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CANTOR LECTURES.

THE MICROSCOPE.

By John Mayall, Jun.

Lecture I.—Delivered November 23, 1885.

Origin of the Microscope.

The authors of text-books on the microscope are almost unanimous in implying that we cannot justly claim the microscope as a distinctly modern invention, but that we owe it—at least in its simplest form, *i.e.*, as a magnifying lens—to the ancients, who, if they did not directly transmit the instrument to us, so far notified it in their writings that we are bound to admit our obligations to them, and the utmost we can justly claim is the re-invention of the instrument, and its greater perfection.

I venture to express my disagreement from these authors. After much consideration I have come to the conclusion that the microscope, as we know and employ it, is essentially a modern invention, hit upon, it may be, accidentally, but hit upon at a period corresponding almost marvellously with the advent of the spirit of modern scientific research, when the need of such an instrument was, so to speak, most intensely felt by those precursors of modern science who first struggled out of the meshes of the ancient empirical methods into the free air of experimental methods.

In assisting at the collection of a large number of the microscopes here exhibited, and, indeed, during several previous years, the evolution of the modern microscope has been a subject of special interest to me. Gradually a conviction has been formulated in my mind that the historians of the microscope have been on the whole too ready in tracking the invention of the instrument to ancient times, too anxious, as it has seemed to me, to claim antiquity and a continuous history for it. I must, of course, except Prof. Harting, of Utrecht University, from any criticism on this point, and must acknowledge the fairness and conspicuous ability with which he has sought to exhibit a general sketch of the history of the construction—a history which will be a landmark as long as the microscope is used as an instrument of research.

The question of the antiquity of the use of magnifying lenses was much discussed in former times, notably by La Hire, Molyneux, Fontenelle, Vettori, Robert Smith, Lippert, Dutens, Lessing, Priestley, Montucla, and Lalande. By the diligence of these writers the various passages from ancient authors were collected and submitted to criticism, not always, as it would seem, in the spirit of candour. More recently, Wilde, Arago, Libri, Harting, Poggendorff, and others, have discussed the subject, dealing more or less with the original texts and the reasonings based upon them by modern critics.

The original discussion was revived by M. T. H. Martin, in 1871, in his elaborate paper, "Sur des instruments d'optique faussement attribués aux anciens par quelques savants modernes," in the "Bulletino* di Bibliographia e di Storia delle Scienze matematiche e fisiche," of Rome in which the original texts are minutely discussed; and his conclusion is, that magnifying lenses were not known to the ancients, or, at least, were not used by them for any practical purpose. As my own views agree in the main with those of M. Martin, I have thought the present a favourable opportunity to summarise his paper in translation, using the materials collected by him, and the inferences he based upon them, in my own way, abbreviating his text or adding to it. The student should, of course, consult the original for the details of evidence; what I here give is but a rough outline.

In Aristophanes' comedy, "The Clouds," Strepsiades is introduced as a worthy disciple of the subtlety of Socrates, by proposing a new method of escaping the payment of his debts, namely, to hold in his hand a transparent

* IV., May and June, 1871.

crystal, such as were then obtainable at the apothecaries, and which, in the words of the play, were used for lighting a fire, and placing himself at a distance with the crystal exposed to the sun, at the moment when the public officer is writing on the wax tablet the declaration of the debt by the creditor, he will efface the writing by melting the wax on the tablet. This passage is sheer ridicule, composed in a spirit analogous to that of our own Swift when he introduces us to the professor in the Grand Academy of Lagado engaged "upon a project for extracting sunbeams out of cucumbers, which were to be put in vials hermetically sealed, and let out to warm the air in inclement summers." That it is sheer ridicule is evident, for it is of a piece with a previous passage, where the same Strepsiades proposes to escape the monthly payment of the interest on debts, legally payable then at the time of new moon, by buying a sorceress from Thessaly who should shut up the moon in a box, and so prevent the arrival of the dreaded date of settlement. From such a passage, then, no serious inference can properly be made that the use of magnifying lenses was known to Aristophanes, upwards of 400 years B.C.

The elder Pliny mentions that physicians cauterised by means of a globe of crystal (*crystallina pila*). He does not inform us whether the globe was solid or hollow, though elsewhere he speaks of a globe of glass (*vitria pila*) filled with water and used likewise for cauterisation.

Alexander, the commentator on Aristotle's "Meteorology," mentions that objects may be ignited by the heat of the sun passing through "a vase filled with cold water, without warming the water in the vase," or at least without warming it sufficiently to account for the fire.

Philopon, the Greek commentator on Aristotle, Lactantius, and others, state, with more or less erroneous explanation, that water exposed to the sun will produce fire.

These citations prove that the ancients knew the effects of burning-glasses acting by refraction, though of the explanation they knew little or nothing.

One ancient author, however, appears to have suspected the real nature of the phenomena—the optician Damien, disciple of Heliodorus Larissus. He refers to concave mirrors burning by reflexion, and then speaks of burning-glasses acting by refraction, stating that through these glasses rays refracted and converging towards the same point ignite objects of a suitable nature placed there. But he gives no theory of this convergence, and says nothing of the form of the glasses, or of their curvatures.

Nothing in the authors cited would indicate that they had any suspicion that these burning-glasses, acting by refraction, could be employed as magnifying lenses.

With reference to the texts of ancient writers where the magnifying power is alluded to, Seneca (in the often cited passages from his "Quæst. Nat." I., 6, § 5) states that "letters, though small and indistinct, are seen enlarged and more distinct through a globe of glass filled with water," and that "fruit appears larger* when seen immersed in a vase of glass;" whence he concludes that all objects seen through water appear larger than they are. Similar statements appear in the writings of Philo Judæus, Ptolemy, and others, down to Aulus Gellius. Seneca adds that "through water we cannot see objects accurately, nor assign to them their true situations."

Several passages might be cited from Archimedes, Ptolemy, and others, to show that though they knew something of the action of refraction at plane surfaces as of water, yet of the refraction at curved surfaces they had no conception. These writers do not appear to have thought that the form of the refractive body was of special importance; they refer indiscriminately to the spherical form, or the disc, or the plane surface of the water, but not one of them speaks of the lenticular form. The passages where magnification is alluded to, show that they attributed the effect wholly to the nature of the water, or again to the nature of the glass or of transparent bodies in general, and never to the geometric forms or to imperfections in the curvatures of their surfaces.

Further, we do not find in any ancient author mention of spectacles for long or short sight, or of magnifying lenses or microscopes. They mention mirrors burning by reflexion, and other instruments burning by refraction, consisting generally of spherical vases filled with water. Occasionally they speak of solid globes, and in one case the discoid form is mentioned; but in view of the notions they held with reference to vision through transparent bodies, it cannot properly be affirmed

* Prof. Baden Powell remarks that "the dependence of this [magnification] on the lenticular form of the glass seems to have been wholly unknown; and this case was confounded together with others, in a way evincing a total absence of all conception of the cause." "Hist. of Nat. Philos.," p. 67, Lardner's "Cabinet Cyclopædia." (1834).

that they really touched upon the theory of dioptric lenses, or that, in view of the fact that they regarded the process of magnification as being in the nature of the refracting substance without reference to the geometric form, they were on the right track to discover the scientific use of optical instruments.

Assuredly, if such instruments had been known to the ancients, Pliny and others would have mentioned them. Certain authors treated specially of optical phenomena, for instance, Aristotle and his commentators on meteorology; in the problems of Aristotle, and the Greek physician Alexander, relative to myopia and presbyopia; in the dissertation of Plutarch on myopy; in the chapters of Pliny on the sight, and on the diseases of the eyes and their remedies; and certainly in the texts of the Greek physicians on the same subject, from Hippocrates to Galen, and from Galen onwards; and in those of the Roman physicians, from Celsus and Aurelian to Theodorus Priscian and Marcellus Empiricus. But no allusion is made to any of these instruments by these authors, nor by any other Greek or Latin author. On the contrary, we find in several writers of the early centuries of our era, texts which are irreconcilable with the hypothesis of the former existence of these instruments. In the 5th century of our era, the Greek physician Aetius has nothing to say regarding myopy, further than that it is incurable; and similarly, in the 13th century, the Greek physician Actuarius alludes to myopy as an incurable infirmity of sight, for which art can do nothing. But since the closing years of the 13th century, that is to say, since the invention of spectacles, they are referred to in the medical treatises, and in other works.

It is unquestionable that the ancient artists have left us works, such as gem-cutting, of extremely minute execution, and many modern writers, as Vettori, Dutens,* and Lippert, have insisted that they could not have been produced without the use of magnifying lenses.

* Dutens, "Recherches sur l'origine des découvertes attribuées aux modernes," Paris (1766). Poggendorff remarks that although Dutens cites many alleged modern discoveries in physics that were known to the ancients, yet he does not adduce a single example of a discovery in physics by the ancients that was unknown to his contemporaries. Hence Dutens asked his contemporaries to subscribe to the very singular coincidence that the ancients knew just as much of physics as was known in 1766, but no more. "Geschichte d. Physik," Berlin (1878). I quote from the French version (Dunod, Paris, 1883), p. 3, of this excellent work, which has had the advantage of annotations by the translators.

Natter and Priestley think that they must at least have known the use of globes of glass, such as Seneca mentioned. But by reason of the distortion which so rude a contrivance would produce, it is hardly possible that it could have been employed. Engraved gems have been mentioned, and ivory carvings, in which the workmanship was said to be too small to have been produced by the unaided sight. In the case of one statement of Dutens (2nd ed. II., p. 224) where reference is made to a seal in the Cabinet of Medals, in Paris, said to have belonged to Michael Angelo, and to date back to remote antiquity, on which fifteen figures were engraved in a circular space 14 mm. diameter—"figures .... not all visible to the naked eye," Mr. Philip Gardner, of the Medal Department, British Museum, has made on my behalf a special inquiry of M. Chabouillet, Director of the Cabinet of Coins and Gems, in Paris, who answered under date the 20th inst. (November, 1885), that it was an error on the part of Dutens "(1) The gem is not antique, *i.e.*, Greek or Roman; (2) it never belonged to Michael Angelo."

Then we have the statement of Pliny, that Cicero had seen a manuscript of the whole Iliad contained in a nutshell. But the ancients themselves may have exaggerated somewhat in speaking of their skill in the execution of such curious work. We need not deny that very minute work was executed by them. But in order to rebut the conclusions that have been deduced from the fact that minute work was produced, it may suffice to note that Pliny, Solinus, and Plutarch, allude to these marvels of workmanship for the purpose of proving by the examples of the artists who executed them, that certain men are naturally endowed with a quite exceptional power of vision. Pliny adds that the more minute portions of these sculpturings "cannot be discerned by ordinary men." Hence it is clear that neither the authors nor the admirers of these minute *chefs-d'œuvre* knew the use of magnifying lenses.

Mr. Murray, of the Gem Department, British Museum, informs me that in his opinion there is no engraved work in our national collection that can be affirmed to be antique, and that is beyond the power of the unaided vision of the specially qualified modern engraver.

In reply to Lippert, who insisted that some of the antique work could not have been produced without the use of magnifiers, Lessing says that, by the admission of trained gem-engravers, everything of this kind that can be done with a magnifier may be done equally well, if not more easily, without.

Galen states that an artist of his acquaintance had made a seal, on which was engraved the figure of Phaeton in a chariot drawn by four horses; the mouths, the front teeth, the reins, and the sixteen feet of the four horses were all shown. "As for me," says Galen, "I could not at first perceive all these details, because of the extreme minuteness, except by turning the object towards a very strong light; even then I could not distinguish everything, and many persons were like myself; but when we could distinguish any part, we were agreed that it was executed with the greatest perfection." By these expressions of Galen, it is clear that neither this learned physician, nor the artist, nor the other persons who examined the seal in his presence, knew the use of magnifying lenses; and surely this must have obtained likewise among his contemporaries.

Pliny, who gives us a multitude of details on the processes employed by the ancients in engraving precious stones, who has even told us of the methods adopted by the engravers to strengthen their sight, and who informs us that to repose their fatigued eyes they looked at emeralds or green scarabæi; Pliny, the industrious compiler of the practical knowledge of antiquity up to his date, would not have failed on this occasion, or in speaking of the uses of glass, crystal, and transparent stones, of which he treated at considerable length, to refer to the use of dioptric lenses by engravers if they had employed them. The silence of Pliny, and of the learned Greek physician, Galen, demonstrates conclusively that in the first and second centuries of our era the use of magnifying lenses was unknown to the Greeks and Romans.

Is it possible, indeed, that if the ancients had ever invented telescopes or microscopes, or spectacles for long or short sight, such inventions would have wholly disappeared from the hands and memory of men? As a matter of fact, the employment of these instruments is found only where they have been introduced in modern times by Europeans since their invention in Europe.

The invention of spectacles for long and short sight is referred to as a quite recent invention in a MS. dating from Florence in 1299.* Bernard Gordon, professor at Montpellier, in his *Lilium medicinæ*, commenced in 1305, mentions spectacles as an aid to defective sight. Giordano da Rivalto, in 1305, says the invention dates back only "twenty years." They were, therefore, invented about 1285. It is known that they were invented by the Florentine Salvino d'Armato degli Armati, who died in 1317. He kept the secret with a view to profit by it. But Alessandro della Spina, of Pisa, who died in 1313, having seen spectacles made by Armati, and having succeeded in making them himself, hastened to publish the secret.

As to the more powerful optical instruments, the telescope and microscope, although it would appear that Alhazen* in the 10th or 11th century, Roger Bacon in the 13th, and Fracastoro and G. B. Porta in the 16th, had some idea that lenses might be made or combined so as to enable one to see distant objects better, or to magnify near ones beyond the power of normal vision; yet it must be held, with Kepler, that no instrument analogous to our telescope was known before the beginning of the 17th century, and that the possibility of the invention is limited to a very few men of that period. And, further, it is certain that the invention of the microscope was not anterior to the last few years of the 16th century.

Before proceeding with my subject in approximately chronological order, I must not omit to refer to the so-called Assyrian "lens," which is in the British Museum, and which was brought somewhat into fame some years ago by the publication of Sir David Brewster's opinion that he regarded it as a "lens," and as furnishing a practical demonstration that magnifiers were known to the ancients. I must also note upon two "bosses" of glass, recently acquired by the British Museum, which will doubtless be considered by some of the supporters of the antiquity of lenses as directly aiding to substantiate their views.

The Assyrian "Lens."—A piece of rock-crystal, of "plano-convex" form was found by Mr. Layard at the excavations of Sargon's palace, Nimroud, which had evidently been shaped oval by a process of chipping and grinding, and of which both the "plane" and "convex" surfaces had been ground and partly polished. This specimen

* Cited in R. Smith's "Optics" (Cambridge, 1738, 2 vols. 4to.), ii., pp. 12-3., and thus translated:—"I find myself so pressed by age, that I can neither read or write without those glasses they call spectacles, lately invented, to the great advantage of poor old men when their sight grows weak."

* R. Smith's "Optics," ii., p. 15; Wilde, "Gesch. d. Optik," i., p. 70.

is now in the Assyrian department of the British Museum, and in Sir David Brewster's opinion it is a "lens" designed for magnifying (*vide* Layard's "Nineveh and Babylon," pp. 197-8); it is shown in Figs. 1 and 2. As it

FIG. 1.

FIG. 2

ASSYRIAN "LENS" (721-705 B.C.)

was found together with certain objects of glass, one of which bears the name of "Sargon," I understand from Mr. Budge, of the Museum, that it has been possible to fix the date with reasonable probability to be not more recent than 721-705 B.C.

After repeated examinations of this piece of rock-crystal, I am unable to agree with Brewster's opinion. I do not suggest the possibility of proving that it is not a lens; but I think no proof whatever has been adduced that it was designed as a lens, *i.e.*, to serve as a magnifier, while the probabilities seem against that supposition.

(1.) I would point to the fact, apparently overlooked by Brewster in his description, that the broad bands of cloudy striæ, extending diagonally and transversely through the substance of the quartz would form a serious drawback to its use as a lens, whereas they would probably be considered as adding to the beauty as an object of decoration. These bands of striæ appear too opaque in Fig. 1. though their general character, as seen under certain effects of light, is faithfully rendered. (2.) The term "convex," as applied to a magnifying lens, is generally understood to mean a smooth spherical figure, such as is produced by grinding in a spherically concave tool. But the "convex" surface in question was admittedly produced by grinding a multitude of irregular facets so as to approximate more or less to a shallow spherical or ovoid surface, much inferior to the surfaces the lapidary of the present day produces in tablets of obsidian, agate, &c., for brooches, bracelets, &c., of the commonest type. A surface of this kind is assuredly not "lenticular," as we apply that term to lenses. The Assyrian polishing was clearly of the roughest character, performed with apparent violence, and without regard to the existence of the deep scratches due to the grinding. The curvature is so irregular, and the polishing of both surfaces so imperfect, that objects appear indistinct even when placed in contact with the plane surface, while, if held some three or four inches away, the indistinctness and distortion render vision through the "lens" almost painful. (3.) Brewster says its "focus" is about 4½ in. from the plane surface. When held suitably to the sun, it is true there is a condensation of light which appears brightest at about 4½ in. from the plane surface; but this blurred mass of light can scarcely be termed a "focus" in the sense in which we apply that term to a lens.

Ancient Glass Bosses.—More recently the British Museum has acquired two antique glass bosses, the external form of which is so regular that if any contemporaneous work could reasonably be regarded as impossible of production without the employment of magnifying lenses, then these bosses might readily be supposed to be such lenses, either completed or in process of manufacture. But until collateral proof is found of the employment of magnifying lenses, any conjectures implying that these specimens were really designed as lenses must be mere guesses. The one specimen is of nearly hemispherical form, about 2½ in. diameter. The surfaces meet nearly in a sharp edge, and spiral and irregular scratches on both sides would suggest some grinding process of manufacture. The curved surface, when viewed by reflected light, appears so regular, that if it was not wholly produced by grinding in a concave tool, or by some equivalent process, it was probably cast in a very smooth and regular mould, and then ground and partially polished. Unfortunately, both surfaces are decomposed and almost wholly covered by a semi-opaque opalescent shell; and where fragments of this shell have broken away, so that the body of the glass is exposed, the surface of the latter is covered with minute pits, and is generally disintegrated so that one cannot see through the substance. The second specimen seems to have been originally about the same size and shape as the former, but is now a broken segment somewhat less than half its original size. The surfaces are much less injured by decomposition than in the former one, but still they are so dull that one cannot see an object distinctly through the substance. The surfaces of fracture show that the glass is clear and transparent, and of slightly straw-colour. When viewed by reflected light the curved surface does not appear so regular in figure as the former one, and may possibly have been moulded by heat without further process. The date assigned to these "bosses" by the Museum authorities is not later than 270-260 B.C.

And now, assuming that we cannot affirm with reasonable certainty that magnifying lenses were employed before the invention of spectacles, we shall not, I think, be far wrong in supposing that the gradual deepening of curves would lead to the production of lenses of shorter and still shorter focus, until a point was reached, when the combination of a convex lens as an object-lens with a concave as an eye-lens, accidentally distanced apart by the hands, would lead to the discovery of the telescope and microscope of the form generally associated with the name of Galileo, but which, from the testimony of Galileo himself, was of Dutch origin,* and of date anterior to his own production of the telescope in 1609. This would appear to be the probable origin of the microscope consisting of a combination of a convex object-lens with a concave eye-lens.

The Keplerian microscope, consisting of a combination of a convex object-lens with a convex eye-lens—which is the simplest form of what is now termed a "compound" microscope—was probably later in date, subsequent even to the publication of Scheiner's "Rosa Ursina," in 1630, in which the actual construction of a Keplerian telescope was claimed by Scheiner, and notified as dating thirteen years previously, when he showed it in action to the Archduke Maximilian.

The optical system was clearly laid down by Kepler, in his "Dioptrice," in 1611. I remark, however, that Descartes, in his "Dioptrique," published with his "Discours de la méthode" (Leyden, 1637, 4to), describes and figures both a microscope and a telescope with concave eye-lenses, and says not a word of the Keplerian forms of these instruments; the inference is, that he knew only the "Galilean" constructions* and the simple magnifying lens at that date. Moreover, the first publication of a Keplerian microscope actually constructed was by Fontana,† in 1646. Manzini, in his work "L'occhiale all' occhio" (Bologna, 1660, 4to.), pp. 174-5, refers to one of these microscopes made by Eustachio Divini, in 1648, which he states could be reversed, noting this reversal as a peculiarity of the construction, but not recommending it in practice; and he speaks of it as made on the Keplerian optical system as devised by Fontana. It would thus appear that we must not assign the origin of the Keplerian microscope, as an actual construction, to an earlier date than 1646. It is true Fontana claims to have devised the instrument in 1618, but that date is wholly repudiated by Montucla and by Poggendorff.

* An able discussion of the evidence regarding the invention of the telescope is contained in Chap. xx. of R. Grant's "Hist. of Physical Astronomy," London (1852), 8vo.

MODERN MICROSCOPES TO THE DATE OF THE APPLICATION OF ACHROMATISM.

It is, perhaps, impossible to assign the exact date of the first production of the microscope (as distinguished from the simple magnifying lens); but those who have given special attention to the early testimony on the subject—notably, Van Swinden, Moll, Harting, and Poggendorff—are agreed that it must have been between 1590 and 1609; and that either of three spectacle-makers of Middelburg, Holland, named Hans Janssen, his son Zacharias Janssen, and Hans Lippershey, may have been the inventor, the probabilities being slightly in favour of the Janssens. Poggendorff considers the official documents found by Van Swinden in the national Archives of Holland, extracts from which were published by Moll in 1831, prove conclusively that Lippershey invented the binocular telescope (with concave eye lens—the "Galilean" form) in 1608, the lenses of which were constructed of rock-crystal in consequence of the extreme difficulty in obtaining clear glass in Holland. By the testimony of Pierre Borel,‡ and from

* Referring to telescopes of this form, which he states were invented about thirty years previously (*i.e.*, about 1607) by Jaques Metius, of Alcmar, Holland, Descartes says.—"Et c'est seulement sur ce patron, que toutes les autres qu'on a veües depuis, ont esté faites...." (And it is on this pattern only that all others seen hitherto have been made). "La Dioptrique," p. 2. Descartes had evidently not met with the Keplerian telescope in 1637.

† "Novæ cœlest. terrest. rerum observ.," Neapoli (1646), 4to.

‡ "De vero Telescopii inventore," Hag. Comit. (1655), 4to. (contains portraits of "Zacharias Iansen" [Janssen ?], and "Hans Lipperhey" [Lippershey ?]).

personal information supplied to him by Willhem Boreel, Dutch Ambassador in Italy, who was a native of Middelburg, and had known the Janssens, father and son; he had often heard from the elder Janssen that he and his son were the inventors of the microscope, and that he had sent one to Prince Maurice of Orange, and another, later on, to the Archduke Albert of Austria. Boreel further stated that when he was Ambassador to England, in 1619, he saw the latter instrument in the hands of his friend Cornelius Drebbel, and described it as having a tube,* eighteen inches in length and two inches diameter, of gilt brass (copper), supported by three dolphins on a base of ebony; and that objects placed on this base were seen considerably magnified through the tube. In 1610 (according to Boreel's recollection), the Janssens succeeded in producing a telescope for celestial observations.

It is upon this evidence generally, supplemented by that of Hans Janssen, the son of Zacharias, given in 1665 (1655?) regarding his father's statements anent his early connection with the invention of telescopes and microscopes, that the possibility of the invention of the latter is pushed back even as far as 1590. And it would appear that the first microscope on record was designed principally to view objects by reflected light, not by transmitted light.

"Janssen's" Compound Microscope.—Some years ago (1866) an old microscope was found at Middelburg, which Professor Harting thought might possibly have been made by the Janssens. It was exhibited at the Loan Collection, in London, 1876, and is shown in Fig. 3. I have here a copy of the original. It is of the Keplerian form, *i.e.*, consists of a combination of a convex object-lens and a convex eye-lens, which form was not published (as an actual construction) till 1646, by Fontana; hence, I think Harting was mistaken in assigning the construction to either of the Janssens. Nevertheless, because Harting thinks it may date back so early, I give it the first place in my budget of illustrations of modern microscopes.

This instrument is strictly a compound microscope in the modern sense, though without a field-lens, and this latter fact enables me to admit that it may, at any rate, have been constructed before the application of the field-lens to the microscope by Hooke, in 1665 (*vide* Preface to Hooke's "Micrographia"). The distance between the lenses can be regulated by two draw-tubes (one of which carries the object-lens in an inner adjustable tube) of thin iron-plate, fitting at either end of a middle-tube serving as a socket, so that within certain limits the magnifying power may be varied. There are three diaphragms in the instrument, one is placed at a variable distance in front of the object-lens, a second is at a fixed distance behind that lens, and the third is at a fixed distance above the eye-lens. This disposition of diaphragms is of great interest, especially if Harting is right in assigning the construction to the beginning of the 17th century. The eye-lens, *b*, is held in a simple

FIG. 3.

"JANSSEN'S" COMPOUND MICROSCOPE.

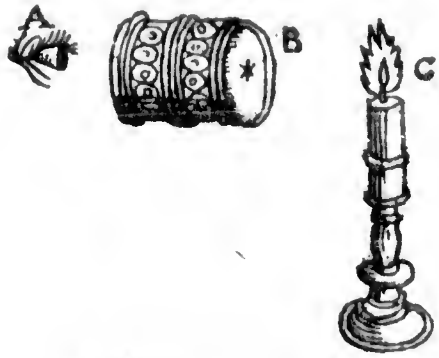
wood cell by means of a wire ring sprung in; the object-lens, *a*, fits against a narrow metal flange at *d*, where it is held by a sprung ring. In the original instrument the latter ring is absent, so that the lens is loose, as shown in the Fig. (at least that appears to me the probable explanation of the fact that the lens is not fixed in its cell).

The "Microscopium Pulicare."—Before passing to the microscopes of which the dates can be fixed with greater certainty, I must call your attention to a form of simple instrument termed by the earliest modern writers on optics the "Microscopium pulicare," "Microscope de puce," or "Flea Microscope." It is shown in Fig. 4 (p. 994), copied from Zahn's "Oculus Artificialis," 2nd ed. (1702), p. 342. The references contained in the first edition of this work (1685), and in earlier works by Kircher, Schott, Descartes, and others,

* I here follow Poggendorff, *loc cit.*, p. 111.

clearly indicate that such instruments were known early in the 17th century.

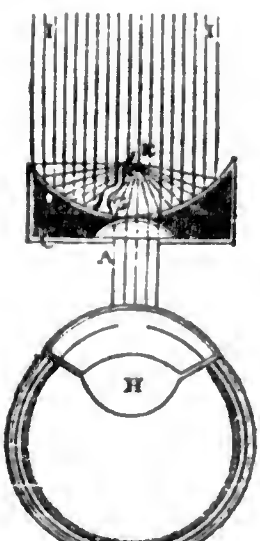
FIG. 4.



MICROSCOPIUM PULICARE.

Descartes' Microscopes.—We now arrive at the earliest published figure I have met with of a simple microscope. It was given by Descartes in his "Dioptrique," in 1637, p. 126, and is shown in Fig. 5.

FIG. 5.



DESCARTES' SIMPLE MICROSCOPE WITH REFLECTOR (1637).

Descartes claimed that it was much superior to the (then) common form of Flea Microscope. You will observe that the arrangement is practically identical with the simple lens mounted in a central aperture in a polished concave metal reflector, generally known as "Lieberkühn's" lens, constructed by Lieberkühn, about 1738. Lieberkühn's device followed the publication of Descartes' figure about a century. Descartes suggested the application of a short spike (seen at G in the Fig.) to hold the object at the focus of the plano-convex (hyperbolic) lens, which was to be directed fully to sunlight.

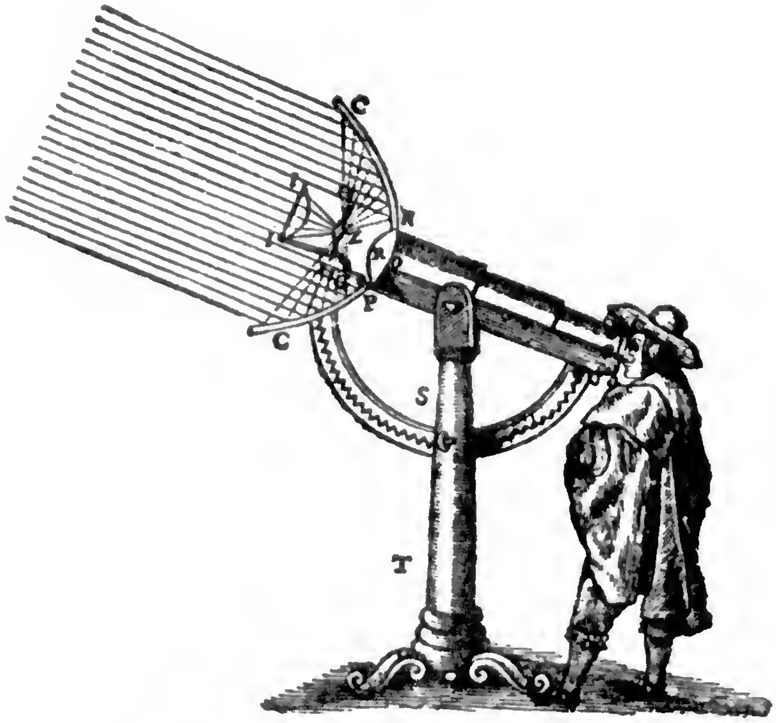
In the same publication (p. 132) Descartes also figured a microscope of colossal size, consisting of a combination of a bi-convex object-lens and a plano-concave eye-lens (both supposed to be worked to hyperbolic curves), and with an enormous perforated parabolic concave mirror encircling the object-lens to illuminate opaque objects, and a condensing lens in the axis of the instrument for illuminating transparent objects. This microscope is shown in Fig. 6 (p. 995). We have here the first combination, I have met with figured, of lenses forming a microscope. No means are provided for focussing except (apparently) the movement of the draw-tube containing the eye-lens. The dimensions and general form seem to me so very impracticable, especially for that early date, that I question if the device ever proceeded beyond the publication of the figure, while Descartes' instructions, that both instruments should be used with full sunlight, would also imply that he had never really used them in this way. I can hardly suggest what kind of object would not be vaporised in a few seconds if exposed at the focus of the gigantic parabolic mirror of the second form of Descartes' microscopes.

Descartes' microscopes were briefly referred to by Kircher ("De lum.et umb.," lib. 10), and by Gaspar Schott ("Magia Universalis," 1657-9, I., p. 535), but have generally been passed over by later writers, including Harting; the larger one has probably been frequently mistaken for a telescope. In the above-cited work, Descartes was, I believe, the first to publish figures and descriptions of machines for grinding and polishing lenses, thus preceding Manzini by twenty-three years, and Hooke by twenty-eight years.

"Divini's" and other Microscopes.—In the above-cited work of Gaspar Schott five forms of microscopes are given (Pl. xxv., p. 525), which are here shown in Figs. 7, 8, 9 (p. 995), 10 and 11 (p. 996). Fig. 8 may have been of the Keplerian form; but this is not certain. Schott states (p. 535) that Fig. 10 represents a microscope constructed by Eustachio Divini; but I have much difficulty in supposing that it can possibly have been intended for any serious purpose. Divini was a distinguished optician of his time, one of the very few in Europe then

capable of producing telescopes for astronomical observations. He was the rival of Giuseppe Campani, Torricelli, and Huyghens, and was referred to in terms of great respect by Manzini (in the work above-cited, where Divini's portrait is given), and by Fabri ("Synopsis optica," Ludg., 1667, 4to), so that I think it improbable that he ever seriously devised a microscope without arrangements for illuminating the object to be examined,

Fig. 6.



Descartes' "Galilean" Microscope (1637).

and of such unwieldy dimensions that the observer had to place himself as shown in the Fig. to look down the tube.

I have already mentioned that Manzini had

Fig. 7

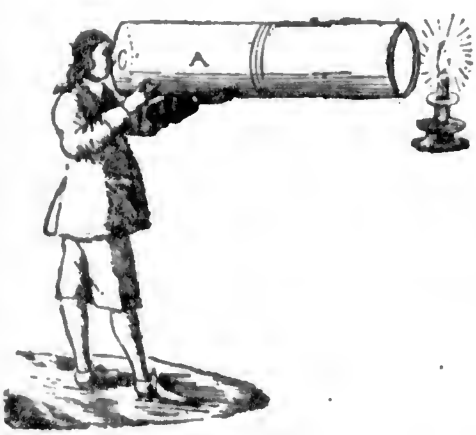
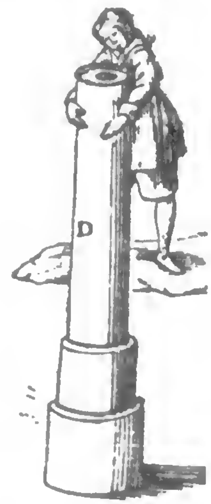


Fig. 8.

Fig. 9.

Fig. 10.



"Divini's" Microscope (1657).

Fig. 11.

seen a Keplerian microscope made by Divini in 1648; we shall presently come to one of his instruments made in 1666-7, showing that he realised the meaning of a microscope of convenient dimensions, and that he aimed at improvement in the optical construction—improvement that was immediately appreciated by Christopher Cock, the optician, of London, who appears to have worked out Hooke's ideas, and which led Grindl to the improved optical construction published in his "Micrographia nova," in 1687.

Campani's Compound Microscope.—The next microscope of special interest is one by Giuseppe Campani, shown in Fig. 12 (about two-thirds linear size). There is no field-lens in this instrument, and as Campani was an optician of considerable note, he would hardly neglect so important an innovation after its publication; we may, therefore, I think, safely assume the date of the construction prior to that of Hooke's microscope of 1665, in which the field-lens was claimed as a novelty. Campani provided a double focussing arrangement, one for regulating the distance between the object-lens and the object, the other for varying the distance of the eye-lens from the object lens. The application of the second plate, held by springs to the base, for clipping the object-slide while permitting a fair range of movement, is good, and may have suggested the spiral-spring arrangement devised later by Bonanni. The central hole through both plates was clearly intended by Campani to enable the observer to examine

Fig. 12.

Campani's Compound Microscope (*ante* 1665 ?).

transparent objects by holding the microscope to the sky or other source of light. The screw-focussing, by which the wooden optical tubes were rotated in a loosely-fitted metal screw-socket, must have been unsteady in practice; it is, however, the first system known to me of screw-focussing applied to a microscope.

For the use of the woodcuts, Figs. 1, 2, and 3, my acknowledgments are due to the Royal Microscopical Society.

Figs. 4, 5, 6, 7, 8, 9, and 10, were reproduced from the original Figs., in the works cited.

Fig. 11 was photographed on the wood-block from a photograph of one of the original instruments, to ensure the accuracy of the drawing.

For the loan of the large collection of microscopes exhibited in illustration of various points touched upon in this and the succeeding lectures, my acknowledgments are due to the Royal Microscopical Society, Mr. Frank Crisp (Secretary of that Society), and M. Alfred Nachet, of Paris.

ELEMENTARY LECTURES.

ELECTRICITY.

By Professor George Forbes.

Lecture II.—Delivered April 10, 1886.

"Currents and Resistance."

In the course of my last lecture I showed you the generation of an electrified condition of space, and the electric forces which were thereby produced, and I explained to you what we meant by saying that two things have a difference of electric potential. I also explained to you the condition which exists when two bodies have a different potential, that is to say, that there is then created electromotive force, and if this electromotive force be free to act through a conductor so that induction takes place, there is a momentary current, and re-arrangement of the electrification. If, however, the electromotive force is acting on an insulator no current can pass, and there is simply a strain created in the insulating medium which is ready to produce the phenomena of induction as soon as a facility is offered by the presence of a conductor of electricity. We are accustomed to measure our difference of potential in terms of some unit, and the unit which has generally been adopted is called a volt. When I say there is a difference of potential between the two knobs of the machine I am using, amounting to 50,000 units, I mean 50,000 volts, and that is about the difference of potential which we are in the habit of employing when we are using the electric machines. When I rub a piece of sealing-wax on flannel I get a difference of potential amounting to an enormous figure like that, and yet I can get no serious injury from it, because the quantity of electricity is so small. We shall be coming on to-day to learn the means which we have for generating electricity in much larger quantities than we can even by means of the Wimshurst machine; but when we come to experiment with batteries, or the other means for generating electricity in quantity, we shall be using very much smaller differences of potential than what we were using in the last lecture. A single cell of a battery may have one or two volts difference of potential, but that difference of potential which exists in a battery is exactly of the same nature as that which exists in the Wimshurst electric machine which you saw last time. The electric current which passes to the earth during a lightning flash is identically of the same character as that electric current which passes through each telegraphic instrument from our batteries, or which is lighting up this room at present by means of these glow lamps. It is hardly necessary, at the present time, to insist on this—that there is only one kind of electric current. In former days it required the researches of the ablest experimenters to prove to the world that the electric current which might be generated by means of apparatus like our Wimshurst machine, was the same in character as the electric current which can be generated by means of plates of metal in acidulated water. But we know with certainty that the effects are the same. I shall simply show you one experiment with the Wimshurst machine, to prove to you that one of the facts which we frequently find in dealing with batteries, can also be produced by means of such an influence machine. I have here a small strip of tinfoil which I shall place between two pieces of glass, and I shall then subject the two ends of the tinfoil to an electromotive force due to the difference of potential between the two knobs of the machine. Then when I discharge this machine by means of the assistance of the Leyden jars which are attached to it, we shall be able to pass an electric current through this piece of tinfoil, and show the heating effect which is thereby produced. This will be an apt illustration of the analogous effects which can be produced by means of this influence machine, and the totally different means of generating electricity which we have in batteries and dynamo - machines. On turning the handle now the spark has passed between the poles, and I will hand round as a specimen one of the pieces of tinfoil which was put their originally, and show you the fused condition of the tinfoil after the spark passed through it. Here is another specimen in which the effect is even more powerfully shown, because not only has the tinfoil been actually fused,

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All communications for the Society should be addressed to the Secretary, John-street, Adelphi, London, W.C.

NOTICES.

"OWEN JONES" PRIZES, 1886.

This competition was instituted in 1878, by the Council of the Society of Arts, as trustees of the sum of £400, presented to them by the Owen Jones Memorial Committee, being the balance of subscriptions to that fund, upon trust to expend the interest thereon in prizes to "Students of the School of Art who, in annual competition, produce the best design for Household Furniture, Carpets, Wall-papers, and Hangings, Damask, Chintzes, &c., regulated by the principles laid down by Owen Jones." The prizes are awarded on the results of the annual competition of the Science and Art Department.

Six prizes were offered for competition in the present year, each prize consisting of a bound copy of Owen Jones's "Principles of Design," and a Bronze Medal.

