dr. Brewster conceives, that if spheres of this substance were made with a groove cut about their equatorial parts, to limit their apertures, and used in homogeneous light, they would be "the most perfect of all lenses, either for single microscopes or the object lenses of compound ones \*."

Having selected the stone, and ascertained its fitness, we must next determine the focus and curves intended to be given to it, remembering that the double convex figure is best adapted for general purposes, as it gives a large extent of field, while the plano-convex, with its flat side towards the object, is preferable for examining minutiae in the structure of an object, though this form does not give good oblique pencils. This inconvenience may, however, be remedied, by turning the convex side towards the object; but in

\* Cabinet Cyclop. Optics, p. 339.

that case the aberration is materially augmented. When the lens is to be a plano convex, the flat side is to be first ground and polished, without ribs or scratches. If the stone is a diamond, it is soldered into a handle, capable of being turned into the proper direction with respect to the laminæ, and polished on a circular plate of sound cast-iron, which is made to revolve rapidly. The other jewels are polished on a small flat disc of copper, in the same manner; (an old penny-piece fixed in the lathe will answer this purpose when turned true and flat.) The tools being ready, must be *paved* with diamond powder, driven into their surface by means of a hardened steel tool, and the grinding or polishing commenced, occasionally adding a little diamond powder, previously mixed with oil, as the process advances. The only difference between the grinding and polishing, is, that in the latter operation you employ very finely powdered diamond, carefully separated from the coarser particles, by washing in oil and pouring off the supernatant fluid.

When the flat side is finished, the sides of the stone are reversed, and a concave tool of the proper curvature being prepared, the convex side is ground and polished in the like manner. The tool should revolve in the lathe about sixty times per second, and a traversing motion communicated to the stone, as it is firmly held against it, to prevent circular scratches, and preserve it of a true *spherical shape*. If the substance is diamond, it should be made of the proper convexity previously to its subjection to the operation of grinding by the abrasion of its surface against another dia-

mond, both being held by handles technically called *sticks*. When the other jewels are worked, they may be turned in the lathe, of a proper convex figure, by a diamond turning-tool, and afterwards ground and polished like the diamond.

I shall now direct the attention of the reader to the specific advantages of Jewelled Microscopes.

The first and most obvious is, the superior amplification we obtain with *shallow curves*, arising from the great refractive power of the precious stones, as before mentioned. This enables us to procure the same magnifying power with a diamond having a curvature, whose radius is 8, as with a lens of glass, whose radius is 3 (as found by actual trial), the sapphire, ruby, and garnet, requiring an intermediate radius of about 5. Now it must be evident, that, as the spherical aberration, (or, in other words, the confusion, arising from the rays which impinge on the various portions of the lens not meeting again in a point) is always in proportion to the depth of the curvature, it is clear that lenses of the precious stones will bear comparatively a much larger aperture than glass, without rendering the vision indistinct. The value of aperture, both in microscopes and engiscopes, is now appreciated by all observers, as it has been duly shown that the penetration of an instrument is mainly dependant upon it.

In order to render the diminution of the spherical aberration in lenses of substances of high refractive

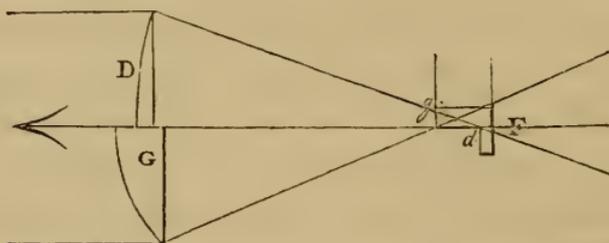
power apparent, I have arranged the following table from the calculations of Mr. Coddington \*, in which the spherical aberration is enunciated in terms of the thickness of a glass lens †.

Refractive Index.	Substances of the average Refractive Power given in the first column.	Proportion of the Radii of a Lens, giving the minimum aberration.	Longitudinal Aberration.	
			Expressed fractionally	Expressed in Numbers, 1000 being the thickness of the Lens.
1, 4	Fluor Spar. Alum. Borax. &c. . . . . }	1 : $3\frac{2}{3}$	$\frac{1}{11}$	1096
1, 5	Glass, Canada Balsam. Emerald . . . . . }	1 : 6	$\frac{1}{14}$	1071
1, 6	Topaz Oil of Cassia, Tourmaline. Sulphuret of Carbon . . . . . }	1 : 14	$\frac{1}{15}$	933
1, 7	Ruby. Sapphire. Jargon . . . . . }	1 : -93	$\frac{2}{3}$	666
1, 8	Lead Spar (least ref.) Garnet . . }	1 : -12	$\frac{5}{14}$	357
1, 9	Glass composed of Lead, 2— Sand, 1 . . . . }	1 : -7	$\frac{1}{6}$	166
2, 0	Sulphur. Phosphorus . . . }	1 : -5	$\frac{1}{6}$	62

\* Treatise on Reflection and Refraction, p. 111.

† The thickness of lenses of the same *focus and aperture* varies constantly with the alteration of their curves: thus a plano-convex lens is always thicker than a double equi-convex. We generally compare aberrations against the thickness of a lens without considering sufficiently this circumstance.

From an inspection of the last column of this table, the great superiority of jewelled lenses in point of distinctness, must be evident. The table does not, however, go so high as the diamond, whose refractive index is about 2.5; and in order not entirely to overlook its aberration, I here append a rough comparison of it and glass, both magnifiers being convexo-plane of the same power and aperture.



In the above figure, G represents the section of a semi-lens of glass, and *d* one of diamond. They are so placed that the principal focus F in each of them shall fall in the same point. The marginal rays will intersect the axis at *d* in the diamond, and *g* in the glass; and the breadth of the space from *d* to F will be the longitudinal aberration of the diamond lens, and the dark space from *g* to F that of the glass lens.

This graphic illustration will, I hope, carry conviction to the understandings of those least initiated in such matters; but to render the subject more complete, I have again availed myself of the work of Mr. Coddington, to complete the spherical aberration, according to an expression given by him in p. 93 of his treatise, which is as follows :

$$-\frac{1}{2} \left\{ \frac{1}{\mu^2 (\mu - 1)^2} + \frac{(\mu + 1)(\mu - 1)}{\mu^2} \right\} \frac{y^2}{f}$$

If we assume the refractive index ( $\mu$ ) of diamond to be 2,5 as a mean (for it ascends as high as 2,755), then the above formula, numerically expressed, will stand as follows :

$$-\frac{1}{2} \left\{ \frac{1}{2.5^2 (2.5 - 1)^2} + \frac{(2.5 + 1)(2.5 - 1)}{2.5^2} \right\} \frac{y^2}{f} = \frac{3}{7} \frac{y^2}{f} \text{ nearly,}$$

or about three-sevenths of its own thickness, while it is well known that the aberration of a glass lens of the same form, and in the same position, is seven-sixths of its own thickness ; but, as the thickness of a diamond lens will be considerably *less* than that of a glass one of the same power and aperture, it will be necessary to compute them respectively ; and it will be found, by taking the proportions given in the graphic illustration, to be for the diamond 255, and for the glass 758. Hence three-sevenths of 255 will be the longitudinal aberration of the diamond lens, viz. 108 ; and seven-sixths of 758 that of the glass, viz. 884 ; or, in other words, the diamond will have only about *one-ninth of the actual aberration of a glass lens of the same power and aperture* \*. It will therefore be obvious that jewelled microscopes possess a double advantage, from their high refractive power. *First*, their spherical aberration enunciated in terms of their own thickness is far less than that of glass ; and, *secondly*, this thickness is also far less than that of a glass lens of the same power and aperture, and

\* Probably the *best form* of a diamond lens would be *meniscus*, and from the table, I presume, the radii of the two surfaces should be as 2 to 5, when the aberration ought to be so reduced as to render it almost *aplanatic*.

these two quantities compounded, express their actual aberration \*.

Another and no less important object is attained by lenses of gem, viz. a vast increase of magnifying power, arising from their enormous refraction; for if we form a diamond into a lens with the same curves as those that are required in glass for one of the eightieth of an inch focus, giving a linear power of 800, the diamond magnifier will possess a power not less than 2133, or about one-two hundredth of an inch focus; and a lens of sapphire or ruby, ground in the same tools, a power of 1333, or about one one-hundred and thirtieth of an inch focus.

It is a fortunate circumstance that the violent refraction of the precious stones happens to be associated with a very low dispersion, or, in other words, a very trifling separation of the prismatic colours; indeed, in the sapphire and ruby it is much less than in plate glass, and in the diamond below water, as may be seen in the following table from Dr. Brewster. If the dispersion, as in some other substances, had been in proportion to their refractive power, so much colour would have been generated as to counterbalance the advantages of their low spherical aberration.

\* Notwithstanding these observations, which admit of mathematical demonstration, I think we cannot with propriety assign them their proper rank among microscopes and engiscopes, till a perfect diamond lens of the *best form*, and of a *focal length*, not exceeding the fiftieth of an inch, has been produced.

Diamond .....	.038
Water .....	.035
Plate-glass .....	.032
Sapphire and ruby	.026

The garnet has also very little dispersion, and forms an excellent lens, although its colour may be objectionable for some observations. It also fatigues the eye when the object is illuminated by white light; but if yellow monochromatic light is employed, the ease and comfort to vision render it a pleasant and agreeable magnifier; and in cases in which the coloured tints of an object are not the subject of observation, it proves a very efficient instrument\*.

Having fully detailed all the advantages and disadvantages of lenses of gem for microscopes, and the art of working them, prefaced by their history, I shall conclude this chapter with a few remarks on their mechanical properties as applicable to these purposes.

*First.*— Their superior cohesion enables us to burnish them into small circular discs of metal, which object cannot be accomplished with glass, thereby permitting them to be taken out of their mounting, and

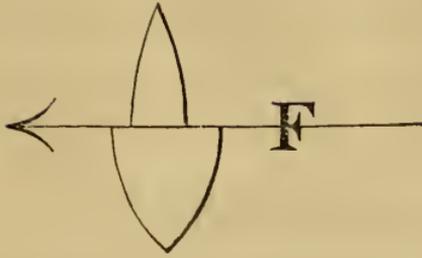
\* It appears Dr. Brewster was the first person who caused lenses to be formed of garnet and ruby, though it is but justice to myself to mention, that it was not till after I had worked upon the precious stones for some time, and my account of them was before the public, that I learnt on the proof sheet of my Treatise on Optical Instruments, that he had preceded me in these pursuits.

cleaned, without any risk of losing, or danger of scratching them. This advantage can only be duly appreciated by those who are in the habit of using deep magnifiers, such as those of one-sixtieth of an inch focus. They well know the danger of such operations, and will often content themselves with using them dirty rather than risk the cleaning\*.

*Secondly.*—The thinness of these magnifiers being much greater than that of glass, facilitates the observation of subjects between plates of glass and talc, a mode of mounting which is necessary with animalcules and other objects in fluids, in order to keep the surface flat, and prevent the speedy evaporation of the fluid. Delicate solid bodies also require a similar protection. The difference between the sapphire † and glass is such, that with a considerable power, when the lens is made of the former substance, there is sufficient space for the interposition of plates, or the admission of instruments for dissection. To render this apparent, I have given the following magnified figures of the halves of two double convex lenses each one-thirtieth of an inch focus, the one of plate-glass, and the other of sapphire.

\* The best method of cleaning a magnifier of gem is to take the disc and lens out of the setting with a stick of wood, by warming the edge of the cell over the flame of a candle, then boiling the disc and lens in a silver spoon with spirits of wine, and afterwards wiping it while hot with a clean piece of muslin; they may then be replaced in the cell, interposing a small thread of sealing-wax, to cement them, if necessary.

† The ruby, garnet, and sapphire, are so nearly alike, that what is said of the one is equally applicable to the others.



In this figure the upper semi-section represents a sapphire lens, whose focus is at *F*, and the lower one is that of a plate-glass lens having the focus in the same point *F*, their apertures and foci are alike, and their curvatures are 3 and 5 respectively.

The durability of the gems speaks for itself; but it is well known that the surface of glass lenses undergoes a certain decomposition in the course of time, and thus loses its polish, to say nothing of the mechanical injuries of which it is susceptible: thus glass magnifiers seldom last a lifetime. If it is thought necessary to construct spectacles of pebbles to prevent these inconveniences, it will surely be admitted that delicate magnifiers of high powers ought to be placed on the same footing, or we shall have no means of verifying the observations of a former age under the same instrument. This was fully exemplified with Leeuwenhoek's microscopes in the possession of the Royal Society, which Mr. Baker found so damaged as to be utterly useless soon after they became its property. Had they been made of the precious stones, future generations might have confirmed his discoveries, or shown from what cause his observations were fallacious.

## CHAPTER XV.

*Description of a new Jewel and Doublet Microscope.*

IN the instrument herein to be described, a more extended range in its application to various classes of objects is proposed, and a greater variety in the methods of illumination, so essential for determining the real structure of minute subjects, while accuracy and simplicity will form its prominent features.

It will be seen that this microscope is capable of being used in every possible direction, and the objects admit of almost every species of illumination. There is no screwing or unscrewing of apparatus, and the objects, magnifiers, and illumination, can each or all be changed with facility and speed.

To append here the reasons which have governed me in its mechanical construction, would be to recapitulate what has been fully explained in the Microscopic Illustrations "on the best possible way of constructing the stands or mountings, &c. of microscopes," the principles of which are now fully established by the fact, that nearly all the microscopes

that have since been submitted to the public, have been more or less constructed according to the rules there laid down, their details and ornaments only being varied agreeably to the taste of their respective makers.

The adjustment of the magnifiers to the objects being the most important part in the mechanical construction of a microscope, I shall briefly state the causes which have led me to deviate from the ordinary methods, and adopt one of my own.

The most usual contrivances for adjusting the distance of the magnifiers from the object, is either by means of a fine screw, or a rack and pinion; other methods not so general have been employed, as the infinite or bent lever, eccentric wheel, &c., but as they are seldom used, I shall confine my observations to the former two.

The advantage of the rack and pinion adjustment is the speed by which the object or magnifier can traverse a long space, a property that is highly useful when the magnifying power of the microscope is required to be augmented or decreased; and when accurately made with a large milled head, is very effective for general purposes.

This method has, however, mostly yielded to the screw adjustment, when high powers are used, on account of the delicate and accurate motion required for them. Again, while the latter is preferred for

such purposes, it is too tedious in its operations for low powers, where speed is necessary. Hence both these methods have occasionally been combined, and thus the desired object has been effected; but unfortunately this has added much to the complexity and expense of the instrument.

Independent of the defect above alluded to in each of these methods, there is another seldom overcome except by very accurate workmanship, and even then a little wear soon exhibits it; it is technically termed the *drop* or *back-lash*, and occurs when the motion is changed; the head of the screw or pinion turns round a certain portion before its operation commences. Hence, when a very minute change is wanted, it cannot be effected with precision.

In the plan here adopted these defects are entirely obviated, while the advantages in each of the methods above referred to are preserved. It consists in employing a fine screw, kept up to its bearing by means of a steel spiral spring for the delicate adjustment, while the whole being connected with a tube sliding within the stem of the microscope, allows of a coarse adjustment: the friction between the tubes exceeds that of the triangular bar, and holds them stationary, while the fine adjustment is effected by the screw; so that either or both adjustments may be made without the assistance of a pinching screw, or throwing it in or out of gear, as will appear from the drawing, and following description.

Plate 11, represents the microscope in four positions, drawn on a scale of about one-third \* its real size ; it also contains figures of the parts separated, some of which are on a larger scale.

Figure 1, shows the microscope set up for viewing transparent bodies by reflected light in an inclined position, but any other position or mode of illumination may be used in observing them. When the instrument is laid in its case, the legs (*a*) of the tripod stand are reversed, and being brought close to the pillar (*b*), the stem of the microscope (*c*) is placed parallel to the latter, and thus occupies very little space. In setting it up for use, the stem (*c*) being first raised, the legs are removed, and screwed *tight on the pillar*, as shown in the figure. On the tubular stem *c* slide the sockets *d*, *e*, the former of which carries the reflector, as shown in place ; the latter (*e*) carries the condenser, which in this figure is omitted. Each of these sockets can be turned about in any direction, or slid up and down the stem, without a tightening screw, having sufficient spring and friction on it, to

\* The size of the instrument might be increased, if required, for a regular *working engiscope* ; but if this is wanted, I should prefer Dr. Goring's construction, described in chapter 5 of the *Microscopic Illustrations*. I have executed two of them, and to the last, which is the most complete working engiscope I have seen, a few slight improvements are added. This instrument exhibits ordinary objects with great delicacy ; it resolves the most difficult tests with ease, and displays them in a very luxurious manner. It is in the possession of G. Leach, Esq.

remain stationary in any position without clamping. The microscope is connected with the stand by the clip *f*. It can be turned about in any position, and is fixed by its pinching-screw *f*, which should be securely tightened before the microscope is used. Within the stem *c* slides a tube *h*, connected by a screw passing through it to the triangular tube and arm *i*. By sliding the tube *h* up or down, the magnifier *k* in the arm *i* is adjusted to the objects situated at *l* (or *m* in figure 2), while the milled-head *k* revolves, and affords a delicate and final adjustment. The stage *l*, fits into the triangular box at the termination of the stem, by means of two pins fixed to it, and can be removed altogether.

Into the stage is fixed (by a bayonet-joint) the spring slider-holder, for carrying objects mounted in sliders: along with this holder may be used stops or diaphragms for limiting the pencil of light, and cutting off extraneous rays; a plate of ground glass for candle-light, or the day-light illuminators, either on Dr. Goring's construction, or that on Dr. Wollaston's; the former is shown in its place, and the latter is represented by dotted lines.

In the following figures the same letters refer to similar parts.

Figure 2 shows the manner in which the instrument may be employed for viewing the habits, &c. of aquatic objects in bottles and vases, without removing

them. In this case the stage is not used; but the vessel (*m*) containing the subjects to be examined, is placed on a stand of a suitable height, or fixed to the stem (*c*), and the magnifier (*j*) is adjusted to them. The Condenser (*e*) may be used behind the vessel, or turned aside, as shown in the figure, and a lamp, or the reflector (*d*), may be employed for illuminating the objects.

In figure 3 is shown the manner in which opaque objects are managed. In this figure the instrument is horizontal; this, however, is not a necessary condition. The stage is removed, as in the last figure, and the pin of the forceps (*n*) is introduced into one of the holes which held it. *Note*—The instrument should be turned to the right or left, according to the eye which the observer employs, and the forceps inserted in the opposite side. In the drawing it is arranged for using the left eye.—The object mounted on a dark disc (see concluding chapter,) is placed before the centre of the concave silver-reflector (*o*), and the light situated behind the condenser (*e*) is thrown on the reflector (*o*), and thence reflected to the object, as indicated by the dotted lines.

The concave silver-reflector (*o*), containing its magnifier, is held in the arm (*i*), like the other lenses, but it is inserted on the side next the object; while, on the opposite side—that is, next the eye—fits a black disc (*p*), a plan of which is shown at figure 4. The arm is shown in plan, figure 5. It is capable of traversing over the object or stage, and has an eccen-

tric and lateral motion. The most useful improvement in this part is in the aperture (*b*), into which the magnifiers are inserted. In the microscopes in general use, this aperture has an internal screw, to receive the magnifiers. The loss of time in changing them, and the difficulty of finding the thread, render this plan objectionable. Hence many observers have had the threads turned off the magnifiers, and have allowed them to drop in. The disadvantage now is, that the instrument cannot be used in any but a vertical position, or they fall out. These difficulties are obviated in my plan, by fitting the one to the other, and cutting open the ring (*b*), to make the magnifiers spring into it. Simple as this contrivance is, it will be found of no small importance to the practical microscopist. On the under side of the arm is a triangular block, which fits into the triangular tube ; it is split down the *front*, to spring tight.

The black disc or shade, figure 4, prevents all superfluous light from entering the eye. In high powers, when the quantity of light admitted by the lens is small, this contrivance is very useful, as, without it, the excitement of the eye by extraneous light, destroys the sharpness and delicacy of the object.

Figure 6 exhibits the microscope in a vertical position, for dissecting, and other purposes, when the object under examination must be in an horizontal plane. This, however, is the *worst* position for observation, and should always be avoided, if possible, as it is injurious to the eye. In this case the stage is

used. When the observer is desirous of employing this instrument for regular dissections, it is advisable to remove it altogether from the stand, and clamp it firmly to a table or board, and thus the maximum of stability may be obtained. The stage may also be enlarged, to admit the fingers, or the hands may be supported on blocks of wood of a suitable height, resting on the table.

I ought not to omit to state, that it is essential, in a complete dissecting microscope, to be able to turn the stage, similar to that in Goring's engiscope, as it often happens that it is desirable to view the different sides of an object without altering its position, or having recourse to the tedious operation of turning it.

Figure 7 is a plan of the stage, with the triangular tube and block. The dotted lines show how it may be enlarged. To examine large objects mounted on glass, &c., which will not go into the slider-holder, an angular double-spring fork is provided, or the one shown in place, and also separate, at figure 8, with its side-view projected below.

Figure 9 is a section of the stem of the microscope, exhibiting its internal construction.

On the top of the stem (*c*) is screwed the box (*r*); into this is fitted the triangular-drawn tube (*t*)\*, which

\* To enable this instrument to carry a light compound body, so as to convert it into an Engiscope, I have had a new set of triangular

holds the arm (*i*). At the lower end of this triangular tube is a small internal block, in which a fine screw works, as there shown. The stem of this screw is fixed to the milled-head (*k*), and turns along with it. Within the sliding-tube (*h*) is fixed a stop, against which the lower end of the spiral spring acts. This stop, however, does not impede the free working of the screw. The upper end of the spiral spring bears against the block in the triangular tube, and the friction of this tube in the box being less than that between the stem (*c*) and tube (*h*), the latter remains stationary, while the triangular tube is raised or lowered by turning the milled-head (*k*), and thus, by the constant action of the spiral spring, the triangular tube and magnifier is always obedient to the screw, and there is no drop or back-lash. To prevent unnecessary friction, the upper end of the spring acts against a collet, which is interposed between it and the block.

Having described how the fine adjustment is effected, it will readily be understood that the whole may be raised or lowered in the stem (*c*), by pushing up or pulling down the tube (*h*), which may be accomplished with sufficient accuracy for low magnifying powers without any assistance from the screw, and for high magnifiers, after a little practice, it will only be necessary for completing the adjustment.

holes and triblets made, for increasing the strength of this tube. It is now amply sufficient to carry either an *achromatic* body, for nice observation, or a *periscopic* one, for amusement. See dotted lines *j*, figure 1.