The following is a list of the successful candidates for the present year:—

1. Margaret E. Jones, School of Art, Cavendish-street, Manchester.—Design for a carpet and border.
2. Hollins Allen, School of Art, Warrington.—Design for a stair-carpet.
3. Walter Clarke, School of Art, Macclesfield.—Design for a silk hanging.
4. John Cassidy, School of Art, Cavendish-street, Manchester.—Modelled design for a panel.
5. Helen Lomax, School of Art, Cavendish-street, Manchester.—Design for printed cotton.
6. Lehmann Oppenheimer, School of Art, Cavendish-street, Manchester.—Design for the decoration of a mineral spring-well room.

Proceedings of the Society.

CANTOR LECTURES.

THE MICROSCOPE.

By John Mayall, Jun.

Lecture II.—Delivered November 30, 1885.

Modern Microscopes to the Date of the Application of Achromatism (Continued).

Hooke's Microscopes.—We now arrive at a specially interesting date in the early history of the microscope—the publication of Hooke's compound instrument, in 1665, in his "Micrographia," whence my Fig. 13 (p. 1008) is reproduced.

Hooke's first claim is for the application of a powerful illuminating apparatus, consisting of a lamp adjustable on a standard, with a globe of water and a deep plano-convex condensing lens on moveable arms, by which the light could be directed as required on the object. He thus describes his method of using sunlight:—

"I place a small piece of oyly Paper very near the Object, between that and the light; then with a good large Burning-Glass I so collect and throw the Rayes on the Paper, that there may be a very great quantity of light pass through it to the Object; yet I so proportion that light, that it may not singe or burn the Paper. Instead of which Paper there may be made use of a small piece of Looking-glass plate, one of whose sides is made rough by being rubb'd on a flat Tool with very fine sand, this will, if the heat be leisurely cast on it, indure a much greater degree of heat, and consequently very much augment a convenient light." (Pref., pp. 16-7).

These suggestions all point to Hooke's practical ability in the actual use of the microscope. He notes very clearly the advantage of employing this diffused light rather than direct sunlight, for "when the immediate light of the Sun falls on" an object, "the reflexions from some few parts are so vivid, that they drown the appearance of all the other, and are themselves also, by reason of the inequality of light, indistinct, and appear only radiant spots." (*ib.*, p. 17). On comparing these practical remarks of Hooke's with Descartes' advice on the same point, namely, to condense direct sunlight on the objects, I am confirmed in my opinion that Descartes had probably not used his microscopes as he recommended.

Hooke describes his microscope in detail, commencing with his application of four draw-tubes for lengthening the body, which was normally "not above six or seven inches long." Then he explains his addition of a third lens to the optical combination, whence we infer that previously the compound microscopes contained two lenses only—an object-lens and an eye-lens. This third lens was applied in a cell on the top of the cylindrical tube, so as to be readily removed; he used it, as he states, "only when I had occasion to see much of an Object at once; the middle Glass [field-lens] conveying a very great company of radiating Pencils, which would go another way, and throwing them upon the deep Eye Glass. But

FIG. 13.

HOOKE'S COMPOUND MICROSCOPE (1665).

when ever I had occasion to examine the small parts of a Body more accurately, I took out the middle Glass, and only made use of one Eye Glass with the Object Glass" (*ib.*, p. 22).

How far Hooke's application of a field-lens to the eye-lens of a microscope may have been suggested by the invention of the compound eye-piece associated with the name of Huyghens* (though attributed by some authorities

* In the notice of Huyghens in the "Biographie Universelle," it is stated that he applied "une combinaison de deux oculaires" to his telescope previous to 1659, *i.e.*, some years before the publication of Hooke's application of a field-lens to the microscope.

to Campani), I cannot determine. In any case, the sole purpose Hooke had in view, according to his own statement, was to increase the size of the field of view, and had nothing to do with correcting the spherical aberration of the eye-lens. His plain admission that he removed the field-lens when he was seeking the best definition is conclusive on this point.

From the description of the mechanism of this microscope, given by Hooke, I think he intended to claim the general design. The ball-and-socket movement of the body to the arm-carrier is thus described:—

"On the end of this Arm [D, which slides on the pillar C C] was a small Ball fitted into a kind of socket F, made in the side of the Brass Ring G, through which the small end of the Tube was screw'd; by means of which contrivance I could place and fix the Tube in what posture I desir'd (which for many Observations was exceeding necessary) and adjusten it most exactly to any Object" (*ib.*, p. 23).

The ball-and-socket movement, as here applied, is certainly not advantageously situated. In the microscopes I have met with constructed on Hooke's general design, this movement was replaced by a strong short screw attached to the ring, G, and fitting in a corresponding screw-socket projecting from, and forming part of, the sliding arm, D; this screw arrangement permitted the lateral inclination of the body-tube, and a thumb-screw at the side of the screw-socket clamped it in position. In several figures of Hooke's microscope, published since 1665, this modification is shown; for instance, in Sturm's "Collegium Curiosum" (1676), Fig. LXX., and in Zahn's "Oculus artificialis" (1685), which we shall examine.

It would appear that Hooke's introduction of the ball-and-socket in the construction of the microscope has met with numerous advocates since; it may not be uninteresting to cite a few examples by way of illustration.

J. Musschenbroek (1702) applied three of these movements, as articulations, to his simple microscope. Marshall (1704) used a large one with a tightening collar at the lower end of the standard to his compound form. Joblot (1718) had three on his simple lens-carrier; and Lyonet applied five to his. Culpeper (about 1730) mounted Wilson's simple, and his own application of the compound to the same, on a ball-and-socket, with adjustment on the top of the standard. B. Martin (1742) used it similarly with his first form of "Universal Microscope." Adams, Jones, Dollond, Pyefinch, Bates, and other English makers of the latter part of the last, and early part of this century, used a sort of chain composed of ball-and-socket joints to carry forceps, &c. A greatly improved form, with a powerful clamp, was devised by Goring to support his "Engiscope" on the top of the standard (*vide* Fig. and description in Pritchard's "Microscopic Illustrations," London, 1830, royal 8vo). More recently we have had stage-movements (by Varley, Powell and Lealand, Smith and Beck, Dancer, and others) controlled by ball-and-socket attached to a lever; in one instance—Varley's small model—two such levers acting together were applied. Microscope-lamps, mirrors, condensers, side-reflectors, illuminating prisms, forceps, and cameræ lucidæ, have all been fitted with ball-and-socket movements. The high-water mark of the application is probably reached in Marten's "Ball-Jointed Microscope,"* in which two of these movements are applied to carry the body-tube, and the stage is a hemisphere moving in a hemispherical cup, specially devised for the examination of large specimens of metals, &c., that cannot be readily viewed by an ordinary microscope.

The facility of movement provided by the ball-and-socket joint would seem to have attracted the notice of designers of microscopical appliances in every generation since its introduction by Hooke. For small accessories, where the leverage need not be considered, the ball-and-socket is convenient, though its use demands, in general, more manipulative skill than is required with the usual pivot mechanism; but it should not be applied as the main support of the inclining movement of the body of a large microscope. Even when made with a powerful clamp, as Goring devised, there is always the risk that when the clamp is released, the instrument may capsize through negligence in handling.

Hooke also explains minutely the construction of the object-stage thus:—

"For placing the Object, I made this contrivance: upon the end of a small brass Link or Staple HH, I so fastned a round Plate II, that it might be turn'd round upon its Center K, and going pretty stiff, would stand fixt in any posture it was set; on the side of this was fixt a small Pillar P, about three quarters of an inch high, and through the top of this was thrust a small Iron pin M, whose top [pointed

* "Zeitschr. f. Instrumentenk," ii. (1882), p. 112 (Fig. 1.); reproduced in "Journ. Roya' Mic. Soc.," ii. (1882), p. 672; the stage was not figured.

end] just stood over the Center of the Plate; on this top I fixt a small Object, and by means of these contrivances I was able to turn it into all kind of positions, both to my Eye and the Light; for by moving round the small Plate on its center, I could move it one way, and by turning the Pin M, I could move it another way, and this without stirring the Glass at all, or at least but very little: the Plate likewise I could move to and fro to any part of the Pedestal (which in many cases was very convenient) and fix it also in any Position, by means of a Nut N, which was screw'd on upon the lower part of the Pillar CC" (*ib.*).

This object-stage seems to me based on sound practical ideas—ideas that have only been duly appreciated in our own time, as shown by the now general application of the rotating stage, which our ancestors almost totally ignored. The link clamped down upon the base was an admirably steady support for the rotating plate, far superior to the generality of stage devices contrived before the system developed by Oberhaeuser was employed (about 1830).

Hooke appears to have been dissatisfied with the lenses he used. He says :—"The Glasses I used were of our English make, but though very good of the kind, yet far short of what might be expected, could we once find a way of making Glasses Elliptical, or of some more true shape." He complains that the "Apertures of the Object-glasses are so very small, that very few Rays are admitted, and even of those few there are so many false, that the Object appears *dark* and *indistinct*....." Of the "best Glasses," he states that "none will admit a sufficient number of Rayes to magnifie the Object beyond a determinate bigness" (*ib.*, p. 16). To remedy the inconvenience due to the want of light transmitted by the microscope he devised the lamp and condensers described above to illuminate the object more powerfully.

It is evident that Hooke discovered thus early the importance of increasing apertures; but the greater apertures he had in view were merely to provide a greater quantity of light from the object to enable him to get higher magnification—the magnification he aimed at being limited by the want of light. He says nothing, nor could he be expected to say anything, regarding any increase of resolving power by the increase of aperture, for the connection between aperture and resolving power could hardly have been seriously considered from any practical point of view, in the construction of either dioptric telescopes or microscopes, before the application of achromatism.

We may infer that other large microscopes were in use at that date, for Hooke states that a blown-glass globule,* prepared and used as he describes, will "make some Objects more distinct then any of the great *Microscopes*" (*ib.*, p. 22). It would appear also that the viewing transparent objects by transmitted light was not yet discovered to be the principal utility of high powers, for Hooke, in explaining that "the larger the Telescope Object Glasses are, and the shorter those of the Microscope, the better they magnifie," qualifies the statement (as relating to the microscope) by adding that it will be exceeding *difficult* . . . to *inlighten* an Object less then an hundred part of an inch distant from the Object Glass" (*ib.*, pp. 19-20). Clearly, then, Hooke thought only of viewing opaque objects with high powers. The difficulty he notes with reference to the illumination would not apply to transparent objects. A proximity of one hundredth of an inch would be no serious obstacle to viewing objects by transmitted light, and would certainly not impose a limit (such as he implies) to the magnification.

Hooke also describes a compound microscope he devised to have two refractions only, consisting of a conical tube, at the small end of which he cemented a plano-convex lens of short radius, with its convex surface outwards, for the object lens, and at the larger end he cemented similarly a larger lens of greater radius; then, by means of a small hole in the side, he filled the tube with water, stopping the hole with a plug. With this arrangement, he states, "I could perceive an Object more bright then I could when the intermediate space was filled with Air, but this, for other inconveniences, I made but little use of" (*ib.*, p. 23).

He also made other forms of microscopes, some of "Waters, Gums, Resins, Salts, Arsenick, Oyls, and with divers other mixtures of watery and oyly liquors" (*ib.*); he adds, "I find generally none more useful then that which is made of two Glasses, such as I have describ'd" (*ib.*), thus leaving his invention of the "Middle Glass," or field-lens, to take care of itself.

Hooke was, I believe, the first to describe a useful method of estimating the magnifying

* Poggendorff ("Hist. de la Physique," p. 357) states that in the production of minute lenses of blown-glass globules Hooke was preceded by Toricelli.

power of a compound microscope. He says:—

"Having rectifi'd the *Microscope*, to see the desir'd Object through it very distinctly, at the same time that I look upon the Object through the Glass with one eye, I look upon other Objects at the same distance with my other bare eye; by which means I am able, by the help of a *Ruler* divided into inches and small parts, and laid on the *Pedestal* of the *Microscope*, to cast, as it were, the magnifi'd appearance of the Object upon the Ruler, and thereby exactly to measure the Diameter it appears of through the Glass, which being compar'd with the Diameter it appears of to the naked eye, will easily afford the quantity of its magnifying" (*ib.*, p. 22).

This method is, obviously, applicable only to objects that can be plainly discerned by the unaided eye.

Hooke was one of the earliest to note upon the difficulty of distinguishing between a "prominency and a depression" with the microscope (pseudoscopy), which he states that he observed when preparing the drawings for the illustrations of his "Micrographia," which would be in 1664, if not earlier. Prof. Govi,* in his work on the "Discoverer of a Singular Optical Illusion," refers to a printed letter of Eustachio Divini to Count Carlo Antonio Marozini, dated 15 July, 1663, in which certain phenomena of pseudoscopy are described; Divini may, therefore, have preceded Hooke in these observations. I remark, in passing, that Divini refers in this letter to "Microscopes with two glasses," and states that when he wanted to see the whole of rather large objects he removed the deep object-lens and substituted a lens of shallower curvature; but, apparently, he knew nothing at that date of the use of a field-lens in the ocular; this would appear to confirm indirectly Hooke's claim to be the first to apply a field-lens to the ocular of a microscope.

The series of drawings of common objects, such as a needle point, a razor edge, snow crystals, spiders, and other insects, &c., as seen under his compound microscope, were doubtless viewed with much astonishment by many of Hooke's contemporaries, and his "Micrographia" soon became a scarce and expensive book. In the descriptions of these objects he touches incidentally upon an enormous mass of details regarding microscopical manipulations, &c., details evincing great industry and acuteness of observation.

In his "Lectures and Collections," published in 1678, under "Microscopium," pp 96-7, we find Hooke no longer advocating the "double" microscope in his former enthusiastic tone. Whether this change of opinion was due to the publication of Leeuwenhoek's successful observations with simple microscopes I cannot determine. Hooke has been suspected by many who have sought to inform themselves of the history of his contributions to science, of being somewhat over-anxious to keep himself to the fore; but this must not prevent our acknowledgement of his real merits. He states that in using plano-convex lenses as single microscopes, "'tis best to turn the plain side towards the object, and the convex to the eye;" and that he himself had not used any less than 1-10th inch in radius of curvature, because they strained his sight, "though in truth they do make the object appear much more clear and distinct, and magnifie as much as the double Microscopes: nay, to those whose eyes can well endure it, 'tis possible with a single Microscope to make discoveries much better than with a double one, because the colours which do much disturb the clear vision in double Microscopes is clearly avoided and prevented in the single."

Hooke must undoubtedly be credited with the first suggestion of immersion lenses, thus:—

"If further, you would have a Microscope with one single refraction, and consequently capable of the greatest clearness and brightness that any one kind of Microscopes can possibly be imagined susceptible of, when you have fixt one of these little Globules as I have directed [globules of blown-glass, the preparation of which he had described], and spread a little of the liquor upon a piece of Looking-glass plate, then apply the said plate with the liquor, next to the Globule, and gently move it close to the Globule, till the liquor touch; which done, you will find the liquor presently to adhere to the Globule, and still to adhere to it though you move it back again a little; by which means, this liquor being of a specifique refraction, not much differing from glass, the second refraction is quite taken off, and little or none left but that of the convex side of the Globule next the eye; by which means as much of the inconvenience of refraction as is possible is removed, and that by the easiest and most practicable expedient that can be desired" (*ib.*, pp. 98-9).

The criticism I have made on Campani's screw-focussing adjustment applies still more to Hooke's microscope, for here the body-tube, being much longer and heavier, would be certain

* "Atti R. Accad. Lincei. Transunti," vii. (1883), pp. 183-3.

to describe series of "curves of irregular curvature" round about what should be the rigid optic axis in the screw-movement of focussing, the object, if small, appearing in the field or disappearing according to the erratic nature of the screw-fitting—the screw-fitting as made at that date.

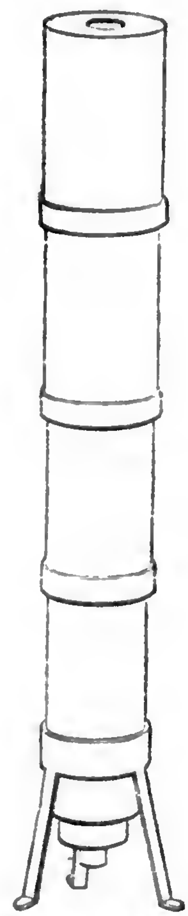
Nothing is said about the application of a mirror, nor have I met with any microscope, provided with a mirror, of date anterior to about fifty years later than Hooke's instrument, *i.e.*, 1710-1720.

Hooke appears to have entrusted the manufacture of his microscopes for sale to "Mr. Christopher Cock, in Long-Acre" (*ib.*, p. 99).

I have dealt somewhat fully with Hooke's microscopes, but not more fully than I think they deserve in view of the fact that he was the first to give a real impetus to English microscopy in the two main branches in which it is divided—the optical and mechanical construction of the instrument, and its application to research—in both of which his influence was conspicuous. It would be an easy task to prove, by citations from the contemporary scientific publications, that Hooke's work as a microscopist gained him European fame. For my own part, I can never forget that one of the most eminent men of science of our day, one whose competence to form a fair and accurate judgment is beyond question—I allude to Herschel—has referred to Hooke as "the great contemporary, and almost the worthy rival of, Newton" ("Discourse on Nat. Philos.," p. 116).

Divini's Microscope.—Soon after the publication of Hooke's compound microscope, we find in the "Giornale de Letterati," I. (1668), pp. 52-4, a description (partly translated in "Philos. Trans.," III., 1668, p. 842) of a compound microscope constructed by Eustachio Divini, which had already been commended by by Fabri, in Prop. 46 of his "Synopsis Optica" (1667). It was stated to be about 16½ inches high, and adjustable to four different lengths by draw-tubes, giving a range of magnification from 41 to 143 diameters. Instead of the usual bi-convex eye-lens, two plano-convex lenses were applied with their convex surfaces in contact, by which he claimed to obtain a much flatter field. In the Museo Copernicana, at Rome, there is a microscope answering to this description so closely that I think we may safely refer its origin to Divini. I made a sketch of it, from which my Fig. 14 has been copied. The tripod base terminating above in a cylindrical socket is of tin; the body-tubes are of cardboard covered with grey paper, and the magnifications of the various lengths are noted on each tube. The lowest tube slides within the metal socket of the tripod, and carries the object-lens in a thin cell of tin slid on the end; the next tube slides over the former, and has an external collar at the lower end, apparently to serve as a stop to the next tube; the third and fourth tubes are similar, but progressively larger, and a diaphragm is

FIG. 14.



DIVINI'S COMPOUND MICROSCOPE (1667-8).

at the upper end. As regards the optical construction, my impression is that it has been tampered with, and I question if anything of the original remains.

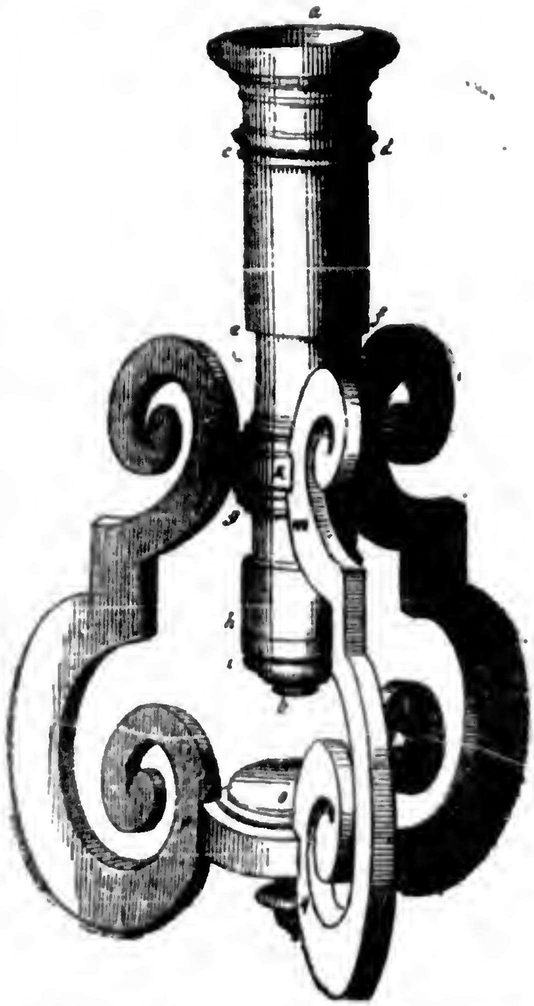
I may mention that in Birch's "Hist. of the Royal Society," a passage (*vide* Prof. Govi, *loc. cit.*) is quoted from the official papers of the Society, dated 11th February, 1668-9, showing that a large microscope (probably of Hooke's general design), made by Mr. Christopher Cock, was to be brought to the Society at the next meeting. This microscope had "five glasses, of which four eye-glasses were plano-convex, two and two so put together, as to touch one another in a point of the convex surface." The eye-piece was thus a modification of that of Divini; whence it would appear that our opticians were alert in seeking improvements. We shall see later on that Grindl (1687) adopted this eye-piece, and applied a similar construction to the objective.

Chérubin d'Orléans' Microscopes.— The next microscope in order of date we shall examine was designed by Chérubin d'Orléans, and published in his treatise, "La dioptrique oculaire," in 1671 (Paris, fol., Plates 30-1, pp. 238 and 261), *vide* my Fig. 15. Chérubin evidently had a high opinion of his microscope, giving minute instructions for its construction with detailed figures. The three "consoles," or scroll supports, were to be of ebony or blackened pear-tree, firmly attached to the base and to the collar encircling the fixed central portion of the body-tube. An exterior sliding tube carried the ocular above on the fixed tube, and a similar sliding tube carried the object-lens below, the sliding tubes serving to focus the image and regulate within certain limits the magnification. He further suggested and figured a screw arrangement to be applied beneath the stage for focussing, the optical body in this case to consist of two tubes only, and the object-lens remaining stationary.

Chérubin also described and figured a stage-disc on which several objects were to be mounted concentrically, and this disc was to be attached to rotate on the focussing stage, so that objects could be viewed successively in the optic axis by the mere rotation of the disc. He was thus probably the inventor of the multiple object-disc, modifications of which have had some vogue in our own time, both in Europe and America, and even in Japan, as we shall see later on. He also figured spring forceps, and a "stab" on articulated joints, to hold insects, &c.

With regard to the optical arrangement of this microscope, Chérubin recommends so many different combinations of lenses that I cannot determine with certainty which he really preferred. His recommendations embody so many items as to remind one forcibly of certain modern specifications of patents, in which it is sought to include every possible (not to say impossible) combination within the sphere of the invention. At p. 217, in referring to a microscope composed of two convex lenses, he states that the object-lens may be $\frac{1}{4}$, $\frac{1}{3}$, or $\frac{1}{2}$ inch focus at most, and equi-convex. "Its eye-glass, not requiring to be far from the objective, must be of a rather larger sphere, for instance, about $\frac{3}{4}$, 1, or $1\frac{1}{2}$ inch focus at most." Another construction, which he states (pp. 220-1) he actually made, contained a second lens in the ocular, having a focus in relation to the eye-lens as $2\frac{1}{2}:1$, or $3:1$; and

FIG. 15.



CHÉRUBIN D'ORLÉANS' COMPOUND MICROSCOPE (1671)

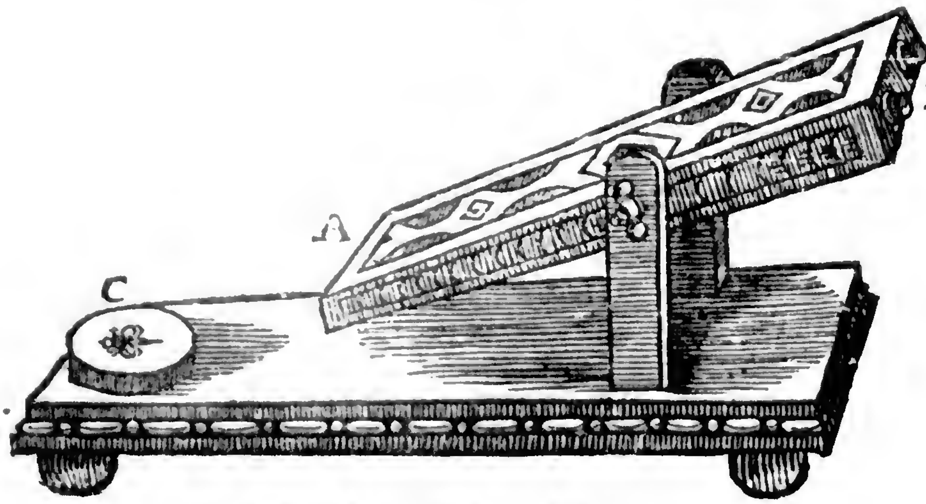
his remarks on the effects observed by placing the field-lens too near to, or too far from, the eye-lens seem based on actual experience. He notes upon the combinations of three and four separate lenses, by which objects may be seen in their natural position (erect), and states that the latter is "much to be preferred" (p. 264).

Chérubin d'Orléans' Binocular Micro-

scope.—Chérubin d'Orléans is generally believed to be the inventor of the binocular microscope, which he published in his work "La vision parfaite," in 1678 (Paris, fol., also the same work freely translated into Latin by himself, "De visione perfecta," Paris, 1678, fol.), and which he states that he actually constructed some years previously, and submitted to the inspection of several of his friends (*vide* Pref., p. viii). His device consisted of two compound microscopes, joined together in one setting, so as to be applicable to both eyes at once; a segment of each object-lens (supposed to be of one inch focus) was ground away to allow the convergent axes starting from the two eyes to meet at about 16 inches distance, at the common focus. Mechanism was provided for regulating the width of the axes to correspond with the observer's eyes.

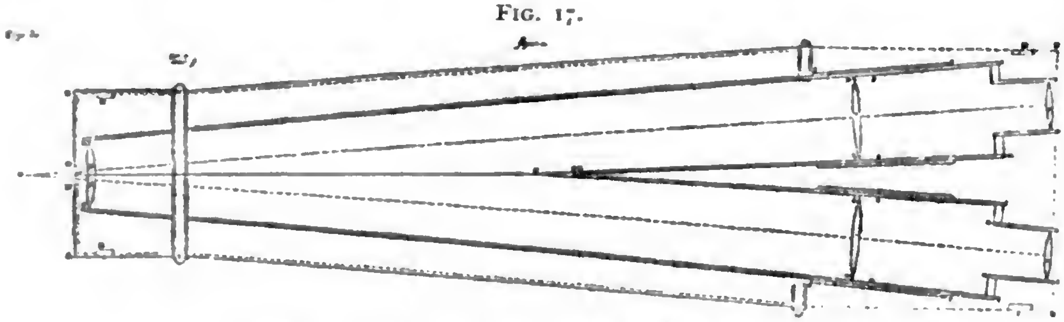
A drawing of this binocular, as known to Zahn, was given in the first edition of his "Oculus artificialis" (1685), and is here reproduced in Fig. 16. As here shown the only method of focussing was to move the object by

FIG. 16.



CHÉRUBIN D'ORLÉANS' BINOCULAR MICROSCOPE (1678).

FIG. 17.



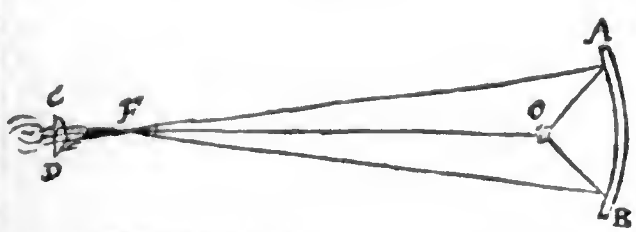
CHÉRUBIN D'ORLÉANS' BINOCULAR MICROSCOPE (1678).

hand. I have, however, met with a binocular made on Chérubin's system, constructed early in the 18th century according to the instructions given in "La vision parfaite," in which the mechanism was excellent. Fig. 17 showing the optical construction, is copied from the original diagram ("La vision parfaite," Tab. I., Fig. 2, p. 80). Hooke criticised the instrument with some asperity ("Lectures, Microscopium," pp. 101-2), probably because Chérubin stated it had enabled him to discover mistakes in certain recently published figures of microscopical objects (alluding to some of the drawings in Hooke's "Micrographia"). Hooke was obliged, however, to admit "failures in some of those draughts, some of my own and some of the gravers committing. *Humanum est.* But those which he [Chérubin] charges for such are not, as he might have seen if he had made use of better glasses than those which he describes, for they are so far short of equalling those I use, that I can demonstrate from his own Description of them, that those I made use of did magnifie 10000 times more than that with which he pretends to have made these great Discoveries." Hooke's opinion was that objects are seen in the microscope far better "with one eye only [*i.e.*, the monocular microscope], which is much to be preferred before that with two [binocular]." And he asks the very pertinent question (which I think has not been satisfactorily answered even by the advocates of the binoculars of our own day), "what Discoveries he [Chérubin] doth make with his binocular Microscope more than was seen before."

Newton's Reflecting Microscope.—In 1672, Newton communicated to the Royal Society ("Phil. Trans." VI., 1671-72, p. 3080), a short note and diagram descriptive of his Reflecting Microscope—the first suggestion of a microscope acting by reflection—as follows :—

"I have sometimes thought to make a *Microscope*, which in like manner should have, instead of an Object-glass, a Reflecting piece of metall. And this I hope they [the Royal Soc.] will also take into consideration. For those instruments seem as capable of improvement as *Telescopes*, and perhaps more, because but one reflective piece of metall is requisite in them, as you may perceive by the annexed diagram [reproduced in Fig. 18], where AB representeth the object metall, CD the eye-glass, F their common Focus, and O the other focus of the metall, in which the object is placed."

FIG. 18.



NEWTON'S REFLECTING MICROSCOPE (1672).

It does not appear that Newton ever had this microscope constructed. The modern instruments termed reflecting graphoscopes are equivalent to Newton's reflecting microscope in construction, except that they are not furnished with an eye-lens.

Leeuwenhoek's Microscopes.—In 1673, Leeuwenhoek commenced communicating his discoveries with the microscope to the Royal Society. Beyond the occasional statement that his observations were made with simple microscopes (as distinguished from the Keplerian compound instrument, for the "Galilean" combination seems to have almost drifted out of memory from its very early construction in the 17th century down to its re-advocacy by Brücke in this century), Leeuwenhoek explained nothing by which his contemporaries could furnish themselves with instruments like those he employed, and this silence added to the mysterious awe with which he and his work were regarded. He was extremely shy of exhibiting his microscopes to any one ; and some of his contemporaries taxed him with a greater love of praise than of truth because of his eagerness in claiming discoveries. Even as late as 1709 the real construction of Leeuwenhoek's microscopes was not certainly known (*vide* "Phil. Trans.," XXVII., pp. 24-27, "A letter from Dr. Archibald Adams to Dr Hans Sloane, R.S.Secr., concerning the manner of making microscopes, &c.," where Dr. Adams, after describing that "they appear'd to be spherules lodg'd between two plates of gold or brass, in a hole whose diameter might not be bigger than that of a small pin's head," adds, "but still their make and truth are unknown").

Now that we know exactly the kind of instruments Leeuwenhoek employed, there can be no difficulty in the admission that his reputation as a discoverer in microscopy was really based on his patience and dexterity in the preparation of his objects, and on the skill he brought to bear on the interpretation of his observations. As to his microscopes, their construction was of the rudest kind mechanically, whilst optically they consisted of simple bi-convex lenses with worked surfaces mounted between two thin metal plates with minute apertures through which the objects were viewed directly. At his death he bequeathed to the Royal Society a cabinet containing twenty-six of his microscopes, which were reported upon by Martin Folkes, Vice-President of the Society, in the "Phil. Trans.," XXII. (1723), pp. 446-63.

In 1740 these microscopes were examined, and reported upon to the Royal Society, by Henry Baker, F.R.S. ("Phil. Trans.," XLI., 1740, pp. 503-19), and it appears that they ranged in power from 1-20 to 1-5, magnifying from 160 to 40 diameters. In 1753 Baker gave two outline drawings representing both sides of one of these microscopes in his "Employment for the Microscope" (Pl. XVII., Figs. 7 and 8, pp. 434-6), whence my Figs 19 and 20 (p. 1016) are copied. The cabinet and the microscopes have disappeared from the Royal Society. Baker's description is as follows :—

"The Eye must be applyed to the Side fig. 7 [my Fig. 19]. The flat Part A is composed of two thin Silver Plates fastened together by little Rivets *b b b b b b*. Between these Plates a very small double-convex Glass is let into a Socket, and a Hole is drilled in each Plate for the Eye to look through at *c*. A Limb of Silver *d* is fastened to the Plates on this Side by a Screw *e* which goes through them both. Another Part of this Limb, joined to it at right Angles, passes under the Plates, and comes out on the other Side (*Vid.* fig. 8 [my Fig. 20]) at *f*: through this runs, directly upwards, a long fine-threaded Screw *g*, which turns in and raises or lowers the Stage *h*, whereon a coarse rugged Pin *i* for the Object to be fastened to, is turned about by a little Handle *k*; and this Stage with the Pin upon it is removed farther from the magnifying Lens, or admitted nearer to it, by a little Screw *l*, that passing through the Stage horizontally, and bearing against the Back of the Instrument, thrusts it farther off when there is occasion. The End of the long Screw *g* comes out thro' the Stage at *m* [?], where it turns round, but acts not there as a Screw, having no Threads that reach so high."

Fig. 19.

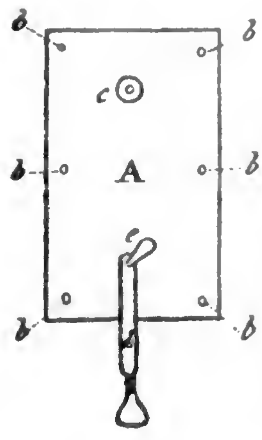
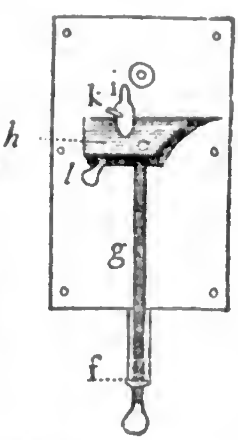


Fig. 20.

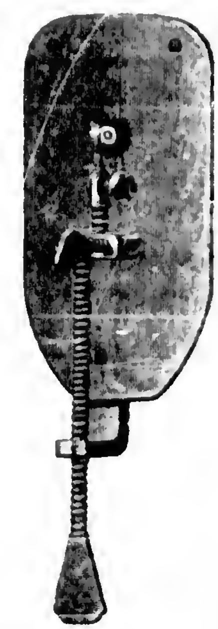


Leeuwenhoek's Microscope.

By the courtesy of Prof. Hubrecht, of Utrecht University, I am enabled to give figures of one of the Leeuwenhoek microscopes belonging to the Museum of that University; it is shown in Figs. 21 and 22 full size. The lens is bi-convex, of about 1-4th inch focus, and is mounted between two concavities provided with minute apertures, made in two corresponding thin plates of brass, which are held together by three rivets, two at the upper end, and one at the lower. The object is held in front of the lens, on the point of a short rod, the other end of which screws into a small block or stage of brass, which is rivetted somewhat loosely on the smoothed cylindrical end of a long coarse-threaded screw acting through a socket angle-piece attached behind the lower end of the plates by a small thumb-screw. The long screw serves to adjust the object under the lens in the vertical direction, whilst the pivoting of the angle-piece on its thumb-screw gives lateral motion. The object-carrier can be turned on its axis, as required, by screwing the rod into the stage. For focussing, a thumb-screw passes through the stage near one end, and presses vertically against the plates, causing the stage to tilt up at that end; the fitting of the long screw-carrier (angle-piece) is such that the stage at the end is sprung down somewhat forcibly on the brass plates,

Fig. 21.

Fig. 22.



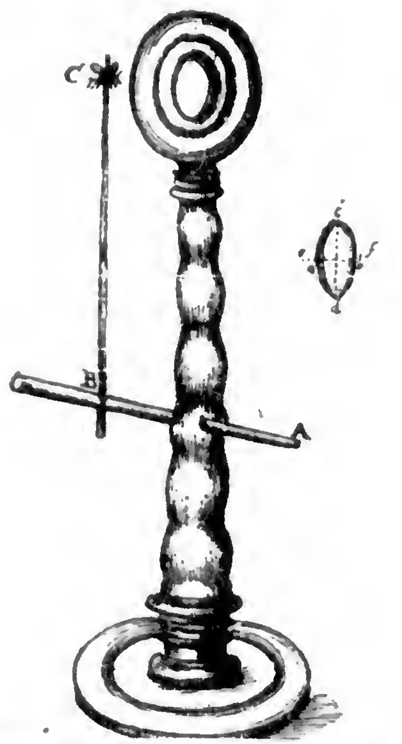
Leeuwenhoek's Microscope.

and it is against this pressure that the focussing screw acts. The metal knob on the object-carrier has a small projection, which appears to have been intended by Leeuwenhoek to fit in the hole beneath, in the brass plates, and thus retain the object opposite the lens.

Simple Microscope (from Sturm's "Collegium curiosum").—A quaint form of simple microscope was figured in Sturm's "Collegium curiosum" (Norimb, 1676, 4to), p. 139, which is shown in Fig. 23 (p. 1017). The arrangement of the focussing rod AB is somewhat primitive—so primitive, indeed, that I suspect the design was of much older date. A section-view of the lens is shown.

On the same page of the original work are two graphic representations (here shown in

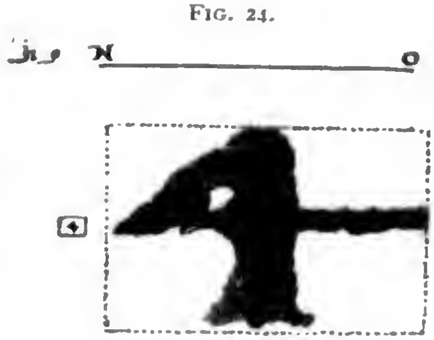
FIG. 23.



SIMPLE MICROSCOPE, FROM STURM'S "COLLEGIUM CURIOSUM" (1676).

Fig. 24) of the magnifying power of this instrument; the one showing the line, *n o*, the original size, and the same magnified fourteen times linear to the size N O (but the draughtsman has exhibited the magnification in length only, not in breadth); the other showing the figure 4 as printed from type, and the same as magnified by the lens. Hooke had previously given a magnified view of a printed "full stop," with the original in juxtaposition; but he used

FIG. 24.



a compound microscope. Sturm also gives a figure of Hooke's microscope as modified probably by one of the constructors who made it for sale; we shall presently come to a figure given by Zahn, almost identical with it.

Microscopes from Zahn's "Oculus artificialis."—The two editions of Zahn's "Oculus artificialis" (1st ed., Herbip., 1685, fol.: 2nd ed., Norimb., 1702, fol.) contain a considerable number of figures of curious microscopes, from which we may select a few.

(1.) *Early English Microscopes.*—In the first edition (1685), under the heading "Microscopii Anglicani" (Fundamentum III., p. 26), we find the six microscopes shown in Fig. 25 (p. 1018). Of these, *Figs.* 1 and 4[*] are early types of the fixed tripod support for the body-tube, which was developed by Culpeper and Scarlet some fifty years later into popular models that were taken up by the Nürnberg toy-makers of that date, and whose successors have continued to manufacture them in large numbers down to our own time. The original models generally had body-tubes of leather or parchment stamped and gilt, with supporting rings of wood. The tripods were of brass attached to wood bases. The lenses were mounted in wood or horn cells, sometimes with screw-rings to fix them, but generally with rings of bent wire sprung in; and caps were supplied to cover the eye-lens. These instruments mostly have large field-lenses; and in the early models the focussing by screwing the body-tube in a socket at the top of the tripod is nearly always met with; the sliding body-tube for focussing was rarely made until fifty years later. In *Fig.* 4 the rotating multiple object-disc appears. *Fig.* 2 shows two supports for the cross-bar in which the body-tube screws; but this model does not appear to have had much vogue. *Fig.* 3 seems to have been a modification of Hooke's model—a modification for the worse. *Fig.* 5 shows another form of rotating multiple object-disc forming the stage itself. *Fig.* 6 is another modification of Hooke's model; the stage is no longer carried on a link encircling the standard. This last instrument is practically identical with the one figured in Sturm's "Collegium Curiosum" to which I have already referred.

(2.) *Simple Microscope with Rotating Multiple Object-disc* (*anonymous*).—On p. 111 *(loc. cit.)* of the same work, Zahn figures

[*] The numbering of these Figs.—1 to 6—is that of the original plate, which is reproduced in *facsimile*.

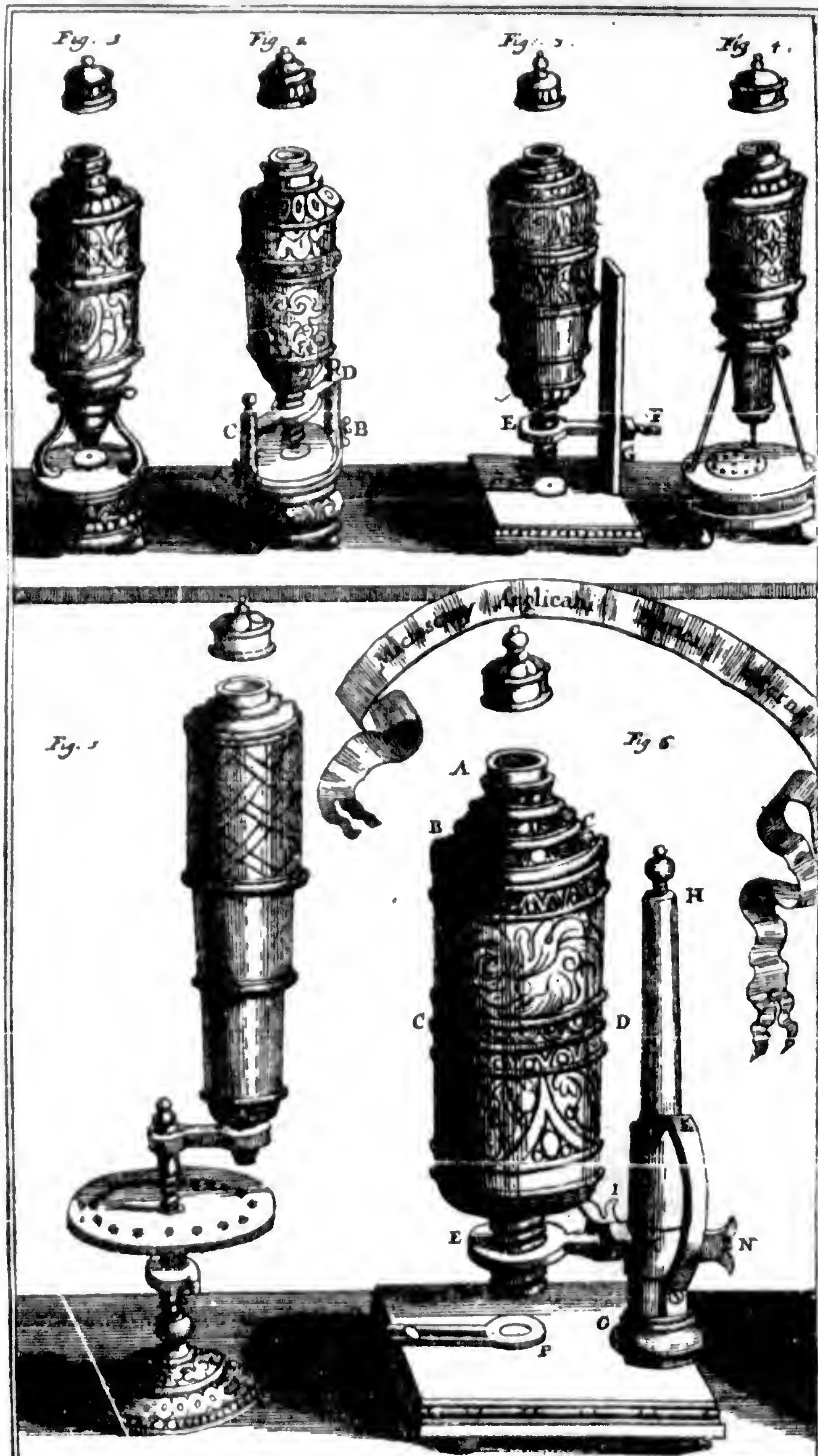
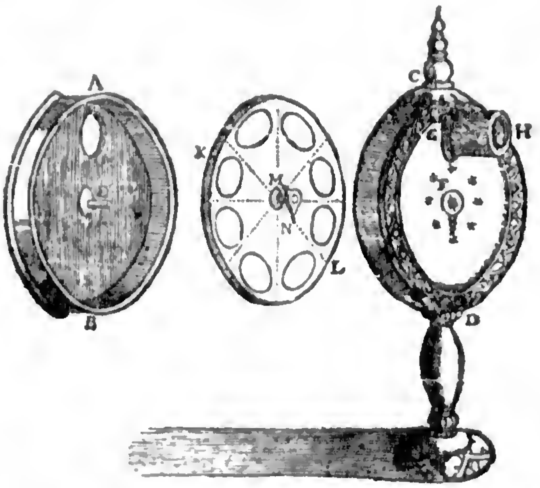


FIG. 25.—EARLY ENGLISH MICROSCOPES (1702).

a simple microscope with rotating multiple object-disc, shown here in Fig. 26.

FIG. 26.

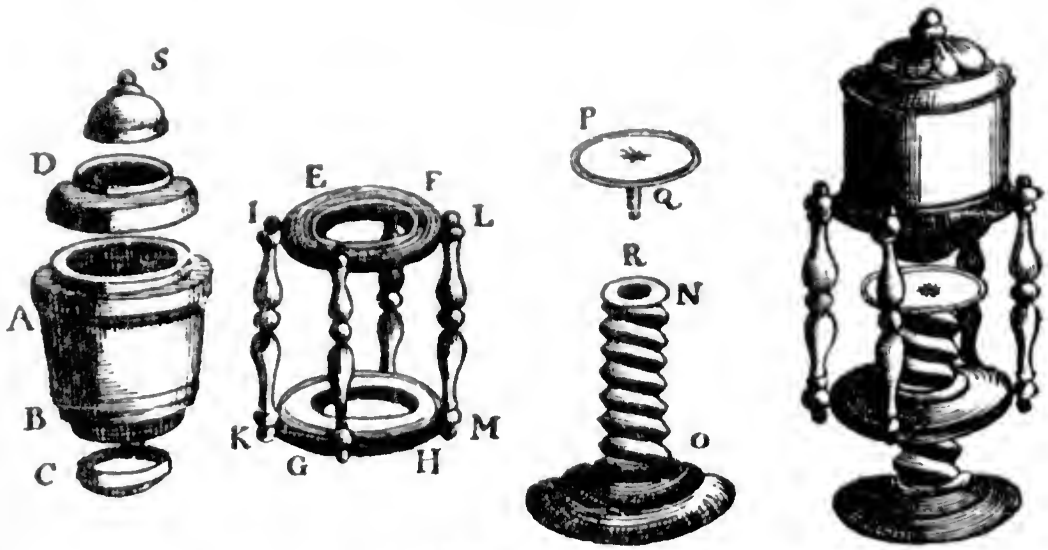


SIMPLE MICROSCOPE WITH ROTATING MULTIPLE OBJECT-DISC (1685).

In the early days of the microscope, attention seems to have been given principally to opaque objects; this instrument, however, was designed to view transparent objects only. The disc, K L, was fitted to rotate on the pin, E, in the centre of the cap, A B, and this cap was applied within C D, so that the aperture would be opposite the lens-carrier, G H. The handle, N, served to rotate the disc, so that the objects passed successively in the field of view. Microscopes, more or less modified from this construction, were devised early in the 18th century by Joblot, who used high-power simple lenses, and hence had to provide delicate means of focussing. The system is still occasionally applied to "popular" microscopes.

(3.) *An "Augsburg" Microscope (anonymous.)*—In the 2nd ed. (1702) of the same work, p. 749, a small microscope is shown,

FIG. 27.



AN "AUGSBURG" MICROSCOPE (1702).

which is reproduced in Fig. 27. I have termed it an "Augsburg" microscope, because the design is very like several other models which are known to have been constructed at Augsburg towards the close of the 17th century. From the number of instruments of this inferior class figured by Zahn, I think we may infer that the microscope was rapidly becoming vulgarised. The system of focussing by rotating the body by means of the socket travelling on the screw-standard must have been very defective in practice.

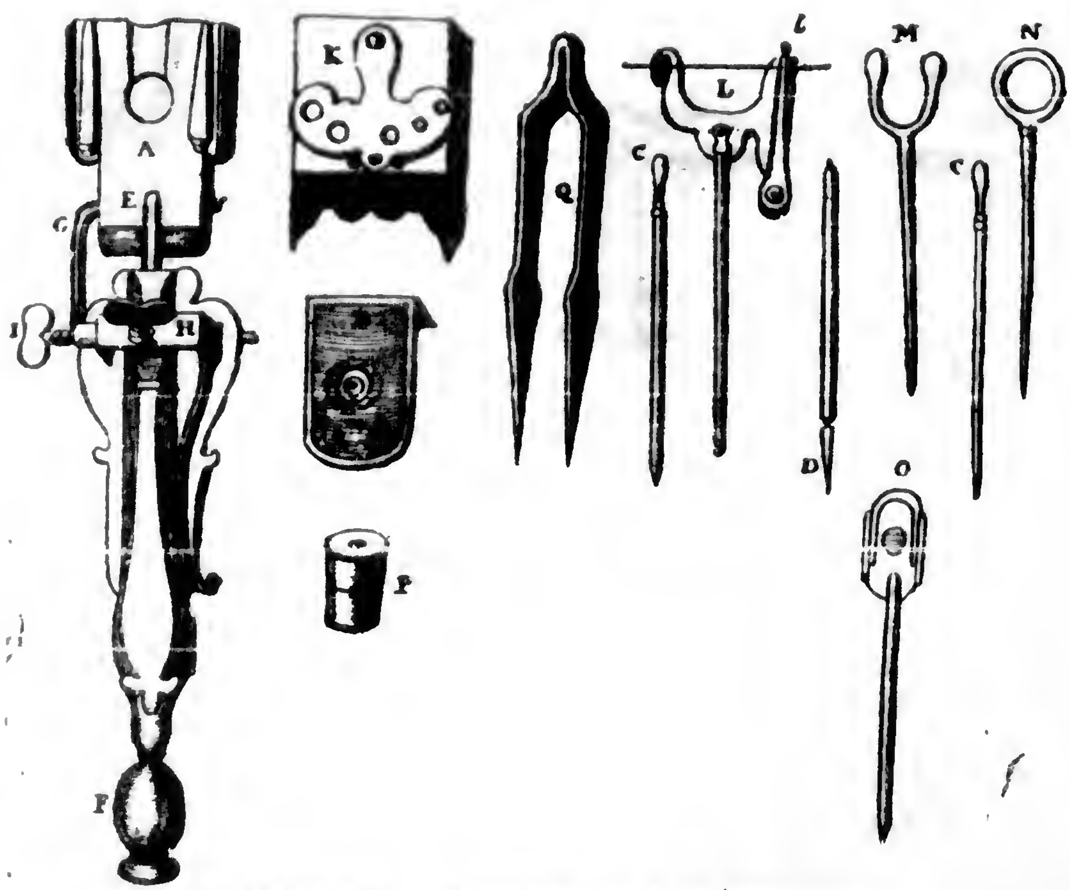
(4.) *Musschenbroek's Simple Microscope.*—In the same work, p. 781, the first form of J. Musschenbroek's simple microscope is figured. My Fig. 28 (p. 1020) is a woodcut from a photograph of one of the original instruments belonging to the Museum of the University of Utrecht. We have here the first application known to me of ball-and-socket movements to a simple microscope to facilitate the examination of objects. We have noted above that Hooke first used it with his compound instrument. The carrier on the left served to hold pointed or forked rods on which objects were fixed, the rods passing through holes in narrow flanges at the sides, and being gripped by a pivoted spring, so that they could be turned as required, without slipping. The disc of wood on the right has a rod beneath, by which it can be slid in the socket that now carries the "stab," and it would then serve as a stage for minerals, &c.

FIG. 28.

MUSSCHENBROEK'S SIMPLE MICROSCOPE (1702).

(5.) A much more elaborated form of Musschenbroek's simple microscope is shown in Fig. 29, copied from the original figure (*ib.*, p. 783). Here we have a hollow handle, through the length of which slides a tube, E, controlled by the knob, F; various forms of object-carriers, such as C, L, D, M, N, or O can be inserted at E; the handle is provided with hinge joints set at right angles, and by means of two thumbscrews, I and H, acting against the pressure of springs, the object can be moved laterally and adjusted to the focus of the lens. The lenses were bi-convex, mounted between two thin plates, B, of brass fitted to slide in metal grooves in the carrier, A, on the exterior of which slides the metal box, K, with its pivoted sector of diaphragms. G is a piece of wire bent to two right angles; one prong slides into a pivoted socket at the back of the instrument, the other passes laterally through A; by this arrangement the lens-carrier, A, can

FIG. 29.

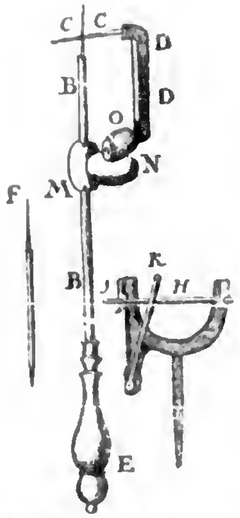


MUSSCHENBROEK'S SIMPLE MICROSCOPE (SECOND FORM, 1702).

be tilted forward or backward, or laterally, in relation to the object.

This system of changing-diaphragms, made

FIG. 30.

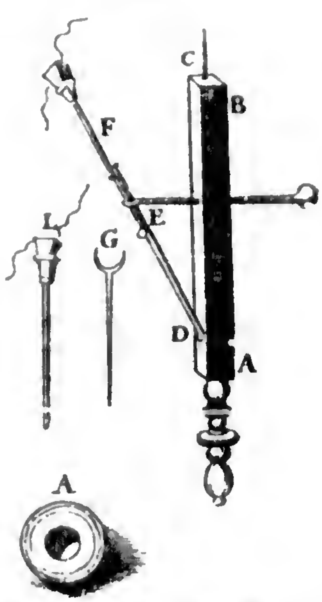


SIMPLE MICROSCOPE (MODIFIED FROM MUSSCHENBROEK'S, 1702).

by cutting them in a zone in a sector pivoted in its centre, is the first I have met with in connection with a microscope.

The workmanship of Musschenbroek's

FIG. 31.



CUNO'S SIMPLE MICROSCOPE (1702).

microscopes is very neat and well finished, very superior to that of Leeuwenhoek's. As to the lenses, those I have had the opportunity of examining were about equal to his.

(7.) Another form of simple microscope is shown in Fig. 30, which seems to have been partly copied from Musschenbroek's (*ib.*, p. 796). B B is the object-carrier on which slides the lens-carrier, C C, pivoted by the arm, D D, at O on the socket, M N.

(8.) *Cuno's Simple Microscope.*—Cuno's simple microscope is figured with the preceding whence my Fig. 31 is copied. The simplicity of this instrument would suggest that it may have been the original from which Musschenbroek, Wilson, and Lieberkühn devised their modifications. We shall meet with a still more primitive arrangement in an Italian work which we shall examine. The lens is mounted in the cell, A, fitting on the spike, C. The object is attached to the rod, F, or the fork, G, which are adjustable on the hinged arm, D; then by means of the screw, E, attached to D, and travelling through the standard, A B, the focus is adjusted.

Figs. 13, 15, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27, 29, 30, and 31 were reproduced from the original Figs., in the works cited.

Fig. 14 is a woodcut from my sketch of the instrument.

Figs. 21, 22, and 28, were photographed on the wood-blocks from the original instruments, to ensure the accuracy of the drawings.

ELEMENTARY LECTURES.

ELECTRICITY.

BY PROFESSOR GEORGE FORBES.

Lecture III.—Delivered April 17, 1886.

In my first two lectures I spoke about statical electricity, and about a current of electricity, and I mentioned that there was a time when it was absolutely necessary to prove that these two manifestations of electrical influence were identical. Now, there is no doubt about it. We know that statical electricity and dynamic electricity are identical, that there are not two kinds of electricity, but that the phenomena we studied on the occasion of the first lecture, and the phenomena we considered on the occasion of the second lecture, are really different manifestations of one identical force. The discharge of the Wimshurst machine is identical with the current from a battery, and the difference of electric potential at the terminals of a battery is of the same character as that at the two knobs of the Wimshurst

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FRIDAY, SEPTEMBER 17, 1886.

All communications for the Society should be addressed to the Secretary, John-street, Adelphi, London, W.C.

Proceedings of the Society.

CANTOR LECTURES.

THE MICROSCOPE.

By John Mayall, Jun.

Lecture III.—Delivered December 7, 1885.

Early Italian Microscopes.—In an Italian work, entitled "Nvove inventioni di tvbi ottici," which appears to have been a communication to the "Accademia Fisico-matematica," of Rome, in the year 1686, signed by "Carlo di Napoli" (but which was probably written by Ciampini, the editor of the "Giornale de Letterati," *vide* Langenmantel's notes on Tortoni's microscope in "Miscell. curiosa," 2nd Decade, 7th year, 1689, p. 444), a Plate is given of a number of curious forms of microscopes which are reproduced in Fig. 32 (p. 1032).

The microscope, shown in *Fig.* 1, is similar to the one we noted from Sturm's "Collegium curiosum." *Fig.* 2 is a sort of goblet with a lens on the top. *Fig.* 3 is not glazed at the sides, so that the objects could be readily changed. *Fig.* 4 seems to me an older form than Cuno's simple microscope, which we have examined, and may be the original design that suggested Cuno's which was improved upon by Musschenbroek, Wilson, Lieberkühn, and others, down almost to our own time; it has generally been termed "The Opaque Microscope." The rod, B, carrying the lens-holder, A, slides and turns in the sockets, D D, and the forceps, G H, fit similarly in E E; D D and E E are pivoted at F. The forceps are sprung open by pressure of the screw I. *Fig.* 5 embodies quite original points (so far as I know); the objects are fixed on the edge of the vertical disc, G, which rotates under the lens in the centre of the disc, D, and different portions of the objects can be brought in the optic axis by the screw-action of the peg, H; C is a spring carrying the lens-holder, D, and by means of the cord, E, winding on the peg, F, the lens-holder was drawn down to the proper focus, or by the reverse action it was raised by the spring, C. *Fig.* 6 is of special interest from the fact that it is stated to have been designed by "Hombergh, Gentiluomo Indiano"—Homberg the well-known member of the "Académie des Sciences," of Paris, and whose "Éloge" was written by Fontenelle. The eye-piece was of peculiar design, the field-lens being mounted at the upper end of an inner tube over which slid an outer tube having the eye-lens at the top; the separation of the lenses could thus be varied. The body was of brass, on which a screw-thread was cut on a length of about two inches, and the focussing was effected by rotating the body in the brass screw-socket, A B; the extended bearing of the screw (which had a rather fine thread) made the movement far more accurate and steady than was usual in microscopes of that date. *Fig.* 7 shows the same model, said to be improved by mounting the body to screw in a ring on an arm on a pillar, instead of the tripod. *Fig.* 8 was designed by "Carlo Antonio Tortoni." For viewing transparent objects, this microscope was to be directed to the sky, the light passing through the aperture, E, in the base-plate. This microscope was furnished with a field-lens, otherwise its similarity to the Campani instrument, we have examined, is manifest. Another somewhat similar microscope, by Tortoni, was communicated to the "Miscell. curiosa" (cited above) by Langenmantel. *Figs.* 9 and 10 are attributed to "Marco Antonio Cellio;" the lower tube, in *Fig.* 10, screws in the socket at A for focussing; the upper is a draw-tube; a field-lens is applied; the object-slide passes through a slot in the base, and is held by springs (shown at E E in the circular figure on the right). Here, again, the modifications from Campani's design (except, of course, the presence of the field-lens) are but slight, as, indeed, noted by the author of the paper. *Fig.* 11 is said to be the "smallest of all the microscopes;" the sides were of wood, and the multiple object-disc (No. 2) was fitted to rotate between them, the portions, N M, projecting at the edges for convenience of turning. The lenses are said to have been made of "crystal," of about the size "of a small grain of millet;" the magnifying power was therefore high; they were mounted in discs as at S (No. 3), and a diaphragm Q was pivoted at R on the other side (No. 1) to regulate the light. A focussing screw (No. 4) was applied

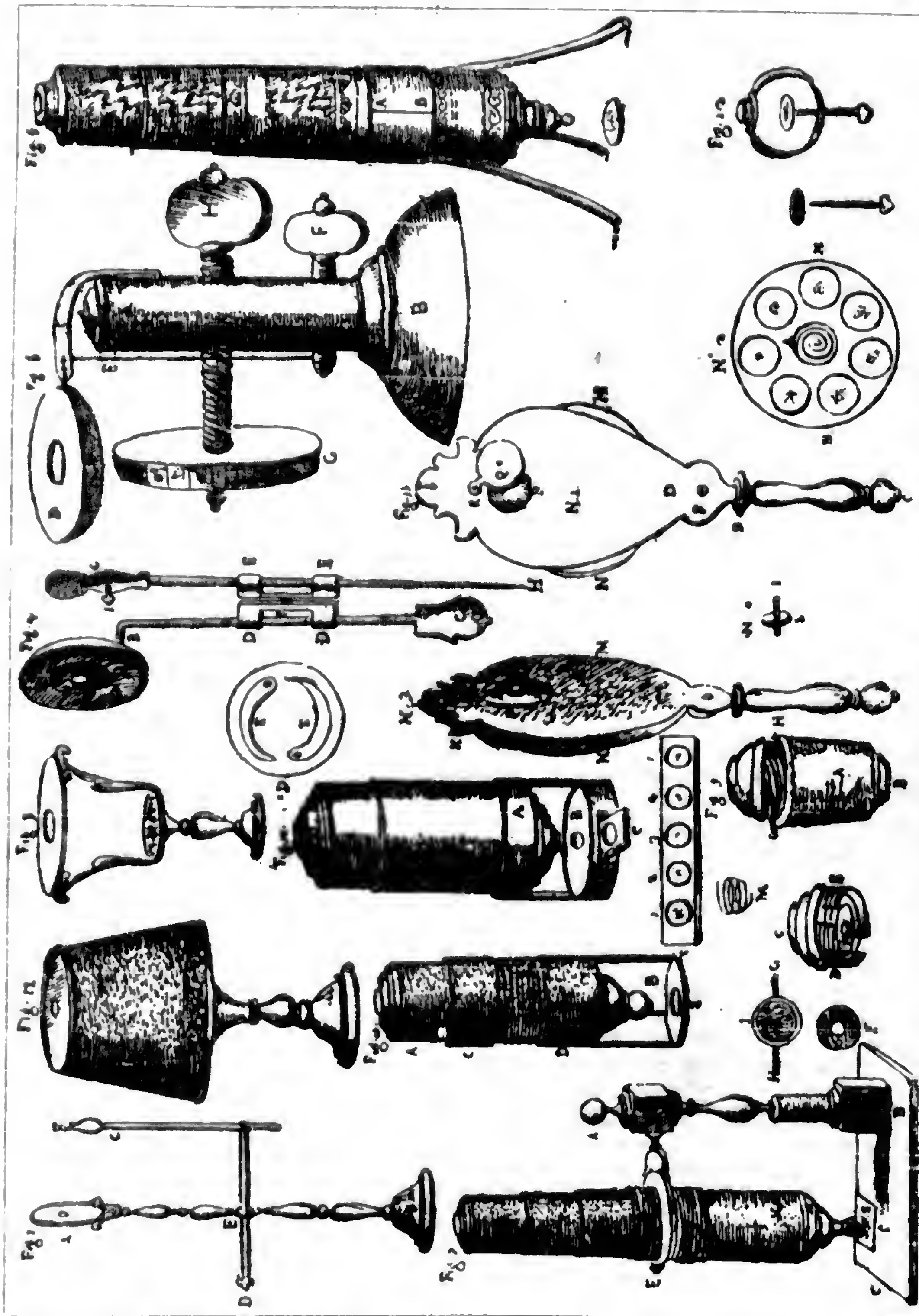


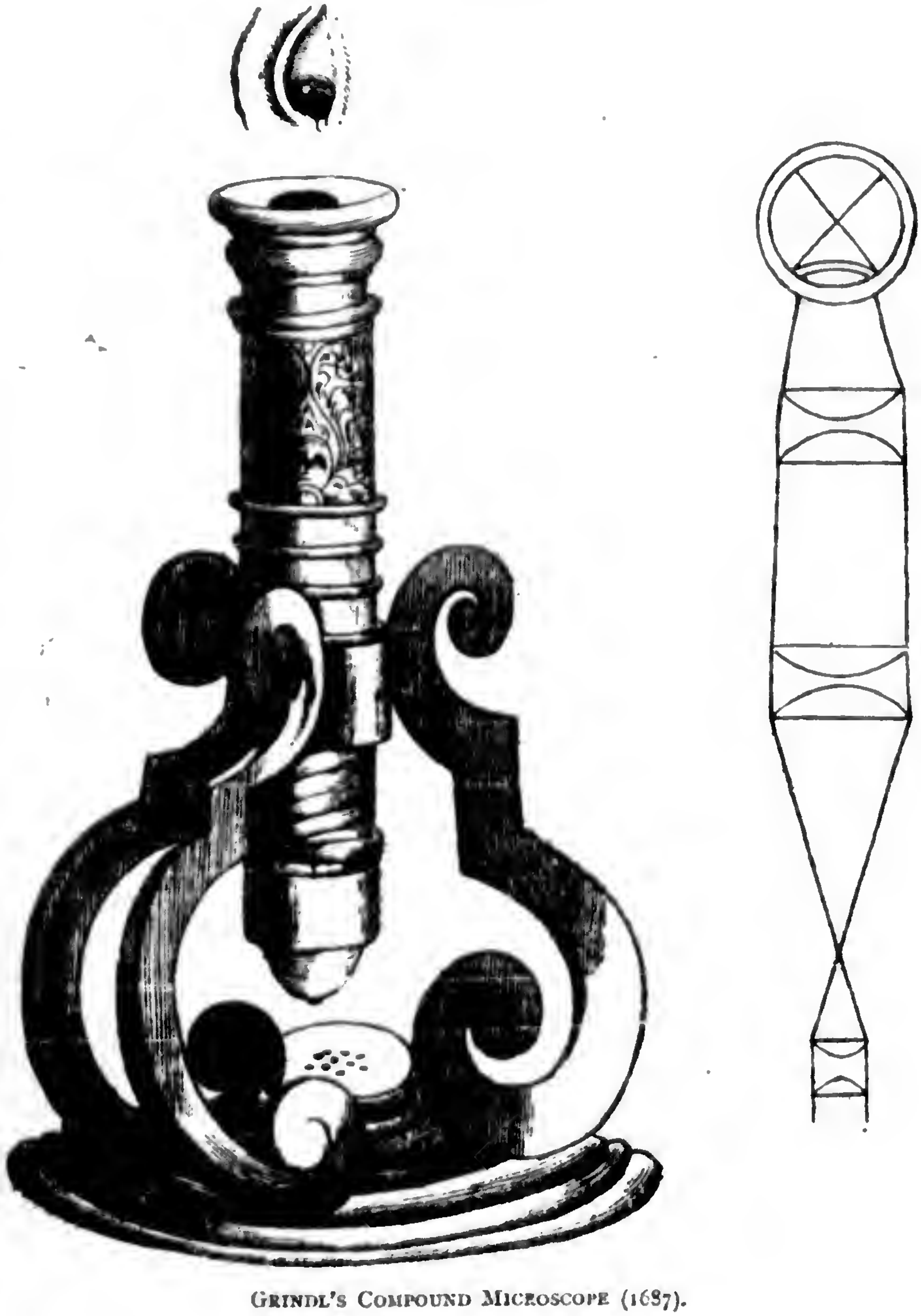
FIG. 32.—EARLY ITALIAN MICROSCOPES (1686).

at the upper end between the sides at I (No. 3), and the milled edge disc, L, projected slightly beyond the top for the action of the finger.

Fig. 12 is said to have been devised by Tortoni; the lens formed the signet of the ring, and on the opposite side of the ring a hole was made, through which a short screw-rod travelled, carrying a small object-plate to the focus.

Grindl's Compound Microscope. — In Grindl's "Micrographia nova" (Norimb., 1687, 4to), p. 7, we find the microscope whence my Fig. 33 is copied. The optical construction is stated by Zahn ("Oculus artificialis," 1685. Fundam., III., p. 234) to have been communicated to him by Grindl in December, 1685.

Fig. 33.



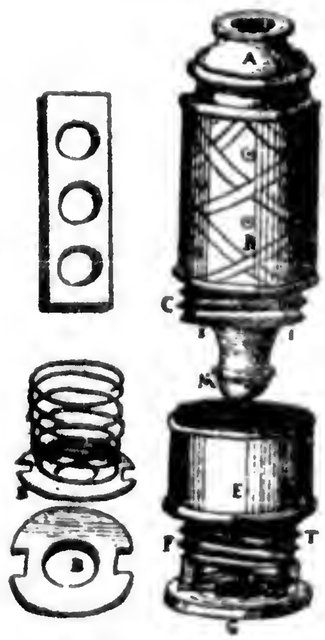
Grindl's Compound Microscope (1687).

I have already noted that Divini combined two plano-convex lenses, with their convex surfaces facing, to form an eye-piece, with which he claimed that objects were seen less curved; and we found that Divini's idea was carried out further by an optician of L on in 1668 (cited under my notes on Hooke's microscopes), who used two pairs of these lenses in his microscope. Grindl combined with the latter eye-piece a pair of similar (but smaller) lenses acting together as an objective, as shown in the diagram.

The form of the stand appears to have been copied from that of Chérubin d'Orléans, modified, however, by the application of an external screw to the body-tube acting in a screw-socket for focussing.

Bonanni's Microscopes. — In Bonanni's "Micrographia curiosa" (Rome, 1691, 4to), p. 26, we find the microscopes shown in Figs. 34 and 35. The interesting point in the design

FIG. 34.



MICROSCOPE OF BONANNI.

of Fig. 34 is that the focussing can be effected by a "screw-barrel" arrangement acting on the object, which is clipped between two plates and pressed away from the object-lens by a spiral-spring. This system of focussing was shown more practically (as we shall see) by Hartsoeker (1694), in combination with a condensing lens; and Hartsoeker's design was clearly the original of Wilson's (1702).

In Fig. 35 the focussing is effected by rotating the body-tube in a screw-socket. The plate, G, was fixed; the object was slid between F and G, and a spiral-spring within E D pressed it in contact with G. The tube, M, was put as a sheath over E I, D I, to exclude all light but that transmitted by the object when the instrument was directed to the sky. The design of this microscope is similar to, but an improvement on, that of Cellio (*vide* Fig. 32, *Fig.* 10), which was but slightly modified from Campani's, as we noted.

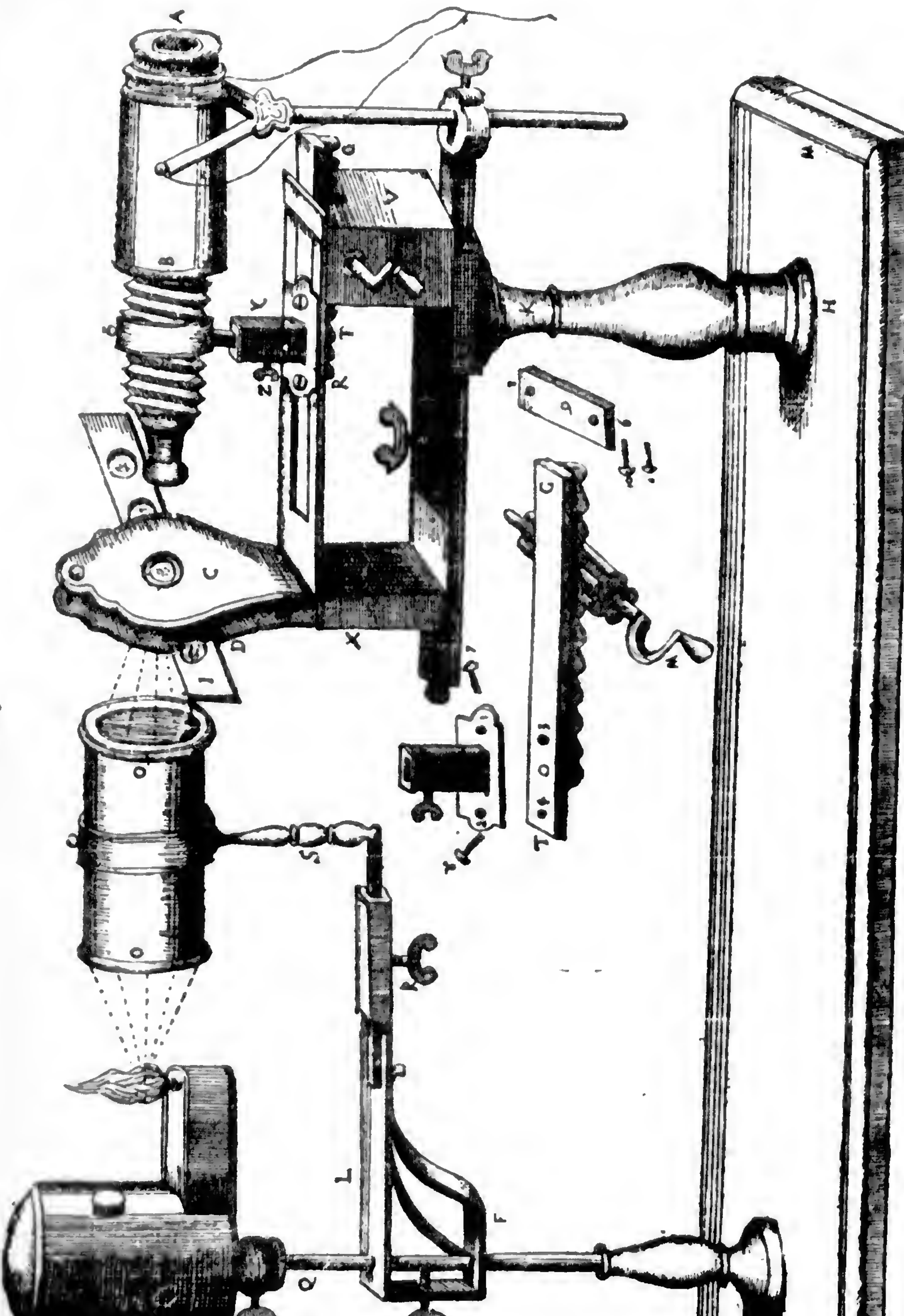
FIG. 35.

MICROSCOPE OF BONANNI.

Bonanni is better known as the author of the horizontal compound microscope in Fig. 36 (p. 1035), which is copied from the original in the same work, p. 28. The convenience of using the microscope in a horizontal position, with a lamp and condenser in the same axis, is obvious, especially in view of the fact that nearly all the compound microscopes designed previously had to be used vertical, or directed to the sky. The mechanism appears to modern eyes somewhat primitive; but we must not be too exacting in our criticisms on this point, We have to acknowledge our obligations to Bonanni for initiating the system of the horizontal microscope, and for a graphical presentation of a compound condenser fitted with focussing mechanism for illuminating transparent objects by transmitted light.

Hartsoeker's Simple Microscope. — In Hartsoeker's "Essay de Dioptrique" (Paris, 1694, 4to), p. 175, we find the microscope shown in Fig. 37 (p. 1036). I must at once call your attention to the fact that in every essential point of design, Hartsoeker's microscope anticipated Wilson's "screw-barrel" microscope (published in the "Phil. Trans.," 1702), which became so popular in the 18th century. The lens-carrier, A B (on which the cell, P, containing the lens, is screwed), screws into the body

Fig. 36.

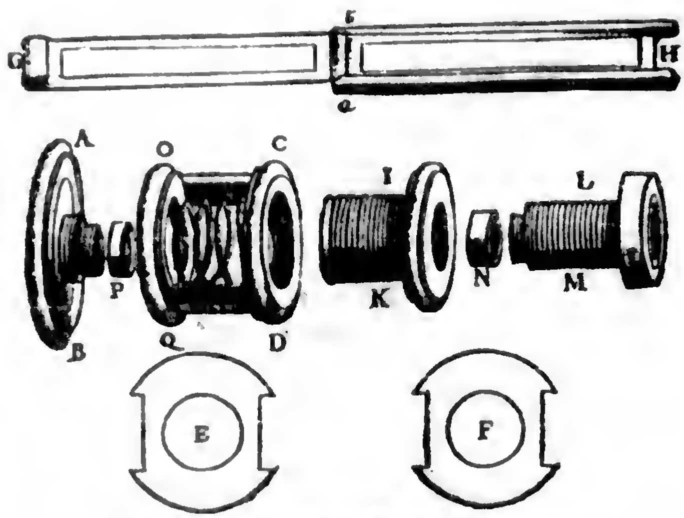


Bonanni's Horizontal Compound Microscope (1691).

O C, Q D, at O Q; the thin brass plates, E and F, fit within the body, the portions cut out allowing them to slide on the short pillars, O C and Q D, and the spiral-spring pressing them towards C D; the object-slides, or an animalcule cage, G H (hinged at *a b* to allow the lid, G, to fit into H, enclosing the objects between strips of talc), slide between the plates, E and F, when in position, and the "screw-barrel," I K, fits into the screw-socket, C D, and regulates the focussing; a condensing lens, N, fits on a second "screw-barrel," L M, which is applied in the screw-socket of I K. This arrangement of the condenser is better than the plan adopted by Wilson, as it allows the illumination to be focussed on the object independently of the focal adjustment of the object to the magnifying lens; whereas, in Wilson's microscope, the condenser being mounted in I K, without facility of adjustment, remained at a fixed distance from the object, and hence the control of the illumination was very limited.