I should observe that the screw (*k*) should never make more than six or seven revolutions consecutively in one direction, in order that it may never be at the top or bottom when the adjustment is nearly completed. If this, however, should happen, which is easily ascertained, by its refusing to turn any further (like a watch when wound up), give the milled-head (*k*) a few turns in the opposite direction, and, after adjusting again by the tube, finish by the screw.

Figures 10 and 11 are sections on a larger scale of the compound magnifiers, or doublets, for moderate and low powers. These may be constructed so as to give a much greater field of view than with single lenses of equivalent power; or, when this is not required, the central pencil of rays may be obtained more perfect.

Figure 12 is a section of the method of mounting single jewel lenses; *s* is the small ring or disc in which the stone is firmly secured. When dirty, this disc, with the lens, may be taken out of the setting, and cleaned.

For viewing the objects described in the preceding pages, and all general microscopic purposes, one of these lenses for a deep magnifier, and a set of four or five glass doublets (figures 10 and 11) of different powers, will be found sufficient for transparent bodies, and three or four magnifiers, in silver reflectors, (*o*, figure 3,) for opaque objects. When, however, a micro-

scope is required for the investigation of the structure of delicate tissues, additional magnifiers must be applied. One construction, of a high power doublet, for such purposes, is shown in section, at figure 13. In that combination the anterior lens, or that next the object, is a jewel; it is combined with a glass one, on Dr. Wollaston's plan.

## CHAPTER XVI.

*Test Objects.*

EVERY important advance in our knowledge of those bodies in the material universe, from which our earth appears as an atom, has been coeval with, and greatly dependant upon, some augmentation of the powers and effectiveness of telescopes. Before the discovery of the double stars and nebulæ, the goodness of these instruments was determined by their capability of showing the planets and their satellites. But, since our acquaintance with the former bodies, telescopes have to undergo more severe tests, and greater accuracy in their construction is required. What has been advanced in regard to the telescope will be found applicable to the microscope; and to the discovery of certain objects which may be considered as tests of the penetrating and defining powers of this instrument, we may justly attribute the grand and magnificent improvements which the microscope has recently received.

Before entering upon my subject, it will be proper to animadvert upon an error common with those who commence the study of microscopic subjects. To set out, as they imagine, fairly, they order an instrument to be so constructed as to show the various subjects of amusement of the larger kind, as aquatic larvæ, crustacea, beetles, cuttings of wood, scales of fish, wings, legs, &c. of insects, and numerous other objects of this class; and at the same time the microscope is expected to exhibit in perfection all the delicate minutiae in the structure of tissues, hair, blood, the organization of animalcules, the mosses, confervæ, and the scales of the insects of the orders Lepidoptera and Thysanura \*, &c. Now, as this is almost impossible—at least I can aver that I never yet saw one that was perfect in all these departments; and this position will, I think, be found correct, until *systems* of achromatic object-glasses, of two, three, and four inches focus, shall be made equally perfect with the deeper ones *in all respects*;—it is therefore better to select an instrument that is efficient for those objects which are the immediate subject of our study, and to get it as nearly so in other respects as the construction will admit. It is true, that in the single and doublet microscope this can be very well accomplished, and also in the compound microscope, or engiscope, by the addition of a number of objectives and eye-pieces; but even

\* The Lepidoptera are those insects which have their wings covered with dust, or scales, as Butterflies and Moths. The Thysanura are those insects without wings, who are furnished with feet-like members along their sides, or appendages, for leaping, as the Podura and Lepisma, whose skins are covered with scales.

with these, if it is sufficiently small and delicate in its construction for the high powers, it will be too weak for the lower ones, and *vice versâ*. In short, we may (to use an expression which has been applied to the telescope) as well expect to have the properties of a high-bred racer and a heavy cart-horse combined in the same animal, as the union of the capabilities I have described *perfect* in one instrument.

This chapter, be it remembered, is more especially devoted to the investigation of the deeper or more powerful class of microscopes and engiscopes.

In the perusal of the works of Leeuwenhoek, Dr. Goring met with a passage describing the dust, or imbricated scales, which cover the wings of the silkworm (*Phalena mori*), from which he was led to suspect there were some peculiar properties in the lines on the feathers and scales of insects, rendering them more difficult to be discerned than other microscopic objects, and the result of his investigation was the discovery of their properties as *tests*—a description of object before unknown in the annals of microscopic science.

Now, as it is undoubtedly of the highest importance to the naturalist that he should know the exact capabilities of his instrument, in order that he may not be led astray in his investigations, by placing undue confidence in it; and as these tests offer the best means of accomplishing this end, I conceive them to be of the greatest value and interest. As no complete

account of them is extant, I shall endeavour to supply this deficiency in the present chapter, and illustrate the subject by accurate drawings of them, greatly magnified.

The passage which I believe led the Doctor to the discovery alluded to, is here transcribed.

“ If we examine the wings of this creature (silk-worm moth) by the microscope, we shall find them covered with an incredible number of feathers, of such various forms, that if an hundred or more of them were to be seen lying together, each would appear of a different shape. To shew more clearly this wonderful object, I caused eight feathers to be delineated, for I do not remember that I ever saw them of so curious a make in any flying insect.”

“ Although the microscope, by which these feathers were drawn, represented objects very distinctly, *the limner could not, through it, see the ribs or streaks in each feather until I pointed them out to him.* Therefore, I put into his hands a microscope, which magnified objects almost as much as that by which the silk-worm’s thread was drawn, desiring him to give the figure of that feather which through it he could see the most distinct.”—*Select Works*, p. 63.

In this passage one point is very remarkable, viz. the incapacity of the artist to see the object unless a higher power was used than that which Leeuwenhoek employed.

Having ascertained that different test-objects require different degrees of perfection in the instrument used to develop their structure, it became an interesting pursuit to discover those which are best adapted for this purpose, and the peculiarities in the illumination, &c. under which they are exhibited with the greatest perspicuity. In this investigation, it was found that there were two distinct properties in a microscope, and that the instrument might possess a very considerable approximation to perfection in the one, and fall short in the other, or *vice versâ*, or might be perfect in both. The lines on the dust or feathers from the wings of the lepidoptera, and those on the scales from the body and limbs of the thysanuræous insects, offered the means of determining their goodness in one particular, viz. their *penetration*, and the structure of the hair of animals, certain mosses, &c. served to ascertain their defining power.

The analogy between telescopes and microscopes is so great, that I cannot be said to digress from my subject by stating that the aforesaid observations apply also to the former of these instruments, which seldom combines the two qualities of penetration and definition to any great extent. Thus, a telescope with a large aperture will frequently resolve clusters of stars, and exhibit nebulæ, while it will fail in defining the disc of a planet, or the moon, with precision; and, on the other hand, one of moderate aperture accurately figured will define the latter, but be wholly inert on the nebulæ and clusters. So a microscope with large aperture and high power will

show the “ active molecules ” and lined objects, while it will not define a leaf of moss, or a mouse hair ; and another with a smaller aperture will define the latter, but prove ineffective on the former. This is very manifest in single lenses which require different apertures for different objects\*.

The *penetration* of a microscope has been shown to be dependent on its *angle of aperture*, and that whenever this was less than a certain quantity, the lined structure of the scales cannot be rendered visible, however perfect the instrument may be ; and the *defining power* is inversely as the quantity of spherical and chromatic aberration.

In order to effect the union of these two properties, it is requisite not only that the aberration be destroyed for a central pencil of rays, but that the whole of the pencils within the field of view should be nearly perfect ; and it is I conceive from this cause that no single lens, or single object-glass, however perfectly achromatic or aplanatic, will so far define an object that the lines and outline shall be distinct at the same time—a property I have only seen in *sets* of achromatic object-glasses. This property, first noticed in combinations of double achromatic object-glasses by Mr. Lister, does not, however, appear to me of much consequence.

\* I have a very beautiful sapphire lens (plano-convex of one-fifteenth focus) that shows the lines on the *long* brassica very distinct and sharp, when its aperture is large, but will not define a moss satisfactorily with this aperture ; but as stops behind the object have the effect of reducing it, with them it shows the latter.

A proof, or test-object, may be defined to be one which requires a certain degree of excellence or perfection in a microscope or engiscope for the development either of the whole, or some particular part of its structure.

Test-objects are separable into two great divisions, but as I intend only to treat on one of them, it is proper here to point out their distinction. In the first division I place those which operate out of focus, and tell us what the defects of an instrument are. The second, those which, if exhibited by a microscope, assure us that it possesses certain good qualities. The first division, as artificial stars, enamel dial-plate, wire gauze, &c. \*, which inform us of the state of their aberration, achromatism, centering, adjustment, curves, &c. I shall pass over, as many persons are not disposed to enter into a scientific scrutiny concerning the *causes* of their demerits, and because they are more applicable to engiscopes, or compound microscopes, than to single and compound magnifiers, and shall content myself by giving some simple means of determining effectiveness by means of the second division.

Before describing the lined test-objects individually, I should notice that they differ much in the facility with which they are resolved. Some are just made out by an ordinary microscope, while others require

\* For a particular account of these objects, see Dr. Goring's Memoirs "On the Exact Method of, &c."

the most perfect instrument and precise tact in the management of the illumination; it will be proper therefore to divide them into classes; the first containing such objects as are most easily resolved; the second, such as require an instrument having very clear and distinct vision; and the last, the most difficult to which the powers of a microscope can be subjected, and requiring the most rigorous perfection in every respect for their resolution. When an instrument shows the last class *properly*, it may be at once pronounced superlative. So difficult are some of these, that I do not know of half a dozen engiscopes or microscopes that will exhibit them satisfactorily.

There are generally some very easy scales and feathers among samples even of the most difficult kind; I must therefore strongly impress upon the observer the necessity of a careful selection of those similar to my drawings. And here I may notice, that the darker the specimen the easier it is made out, and, in general, the black ones are no proofs, while, on the other hand, the more transparent the tissue, the greater the difficulty there is in developing its structure. Another point I shall dwell upon, is, their proportions, or the length and breadth of the object; for, in some cases, the narrow long specimens are very difficult, while the short broad ones are very easy.

The study of the manner in which these subjects are exhibited, is also of paramount importance, for in proportion to the excellence of the instrument will

the darkness and blackness of the lines be increased, and the transparency of the spaces between them augmented; therefore, in comparing two instruments of the *like construction* on the *same object*, and under *similar illumination*, I should say, that which shews the lines blackest, and the spaces most transparent, is the best. In this comparison I assume, as a matter of course, that their magnifying powers are to be equal. The instruments should also be of the same optical construction, or the experiment will be unfair; for I have observed, that in instruments of different kinds, all equally perfect, the doublet (with Dr. Wollaston's illumination) shews them palest; next come single lines and the achromatics; and, lastly, the reflectors.

In selecting a test for comparing the performance of two instruments, it is best to employ one that can be resolved by both of them, otherwise you have no measure of their relative value; and remember that the illumination is properly conducted with each, otherwise a good microscope may be rejected, and a worse one, by better management, allowed to carry off the palm of victory; for with difficult objects the illumination requires the utmost tact. I have seen artists with instruments of the very first quality spend much time before they could exhibit an object, which, at other times, they have shown instanter.

The following objects I have selected for tests, being easily procured. They are arranged somewhat in the order I have proposed; but it is difficult to

divide them with precision, owing to the diversity of specimens from different subjects of the same kind.

### PENETRATION.

#### *First section (easy).*

Scales of *Petrobius maritimus*.

*Lepisma saccharina*.

#### *Second section (standard).*

Feathers of the *Morpho menelaus*.

*Alucita pentadactyla*.

*Alucita hexadactyla* (from  
the body).

*Lycenæ argus*.

*Tenea vestianella* (from un-  
der side of the wing).

#### *Third section (difficult).*

Feathers of *Pieris brassica* (Cabbage Butterfly).

Scales of *Podura plumbea*.

### DEFINITION.

Hair of Mouse (*Mus domesticus*).

— of Bat (*Vespertilio murinus*).

Moss, leaf of *Hypnum* (species unknown).

*Lycenæ argus* (spotted scales).

(1.) *Lepisma Saccharina*. The insects of the families Lepismenæ and Podurellæ are comprehended in the order *Thysanoura*\* of Cuvier and Latreille; they are small, frequenting damp places, and are of various colours; they leap like fleas.

\* It is singular that in the large English edition of Cuvier not a single figure of this order is given.

The scales of these apterous insects must be taken from fresh specimens, for, when long dead, they adhere so firmly to the insect, that they cannot be detached without injury.

Their longitudinal lines slightly radiate from the point of insertion; they are readily seen, and appear flat or square, like the indentations on some bivalve shells: these are the prettiest scales I am acquainted with. There are other lines in various directions, as shown in the drawing of a magnified scale at figure 1, Plate 12. When the candle is so placed as to bring out the latter strongest, and the scale is turned round in the axis of the microscope in certain positions, they will cease to appear connected. In this object it is the sharpness and cleanness of the spaces that chiefly evince the goodness of a microscope, for the longitudinal lines are easily developed.

Another species of this family (*Lepismenæ*), viz. the *Petrobius Maritimus*, found under stones near the sea-coast, has longer scales than the former, and very strong cross striæ, which afford excellent common tests. As their general form is similar to the first, it is unnecessary to give a drawing of it.

(2.) The *Morpho Menelaus*. This butterfly is indigenous to America, the wings are indented, and their superior surface of a highly-polished blue colour.

The imbricated scales from the centre of the super-

rior side of the wing are of a pale blue, mixt with others almost black. The former are mostly broader than the latter, and are the test-objects required; they measure about one one-hundred and twentieth of an inch in length. When viewed in a microscope, they exhibit a series of longitudinal stripes or lines, as shown in the magnified drawing, figure 2, plate 12. Between these lines are disposed cross striæ, which, with the lines, give it the appearance of brick-work.

The microscope or engiscope under examination should be able to make out these markings, with the spaces between them, clean and distinct. The cross-striæ, which give the brick-work appearance, are seldom to be seen all over the feather at once. The tissue that covers this scale or feather contains the largest portion of colouring matter, and is often destroyed in removing them from the wing, and along with it the cross-striæ. In such cases, the longitudinal lines only can be visible. The damaged specimens are easily known by their paleness.

(3.) (*Alucita pentadactylus*, and *hexadactylus*.)—The ten and twenty Plumed Moths.—The structure of the wings, or, more properly, plumes of these insects, is so peculiar, that few persons acquainted with entomology are strangers to it.

The twenty-plumed moth is more delicate in its form than the other. The feathers or scales, employed as proof objects, must be taken from the body of the insect, and not from the plumes or wings. Their breadth is generally greater than their length, and

their form is never symmetrical. They are transparent, and about one one-hundred and eightieth of an inch long. The scale is often partially covered by a delicate, uneven, membranous film, which obliterates the lines on those parts. The longitudinal lines are not difficult to resolve, but their proximity is such, that they require a considerable power and careful illumination to separate them distinctly. They are elegant microscopic objects, but rather scarce.

(4.) The *Lycenæ*.—The feathers of all the species of these small butterflies are charming subjects for the microscope, the studded blue (*Lycenæ argus*) in particular. As proof objects, the *lined* specimens have nothing remarkable; those from the inferior side of the wing are of a bright yellow colour, and the spaces between the lines very transparent. The spotted scales found along with these, will be noticed hereafter.

(5.) The *Clothes Moth*.—(*Tenea vestianella*.)—These small brown moths possess very delicate and unique scales, requiring some tact in the management of the illumination, to resolve their lines distinctly. I should observe, that it is the small feathers only, from the under side of the wing, that must be considered as tests; the others are easy. A magnified view of a small one, about one four-hundredth of an inch long, is given in figure 3 of plate 12. They are readily made out under the single and doublet magnifiers. This is a favourite object with some, who exhibit it as the standard of excellence. I do not consider it very difficult; though it must be admitted, to bring out the lines sharp and clean, requires an excellent instrument.

(6.) *Pontia brassica* \* (Leach.)—The pale slender double-headed feathers, about one-eightieth of an inch long, having brush-like appendages at their insertion, obtained from some portions of the wing of this large cabbage butterfly, afford an excellent criterion of the goodness of a microscope. Some Connoisseurs prefer them to all others, and form an accurate judgment of an instrument by the manner in which it demonstrates this single object. They are easily detached from the wing by the point of a quill, but must be gently handled, for, like many others, they are soon mutilated; indeed I have seldom seen them perfect in the ordinary sliders. Those specimens which are easily resolved are readily distinguished, being short, broad, and more opaque. There are also found, on the same wing, two or three other sorts, but they are unworthy of notice as proof objects.

In Plate 12, at figure 4†, is represented a sample of the regular proof feather. It is very transparent, and has a yellowish tint; the surface is seldom smooth, as indicated at the part *a*. In the engiscope these inequalities are not so observable, and therefore, when the lines appear strong, the surface is more uniform than in the microscope.

This object requires the light more oblique than any other of the lined kind. On this account I have

\* This is the *Pieris Brassica* of Latreille.

† The reader should examine this and the other figures with a hand magnifier.

seldom been able to see the lines satisfactorily with Dr. Wollaston's illumination, unless the magnifier was much out of the axis of the perforation. If we throw the light of a candle (placed a few inches behind the stage) obliquely on them, they can be seen very sharp. I have seen them in this way with a simple jewel lens, of only one-fifteenth of an inch focus.

Independent of their longitudinal lines and cross striæ, shown at *a*, figure 4, there are two sets of oblique lines\*, disposed in the manner of those drawn at 4 *c*. These are always fainter than the others, and both sets are never seen together. I have seldom seen them by day-light, and even with artificial light are not easily resolved. They require a very large angle of aperture, and for this reason are best made out by the engiscope, especially the reflector, whose darkness favours their developement. In a reflecting engiscope, in which the object-metal was three-tenths of an inch focus, and the same aperture, they do not appear continuous. In the achromatic they appear more uniform, and, by placing the light very oblique, may be seen through single magnifiers.

(7.) The *Podura Plumbea*—(*Lead-colour Spring-tail*.)—As before noticed, these insects belong to the same order as the *Lepisma*. They are about the tenth of an inch long, and leap about like fleas (*Pulex irritans*), though not so high. They are found among saw-dust and damp wood, abounding also in wine-cellars; they are very active, and consequently

\* See hints on these lines, p. 160.

difficult to catch. I here give a method to take them. Sprinkle a little oatmeal or flour on a black piece of paper, and place it near their haunts; after leaving it a few hours in the dark, the paper must be carefully placed in a large *glazed* bason, so that, when they leap from the paper, on being brought into the light, they may fall into the bason, and thus separate themselves from the bait.

The body and limbs of these insects are covered with scales, which, from their extreme delicacy, require great care in removing. They are also very soft, and easily wounded. The fluid which exudes from the injury so completely adheres to the scales as to obliterate all their markings. Hence they must be cautiously handled. Those who are desirous of preserving these insects, should keep camphor along with them; through omitting this, I once had a large collection of them consumed by a species of mite (*Acarus*), which had insinuated itself into the box.

I have remarked, that, with the discovery of any more difficult object than what is already known, an improvement in the microscope has soon followed. This was strikingly exemplified in the discovery of the lines on the scales of this insect; they were observed accidentally by the late Thomas Carpenter, Esq, of Tottenham, while making some experiments with a plano-convex jewel lens, employed as the objective of an engiscope, having an Huyghean eyepiece. They were then submitted to various instruments, and, from the difficulty with which

they exhibited the lines, even on the larger dark specimens, this object became of great consequence to the microscopist, and some of them were immediately transported, that our neighbours the French might try their microscopes on them.

I have never been able to see the lines on them with a power much below 350 (that is, one thirty-fifth of an inch focus), and therefore microscopes of a lower power cannot be expected to show them, except of very superior quality; for it must constantly be kept in mind, that that instrument is the best which exhibits an object with the *least amplification*, all other things being equal.

It is also proper to notice, that single magnifiers will resolve them, but not without considerable attention is paid to their illumination; good doublets, of sufficient power, show them readily with Dr. Wollaston's illumination; but they are most easily made out, by the simple light of a candle, in the aplanatic engiscope, if it possess an angle of aperture of about fifty degrees, exhibiting all their delicate minutiae with precision.

It is affirmed, by a very acute experimenter, of these scales, that "all are difficult, and some seem to defy all power of definition." The latter part of this quotation is perfectly accurate; but I differ in the former, because many specimens, especially the French ones, are very easy, and unworthy the title of *proofs*; and, as they might be substituted for those I am describing,

and thus a common instrument might pass for one of superior excellence, I feel justified in giving this caution.

The size of these scales varies from one nine-hundredth to one-hundred and sixtieth of an inch in length, and, as they decrease in size, become more transparent. They are of different forms, but possess a general character, easily recognized, by the want of any sharp angles. Under a microscope not having sufficient penetration, the tissue appears devoid of structure or markings; but, when placed in a superior one, and the illumination properly made, they show a series of lines or cords on their surface, and present a much greater variety in their arrangement than the scales of any other species of insect. Some have the lines straight, as shown in the magnified scales, Plate 12, figures 5 and 6, and have two sets of oblique lines on them, similar to figure 8\*; others are waved and curved, as shown in figures 7, 9, and 10, while on some of the small ones, as figure 11, nothing satisfactory has yet been developed. In these figures I have endeavoured to give the appearances which the objects present under the microscope; and it will be observed, on a careful inspection of them, that the lines on figures 9, 10, and 13, (which are only portions of scales) are very different from those on figures 5 and 6, the former ones not being so sharp and defined as the latter.

\* As in the scales of the *pontia brassica*, only one system of oblique lines can be seen at once; the other system is similar to those in figure 8, but running in a direction at right angles to them.

As a general rule, it will be found that the smaller the scales the more difficult the test; those in figure 6, however, cannot be included as tests, as they are very easily resolved. I must not omit to notice, also, that the cords on these scales are loosely attached to the tissue, and are often rubbed off in mounting. Of course it will be fruitless to examine such specimens. Those on which the greatest reliance may be placed are similar to figure 5, though the same scale will assume all the appearances of figures 8, 9, 10, and 13.