Hartsoeker appears to have been an expert in microscopical observations at a very early age. According to his "Éloge" by Fontenelle, when still a student of geometry, he constructed microscopes of blown-glass globules, and used them in the observation or discovery of minute forms of life with so much success, as to excite the jealously of Leeuwenhoek. His skill in the construction and use of the microscope brought him to the notice of Huyghens, by whose recommendation he was made a member of the "Académie des Sciences," of Paris.

FIG. 37.

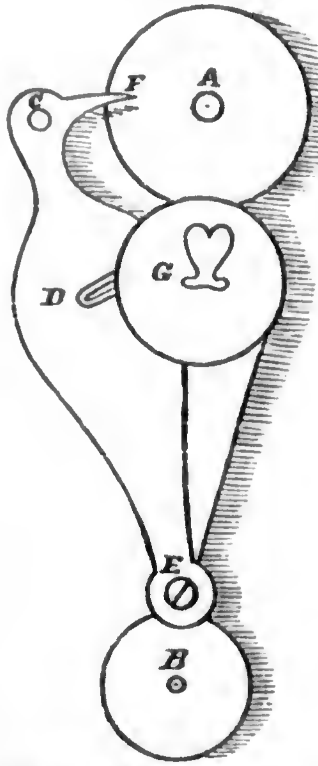


HARTSOEKER'S SIMPLE MICROSCOPE (1694).

In mentioning Huyghens in connection with microscopes, it may not be uninteresting to note that in Vol. X (1730), pp. 608-9, of the "Mém. de l'Acad. Royale des Sci.," it is stated that in 1678 he reported having brought microscopes from Holland, consisting of "minute spheres of glass," some of which were not larger than a grain of sand.

Gray's "Water Microscope."—In the "Phil. Trans.," XIX. (1696), pp. 353-6, Gray communicated the design of his water microscope, shown in Fig. 38 (p. 1037), together with notes on its use. He had previously figured and described (*ib.*, pp. 281-3) a simpler form, consisting of a plate of brass with minute holes in which drops of water were to be placed, but without arrangements for holding the objects to be examined. Here, however, we have an object-holder, C D E, pivoted at E on the lens-carrier, A B, the point, F, serving for such objects as could be fixed upon it, while the hole, C, was intended for drops of the fluid to be examined; G is a thumb-screw acting through the plate, A B, by which the object-carrier was focussed under the water-lens at A, the slot, D, enabling the carrier to pass the screw, G, the disc under G serving as a "washer;" the carrier was made of well-hammered brass, and sprung somewhat up from E so as to follow the movement of G. At A was a concavity about 1-8 inch in diameter, with a hole through the plate 1-32 inch in diameter—the plate itself being 1-8 inch thick—and on the other side was a corresponding concavity of 1-16 inch diameter, the two meeting in an edge in the plate. Drops of water were put in these concavities, forming a bi-convex lens of unequal curvatures, by which, with care, interesting observations could doubtless be made. At H a cylindrical hole 1-10 inch was made, and in this either a shallow lens was formed by not inserting too much water, or a fluid containing organisms was inserted gradually until both surfaces were deeply convex, then, applying the eye suitably, one was expected to see the organisms by means of pencils that had undergone total reflexion within the water before being refracted

FIG. 38.



GRAY'S "WATER MICROSCOPE" (1696).

to the eye—which process of observation was, I should say, both ingenious and useless.

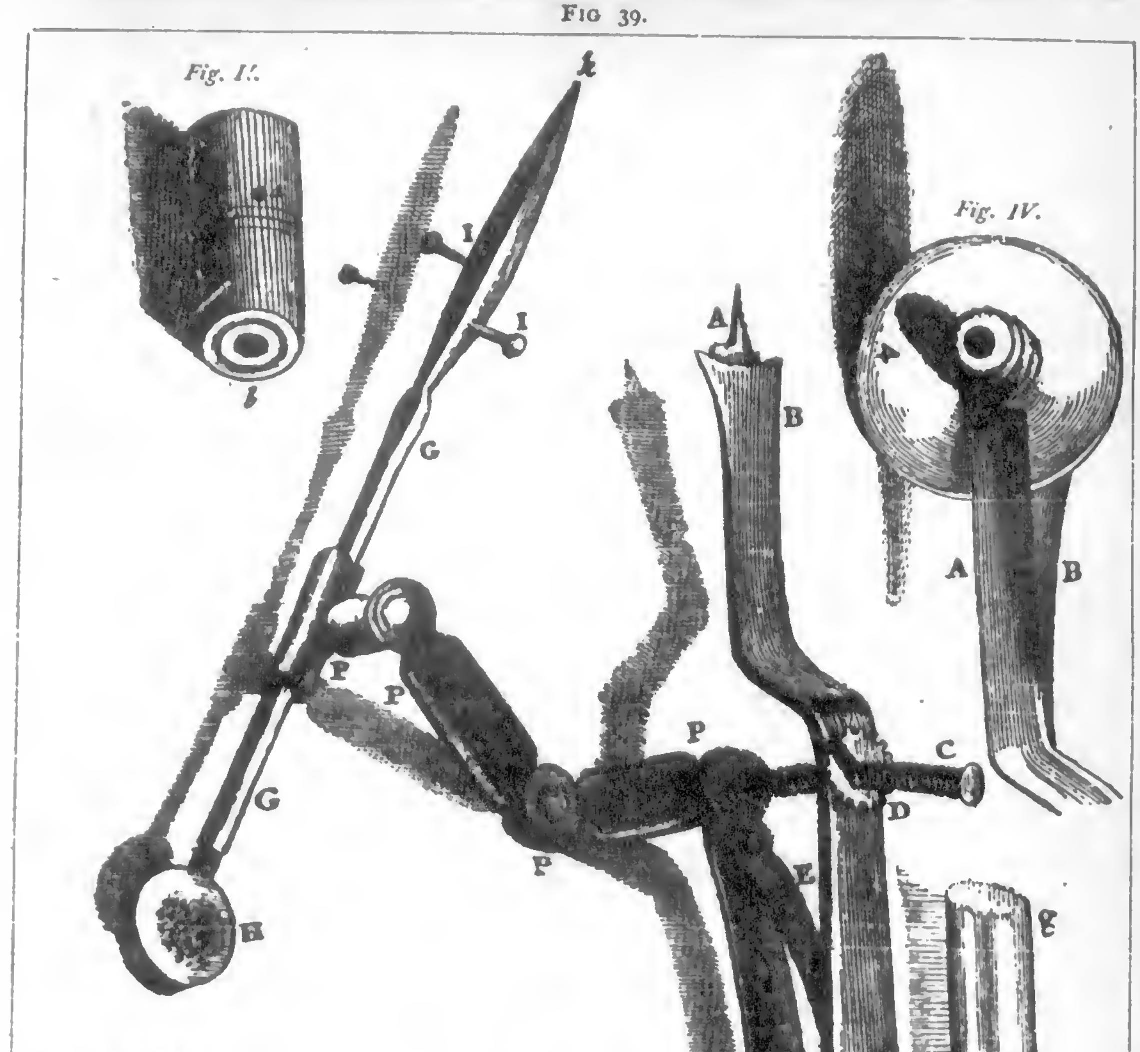
In the early part of this century Brewster attempted to revive the use of fluid lenses, in some experiments following those of Gray, with modifications. Gray had made lenses by allowing drops of a warm solution of isinglass to solidify on plates of glass, either on the upper surface or suspended beneath. Brewster improved on this plan by using drops of Canada balsam, which would dry hard and be more transparent and less liable to injury. He also proposed (in conjunction with Dr. Blair) a number of combinations of fluids and lenses to obtain achromatism, and, in fact, he appears to have sought to exhaust the subject of fluid lenses. Many of Brewster's favourable criticisms* on the fluid lenses he devised have failed of any practical issue; and, except by here and there an enthusiast—especially those who are unaware of Gray's and Brewster's priority—lenses consisting of drops of water, or other fluids, applied with more or less ingenuity to form practical microscopes — are generally regarded as things of the past, not worth reviving. The possibility of seeing objects greatly magnified by means of a drop of water used as a lens should be known to botanists and others who may happen, in an emergency, not to be provided with better means.

Wilson's Microscopes.—In the "Phil. Trans.," XXII. (1702), pp. 1241-7, we find a description, with four *Figs.* of the two "small Pocket Microscopes" shown in Fig. 39 (p. 1038). *Fig.* 1 is the simple microscope that was termed, later on, the "screw-barrel;" its resemblance to Hartsoeker's instrument is obvious. The object-lens (of which there were seven of different foci, *Fig.* 2 representing the lowest power, mounted in "a little Barrel Box of Ivory") was mounted in the disc, B, screwing in the tube, A A, below; the object-slide, as *e e*, or an aquatic tube, *g g*, was applied in the the centre between the plates at E E, the spiral-spring, H, pressing it upwards; D was a hollow cylinder with an exterior screw-thread travelling in a screw-socket at the upper A A, thus controlling the focussing. C was a cell, containing a condensing lens, forming a convenient grip for actuating the screw movement of D. In action, the lens in B was applied to the eye, and the instrument directed to the sky or other source of light.

This form of microscope, with slight modifications, became very popular in the 18th century. It was originally made of ivory; but the great majority were of brass; occasionally it was made of silver. Its great success was probably due to its simplicity, whence it could be produced in large numbers at very moderate cost. The size rendered it easily portable, and the design was so plain and substantial, that it could be used by the veriest novice without risk of injury. The form lent itself readily to the application of a handle; then it was easily mounted on a pillar, and used

* Published in his "Treatise on New Philosophical Instruments," Edinb. (1813), 8vo., in the "Edinb. Encyclop." (Art. "Microscope"), in the "Encyclop. Britan." (7th and 8th editions, Art. "Microscope"), and many other works.

FIG 39.



WILSON'S MICROSCOPES (1702).

with or without a mirror; a very simple addition rendered it convenient for viewing opaque objects; the compound body could be added without difficulty, which was done by Culpeper, as we shall see, and diaphragms were applied to the condenser; with slight modifications it was combined with various forms of heliostat, thus becoming an essential feature in the solar microscope; and, combined with a system of large condensers, it became the lantern microscope, as used far into this century.

Fig. 3 shows the "opaque microscope" devised by Wilson. The series of magnifiers made for the above instrument were also used with this; they were each provided with a small hole, at the side of the ivory cylinder in which the lens was mounted, by which they could be fixed on the spike, A (as shown in *Fig.* 4). The object was held by "a small pair of Tongs, G G," or placed upon the black or white side of the ivory disc, H, at the other end. The focussing was effected by the milled nut, D, acting on the screw, C, which was fixed in the arm, P, the spring, E, giving the reverse motion when the nut was turned the opposite way. The pivoted arms gave ample range of motion to adjust the object under the lens.

This instrument was a decided improvement on Cuno's Simple Microscope (Fig. 31), and on the Italian form shown in Fig. 32, *Fig.* 4.

Before passing on to the examination of other models, we will note upon some of the modifications of Wilson's "screw-barrel" microscope that were devised in the 18th century.

(1.) *Culpeper's Simple Microscope* (Wilson's form).—Fig. 40 shows Culpeper's application of a folding tripod base with pillar to Wilson's model, with the addition of the lens-carrier on an arm to enable the instrument to be used with opaque objects. I have not been able to fix the date of this instrument; but as none of the examples I have seen were furnished with "Lieberkühns," we may infer the construction was probably anterior to 1738. A ball-and-socket joint supports the microscope, and with so small an instrument it was not so defective as with larger ones on the pillar. A complex system of articulations clamped on the pillar carries a condensing lens for illuminating opaque objects, or a plane mirror, as in Fig. 41 (p. 1040). For viewing opaque objects the lens was removed from the body-tube, and a disc, having a pivoted arm terminating in a ring, substituted; the low-power lens, in a horn mount was then screwed in the ring, and was thus held some distance away from the body of the instrument, so that the object could be properly illuminated. This arrangement is shown in the Figure.

Fig. 40.

Culpeper's Simple Microscope (Wilson's Form, *ante* 1738 ?).

(2.) *Culpeper's Compound Microscope.*—In Fig. 41 we have the same instrument as the preceding, but with a compound body-tube of ivory, with draw-tube substituted for the lens-carrier. A plane mirror takes the place of the condensers on the articulated arm; in later constructions, Culpeper applied the mirror on one of the feet in a line with the optic axis. A set of three diaphragms (of which one is shown in front) can be placed over the condenser in the lower end of the "Wilson" screw-barrel. The ivory handle is shown, on which the "Wilson" is held when unscrewed from the ball-and-socket; the box end is unscrewed where discs of talc, and brass wire rings, for holding the talcs in cells, were stored. An early form of animalcule cage is shown in front, having four concave discs of glass mounted in apertures in a plate on which a similar plate, with four corresponding apertures and plane discs, is hinged to open or close.

The instruments of Culpeper's manufacture were sometimes covered with ornamental engraving. In this example, the lens-carrier for opaque examinations, the forceps-plate, the articulated mirror-arm, the tripod, and the disc at the base of the pillar are engraved in this manner; and I have met with other examples in which the Wilson "screw-barrel" was similarly engraved.

(3.) *Wilson's Simple Microscope* (as made by Adams).—In Adams's "Micrographia illustrata" (1746, 4to), Pl. 5, we find the Wilson "screw-barrel" microscope, shown in

FIG. 41.

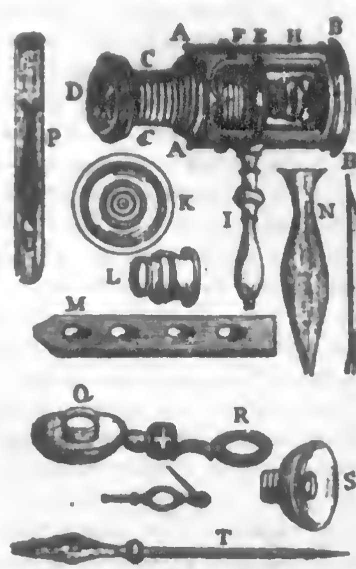
CULPEPER'S COMPOUND MICROSCOPE (*ante* 1738 ?).

Fig. 42. The lens-carrier, Q R, for opaque work, is similar to that made by Culpeper. The forceps-plate was (apparently) no longer in vogue, though it was useful with the Wilson model, as I can testify by practice. A lens combined with a "Lieberkühn" is shown at S, which enables us to fix the date as later than 1738.

(4.) *Wilson's Simple Microscope on Scroll Standard* (as made by Adams).—In the same work *(loc. cit.)* the Wilson model is shown mounted on a scroll standard, and with a mirror mounted on the base in a line with the optic axis (Fig. 43, p. 1041).

One of the most symmetrical arrangements of the Wilson model (and of the adaptation of the compound body) that I have met with, was constructed in the last century by Cramer, of Groningen, Holland. The "Wilson" part is of brass, the lens-mounts, the compound body, and draw-tube are of ivory, the scroll standard is of brass with ornamental chasings, and the

FIG. 42.



WILSON'S SIMPLE MICROSCOPE (AS MADE BY ADAMS, 1746).

shaped ebony base stands on three chased ormolu claws, the whole fitting in a truncated pyramidal box.

FIG. 43.

WILSON'S SIMPLE MICROSCOPE ON SCROLL STANDARD (AS MADE BY ADAMS, 1746).

Marshall's Compound Microscope.—In Harris's "Lexicon technicum" (1704, 2 vols. fol.), under the word microscope, Marshall's compound microscope (Fig. 44, p. 1042) is described and figured. Several important innovations in microscopical construction were here embodied. (1.) A fine-adjustment screw, F, is connected with the sliding socket, E, supporting the arm, D, in which the body-tube is screwed; the focussing could thus be controlled in a far more effective manner than by any system previously applied to a large microscope. The previous systems involved the direct movement of the body-tube, either by rotating in a screw-socket (as in Hooke's), or by sliding in a cylindrical socket (as in Divini's and Chérubin's); in a few instances the object was moved in relation to the object-lens; but all these plans were more or less defective, especially with microscopes of large dimensions. Marshall's system was a distinct mechanical improvement, for the object could now be viewed during the actual process of focussing, as the image would remain steadily in the field. (2.) Hooke's arrangement of a link to encircle the pillar and carry a rotating stage, is here modified into a fork, N N, and, instead of being clamped on the base by a thumb-screw on the fixed pillar, it is here applied with a similar thumb-screw clamp, O, on the pillar itself. (3.) Hooke's ball-and-socket joint, which was applied to the arm, I, is here shifted to the lower end of the pillar, where it would give the movements of inclination to the whole microscope, instead of to the body-tube only, as in Hooke's; the ball, L, could be tightly clamped by the screw-collar, M, in which slots were cut to give spring. In one example I have met with, the slots were not cut, whence I infer that it may have been one of the first of the kind constructed, before the slots were applied. (4.) A condensing lens on jointed arms appears; I think this was the first application of such adjustments to the condenser. From the singular position of the candle beneath the condenser, I think we may infer, without doubt, that the mirror was still unknown as a microscopical accessory in England.

As a matter of fact, I have met with this model of Marshall's microscope bearing the date, 1718, still without mirror. The earliest instrument I have seen provided with a mirror was a modification of Marshall's, in which the ball-and-socket was replaced by a rigid pillar, and the open-link stage-carrier was replaced by an arm, attached to a socket rotating on the pillar, and fitted with appliances decidedly in advance of those figured by Harris, or indeed of any belonging to actual models I have seen of Marshall's; and the date of the construction I should assign would be 1718-1730—probably earlier than the Culpeper instruments we have examined, in which the articulations of the mirror-support point to an experienced use of the mirror.

Harris commends Marshall's arrangement of the fish-trough with the "Lead Coffin," M, "to be put on the Fish to hinder it from springing away, and moving his Tail out of the Light" while under examination. The series of object-lenses were apparently regarded as novel in connection with a compound microscope. The numbers on the standard were to indicate approximately the position of the coarse adjustment for the different powers. To counterbalance the instrument when in use, as figured, the opposite end of the base had a large block of lead fixed inside.

The figure of Marshall's microscope has been reproduced very frequently in Encyclopædias, and other works; and occasionally the position of the candle has been said to be more favourable for depositing soot on the condenser than for illuminating the object. The instrument should be judged by com-

FIG. 44.


IOHN MARSHALL'S
New Invented
DOUBLE MICROSCOPE,
For Viewing the
CIRCULATION of the BLOOD
Made & Sold by him at the Archimedes &
Golden Spectacles in Ludgate Street.
B
X
W

(1704).

parison with the microscopes of its day. Harris tells us that Mellen's and Leeuwenhoek's simple microscopes were the best then in use, and he concludes his notice of Marshall's thus:—"I have had *Mellen's* Glasses, and seen *Lewenhoeck's* and *Campani's*, but I would sooner have the *Double Microscope* [Marshall's] than any of them, and the price is much easier."

Joblot's Simple Microscope.—In Joblot's "Descriptions et usages de plusieurs nouveaux Microscopes" (Paris, 1718, 4to), several different forms of microscopes are figured and described. I select the one shown in Fig. 45

FIG. 45.

JOBLOT'S SIMPLE MICROSCOPE (1718).

as typical, at least, of the ornate designs proposed by Joblot. The lens was mounted in the small cylindrical tube in the centre of the vertical plate on the right, to the lower part of which a rod was attached passing into the lower horizontal tube, and with a screw at the other end acted upon by a nut for focussing.

Joblot's principal claim to recognition as a designer in connection with the evolution of the microscope, is the fact that he devised a rotating object-stage (applied to the model here figured) that may have suggested to Oberhaeuser the plan he worked out so successfully; but on this latter point I speak with reserve, for the similarity in the mechanism is not a proof that the one was based on the other.

Joblot mounted a simple lens on an arm composed of three ball-and-socket joints attached to a short stem; it is in connection with this construction that his name has been handed down to us in the succession of works treating of the microscope. He was, however, so distinctly preceded by Musschenbroek in the essentials of his design, that I pass over that form. For the same reason I pass over Lyonet's Simple Microscope, which differed from Musschenbroek's and Joblot's, in being attached to an oval stage of wood, supported at one end by a brass pillar connecting it with the base, and with an aperture through which the light from a mirror was reflected on the object.

Barker's "Catoptric Microscope."—In the "Phil. Trans." XXXIX. (1736), pp. 259-61 (5 Figs.), Barker described this instrument (Fig. 46, p. 1044) as "contrived .... on the Model of the Newtonian [Gregorian] Telescope ..." It was arranged to magnify "from the Distance of 9 Inches to 24 Inches," so that opaque objects could be easily illuminated and viewed. The focussing was effected as with the Gregorian telescope, *i.e.*, by means of a rod and screw, M L, (*Fig.* 2) acting on the small concave speculum, C D. The eye-piece had a plano-convex field-lens, G H, and a bi-convex eye-lens. The instrument was mounted on a cradle-joint on the top of a pillar, and was not connected with the object (*Fig.* 1).

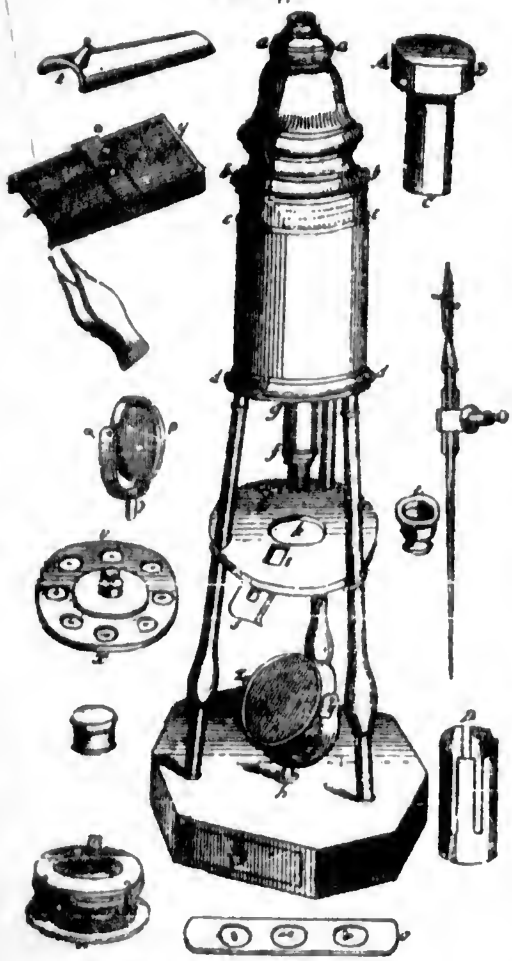
The construction was simply that of a Gregorian telescope of very short focus, with an extra range of movement for the small speculum to focus objects distant only from 9 to 24 inches.

The diagram, *Fig* 5, shows the path of the rays from the object to the eye. By bringing the small concave nearer the large one, more and more distant objects would be viewed, until the instrument would become a telescope proper; thus furnishing an example of the conversion of a microscope into a telescope, or, conversely, "Thus a telescope used for viewing very near objects becomes a *microscope*," as stated by Herschel ("Encyclop. Metrop.," art. "Light," p. 403).

its image were the two conjugate foci of the speculum, he saw the magnified image at *a a*.

The general design of this microscope was

Fig. 47.



Culpeper and Scarlet's Compound Microscope. (1738).

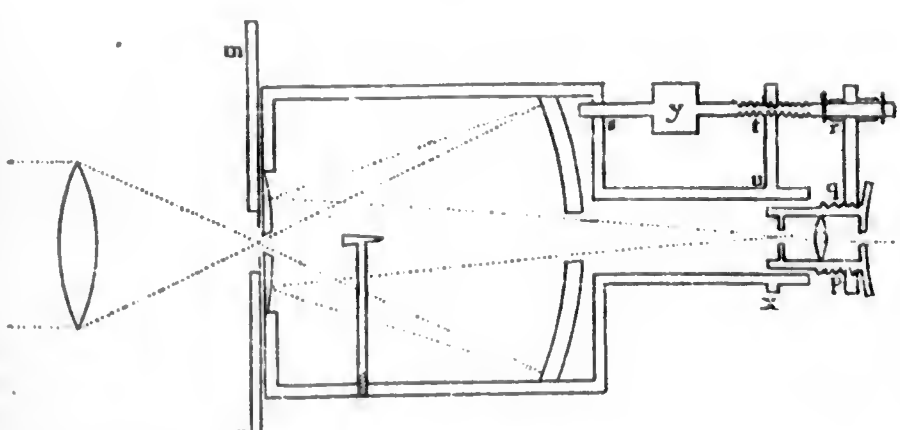
much in vogue in the 18th century, and was modified by Adams, Dollond, and others. In some instances the pillars were made very ornate, especially by Italian opticians. Adams added a fourth pillar, and applied a rack-and-pinion to the body-tube and socket for focussing. In odd examples I have met with, the construction of which suggested that they were probably made by Brander, of Augsburg, the socket of the body-tube was hinged on the stage by two short pillars, so that the upper part could be inclined in relation to the stage. The Nürnberg toy-manufacturers seem (as I have already noted) to have popularised this tripod form, probably because the design could be carried out easily in wood and cardboard at a small outlay; occasionally they applied two or more draw-tubes, and added to the body-tube an arrangement similar to Bonanni's (Fig. 35) for holding the objects.

Smith's Reflecting Microscope.—In the same work (II., pp. 95-7. Fig. 169), the construction of a reflecting microscope of the Cassegrainian form, shown in Fig. 48, for viewing transparent objects, is given in detail.

This microscope was similar to the Cassegrainian telescope, but with an extra long eye-piece tube to permit the focussing by movement of the eye-lens. The object was placed at M N; the image was taken up by the concave, reflected on the convex, and again reflected to the eye-lens. He advised the use of a condensing lens for the illumination, to prevent "the mixture of foreign rays with those of the object," otherwise the instrument gave confused images of distant objects when it was used as a microscope.

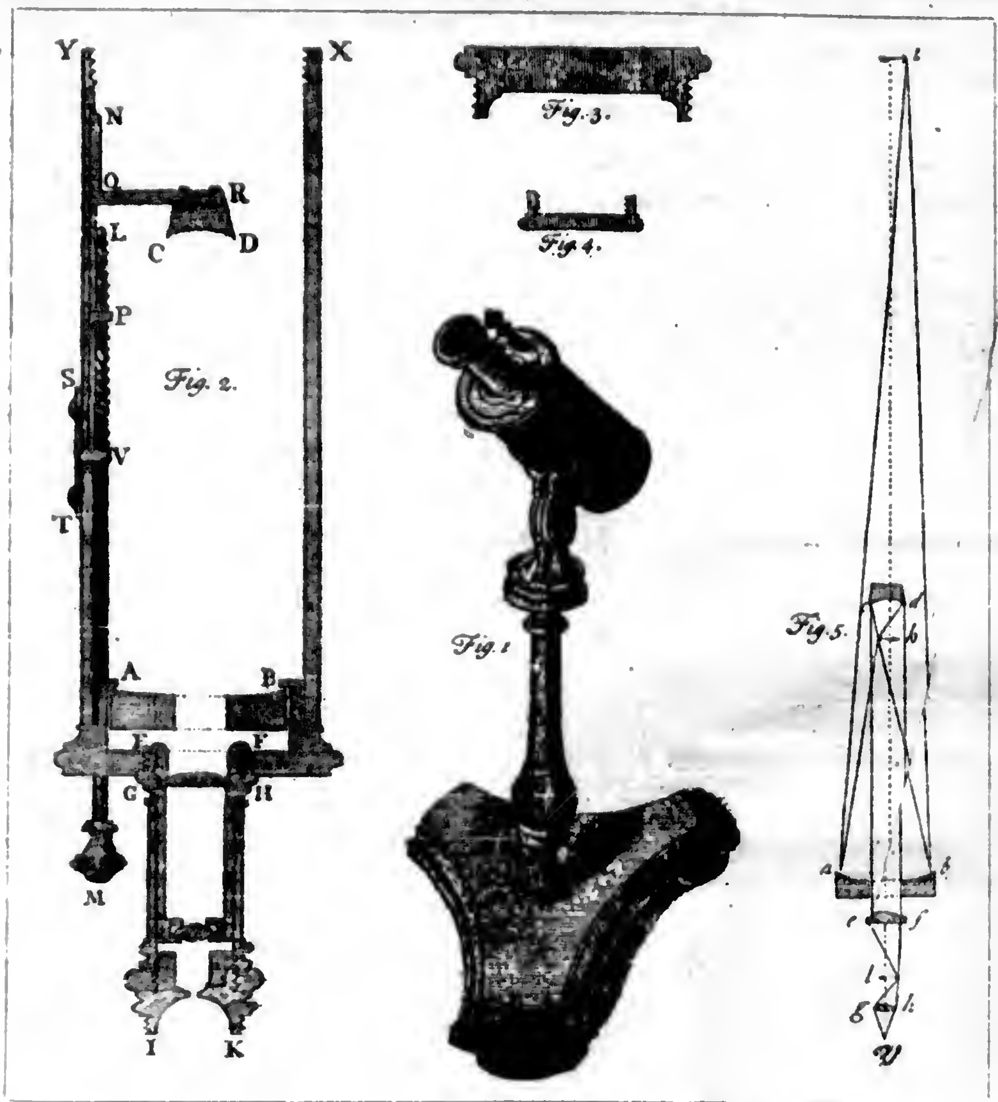
In the one instrument of this form I have

Fig. 48.



Smith's Reflecting Microscope (1738).

FIG. 46.



Culpeper and Scarlet's Compound Microscope.—This microscope (Fig. 47, p. 1045) was published in R. Smith's "Opticks" (Camb., 1738, 2 vols., 4to), I., p. 407, and was considered by Smith as a better form than any that preceded it. From our point of view this commendation appears strange, for the general design does not suggest a convenient working instrument. There was no fine adjustment, and the focussing was effected by sliding the body-tube in the socket. A rotating multiple object-disc, *v x*, is seen (reversed in the Fig. to show the "button" in the centre by which it was fitted in a slit, *i*, and held by the small brass sliding plate, *s*, under the stage). The spring-stage, *m n*, fitted in the aperture, *k*, and acted after the manner of modern safety stages. The fish-trough, *q* (shown reversed), was applied at *i*, and the "coffin," *t* (devised by Marshall), held the fish still. From Smith's reference to the "concave looking glass, *y z*," I think we may infer that the application of a mirror was new to him.

Smith mentions that he had occasionally used this model as a Reflecting Microscope, after the method explained by Newton (see Fig. 18). For this purpose he removed the mirror, *y z*, and substituted the slotted spring-tube, D, in which a concave speculum, cemented on the top of A B, was adjustable by means of a small wooden cylinder, *c*, beneath; then he removed the field-lens from the eye-piece and the object-lens, *f*, from the body-tube, placed an object on a piece of clear glass at *k*, condensing light upon it by the lens, *α β*, applied at *l*, and by sliding the speculum up or down, and adjusting the eye-lens correspondingly, so that the object and examined, the objects are magnified very clearly, though there is no condensing lens.

Lieberkühn's Simple Microscope (as made by Adams).—About 1738, Lieberkühn devised a combination of a simple lens, mounted in a central aperture in a polished metal reflector, which he applied to a small hand-microscope (similar to the second form of Wilson's, *vide* Fig. 39) for the special purpose of viewing opaque objects. Fig. 49 shows the microscope as made by Adams (*vide* "Microgr. illustr.," *loc. cit.*). The combination of a lens and reflector (shown at K) is practically identical with that of Descartes (1637), but the application to a convenient hand-microscope rendered it infinitely more serviceable. As proposed by Descartes, the object had to be viewed as it happened to be attached to the spike, and required complete re-adjustment for every different view; but Lieberkühn's application by which the lens was no longer fixed to the object-carrier, left the latter free to be turned and adjusted as required by the forceps, &c.

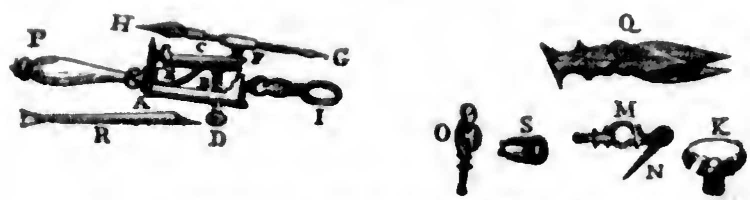
Cuff, the English optician, is stated to have improved upon Lieberkühn's original construction (where one reflector served for lenses of different foci) by making a series of reflectors to correspond with the foci of the lenses, so that the objects were more perfectly illuminated.

Lindsay (1742) used not only spherical concave reflectors, but also hollow cones of polished silver.

Dellebarre (1777) made extra large reflectors of silver, and also of silvered glass, for his compound microscope (*vide* Lalande's description in Montucla's "Hist. des Mathématiques," 2nd ed., 1799-1802, III., p. 511). In several of Dellebarre's microscopes that I have examined, the large perforated silver mirror was adjustable on the nose-piece of the body-tube, with a range of upwards of an inch of screw-motion.

The "Lieberkühn" was readily modified in construction so that it could be applied to achromatic objectives by means of a cylindrical tube sliding on the end of the mounting, and has thus held its own to this day.

FIG. 49.

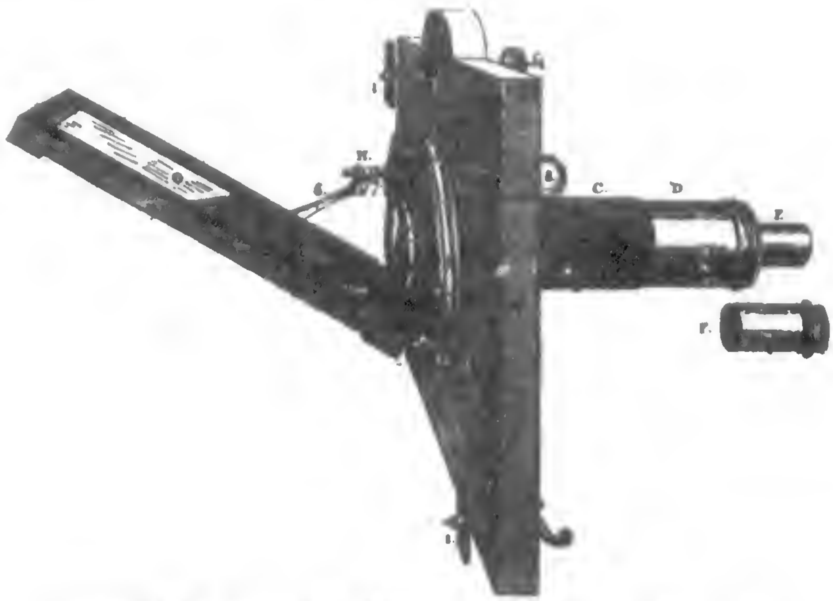


LIEBERKÜHN'S SIMPLE MICROSCOPE (1740).

Charles Chevalier (1830) made use of a perforated silvered mirror of glass to avoid the inconvenience of tarnishing, especially where chemical re-actions were under observation. Amici (1840) made some extremely small "Lieberkühn's;" in one I have met with, of silver, the concavity was less than 1-8th inch in diameter.

Lieberkühn's Solar Microscope (as improved by Adams). — Lieberkühn was the inventor of the solar microscope (1738). As first devised, there was no mirror, the microscope with the condenser had thus to be directed to the sun, which was done by means of a "Scioptric Ball and Socket," and the screen upon which the magnified image was projected had to follow the movement of the microscope. The English optician Cuff is said to have improved upon Lieberkühn's arrangement by the application of a mirror (heliostat) with mechanism, by which the sun-light could be directed constantly through the microscope, and the magnified image projected on a fixed screen. In the earliest form of solar microscope I have seen by Cuff, the rotation of the mirror on the axis of the microscope was effected as shown in Fig. 50, p. 1047 (copied from Baker's "The Microscope made easy," 3rd ed., 1744, p. 22), by means of a cord encircling a large grooved wooden disc, B, on which the mirror was hinged at one end, and carried over a second and much smaller disc or wheel, 4, connected with a thumb-screw, 5; the other movement of the mirror being controlled by a rod, H, connected with the mirror-frame by a jointed arm, 6, and passing through a metal friction-socket in the rotating disc, H, terminating in a ring, 8, by which it was moved. The heliostat was also made in this way by Martin in his earliest examples. The arrangement was improved shortly afterwards by making the moving parts of brass; the disc, B, was toothed on its circumference, and a pinion controlled the rotation; a worm-wheel and endless-screw gave the other motion. I cannot say who devised these improvements; the latter one was, however, shown by Adams in 1746 ("Microgr. illustr.," Pl. IV.), together with his application of his "New Universal Single Microscope" (Fig. 51). Martin claimed the former, if not both; at any rate, in his "Micographia nova" (1742), his description of the solar microscope refers only to a "Scioptric Ball and Socket" arrangement, so he did not know of the application of a mirror at that date.

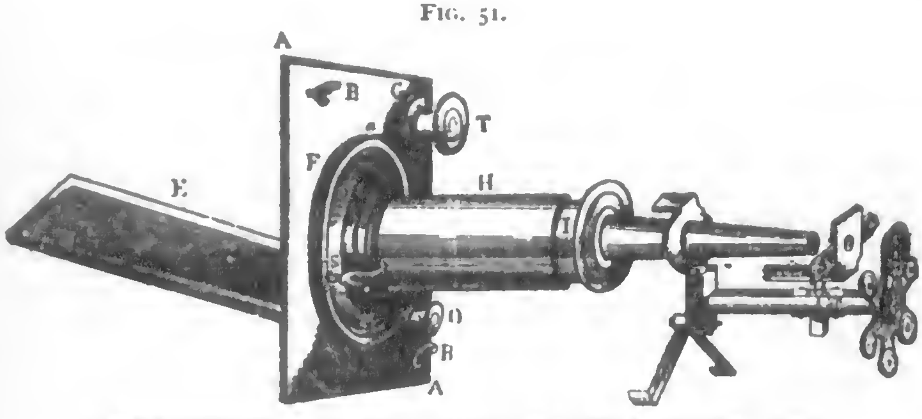
FIG. 50.



LIEBERKUHN'S SOLAR MICROSCOPE (AS IMPROVED BY CUFF, 1744).

The various references to the use of the solar or *Camera obscura* microscope, published in the last century, show that far too much was claimed for it. Martin, Adams, and Baker seemed to vie with each as to who could speak of it in terms of highest admiration, admiration which is now seen to be out of all proportion to the solid merits of the instrument. The modifications by which the lucernal microscope was developed—where a lamp was used instead of sunlight, and the image was received on a ground-glass screen—may have contributed to render the microscope a means of amusement, but I do not think these applications have added to its scientific value, certainly not in a measure proportionate to the attention they received at the hands of the opticians.

FIG. 51.



LIEBERKUHN'S SOLAR MICROSCOPE (AS IMPROVED BY ADAMS, 1746).

Lindsay's Simple Microscope.—This miniature microscope (Fig. 52) is of two-fold interest to us: (1), it was the first microscope for which a patent was registered (1742); (2), the design is so neat and compact and so novel, and the workmanship so superior to the rivals of its day, that one has a difficulty in accepting the fact of its construction in 1742.

The focussing is effected by a lever at the side raising or lowering the stage in grooves.

FIG 52.

LINDSAY'S SIMPLE MICROSCOPE (1742).

Single lenses are mounted in two plates (as shown in the box-lid) sliding in the grooved lens-carrier at the top of the instrument. The lowest power is mounted in a Lieberkühn reflector; and a hollow conical reflector is shown in front. The stage-forceps, fish-plate, mirror, jointed stem, folding tripod, &c., are all designed to pack with the instrument in the box about $4\frac{3}{4} \times 2\frac{1}{2} \times 2$ inches. The microscope figured is made of silver, and is one of the best examples of eighteenth century workmanship that I have met with.

Figs. 32-37, 39, 42-51, were reproduced from the original Figures in the works cited. Fig. 38 was copied from a tracing of the original.

My acknowledgments are due to the Royal Society for permission to reproduce Figs. 32, 38, and 46, from the "Philosophical Transactions."

Fig. 52 was photographed on the wood-block from the instrument.

ELEMENTARY LECTURES.

ELECTRICITY.

BY PROFESSOR GEORGE FORBES.

Lecture IV.—Delivered May 8th, 1886.

In a previous lecture, when we were examining the current, we saw the means by which we could create electric currents, and we saw something of the way in which these electric currents act. It will be my endeavour to-day to show you some experiments illustrative of the enormous progress which was made during the years 1820 to 1830, the results of which have formed the foundation of the whole of the most important developments and practical applications of electricity since that date. Previous to the year 1820, there were but few phenomena known connected with the electric current. We knew that the electric current would heat up conductors; we knew that we could get a spark from the charcoal points from Humphry Davy's celebrated experiment, which led eventually to the construction of the arc light; we also knew that chemical substances could be decomposed by means of the electric current, but beyond that practically nothing was known. A certain number of facts, isolated and non-reproducable, apparently had been collected. It had been found that there was some sort of connection between magnetism and electricity, but as to the nature of this connection nothing was known. It had, however, been observed that frequently on board ship, during a thunderstorm, when a flash of lightning struck the vessel, the compass needle was either rendered useless, or it might be caused to point in the exactly opposite direction, its north end pointing south, and its south end pointing north. It appeared then that this electric current and the discharge of lightning had some connection with magnetism, but up to the year 1820, there was no clue as to what the connection between those two was. In my last lecture I showed you what very intimate connection there would now seem to be between electricity and magnetism; and every step of our progress to-day will show you the connection still closer. In the year 1883 there was a grand exhibition of electric appliances in Vienna, and I remember well, after wandering round that enormous building in the Prater, where was collected a display—the developments of electric science in every department—in telegraphy, telephony, electric lighting, electric clocks, and all kinds of electric appliances; after having examined all these dynamo machines, arc lamps, and other things, I came, in a secluded corner, upon a minute exhibit, which made me pause with a feeling of respect, and almost of awe, when I looked at this small apparatus, and thought of the consequences which had followed from the experiments made with it. This was simply a compass needle placed on a stand with a glass shade over it, and above the compass needle was a bust of the man who had used this simple apparatus. I assure you that when I thought of the experiment that had been made with that compass needle, and when I saw that, from that single experiment, the whole of the principles involved in the vast assemblage of electric apparatus in that building almost immediately followed, one could not help feeling that there was something to have respect for. I need hardly say, the exhibit I was looking at was the compass needle, and that the bust behind it was the bust of Professor Oersted, of Copenhagen. His grand experiment was the genesis of all that has been done in electro-magnetism since then, and I think that you and I shall be able to see this afternoon, as we take up one experiment after the other, how it might have been possible almost to have foretold from that one experiment a vast number of phenomena which were discovered afterwards, and which form the fundamental principles of our science. The experiment of Oersted was in bringing a wire through which an electric current was passing into the neighbourhood of a suspended compass needle. Here I have a compass needle suspended on a pivot. In my hand I hold a wire, through which I am able to pass an electric current by connecting its two ends with a battery. The direction of the current is shown by the arrow on this wire. The result is, that if the wire containing the current be held parallel to the needle, it will be deflected in one direction or the other, and the direction in which the magnet is deflected depends partly on the direction of the current, and partly on the position of the current above or below the needle. First, I place the current travelling from north to south, and I place the current over the compass needle. You will then see that the north pole, which is the one to my right, moves towards me, that is to the east. I reverse the current, and make it travel from south to north, and immediately the motion is checked, and more rapid motion in the opposite direction is produced. By reversing the direction of the current, then I am able, to reverse the direction of the motion of the compass needle. I will place the current travelling from north to south, but under the needle, and the north pole will go away from me instead of towards me as it did before. I reverse the current once more, and now it will be going from south to north, and then we shall see, when it is below, the north pole will approach me. Now let me show you what conclusions you might legitimately draw from these facts. It has nothing to do with the vertical position, except that the pivot being vertical the magnet can only travel in a horizontal plane, therefore we must not define the action as being dependent on the position of the current above or below. But I will give you a law which has been very generally used as a sort of aid to memory. If I be facing the magnet, and if my body be lying in the direction of the current so that I am as it were swimming with the current, the current coming in at my feet, and going out at my head, and if I be looking at the north pole, I shall see the north pole going to my left-hand side. That is a general statement that includes a statement for all cases. If it were a south pole I was looking at, it would be urged in the opposite way.

Another thing which follows immediately from this observation of Oersted's is this; it follows that each one of these poles is trying to go round the current. When I have the current near the compass needle the north pole is trying to go round the current, and would go round it continuously, but that it is restrained in its action by its connection with the south pole. Therefore, I have both the north pole and the south pole wishing to go round the wire in opposite directions; they cannot go round in opposite directions because they are rigidly connected, therefore the most they are able to do is to move in a position at right angles to the current. But we see clearly enough that if we could arrange matters so that only the north pole was tending to go round the current, and the current did not extend over the south pole, then we should be able to get continuous rotation of the north pole round the current. I think you will agree with me that is a conclusion we naturally have arrived at, and which ought to be evident from the experiment of Oersted. I will try that experiment with a small piece of apparatus I have on the table. It consists of a magnet which is in a bent form. The vertical magnet is pivotted by a wire at the top and bottom. The current goes down through the top pivot alongside of the north pole, but it is stopped at the middle of the magnet, and carried away by a wire dipping into a trough of mercury so that it does not come down near the south pole. It passes only in the neighbourhood of the north pole. If our conclusion is right, that north pole ought to travel continuously round the current, and we should have continuous rotation of this north pole round the current when we connect with the battery. The presence of the current is rendered evident by the luminosity of the little piece of platinum wire which is bent round so as to dip into the mercury cup. We find when it is adjusted that we shall get continuous rotation of the magnet round the current. I will now describe another experiment which is a simplification of this, a very remarkable thing, too. This consists of a compass needle north and south; it forms its own axis, being pivotted top and bottom, but there is a platinum wire as before dipping down into the mercury cup which carries away the current from the middle of the magnet, so that the current only traverses half the magnet, then passes away, and does not come near the south pole. In this case also the north pole, which is at the top, ought to travel round itself. This experiment illustrates it equally well with the other, although it is a step in advance, perhaps. The north pole rotates round itself in a continuous direction.

It appears, then, so far as the action of the current on a magnet is concerned, it is this. There is a tendency to cause the north pole to move perpendicular to the direction of the current, and for the south pole also to move perpendicular to the direction of the current, but in an opposite way. In other words, the current has the power of creating magnetic force in its neighbourhood, that is, of influencing a magnetic pole. If it has the power of creating magnetic force, we know that there are many things it is capable of doing, that it is not only capable of moving a magnetic pole, but that it is also capable of creating a magnetic pole in a piece of iron. And you remember in the experiments of last lecture I threw some images of iron filings on the screen in a magnetic field, and showed that the direction taken by those iron filings indicated to us the direction of the magnetic force; so you will easily see that we ought, if we sprinkle filings round the wire, to be able to see these lines of induction by circles round the magnetic pole. I will now throw this on the screen.

When we have a current going through a coil of wire, making a ring of current, what is the condition of the magnetic force? We know that any part of a coil through which the current is traversing is tending to move the north pole continuously round it in a certain direction. Every part, then, of the coil of wire is tending to move north poles round the outside of the ring and in through its centre; they all combine to tend to move the north pole through the centre of the coil. You remember that when I had this floating battery with this coil of wire attached there was a tendency for the magnet to suck this coil over itself, and now we see clearly that the opposite effect is capable of being produced, and that the coil would naturally tend to create a magnetic force through its centre, and a complete magnetic circuit would be established round its outside, and back again through its centre. This action can produce certain effects. This creation of a magnetic field can cause a magnet pole to be moved, so that if we have a compass needle suspended inside this coil the current would tend to turn the needle at right angles to the coil, the north pole being moved through the coil in one direction, and the south pole being moved in the other direction. This is the principle of the construction of our galvanometers, of which I have one on the table here. We have two coils of wire both wound in the same direction, and the current circulates through these wires. On the central stand there is a compass needle which naturally points north, parallel to the plane of the coils, but when the current is complete both these coils tend to move the north pole to the right if the current is in one direction, and the south pole to the left, or the north pole to the left, and the south to the right if the current is in the opposite direction. This is one of the actions which a coil can produce owing to the magnetic condition of the space in its neighbourhood.

Another thing which a magnetic force can do is to create poles in a piece of iron. Thus if I put this piece of iron into the centre of this coil, and if I hold a few iron tacks in my hand under it, they are not attracted, but if we turn on the current, those tacks will be attracted and hang there. The moment the current is broken the tacks fall down again, showing that this coil, with a current passing through it, created magnetic force in its neighbourhood, and is also able to induce polarity in a piece of iron.

The third action is the combined effect of the two. This coil has the power, when I suspend my iron by a piece of thread in front of, and co-axially with the coil, of creating polarity in the piece of iron, and then of causing the pole to move in accordance with the rules we have already described. On passing the current, you see the iron sucked into the coil. This sucking action is applicable to a great many pieces of apparatus, and I might illustrate it by a small piece of apparatus which has been called an electric hammer. Here is a vertical tube, wound continuously with a coil of wire from the bottom to the top. At every fifth turn there is a separate wire led away to one of these pieces of brass, of which there are in all fifty round the stand. The lowest five turns are connected with the piece of brass next to me; the second five with the next piece of brass; the third with the third piece, and so on, until the last piece furthest from me is connected to those coils which are at the very top of the column. If I introduce into this column a piece of iron, I have the means of causing any set of these turns of iron round the vertical column to have a current passing in them. The wires from my battery come to this piece of wood which has two contact pieces on it, and they just cover ten of these brass pieces on the flat board, so that by moving the wood along the flat board I make contact with the different pieces of brass, and I can send the electric current through any ten of these sets of turns which I please from the bottom of the vertical column right up to the top. Thus, if I introduce a piece of iron into the tube by making contact, and sending current through these coils, I can suck the iron right up to the top, and drive it down with very considerable force. I put a piece of paper on the top of the tube, so that you may see the rise of the iron. The force with which I am able to bring it down produces a very considerable blow. The arrangement, of which this is a model called an electric hammer, was shown in the Munich Exhibition of 1882 on a considerable scale, but more as one of the evidences of what we may expect the applications of electricity to lead to than for any purposes which it served at that time.

I have said that a study of these phenomena, resulting simply from Oersted's grand discovery, should lead us to many new facts even before we had performed the experiments, and I am going to ask you to think about that very connection in order that you may be led to one of Faraday's beautiful discoveries, and I believe that in so thinking over Oersted's experiment, and leading up to Faraday's great experiments, we shall be following somewhat in the path over which Faraday travelled. Faraday never told us that he knew beforehand what results he was going to get. He always described his experiments simply as they came, but at the same time I have little doubt he reasoned somewhat in this manner. We have found that a north pole tends to move in a certain direction round an electric current. Now it is a grand law which we have known since the time of Newton that action and re-action are always equal and opposite. Let me say a few words to show what I mean. If one of you and myself were sitting on two chairs on casters connected by a rope, and I was to pull, you must not imagine that you alone would be pulled along the floor towards me, I also should be pulled towards you, or if you were to pull both of us would be moved towards each other. In every case whoever may do the work there is always a re-action equal, and opposite in direction, to the action. When a planet is going round the sun, the planet is drawn towards the sun by the force of gravitation, but you must not suppose that the sun is not also drawn towards the planet; it most undoubtedly is. And although the mass of the sun is so great that its movement is small, the total amount of re-action is exactly equal to the action of the earth in moving towards the sun. When a stone falls from the hand towards the ground, it falls by the force of gravitation of the earth attracting it, but the stone is at the same time attracting the earth, and the earth moves in the opposite direction to the stone, and the total action which we observe by the fall of the stone is exactly equal to the reaction in that motion of the earth upwards to the stone, only the mass of the earth is so great that of course its motion is totally insensible. Now with these preliminary remarks, let us return to the experiments we have been considering. We find that a magnetic pole tends to rotate round an electric current. We know that action and reaction are always equal and opposite, therefore, before we try an experiment, we know with absolute certainty that a current will tend to rotate round a magnetic pole. This is the sort of argument which I have always imagined to myself Faraday must have used in studying Oersted's experiment as leading up to this beautiful experiment which he produced, showing that an electric current rotates round a magnetic pole. This apparatus is exactly the converse of that smaller apparatus which showed us the other experiment. Here I have a vertical magnet with its south pole uppermost. Pivotted on the top of the magnet is a conductor, a piece of copper wire in fact, which travels parallel to the magnet, and dips down into a trough of mercury. The current then enters the magnet, goes up to the pole at the top, traverses the pivot, goes down the wire which is parallel to the magnet, but outside it, then into the mercury, and back to the battery. Now, when we turn on the current, we shall find that the wire is rotating round, showing the accuracy of the principle, that action and reaction are equal and opposite. I have only to change the direction of the current in order to show you that the motion is in the opposite direction. I shall now simply show you the effect of reversing the polarity. You noticed that the wire went round, if you looked down upon it, in the direction of the hands of a watch. I have now reversed the magnet, and put the north pole uppermost, and we shall find that the current, which is in the same direction, will go in the opposite direction. This experiment led Faraday to a large number of very beautiful experiments, all illustrating the same point; but the general fact remains, that when we have an electric current in a magnetic field—that is to say, in a part of space where there is a magnetic induction—and cutting the lines of magnetic induction, then there is a force tending to move that current and tending to move the magnet, and whichever is free to move will move, and if both are free to move, both may move. I should like to say a little more about the direction. I told you, when I was using the suspended magnet, the law derived from Oersted's experiment was, that if you supposed yourself a conductor carrying a current, your head pointed in the direction of the current, and you looked towards the north pole, that then you would see the north pole moved to your left. Another way is to place the face of your hands with the palm towards the north-pole, and stretch your thumb away from your fingers, and point your thumb in the direction of the current so that the current may come down your thumb. If the current is coming from the point of your thumb towards your hand, and the palm of your hand is facing towards the north pole, then your fingers will show the direction in which the north pole of the compass tends to move. That is, perhaps, a little simpler than the way I previously described it. Another way has been put very clearly thus. Suppose you are using a corkscrew, you turn it round in the direction of the hands of a watch, and at the same time the corkscrew moves through the cork. That gives you a relative idea of the direction of the rotation, and a motion perpendicular to the plane of the rotation. Then I would say, when the current is going in the direction in which the corkscrew moves, that is into or out of the cork, then the north magnetic pole will be seen to turn in the direction in which the corkscrew turns. I give you these three rules because it is very easy to choose one of them and fix upon it, but you are apt to get confused if you do not fix on the one which you are going to use for the future. I recommend each one who has not a rule of his own for the purpose, to fix on one of these and keep to it as to the direction in which the compass needle moves. Then when you want to know in which direction the current moves, you always have to remember that by the law that action and re-action are always equal and opposite, therefore, under these circumstances, if the north pole tends to move in one direction, you know that under the same circumstances the current tends to move in the opposite direction.

Now I must come to another set of phenomena; the action of a coil on a piece of iron is to magnetise it, and this action tends to make that magnet move. In fact, the action of this coil is to create a magnetic field. The action of the coil is identical with the action of a magnet. The magnet could be constructed of definite proportions which could behave in exactly the same way as this coil does on all external objects. I do not say on objects in the interior of it, because there there would be a difference, but on the exterior object. If the action of this coil and the magnet which could be made would be identical. Now if this coil attracts the magnet, and another coil will act as a magnet it is perfectly clear the two coils ought to attract each other. Each of these coils before you is acting as a magnet, and, therefore, they ought to be able to attract each other, or to repel each other according to the position of their axes, and according to the direction in which the currents are rotating around the coils of wire. This is a part of the development of those grand researches which were undertaken by the French philosopher, Ampère. Ampère thought there ought to be some action between conductors which carry currents of electricity, and on studying these actions he was able to bring out some general laws. He aimed at putting his conclusions in a certain definite form. He supposes we have two circuits, whether they are coils, or whatever they may be, with electric currents, each little bit of a current in the one circuit was acting with some force or another upon each little bit of a current in the other circuit, and that the total action observed was the sum total of all these little independent actions. This was a very difficult way of attacking the problem. He did attack it from a purely mathematical point of view, and worked it out mathematically to find what law it would be necessary to assume in the action between little pieces of current in order that all the phenomena which are observed might supervene. One result he showed to be that two little bits of current parallel to each other either attracted each other or repelled each other according as the directions of the currents in the two were the same or opposite. I have the means there of showing you this by means of a flat coil of wire. The wire was simply wrapped between two boards, the wire being insulated and wound round itself constantly, always being coiled between two boards until we get a flat spiral of considerable size, and exposing a considerable surface, which might be subjected to an attracting or repelling influence. The suspension of the the coil is effected by means of the wire itself; the two ends of the coil are continued up to the beam over my head, and thence wires go to the battery, so that I am able to send a current circulating through that coil. I have here another coil or flat spiral, exactly similar to the one I have been describing. I have a battery also attached to this spiral, and a separate battery attached to the other spiral. The current is now circulating through the suspended coil, but there is no current at present circulating through the coil I hold in my hand. I bring this coil in the neighbourhood of the suspended spiral, and there is no motion whatever, whether I hold one side towards it or the other. Now if we put on the current, you will see immediately an attraction. It draws the other spiral to it, and tries to stick to it; on breaking the contact it flies away immediately. Here, then, is a case in which the two currents of electricity were circulating round these two coils in the same direction, and the parallel currents, going in the same direction, attract each other. Now we will reverse the direction of the current of electricity, so that the currents in the two coils will be going in opposite directions. I am now holding my coil close to the suspended one, and there is a violent repulsion when I bring the coils close together; they try to slide over each other, and get away from each other. I could get up quite a swing by following it about a little time, and I can check the swing by a judicious movement of the one I hold in my hand. I will now simply turn my coil round, and ask Mr. Davenport to put on the current in the same direction in which he had it just now, and there is immediate attraction. So that you see when I reverse the position of the coil, I am doing exactly the same as if I had reversed the direction of the current by the commutator. We have attraction when the one current is circulating in the same direction, just as we always found that we had attraction when the current of electricity was rotating in the same direction in the two spirals.

I will now show you by means of a piece of apparatus on the table, the truth of Ampère's conclusions, viz., that two parallel currents attract each other when they are going in the same direction, and repel each other when they are going in opposite directions. This piece of apparatus consists of a vertical column supporting at its top, on a pivot, a horizontal wire, which is then bent downwards, and dips into a trough of mercury, the base of the vertical column. I shall be able to put on a current immediately, and the direction of the current I have carefully observed before. The current is coming from the copper and going to the zinc of the battery, and goes up through this part of the external circuit. The current of electricity in the wire which I hold in my hand is also going in the direction of the arrow which is attached to the conductor I hold in my hand. The currents are now circulating in this direction. In the first place I will keep both currents in the same direction. As I bring mine near the suspended one, you immediately see an attraction producing a rotation of the whole apparatus round the central pivot. I reverse the action by bringing it the other side, the two currents being parallel, and there is the same attraction, showing that two parallel currents going in the same direction attract each other. I will now steady it, and hold my current in the opposite direction with the point of the arrow downwards, and cause the current to flow downwards whilst that in the apparatus goes upwards; bringing them near to each other we shall see there is a decided repulsion. These two main principles of Ampère's experiment appear to be true, viz., that two parallel currents attract or repel each other according as the direction of the currents are in the same or opposite directions.

There is another part of Ampère's conclusions to which I would also direct your attention. He also showed us that if two wires both carry currents, and cross each other, and if they can rotate about the point of intersection, then if the currents are going both to or both from the point of intersection, we have attraction. If one is going to and the other from the point of intersection, we have repulsion. I have an apparatus here which will show this action very well. This is a beautiful piece of apparatus which I happened to come across the other day. I daresay it is very common, but I never saw it before. There are two coils of wire, both on vertical pivots, and both capable of rotating about that axis. A current of electricity can be independently sent through these two wires. Both of them in rotating are able to make contact with mercury, which is contained in little cups. The ends of the one coil always dip into the same cups of mercury, and therefore the current always goes in the same direction through that coil. The ends of the other coil dip into a cup which has a partition, and the mercury which is in the cup rises by capillary force above that partition so as to meet; and thus we have two mercury sectors into which the wires can dip, and this acts as a commutator tending continually to reverse the direction of the current; so we shall find that there is attraction tending to bring the currents together up to a certain point. As soon as that point is reached the current is reversed, and then the force is converted into repulsion, tending to continue the rotation. By this ingenious device we can get continuous rotation of these two coils round the vertical axis of two coils rotating in opposite directions. That illustrates the action I have just been describing, showing the attraction or repulsion between these two cross conductors at the top and at the bottom of the pivot, combined with the attraction of parallel conductors which are at the sides, and it forms a very pretty illustration of the principle.

In conclusion, I will show you an experiment which further illustrates the attraction of currents for each other in a very simple way. I have upon the stand a spiral of copper wire forming a vertical coil freely suspended from its top. The lower end of the copper wire dips into a small vessel of mercury. Now when I turn on the current we know that there will be attraction between each one of those spirals and its neighbour, and the attraction is simply due to the creation of a magnetic field in the way in which we have evolved these things from Oersted's experiment. By the creation of a magnetic field there is an attraction produced between the turns of spirals. If I were to put a piece of iron into the centre of it, the intensity of the magnetic field would be increased, but even without that there is a magnetic field created there producing attraction between the spirals of this copper wire. The result is to lift the point right out of the mercury, so that if a current of electricity has passed through the spiral and lifts the spiral above the mercury the current of electricity would be stopped as soon as this action has commenced to take place. Immediately then, the current having ceased, the spiral resumes its normal length, and sinks again into the mercury. Then the current acts again, a magnetic field is created, the attraction ensues, and it is lifted out of the mercury again, so that in that way it is alternately lifted and dropped at a very rapid rate. The sparkling indicates the change, and you can also hear it. I want you to notice the rapidity with which the sparkling takes places which makes the action perfectly evident.

General Notes.

MANGANESE IN RUSSIA.—From an official report lately issued it appears that the production of manganese in Russia is steadily increasing. The exports for the first four months of this year amounted to 9,000 tons, as against 4,500 tons for the corresponding period of 1885. This is shipped principally from Poti, where it is conveyed by the Transcaucasian Railway from the mines, in order not to interfere with the petroleum trade of the neighbouring port of Batoum. Owing to the bad condition of the conveyance used in transporting it from the mines at Tchiatoor to the Transcaucasian Railway, large lumps of ore only can be carried, the result being that the smaller pieces, which are equal to two-thirds of the total quantity extracted, are wasted, although equal in quality to that exported.

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Proceedings of the Society.

CANTOR LECTURES.

THE MICROSCOPE.

By John Mayall, Jun.

Lecture IV.—Delivered December 14, 1885.

Modern Microscopes to the Date of the Application of Achromatism (Continued).

Martin's "Pocket Reflecting Microscope."—This microscope (Fig. 53, p. 1056) was figured in B. Martin's "Micrographia nova" (Reading, 1742, 4to). The point of interest is the application of a screw-micrometer in the eye-piece, having a certain number of threads to the inch, by which accurate measurements could be made. Martin was, I believe, the first to provide accurate means of determining the exact magnifying power of any object-lens, so that the observer might state definitely that he used an amplification of a certain number of diameters. He describes his method thus:—

"Take any Ruler, &c., which has inches divided into *Tenths*, and place it under the Microscope so that you may have one of these Tenths in full View in the Image, then measure it carefully with the Micrometer, and count how many turns were made in so doing; divide that number by 5, and the Quotient will show how many times the Image is bigger than the Object. Thus suppose in Measuring one of those Tenths I make 40 Turns, that divided by 5 quotes 8; and so many times does the Microscope magnify with the glass. *Note*, the Reason why you divide by 5, is because there being 50 Threads to an Inch, 5 must be equal to one Tenth in the Object; therefore as many times 5 as there are in the Image, so many times must the Object be magnified" (pp. 12-3).

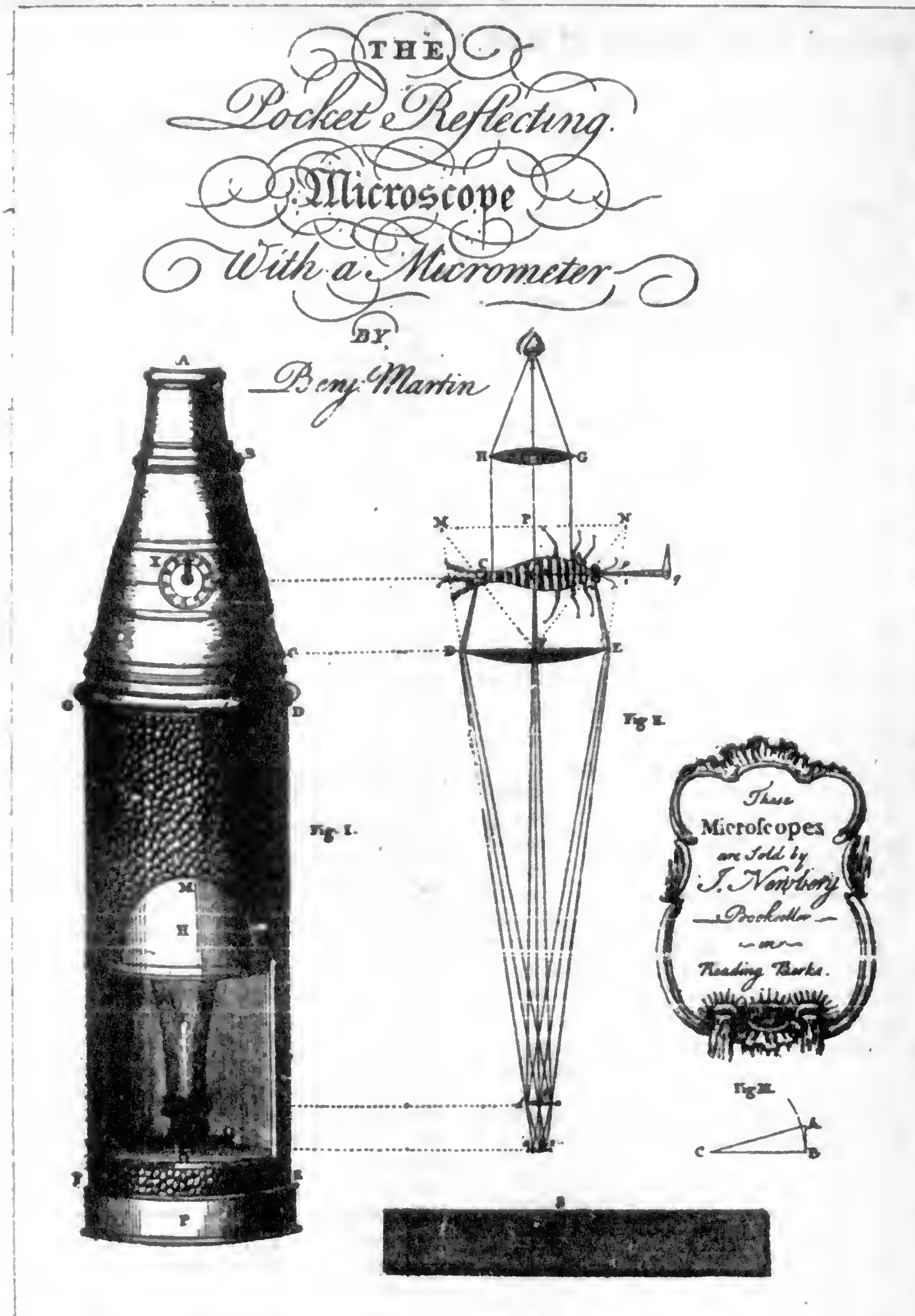
This instrument had a mirror fitted in the cylinder-base, and was hence termed by Martin a "reflecting" microscope, though, in fact, it was a compound dioptric form. Martin regarded the base as a special point in the construction "for the instrument to stand upon." In later constructions the tubes were of brass, and the outer one was cut away to facilitate the placing of object-slides on the stage, and the mirror was hinged exactly as we see in the "Microscope à tambour," which is now largely manufactured in Paris as a low-priced instrument.

I do not think that any other microscope has a better claim than this one to be regarded as the original form of the modern "drum" microscopes, which Frauenhofer revived in the early years of this century, and which was modified by Oberhaeuser into his well-known form of dissecting compound microscope. This latter has gone through a series of alterations—conducted with admirable skill and foresight by Oberhaeuser, Hartnack and Prazmowski, Zeiss, Nachet, sen., and his son and successor, Alfred Nachet—resulting in the general type of microscope known as the "Continental model," with which I believe it is no exaggeration to say that 90 per cent. of the useful microscopy of our time has been produced.

Martin's "Universal Microscope."—In the same work Martin figured and described his "Universal Microscope, mounted on a Ball and Socket" (Fig. 54, p. 1057).

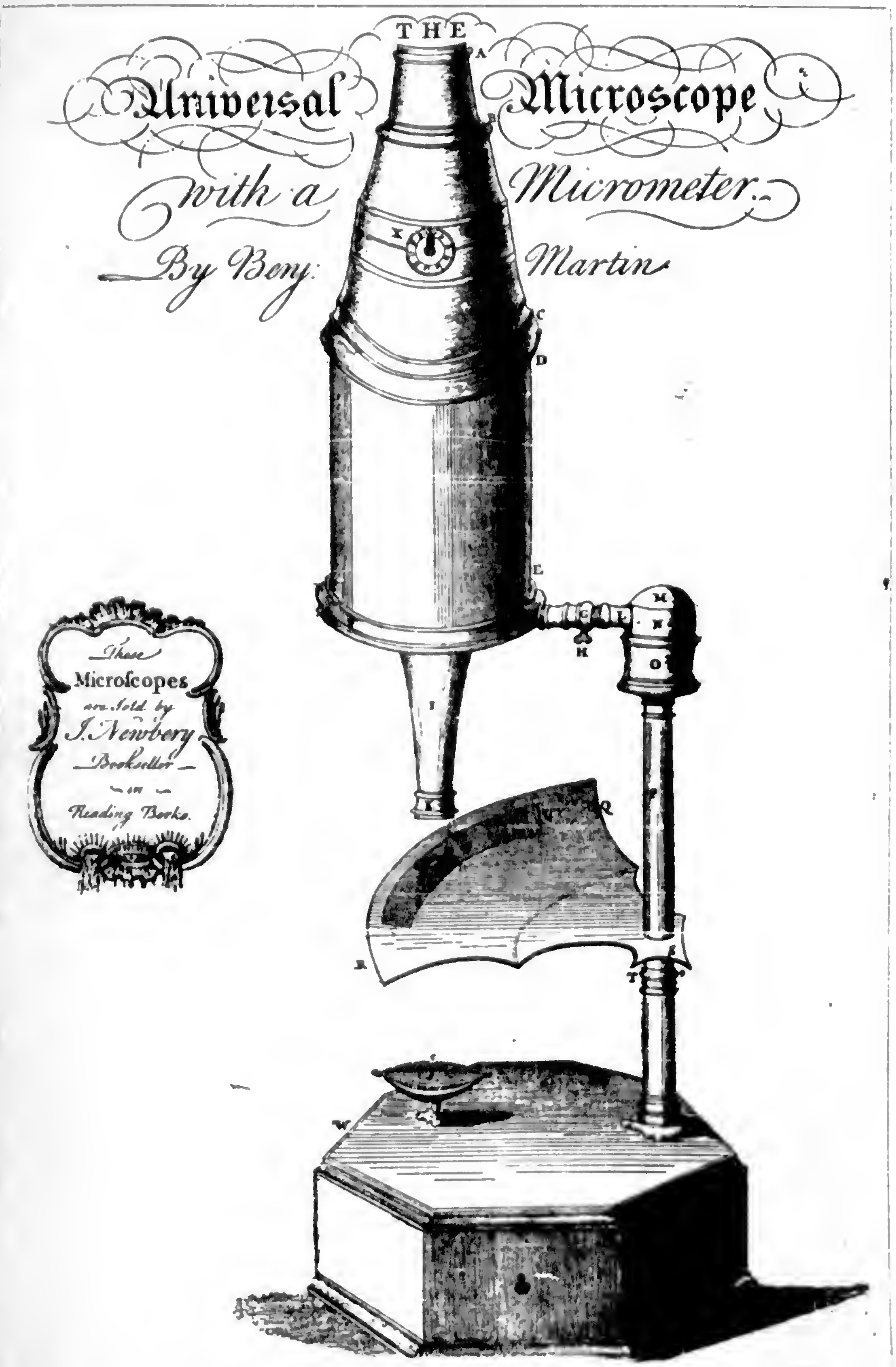
Martin appears to have considered his application of the ball-and-socket as of prime importance, and he introduces it with a criticism on the inconvenience of the "usual Construction of the large double Microscope," of the tall tripod form, referring, doubtless, to Culpeper and Scarlet's model. He claims that with his ball-joint one can "view all Kinds of Objects in every possible Position or Situation" (p. 13). No fine adjustment was applied; the focussing was effected (presumably) by sliding the body-tube within the sheath, D E. The "Quadrantal" stage, R Q, moved horizontally on the pillar, P, and the zone-section, V U, was of glass placed over an opening of similar shape in the stage and concentric with the pillar, hence "the Object, once well posited, is not moved, but the Plate whereon it lyes passes thro' the whole Length of it under the Object Glass" (p. 15).

Fig. 53.


THE
Pocket Reflecting
Microscope
With a Micrometer
BY
Benj. Martin
Fig. I.
Fig. II.
Fig. III.
These
Microscopes
are Sold by
J. Newbery
Bookseller
in
Reading Berks.

(1742).

FIG. 54.


THE
Universal Microscope
with a Micrometer.
By Benj: Martin
These
Microfcopes
are sold by
J. Newbery
Bookseller
in
Reading Berks.

(1742).

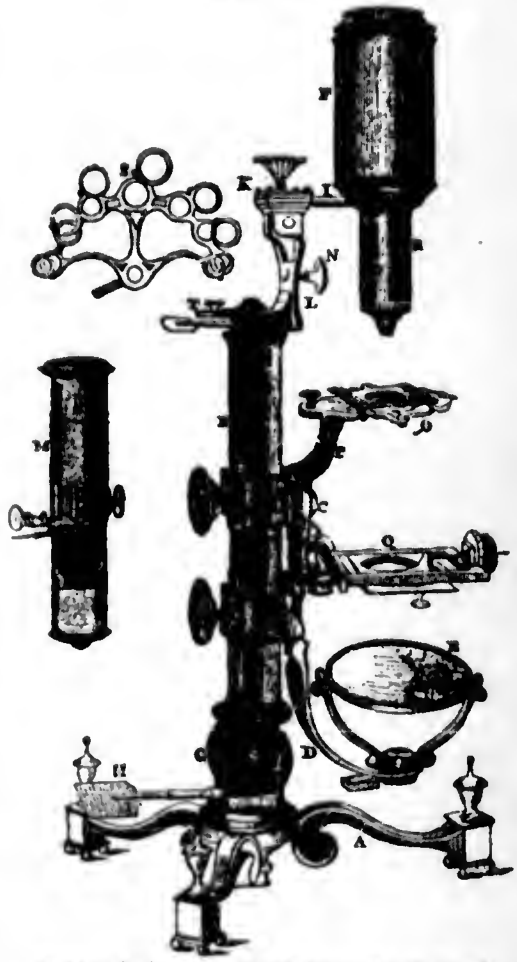
Martin devised numerous improvements in the mechanism and optical arrangement of the microscope. He appears to have suggested the rotating multiple lens-carrier nosepiece, in which he placed six different powers to rotate successively in the axis, first applied to a simple microscope and later to a compound. The invention of the multiple system of pocket lenses is attributed to him. He applied to a simple microscope a fine adjustment (after Cuff's design, but acting on the stage—not on the optical body, with "the constant pressure of a Spring" to check the motion—(*vide* "Optical Essays," p. 9, Fig. XVI.). He also applied to simple and compound microscopes rack-and-pinion focussing adjustments; to the latter he added inclining movements to the pillar carrying the stage and mirror, and rectangular mechanical motions to the stage.

Martin's Large Universal Microscope.—This instrument (Fig. 55) was formerly in the possession of the late Professor Quekett, who presented it to the Microscopical Society of London. After a general reference to "the extent and variety of its accessory instruments ...." in which "it is perhaps one of the most complete instruments ever manufactured in this or any other country," Quekett describes the microscope as follows:—

"This microscope .... stands about two feet in height, and is supported on a tripod base, A; the central part or stem, B, is of triangular figure, having a rack at the back, upon which the stage, O, and frame, D, supporting the mirror, E, are capable of being moved up or down. The compound body, F, is three inches in diameter; it is composed of two tubes, the inner of which contains the eye-piece, and can be raised or depressed by rack and pinion, so as to increase or diminish the magnifying power. At the base of the triangular bar is a cradle joint, G, by which the instrument can be inclined by turning the screw-head, H [connected with an endless screw acting upon a worm-wheel]. The arm, I, supporting the compound body, is supplied with a rack and pinion, K, by which it can be moved backwards and forwards, and a joint is placed below it, upon which the body can be turned into a horizontal position; another bar carrying a stage and mirror, can be attached by the screw, L N, so as to convert it into a horizontal microscope. The stage, O, is provided with all the usual apparatus for clamping objects, and a condenser can be applied to its under surface; the stage itself may be removed, the arm, P, supporting it, turned round on the pivot C, and another stage of exquisite workmanship placed in its stead, the under surface of which is shown at Q.

"This stage is strictly a micrometer one, having rectangular movements and a fine adjustment; the movements being accomplished by fine-threaded screws, the milled heads of which are graduated. The mirror, E, is a double one, and can be raised or depressed by rack and pinion; it is also capable of removal, and an apparatus for holding large opaque objects, such as minerals, can be substituted for it. The accessory instruments are very numerous, and amongst the more remarkable may be mentioned a tube, M, containing a speculum, which can take the place of the tube, R, and so form a reflecting microscope. The apparatus for holding animalcules or other live objects, which is represented at S, as well

FIG. 55.