Before leaving the subject of the lined objects, I should notice, that all objects of similar structure are more or less tests, as the lines on the scales of some beetles, one of which, from the diamond beetle (*Curculio imperialis*) is shown at figure 12, plate 12 \*. The lines

\* The scales from the body of the diamond beetle, either as transparent or opaque objects, are by far the most brilliant, in point of colour, of any of the lined class. In viewing them as opaque objects, with single lenses, in order to exhibit the lines, the scale must be brought a little within the focus, and the illumination carefully arranged. As you cannot exhibit them with single lenses of a one-twentieth or one-thirtieth of an inch focus without using silver cups, it is difficult to procure oblique light. As transparent objects, they are much easier managed. They present a mottled sort of colour, composed of the brightest carmine, mixed with purple, blue, and yellow, and their lines are distinctly seen, as shown in figure 12. As the lines on some of these scales are of easy resolution, it will not be advisable to trust every specimen as a *test*. The small ones from the legs of the Brazilian beetle are the most difficult, and many of these require the most rigid adjustment of the focus and illumination to resolve the lines, and the slightest tremor, though not enough to occasion any sensible dancing (as a carriage at a distance), is sufficient to render them invisible.

and markings on certain vegetable tissues, and many others too numerous to name, may also be employed as proof objects. The reason for making a selection of those above described, has been, in order to render the task of judging of the merits of an instrument by different individuals more simple and satisfactory, so that by the assistance of the drawings, and a sample of the objects, they may ascertain the quality of an instrument without the trouble of comparing it with others, which are often difficult, and sometimes impossible, to procure.

#### DEFINITION.

The defining power of microscopes and engiscopes depends on their capability of collecting together all the rays from any one point of the object, or, in other words, their freedom from aberration, and is independent of their penetration ; for, if we take an engiscope and view a lined object with the aperture of the objective, as it is usually sold in the shops, its defining power may be very fair ; but if we enlarge the aperture so as to enable us to develop the lines which it will then accomplish, the defining power of the instrument will be injured to such an extent as to render the outline quite confused. The great desideratum, then, in microscopes and engiscopes, is to obtain these two qualities combined, which, however, is only rarely attained.

Cylindrical or spherical bodies appear the best suited for ascertaining the goodness of an instrument,

as regards definition; and the following examples, which are prefaced by remarks on the method of illuminating them, I deem sufficient for this end.

In the preceding class of objects, *oblique diverging rays* appear to be essential for the developement of their structure, the degree of obliquity varying, however, with different specimens of scales. The extremes of this variation are the *Podura-plumbea* and *Pieris brassica*, the delicacy of the former requiring almost central light, while the latter requires it very oblique. From this cause artificial illumination is to be preferred to day-light for this class of objects, as the light of a lamp or candle gives the rays diverging without any apparatus whatever. The same effect, however, may be produced in day-light either with Dr. Wollaston's or Dr. Goring's illuminator, where the rays, after meeting at the focus of their illuminating lens, are permitted to diverge, and, by placing the object out of the centre, oblique vision is obtained. In the investigation of the class of objects now to be described, *direct parallel rays* are preferable, and, indeed, in most cases are essential, and on this account they are scarcely ever well defined by candle or lamp light. In these, therefore, clear day-light, directed through the axis of the instrument, should be employed.

In the selection of the hair of animals for microscopic examination, either as opaque or transparent objects, the lightest coloured ones should be preferred, as they permit us far more easily to observe their internal conformation, while the colouring matter (*réte*

*mucosum*) in some black hair is so considerable as to render them incapable of transmitting the most feeble ray, and are therefore unfit for this purpose. Those on the inferior side of such animals as the mouse, dog, &c. should be on this account selected. Like the scales on insects, the hair from different parts of the same individual varies considerably in structure.

1. The hairs of the common mouse (*mus domesticus*) differ both in size and form ; the principal varieties, with their relative diameters, are shown in Plate 12, figures 14, 15, and 16. These are drawn, as seen by transmitted light, and as proof-objects should have their transparent parts clearly and distinctly separated from the darker portions. This remark holds good for the whole tribe of hairs and mosses, and it is from the sharpness with which the parts are separated that a correct opinion of the goodness of an instrument can be obtained. When these hairs are seen by reflected light, that is, as opaque objects, their appearance is altered, the dark solid parts reflecting more light than the transparent portion ; hence they are lighter than the latter. A peculiar and interesting variety of a large hair viewed in this way is shown at figure 17 ; it is engraved from a drawing made by Dr. Goring.

The diameter of the mouse's hair varies from one two-thousandth to one three-hundredth of an inch ; the real diameter of the hair, figure 14, is one one-sixteen hundredth of an inch ; they do not require a very high power to see them.

2. The hairs of the field-mouse (*mus sylvaticus*) possess a structure totally different from the former species, and is a good microscopic object.

3. The hair from the wing of the bat (*vespertilio murinus*). Although this creature is supposed to bear some affinity to that of the mouse, the structure of the hair of these two animals is entirely different: there are, however, great varieties, the principal of which are shown at figures 18 and 19. The hair in the latter figure is spiral; the former like a succession of cones, the apex of one being inserted into the base of the following.

Many other kinds of hair might be enumerated for the purpose to which I have applied the above; but I deem these amply sufficient to illustrate this part of the subject. As, however, the diversities in the structure of different kinds of hair are worthy of investigation \*, I have sketched a few of the most interesting varieties. They are all magnified in the same proportion as the mouse and bats' hairs, which accompany them in Plate 12.

Figure 20 is a hair from the larva of the common dermestes.

Figure 21 is a white hair from a young cat.

\* The serratures on the surface of the human hair, especially those from an infant, afford excellent tests, and are very beautiful objects.

Figure 22 is the hair of a Siberian fox ; and

Figure 23 the hair of a common caterpillar \*.

4. The *Lycenæ Argus*.—Among the scales on the underside of the wing of this elegant blue butterfly, are some whose conformation is remarkably singular; their form is represented in figure 24; their general appearance is not unlike a child's battledore, with its surface covered with spots. I have not been able satisfactorily to demonstrate its structure; but it appears to consist of two delicate tissues, having regular rows of conical spines on the upper one. As a test-object these spots should be clearly, and distinctly separated. When the light is thrown obliquely they are blended together, appearing like a stripe of unequal breadth; similar to many of the other tests, it is the manner in which they are seen rather than the mere exhibition of them that should be observed. This object I employ for the same purpose as the leaf of an unknown species of moss belonging to the genus hypnum, which, as it is difficult to procure, renders this substitute an acquisition to the microscopist.

Before I conclude this chapter, it may not be amiss to notice another class of objects, which by the vulgar are considered as positive proofs of the efficiency of an instrument; I allude to the animalcules. Nor

\* The form of these hairs varies in every species: in some they resemble the feather of the peacock's tail in miniature; others are furnished with tufts of fine hair, and beset with spines.

does this opinion seem confined to those unacquainted with this subject; but we find it stated by Adams, in his quarto work on the Microscope, p. 430, that the *monas termo* (one of the most minute of all the animalcules very abundant in vegetable infusions), “eludes the power of the compound microscope, and is but imperfectly seen by the single.” Now, all that is requisite for seeing this object, or any other of the same kind, is to cut off by stops, or otherwise, all superfluous light, so as to reduce the quantity and intensity\* of the illumination, for, when too much light is admitted, these minute and delicate bodies are completely drowned. All that is necessary for *seeing* these objects, even in the ordinary compound microscopes (engiscopes) providing they have sufficient magnifying power, is to employ a faint illumination. If, however, the observer is desirous of examining the structure and organization of them, of course he must use an instrument of superior quality, for in this case not only sufficient magnifying power and proper illumination are necessary, but penetration and definition.

\* The reader should observe that quantity and intensity are distinct from each other: thus, when we employ a small wax taper close to an object, it will be *intensely* illuminated though the quantity of light is small; but if we employ the flame of a large lamp, &c. at some distance from the object, its intensity will be small though the quantity of light be great. It will be found generally preferable to employ a small quantity of intense light rather than a larger portion of weak light, and, if possible, avoid the use of lenses or mirrors either for condensing or changing the direction of the light.

*Hints on the Nature of the Oblique Lines on the Scales from the Podura plumbea and Pieris brassica.*

IN the foregoing account of the different scales from the wings and bodies of insects, the design has been to give their *appearances* under Microscopes or Engiscopes without in the least determining their actual structure. When it is considered that these lines are less than the one-twenty-thousandth of an inch distant, it must be allowed there is some difficulty in accurately determining their construction. The *morpho menea* and *lepisma saccharina* are of sufficient size to distinctly perceive they are composed of two delicate tissues with longitudinal cords (probably tubular) disposed between them; but in the two delicate ones, the subject of these remarks, we perceive other systems of lines disposed obliquely, and as they are extremely delicate, it becomes a question whether they actually exist, or whether they are appearances produced under certain modifications of the illumination. As there is only one set shown at a time, and I have never been able to see them in the decided way of the longitudinal lines, I have been induced to consider them as appearances only, and not real lines. To determine this point, it became necessary to ascertain the cause that would produce such an effect; and it immediately occurred to me

that these oblique lines were occasioned by the disposition and pressure of the superambient scales in the same manner as the watering or wavy appearance communicated to corded silks and moreens by the pressure of two pieces passed between rollers\*. In examining the scales of the *Pieris brassica* under a deep power and large angle of aperture, I found them broad in some parts, and almost invisible in others; and the same appearance presented itself in the curved lines on the scale of the *Podura plumbea*, some idea of which may be obtained by examining figures 9 and 10 of Plate 12.

The motive that has induced me to offer the above remark, is, that it may lead to a complete investigation of the subject. What is here given is merely the crude idea that presented itself in the course of their examination as proof-objects.

\* I have since examined the *Petrobius maritimus* as an opaque object, which confirms this view of the nature of the oblique lines on its scales.

## CHAPTER XVII.

*On Doublets and other compound Magnifiers for Microscopes, and their Illumination.*

COMBINATIONS of two or more lenses \* were employed by the early microscopic observers, and the advantages which they sought to obtain over single ones, was a greater extent of view without increasing the aberration: an account of a doublet for this purpose will be found in an early number of the Transactions of the Royal Society †. Since then little or no attention has been bestowed upon them till Mr. Herschel's elegant investigation of the aberrations of object-glasses and compound magnifiers, given in the same Transactions for 1821. In this paper two kinds of doublets are described, the one by which a maxi-

\* This term denotes what is commonly called a magnifying glass, but as magnifiers are not necessarily made of glass, the word *lens* is more appropriate.

† On the performance of this combination, we are told "it hath this peculiar—that it shows the objects flat and not crooked, and altogether it takes in much, yet, nevertheless, it magnifieth extraordinarily." 1668, No. 42.

imum of field may be obtained, the other having the aberration destroyed for the central pencil of rays\*. In both these combinations the lenses are in contact, and one of these lenses in each has a negative, or concave surface, which detracts from the magnifying power. I have executed some of the latter, or aplanatic combinations, for the objectives of engiscopes, for which they answer remarkably well, but their angle of aperture is small compared with combinations of double achromatics.

Subsequent to these investigations of Sir J. Herschel, this subject has been examined practically by Dr. Wollaston, who, by combinations of two plano-convex lenses, with their plane sides towards the object, has obtained by far the best magnifier for exploring the structure of minute tissues with which we are acquainted, and is undoubtedly the greatest improvement in combinations of positive lenses that has hitherto been effected. The construction of his doublet is here quoted from his paper.

“ The consideration of that form of eye-piece for astronomical telescopes called Huygenian, suggested the probability that a similar combination should have a similar advantage of correcting both chromatic and spherical aberration, if employed in an opposite direction as a microscope.

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“ The compound magnifier consists of two plano-convex lenses; the proportion of the foci of these

\* See Optical Instruments, p. 41 and 42.

lenses being about as three to one; they are fixed in their cells, having their plane sides next to the object to be viewed, their plane sides being distant from each other about one and four-tenths, or one and a half of the length of the shorter focus \*.”

In the construction of Huygen's eye-piece the lenses are placed at a distance from each other, equal to about half the sum of their two focal lengths, the focus falling between the lenses, where an image previously formed is viewed, and it is only on this condition that it corrects the chromatic aberration. It must therefore be evident, on a little consideration, that Dr. Wollaston's combination is quite distinct from that of Huygen's in principle, and I shall now show that its construction is also different, without, I hope, in the least degree detracting from the merits of the doublet which that distinguished individual has presented to us.

Having mounted some plano-convex lenses of the relative foci named by Dr. W. in such a manner that the distances might be varied at pleasure, I was surprised to find that after the doublet was adjusted *by trial*, so as to obtain the maximum of distinctness, that the distance between the lenses did not accord either with the rule given by Huygen, or that of Dr. Wollaston. Supposing that I had not got the combination intended by Dr. W. I procured several doublets made by different artists, and to my astonish-

\* See Philosophical Transactions for 1829, p. 9; also Brewster's Journal, vol. i. p. 323, N. S.

ment found they agreed with my own, and therefore presumed the Doctor was mistaken in the distance by the thickness of the lenses, and the minuteness of the space between them. The distance which appeared to me essential to obtain the best effect is *the difference of the focal length of the two lenses, making a proper allowance for their thickness*. The proportion of the foci of the two lenses may be varied *ad libitum*. All that is requisite in this respect, is, that the difference must be greater than the thickness of the anterior lens, while it may be observed (in high powers), that the greater the difference between their two focal lengths, the more space will be left in front, and as this is of great practical importance, they should never be less than as one to three. I have made some very good ones, differing as much as one to six. Another advantage resulting from attending to this point, is, that we do not lose so much magnifying power in such combinations as when the difference between the lenses is less.

The delicacy and beauty with which these doublets exhibit the structure of tissues will justify my entering into some minute details respecting them. The following is necessary to ensure their goodness.

*First*—The convex surface of each lens must be *truly spherical*. If this is not obtained, it will be in vain to procure a good doublet, however beautifully the lenses may be polished, or accurately adjusted. From this circumstance I have found globules perform very well, providing they are free from air bubbles, which,

however, is rarely the case. It should be observed, that a slight scratch on their surface is trifling compared to air bubbles, for the latter not only stop the light, but by the reflections around the edges of each bubble, produce considerable fog and glare. *Second*—The distance between the lenses is the next point of importance; its adjustment is best accomplished by trial, mounting the lenses in such a manner that their distance can be varied at pleasure, and capable of being turned round so as to adjust the centering. When this is obtained, they should be fixed so that their distance and position cannot be altered. This it is necessary to regard, as I have sometimes spent whole days in re-adjusting a doublet that had been separated to examine the lenses singly. *Third*—The stop or diaphragm, for limiting the aperture in these combinations, should be placed immediately behind the anterior lens. From the difference of the situation of this stop in the various doublets I have examined, it would appear that their makers did not know that the field of view depended upon the place of this stop. I have found, that when the stop is situated *close* behind the anterior lens, no other is required, and the field is enlarged without sensibly augmenting the aberration. On this account the lenses of the finest doublets, when used singly with the same aperture as combined, has so much aberration and distortion, that distinct vision cannot be obtained even with the most rigid adjustment of the focus. From the difficulty of procuring a flat surface, some makers have worked the anterior surface of the lens next the object concave: these lenses do not possess any advantage in point of

performance, not even to compensate for the loss of power from the negative side.

On the same principle as these doublets may be constructed triblets, the additional posterior lens being of longer focus: this requires greater precision in the adjustment; there is also greater difficulty in the centering, but when perfected they amply repay the pains bestowed upon them, in the accuracy with which they exhibit the most difficult *lined* objects, though it is to be regretted that neither these, nor the doublets of deep power, will show pleasantly cylindrical bodies of large diameter, such as a large mouse or bat's hair.

When the lens next the object is a jewel, the performance of the doublet is improved, but I have not observed any advantage when both lenses were gems\*. The space between the object and the lens is greater when a jewel forms the front lens, a circumstance of much importance. As on an average not more than two glass doublets out of a dozen will support the high character given above, the same perhaps

\* The best jewel doublet I have constructed was formed of sapphire lens, one-sixtieth of an inch focus, combined with a glass lens one-tenth focus: with this combination the lines on the podura and brassica were exhibited decidedly equal to any engiscope I have seen, but, like other doublets, it was left behind when tried on the mouse-hair.

Combinations of garnet and glass produce pleasant magnifiers: the colour of this jewel is almost entirely subdued, and the vision is remarkably distinct.

applies to the jewelled combinations; but the few already existing have not decided this point. The great difficulty of procuring superior doublets, although their construction is so very simple, compared with the achromatics, renders them scarce and expensive, like the latter.

The same may be observed of the triblets, whose performance no engiscope can surpass on tissues and flat objects\*, while they possess some advantages over them in informing us of the different planes in which the markings are disposed; though this circumstance, in another view, is objectionable, as it prevents us obtaining a view of the whole at once, which achromatic combinations effect. These doublets and triplets may be employed as the object-glasses of engiscopes, but, as their power is sufficient without any increase from the eye-piece, it is not advisable to use them in this manner, except absolutely necessary, as with opaque objects, and in all cases the eye-piece should be of *low power*, as the aberration is rendered very sensible. The best construction is the Huygean †.

#### THE ILLUMINATION

which Dr. Wollaston employs with his doublets being of importance to their due performance, it will be

\* The adjustment for these magnifiers requires to be very delicate; hence they cannot be applied to common instruments with success, unless some addition is made to obtain an accurate movement.

† It has been asserted that it is unnecessary to correct the dispersion of object glasses: if any one, unprejudiced, will carefully exa-

proper first to describe it, and afterwards to offer a few remarks, and explain its different modifications.

This illumination consists of a tube (A B) six inches long, figure 14, placed under the object, whose axis is coincident with that of the doublet: within this tube is fixed a plano-convex lens of about three-fourths of an inch focus, as shown at I; at the lower end of the tube (B) is placed a circular perforation, or stop (S), of about three-tenths of an inch in diameter, for limiting the light reflected from a plane mirror, placed under it. A neat image of this perforation (S) is to be formed by the lens (I), at about eight-tenths of an inch from it (see the black circle on the line P), by adjusting the distance of the stop S from the lens till it is obtained.

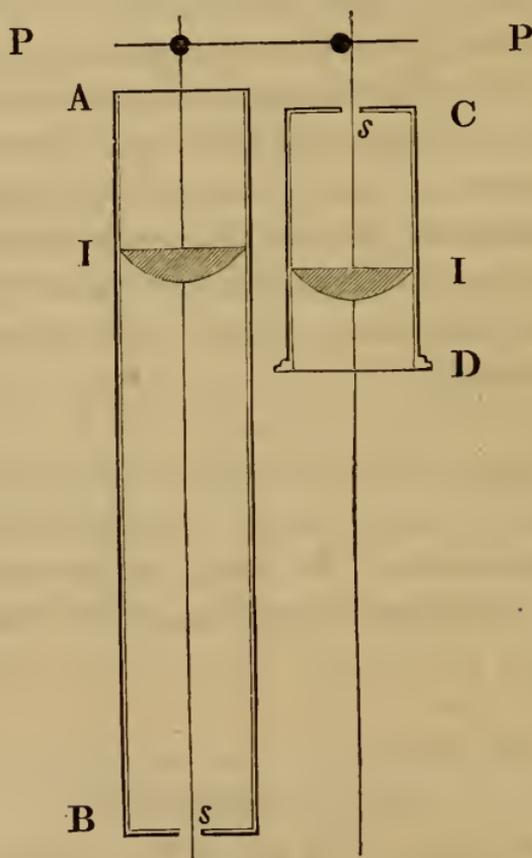
Dr. W. says, “the intensity of illumination will depend upon the diameter of the illuminating lens, and the proportion of the image to the perforation, and may be regulated according to the wish of the observer.”

To use this illuminator most effectively, the rays should be in the act of diverging, and the object, if of the lined class, a little out of the centre, so as to obtain an oblique pencil of rays: to obtain the maximum of effect it requires to be carefully adjusted for every object. To accomplish this, the stop is raised

mine an engiscope of this construction, which certainly is the most favourable to their view (the apertures being very small), they will not fail to detect it.

or lowered, or, what is preferable, slide the whole tube (A B), as shown in figure 1 of plate 11, till the best effect is produced, and also move the arm *i*, plate 11, fig. 1, over the spot of light, till the proper eccentricity is obtained. I may also notice that it is much improved by placing another stop or diaphragm at A.

*Fig. 14.*      *Fig. 15*



A modification of this illuminator has been adopted by Dr. Goring. The main difference between the two is, that Dr. G. employs a real diaphragm, and the apparatus, being short, is easily applied to any instrument. Figure 15 is a section of it, of the real size ; it

consists of a tube C D, having a lens I, similar to that in figure 14, and a perforation or stop of about one-tenth of an inch in diameter is placed in its focus *s*. This stop is either made eccentric, or the magnifier is placed out of the axis, so as to obtain oblique diverging rays; see the black spot on the line P, where the object is to be placed.

This illuminator is easily managed, and is adjusted within the slider holder shown at *b*, figure 1 of plate 11, in the same manner as figure 14. I have usually inserted another stop at D, which I think improves it, especially when we view delicate objects, *not lined*. These stops have the same effect as when the aperture of the magnifier is reduced, so that instead of having two magnifiers, one for lined objects with a large aperture, and another for definition with a small aperture, these stops render the former sufficient.

The best method to ascertain what effect is produced on the visual pencil, is to examine it with a magnifier: in this way much information may be obtained of the conditions under which an object is seen.

If you take a hand magnifier of about three-fourths of an inch focus, and examine the aperture (*visual pencil*) of the doublet after it is adjusted to an object, and the illuminators just described, when the doublet consists of plano-convex lenses the image or spot of light assumes the form shown in figure 16, if not completely illuminated; but when these illuminators

are applied to an engiscope this seldom occurs, and it exhibits a circular spot of light, as figure 17, the outer circle in each figure representing the *visual pencil*, and the black spot in each the illuminated portion, which, in fact, is the *acting visual pencil*, the other portion being cut off by the stops as effectually as if the real aperture of the microscope had been reduced. There is, however, this advantage resulting by employing stops, viz. that the vision is more pleasant, and does not fatigue the eye so soon as when the real aperture is reduced.

*Fig. 16.**Fig. 17.*

This method of analysis may be applied to other illuminators, and will also be found useful to ascertain whether a mirror gives a proper pencil of light\*.

\* On the Principle of Illumination for Microscopic Objects, see a paper by Dr. Brewster in his Journal, vol. vi. p. 83, N. S.