MARTIN'S LARGE UNIVERSAL MICROSCOPE (*ante* 1782).

as a plate of glass 6 inches in diameter, with four concave wells ground in it, can be applied to the stage; so that each well may be brought in succession under the magnifying power. The lenses belonging to this microscope are twenty-four in number; they vary in focal length from 4 inches to 1-10th of an inch; ten of them are supplied with Lieberkühns. A small arm, capable of carrying single lenses, can be applied at T, and when turned over the stage, the instrument becomes a single microscope; there are four lenses suitable for this purpose, their focal length varying from 1-10th to 1-40th of an inch. The performance of all the lenses is excellent, and no pains appear to have been spared in their construction. There are numerous other pieces of accessory apparatus, all remarkable for the beauty of their workmanship." ("A Practical Treatise on the Use of the Microscope," 3rd ed., London, 1855, 8vo., pp. 25-6).

In addition to the movements described above by Quekett, the body-tube, with its support, can be moved in an arc concentrically with the axis of the triangular pillar, H, on the top of which it is fitted with worm-wheel and endless-screw mechanism, actuated by the screw-head below T.

Though I cannot endorse Quekett's criticism on this instrument, namely, that "in point of workmanship" it "can probably not be surpassed, even in the present day," not even with reference to the workmanship of his day, for microscopes by Powell, Ross, Pritchard, Charles Chevalier, and Smith and Beck, were then constructed which were superior in every essential point of workmanship; yet I must admit that Martin led the way far beyond his contemporaries, both in the design and the execution of this microscope. From my point of view, any detailed comparison of the design with that of our best modern microscopes would lead to such a disparagement of Martin's *chef-d'œuvre*, that I prefer not engaging upon the task.

I cannot, however, pass over Martin's work in connection with the microscope without calling attention to the fact that he was the first to construct an achromatic objective, and at a date so early in the history of the application of achromatism that his priority as a mere question of date cannot be disputed. In his "New Elements of Optics" (London, 1759, 8vo), published in the year following Dollond's communication to the Royal Society of his successful construction of an achromatic telescope (1758), Martin dealt with the principle of achromatism, and after stating the results of his comparisons of achromatic telescope object-glasses with reflecting telescopes of the same magnifying power, in which he gave the preference to the latter, he informs us that he made a similar comparison between an achromatic object-glass and a speculum, applied as an object-glass in a compound microscope. He thus describes his experiment:—

"Having found so great a Difference in the Appearance of Images formed in the solar Focus of a compound [achromatic] Lens and Speculum, I thought it would be necessary to compare the Appearance of the Images form'd in the proper or conjugate Focusses of a small triple [achromatic] Lens and Speculum, applied as an Object-Glass in a compound Microscope, ... which I did by giving the same Length to the Images, and viewing them with the same Eye-Glasses; and consequently the small Objects were equally magnified in the refracting and reflecting Microscope, but with how great a Difference in point of Clearness and Perfection in all the Circumstances of Vision, those only will be able to conceive who shall try the Experiment themselves" (p. 96.)

Martin states that he made similar comparisons between "a double *achromatic* Lens, and a Speculum of the same focal distances" applied to a *Camera Obscura*, and also as "Solar Megaloscopes," and in each case the advantage was with the speculum.

When we consider the severity of the tests he applied, and that even now there are astronomers who prefer the reflecting to the refracting telescope, we need not be surprised that Martin's achromatic microscope objective should have proved in his hands inferior to the reflecting microscope. The case could hardly have been otherwise, for reflectors up to a moderate size were nearly as well made then as they can be made now; but the construction of achromatic objectives for the telescope, microscope, &c., was a quite new art, involving enormous extra difficulties of workmanship at that date. If we were to test some of our inferior 1 inch or 1-2 inch achromatic objectives against some of Cuthbert's reflectors of the same magnifying power, I suspect we should have to endorse Martin's judgment in favour of the reflectors.

But the question I have in view is—Whether or not we shall be justified in assigning to Martin the credit of the first production of an achromatic microscope-objective?

By his own admission he made one, and we know that he published the fact in 1759, for the publication is before us. That he did not succeed in such a manner as to induce him to adopt the achromatic system to the exclusion of the older systems is a difficulty I admit; it shows, at any rate, that he did not fully appreciate the value of achromatism in microscope-objectives. If he had sent his achromatic objective to the Royal Society instead of publishing the result of his comparison of it with a reflector (as cited above), there can be no doubt he would have had full recognition as the inventor of achromatic microscopes, quite regardless of the mere quality of his work.

If the criterion of invention be the *first* *construction* combined with *first publication*, then Martin must be regarded as the inventor of the achromatic microscope.

Cuff's Compound Microscope.—This microscope (Fig. 56, p. 1061) was figured and described by Baker ("Employment for the Microscope," 1753, 8vo, pp. 442-6) who considered it more serviceable as a working instrument than the tall tripod form of Culpeper and Scarlet. The stage was more accessible, while the application of a fine adjustment of greater delicacy than any previously in vogue shows that Cuff aimed distinctly at improving the mechanical construction. The slotted tube, I, carries a polished reflector, *h*, at the lower end, and is adjustable on the lower part of the body-tube for illuminating opaque objects. R is a conical diaphragm fitting beneath the stage. Q is a Lieberkühn lens.

Soon after the publication of this model, Adams and others improved upon it by applying a cradle-joint to the lower end of the pillar, on which the instrument could be inclined; the mirror was then attached to the pillar, first by a horizontal rod passing through it, and connected with the gimbal, and then, with the addition of an arm, giving lateral swing. I believe Martin was the first to apply a separate stem, of square section, on which the mirror could be slid up or down; then he made the mirror travel by rack-and-pinion on the standard itself, as we saw on his large Universal Microscope.

Nairne made Cuff's microscope in a very substantial manner, fitting it on a cradle-joint to shut down in a box; and he was one of the first makers of compound microscopes to plan the instrument with a view to portability. Other opticians, both here and abroad, worked out various plans for rendering this microscope portable, such as by screwing the pillar within a box; but Nairne was the most successful, for his plan did not diminish the general stability of the instrument. Passemant, of Paris, copied Cuff's model exactly, in some cases gilding the metal work throughout; he also added ornamental scrolls, &c., in one example I have seen, these ornaments were carried to the verge of absurdity—a not uncommon defect in the designs of microscopes, &c., in France during the last century.

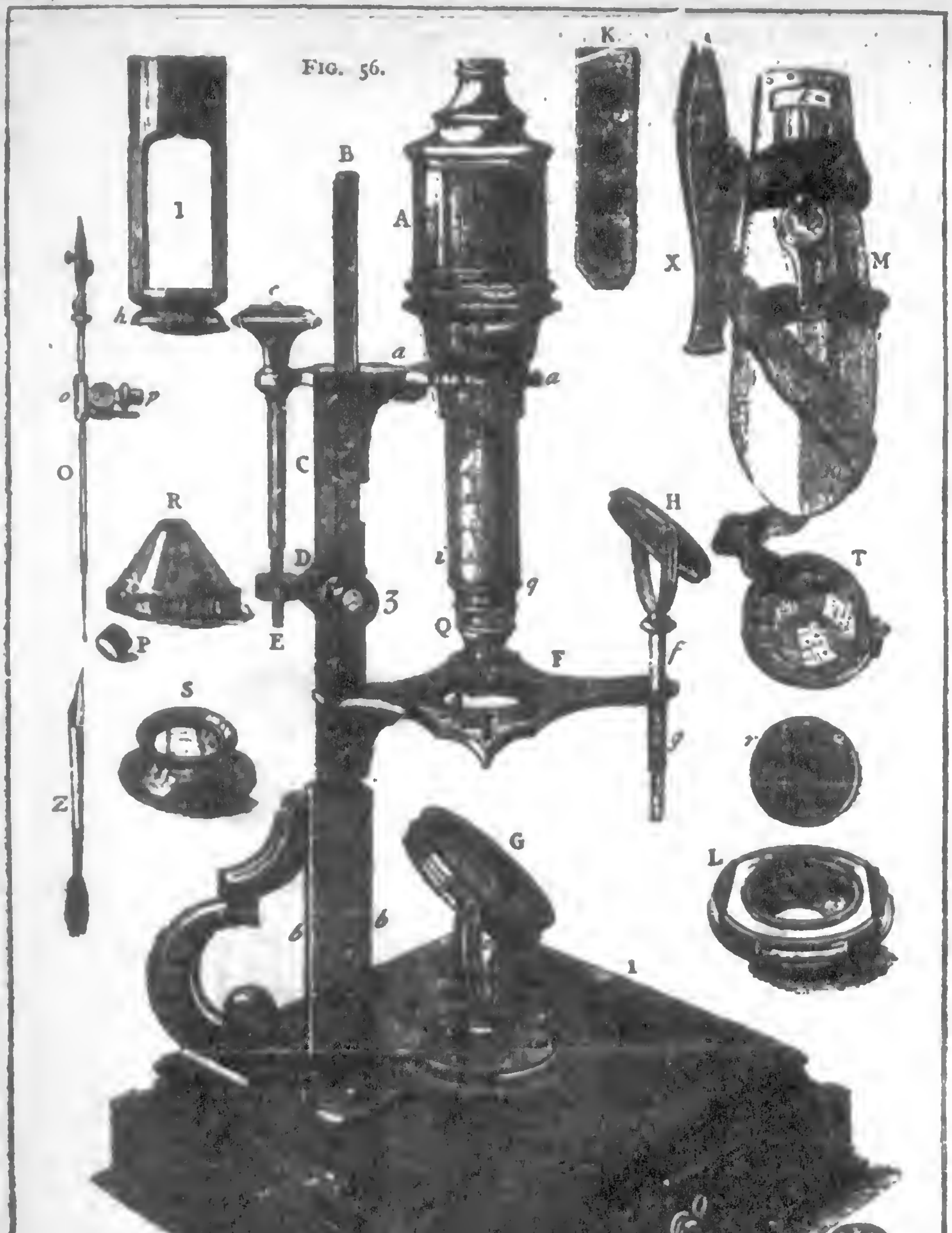
Baker states that in 1747 Cuff contrived a micrometer for his microscope, consisting of a "Lattice of fine Wires," distant from each other 1-50th of an inch, and intersecting at right angles; this was placed in the focus of the eye-lens so as to "divide the whole visible Area of the Microscope into Squares, whose Sides are each 1-50th of an inch" (*vide* description by Martin Folkes, P.R.S., *ib.*, p. 426).

Folkes mentions that he had been informed that "silver wire may be had to make these lattices of, whose diameter is rather less than the seven hundredth part of an inch" (*ib.*, p. 430).

Ellis's "Aquatic Microscope" (made by Cuff).—In Ellis's "Essay towards a natural History of Corallines" (Lond., 1755), this microscope (Fig. 57, p. 1062) is figured. We have here the model which we may safely regard as the original from which our best forms of simple dissecting microscopes have been developed. A disc of plane glass, C, or a concave, M, was applied on the stage on which dissections, &c., could be made; a mirror, I, was fitted in a gimbal with a stem sliding in a socket in the pillar; the lens-carrier, F, alone, or with Lieberkühn, F, screwed in a ring on the end of a horizontal arm, E, sliding through a socket, attached to a vertical rod, D, sliding and rotating in a socket at the back of the pillar for focussing, &c. The pillar screwed on the lid of the box, within which the instrument was packed with sundry accessories.

About 1835, Raspail was connected with a modified form of this microscope which became very popular in France; the horizontal arm was made to move forward or backward by means of an internal screw controlled by a milled head at the back, and these movements, together with the rotation in the vertical socket, enabled the observer to view different portions of the object in a manner equivalent to the use of mechanical movements of the stage. The success of Raspail's model roused much jealousy among the opticians in Paris. Vincent and Charles Chevalier, then regarded as the leading manufacturers, took especial umbrage at certain laudatory notices of the "new" microscope, and the latter addressed (April, 1835) a communication of "Notes justificatives" to the "Académie Royale des Sciences," characterising the model as a mere plagiarism on Cuff's (Ellis's). Shortly afterwards, however, C. Chevalier proceeded to modify the instrument, improving it both optically and mechanically; but, notwithstanding his efforts to disconnect Raspail's name from the design, it is still best known as the "modèle Raspail," and Chevalier's improvements have been almost wholly ignored. Andrew Ross applied a fine adjustment to his modification of this model.

FIG. 56.



A new constructed Double Microscope, as made & sold by the Inventor JOHN CUFF *in Fleet Street London.*

Publish'd according to Act of Parliament September 20th 1744

Adams's "New Universal Single Microscope."—In Adams's "Microgr. illustr." (cited above), this microscope (Fig. 58, p. 1063) appears as the frontispiece. He introduces his description of the instrument as follows :—

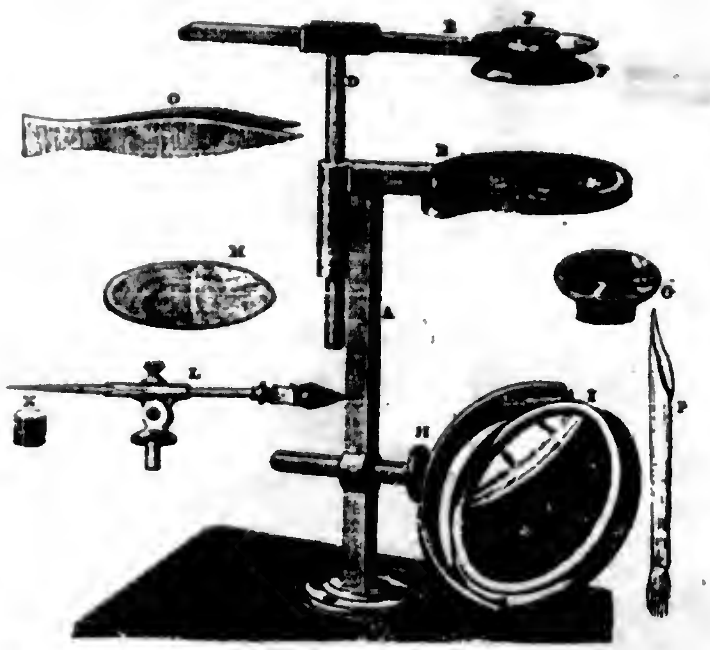
"It hath long been the Desire of the Curious and Inquisitive Part of Mankind, to have a Microscope which would be Portable and Universal, that is to say, ONE ONLY *Instrument*, by which all Sorts of minute Objects might be observ'd" (p. 1).

He tells us "This Microscope is made either of *Brass* or *Silver*, and is composed of *six* double convex *Lens* of different Foci" (*ib.*).

The disc, M M M, containing the six lenses, could be rotated in a collar-fitting on the top of the pillar, so as to bring the different powers to bear upon the object. N is an eye-guard connected with the top of the pillar by a short arm, under which the lenses pass. O is a "reflecting Speculum of Silver, or other Metal, highly polished; which when an opake Object is to be viewed, must be placed under the Eye-piece N" (p. 2). This reflector was not yet (1746) termed a "Lieberkühn."

The mirror, F, is supported by a hinge, V, in the centre of the back, on a short pillar, H, rotating in the disc, G. The feet, A and B, pivot on C, and fold under D for convenience of packing. A fine adjustment screw passes through the pillar, and is actuated by a milled head, P, and connected with the stage. Adams remarks that "the screw P is to be turned as your hands and arms are resting upon the table, which is a conveniency to be met with in no other Microscope" (p. 5).

FIG. 57.



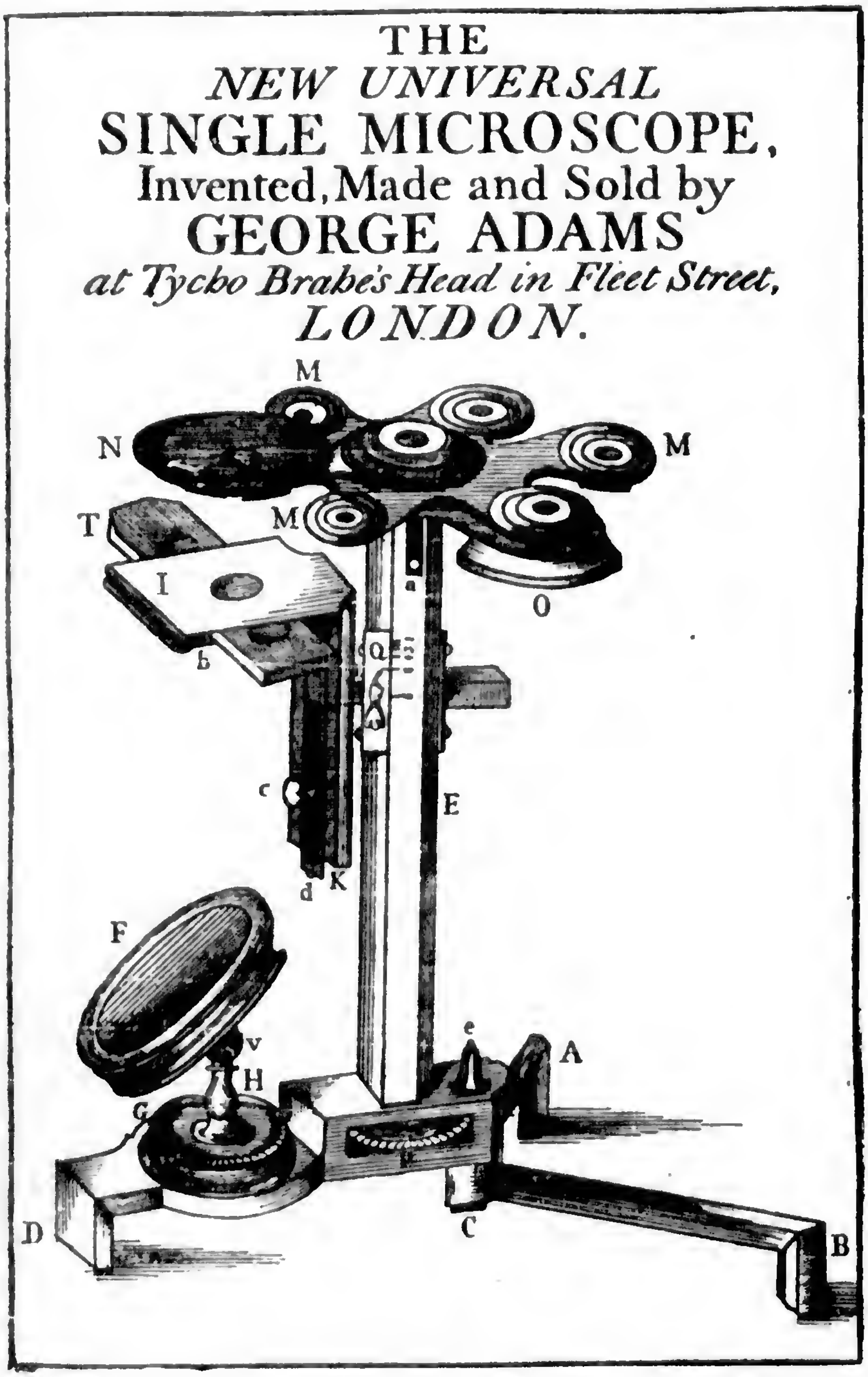
ELLIS'S "AQUATIC MICROSCOPE" (1755).

The numbers engraved on the pillar "shew the respective Distances of the Object from the Magnifiers, according as each Glass magnifies more or less. For instance, if you use the 5th magnifier, first place it under the Eye-Piece N, and then with your Finger and Thumb turn the Screw P, till the Finger of the Hand which is engraved on the Sliding-piece Q, points to the Mark 5 on the Pillar; then will the Object be very near its exact Distance from the Magnifier; so that by a Turn or two of the Screw P, either backwards or forwards, to be found by trial, you may soon fit it exactly to your Eye" (pp. 2-3).

The combination of this instrument with a heliostat, forming a solar microscope, was shown in Fig. 51. The connection was made by removing the mirror, F (Fig. 58), and the disc, G, from the front foot; then the microscope was placed horizontally, and the conical-ended tube, forming a draw-tube to the solar apparatus, was screwed in the place of G, through the under side of the foot.

In practice, as a simple microscope, this large disc lens-carrier is very inconvenient; in order to apply the eye close to the eye-guard, one is obliged to turn the head awkwardly. The instrument is so light that one is obliged to hold it firmly with one hand whilst

Fig. 58.

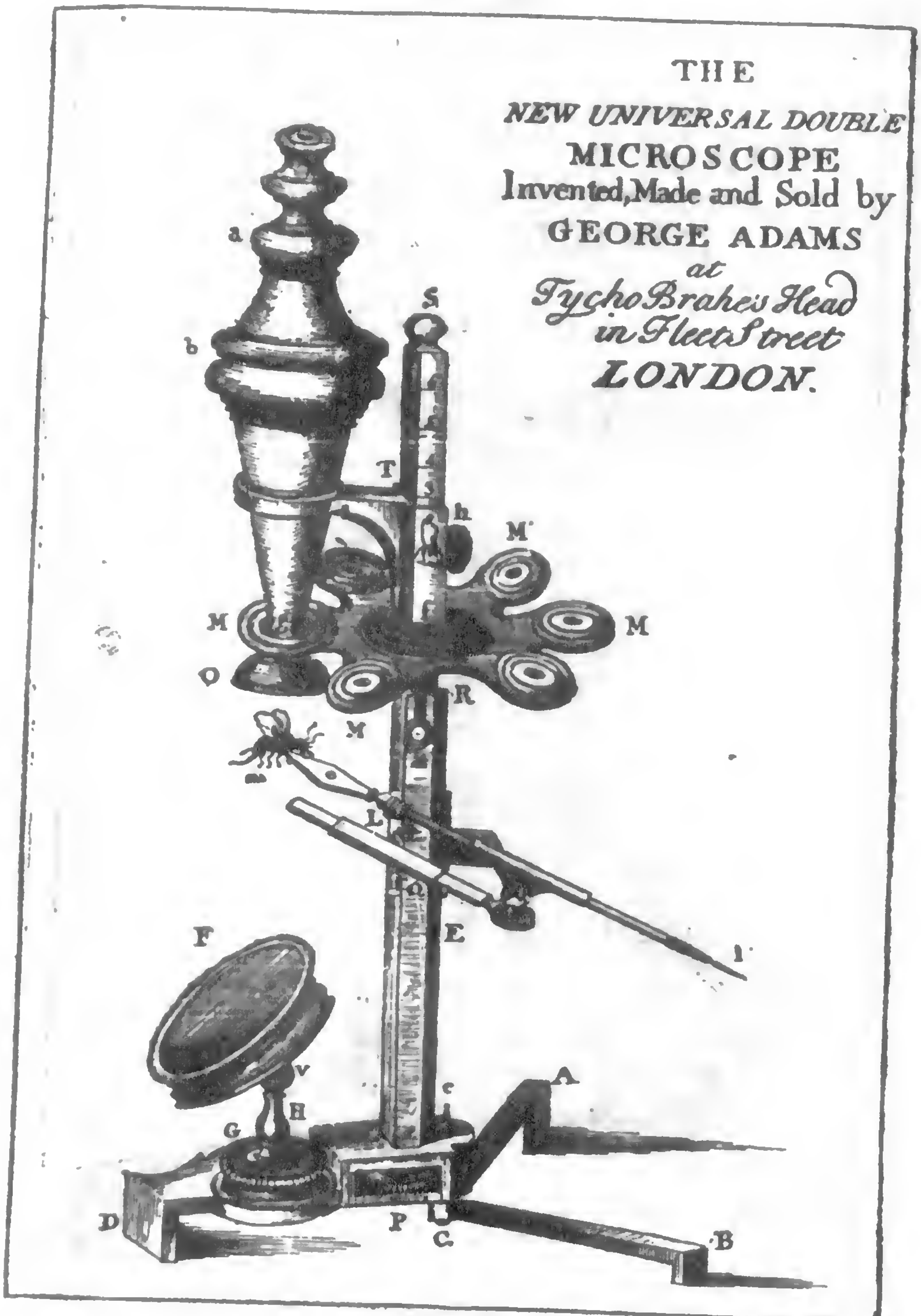


(1746.)

actuating the fine adjustment with the other hand—not a commendable arrangement.

Adams's "New Universal Double Microscope."—In the same work, Pl. III., we find this microscope (Fig. 59, p. 1064). The hexagonal pillar of the instrument, shown in Fig. 58, is here continued above the disc, MMMM, of lens-carriers, by a pillar of square section, RS; attached by the screw, x: the disc rotates as before in the collar-fitting, F, which is connected with a sliding socket (moving on RS) having an arm, T, and ring to support the

FIG. 59.



(1746).

compound body-tube. The focus was adjusted roughly by sliding the socket to the numbers on the pillar corresponding with the powers, and then the fine adjustment screw, P, acted on the object-carrier, U, as in Fig. 58.

No stage is shown in the Figures, but in the instruments I have examined, the stage was applied by means of a short stem at the back fitting in a hole, L, in the pillar, E (Fig. 58).

Adams explains how "these two new microscopes are best illuminated by Candle-Light," using a globe of water as a condenser, "and if that should prove too glaring, as it sometimes does, interpose between the globe and microscope a piece of thin oil'd paper, by which means most sorts of objects may be view'd as well by night, as in the day time" (*ib.*, p. 7), which plan was equivalent to that of Hooke, as used with sunlight.

Adams's "Variable Microscope."—In the 4th ed. (1771) of Adams's "Microgr. illustr." this microscope (Fig. 60, p. 1066) is figured and described (pp. i-vi. Pl. II). Adams states that "We owe the construction of the variable microscope to the ingenuity and generosity of a noble person. The apparatus belonging to it is more convenient, more certain, and more extensive than that of any other at present extant; consequently the advantage and pleasure attending the observations in viewing objects through it, must be as extensive in proportion."

In this instrument Adams claims to have embodied a number of improvements on all previous constructions. He applied "two eye-glasses at A, a third near B, and a fourth in the conical part between B and C," by which he increased "the field of view and of light;" draw-tubes were at A and B, by which these lenses could be separated more or less. He also arranged the object-lenses, or "buttons," A and B, to be combined; seven "buttons" were provided, "also six silver specula ["Lieberkühns"] highly polished, each having a magnifier adapted to the focus of its concavity, one of which is represented at E," and the "buttons" could also be used with "any-one of these specula," by means of the adapter, D.

The body-tube, A B C, with its arm, F (in which it screwed at *f*), and stem attachment with the fine adjustment, were clearly modified from Cuff's design (Fig. 56). The large ivory head, I, actuated a pinion and rack for raising or depressing the body-attachment on the stem. The stage and mirror were adjustable on the stem. The large ratchet-wheel controlled by the pinion-handle, S, gave the required inclination to the stem.

Nos. 1 and 2 were ivory and glass "sliders" for objects, to be applied in the spring-stage No. 3 fitting at T; the "hollow at K [No. 3] is to receive the glass tube No. 10." No. 4 was a diaphragm fitting in the lower end of No. 3, "to exclude some part of the light which is reflected from the mirror Q." The forceps, No. 5, could be placed "in one of the small holes near the extremities of the stage, or in the socket R, at the end of the chain of balls No. 6." No. 6 was an arm composed of a series of ball-and-socket joints, similar to the system employed by Musschenbroek (Fig. 28), by Joblot, and by Lyonet, to which I referred in my remarks on Joblot's microscope, and was intended to be applied at W, when the stage was removed. No. 7 was a box of ivory in which discs of talc, and brass rings were packed; No. 8, a hand-magnifier; No. 9, a sliding arm lens-carrier fitting on Z, when the instrument was required to be used as a simple microscope; No. 11, a rod of wire with spiral at the end for picking up soft objects from bottles, &c.; and No. 12, an ivory disc, black on one side and white on the other, fitting at T to carry opaque objects.

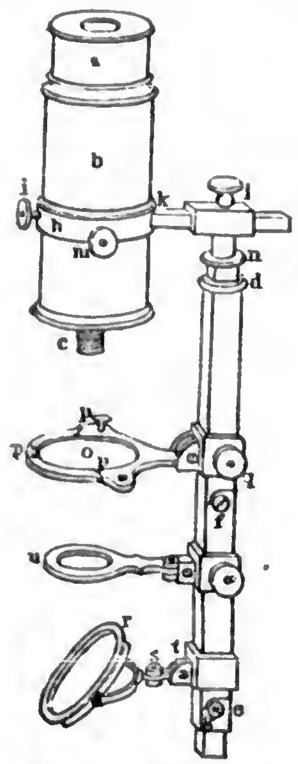
To use the instrument as a simple microscope, the body-tube, A B C, was removed from the ring, F; the lens-carrier, No. 9, was placed on Z, and a lens with reflector, E, screwed in the ring, C; the ball-and-socket arm, No. 6, was applied at W, by the part X, and the object held by either of the forceps could be turned and viewed as desired. For dissections, &c., the stage could be screwed on at F, and a glass plate applied at T.

One of the best examples of this design that I have seen, has a nose-piece with a slide carrying three objectives—the first arrangement of "triple nose-piece," or, indeed, of changing nose-piece for objectives (as distinguished from simple lens-carriers), that I have met with.

The inclining movements that were applied previous to the date of this instrument were generally defective. The ball-and-socket as employed with large microscopes by Hooke, Marshall, and Martin, could never have been a really serviceable arrangement; the cradle-joint at the lower end of the pillar, as employed by Cuff, Adams, and Martin, though better than the ball-and-socket, could not have been quite satisfactory. In the "Variable Microscope" Adams made a new departure as regards the mechanism of the inclining movement, by placing it far more under control than any previous system. Were we disposed to criticise this mechanism, we might easily show that Adams here applied an extremely complex system to arrive at a minor result, and that he passed over feeble points in his design apparently oblivious of their existence. But from his above-cited statement we may fairly assume that he was not wholly responsible for the design. Adams and his son (the author of the well-known "Essays on the Microscope"), and W. and S. Jones, were the originators of the model adopted by Vincent and his son Charles Chevalier for their early achromatic microscopes, and hence should be entitled to special consideration in any detailed estimate of individual services rendered towards improving the design of microscopes.

Dellebarre's "Microscope Universel."—This microscope is shown in Fig. 61 (copied

FIG. 61.



DELLEBARRE'S "MICROSCOPE UNIVERSEL" (1777).

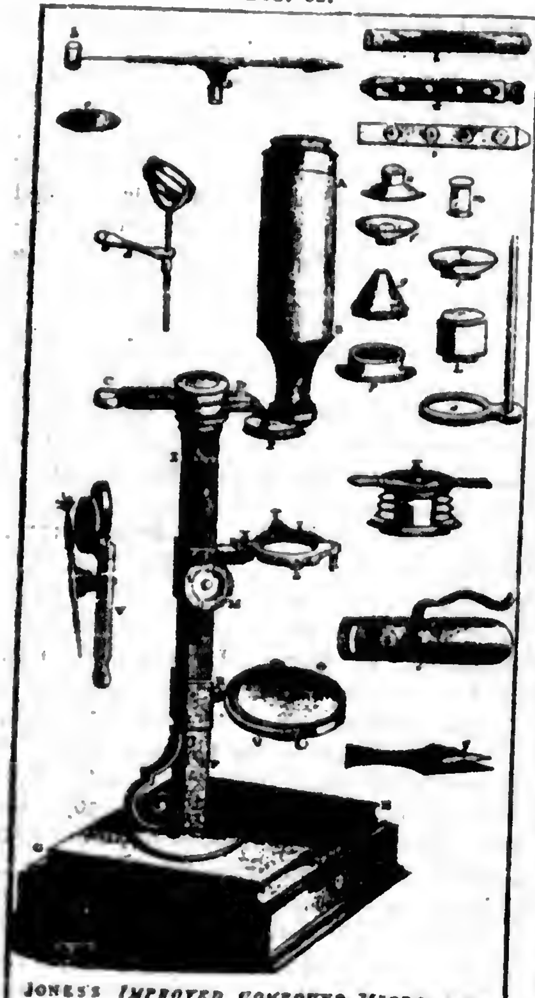
from Harting's "Das Mikroskop," German trans., 2nd ed., 3 vols., 8vo, Braunschweig, 1866, III., p. 123). The pillar was hinged at *e* for ordinary inclination, and at *f* to enable the body-tube to be placed horizontal, in the latter case the stage, *p p p*, could be inclined with the upper part of the pillar, or slid down below the hinge, when it would remain horizontal, and bottles, &c., could be stood upon it. The body-tube, *a b c*, was carried in a hinged ring, *h*, shutting by a spring-catch, and the screws, *i* and *m*, served to hold the body-tube firmly; the ring, *h*, was attached to an arm, *k*, sliding through a socket, and could be fixed by the screw, *l*, the socket rotated on a long pivot fitting in *n*, and a screw (not shown) fixed it. The stage was hinged to fold against the pillar, the condenser, *u*, was hinged to move laterally also (the hinge for the folding motion is not shown in the figure, but should be like *t*), and the mirror, on gimbal, similarly fitted, also folded against the pillar for convenience of packing. At *c* the long screw-thread is shown on which a large silver reflector was adjustable for illuminating opaque objects, to which I referred in my notes on Lieberkühn's microscopes.

This form of Dellebarre's microscope was applied by a long pivot fitting in the centre of a scroll tripod stand, the feet hinged to fold downwards; in later models the lateral-folding tripod was adopted. Dellebarre also applied a rack-and-pinion to a movable socket connected with the stage, and adjustable by a clamp-screw on the pillar, which was a very inferior arrangement for focussing. In other constructions, however, he applied the rack in front of the pillar, which was a better place.

Dellebarre's microscope was described in detail by Lalande (*vide* Montucla's "Hist. des Mathémat.," III., p. 511), and appears to have been the subject of a special report to the "Académie des Sciences," in June, 1777, by MM. Montigny, Le Roy, and Brisson. He was much commended for his application of six or seven lenses to be used in various combinations as eye-pieces. Lalande states that he deserved special credit for having constructed a microscope composed of six lenses; but his description is too vague to enable us to say whether or not this design followed on the lines of that of Adams (Fig. 56). He dwells upon the fact that Euler had computed a combination of six lenses for a microscope, and also certain achromatic eye-pieces, and appears to imply that Dellebarre carried out the construction; and he refers very distinctly to Dellebarre's "Large Achromatic Microscope" to be seen at La Haye, in 1771, and promises to treat of it later, in "Art. viii.," but on referring to Art. viii. I find nothing by which I can identify the instrument as an achromatic construction. I think Lalande must have been mistaken on the matter, for though I have examined upwards of twenty of Dellebarre's microscopes, some evidently of his early constructions, and some dated from Delft, as late as 1796, and Paris, 1805, I have never seen any eye-piece or objective of his of achromatic form. The value of the combinations of lenses for eye-pieces, so highly commended by Lalande, seems to me very much exaggerated.

The general form of Dellebarre's instruments was much inferior to the best contemporary work produced in England. Fresnel, in his "Rapport sur le Microscope Achromatique de M. Selligue" (1824), remarks (p. 15) that, other things being equal, those microscopes which have the largest field fatigue the eye the least; judged by that criterion, Dellebarre's

FIG. 62.



JONES'S IMPROVED COMPOUND MICROSCOPE AND APPARATUS.

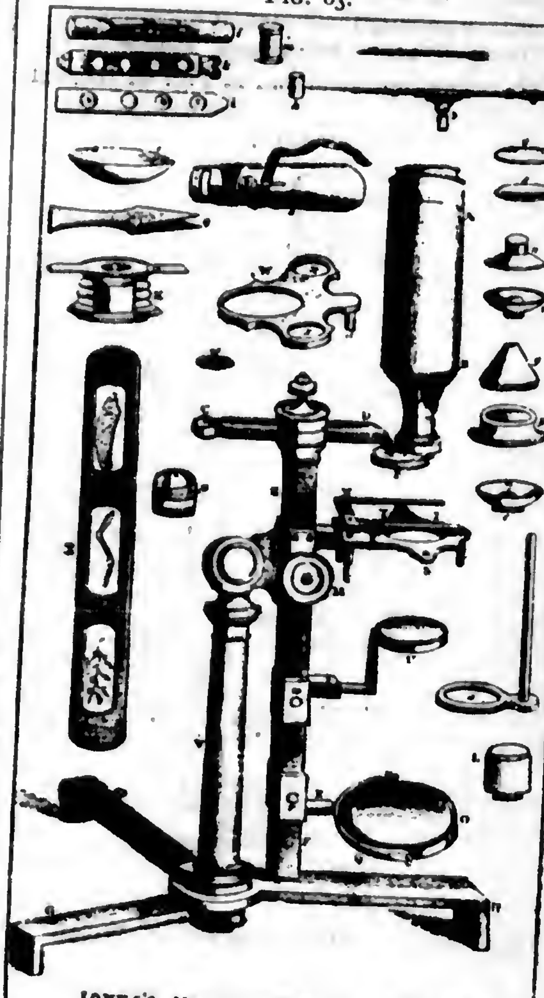
(*Ante* 1798).

were inferior to the microscopes of Amici and Selligue, and these were inferior to the English microscope of Adams (which was practically identical with Jones's, Fig. 63). Classifying the microscopes according to the "sharpness of the images," Fresnel found Delebarre's "the worst," Adams's next, and Amici's and Selligue's were "greatly superior" (*ib.*).

Jones's "Improved Compound Microscope."—In Adams's "Essays on the Microscope" (2nd ed., 1798), Pl. IV., this microscope (Fig. 62) is given.

We have here Martin's rotating multiple disc, P, of object-lenses; the arm, C D, carrying the body-tube (A, B) slides in a rotating socket on the top of the pillar, to view different portions of an object; a rack-and-pinion acting on the stage is applied for focussing; a carrier, *a*, for the condenser, L, or silver speculum, *e*, with a stem, is to be applied in a sliding

FIG. 63.



JONES'S MOST IMPROVED COMPOUND MICROSCOPE AND APPARATUS.

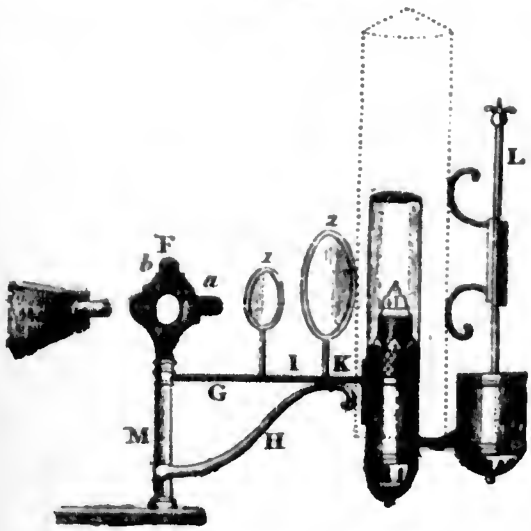
(1798).

socket in the front of the stage above or below; another condenser, D, with gimbal, sliding stem, and arm, can be applied at S or T to illuminate opaque objects; at V the arm, C D, with the disc of lenses, P, is shown in combination with the forceps, B, in use as a simple hand microscope. The other pieces of apparatus need not be described.

Jones's "Most Improved Compound Microscope and Apparatus."—In the same work (*loc. cit.*) this instrument (Fig. 63, p. 1068) is also figured.

The folding tripod base is adopted. The inclination of the stem on a cradle-joint on the top of the pillar was unquestionably the best system devised up to that date. The arm carrying the body-tube is here provided with a rack-and-pinion, as well as a rotary motion on the top of the stem, E, by which different parts of an object would be viewed better than with Jones's previous arrangement. The stage has clips to hold the objects, and an extra carrier, W, for discs of glass, &c., pivots at S, so that the objects pass successively in the optic axis. The condenser, U, slides on the stem by the socket *u*, the bent arm allowing space for the rack focussing of the stage; the mirror also slides

FIG. 64.



JONES'S RADIAL SWINGING SUB-STAGE (1798).

on the stem. A brass cell, *y*, contains a high power, 1-30th or 1-40th of an inch focus, and screws on the nose-piece when the lens-disc is removed.

I regard this form of microscope as the best that was produced in the last century, with the exception of Martin's "Large Universal Microscope" (Fig. 54, p. 1057), of which I believe only two examples are known, and which hardly entered the field of competition.

Jones's Radial Swinging Sub-stage.—In the same work, Pl. IX., this apparatus (Fig. 64) is figured. F is the stage of a lucernal microscope, of which the axis passes through the socket, M, to the base-support; G is a tail-piece swinging laterally by the socket, M, on he axis of the stage, so that the illumination from the lamp, passing through the condensers 1 and 2, strikes on the centre of the stage, and remains on it during the lateral swinging—thus providing radial illumination at all obliquities for transparent or opaque objects. In the earliest form I have seen of this apparatus, bearing the names "W. and S. Jones," no lamp was attached to the tail-piece, but a mirror was made to slide on it.

Adams states that the apparatus was suggested by "the Rev. John Prince, LL.D., now of Salem, Massachuset's States, North America," and that the lamp was attached to it at the suggestion of Mr. John Hill, of Wells, Norfolk.

The modern swinging sub-stage, known as Zentmayer's, which he exhibited at the Philadelphia Exposition, in 1876, acts on the same principle as the above; and the addition of the lamp to the tail-piece of Zentmayer's form by Bulloch, of Chicago, was a revival of Hill's suggestion.

Cuthbert's Reflecting Microscope (Amici's form).—In the early years of this century, Frauenhofer, Amici, and others, experimented with the construction of achromatic objectives, and, despairing of success in consequence of the difficulties of manufacture, they turned their attention to the improvement of reflecting microscopes. Amici is said to have made such improvements in the latter, that even after the announcement (1824) of Chevalier's success with achromatic combinations, he still worked at his reflectors.

In England, Cuthbert, acting with the advice of Goring, brought the construction of reflecting microscopes to the highest point of excellence ever reached, improving even upon Amici's; one of his latest instruments is shown in Fig. 65, p. 1070 (copied from the "Encyclop. Britan.," 8th ed., art. "Microscope," p. 786), which served also as a compound achromatic (dioptric) microscope. Six sets of reflectors were supplied, varying from 2 inches to 3-10ths in solar focus, and of angles of aperture from 13° to 55°. Each set was applied in a separate tube, *b c*, and the three lower powers were supplied with Lieberkühns sprung on the tubes, for illuminating opaque objects; the higher powers were useful for transparent objects only, on account of the shortness of the focus.

Mechanical movements, *m*, are applied to the stage, the construction of which is similar to that known as the "Turrill" system, the two milled heads working on one axis. The fine adjustment is a modification of Cuff's.

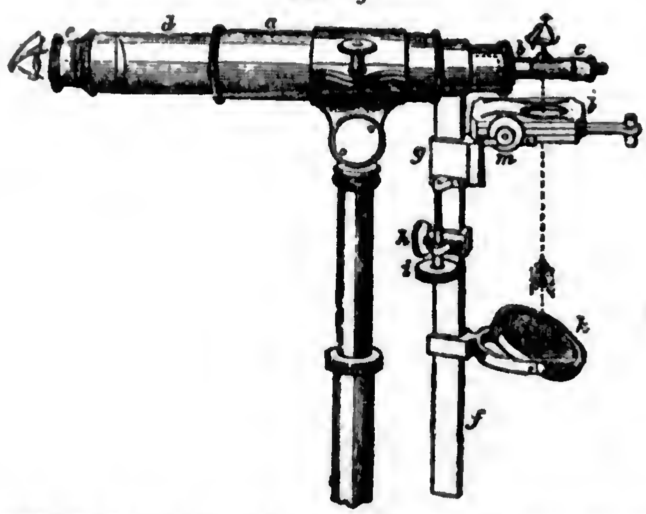
In action as a dioptic microscope, the tube, *b c*, was removed, and an achromatic objective substituted, then by means of an angle-piece the stem, *f*, was carried at right angles to the position shown, so that the stage and mirror were in the optic axis.

I have examined several of these microscopes, and can testify to their general excellence. Cuthbert's work was superior to Amici's, as I found by comparison.

In concluding my notes on non-achromatic and reflecting microscopes, a few remarks may be made by way of *résumé*.

Of simple microscopes we may note that the earliest forms were mere hand-lenses. The next step was probably effected by mounting them at one end of a tube of card-board or wood, the object being held on a needle at the focus, or attached to a plate of glass, or between two plates, and viewed as shown in the "Microscopium Pulicare" (*Vide* Figs. 4, 23, &c.); for magnifying larger objects, the instruments shown in Figs. 7, 9, 10, and 11, were employed with more or less modification. Where higher power was needed, some system of focussing would be adopted, either by sliding the object-carrier or the lens. For still higher power, where the difficulty of making the lenses would limit the power, globules of blown-glass were used; the first production of such globules was by Toricelli (*vide* Poggendorff's "Hist. de la Physique," p. 357). Hooke gave detailed instructions for making these globules, and he

FIG. 65.



CUTHBERT'S REFLECTING MICROSCOPE (AMICI'S FORM, 1827-8).

appears to have partly ground and polished them. The names of Butterfield (1678) and Della Torre (1765) appear in the "Phil. Trans." in connection with various processes they devised for the production of these globules, and the latter was said to have been specially successful in making very small ones. In some cases the globules were melted on the end of a needle or fine silver wire in a spirit-flame and left adhering, so that they could be handled with facility. Another and apparently better plan was adopted by Sivright (1829), who placed a fragment of glass on a minute hole in a thin plate of metal, and then by means of a blow-pipe and spirit-flame melted the glass so that it ran through the hole, and with careful manipulation it was said that a serviceable lens could be produced having a small diaphragm in its centre, the plate thus forming a substantial mount for the lens. But the uncertainty of the successful production of these globules must have struck every serious worker; and thus we find that Leeuwenhoek used only lenses with ground and polished surfaces, and except in the matter of mounting such lenses in cells so as to be more conveniently applied or changed, no essential improvement was made in their construction until Wollaston, Brewster, Goring, Herschel, Tully, and Coddington worked out by theory and practice the best forms and combinations of simple lenses, resulting in the well-known "Doublets," "Triplets," the "Herschel combinations," the "Bird's-eye" or "Coddington," the "Stanhope," the "Crossed-lens," &c., all produced between 1790 and 1830, *i.e.*, during the years when the possibility of applying achromatism to the microscope presented itself to the same investigators, with the addition of Beeldsnyder, Van Deyl, Fraunhofer, Amici, Selligue, and the Chevaliers, as a problem to be solved by practical constructions.

With regard to the sequence of construction in the period of nearly two centuries we have dealt with, we cannot affirm that in either the optical or the mechanical design the construction of compound microscopes progressed steadily from generation to generation. Until about 1824, the optical arrangement seems to have drifted about almost aimlessly, with little or no reference to any question of the theoretically best forms or combinations. In Hooke's microscope the field-lens was applied or withdrawn without any apparent conception that a combination might be devised of permanent service, and during the next hundred years the compound eye-piece was hardly improved. The improvement then initiated was in the more accurate mounting of the lenses rather than the adoption of a better optical system.

Then with reference to the object-lenses for compound microscopes, from the date of Hooke's instrument (1665) to the end of the 18th century, plano-convex, or bi-convex lenses were used almost hap-hazard. In the few cases where a combination was attempted, the experiments seem to have been limited to the rude system of placing the plano-convex lenses with their convex surfaces as close together as possible; and even this improvement devised by Divini, and carried somewhat further by Christopher Cock, and by Grindl, led to no permanent advance—the suggestion died out.

If we examine a consecutive series of object-lenses produced during this period, we shall find Campani used a bi-convex lens placed loosely in a wooden cap, with a small central hole, which was screwed on the nose-piece, the lens accommodating itself to the axis without reference to any exact process of centering. In the Hooke instrument the nose-piece was a small cylindrical tube of brass, and the end was made slightly concave (perhaps accidentally); the lens was placed in the concavity, and a brass cap with a plane perforated end was slid over it. In Divini's a similar arrangement was adopted. Later on the lens was held in its cell by a sprung-ring, as in Marshall's, and the higher powers were mounted between two perforated concavities moulded in small cups of thin sheet silver or brass, the cups being held in the cells by sprung-rings; and this latter system was applied to the lower powers also by Culpeper, Cuff, Adams, Martin, Dollond, and others, the perforations in the plates serving as diaphragms, for the opticians soon found that with compound microscopes small diaphragms were essential to render the image tolerable to the eye. In the mean time, in England, and on the Continent especially, many compound microscopes were made with wood, ivory, or horn nose-pieces, in which the lenses were sometimes dropped and held by a sprung-ring, or on which perforated caps of similar materials fitted by screws. Whatever system was adopted, the result was that the lens had not the slightest pretence of being exactly centered. Towards the end of the century Martin, Adams, Dollond, and Jones, in England, and Dellebarre and others on the Continent, began to mount the lenses in accurately fitting cells, in some cases burnishing them in immovably, as was commonly done with achromatic telescope object-glasses. This latter plan was adopted also for the lenses of the eye-piece. There can be no doubt that the severe attention to accuracy of optical workmanship required for the successful production of achromatic telescopes had much influence on the microscope, especially in England, where the best opticians generally constructed both telescopes and microscopes.

As to the mechanical construction, no regular progress was made, and this was probably due (1) to the small number of microscopes manufactured, and (2) to the difficulty of communication, whence the opticians were informed of the improvements devised by their rivals by printed or oral descriptions only, and seldom had the opportunity of actually inspecting the instruments. The large body-tubes, with draw-tubes of the early constructions, imply that low powers were generally used; and conversely, as the body-tubes were diminished in diameter, higher powers were employed, for here the extra-large field would be useless so far as definition was concerned.

The fluctuations in the application or the omission of fine adjustments point to the fact that no pressing need was felt for delicate focussing; the extremely minute diaphragms applied to the object-lenses would account for this partially. And again, the fact that very little original and difficult investigation was attempted with the microscope—the majority of instruments serving for the merest *dilettanti* purposes only—would indicate that the instrument was seldom sufficiently familiarised to betray its weak points; hence the progress in the design was slow and intermittent. It may appear strange, but it is nevertheless true, that on examining the proboscis of a blow-fly with the Campani microscope (Fig. 12), which I believe was made before 1665, I cannot say that the image was inferior in definition, with equal magnification, to that given by microscopes by the whole series of makers preceding the general application of achromatism (1824-1830).

The application of achromatism infused new and vigorous life into the use of the microscope, and gave a great impetus to its development, both optically and mechanically, as we shall see.

ACHROMATIC MICROSCOPES.

I have already stated that B. Martin published the fact of his having constructed an achromatic microscope objective, and have cited from his "New Elements of Optics" (1759), the passage wherein he described the result of his comparison of the objective with a reflector giving the same magnification. It does not appear that Martin followed up the subject beyond the trials he then described, though in the same volume he promised to treat of the theory and practical construction of achromatic objectives for the microscope, and refers us to a later portion of his treatise, where we find the matter briefly alluded to (Part VI., p. 114) and dismissed.

Euler touched upon the theory of achromatic miroscopes as early as 1762, and in 1771 ("Dioptrica," Petrop., 3 vols., 4to), he dealt with the subject more fully. In 1774, his pupil and friend, Nicolas Fuss, published a small vol. ntitled "Instruction détailée pour porter les unettes . . . au plus haut degré de perfection . . . avec la description d'un microscope . . . le plus parfait dans son espèce" (St. Petersb., 4to), in which plain instructions were given whence any practical optician could construct an achromatic microscope. In 1778, Klügel translated Fuss's work into German ("Anweisung von Fernröhren," Leipzig, 4to), adding further notes and diagrams; and in his "Analytische Dioptrik" (Leipzig, 1778, 4to) the subject was treated of more distinctly from his own point of view.

With reference to fixing with accuracy the dates of the early applications of achromatism to the microscope, and the various modifications in the designs of the instruments issued by the different opticians, I have found so much evidence of inaccuracy among the early writers that, except in the cases where original references are cited, I give *all* other dates under reserve; for in the majority of instances every petty modification has been a subject of more or less controversy as to priority of invention.

Beeldsnyder's Achromatic Objective.—I have not been able to trace any practical outcome from Euler's, Fuss's, or Klügel's theoretical discussions of nearer date than the achromatic objective (Fig. 66) made by François Beeldsnyder in 1791 (*vide* Harting, *loc. cit.*, p. 132), which Harting presented to the Museum of the University of Utrecht. The combination consists of two bi-convex crown-glass lenses, with an interposed bi-concave flint lens; the focus is slightly less than 1 inch. The workmanship is inferior, and

FIG. 66.

BEELDSNYDER'S ACHROMATIC OBJECTIVE (1791).

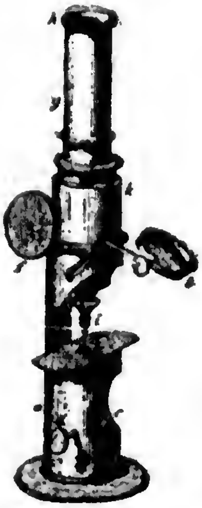
the definition leaves "much to be desired." If Martin's achromatic objective of 1759 was not better than Beeldsnyder's of 1791, I am not at all surprised that he was not encouraged to throw aside his older constructions in favour of achromatism.

Van Deyl's Achromatic Microscope.—Harting (*loc. cit.*, p. 133-4) figures and describes an achromatic microscope which was constructed by Van Deyl in 1807; the mechanism was similar to that of Jones's microscope (Fig. 62, p. 1068), except that Van Deyl applied a tripod base, and the pinion for focussing by the stage passed through the pillar and was actuated by a milled head at the back.

Between 1800 and 1810, M. Charles, of the "Institut," Paris, is said by C. Chevalier ("Des Microscopes," Paris, 1839, royal 8vo, p. 86) to have made small achromatic lenses, which were to be seen at the "Conservatoire des Arts et Métiers;" but Chevalier says they were so imperfect in workmanship that they could hardly have been used as microscopes.

Frauenhofer's Achromatic "Drum" Microscope.—In 1811, Frauenhofer is said (*vide* Harting, *loc. cit.*, p. 136) to have made achromatic doublets; but he does not appear to have been satisfied with them. Whilst his attention was engaged on the construction of microscopes, he modified Martin's later model of his "Pocket Reflecting Microscope" (*vide* my notes under this heading) by adopting eye-pieces of different power, and a condenser on two arms pivoted on the body-tube for illuminating opaque objects (Fig. 67); otherwise

FIG. 67.



FRAUNHOFER'S ACHROMATIC "DRUM" MICROSCOPE (1811).

the difference in the mechanical constructions was hardly distinguishable. Frauenhofer also attached the microscope on a box, thus rendering it more secure in use.

In 1815, Amici worked at achromatic microscopes, and abandoned them entirely in favour of reflecting instruments until after the publication of Fresnel's favourable report on the construction of Selligue's achromatic objectives, in 1824.

C. Chevalier, in his "Notes Justificatives" (Paris, 1837, 4to), gave a summary of dates relating to the early history of the achromatic microscope, from which I select those of which he probably had personal knowledge:—

(1.) In 1823-4, Messrs. Vincent and Charles Chevalier made an achromatic microscope with four doublet lenses superposed, according to the plans of Selligue, who exhibited it at the "Académie des Sciences" [on April 5, 1824].

(2.) In 1824-5, Messrs. Chevalier exhibited at the "Société d'encouragement" their improved "Microscope d'Euler."

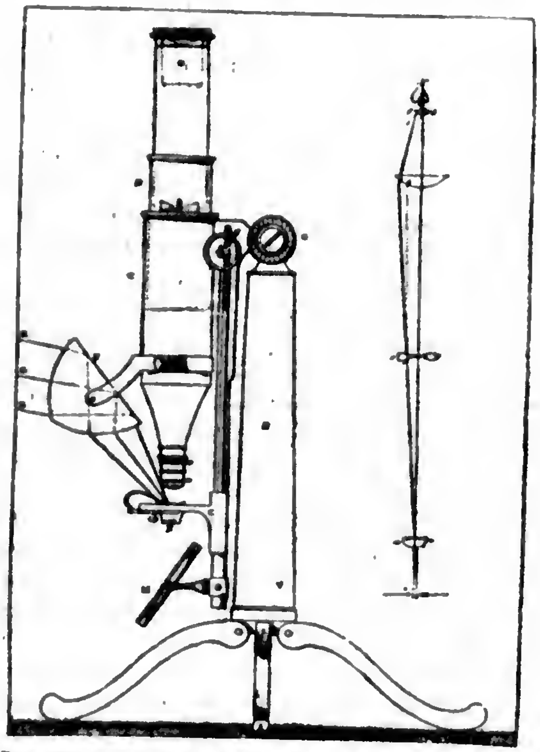
(3.) In 1827, Amici exhibited in Paris his horizontal dioptric microscope, the novelty of which was much admired. Amici applied a series of oculars, cameræ lucidæ for drawing, a movable object-carrier, and "very good" superposed achromatic objectives, but of longer focus than those of Messrs. Chevalier.

(4.) In 1827, a few months after Amici's visit, Messrs. Chevalier exhibited at the Louvre an "Amici" microscope of their construction, which was highly commended by Arago.

Selligue's Achromatic Microscope.—Selligue (1823) was the first to suggest the plan of combining two, three, or four plano-convex achromatic doublets of similar foci one above the other, to increase the power and the aperture, which plan was carried out for him by Messrs. Chevalier.

Fresnel, the eminent mathematician, was appointed to make a special report on Selligue's microscope (Fig. 68) to the "Académie Royale

FIG. 68.



SELLIGUE'S ACHROMATIC MICROSCOPE (1823-4).

des Sciences" (August 30, 1824). Fresnel states that he compared the objectives with those of one of Adams's best non-achromatic instruments (of which the lenses had been "re-touched" and improved by Selligue), and up to a magnification of "two hundred times" Selligue's was decidedly superior; beyond that limit Fresnel did not find the achromatic superior to the non-achromatic—"the contours of the images did not appear more indistinct than in the microscope of M. Selligue" (*vide* reprint of Fresnel's "Rapport, &c.," Paris, 1824, 8vo., p. 11). For prolonged observations Fresnel preferred Adams's microscope, because it gave a larger field than Selligue's; this defect in the latter instrument was due to the use of too small a diaphragm "above the objectives" (*ib.*, p. 15). Fresnel specially commended Selligue's plan of placing a small diaphragm between the mirror and the object at N; in one of the Selligue instruments I have examined, the diaphragm consisted of a plate with a graduated series of apertures sliding in a slot, as shown at N.

The mechanism of Selligue's microscope was similar to that shown in Fig. 63 (p. 1068), though Fresnel thought the English model superior (his comparison was with a microscope by Adams, whose model was practically indentical with that of Jones). The focussing was by rack-and-pinion, F, acting on the stage, the pinion remaining stationary and not travelling on the rack; which seems to have been a modification of one of Dellebarre's plans. Two draw-tubes, A and B, were applied within the body-tube, C, the upper one having a bi-concave lens, S (of which two of different powers were provided), at the lower end serving as an amplifier; this was, I believe, the first application of the "Barlow" lens to a microscope. A lenticular prism, P, was attached to a gimbal connected with a ring encircling the body-tube for illuminating opaque objects, which seems to have been a modification of Fraunhofer's plan of pivoting a condenser with two arms on the body-tube of his "Drum" microscope.

Fresnel states that the range of amplification was from 40 to 1,200 diameters. The objectives were composed either of two doublet systems for low-power work, or the four doublet systems were all screwed together for high-power work. The two amplifiers were used either separately or together, and two oculars of different power were supplied.

The diagram shows the path of the rays through the instrument. It should be noted that the convex (crown) was turned towards the object.

C. Chevalier states ("Des Microscopes," p. 87) that Fresnel was unaware at the date of his report that the objectives were constructed by the Chevaliers.

Chevalier's Achromatic Microscope (Euler's system).—Soon after the completion of Selligue's objectives, the Chevaliers found that better results were obtained by turning the plane side of the flint to the object; and in their improved "Microscope selon Euler" they carried out this modification. The mechanism was very similar to that of Jones's microscope (Fig. 63) except that the body-tube was attached to the stem directly, as in Selligue's, and not to an arm as in Jones's.

Tully's Achromatic Microscope.—In 1824, Tully, the well-known optician of London, was induced by Dr. Goring to work at achromatising the microscope, and his first constructions appear to have been at least equal to those of the Chevaliers. The increase of apertures Tully obtained by the achromatic system appears to have betrayed the need of better mechanism in the microscope, accordingly we find him devising sliding rods, similar to those in use with telescopes, to connect the body-tube with the feet, by which greater steadiness was secured; and he also applied mechanical movements to the stage.

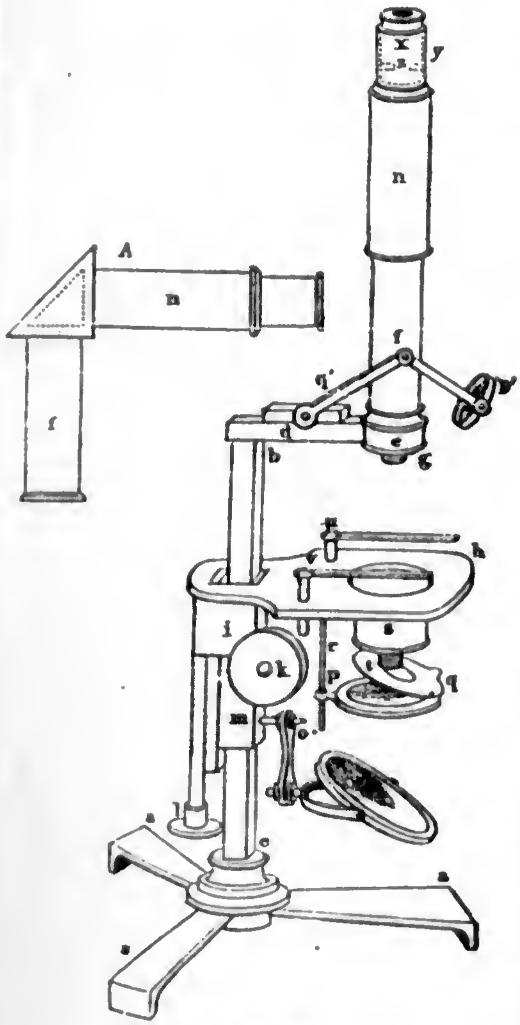
Amici's Microscope.—In 1827, Amici exhibited in Paris his horizontal microscope, in which he is said to have increased the apertures of his objectives by combining doublets with triplets. The point of novelty in Amici's construction was the application of a right-angled prism immediately above the objective, to deflect the rays through the horizontal body-tube. The great convenience of this arrangement—especially for microscopical dissections—was at once appreciated, and the Chevaliers hastened to adopt the model with many modifications.

Merz (1829), successor to Frauenhofer, also applied Amici's system of horizontal body-tube, by placing the right-angled prism in the middle of the body-tube, which modification was adopted by Amici later on.

Fig. 69 (p. 1075) shows one of Amici's constructions, which Harting states was made some years later. In examining a large number of Amici's microscopes, I have found much difficulty in assigning the probable dates. An apparent advance in design in Amici's instruments does not necessarily indicate that the construction was later. This model seems to have been modified from his very early dioptric constructions by the application of a fine adjustment, *l*, at the back acting on the stage, and by the adoption of Merz's plan of using the prism, *a*, in the middle of the body-tube, *f n*, instead of placing it immediately above the objective, as shown in the next Figure.

Chevalier's "Microscope Universel."—This instrument (Fig. 70, p. 1076) was brought out by Charles Chevalier in 1834, shortly after he started a separate establishment from that of his father. He here combined Amici's reflecting microscope with his own dioptric system, together with a number of improvements—especially in workmanship—by which the construction was carried quite beyond the point reached with any microscope of earlier date. The design embodied so many combinations, that the title of Universal Microscope was more justly applied to it than to any of its predecessors, including the Large Universal of B. Martin.

FIG. 69.



AMICI'S MICROSCOPE.

Fig. 1 shows the instrument arranged as a horizontal microscope. The right-angled prism for deflecting the rays into the horizontal body-tube, R, is within the angle-tube, V X. The coarse adjustment is effected by rack-and-pinion, O, to the stage, and a fine adjustment screw, Q, with ball-socket bearings, is also applied to the stage by means of an extra slide in front. The mirror (plane and concave) racks on the stem by the pinion, N. The stage has rectangular motions, actuated by mechanism similar to that known in England as the "Turrill" system. The body-tube pivots laterally at *a*, to facilitate changing the objectives; the draw-tube, T, is moved by a rack-and-pinion at U. In *Fig.* 2 the angle-tube, V X, containing the prism is removed, and an adapter, V, is substituted, in which the objective, Y, is screwed, then the body-tube is raised to the vertical by means of the hinge, *c*, and on removing the pin, G (*Fig.* 1), the instrument can be inclined on the cradle-joint on the top of the pillar. *Fig.* 3 shows the adaptation of the horizontal body-tube for the observation of chemical reactions, &c.; the angle-tube, V X, is turned upwards, and an extra stem carrying the rack stage, *l*, the mirror, *g*, and the rotating disc of diaphragms, *h*, is applied by a socket, *d*. *Fig.* 3 *bis* shows the application of a stage, *l' l'*, carrying a disc of glass, O, to be heated by the lamps, *m m*, also for the observation of chemical reactions, &c. *Fig.* 4 shows the ordinary dioptric arrangement of *Fig.* 2, but inclined to the horizontal, and a powerful compound condenser, *s s'*, applied to rack on the stem. In *Fig.* 5 we find a condensing lens, M, on jointed arms, connected with a socket, *d*, sliding over the tube, X, for illuminating opaque objects. In *Fig.* 6 a silvered glass "Lieberkühn" is shown. In *Fig.* 7 polarising and analysing prisms are shown. *Fig.* 8 shows the combination of the body-tube with Amici's reflecting microscope, the tube, I I', carrying the speculum and Lieberkühn (2); 3 3 is an object-carrier applied on the stage to bring the objects close to the tube. *Fig.* 9 is the condenser (*p* of *Figs.* 1 and 2) with disc of diaphragms.

This microscope was directly traceable to the application of achromatism. Chevalier applied numerous pieces of accessory apparatus to the instrument, such as a screw stage-micrometer, eye-piece micrometer, a series of different eye-pieces, compressoria, &c. Independently of the diversity of the movements, the whole mechanism evidences care and precision, entitling Chevalier to high praise.

Chevalier's Simple Dissecting Microscope.—Charles Chevalier modified Ellis's "Aquatic Microscope" as we see in Fig. 71. He applied rack-work focussing to the lens-carrier, and a gimbal and sliding socket to the mirror (plane and concave); his principal improvement was the rotating disc of diaphragms fitted beneath the stage.

This microscope was brought out as a "counterblast" to the "modèle Raspail." In later constructions Chevalier added horizontal screw-mechanism at *b*, passing through the arm-support of the lens-carrier, which was also pivoted at *b*, to facilitate the examination

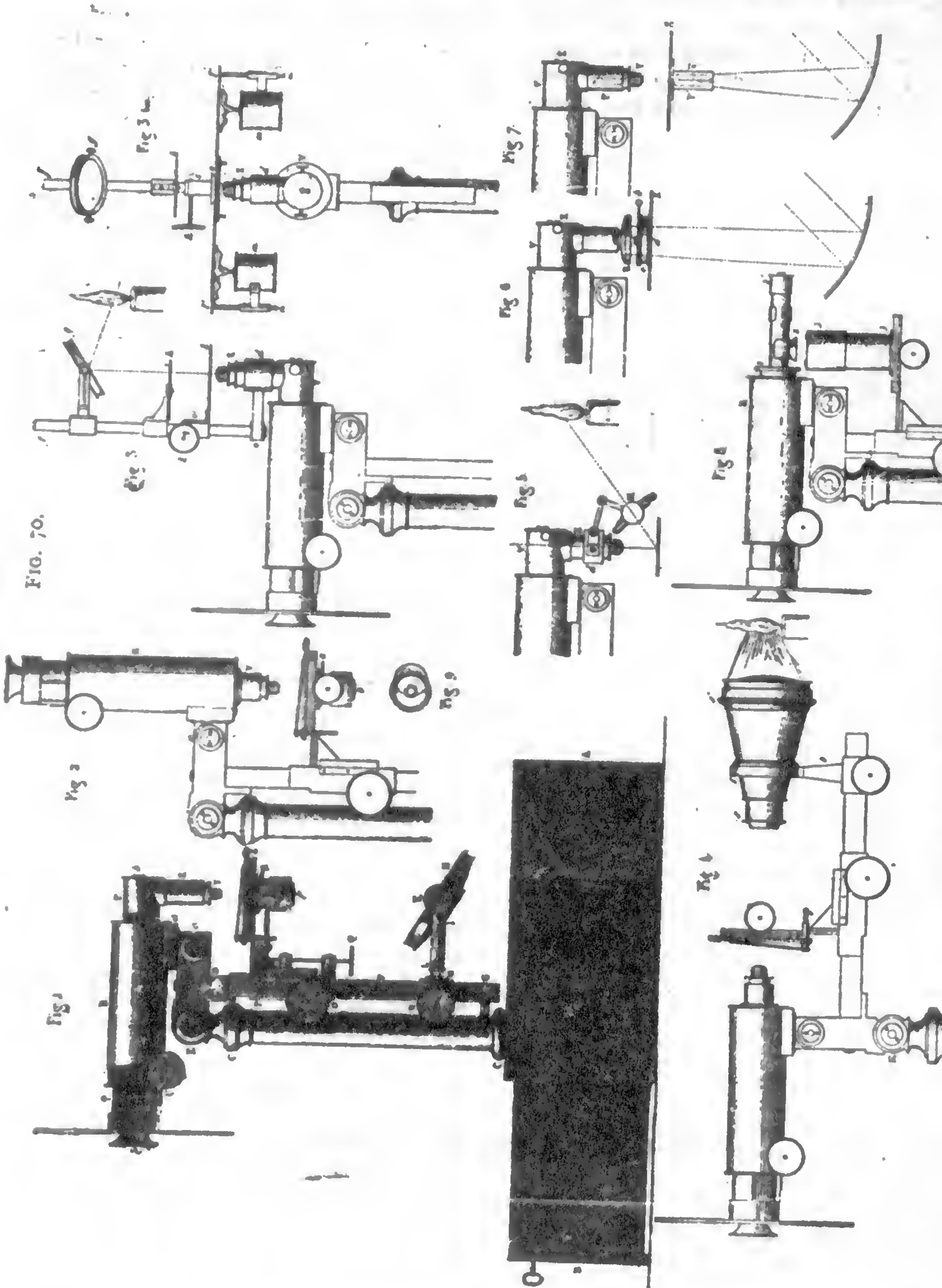


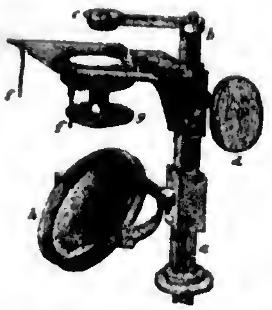
FIG. 70.

C. CHEVALIER'S "MICROSCOPE UNIVERSEL" (1833-4).

of different parts of the object. The modifications applied to this form of microscope by different makers in Paris were the subject of much controversy. The fact, however, is clear that, after having alluded to the "modèle Raspail" as a mere copy of Cuff's, Chevalier adopted the model, and improved it in many important points.

Andrew Ross improved upon Chevalier's model, by applying a fine adjustment for focussing, which was much needed when doublets and triplets of 1-20 inch focus were employed.

Fig. 71.



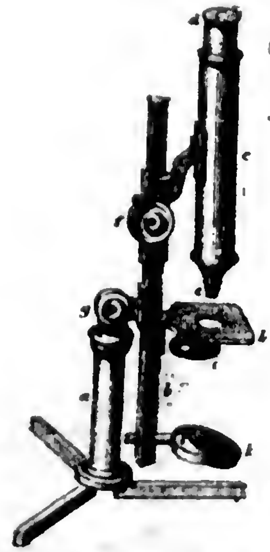
Chevalier's Simple Dissecting Microscope.

Between 1820 and 1835 the English opticians, Tully, Pritchard, Dollond, Andrew Ross, and Powell, encouraged by the advice of Wollaston, Brewster, Goring, and others, worked out innumerable combinations of single and compound lenses to be used as simple microscopes. In some cases lenses were made of sapphire, spinel, and diamond, which Brewster and Goring seemed to think would supersede all other forms of single lenses, or even achromatic combinations, for simple microscopes, by reason of the greater working distance their higher refractive indices gave with equal magnification. Pritchard devoted special attention to these "jewel" lenses, carrying the focus as high as 1-100 inch; but the difficulties of manufacture were so great compared with the production of glass lenses, and their general utility was so small compared with that of compound microscopes, that they were abandoned.

Schick's Microscope.—About 1828 1835, Schick, of Berlin, and Plœssl, of Vienna, and Pistor, carried out the general form of microscope shown in Fig. 72. The body-tube here travels by means of an arm and rack-and-pinion socket on a stem of triangular section, on which the stage and mirror are also carried. In some cases a fine adjustment was applied to the stage after the design of Cuff's, or again to the travelling-socket—systems more or less complicated, and persevered in, as it would seem, from sheer unwillingness to abandon obsolete forms of mechanism.

The stem, however, may have suggested to Andrew Ross some of his earliest designs of large microscopes, in which he mounted the body-tube, stage, and mirror on a bent stem (bent to provide space for a large stage), carrying the body-tube on the upper part and the mirror on the lower part, so as to be on the same axis, which construction preceded, I believe, the suggestion of a similar design by Jackson.

Fig. 72.



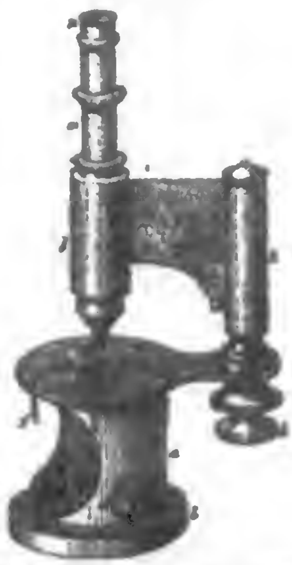
Schiek's Microscope.

Oberhaeuser's Compound Dissecting Microscope.—About 1830, Oberhaeuser, in conjunction with Trécourt and Bouquet, brought out the instrument shown in Fig. 73 (p. 1078). Oberhaeuser's design was evidently based on that of Frauenhofer's "Drum" microscope (Fig. 67), but the modifications and improvements were so great as to overwhelm Frauenhofer's slight modifications of Martin's original constructions of the last century; so that Chevalier's attempt to fix upon Oberhaeuser the charge of being a mere plagiarist is absurd—hardly needing consideration.

The application of the socket-support, *l*, for the body-tube, and bracket, *i*, connecting it with a second socket, *h*, mounted as a sheath on a pillar through which a fine adjustment screw, *k*, acted for focussing, was in itself an improvement of first-rate importance; Oberhaeuser, however, combined this improvement with another equally important one, by mounting the pillar on a plate made to rotate on the optic axis on a drum-base, and serving as the object-stage—a combination of improvements in the mechanical design of the compound microscope entitling Oberhaeuser to a conspicuous place among the inventors who have sought to perfect the instrument.

For the purpose intended, *i.e.*, as a compound dissecting microscope, no instrument of previous date was made at all comparable with this of Oberhaeuser's for convenience. The stage was so well supported that the dissecting operations could be observed without the slightest trace of flexure or tremor, even with the hands resting on the edge; whilst the convenience of rotating the object so as to view each part most favourably, and without lateral movement in the field, must

Fig. 73.



Oberhaeuser's Compound Dissecting Microscope (1830 ?).

have presented itself as a new and most important advance to the microscopists of that date. The success of the model was, I believe, quite unprecedented in the history of the microscope. The design was copied by the Ingénieur Chevallier, Lérebours, Soleil, and Nachet, senior, with modifications principally with reference to the mechanism of the sub-stage; in some cases the sub-stage was mounted in a gimbal actuated by a lever, in others a rack-and-pinion movement was applied, and here and there more convenient means were applied for changing the cylinder-diaphragms or the condenser. Prisms were occasionally applied to the body-tube either to form a horizontal arm or to be more or less inclined. Rack-and-pinion movement was applied to the body-tube by Oberhaeuser in addition to the sliding socket; and a similar movement to the draw-tube (first devised, I believe, by Dr. Cuno Fischer, of St. Petersburg) made a "pancratic" arrangement.

Hartnack's Microscope (Oberhaeuser's form).—The substitution of the horse-shoe base and pillar (Fig. 74) for the drum-base of Oberhaeuser's model was, I believe, carried out by Hartnack, Oberhaeuser's nephew, and was evidently devised to facilitate the use of oblique light. With the drum-base the mirror remained in the axis, and thus could not be used to provide oblique light beyond a

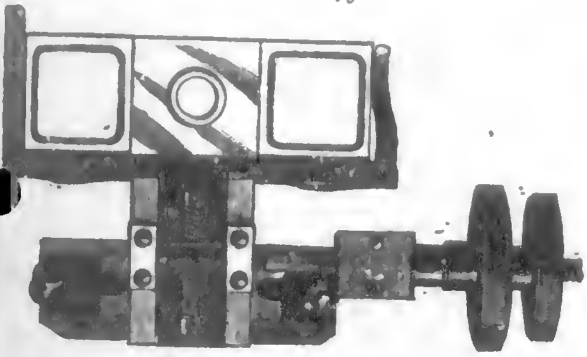
Fig. 74.

Hartnack's Microscope (Oberhaeuser's Form).

few degrees from the axis, depending on its size and focus; but the horse-shoe base allowed the mirror to be swung on a pivoted arm sliding in the pillar, which was, of course, an improvement. The cylinder-diaphragms or a condenser were contrived to fit in a sliding sub-stage, with a cylindrical socket which can be centered to the optic axis by the optician, but which the amateur adjusts with much difficulty. In the early models of this design the focussing-screw remained, as before, at the lower end of the pillar, and then the microscope could not be inclined; Hartnack moved the actuating milled head to the top of the pillar, so as to permit the application of a horizontal axis to the upper ends of the pillars on which the body-tube, stage, and tail-piece could be inclined.