## CHAPTER XVIII.

*Memoir concerning the Verification of Microscopic Phenomena, with fruits of experience relative to the analysis of Test Objects, and the defining and penetrating powers of Microscopes and Engiscopes.*

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BY C. R. GORING, M. D.

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THAT there may be no disputes or mistakes concerning terms or *words*, it is necessary to determine accurately what I mean by defining and penetrating powers as distinct from each other. It will, I believe, be found, from the consideration of various passages in my writings, that, by *defining power*, I mean nothing more than *a destitution of both kinds of aberration*, considered independently of the aperture of the microscope or engiscope; and, by *penetrating power*, merely a *large angle of aperture*, which may or may not be associated with an aplanatic and achromatic construction. The union of these two properties of course constitutes the perfection of an instrument, and is, by some writers, resolved entirely into defining power, which is or is not accurate, according to the sense in which the word is used. As, however, by Sir W. Herschel, the powers of telescopes have been separated into two parts, and penetrating power considered distinct, from a power of

shewing objects of difficult definition, I have acted in the same spirit relative to the less important instruments. Thus, a telescope, having a very large aperture, though of an erroneous figure, will shew nebulae, and clusters of stars, totally invisible by a small telescope of the most perfect kind; and the latter again will, in its turn, shew double stars and other minutiae, which the former would be utterly incompetent to render manifest. In the same manner, an engiscope of a small angle of aperture will define, and shew very exactly, an enamelled dial plate, the *outline* of the brilliant scales of a variety of beetles, animalcules, and an innumerable quantity of common objects, too tedious to mention; but it will utterly fail upon the *lined objects*; while another, having a large angle of aperture, though replete with aberration, will nevertheless shew many of these, (though not so well, of course, as if aplanatic and achromatic;) while, if tried on a dial plate, or a piece of diamond beetle, &c. it will exhibit its imperfections in a most glaring manner, and shew a total deficiency of what I call defining power. There are objects which at once serve to exhibit the perfection of a microscope, or engiscope, both as to defining and penetrating power, provided the *manner* in which they are shewn is duly attended to. Thus, as was first remarked by Mr. Lester, the lined objects, when their outlines and lines, striae, &c. are shewn simultaneously at one and the same adjustment of the focus, both as transparent and opaque objects; and an artificial star, *intensely illuminated*, when it exhibits a *very small* spurious disc, free from coma and rings, &c.

The following aphorisms will serve to express my views relative to the subjects of this memoir.

1. A *test* is an object which serves to render sensible both the perfection and imperfection of an instrument, as to defining and penetrating power.

2. Proof objects may be ranged under three heads: First, those which render manifest chromatic and spherical aberration; secondly, those which give evidence of the presence of a large angle of aperture; and thirdly, those which shew the union of the above properties, and consequently the greater or less approximation of an instrument to its most perfect condition.

3. Chromatic aberration is rendered sensible by almost any transparent object, *when the light falls upon it obliquely*; but more especially by such as are not transparent, but only illuminated by intercepted light, of which a very good example may be seen in a piece of fine wire sieve, treated like a diaphanous object, also in a thin plate of metal, perforated by very small holes. The various colours are seen according to the order of their refrangibility, by putting the object both without and within the focus, as well as by viewing it at the focal point; all brilliant opaque objects also exhibit chromatic aberration strongly, when managed in the same way.

4. Spherical aberration is most sensibly felt in viewing opaque objects, especially if of the brilliant

class ; it shews itself in a variety of ways : first, as a diffused nebulosity over the whole field of view ; secondly, as a confined nebulosity, extending only to a certain distance from the object ; and thirdly, in a want of sharpness and decision in the outline caused by a penumbra or double image, which can never be made to lap perfectly over the stronger or true one. Aplanatism, or a destitution of the aberration of sphericity, is evinced by the absence of these appearances, and by the vanishing of the image immediately the object is put out of focus either way.

5. A deficiency of angular aperture is shewn by a want of light, producing unsatisfactory vision, which is rather increased than ameliorated, by augmenting the intensity of the artificial illumination,—by an incapacity of shewing lined objects, except such as are of the lowest class, and by giving very large spurious discs, with artificial stars ; also by shewing easy test objects, with the lines faint, while the spaces between them are darker and more opaque than they ought to be.

6. When the spherical and chromatic aberration is small and faint, and the angle of aperture considerable, the lines on proof objects become fine, sharp, and dark, and the spaces between them clear and bright, (provided the illumination is properly conducted :) they moreover become visible in a very faint light ; if the instrument is perfectly aplanatic, the outline and the lines are seen at once, as has been already observed, and the spurious discs of all brilliant points are very sharp and small.

7. An instrument, possessing an *aplanatic pencil of 55 degrees*, shews all the easy lined objects anyhow; there is no management whatever required to bring them out; the light may be thrown through them as directly as possible, and still they will not disappear; for in this case the penetration of the optical part is so great as to get the better of all imperfections in the illumination, and to exhibit the object in a manner, *in spite of the illumination, rather than by its assistance.*

8. Notwithstanding this fact, in order to obtain a maximum of distinctness and effect, it is in every case requisite that the illumination should be of the most exact kind; and if the instrument has only an aperture just sufficient to render a particular object visible, it is absolutely necessary that it should be so, to render it visible at all.

9. This illumination consists in causing the light to fall upon the object *obliquely*; moreover, the line of the said obliquity must traverse the system of lines intended to be brought out nearly at right angles, though there are some anomalies in this respect; and the intensity of the light must be such as to produce a maximum of blackness or darkness in the lines, for which purpose a faint illumination, whether the light is artificial or natural, invariably answers best. All condensations by concave mirrors and lenses are hurtful, and cause the lines to assume a faint nebulous appearance, as if drawn with a pencil instead of a pen and ink. There is also another false phenomenon

produced, by condensing light on the plane of the object; for example, on the lozenges, on the scales of the podura, which I have sometimes seen exhibited by such illumination, just in the opposite way to which they ought to be shewn, namely, *with the spaces between the lines dark, and the lines themselves faint*; so that the scale somewhat resembled a sample of the moss hypnum. I have, moreover, seen this style of vision very much admired by connoisseurs. The pieris brassicæ (a superior test object even to the podura), subjected to the same illumination which shews the podura in the manner reprobated, will exhibit only a spotted or mottled appearance, without displaying any one of its four systems of lines; so that a person who had never seen it, and who did not know that it really was engraved, could pronounce, *with certainty*, whether it had continued lines on its surface or not.

10. There is an infinite number of ways in which lined objects may be illuminated, so as to fulfil the aforesaid indications more or less perfectly; but I am of opinion that there is nothing equal to a wax taper placed behind the stage, without any other apparatus whatever\*, both from its simplicity and its very

\* The construction of the aplanatic engiscope, described in the "Microscopic Illustrations," admits of this *modus operandi*. In proof of the superiority of it, it will be found that lines of some sort or other may be brought out in this way on *every one of the scales of the podura*, many of which will be found to resist the penetrating power of the most perfect instruments with any other mode of illumination. The lines on many of the scales are altogether unique, being curved and wavy, like moderately curled human hair.

manageable nature. It is sometimes advisable to put the slider-holder on the wrong way, that is, on the opposite side of the stage to that on which it is customary to fix it, so that there may be no aperture of any description behind the object, which is thus left perfectly exposed to the most oblique ray. This method, moreover, allows the candle to be brought extremely near to the object—an arrangement sometimes, though rarely necessary, with certain objects not of the lined kind. The objective end of the engiscope may then be introduced into the interior of the slider-holder. It is impossible to lay down rules concerning the angle of deviation from direct light, which it is most advisable to employ, in order to bring out any particular set of lines most satisfactorily; this must be left to the *taste* of the observer: neither can the distance of the candle from the object (on which the intensity of the illumination depends) be determined, so as to meet the views of every microscopist; from two to six inches may, however, be roughly stated. *Whatever distance, and whatever degree of obliquity, brings out the lines darkest, and the spaces between them clearest, according to the vision of the individual who uses the instrument, is the best* \*.

\* In order to procure specimens of lined objects in the best possible state for observation, it is recommended to naturalists to steep the insects from which they are derived in sulphuric æther; this dissolves the grease which frequently tarnishes and clogs up their minute lines and markings, while it accumulates and licks up dust, &c., thus rendering them unfit for observation; on removing the insect from the fluid the æther will evaporate rapidly, and leave it dry, when the scales may be removed.

The following rule will serve to shew when the light is direct, and when it is oblique. If the penumbra of the object, when put out of focus, appears stationary, and *to go within and without the focus without changing its position, the light is direct*, supposing the object glass to be in adjustment; *but if it seems to travel from one margin of the field of view to the other, then the light is oblique, and the direction of it is in the line in which the object seems to travel.*

11. When daylight is used (which can never be rendered equal to artificial light by any arrangement, at least for lined objects, with any sort of instrument), vision is much improved by the use of diaphragms: these, however, *are inert, unless the image of them in the visual pencil is less than that of the aperture of the object glass, or magnifier, with which they are used*: for example, if we put a diaphragm one-twentieth of an inch in diameter in the focus of a one-twentieth of an inch lens, having also one-twentieth of an inch of aperture, or, of course, in one of shorter focus, *because the aperture of the lens, when viewed by a magnifier, will be found illuminated throughout its whole extent, just as if no diaphragm was used*; but, when it is placed out of the plane of the focus, say half, or three-fourths of an inch off, then its effect will be very decided. In this case, it reduces the intensity of the illumination, and prevents faint objects from being drowned in an excess of light, while the darkness and strength of all the markings of the object are decidedly increased; it moreover seems to improve the oblique pencils of any

instrument, and renders spherical aberration, if not very strong, almost insensible. In fact, *the quantity of light in the visual pencil is reduced exactly in the same manner as if the aperture of the object glass or magnifier was cut off to the standard of the image of the diaphragm seen in it.*

12. There is no modification of daylight illumination superior to that invented by Dr. Wollaston, provided it is used in a proper manner, whether the object is of the lined or proof kind, or not. In order to obtain an effective oblique light with it, it is necessary that the axis of the optical part of the instrument should not be in the same right line with the centre of the perforation, but deviating considerably from it, which gives oblique light in a line drawn from the centre of the aperture of the lens, or doublet, or visual pencil in an engiscope, to the centre of the image of the perforation in it. An engiscope, treated with this system of illumination, shews, in the margin of its visual pencil, a round image of the diaphragm, but, in plano-convex, single, or compound magnifiers, with their plane sides towards the object, this image assumes a semilunar figure. The intensity of the illumination is regulated by the distance of the image of the perforation, or of the focus of the illuminating lens, from the plane of the object; and if the light of a southern window, on a bright day, is employed, the instrument will be found to perform best, when it is made equal to about half or three-fourths of an inch; the intercepted light in this method is divergent. The modification of Dr. W.'s illuminator, contrived by me,

which has a real diaphragm, instead of the image of one, has an advantage over the original construction, in being more portable, and in adapting itself easily to any construction\*.

13. There are certain classes of objects which can never be seen completely well with artificial light of any kind,--such are animalcules and aquatic insects, the hairs of a variety of animals, mosses, the tissue of *confervæ*, and an infinite number of common objects. When it is necessary to exhibit them by candlelight, they are best seen with the flame very close to them, as already described; or if the construction of the instrument admits not of this arrangement, then, by rendering the illuminating rays parallel, by a bull's-eye lens, and afterwards reflecting them by a *plane* mirror, and using diaphragms under the stage, any condensation, by destroying the parallelism of the rays subverts the effect of the bull's-eye lens, and will be found prejudicial. I think, moreover, that when the construction of an instrument does not admit of the position of the flame of a taper behind the stage, this is, perhaps, the next best way of bringing out the lined objects; but the taste of mankind in such matters varies incessantly; every man may be said to see best in his own microscope, &c., and in his own way too, be it what it may.

\* A small hand microscope could be made with an illuminator of this description, which might be used by simply presenting it against the sky; *an equestrian might examine test objects with it on a rough-trotting horse*; a snuff-box might moreover form part of its case, and the whole concern termed *a microscopical snuff-box*, which, both with regard to price and size, would adapt itself to any man's pocket.

14. Single and compound magnifiers, as they exhibit the real object, instead of an image of it, do not require so exact an illumination as engiscopes, and are therefore more easily managed by the inexperienced. An engiscope is always very fastidious and ticklish as to its illumination, no error in which can be committed without seriously injuring its performance. Thus, *whatever illumination will suit an engiscope, will be sure to suit simple microscopes and doublets*; but what will suit the latter pretty well, will by no means accord with the former.

15. Opaque objects sometimes require an illumination by means of cups, and sometimes only the natural light of the atmosphere, or of a small wax taper, or rushlight, placed before the stage, as near as may be to the object. With the latter species of illumination the lines on the scales of beetles and butterflies are, perhaps, best brought out; sometimes, however, a condensation, by means of a lens, is more effective. They can never be seen well with cups, which give an intense direct light; this, however, exhibits flies' feet, and other opaque objects of the same nature, with the highest effect.

16. The verification of the real nature, form, and construction of a vast variety of opaque objects, which elude the sense of touch by their extreme minuteness, can only be made out by an attentive study of their appearances under a variety of methods of illumination, conjointly with a consideration of the phenomena presented by bodies when seen in perspective, or, as

painters term it, foreshortened. We are particularly perplexed in microscopic observations, by the circumstance that only a point of an object can be seen at a time, if the power used is considerable; we must, therefore, always begin to study them with low powers at first, and increase them gradually, so that we may always be able to recognize the particular part of the object we are looking at, otherwise all will be confusion. When we see an opaque object represented by a drawing, we see it as it never can be seen by a microscope, because, in the latter instrument, its various features can never be in focus at the same time, as before observed, and it would be impossible to represent it on paper exactly as seen at a variety of adjustments, without an infinite number of views of it.

I particularly recommend observers, in examining and verifying opaque objects *too small to be dissected*, to use the simple light of a candle before the stage, as its divergent rays bring out more strongly their various component features, and render them more intelligible than can be done by any other method. The oblique light of the taper plays over their various prominences and depressions like that of the evening sun over common objects, giving broad lights and shadows; and, if the observer has any knowledge of the operation of light, and the manner in which it is broken and intercepted by ordinary bodies, he will hardly fail to arrive at a tolerably clear idea of the nature of the minutiae he is contemplating. The light of the sun must never on any account be used,

as it gives rise to an infinity of indescribable deceptions, both as to colour and form ; it renders every opaque object a mass of confusion.

17. There are a variety of optical deceptions produced by microscopes and engiscopes, against which observers cannot be too strongly guarded, as inadvertent persons have brought great disgrace on microscopic science by trusting too much to the testimony of their instruments. It requires long and repeated observation to enable us to be quite certain of the nature of what we see : for—1st, we are seldom or never in the habit of viewing common objects by *intercepted light* ; vision by it is therefore altogether new to us, and the phenomena presented by bodies subjected to its influence are totally different to what they assume as opaque bodies, which is the usual way in which we see common objects ; — 2dly, all microscopic vision may be considered as accomplished under very large angles, which is again a totally new way of seeing to the uninitiated. The object is in a manner placed in a most unnatural state of proximity to the eye, and consequently assumes a totally different character to that produced by objects at our common visual distance, which must inevitably perplex us till we become habituated to it. There is one general law to which all transparent objects are subjected ; namely, that those parts which appear brightest and clearest in them, are almost invariably the *thinnest* ; a want of transparency nearly in every case argues thickness and substance. Much may be done towards their verification *by examining sections*

*of them as opaque objects\**, where this is practicable; and care should be taken *never to view them both as opaque and transparent bodies at the same time*, as this is sure to produce deception, and on this account they should be shaded from all incidental rays. Their true colours can never be seen properly by high powers: in order to ascertain them correctly, a low power should be employed, with the light of the sun reflected by a plaster of Paris disc †.

Observers should study the effect of intercepted light on ordinary transparent bodies, of the real nature of which there can be no doubt, in order to be able truly to appreciate microscopic phenomena. There are a number of glass toys made, which will make very good subjects of this description; and so do ordinary glass tubes, and solid rods of glass—the former being filled with other transparent objects, and afterwards with water. We frequently meet with bodies in transparent objects which operate like lenses on surrounding objects, of which they form

\* EXAMPLE.—In examining the eye of a libellula, which had been long kept, with the light of a taper behind the stage, I was much surprised to find that its lenses gave erect images of the candle instead of inverted ones. I therefore made a section of it, and examined it as an opaque body, and thought that I ascertained in this way that *the lenses had become concave instead of convex*, from collapse, or from the drying up of the substance between their exterior cases or laminæ. I have attempted to treat lined objects in this way, but could never succeed in developing their mysterious tissue, owing to their extreme minuteness.

† Vide the description of this piece of apparatus in the Microscopic Illustrations, p. 42.

miniature images, very remarkable to those who are not aware how the effect is produced.

In short, we must consider, that in all bodies viewed by intercepted light, there is, properly speaking, neither light nor shade, in the ordinary acceptance of these terms; there are only dark and light parts, which again assume new aspects as the light is more or less direct or oblique. Thus depressions on transparent objects are almost sure, under the action of oblique light, to assume the effect of prominences; but prominences seldom or never the semblance of depression. As almost all diaphanous bodies can be examined as opaque objects, a scrutiny of them in this way will generally be found greatly to assist our judgment concerning their nature, whether they admit of being cut into sections or not. It would be easy to write a volume on this subject only, if we commenced an illustration of particulars which could not be rendered clear and satisfactory without a vast number of figures. Long practice must after all determine our opinions, and scepticism should ever form a leading feature in them; we should *suspect rather than believe*.

18. Opaque objects are not upon the whole so liable to produce optical deceptions as transparent ones, because we are more in the habit of viewing ordinary bodies by reflected or radiated light. The most common illusion presented by them is that of shewing a *basso-relievo* as an *alto-relievo*; the reverse deception sometimes occurs also, but more rarely.

This effect occurs in ordinary objects viewed by the naked eyes, as well as in microscopes, especially if but one eye is employed\*. Thus, if we look intently for some time at a basso-relievo (a die of a coin, for example), *illuminated with very oblique light*, it at first appears in its true character; but, after a little while, some point on which we more particularly direct our gaze will begin to appear *in alt*, the whole rapidly follows; in a little time the effect wears off, and we again see it in bas-relief; then again in alt; and so on, by successive fits. This deception arises from the simple circumstance that *the lights and shades in bas-relief are very nearly like those of an alto-relievo of the same subject, illuminated from the opposite side*; our understanding in this case instantly corrects the false testimony of the eye, when we *consider from which side the light comes*. (If we observe with an engiscope, we must always remember that its image is inverted, and that in consequence the light must be considered as proceeding from the side of the field of view opposite to that where the source of illumination actually exists.) It will also be highly advisable, when we are in doubt as to the

\* The angle formed by the convergence of the two axes of our eyes directed to any particular object, the distance from eye to eye being the base of the triangle, enables us to judge pretty accurately of the distance of near objects; but, if only one eye is used, of course our measure of distance is gone. Now, as the distance of a depression below or beyond a given plane must always be greater than that of an equal elevation above or within it (*cæteris paribus*), we are naturally less likely to be deceived when we use both eyes than when one is rendered inactive, as must be the case in all optical instruments not of a binocular construction.

manner in which an instrument shews prominences and depressions, to verify its vision by observing some *known object* with it, of the real state of which, as to inequality of surface, we have been previously informed by the sense of touch, to which it has been well said there is no fellow\*.

19. Illumination, by cups or silver specula, does not produce these illusions, because they create no shade—the whole object is one mass of intense light; other false perceptions are, however, occasioned by them. Thus, all globular bodies, having polished surfaces, reflect an image of the cups, and the *pout*, if there is one, appears as a dark spot in the centre. The eyes of insects, illuminated in this way, shew the semblance of a pupil in the centre of each lens, which deception may be verified by examining small globules of mercury in the same manner. Spherical bodies, with bright surfaces, will even, on some occasions, reflect an image of the object-glass and its setting, on the same principle; so that we must perpetually consider the laws of the refraction and reflection of light, in all the conclusions we draw from the evidence even of the very best instruments, used with every possible precaution.

20. Lastly, it must be observed, that in using engiscopes, we must never attempt to verify an object

\* We usually see objects illuminated from *above* with the *shadows below* the prominences: now, unless the light is below an opaque object, when we view it in an engiscope, we shall see the *shadows above*, giving the prominences the appearance of depressions, and producing a very unnatural effect.—A. P.

concerning which we are uncertain, by increasing the depth of the eye glass immoderately, so as in this way to obtain a very high power. A negative eye-glass, of about one-fourth of an inch focus, is the deepest which should ever be employed, even with a short body; for an engiscope only shews a *picture* of an object, and the more it is amplified the more its imperfections are developed. It is, on this account, much safer to trust to moderate powers in these instruments, in preference to high ones, *unless they are obtained through the medium of the depth and power of their objective part*. It is the nature of deep eye-pieces to cause all luminous points to swell out into discs, and to render the image soft, diluted, and nebulous; at length all certain vision fades away, and the imagination is left to its uncontrolled operation. Single and compound magnifiers, having to deal with the real object, may be made of any power which can be used; and if our eyes are strong, and habituated to their use, we may place great reliance on their testimony; but we must never allow them to persuade us to believe marvels which are manifestly impossible, or contrary to the known laws of nature and right reason.

## CHAPTER XIX.

*An exact Method of appreciating the Quality of  
Microscopes and Engiscopes, &c.*

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BY C. R. GORING, M. D.

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AT the present epoch, it appears absolutely necessary that the public should be put in possession of some exact means of appreciating the excellencies and defects of microscopes and engiscopes. It is true that the proof objects originally discovered by me are sufficient for that purpose *in honest hands*, and when used with the precautions I have pointed out. But it is well known that they have been shamefully abused, owing to the various facilities of resolution which exist between different specimens of lined objects, the external characters of which closely resemble each other; so that it may be said that *these are proof objects, to suit the capacities of all sorts of microscopes*; nay, they are actually perverted to the purpose of deceiving the unscientific part of the public in a much

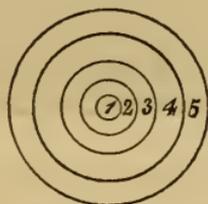
more effectual manner than could possibly have been done without them ; moreover, the works of superior artists, such as metals of the most exact figures, and *aplanatic* object-glasses, having their aberrations balanced with the most exquisite nicety, are totally unappreciated by the mass of observers, who nevertheless fancy themselves perfect judges of the merits of all sorts of instruments by the help of samples of spurious lined objects.

The art of working metals and object-glasses is one of extreme delicacy,—I know of no parallel to it ; it ought perhaps to be called one of the fine arts, for it ultimately consists in producing, though indirectly, the most exact pictures of objects which the imagination can possibly conceive. No injury, I think, can result to the interest of superior opticians by giving the public the power of perceiving the excellency of their productions. Inferior artists, however, who can produce nothing good, will naturally love darkness rather than light—and for why?—truly, because their works are evil. If the public had no certain means of knowing the exact rate of the going of chronometers, how could the makers of them expect to be remunerated for the better sorts according to their real value? and if a workman is not content to be paid for his instruments according to the quality of them, be it what it may, all that can be said, is, that he must be both a knave and a fool. Very fine optical instruments of all sorts are exceedingly scarce, and ought to be exceedingly valuable, as will be seen hereafter.

I shall now proceed to lay down certain self-evident propositions relative to the metals and object-glasses of engiscopes, which, simple as they are, will be found sufficient to place the reader in possession of a key to the knowledge of what is good and evil in these instruments.

1st. In all object-glasses and metals the main body of the light comes from the periphery, and not from the centre; so that if they are divided into a number of annuli of equal breadth, those which are farthest removed from the centre must inevitably, from their greater size, reflect or refract the greatest quantity of light, (see 1, figure 1, and the rings, 2, 3, 4, 5); the outside rays, therefore, are by far the most important, and their condition must be particularly attended to in judging of the merit or demerit of any optical instrument. The inside rays, *if taken very near the centre*, exhibit no sensible aberration, however bad the object-glass or metal may be, as, for example, the little disc in the centre of figure 1, marked 1.

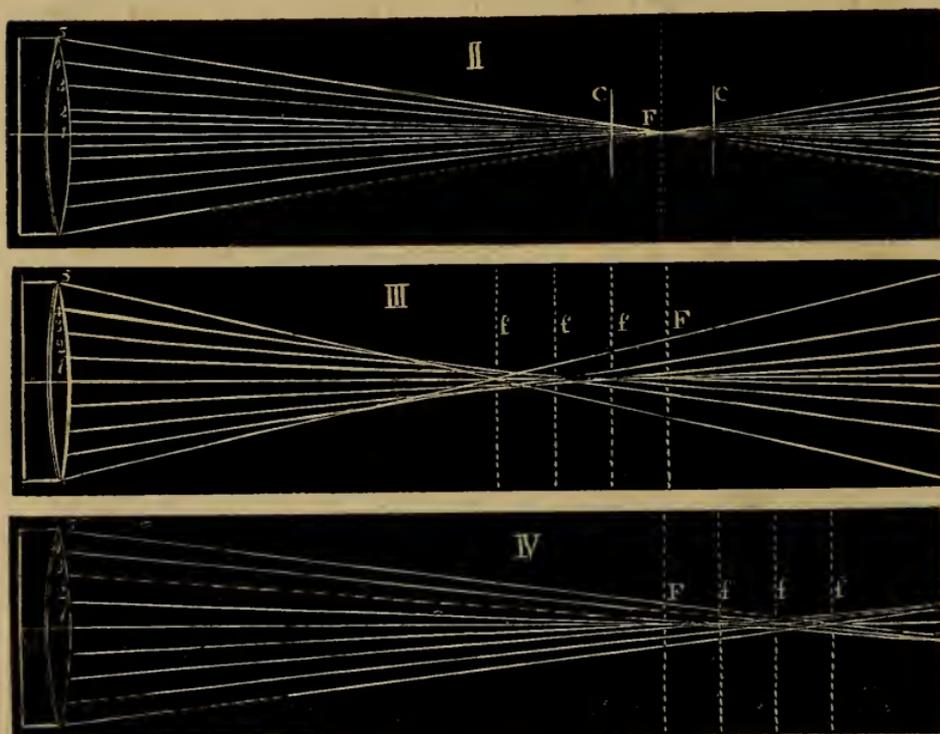
*Fig. 1.*



2dly. Every perfect object-glass and metal draws every pencil of light forming the image to a perfect point, see F, figure 2; consequently *the rays must*

*be in the same state, and there will be the same degree of brightness and intensity of light, both within and without the focus, at any two given points, as C and C, equidistant from the focus either way\*.*

3dly. Imperfect metals and object-glasses have their outside rays either shorter or longer than those which form the principal focus; in which case it is evident that if the marginal rays are too short the chief condensation of light will take place within the focus F,



\* The reader must not suppose that I mean to assert that there is not exactly the same *quantity* of light at any point taken from the object-glass or metal, &c to an infinite distance from it, under every possible circumstance, both of aberration and of freedom from it. What is asserted relates only to the *distribution of the rays, or to their state of condensation or diffusion.*

figure 3, at the points  $f f f$ : if too long, then without the focus, at the points  $f f f$ , figure 4, beyond the principal focus  $F$ . To these defects may be associated inequalities produced by irregular working, frequently giving rise to two or more curves in their surfaces.

4thly. Object-glasses are subject to imperfections, arising from an imperfect correction of their chromatic aberration\*; for example, they may be under or over corrected; that is, the concaves of flint glass applied to them may be either of too shallow or too deep curvature to produce correction, both of which defects are nearly equally injurious to them; nor can their colour, strictly speaking, ever be totally subdued, owing to what opticians call the irrationality of the coloured spaces in the prism producing what is termed the secondary spectrum; moreover, their component lenses may be imperfectly centered, and their curves not spherical; and, to crown all, they may be out of adjustment.

5thly. All spherical metals and common convex glasses, may of course be roughly considered as *very much under corrected*; accordingly their outside rays are well known to be much shorter than the inside ones, when acting either with parallel or diverging light; the colour of the glasses may also be considered as *very much under corrected*, being, indeed, in its primitive state of dispersion. Now this simple proposition will, in the sequel, conduct us to the knowledge of the discriminating characteristics of

\* Readers unacquainted with this subject are directed to the works named in page 102.—A. P.

object-glasses and metals in all states of correction and aberration ; for example, those of an object-glass over corrected both for sphericity and dispersion must inevitably possess exactly opposite characters to one under corrected, while one which is perfect will be neutral in the phenomena which it will exhibit, and resemble neither. In order to discover the state of the rays both within and without the focus, we must of course put the lens, object-glass, or metal, out of focus, and we shall discover the state of the rays both as they advance towards and recede from the focal point. We may confirm this method by using a common lens of *large angular aperture*, to form an image of the sun, or of a candle, on a piece of rubbed glass, and observing the state of the rays upon it as they approach or pass off from the focal image, when it will be found that the image within the focus will resemble figure 9, plate 13, with the addition of a luminous spot in the middle ; that without it figure 7", and the focal one figure 7'. In this case parallel rays are of course employed, and the aberration of the lens will be greater with them than with diverging ones ; but the image of a radiant point formed by a solar microscope, with conjugate foci, of the same length as in an engiscope, is a case in point, and will be found to present a very similar result.

The following are observations made upon the chromatic and spherical aberration of a plano-convex lens of nine-tenths of an inch focus and four-tenths of an inch aperture, with its plane side towards the radiant, employed as the object-glass of an engiscope, having an achromatic Huygenian eye-piece. The objects used were,

first, a piece of watch-dial plate, with figures enamelled white, upon a black ground, see figure 5'; and secondly, artificial stars formed by crushing a globule of mercury with a piece of iron on a slip of black glass, so as to form very minute spheres of quicksilver, reflecting the light of the sun, a candle, or a window, at the pleasure of the observer, (see figures 5, 6, and 6'.)

#### SPHERICAL ABERRATION.

1st. Dial Plate.—There is a strong nebulosity diffusing itself around the borders of the white figures, and extending to a considerable distance from them, so that they are very ill defined, (see figure 7'''); when put out of focus, the following phenomena present themselves. The principal condensation of light is not at the focal point, but within it; beyond the focus it is evidently much fainter than at the focus; the field of view is manifestly brighter within the focus than any where else. Some still more remarkable peculiarities present themselves to the close observer, as the image vanishes both within and without the focus;—thus the object may be *put a certain distance beyond the focus without disappearing*, which, however, it ultimately does, *enveloped in a strong fog*; within the focus it may be said to disappear instantly, but quite in a different manner from what it did beyond the focus, for the white figures swell out at the edges, *forming a penumbra, or well-defined border*, without any nebulosity about it, (see figure 8'''.) It is evident that there is *no diffusion of light within the focus*.

for the black ground of the enamelled plate appears quite black.

On applying Dr. Brewster's monochromatic lamp, the fringe of prismatic colour, which was mixed up with the foregoing phenomena, disappears, and allows them to be more distinctly seen.

2d. Artificial Star—used with the light of a window.

The appearances exhibited by the dial-plate are confirmed, and rendered still more striking, by this brilliant object. In focus there is a strong coma surrounding the miniature image of the window seen in the globule, and extending to a considerable distance from it, so that the outline or figure of the globule cannot be seen (figure 7.) *The globule may be put some distance beyond the focus without causing the spectrum of the window to disappear, which it does at last, in a diffused nebulosity, (see figure 7".)* Within the focus the light of the window *instantly swells out into a circular disc*, the light of which is much more intense at the periphery than any where else, (see figures 8' and 9); it decreases as it approaches the *centre*, where there remains, however, *a strong luminous point*, (figure 8'.) There is no diffusion of light, for the *disc is perfectly well defined*, and the *black ground quite black close to it*, continuing so for a long way within the focus.

On applying Dr. Brewster's monochromatic lamp, the strong annuli of colour, confounded with the spher-

rical aberration, disappear, and leave a yellow disc; a new phenomenon now becomes visible, before hidden by the chromatic aberration, viz. the appearance of an infinite number of concentric annuli in the disc of light formed by the globule (figure 8'); they are perfectly regular, and increase in brightness as they spread away from the central point of light.

On examining the aforesaid objects, in and out of focus, with a *spherical* metal of the same focus and aperture (used without a plane mirror, by merely placing the dial-plate and star in its focus), the same phenomena, as to spherical aberration, are seen much more distinctly, because, in this case, there is no chromatic confounded with it; the aberration is, however, evidently far fainter. The spherical aberration of metals follows the same law as that of object-glasses, and is represented in figures 3, 4; when too spherical, they have the condensation described within their focus; but when too flat at the edges, or beyond their true figure (which is an ellipsis for the engiscope)—for example, supposing them to have become parabolical, hyperbolic, or ultra hyperbolic—then *their outside rays will become too long*; they may be considered as over corrected, and in this state present the same phenomena as an over corrected object-glass; that is, the principal strength and intensity of the light will be beyond the focus, and the diffusion will take place within it, as represented in figure 4. The indications of over correction will be more particularly dwelt upon hereafter. On cutting off the aperture of the nineteenth plano-convex lens to three-fortieth of an inch, the

spherical aberration becomes insensible, unless the light of the sun is used, and the distinctness as perfect as the want of light will permit.

We may now obtain from it the characteristics of an object-glass of very small aperture, free from spherical error, which are as follow :—There is the same strength and intensity of light within and without the focus evinced both by its action on the dial-plate and on the artificial star. There is no diffusion of light either within or without the radiant point ; the objects are perfectly well defined without coma or nebulosity (see figures 6, 6', 6'') when in focus, and vanish, exhibiting alike a penumbra in the case of the dial-plate (figure 8''), and a circular disc (figure 9) in that of the artificial star when put out of focus either way.

#### CHROMATIC ABERRATION

Can never be seen in perfection until it is fairly separated from spherical. It is amusing to see how the two kinds of aberration mutually keep each other in countenance.

The same nine-tenth plano-convex lens, already described with the same aperture, is used in the following observations on the aberration of colour or refrangibility ; the object is rather a large globule of quicksilver, and the illumination that of a southern window on a bright day (figure 6.)

*In focus.*—The image of the window is seen tinged

with orange light, which is encircled with a diffused disc, of a greenish yellow, extending to some distance from it. This halo is surrounded by a margin of a brighter and stronger green, which is succeeded by a blue, indigo, and purple annulet, gradually melting into each other, as in the prism, beyond which the black ground on which the globule of quicksilver was placed, becomes visible.

*Phenomena beyond the focal point.*—These may be rendered sufficiently intelligible by observing that on putting the globule beyond the focus, the colours already enumerated are still visible in the same order and arrangement as before, but fainter, because the discs or halos gradually swell out and become spread over a larger surface, and at length totally disappear in nebulosity.

*Appearances within the focus.*—On bringing the globule a *little* within the focus, the warm colours instantly present themselves; thus the image of the window is now of a bluish tint, and around it is a disc of bright yellow, succeeded by an annulet of orange, passing into one of strong crimson, which is again surrounded by nearly the same colours before described as visible at the focal point, viz. borders of bright green, blue, indigo, and purple, blended gradually together. If, however, the globule is brought *considerably* within the focus, then the following change takes place; the image of the window disappears altogether; in lieu of it is seen a central disc of purple, gradually shaded off into bright blue, which is con-

tained within borders of colour, in the following order—green, yellow, orange, and red, which continue in the same state for a long way within the focus, until they disappear altogether. By cutting off the aperture to three-fortieths of an inch, the colour becomes insensible, unless the globule is illuminated by the light of the sun. The same phenomena are more faintly exhibited by a dial-plate, treated in the same manner as the globule, and indeed by all objects, more or less.

As it would be exceedingly difficult to give an exact pictorial representation of the phenomena of chromatic aberration, it has not been attempted.—The spherical and chromatic aberration of all single and compound magnifiers may be tried in the methods already pointed out, by merely looking through them at an artificial star or dial-plate, &c., provided always that *their focus is not so short as to preclude the illumination of the objects in the manner indicated, and that there is room to put an object sufficiently within their focus to cause the phenomena* I have detailed to exhibit themselves; but this is an operation of extreme delicacy, and requires the sharpest and most practised eye to attain any certainty as to the result.

We thus obtain the characteristics of *uncorrected* and *under-corrected* object-glasses and lenses, both with regard to spherical and chromatic aberration, and moreover those which denote the absence of both, constituting a state of aplanatism and achromatism.—What we now want to know, are, the distinguishing

marks of objectives and lenses when *over corrected both for sphericity and refrangibility*, for this state must inevitably often occur, as it is quite as easy to cause the application of a correcting concave lens of flint glass to operate too strongly as too weakly, and exceedingly difficult to make it exactly neutralize the errors of one or more convex lens, without falling short of or surpassing the true mean.

First, then, with regard to spherical aberration, it must be evident, by a bare inspection of figure 4, that, in the case of over correction for sphericity, the conditions before stated relative to an uncorrected lens or object-glass must be more or less reversed; that, as the main body of the light will be thrown beyond the focus (F), where there will be no diffusion of light, as at the points (f f f), but a certain diffusion within the point F, or principal focus; as it is known to be very easy to ascertain both the figure and focus of a concave of flint glass requisite to over correct a given convex of crown or plate, this method has been resorted to in order to procure data as to the phenomena which it will produce when in combination with a convex too weak for it, which are as follows:—First, there is a diffused nebulosity at the focus, (see plate 13, figure 7<sup>'''</sup>, dial-plate); (figure 7, image of a window in a globule of mercury); (figure 7', ditto, with the image of the sun), but not so extensive as in the case of the uncorrected lens; figures 8' and 8<sup>'''</sup> now represent the appearances beyond the focus, and figure 10 those within it, consisting of a strong burr, with annuli in the centre, which are but barely visible in a small

globule on a bright day, and not to be recognized at all in a large one in dull weather; all fully confirming the testimony of figure 4. The indications caused by over correction, for colour, will be rendered evident, by a consideration of the fact, that, if a prism of flint glass is made so powerful as completely to get the better of another of crown or plate applied to it, so that their refracting angles shall be opposed to each other, the dispersion of the flint one will alone be perceptible, and the colours will in consequence be refracted in the contrary order to that in which they would have appeared had the prism of plate or crown an equal mastery over the flint one. As the analogy between prisms and lenses is nearly perfect as to refractibility, we may therefore assume that the same phenomena will be presented by lenses under similar circumstances, and the order of the colours already described will therefore be reversed within and without the focus, in cases where over correction has occurred; and this fact may be very easily verified, like that relative to spherical aberration, by applying a concave of such a focus and specific gravity to a convex as we know must infallibly prove an over-match for it; therefore we have only to repeat that the phenomena already stated under the head of chromatic aberration will apply more or less to all states of over correction, *by reversing the appearances stated to exist in an ordinary lens within and without the focus*; that is, the warm colouring will be found beyond the focus, the cold tints within it; *red, orange, and yellow, without; blue, indigo, and purple, within, &c.* As to achromatism, it must always speak for itself, being

an absence of all colour (save that of the secondary spectrum, which is imperceptible in small object-glasses), both at the focus and within and without it.

MISCELLANEOUS DEFECTS OF OBJECT-GLASSES  
AND METALS, &c.

These chiefly consist in inequalities produced by bad working and bad adjustment, all of which may be looked into by putting them out of focus. Thus fig. 11, plate 13, represents the appearance presented by a metal or object-glass, the figure of which has not been properly preserved in the working, though perhaps the spherical aberration may be but trifling. If we take an example of a metal, we shall suppose that its figure has been truly generated by the revolution of some conic section, but that it has afterwards been rendered unequal in different places, either in the polishing, from being kept too long on the tool, or made so on purpose, by abrading its surface in different places. In this case the contour of the disc is irregular, and the annuli correspond with it, but generally become truer as they approach the lucid point at the centre. But the reader must recollect, that, when a metal operates along with another, there will be a shadow of the small one, and its arm projected on the disc, as at figure 8", which represents the appearance of the Amician reflecting engiscope, shewing an artificial star out of focus: the same observation will apply to all discs generated by reflecting instruments.

By observing what part of the metal it is necessary to cover, in order to obliterate the image of some irregular part of it, the identical portion of its surface which is in fault may be discovered and amended.

These irregularities are chiefly observable in object-glasses and metals of small angles of aperture. It would be useless to specify all the varieties of error which may occur; but an oval disc is perhaps the most common.

Sometimes, in the process of working, two or more curves are generated in place of one, or it may be several curves of the same figure and focus which do not bear upon one focal point; in this case, the metal or object-glass shews two or more discs, which do not lap over each other, as at figure 12, and in this way give a false contour, but which may always be discriminated from figure 11, by observing the direction of the annuli, and the outline of the overlapping discs.

The figure of concave lenses may be tried upon the same principle as metals, for they will reflect enough light from a real or artificial star to allow us to judge of the nature of their curves. When a plane metal operates along with a concave one, as in the case of the Amician reflecting engiscope, an irregularity in the outline or contour of a disc out of focus is sometimes generated by an imperfection in the surface of the former, which may be known by trying the concave on a lucid point *by itself*, when, if the plane one only is in fault, of course the irregularity of the disc

will disappear. The state of a plane reflecting surface as to exactitude may be known by observing the manner in which it reflects the image of some regular-shaped body (a right line is as good as anything), placed a distance from it, the eye being also considerably removed from the metal; and still better by adjusting very exactly the focus of a telescope upon some distant body, and then reflecting an image of it by means of the plane metal to be tried (which is to be placed at some distance from the telescope), and viewing the same object again in the telescope, when, if the plane metal is perfect in point of figure, *no difference of adjustment will be required to produce distinctness.*

#### IMPERFECTIONS IN CONCAVES OF FLINT GLASS, &c.

These rarely occur in the small lenses used for the object-glasses of engiscopes; they may be seen when they exist, by adjusting the instrument upon some lucid point, and then removing the eye-piece and looking at the object-glass with the naked eye, when the striæ in it will become manifest; also by holding it up and causing it to form an image of a candle, so close to the eye that the whole disc of the lens shall appear illuminated, which will be when the image of the candle falls on the cornea; defects of polish and impurities, and rudeness, &c. in the cement uniting glasses, will become evident by holding the lens so that the light of a candle shall fall *obliquely* upon it, and may be farther verified by examining it as a microscopic object.

A flat piece of flint glass may be examined by looking through it in the direction of its thickness, also by cementing a plano-convex lens of plate glass to it, so as to give it the power of refraction, as if the whole was a solid object-glass, and treating it accordingly.

#### POLARIZATION OF GEMS AND JEWELLED MICROSCOPES.

The polarization of precious stones may be seen by working a small portion of them flat, to which a small aperture may be cemented, through which a candle must be viewed in a dark room; when, if there is no polarization, but one image will be visible; but more than one, if it exists. A plano-convex lens may also be cemented to a plate formed from a precious stone, and the effect tried in this way, on a bat's or mouse's hair, which will present several images, if double refraction is present; or the whole may be made to form a miniature image of a candle, as the object-glass of a little telescope, which will give only one image of the taper, if the refraction is single. A plate of gem may moreover be tried as to polarization, by placing it between two tourmalines, which will be sure to exhibit the two or more polarizing axes, as spots of light, surrounded by halos, &c.

The polarization of lenses of gem may always be seen, by trying them on a bat's or mouse's hair, which will be sure to give more than one image, where it exists; crystallizations and flaws are best seen by

examining them as microscopic objects with oblique candle-light; they moreover produce a muddiness in the vision of all objects, but are not necessarily associated with polarization.

#### CENTERING OF LENSES.

The centering of a lens may be suspected of inaccuracy when it is impossible to bring an object-glass into which it enters as a constituent part into adjustment, (supposing that there is no fault in the turning of its setting); in which case its component annuli will not be concentric with each other, nor will the lucid point at the centre of the disc be truly in the middle of it, but give an appearance as at *a*, 14. Convex lenses are seldom ill-centered, but concaves frequently are. The former, in this state, have not their maximum of thickness—nor the latter their's of thinness at the centre.

#### ADJUSTMENT OF OBJECT-GLASSES AND METALS.

Bad centering may be confounded with, or mistaken for, bad adjustment, and *vice versâ*. When an object-glass is out of adjustment, its component lenses are not so posited in their setting that their axes shall be in one right line, which must moreover coincide with the axis of the tube in which they are fixed. This defect is easily known, by observing the position of the luminous point in the centre of the discs they generate, which, if perfectly central, indicates perfect adjustment, while the degree of its eccentricity

denotes the magnitude of the error in this particular: thus, (13) shews the phenomenon presented by a triple object-glass thrown violently out of adjustment; and (b, 14), another disc, of a similar description, but more out of focus. In observing for adjustment, it is especially necessary that the object employed should be placed *exactly in the centre of the field of view*, for it is impossible that an object glass can be *rigorously* adjusted for more than one pencil. This may be either a direct or an oblique one, as we please; but it is impracticable to make a *perfect* adjustment for one pencil consist with a *perfect* adjustment of another; for whatever part of the field of view the adjustment has been effected, there the maximum of distinctness will be found. The state of adjustment may moreover be determined upon by using the rings 5' on a dial-plate; if it is perfect, it will be well represented by 8''', where the penumbra goes off equally on all sides of the ring alike, leaving a dark central spot, and a true circular figure at the margins. The adjustment of metals with each other is denoted by precisely the same phenomena as that of object-glasses, always allowing for the effect of the shadow of the small metal and its arm.

N. B. The indications given by large globules of quicksilver frequently differ widely from those given by small ones, *in all respects*. We may term a globule large when it is visible to the naked eye, as at (5); small, when it is not. Thus, a large globule, giving an image of a window in focus, will, when put out, present only a disc, like (9), without annuli, growing

gradually brighter towards its periphery, while a small one will give only a disc, as at (6'), in focus, and exhibit annuli and a central spot out of focus, as at (8); (9) will perhaps shew no difference of aspect, when put out of focus, either way, with some particular object-glass or metal, but (8) instantly will. *The large globules are best to exhibit chromatic aberration, but for every other purpose it may be laid down as a maxim, that small globules, strongly illuminated and put but very little out of focus, are most to be depended upon.* Thus, an instrument will appear to be in perfect adjustment, if a globule is put a good way out of focus, but far from it if only very little.

There is sometimes a discrepancy between the evidence given by a dial-plate and an artificial star; an instrument will appear quite perfect, and destitute of aberration, when tried only by a dial-plate, but considerably in error when submitted to the ordeal of an artificial star. I believe, in such a case, it may be considered that it is *perfect for all practical purposes, if it shews the dial-plate in a proper manner in and out of focus*; for aberration and all other imperfection must be considered as of a relative nature. For example, an instrument may be said to aberrate when applied to some intensely luminous point; but not so when viewing an object of the ordinary degree of brightness; or it may aberrate with an opaque, but not with a diaphanous body; artificial stars must therefore rather be considered as a theoretical than practical test of the goodness of an instrument, which

must always be considered as made not for viewing these fastidious niceties, but the ordinary run of natural objects. Telescopes have been made which have shewn stars, both natural and artificial, in the most exquisite manner, while their performance on the planets and other objects has been very indifferent, and by no means equal to that of other instruments of the same class, which failed in exhibiting stars in a satisfactory manner. Engiscopes are certainly to be met with which leave nothing to be wished for or desired in their performance on natural objects, which nevertheless show much imperfection in their operation on luminous points. We must never forget, that as man is an imperfect being himself, so all his works partake of the imperfection of his organization ; that, in short, absolute perfection of any kind is a chimera.

I state it as the result of my own experience, that where instruments are not aplanatic, it is best for them to be a little under-corrected for spherical aberration ; and, when not achromatic, they are most to my taste when over-corrected for colour.

#### DEFECTS OF EYE-GLASSES.

The state of these as to achromatism may be determined by trying them along with an object-glass previously known to be achromatic ; when, if any colour appears, it is of course to be attributed to the eye-glass, when tried along with metallic objectives, though achromatism of an Huygenian eye-piece should be

*absolute and perfect* ; as much so, in short, as if the vision was entirely accomplished by reflection. The imperfections of eye-glasses, such as rudeness, bubbles, black specks, and the like, when visible to the eye in looking through them, will always revolve along with the revolution of the eye-piece, just as those arising from an object-glass will travel when it is turned round. By this rule the imperfections of the one may be distinguished from those of the other. In the vision of luminous points an eye-glass of a crystallized structure will often give an appearance of several points of light which do not exist ; these, however, will always move as the eye-glass is turned about. Defects in the polish of eye-glasses may be tried by looking at them by oblique candle-light.

An inverting eye-piece cannot be made of more than two glasses, without causing a dimness or muddiness in the vision of opaque objects, and other deceptions, still more disagreeable, with diaphanous bodies : the first of these is a luminous spot in the centre of the field of view, which seems to be an image of the object-glass produced by reflection from the numerous surfaces. This is most perceptible when an object is placed in the centre of the field of view, which only partially fills it, and happens at the same time not to be very transparent in the middle. When a candle is placed behind the stage, an image of it may generally be seen in the axis of an engiscope, having an eye-piece consisting of more than two glasses, and not unfrequently a miniature image of the object viewed, if we look a little obliquely into

the instrument. If an engiscope, with a triple or quadruple eye-glass, is made to form the image of a solar microscope, the aforesaid phenomena are rendered very striking, from the intensity of the illumination; but they are not very perceptible when daylight only is employed, and we merely look through the instrument.

Complicated eye-glasses, for the purpose of enlarging the field of view, will, I think, almost invariably be found to do more harm than good, and should be rejected on the same grounds, or nearly so, in engiscopes as in telescopes.

The *juste milieu* is the double eye-glass. The defects of eye-glasses as to the state of their oblique pencils, may be tried by a micrometer, or ivory scale; but recollect that you must not confound the aberration of the oblique pencils of the object-glass with those of the eye-piece, for the former are irremediable, or nearly so, by the latter. On this account it will be most advisable to use some object-glass which has the aberration of its oblique and central pencils nearly in the same state over the whole image, such as a grooved sphere, with which a pretty accurate estimation may be formed of the quantity of error produced by the edges of an eye-glass.

Positive achromatic eye-glasses for micrometrical measurements, composed of two double achromatics, may be examined as to their state of effectiveness by the rules already laid down for trying ordinary single and compound magnifiers.

*Method of examining the Progress of the Rays through an Engiscope.*

This may be effected with a pencil of *intercepted light*, in the following manner. Let *d*, figure 21 \*, represent a *very small* diaphragm; *c* the flame of a candle placed behind it, *o* an object, which, in the present case is a piece of thin copper perforated with nine small needle-holes; *l* a lens, forming the object-glass of the engiscope. In this case the progress of the rays is truly represented in the engraving from *o* to *p*, which is the image just as they may be seen on a piece of rubbed glass, presented to receive them any where in the interval between *o* and *p*; they intersect at *i*, and the nine holes are there reduced to one lucid point; the conjugate foci are *o* and *p*. If several diaphragms are employed, then there will be an equal number of points of intersection at *i*. No eyepiece was used in the present experiment; but the rays may be traced through one with skeleton glasses as far as the visual pencil, and indeed through other systems of glasses also, if thought advisable, in the same way. It is proper to remark, that the experiment must be performed in a dark room, or the nascent images on the rubbed glass will not be visible.

An ordinary microscopic object may be substituted for the perforated piece of copper. In this case the image will become smaller and smaller, till it arrives at *i*, where it will vanish in a point of light. It does not become inverted until the intersection of the rays

\* See this figure at p. 246.

has taken place, when it gradually expands in magnitude, but does not acquire its full size and distinctness until it has reached the conjugate focus,  $p$ . The image of a transparent object, formed by intercepted light, is in fact nothing more than *a magnified and very exact shadow of it*.

#### ABERRATION OF OBLIQUE PENCILS OF RAYS.

The spherical aberration of the oblique pencils in double achromatic object-glasses is very violent when their angle of aperture is considerable; (15, plate 13), represents the burr produced by a globule of quicksilver in one of an inch focus, and a quarter of an inch of aperture,  $c$  being the effect of a large, and  $d$  that of a small globule placed near the edge of the field of view, and seen in focus; (16)  $e$  and  $f$  represent the appearances out of focus,  $e$  being that where the greatest condensation of light is found; while (17) shews the contrast of the pencil of a triple object-glass of nine-tenths of an inch focus, also of a quarter of an inch of aperture.

#### METHOD OF FINDING THE DOUBLE APLANATIC FOCI OF OBJECT-GLASSES HAVING THEIR INTERNAL CURVES IN CONTACT.

For the discovery of these, it will be advisable to have an engiscope constructed with a pull-out tube capable of considerable contraction and elongation; the rules already laid down will suffice for their de-

tection, with the help of some extracts from the invaluable paper of Mr. Lister in the *Phil. Trans.* for 1830, p. 187. Mr. L. says, p. 195, "in general an achromatic object-glass, of which the inner surfaces are in contact, or nearly so, will have on one side of it two foci in its axis, for the rays proceeding from which it will be truly corrected at a moderate aperture; that for the space between these two points its spherical aberration will be over corrected, and beyond them either way under corrected." Again, p. 196, "the longer aplanatic focus may be found when one of the plano-convex object-glasses is placed in a microscope, by shortening the tube; if the glass, shews over correction; if under correction, by lengthening it, or by bringing the rays together, should they be parallel or divergent, by a very small good telescope.

"The shorter focus may be got at by sliding the glass before another of sufficient length and large aperture that is finely corrected, and bringing it forwards till it gives the reflection of a bright point from a globule of quicksilver sharp and free from mist, when the distance can be taken between the glass and the object.

"The longer focus is the place at which to ascertain the utmost aperture that may be given to the glass, and where in the absence of spherical error its exact state of correction as to colour is seen most distinctly."

P. 197. "One other property of the double object-glass remains to be mentioned, which is, that when the longer aplanatic focus is used, the marginal rays of a pencil not coincident with the axis of the glass are distorted," (*c* and *d*, 15, plate 13,) "so that a coma is thrown outwards, while the contrary effect of a coma directed towards the centre of the field is produced by the rays from the shorter focus. These peculiarities of the coma seem inseparable attendants on the two foci, and are as conspicuous in the achromatic meniscus as in the plano-convex object-glass."

In the original paper will be found a number of curious particulars, which the reader cannot be too strongly recommended to consult.

#### METHOD OF MEASURING THE ANGLE OF APERTURE OF OBJECT-GLASSES, METALS, AND LENSES.

We have already seen that all object-glasses and lenses may have their outside rays cut off, and their apertures restricted, until they shew no sensible aberration, however bad their figures and quality may be; it therefore becomes of the last importance that we should know what aperture they really have, since that is the measure of their value and effectiveness when associated with aplanatism and achromatism. The apertures of lenses and object-glasses, used for microscopic purposes, must of course be determined by the size of the pencil of light they admit, since

they operate on diverging rays; that is, we must measure the angle formed by the margin or edge of their acting aperture with the acting focal point.

There are a variety of methods of effecting this object: thus, if we know the acting focus and the acting aperture, we have only to make a diagram on paper of them (which should be on a magnified scale for greater exactness), and measure the angle with a protractor. In general, it will perhaps be most advisable to calculate the angle of aperture for parallel rays, (and for magnifiers this method is the only correct one.) In this case the angle will always be a fixed one, whereas if it is taken for diverging rays, every alteration in the length of the body of the engiscope will cause some trifling alteration in the length of the anterior conjugate focus, so that the angle of aperture will always be less with a short than with a long body.

A very material point to be predetermined in this mode of measurement is the real focus of the lens, &c. to be measured; and as few persons know precisely how to settle this in an effective practical way, the following method is given as pretty exact:—A triple object-glass must be procured, having a focus of some length, which may therefore be very exactly measured (reckoning from the middle of its thickness): it will be most convenient if its focus will come out in a round number, say twenty or thirty inches. The lens, whose focus we want to know, is to be applied to it as an eye-piece, and adjusted for dis-

tinct vision on a star, then with a good dynameter measure the power, which we will say turns out to be twenty, with a twenty-inch object-glass.

It follows, therefore, that the focus of the eye-glass must be one inch.—N. B. If this method is too troublesome, get an optician to measure some particular lens for you. Having once got a lens whose focus we know for certain, that of all others may be easily obtained by converting them into the object-glasses of an engiscope, having a micrometer in its eye-piece, and measuring with them the size of the image of a division on another micrometer placed on the stage, which, if twice as large as that given by the inch lens, denotes a focus twice as long; if only half the size, one of half the length; if one-tenth, one-tenth of the length, &c.

Great care must be taken in these measurements to preserve the same length of body exactly with all the different lenses whose foci are to be measured; and the apertures must always be reckoned from the side of the lens next the eye-piece, taking care that it is not altered by the effect of stops in the body.

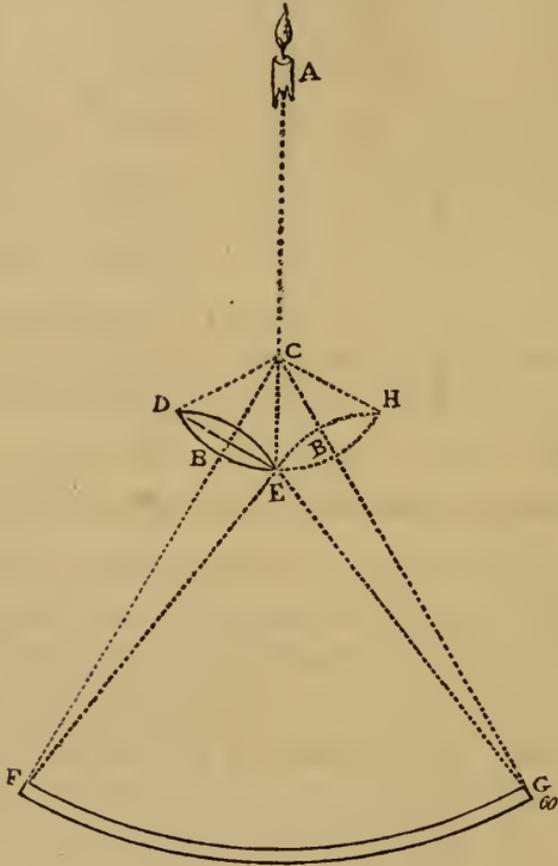
The following table serves to shew the angle of aperture of metals and object-glasses whose apertures bear the following proportions to their foci: the measurements were executed with a metal, in order that the thickness of glass lenses might not operate to occasion uncertainty and variations.

Aperture expressed in Terms of the Focus for parallel Rays.	Angle of Aperture.
$\frac{1}{15}$	Degrees, $5\frac{1}{2}$
$\frac{1}{8}$	$6\frac{4}{8}$
$\frac{1}{4}$	$13\frac{3}{4}$
$\frac{1}{3}$	$18\frac{1}{3}$
$\frac{1}{2}$	$27\frac{1}{2}$
$\frac{2}{3}$	$36\frac{2}{3}$
$\frac{3}{4}$	$41\frac{1}{4}$
1	55

The acting focus of an object-glass is very difficult to be exactly found, on account of its thickness, and still more so, if several are combined together, by the methods already given; but Mr. Lister has discovered a very exact and satisfactory method of doing this, which he has given in the paper already alluded to, p. 191. The principle of it may be seen in figure 18. **B** represents the object-glass of an engiscope placed in a horizontal position, and **C F** its axis, directed so far on one side of a candle **A**, placed at a few yards distant, that the light of it shall bisect the field of view vertically, leaving half of it dark: then **C** being the focus of the object-glass, is to form a pivot, round which the body is to revolve horizontally to the other side of the candle till the opposite half of the

field is illuminated as before, and the object-glass has arrived at the position denoted by the dotted lines (B),

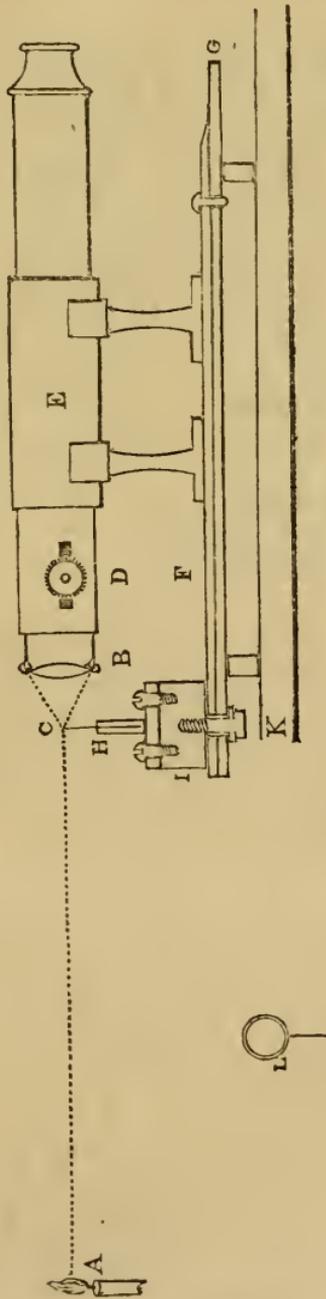
*Fig. 18.*



and the axis of the body into the line  $C G$ . The space travelled over by the body from  $F$  to  $G$  is the angle of aperture; in the present case equal to  $60^\circ$ , for it is evident by construction that the angles  $D C E$  and  $E C H$  are equal to the angle  $F C G$  made equal to  $60^\circ$ .

DESCRIPTION OF AN INSTRUMENT FOR MEASURING ANGLES OF APERTURE.

Figure 20 represents an elevation of an instrument for measuring angles of aperture; E is the body; B



the object-glass to be measured ; D an adjustment for the focus ; C the focal point ; H a tempered steel needle inserted into a hole in a piece of brass H, which can be adjusted into the line of the axis K, by means of the two screws at I ; F is a plate of brass revolving over another G, on which is a graduated arc, the body being secured to the upper plate by two firm supports, and the inferior plate having also two rests ; A is the flame of a candle, which must be placed truly in the axis of the body, or the field will not be bisected in a vertical line, or the angle of aperture truly obtained. If the object-glass is used without the eye-piece, the flame of the candle appears as a lucid point at one end of the horizontal diameter of the aperture of the object-glass, when in such a position that its flame would bisect the field of view if the eye-piece was attached.

L is a disc of glass so adjusted, that when it is inserted into the hole occupied by the needle at H, the surface next to the object-glass shall be exactly in the plane of the focus ; on this the scales of butterflies, &c. may be placed, and the angle of deviation from direct incidence in the illumination (supposed to be the flame of a candle), found requisite to shew their lines most perfectly measured : thus, in figure 19 \*, A represents the flame of the candle behind the stage, or locality of the object C, situated in the plane D E ; B the body of the engiscope ; G A its axis adjusted for *direct light* ; the dotted line F K represents the axis of the body ; and H I the plane of the object adjusted for the most perfect vision of the lines by oblique

\* See this figure at p. 246.

light. It is evident that the angle  $A C K$  must be equal to the angle  $F C G$ , which is the number of the degrees; the axis of the engiscope will be placed out of the axis of direct light in order to exhibit the lines.

My aplanatic engiscope, described in the Microscopic Illustrations, may easily be made to measure angles of aperture. All the extra apparatus required for this purpose will be to cause the pin on which the stage is fixed to be truly drilled, so as to receive the tempered steel pin, which will thus be in the line of the axis of the ball and socket, which will also be in that of the pillar, when the body is truly horizontal. The milled head, which lets down to steady the legs, must be removed, and in its place a piece of brass, armed with a point, screwed on, to mark the apex of the angle on a piece of paper placed under the instrument; the angle of aperture is then measured upon the same principle as in the instrument already described, by attaching the diagonal camera lucida to the eye-piece, and making the legs of the angle on the paper to be afterwards measured with a protractor.

The method here given for appreciating the quality of microscopes applies also to all erecting eye-pieces having an external focus in front of the bottom glass, such eye-pieces being in fact neither more nor less than compound microscopes, or engiscopes. I have called it *exact*, and *prodigiously exact* it must be, for it is quite capable of rectifying some of our modern optical theorists. No working optician can *finish* an

instrument unless he is acquainted with it, and it will be seen whether erecting eye-pieces, &c. can be made achromatic with only three lenses; whether their compensation for colour can take place *any how*, and whether it must not exist both in that part which forms the image, and in that which views it, to produce achromatism on the whole; and whether their spherical aberration can be reduced so low *with the naked aperture of the bottom glasses* as analysis would lead us to believe. If the curves of an object-glass are calculated falsely, and give an excess of aberration either to the concave or convex lenses, it will be instantly detected.

It will be easily seen that whatever may be the peculiar advantages of the method of estimating the quality of optical instruments given in the preceding Memoir, it is by no means calculated to supersede the use of the regular proof objects\*, which afford to the *public at large* by far the *best means* of scrutinizing the perfections and imperfections of microscopes and engiscopes, at least *when genuine, and used fairly without trick or fraud*; but (if I may be allowed the expression), the one mode drives the nail to the hilt, and the other clenches it; I therefore do not destroy, but confirm the first method.

\* Chapter 16.

## CHAPTER XX.

## CONCLUSION.

*Miscellaneous Fragments.*

1. *On stopping false light in Microscopes and Engiscopes.*—This is one of the most important requisites in an instrument, for however perfect it may be, if there is the least light reflected from the mountings of the glasses, or within the tubes, the fog and glare produced will materially deteriorate their performance; it therefore is absolutely necessary that all their surfaces be made as sombre as possible. The usual method of effecting this is to cover the parts while hot with a black lacquer, made by mixing *lamp-black* in a solution of shell-lac in strong spirits of wine. A more elegant method, and better suited for delicate work, is to wash the surface, previously freed from grease and tarnish, with a solution of platina in nitro-muriatic acid (*chloride of platina*): after remaining on the work a few minutes it is wiped off, the surface having assumed a deep black colour. If these are not at hand a strong solution of muriate of ammonia will answer for temporary purposes, but I have never found any thing equal to bronzing the surface by the solution of platina. Another method of stifling false light is by

stops; these are very useful in the body of an engi-scope (compound microscope). These are diaphragms, are made of plates of metal or wood, having a hole in their centre, and then blackened. Persons should be on their guard in examining an instrument having these stops, for they are often put in to *cut off* the aperture of the object-glass, and thereby deceive the unexpe-rienced, who, seeing the size of the object-glass, imagine the whole is used, whereas the most import-ant portion is not employed: this is a very common case, and ought to be exposed.

2. *Mounting transparent objects.*—The most usual method of preserving these objects in a dried state is between plates of talc or mica, fitted into cells formed in ivory sliders, having a split ring of wire to secure them. The bottom of these cells should be turned quite flat, to afford a good bearing for the mica, and of sufficient thinness to permit the magnifiers to ap-proach the object. In using these sliders, like every thing else, there is a wrong and right side, which must be observed, or the student will not be able to approach close enough to the object with the high powers. The ring side should always be placed downwards, or *from the microscope*, and the other side next the eye or instrument. The softness of mica prevents it being cleaned like glass; it should therefore be kept as free from dust as possible, and only brushed lightly with a camel's-hair pencil when necessary, and never touched by the fingers. When test-objects are to be mounted in this way, only one or two cells should be made in each slider, which will lessen their liability to injury.

3. *Method of mounting very minute transparent objects in brass sliders.*—A simple and convenient method of preserving such objects (contrived by Dr. Goring) is between plates of talc within a folded piece of very thin plate brass, as shown in the annexed figure.



These sliders are so easily formed that any person with a penknife and scissors can make them. Procure a piece of latin brass about the thickness of note paper, and cut off a slip the length of the intended slider, and twice its breadth; then fold it down the middle, and make a small hole for the object (see the figure): now take a piece of talc a little narrower than the brass, and make a slit with the penknife down the middle, leaving a portion uncut at each end, so as not to separate it; then put in your object, and fold it as you did the brass; lastly, insert the talc thus folded between the sides of the brass, and pinch the edges of the latter close, and the slider is completed\*. As their size need not exceed that of the diagram, several of these sliders with test-objects may be carried in a pocket-book, and are always ready to examine the merits of any instrument that may present itself.

4. *On mounting transparent aquatic objects and dissections.*—Many small subjects of natural history are

\* If thought necessary, the edges may be cemented: if the hole is small it acts as a stop, and a known object is easier found.

so delicate that when dried their parts are shrivelled so much that it is with difficulty their features are recognised. This is especially the case with such objects as those represented in the coloured illustrations of this work ; it therefore becomes important to discover some method to preserve, as much as possible, their beauty, colouring, and lineament. This I have found is best accomplished by placing the object on a slip of glass, and covering it with a piece of talc, interposing a drop of a thick solution of gum and isinglass : by this means the object is prevented from drying, and when the gum has hardened is effectually preserved. In this way may be mounted all the aquatic objects described in this work, many of which cannot be preserved in any other way ; they are the nearest approach to living subjects I have seen \*. These sliders should have a piece of paper pasted over the talc, to protect it from injury, leaving an aperture in the centre for the object, and made of an uniform size.

5. *On preserving objects in fluids.*—Take a slip of glass, and spread a little white-lead ground in oil on the upper side, leaving an aperture in the middle to receive the object. This paint being laid on of the thickness of the object, the little pool or cavity is filled with weak spirits of wine ; then lay in your object. Having cut a piece of talc the proper size, lay it on the top, and with a stick of wood rub it close down on the paint, beginning at one end, and passing across the slider to the other, so as to exclude all air-bubbles.

\* I have caused Mr. New to prepare me several sets in this way, some of which are very choice objects.

In this way the delicate vessels of plants, &c. &c. may be preserved: I have mounted animalcules and small crustaceæ in this way with complete effect. Active molocules may be kept thus mounted for months. Other fluids, such as a solution of common salt or corrosive sublimate, might in some cases be preferable to spirits.

6. *Mounting opaque objects.*—The best method of exhibiting opaque objects of small dimensions, where central light is beneficial\*, is shown in figure 3 of plate 11; the objects being mounted on short *black* cylinders of cork or ivory, as seen in that figure. These mountings are made of cork (the most convenient material,) by punching them out of a slice of that substance whose thickness is equal to the length of the cylinder, and passing a common pin through them, as shown in that figure; they must be blacked with common lacquer and lamp-black, holding them a few seconds over a candle, to dry. When made of ivory, the inside should be turned hollow, like a small box, and the pin as before running through the middle is to be the support of the object instead of the surface, as in the cork cylinders. When the ivory is dyed black, and the inside as sombre as possible, they enable the observer to see the delicate structure of an object more distinctly; indeed it is the only method by which we can develop the structure of some objects, such as the minute sponge-like glands over the foot of the common fly. Remember that the

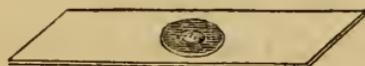
\* See p. 183.

darker the object the more black and sombre must be the mounting, to heighten the brilliancy of the object by the contrast. This is necessary to name, as some individuals have thoughtlessly mounted their objects on the white ivory; the glare and fog produced by this omission is sufficient to injure the vision of the most perfect instrument. The best means of fixing the objects on this mounting is a solution (in spirits of wine) of isinglass and gum-arabic, which affords a strong and tough glue. These objects when used are held in the forceps by the pin; if the forceps are large, they should have a hole made through their sides, to secure the *head of the pin*, which is otherwise liable to slip out: this enables us also to turn the object about the head as a centre, without any risk of its escaping: see s, figure 23, of "Microscopic Illustrations."—These cylinders may be made of various sizes, and arranged in cabinets, the bottom of the drawers being covered with cork about a quarter of an inch thick, into which the pin is inserted. The blank end of the cylinder should have a number painted in white, corresponding with another in the list of the names: all the pins should be slightly inclined in one direction, with their numbered ends upwards, which enables you to take out any object by referring to the list, and also protects the objects from dust falling upon them. A vast number of objects, by proper arrangement, will thus occupy very little space.

7. Some persons find it inconvenient to manage these mountings in the forceps; in such cases it is best to

cement the blank end of the disc to a slip of glass, and place it under the spring of the slider-holder, the disc and object projecting sufficient to enter the silver reflector *i*, figure 3; in this case the stage is used, and the condenser *e*, &c. as before.

8. When the objects are large, and do not require a very high power, they may be cemented on the slip of glass itself with a piece of black paper under them, or a wafer may be fastened to the under side of the glass, to give a back-ground when viewed as opaque objects, and removed when examined by transmitted light; or a blank cylinder of cork may be held under a transparent object to view it by reflected light. The mode of mounting large objects on slips of glass with paper under them, is here shown. These sliders



should be arranged in shallow drawers, like transparent objects, as hereafter mentioned. When the objects are very minute, and the magnifying powers high, the objects may be mounted on the heads of common pins; but remember that this method should not be adopted when the aperture of the magnifier is larger than the head of the pin, as the direct light from the condenser would be admitted, and produce glare.

9. *Method of viewing the internal organization of animalcules.*—The usual food of these animals assi-

milates so closely in colour to themselves, that it is impossible, under ordinary circumstances, to perceive the form of their digestive functions. During the investigation of the polype by Mr. Trembely, he endeavoured to ascertain whether the small glanular bodies dispersed over its surface were digestive cavities, and for this purpose fed these creatures on coloured substances, such as a solution of indigo: this idea has recently been followed up by Dr. Ehrenburgh, of Berlin, who has successfully employed minutely divided solutions of coloured substances, such as indigo, carmine, and sap-green, for ascertaining the form of the digestive cavities in animalcules. It is essential that whatever colouring matter we employ be pure and free from any metallic impurities, and that it be only mechanically, not *chemically*, soluble in water.

10. *On exhibiting animalcules.*—These creatures, found so abundant in stagnant waters containing infusions of organised matter, afford considerable amusement and instruction in the inspecting of their habits, &c. They usually congregate around the edges of the vessel, and on the surface of the fluid. The best method of placing them under the microscope is by means of the *feeding-pin*, represented in the annexed cut; it consists of a glass thread inserted into a convenient handle, the end of the glass being enlarged like the head of a common pin, which is to be dipped into the infusion. In this way a small drop of the fluid containing them may be placed on a slip of glass, and covered with a piece of talc, to prevent evapo-

ration, and keep the surface flat, or put into an aquatic box for examination. When it is desirable to ex-



amine the contents of different infusions, the feeding-pin should be washed in distilled water between each dip, to prevent any mixing. This little contrivance will be found more effective and useful than the point of a quill, or a camel's-hair brush.

11. A very amusing exhibition of animalcules is made in the following manner; it is especially calculated for the solar microscope, or, indeed, any other where the objects themselves are not under immediate inspection. The main feature is the apparent control of the exhibitor over the actions of these minute beings, and their obeying his commands. Procure a water-trough similar to the one here represented,

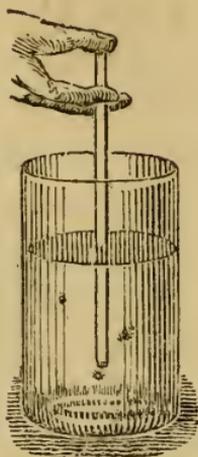


*c a b*

composed of two slips of glass, cemented on each side of a plate of metal of the proper thickness, and of the form shewn in the figure, the light part being that which is removed. If it is now filled with clean water, and the middle cell, *a*, placed before the microscope, and a drop of the infusion containing the animalcules\* put into the cell, *b*, on the command of the exhibitor the animalcules will commence marching across the field of view, and to those unacquainted with the plan it will appear in obedience to the order, but which is merely their desire to spread themselves. In the same manner, when the cell, *a*, is full, *c* may be put under the instrument, and the marching again commences, the little animals only being able to pass from one cell to the other singly.

12. *Method of selecting Aquatic Larvæ, and other small animals.*—The animals described in several of the preceding chapters are large and visible to the eye; these require to be kept in vessels of considerable dimensions, which renders it difficult to select any particular specimen, as is also the case with the more minute ones in phials. For effecting this purpose, Ledermuller has described and figured, in Plate 87 of his work, a very ingenious contrivance for this purpose; it is simply a glass tube, open at both ends, and is employed in the following manner:—

\* The *Rotifer vulgaris*, Chapter 6, answers this purpose very well.



Hold the tube by the upper end between the fingers, and close the orifice by the thumb (see the annexed figure); then immerse the lower end in the vessel of water, and the instant the insect desired approaches the tube, remove the thumb from the upper end, and the pressure of the atmosphere will force the water with the insect up the tube, when the thumb is again to close the upper aperture, and the tube with the object is to be removed. These tubes may be of different diameters, to suit the various objects.

13. *Net Spoon*.—Some of the larvæ of insects are very delicate, and require very gentle means for removing them into aquatic sliders, or boxes, for examination. This may be very carefully done with the *net-spoon* here figured. It consists of a wire, bent in the form there shown, and covered by a piece of muslin or net.



14. *Aquatic Sliders for Live-Objects.*—These are made in various ways. The best for large objects is the *water-trough*, represented in the annexed figure; it is composed of two plates of glass, having a plate of metal or a lump of sealing-wax between them, leaving a space in the middle for the object and water; they may be executed of various lengths and thickness, and have their sides parallel or angular; the latter is sometimes useful, as they confine the insects at the bottom, and are thus prevented from going out of the field of view. For the solar microscope this method of displaying them is preferable to the aquatic boxes (§16), and, when of sufficient size, under low powers a branch of moss may be inserted, which will produce an interesting spectacle, among a group of different insects, who will exhibit a variety of diverting pranks and tricks, some engaged in a fierce and obstinate combat; others darting between the branches in search of prey; and others cautiously avoiding the more predaceous ones.



15. Another plan is, to confine the insects, as shown in the adjoining figure, which represents a plate of glass covered by one of metal, of suitable thickness, cemented to it, and having an aperture in the latter to receive the insect, which is covered by a plate of talc.



16. *Aquatic Live-Boxes*.—The most useful of all these contrivances is the aquatic box, represented in figure 21 of the Microscopic Illustrations. It consists of a short piece of tube, the lower end of which is fitted to the stage of the microscope, or fits into the slider-holder, having a circular piece of glass fixed to its upper end; over this fits another piece of tube, forming the cover, with a *thin* circular plate of glass fixed to it, the objects being situated between the box and cover. They may be made of various sizes, and, by sliding the cover more or less on the box, the distance between them is varied to suit the thickness of any object. When required for high power, the cover should have a plate of talc, instead of glass, to permit the magnifier to approach closer to the object. In the larger boxes a small hole is made in the side of the cover, for the escape of air and superfluous water.

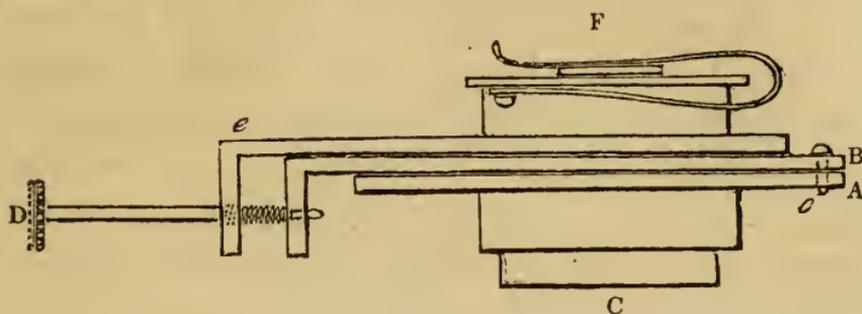
To render these aquatic boxes more useful, the bottom glass should have a series of lines cut on its surface, for measuring the size of the object, which in this manner is done without any additional trouble, and renders them a valuable addition to a microscope, serving the purpose both of a micrometer and object-holder. The divisions most useful are from one hundred to five hundred in an inch.

17. *Arranging Transparent Objects*.—The method I adopt is to have a cabinet with a number of shallow drawers; (twelve of them occupy a depth of four inches and a quarter :) the sliders are laid flat, with the talc

side upwards, in double rows, the outer ends of each row fitting under a ledge in the side of the drawer; their other ends, meeting in the middle, are fastened down by a thin slip of wood, jointed at the back. In this plan there are no loose parts, and as all the objects are seen without removing, we can instantly make a selection of a proper one, and moreover, they are protected from dust. The same cabinet may have a drawer for opaque objects, &c.

18. *Traversing motion for Objects under the Microscope.*—It is often desirable to move the object across the field of view without altering the illumination, especially with very minute ones, and in the case of animalcules it is sometimes wanted; but with aquatic larvæ the motion must be given to the magnifier, not the object, as they are so very restless that the slightest motion disturbs them. When a motion is to be communicated to the objects, it is generally effected by two screws working in separate plates at right angles to each other. By this means a motion is obtained in any direction by turning first one and then the other; or the same is effected by two racks and pinions, or by levers: the latter is the simplest, but, unless properly constructed, is very liable to become unsteady, and is often in the way, preventing a candle, &c. from approaching close behind the stage; the disadvantage of the other methods is, that the observer is compelled to use both hands in this adjustment. The plan I adopt is a single screw, which is made to act at the same instant as a lever: by this all the

motions are obtained in a very simple manner, as shewn in the annexed figure.

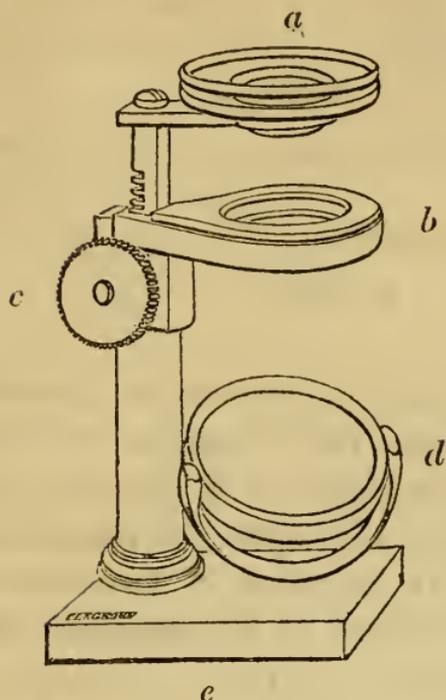


The end, C, which is cylindrical, fits into the stage of the microscope, or the lower immoveable plate, A, may be the stage. This plate, A, is fixed to the part, C; it has a circular aperture in the middle, and a small hole at *o*, which acts as the centre of motion for the plate, B, to turn about: on the top of this plate is another, *e*, which carries the slider-holder and object, F. This plate is moveable to and fro, by turning the screw by the milled-head, D; and, at the same time, a cross motion may be communicated to the object by moving the head, D, laterally, which carries along with it the plate, B, the centre of motion being *o*. The plates, A, B, *e*, must be fastened together, which, however, is unnecessary to shew.

By this contrivance a traversing motion in any direction is obtained with the milled-head, D, by one hand; no part is in the way of the illumination, nor liable to derangement.

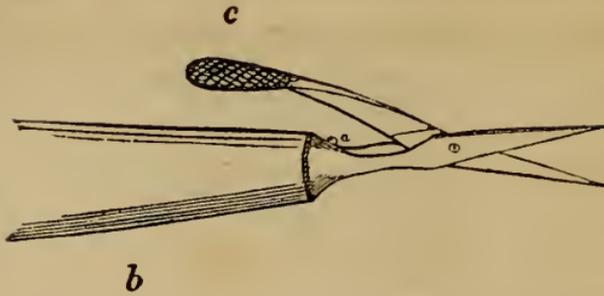
19. *A new Pocket Microscope.*—Portability is a quality so essential in the opinion of many persons, that I have been induced to construct a small instrument for their use, which at the same time should be more consistent in its principles than those in common use, and I believe will be found much more simple, and equally useful. In similar instruments before the public, to render them portable they separate into two or more pieces; this is obviated in my construction by the bar running within a tubular stem. Another objection in the common ones is, that in using high powers the illumination is more feeble than with low powers; but it must be evident that the reverse ought to be obtained, for the more we amplify an object the darker it becomes. In their construction, they remove the object farther from the light, the higher the magnifying power; in mine, the magnifier is brought to the light, the object being stationary. The bar is *triangular*, and therefore less liable to shake and loosen than square ones. A rough sketch of the microscope, with the triangular bar partly drawn out to shew the rack, is here given.

*a* are two magnifiers, of which there are four; they fit by a spring into the arm at the top of the bar; these magnifiers are adjusted to the object placed upon the stage, *b*, by the milled-head, *c*, of the pinion, and the light is directed through it by the mirror, *d*, which can be turned about in any direction, and fits into the stand or block, *e*. When the bar is lowered, and the magnifiers taken out of the arm, the instru-



ment, which is now only two inches and a quarter long, fits into a case (about the size of a snuff-box) one inch and three-quarters wide, by one inch deep (inside measure); the four magnifiers packing between the stage and mirror, do not occupy any extra space. If it were desirable, additional magnifiers might be added for viewing test-objects; a finer adjustment might also be applied, and Dr. Goring's illuminator or stops. A useful appendage is a large condenser placed before the reflector.

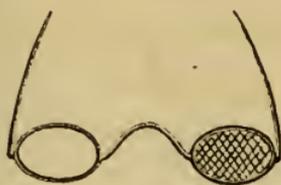
20. *Scissors for dissecting minute objects.*—These are far preferable to knives or lancets for the division of delicate bodies; the best mode of constructing them is shewn in the annexed figure.



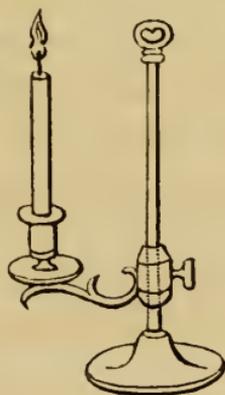
They are held by the handle, *b*, which is fixed to one blade, so that the fore-finger is at liberty to press upon the prolongation, *c*, of the other to close them; they are always kept open and ready for cutting by a spring, *a*. It is stated of Swammerdam, who has surpassed all others in his directions, by his biographer Boerhaave, “ that the constructing of very fine scissors, and giving them an extreme sharpness, seems to have been his chief secret. These he made use of to cut very minute objects, because they dissected them equally; whereas knives and lancets, let them be ever so fine and sharp, are apt to disorder delicate substances, as in going through them they generally draw after them and displace some of the filaments.”

21. *Eye-shade for looking through Microscopes.*— It is necessary, when we examine with one eye an object through an instrument, not to permit any excitement on the other, and to shade it from surrounding lights. In compound microscopes it is easily done by a large disc of card-board, having a hole in its centre, placed over the eye end of the instrument; but the best plan for general purposes is to have a

pair of spectacles, with a thin black disc in one aperture, and the other empty, as here shewn.

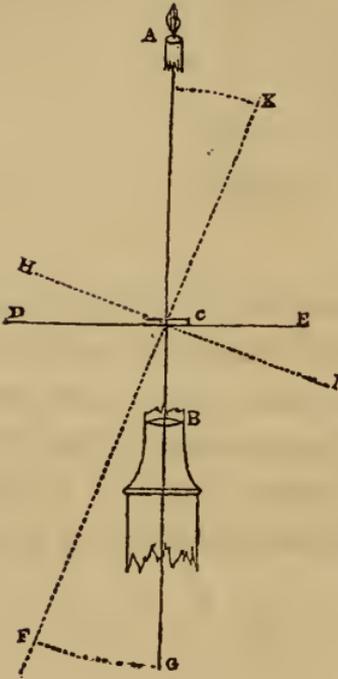


22. *Candlestick for microscopic purposes.*—It is very desirable with artificial light to be able to turn it about in any position; this may be effected by employing a candle or lamp holder, like the one shewn in the annexed figure, which is capable of being raised or lowered, and turned in any direction.

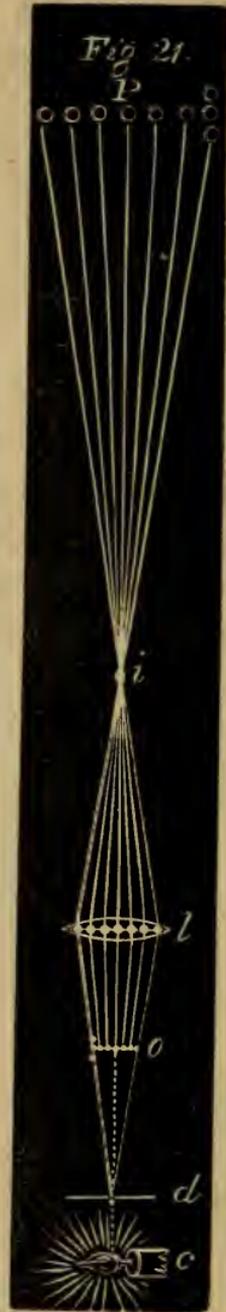


It is sometimes advisable to shade the light from the surrounding objects; in this case, a copper tube, with a small aperture in its side, should be made to fit over the flame: we must now use the flame of a lamp, as a candle would melt in such a situation.

Fig. 19\*.



\* Figure 19 refers to page 224, and figure 21 to page 215.



THE END.

PRICES of the Optical Instruments, described and drawn in the "*Microscopic Cabinet*," and the "*Microscopic Illustrations*."

§ 1. Goring's Operative Aplanatic Engiscopes, described in the "*Illustrations*," p. 50. from £ s. d.  
30 0 0

2. Pritchard's Jewel and Doublet Microscope, with Tripod Stand, five Doublet Magnifiers, and a Jewel lens for Transparent Objects; two Magnifiers in silver reflectors, for Opaque Objects; Woollaston's Illuminator, &c. described in "*Cabinet*," p. 124 ..... 10 10 0

Note.—As many observers prefer the simple adjustment, by a Rack and Pinion, it can be applied to the above instead of the Screw, at the same cost.

3. Ditto, with plain stand, Rack adjustment and deep Magnifier of Glass instead of Jewel ..... 8 8 0

4. Moveable Stages, (described in "*Cabinet*," p. 240,) to the above ..... 1 1 0

Achromatic bodies fitted to instruments, § two and three, .....from £5 to 15 0 0

5. Pritchard's Pocket Microscope, described in "*Cabinet*," p. 242, with four Magnifiers, giving seven powers, forceps, &c. .... 2 2 0

This simple little Microscope exceeds, in utility and stability, many of the larger and more costly instruments, and may be used, like the above, in dissecting subjects of Botany and Natural History. Stops, Condenser and extra powers may be added at pleasure.

6. Set of Aquatic live Boxes, 24s. with Micrometers 2 2 0

Best Single and Doublet Magnifiers.

Focal lengths in parts of inch.	Magnifying Power.		Single lenses			Doublets.		
	Linear.	Superficial.	£.	s.	d.	£.	s.	d.
1-10th.....	100.....	10000 times.....	0	10	0*	1	0	0
1-20th.....	200.....	40000 —.....	0	14	0*	1	10	0
1-30th.....	300.....	90000 —.....	0	16	0*	1	15	0
1-40th.....	400.....	160000 —.....	0	18	0.....	2	0	0
1-50th.....	500.....	250000 —.....	1	4	0.....	2	10	0
1-60th.....	600.....	360000 —.....	1	10	0.....	3	0	0
1-80th.....	800.....	640000 —.....	1	15	0.....	3	3	0

\*These lenses in concave silver reflectors for opaque objects, 8s. extra, each.

Tests and other objects, in sets or cabinets. Triplet Magnifiers, &c.



*Pritchard's Microscopic Cabinet.*



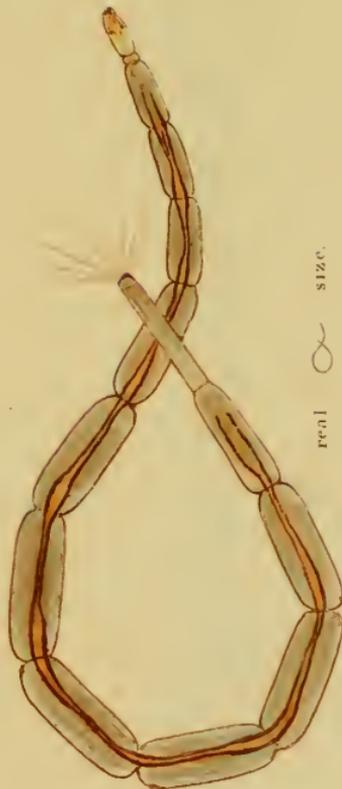
*Zygoptera*

W. Kelsall

Published for the Author April 1832



*Pritchard's Microscopic Cabinet.*



real size.

*W. Keble*

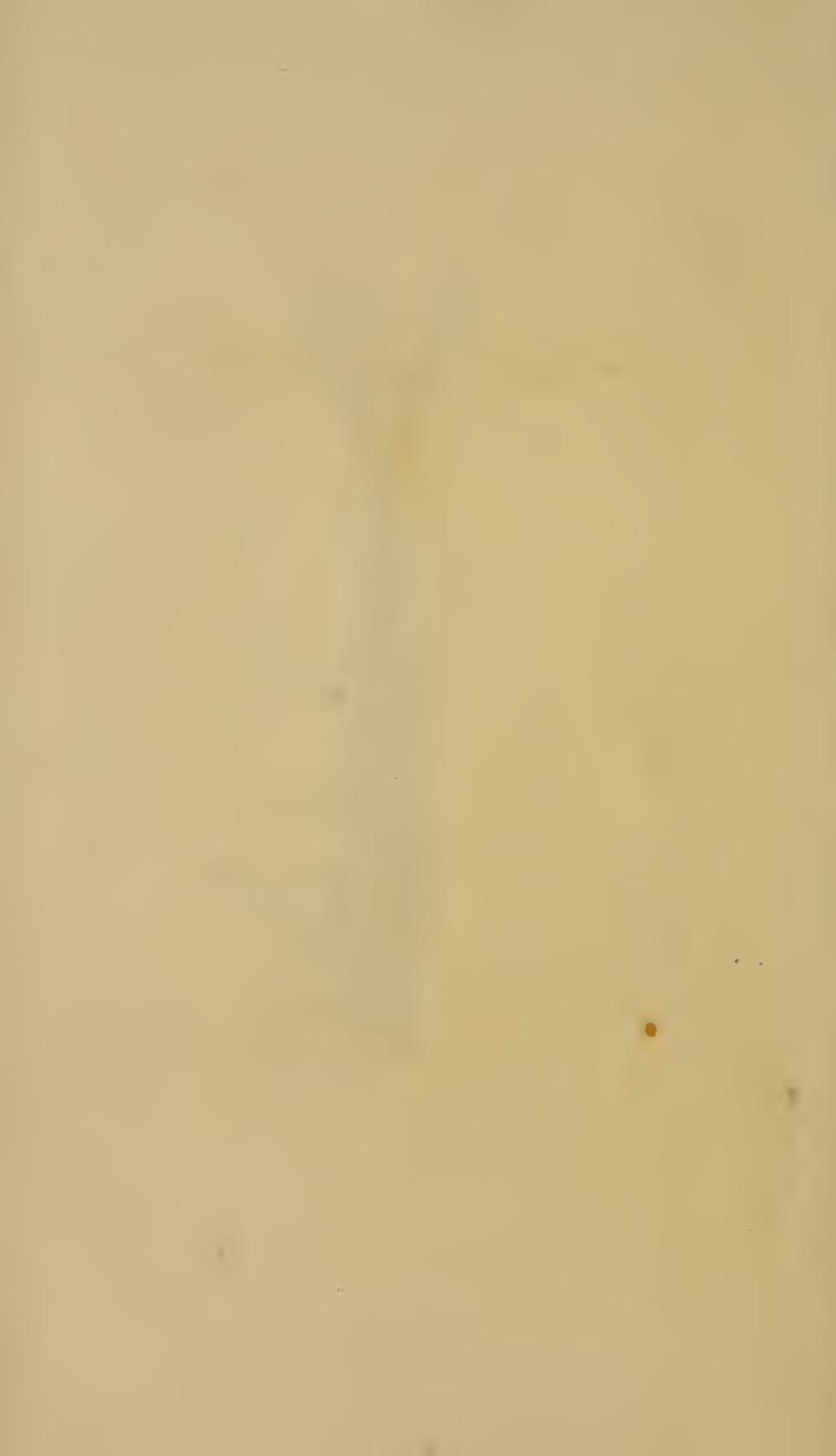
*W. Keble*

*Published for the Author, April, 1832.*



Richards. Microscopic Cabinet.





Pritchard's Microscopic Cabinets

Fig. 1.

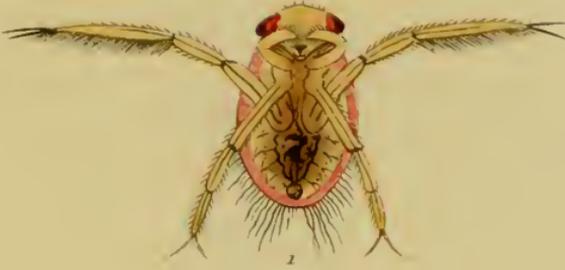


Fig. 2.



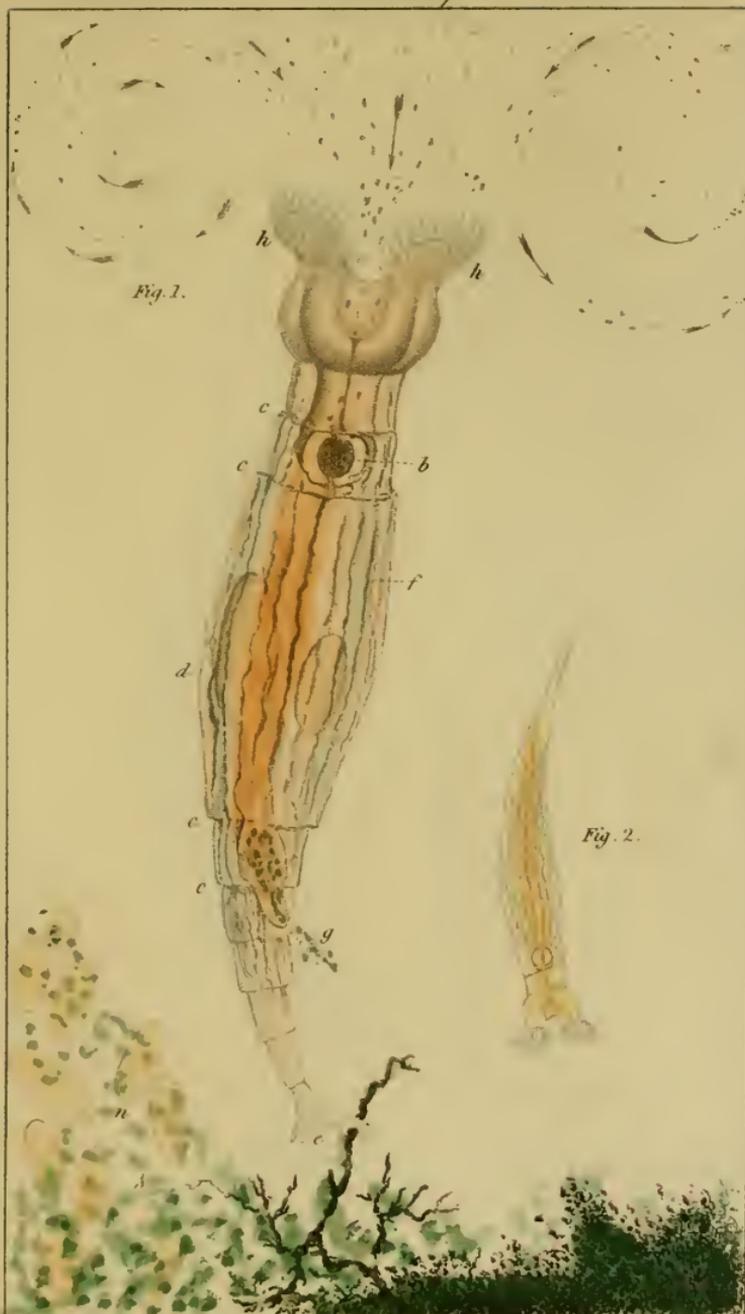
D<sup>r</sup> Goring del

W Kelvall sculp

Published for the Author April 1832



Pritchard's Microscopic Cabinet.

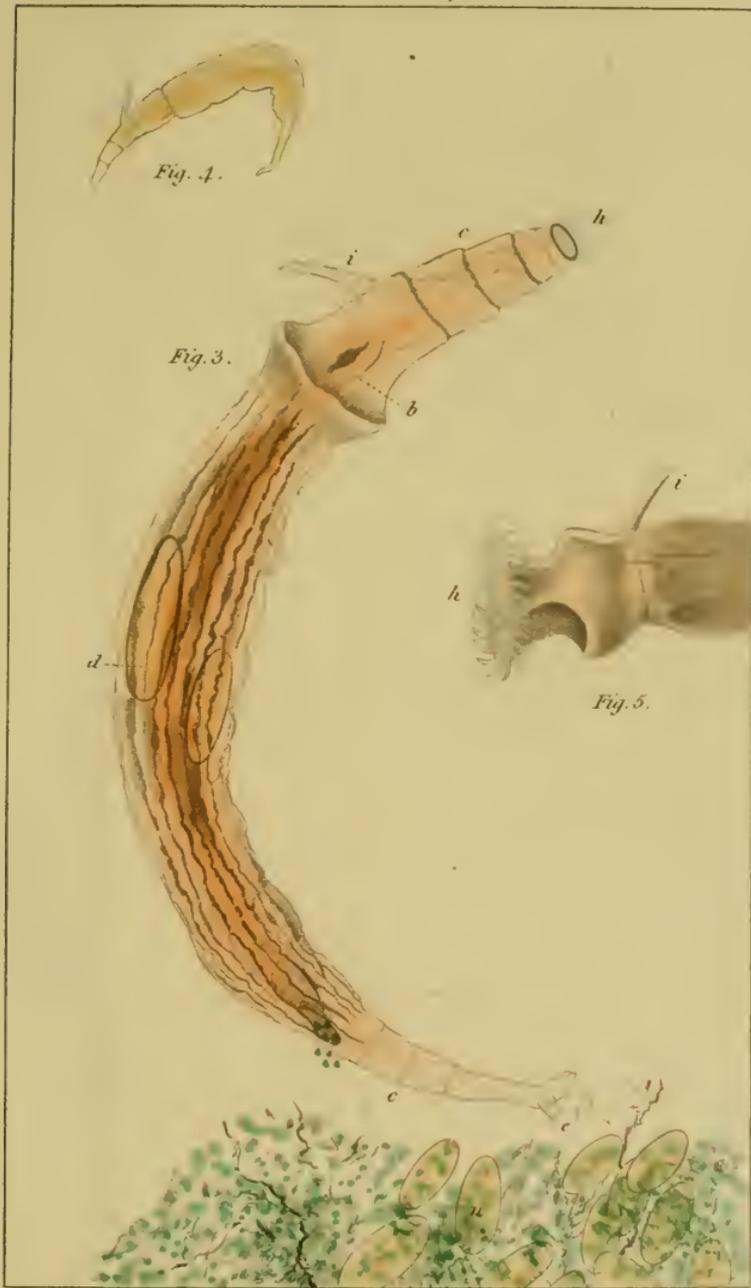


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W. Keblet sculp.

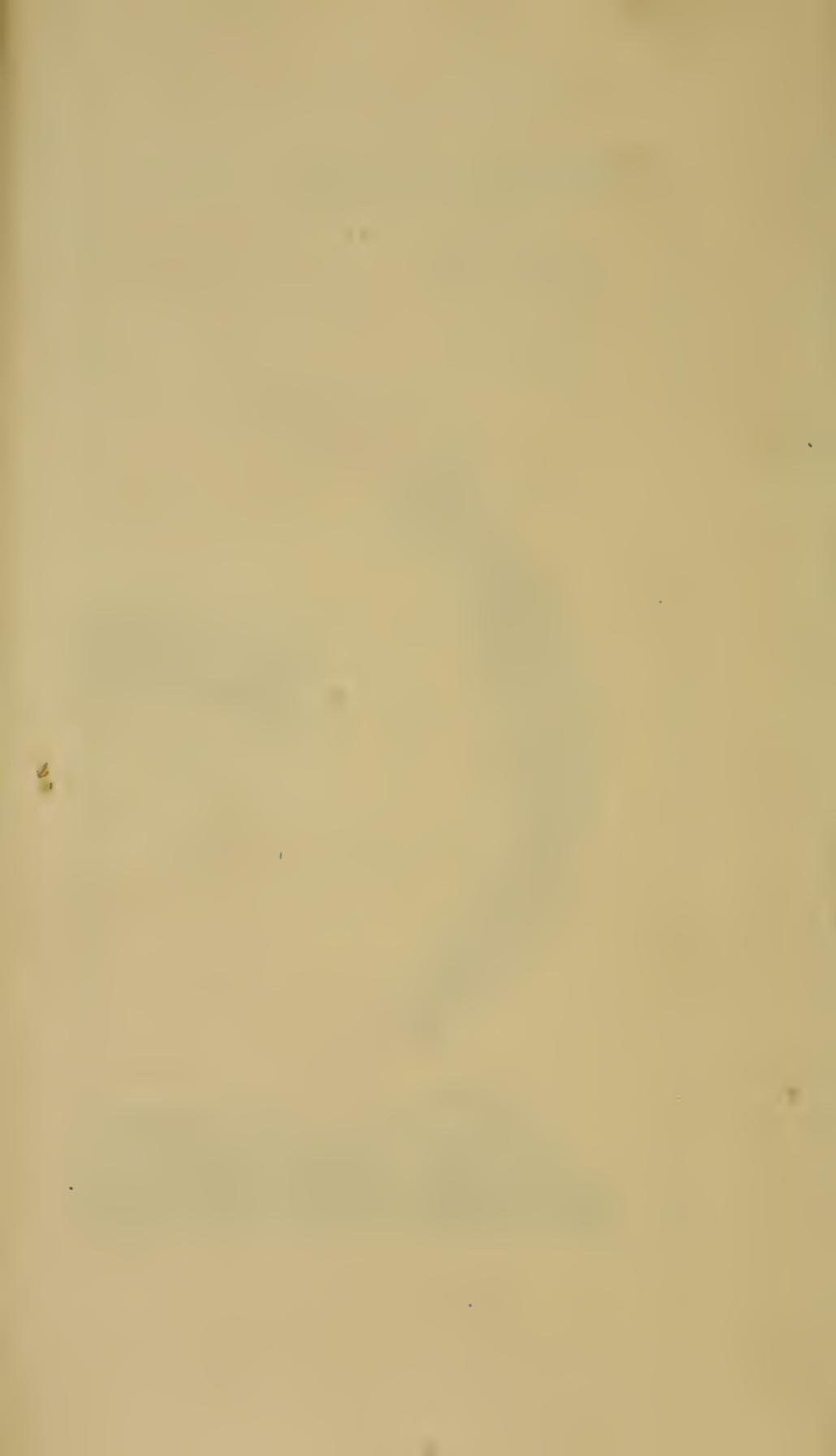


*Pritchards's Microscopic Cabinet.*



*D<sup>r</sup> Goring del.*

*W Kelsall sc.*



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*Pritchard's Microscopic Cabinet.*

Fig. 1.



Fig. 2.



Fig. 3.



*D. Goring del.*

*W. Keleall sc.*

*Published for the Author April. 1832*

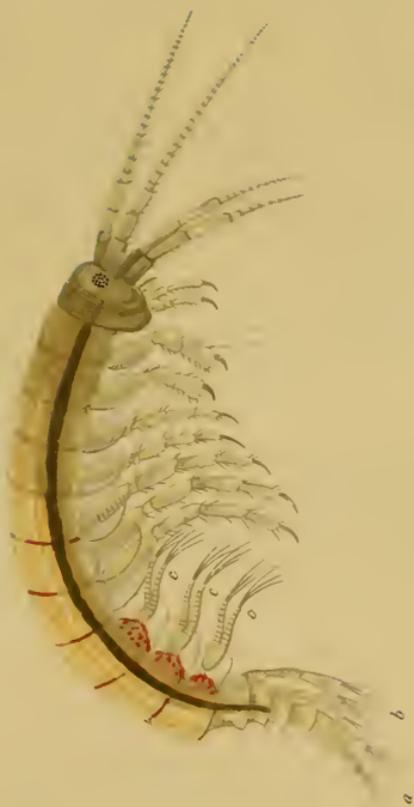


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*Pritchard's Microscopic Cabinet*

Plate 10.



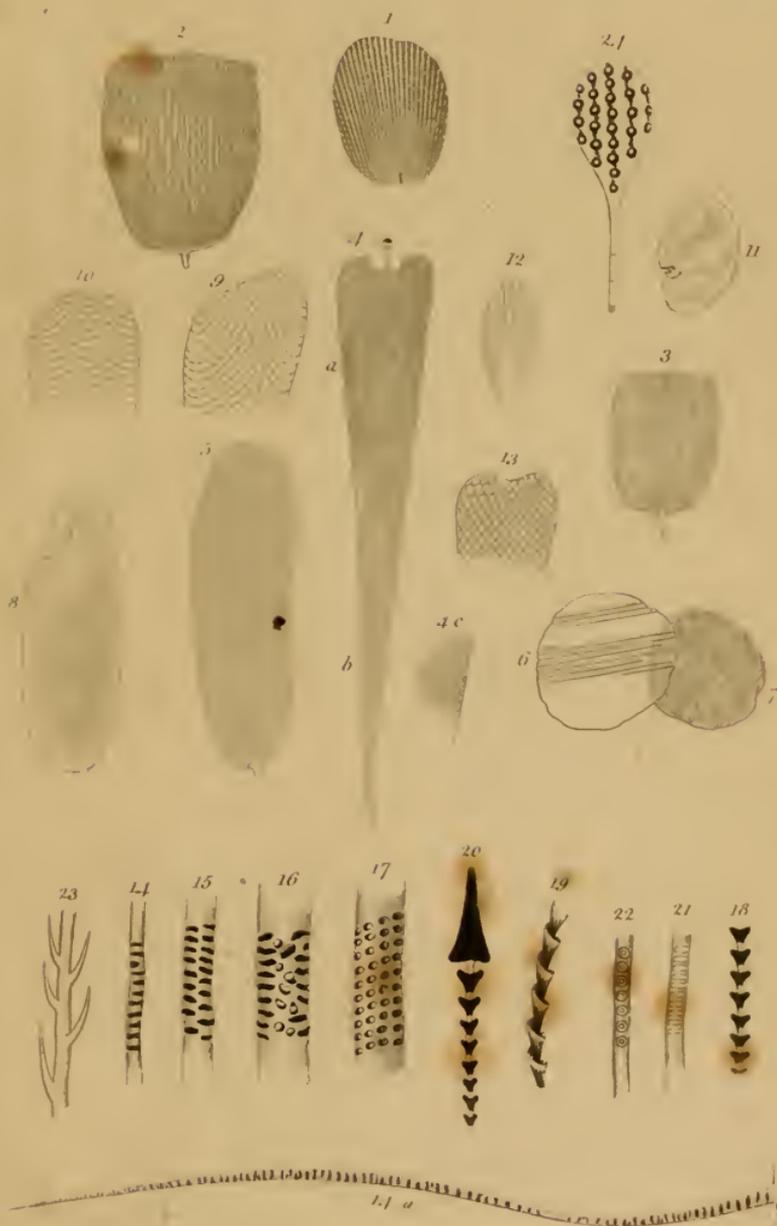
*D. Goring del.*

*Published for the Author, April 1832.*

*W. Woodcut or*



*Pritchard's Microscopic Cabinet*



Drawn by A. Pritchard

W. Keirill sc.

Published for the Author April 1832.

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