This form of microscrope has been generally adopted on the Continent, and is known as the "Continental model." As a working instrument, the general design is, in my opinion, the most serviceable extant. That the mechanical arrangement is susceptible of improvement, I have no doubt; for example (1), the base is not safe when the stage and body-tube are inclined (which difficulty has been met by Nachet and Zeiss, and others, by extending the base behind the pillar supports); (2) the sub-stage should be applied to the tail-piece with rack-work and centering arrangements, on the plan adopted in the better class of English microscopes; (3) the fine adjustment screw is far too rapid in action for high powers; (4) a convenient mechanical stage is needed, that can be readily applied or removed (my next Figure shows a design I have suggested for this purpose).

Fig. 75.



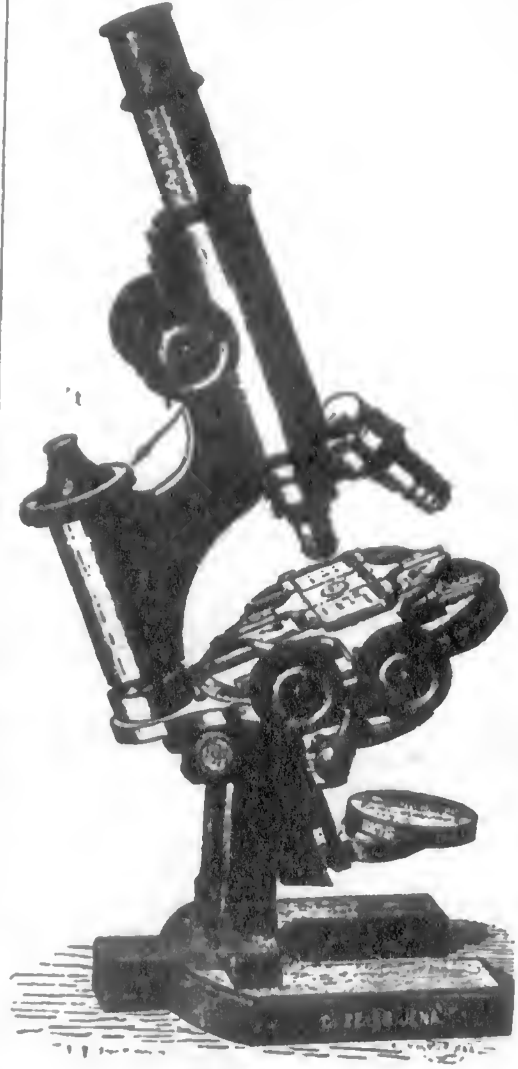
Mayall's Mechanical Stage.

Mayall's Mechanical Stage.—The aim of this device is to provide mechanical movements for the object-slide, without the use of travelling plates. The slide is placed on the surface of the stage (in the Oberhaeuser form, or on the rotating stage-plate of the usual English model), being held in a hinged frame connected with the mechanical movements.

The apparatus is shown in Fig. 75, as made by Swift and Son; it is attached to the surface of the stage by the milled-head screws shown at either end of the lower part. The curved arm on the right, and the straight arm on the left, are hinged with sprung fittings like the blades of a pocket-knife. As the slide lies in contact with the surface of the stage (or of the rotating stage-plate), the flexure that is found more or less in every form of mechanical stage, acting by one or more superposed plates, is obviated.

In practice I have found it advisable to gum a narrow strip of paper near the ends of the under surface of the glass slides, to remedy the inconvenience due to any unevenness of surface.

Fig. 76.



Zeiss's Microscope.

Zeiss's Microscope.—In several points of detail the mechanism of Zeiss's microscope (Fig. 76) is superior to Hartnack's, while the application of Abbé's condenser has added to its general efficiency, especially for oblique illumination. In Zeiss's latest models mechanical movements are applied to the stage, as here shown.

Nachet's Microscope.—In this latest model

(Fig. 77) M. Nachet claims to have much improved on the older forms of fine adjustment used with the "Continental model," by reversing the action of the spiral-spring. It is now arranged to draw the sheath connected with the body-tube *downwards*, instead of pushing it upwards as formerly; by this alteration the fine adjustment screw con-

Fig. 77.

Nachet's Microscope.

trols the movement by the contact of its point with a hardened steel-plate, greatly reducing the friction, whereas formerly the screw passed through the nut on the top against which the spiral spring pressed upwards, causing much friction.

The *sub-stage* is centering, and, to change the condensers, &c., can be turned away from the axis of the body-tube on a pivot, which can also be removed when required, being attached to a short arm sliding in grooves in the tail-piece, and controlled by a lever. The pivot contains a slow motion (by screw), allowing the sub-stage condenser to be focussed exactly on the object.

The *mirror* is attached by a series of short arms with three articulations acting at right angles to each other, so that it can be moved in all directions for oblique illumination.

Mechanical movements are applied to the stage, and M. Nachet has devised a special arrangement of small mirrors, by which the approach of the objective to the cover-glass can be readily seen—a matter of importance to those who use high powers only occasionally.

Figs. 53, 54, 56-65 are reproduced from the works cited; Fig. 55, from Quekett's "Treatise on the Microscope" (above-cited), p. 27; Figs. 66 and 75 were photographed on the wood-blocks from the instruments; Figs. 67, 71-73 reproduced from Hannover's Treatise "On the construction and use of the Microscope," English trans. by John Goodsir, F.R.S.E., Edinb., 1853, 8vo.; Fig. 68, from the Plate in the above-cited reprint of Fresnel's "Rapport, &c.;" Fig. 69, from Harting's "Das Microskop" (above-cited), iii., p. 169.

ELEMENTARY LECTURES.

ELECTRICITY.

By Professor George Forbes.

Lecture V.—Delivered May 15, 1886.

In my last lecture I commenced by showing you the remarkable experiment which was made by Professor Oersted, of Copenhagen, and I proceeded to tell you that nearly all the phenomena of electro-magnetism, which have been the foundation of the great progress in electrical science and its applications since that date, could have been deduced from that experiment of Oersted. Oersted's experiment has been spoken of by some as having been an accident. At the moment that he saw the influence which a wire carrying a current had on a magnet he was trying to detect the influence in a totally different manner, he was trying to detect the influence of the heat generated upon the magnet, but instead of that he found the remarkable result which formed the basis of our demonstrations in the last lecture. It has been said by some that Oersted's experiment was the result of an accident, but I protest against any such interpretation being put upon it. It shows a comparatively feeble knowledge of the means of progress in scientific discovery. It is by such constant labour, and the readiness to grasp the importance of unexpected phenomena that present themselves, that the greatest discoveries have been made. Were we to say that the philosopher studying in his laboratory at numerous experiments, when he first happens to come across something he had never found before, and tests it, and finds it to be a new fact—were we to call that an accident, then forsooth we should have to say that the discovery of the planet Uranus was an accident, that the discovery of the many continents and islands of the world, and half the discoveries of philosophers in their laboratories, have been accidents. As the result of that brilliant discovery of Professor Oersted, we saw last week that several conclusions could be drawn. The continuous rotation of a magnetic pole round an electric current, the motion of a wire carrying the electric current in the neighbourhood of a magnet, and the attraction or repulsion of two parallel currents according as they were in the same or in opposite directions, these discoveries of Faraday and Ampère are the necessary conclusions from Oersted's experiment. At the same time that does not detract in the least from the originality or the merit of these great men who followed out the experimental work, and proved the truth of these facts which were new to science. And so it is in the present day; frequently we find new discoveries which, upon investigation, are found really to be deducible from what we knew before, but that in no way detracts from the merits of those investigators who by their laborious researches have introduced facts which were new at the time to science, and especially is this the case in electrical science. Frequently we have new facts presented to us—facts which none of us before have been acquainted with, and it is common to say, "Oh, such facts are perfectly deducible from the theory of electricity." That may be so, but it does not in the least detract from the value of these new researches.

I will, with your permission, before going on to the question of induced currents, which is a mere continuation of the deductions which were made from Oersted's experiment, illustrate the subject of the last lecture by means of a different apparatus—a piece of apparatus of great beauty, and one which with the same

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Proceedings of the Society.

CANTOR LECTURES.

THE MICROSCOPE.

By John Mayall, Jun.

Lecture V.—Delivered December 21, 1885.

Achromatic Microscopes (Continued).

I have said that the application of achromatism to microscopes by Tully, in England, appears to have at once shown the need of better mechanism, and that he commenced the improvement by applying steadying rods to the body-tube, and mechanical movements to the stage. Then, as the apertures of the objectives were increased, and the focal planes became correspondingly shallower, it became necessary to apply a more sensitive system of focussing than any previously employed.

Cuff's system of a direct-action screw moving the socket-support of the body-tube, which Martin adapted to act on the socket-support of the stage, fell into disuse for compound microscopes, and during many years was superseded by the rack-and-pinion motion variously applied. The Cuff-Martin system was still used as far as the early years of this century for simple microscopes, such as Jones's "Pocket Botanical and Universal Microscope," where two or three single lenses were pivoted on a pillar, to act singly or together over a stage and mirror, which differed from Ellis's Aquatic Microscope only in minor points, contrived specially to render the instrument more portable.

In Cuthbert's Reflecting Microscope we saw the Cuff-Martin focussing screw applied to the stage; and in Chevalier's "Microscope Universel" a similar, though improved, arrangement was employed; and in Schiek's microscope, Pistor's, and Ploessl's, I have stated that inferior plans, somewhat similar, were persisted in during several years, when far more accurate and better focussing systems were generally known.

On the Continent, the direct-action screw seems to have found much favour, and it would not be difficult to select from the microscopes that are known a series directly converging to the plan employed by Oberhaeuser; but we have other matters to engage our attention.

In England, the Cuff-Martin focussing screw was not much used with achromatic microscopes; indeed, it may be said to have died out with Cuthbert's Reflecting Microscope. Our opticians began by improving the rack-work, so that great precision of focussing movement was thus attained, a precision which has, on the whole, been steadily maintained down to our own time, and which the American opticians—judging from the rack-work of Tolles, Zentmayer, Grunow, Bulloch, Bausch, Lomb, and others that I have examined—have at least equalled. But, however well the rack-work was made, still more sensitive means were required for focussing, and the opticians attacked the problem with much energy. An immense number of devices resulted, some of which are bizarre in the extreme as well as ingenious; in others the ingenuity has been tempered by distinctly practical aims, and in a very small minority of cases the practical aims have been so well supported by mechanical skill and experience, that great success has been attained.

Among the bizarre contrivances for fine adjustment, there is one arrangement which I notice on account of its singularity, and because it is one of the most recent, and devised in the face of our modern systems as if in defiance of all the experience, optical and mechanical, of which we stand possessed; I allude to D'Arsonval's system of water focussing, where the fine adjustment is effected by pumping more or less water into a specially arranged body-tube. Other bizarre systems have consisted principally in the applications of cat-gut to actuate the mechanism, or, again, of levers of extraordinary length acting on the body-tube, causing it to tilt towards or from the object. This latter system has had (and still has) its equivalent in systems employed by Amici, and Nobert, and others, where the stage has been made to tilt upwards or downwards, *i.e.*, obliquely in relation to the optic axis, by the action of a screw, the upward motion being sometimes due to the spring of the bent stage-plate itself (as in one of Amici's models), or to a spiral-spring raising the stage-plate on a hinge; and in some cases —notably in Nobert's model—the stage was suspended on two points serving as pivots, and a lever beneath, acted upon by a screw passing through the pillar, caused the upward motion, the reverse motion acting by gravity alone, so that, in practice, the position of the microscope was intended to be vertical only. These and analogous contrivances were mostly designed to economise the expense; from any other point of view they cannot be approved.

A less objectionable plan was devised (by Oberhaeuser, I believe, but I have met with it in microscopes of early date by C. Chevalier, and by Pritchard—in the latter case bearing strong evidences of Chevalier's workmanship), where the stage-plate was raised or depressed at right-angles to the optic axis, by a direct-acting screw, with or without the combination of a spiral-spring encircling it within a sheath.

Our earliest real designers of fine adjustments for the compound achromatic microscope, James Smith, Andrew Ross, and Hugh Powell (I purposely exclude Cornelius Varley, for, in my opinion, most of his contributions to the mechanism of the microscope bordered so much on the bizarre, that their influence has rather retarded than advanced the best points of construction), seem to have been undecided as to the best position for the fine adjustment; hence we find very early, and apparently contemporaneous, efforts made to apply the movement to the nose-piece by a conical-ended lifting screw, and to the stage by means of a moving frame with three wedges, acted upon by a screw, variously placed (for which mechanism Powell was awarded the Silver Isis Medal by the Society of Arts in 1834). Or, again, modifications of Oberhaeuser's system were tried, either by a screw acting directly on the sheath-support of the body-tube, or in combination with a short lever at the back, or the screw passed through the tail-piece, and the actuating milled head was at the end. In these latter modifications Powell does not seem to have taken part; his best early models had the fine adjustment applied to the stage, as I have noted, and it is only justice to him to admit that, as a focussing movement, his mechanism acted with great precision—a precision hardly surpassed at the present day.

At this early period the best microscopes were made of what would now be regarded as unwieldly size—veritable monuments of mechanism. Smith and Ross built up their great models without any apparent intention of simplifying the movements. We find mechanical stages of six or eight inches diameter, and two or three inches in thickness, with controlling pinions projecting horizontally two or three inches laterally, or at the back, or shortened somewhat, and applied vertically beneath by means of brackets or angle-pieces, the arrangements defying description. In some of Powell's models we find his "Turrell" stage-mechanism with two screw stage-micrometer movements acting at right angles, and the focussing movement all combined in one stage.

I cannot determine who first applied the fine adjustment to the nose-piece. I have met with very early models by Powell, with a conical-ended screw lifting the nose-piece by the contact and movement of the coned surface; and he appears to have tried various positions for the actuating screw, placing it even near the eye-piece. Ross appears to have tried the plan now known as "Jackson's" fine adjustment earlier than 1835, according to the recollection of some opticians I have met, who were connected with the manufacture of microscopes at that date; and he appears also to have mounted the socket-carrier of the body-tube on a strong stem with rack, bent in the middle to provide space for a large stage, and continued beneath the stage, in a manner quite analogous to that known as the "Jackson" form.

It seems to be generally admitted that Ross devised the plan of carrying the body-tube on the end of a hollow cross-bar on the top of, and at right angles to, the rack-stem, which was planned to enable him to use his system of fine adjustment consisting of a fine screw with large milled head, acting by a point on the long arm of a lever, the short arm of which ends in a fork in contact with a stud on either side of a cylindrical sliding-tube, forming the nose-piece of the body-tube in which the objectives are screwed; a spiral-spring presses down the nose-piece, and it is against this pressure that the screw and lever act.

This system appears to be the first really sensitive focussing applied to the nose-piece; and it was, and probably still is, the most delicate system ever applied to the microscope. It has had a long period of popularity, and it still survives applied to Powell and Lealand's microscopes, which are generally considered, by experts in the use of the microscope, to stand alone in their excellence for all purposes where extreme exactness and delicacy are needed.

The rival system of fine adjustment—the short lever and screw applied externally to the body-tube—known as the "Jackson" system, which seems to have been contrived to allow the body-tube to be supported more substantially on the limb or stem, has had its merits ably realised in the microscopes of Smith and Beck and their successors, and by Tolles, of Boston, and, except as modified by the present firm of Ross (Schroeder's form, which we shall examine later on), I believe the consensus of opinion among the experts in manipulation is that it has been superseded by other plans applied to the "Jackson" form of microscope.

As I could not illustrate the various phases of the development of these fine adjustments without far more time and space than could be properly assigned for the purpose, I have thought it advisable to pass over this period with these general remarks, and come at once to the best typical example evolved by the combined efforts of Ross and Powell, and shall, therefore, ask your attention to Powell and Lealand's microscope; premising, however, that it represents not only the best points of construction devised by Andrew Ross, but other and better points added or modified by Messrs. Powell and Lealand. We shall examine several phases of construction of the "Jackson" form later on, and compare them incidently with this microscope.

Powell and Lealand's Microscope.—In this instrument (Fig. 78, p. 1098) we have a broad tripod base, forming the most substantial support ever devised for a microscope without unduly increasing the weight; the position of the horizontal (inclining) axis is such that the balance of the instrument is well maintained from the vertical to the horizontal.

The coarse adjustment is effected by rack on a large prismatic stem, moving within a sheath or box through the front of which passes the horizontal axis; on the top of the stem is attached the cross-arm carrying the body-tube—the cross-arm enclosing the lever-mechanism for the fine adjustment, as devised by Andrew Ross. This cross-arm is much longer than that used by Ross, and thus carries the body-tube more forward, so as to provide radial space for the complete rotation of the stage on the optic axis, while, at the same time, the lever of the fine adjustment is lengthened, and greater delicacy of motion is secured without rendering the actuating screw or other parts of the focussing mechanism too fragile for long service.

The stage has mechanical movements on the "Turrell" system, which Powell first constructed for Edmund Turrell, and for which the Society of Arts awarded a medal in 1832; it also rotates completely on the optic axis by means of an obliquely placed pinion acting on a bevelled rack on the inner face of the stage-ring, supporting the mechanism. "Finders" are engraved on the plates, and the main support of the stage-ring is graduated for angle measuring, a pointer on the ring marking the amount of motion in arc.

The sub-stage is carried by rack-work, and has rectangular centering movements, supporting an inner socket that can be rotated by rack-and-pinion, in which sub-stage apparatus is placed. In the latest models, a fine adjustment by screw-cone and stud is applied by means of an extra slide in front of the rack slide.

The mirror (plane and concave) is mounted in a half-gimbal, with two arms and a socket sliding and rotating on the tail-piece, and a clamp-screw fixes it where required.

The stage is attached to the sheath of the stem by a special arrangement of screws, by which the rotation in the optic axis can be centered; and sliding spring-clips, and a removable and adjustable angle-piece to hold the slides, are applied on the upper surface.

The body-tube is pivoted to move laterally on the top of the stem, and an adjustable steel stud beneath serves to stop the movement in the axis.

In venturing to note upon what I consider to be points where improvement might be made in the design of this microscope, I feel that I must be—

> ". . . . careful of my motion,
> Like the skater on thin ice that hardly bears him,"

for it represents the result of nearly fifty years steady devotion to the perfecting of the instrument by Powell and Lealand, embodying at the same time the best ideas of mechanism and design by Andrew Ross.

I find the mechanism of the stage movements always in a condition of flexure, due to the system of superposed plates sliding in grooves; and I think some such system as that I have suggested (Fig. 75, see *ante*. p. 1079) would get rid of the flexure, especially if the surface of the rotating stage-ring were of glass, without in any way diminishing the command over the movement of the object-slide. By dispensing with the moving plates, the thickness of the stage would be considerably reduced, and the arrangement would be available for supporting some useful form of oblique illuminator — preferably on the homogeneous-immersion system—not needing other adjustments than could be easily combined with its own fitting; or again, allowing the ready application of a simple system of graduated

Fig. 78.

Powell and Lealand's Microscope.

diaphragms, stops, &c., to be used *above* the sub-stage condenser.

Before we come to the other English and American microscopes designed to compete with Powell and Lealand's as instruments of the highest class, I must note that they have all been very considerably influenced by the construction of Zentmayer's "Centennial" Microscope, exhibited at the Philadelphia Exposition, in 1876, in which the tail-piece was arranged to swing laterally on an axis, in a line cutting the optic axis in the plane of the object on the stage. Zentmayer's idea was, I believe, quite original so far as he was concerned, though, in fact, it was a revival of Jones's system, shown in Fig. 64. Singularly, too, the idea had been realised in a different manner by the late Thomas Grubb, in a microscope he devised in 1853, patented in 1854, and which he improved in 1858, and described firstly in vol. v. of the "Proceedings" of the Royal Irish Academy, and secondly (the improved form) in a paper communicated to the Royal Dublin Society, 26th March, 1858.

Grubb's Sector Microscope.—In this microscope (Fig. 79) the principle of radial illumination was shown in the application of a grooved sector, H *h*, in which the lenticular prism, E, is moved by hand through any required arc concentric with the object on the

FIG. 79.

GRUBB'S SECTOR MICROSCOPE.

stage, so as to provide illumination at all obliquities in altitude: the rotation of the toothed wheel, L, by means of the pinion and milled head presenting the object to the illumination in all azimuths.

I is the stage; *i i*, upper and lower milled rings, which produce, on being turned by hand, the slow motions in two directions of the object-plate of the stage.

M is a dovetailed slide carrying both stage and sector, with the illuminating prism. A screw and its bent lever (the latter passing to the back of the instrument) are partially shown at N; and at O is a spiral-spring which keeps the slide, M, in close contact with the screw, N. The body-tube is mounted in a centering ring controlled by the screws, P P.

This microscope appears to have passed

almost wholly unnoticed in England until about 1880. As a working instrument, I should say there are very few points in it that would now commend themselves for imitation. In my opinion, however, for the purpose of radial illumination, Grubb's sector is a more serviceable system than that employed by Zentmayer. With the sector, the adjustment of the illumination can be effected without causing the image to sway about in the field, because the illuminator is practically free from contact with the stage; but with Zentmayer's swinging tail-piece, suspended, as he devised, on a tubular sheath through which the conical axle-support of the stage passes, every touch on the mirror or substage is translated into unsteadiness in the image.

Zentmayer's "Centennial" Microscope.—This microscope (Fig. 80, p. 1101) was contrived by Zentmayer, of Philadelphia, to provide greater facilities for oblique illumination, by mounting the sub-stage and mirror or arm suspended as I have just described.

The fine adjustment is effected by means of a second slide, behind the slide of the coarse adjustment, which is acted upon by a lever (within the bent limb) and screw. This system of fine adjustment which acts sensitively only in the vertical direction, and does not respond to the backward motion of the screw where the instrument is inclined to the horizontal—the downward motion acting by gravity only—was employed by Grunow, in a microscope which I examined more than ten years ago, and which had then been made several years. The principle of making the delicate-fitting slides of the fine adjustment bear the weight and rough usage of the "Jackson" coarse adjustment, seems to me wholly defective. No arrangement of this kind that I have examined would bear any critical testing.

As to the particular mechanism of the swinging tail-piece contrived by Zentmayer, I have already said that I regard it as inferior to Grubb's sector arrangement.

With this microscope, Zentmayer supplied two extra stages, one with mechanical and rotary movements, the other of special thinness, with rotary movement only, for diatom work. The workmanship is excellent, as also that of the "Tilghman" friction-stage shown in the figure. The mechanical stage, however, is so contrived that the rotating plate is mounted on the top of the plate actuated by the mechanism of the rectangular movements, so that the rotation has no direct correspondence with the optic axis; that such an arrangement should have been devised for a modern instrument entering the lists as a first-class miscroscope, is another item which I cannot approve.

Bulloch's "Congress" Microscope (second form).—In this instrument (Fig. 81, p. 1102) Bulloch improved upon Zentmayer's design, by attaching the stage to the limb by an angle-piece, so as to be free from the tail-pieces, of which two are applied, one for the sub-stage, and one for the mirror.

The arrangement for carrying the lamp, so that the illumination can be moved concentrically with the object on the stage should be compared with that shown in Jones's Radial Swinging Tail-piece (Fig. 64).

Bulloch modified Zentmayer's fine adjustment by applying a box-fitting to the slide, and by adjusting a spiral-spring to give the downward motion; but the arrangement is utterly vitiated by carrying the coarse adjustment on the front of the delicate slides of the fine adjustment.

Tolles's Microscope with Vertical Disc.—In this microscope (Fig. 82) Tolles mounted the stage on a disc, the centre of which corresponds with a line cutting the optic axis in the plane of the object on the stage. Near the edge of the disc the substage travels in a groove, carrying the condenser in arc round the object as a centre, in a manner analogous to that shown in Grubb's Sector Microscope (Fig. 79).

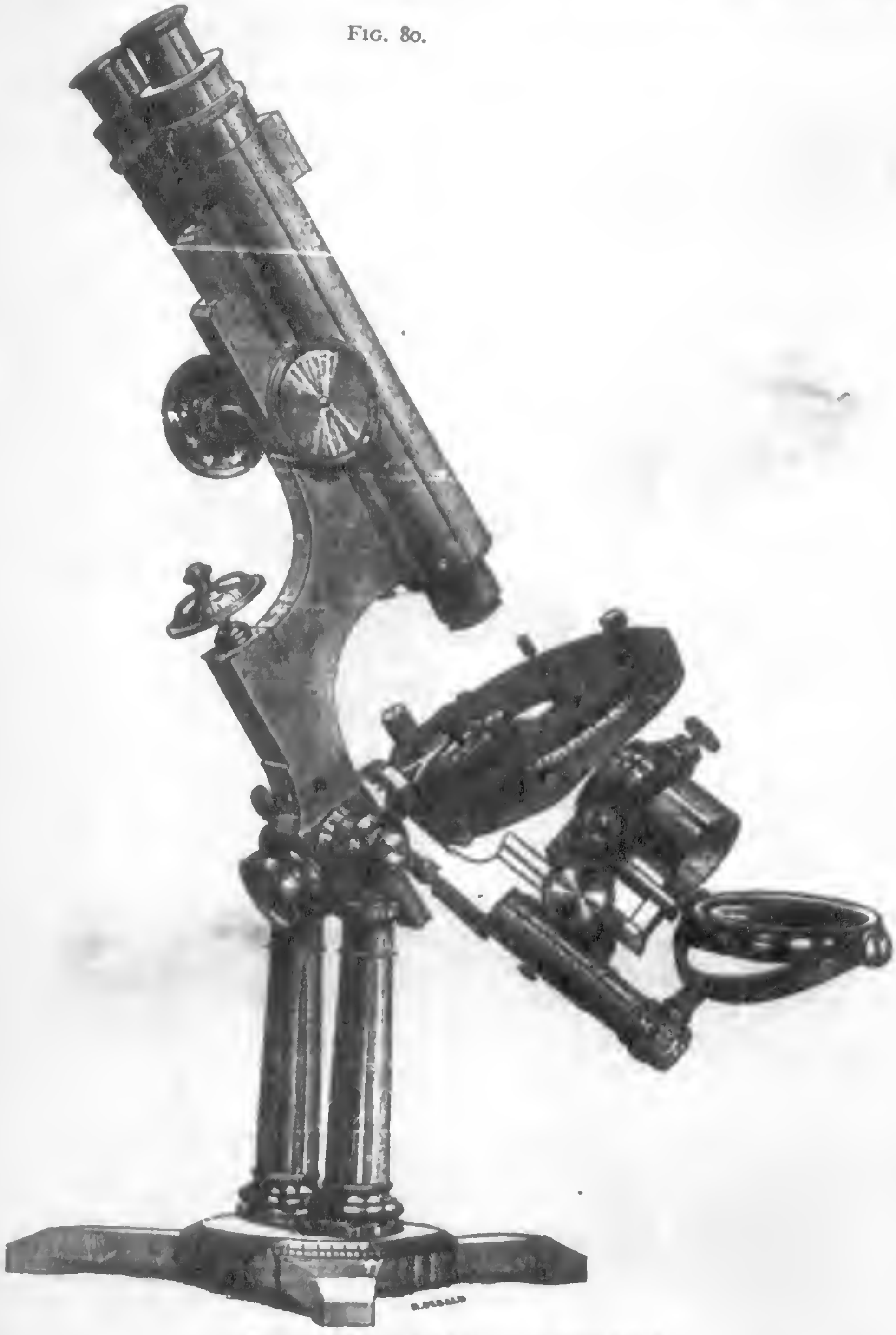
For obtaining radial illumination on the object, this arrangement of Tolles's is an elaboration of his Traverse Substage, which I have long regarded as the best practical accessory apparatus that has been applied for the purpose. Some of the details of the construction, which depend to a great extent on the application of the disc, do not commend themselves to me; for example, I find the narrow zone on which the substage is supported far too weak, and the attachments and general mechanism of the substage are too slight, so that the centering-screws, diaphragms, &c., cannot be touched without betraying flexure.

In later constructions of this form of microscope, Tolles applied a mechanical stage acting by two plates about 1-50 inch in thickness, actuated by two pinions vertical to the surface of the stage. By this arrangement of the pinions, the movements were effected entirely within the circumference of the stage, so that a complete rotation of the latter was obtained without the necessity of carrying the body-tube more forward. In previous constructions of the

"Jackson" form, the rotatory movement of a large mechanical stage, with lateral projecting pinions, had always been stopped on either side by the limb.

When this stage was examined by Mr. Wenham, he at once proposed to improve the mechanism by removing the lower of the two plates, and by combining the pinions on one

FIG. 80.



ZENTMAYER'S "CENTENNIAL" MICROSCOPE.

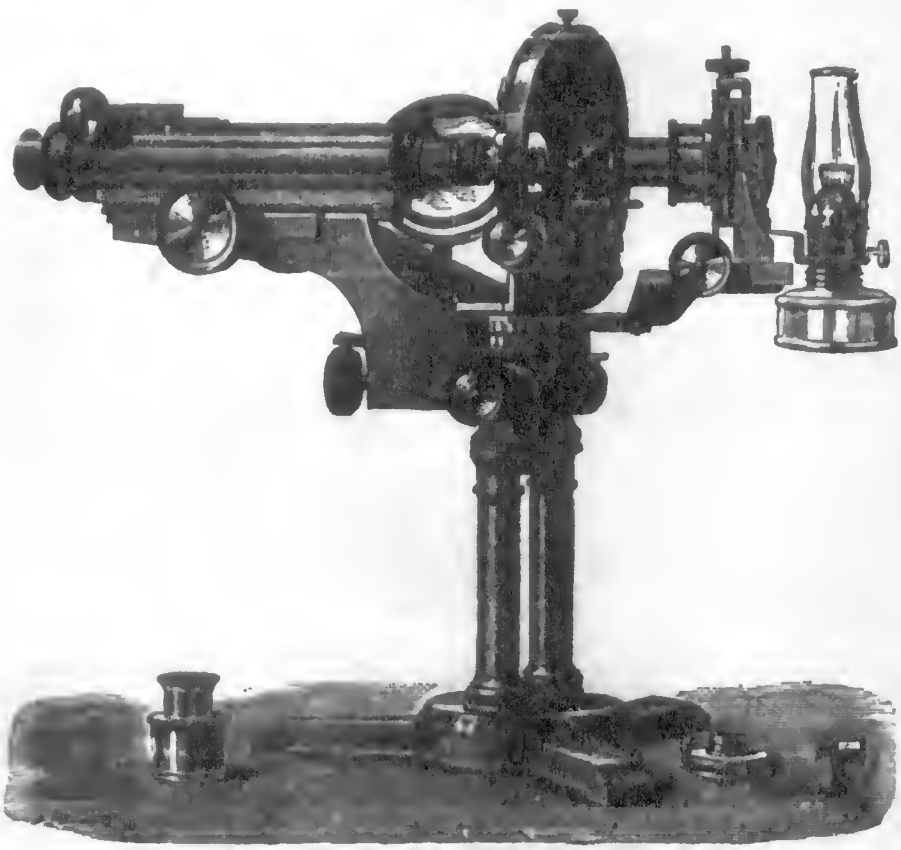
axis—a modification of the "Turrell" form—which we shall see adopted in the Ross-Wenham Radial Microscope. Tolles also worked out practically the same system; but, as a matter of fact, he was preceded by Mr. Wenham. In Tolles's later form he gave greater rigidity to the stage by adding a flange to the upper edge that gradually increased in thickness towards the shoulder by which the stage was attached to the vertical disc; by this arrangement the stage remained very thin—hardly more than 1-8 inch—and the under surface was plane, so that the manipulation of apparatus beneath was as free as possible. Swift and Son have adopted this plan of strengthening the stage in one of their recent models.

In Tolles's later microscopes we find an extra radial arm mounted on a second disc, behind the large one, to carry the mirror; this was applied as a ready means of condensing light on the surface of the stage, or for utilising a second beam of light for particular resolutions.

Tolles devised many arrangements for oblique illumination; his best apparatus of this kind was the "Traverse Substage," which consisted of a graduated semi-circle of brass, having a hemispherical lens applied slightly below the centre of the arc, and in a zonal groove near the edge a carrier is fitted to slide and carry a small condenser. This contrivance is made to rack in the place of the usual substage, and the hemispherical lens is adjusted in immersion contact with the base of the slide; then the movement of the condenser in the zonal groove from the axis to near the horizon of the hemispherical lens gives the required obliquity of illumination, slight touches of the mirror directing the light through the condenser. Tolles also applied a system of prisms to this device, so as to reduce the amount of adjustment required of the mirror; and he added other hemispherical lenses of different radii for use with various classes of work; a special arrangement of collimated diaphragms was also adopted for measuring angles of aperture by means of a lamp or candle carried in the zonal groove. In the most complete form of this apparatus, he applied two socket-carriers for condensers, placed about 45° apart, and in one example I have seen, the intention was to dispense with the ordinary stage of the microscope, and employ the Traverse Substage alone.

With careful manipulation, it is possible, with this apparatus, to register the precise obliquity

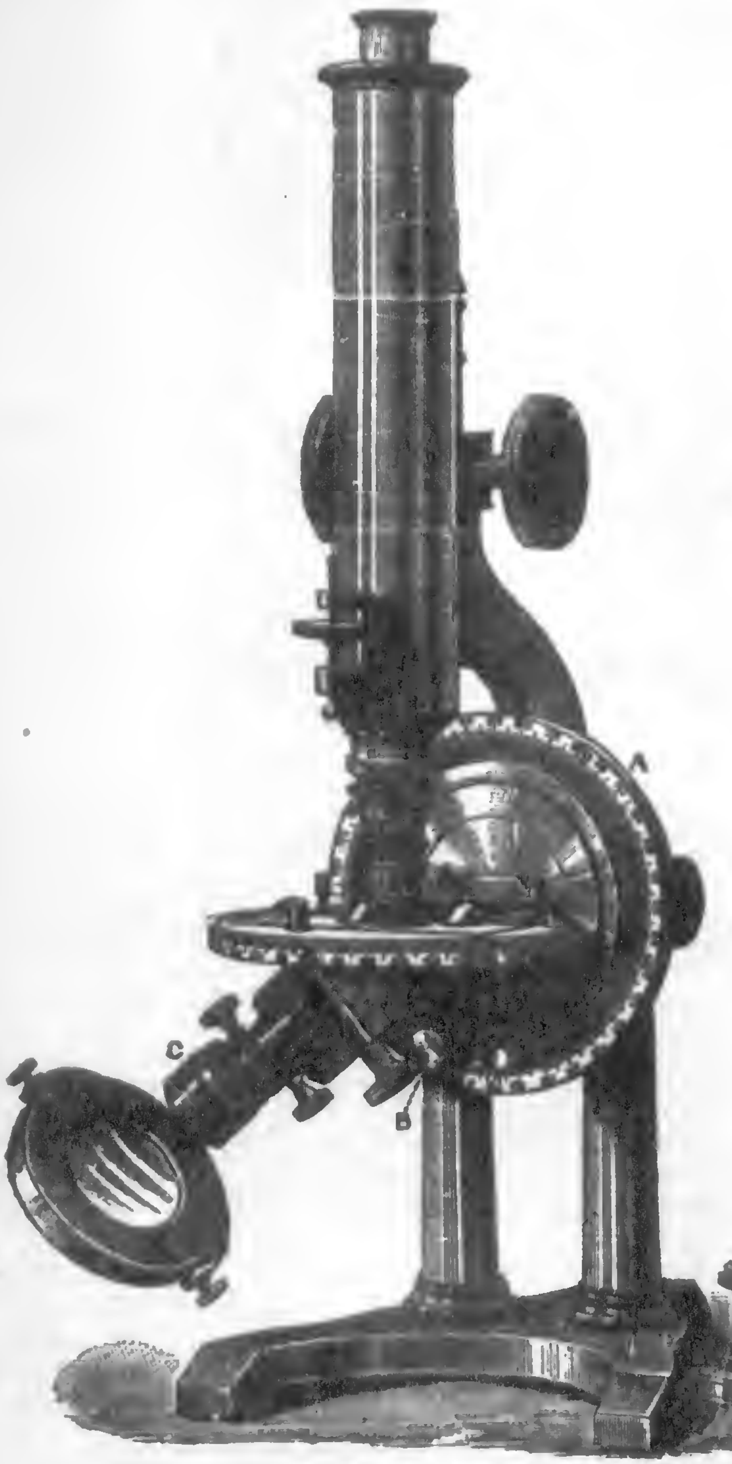
FIG. 81.



BULLOCH'S "CONGRESS" MICROSCOPE (SECOND FORM).

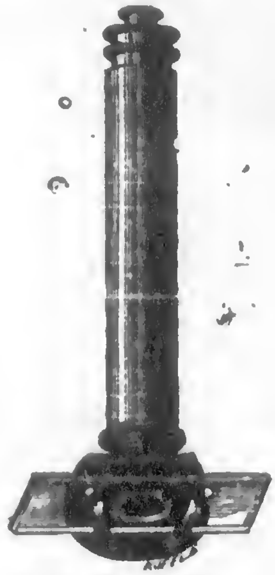
of illumination requisite to obtain a series of fine resolutions, and thus to repeat the experiments exactly. With such an apparatus one could determine how nearly we have approached the theoretical limit of resolution for each extension of aperture in our objectives, under

FIG. 82.



TOLLES'S MICROSCOPE WITH VERTICAL DISC.

FIG. 83.



TOLLES'S CLINICAL MICROSCOPE.

given conditions of illumination, and viewing fine rulings like Nobert's Test-plates. By making photographs with careful registrations of the whole conditions, we should have the problem demonstrated beyond dispute. The general application of this form of Traverse

Substage as an accessory apparatus would wholly supersede Zentmayer's swinging tail-piece and similar contrivances.

The body-tube and fine adjustment of Tolles's best microscopes were of the "Jackson" form; I may, therefore, say a few words on the comparative merits of this and of the Powell and Lealand form.

From my point of view, the choice of one or the other form, considered as microscopes of the highest class, must necessarily turn on the question of the best fine adjustment. With equally good fine adjustments, the preference will certainly be given to the "Jackson" form, on account of the greater stability of the body-tube, and the less liability to injury. Every other point of excellence in the Powell and Lealand form is perfectly applicable to the "Jackson," or to well-known modifications of it. Assuming that Tolles made the "Jackson" form as well as any other optician of our time—and his skill in workmanship did not fear rivalry—then the fine adjustment, not being at all comparable in delicacy and precision with that of Powell and Lealand, I am forced to the conclusion that it is not the workmanship that is at fault, but the principle.

One of the best manipulators known with the microscope in our time was the late Dr. J. J. Woodward, of Washington, who was frequently pressed to state his objection to the "Jackson" form of instrument. His invariable answer was that he had never found the focussing sensitive enough to enable him to use it for photo-micrography with high powers.

Tolles's Clinical Microscope.—A small microscope (Fig. 83, p. 1103) was devised by Tolles for clinical purposes, which seems to me so good in every way that I must ask special attention for it. The objective is screwed on a tube sliding within the one shown, and, for roughly focussing, the sliding motion suffices; for fine adjustment, the sheath is made to turn on a fine screw-thread on a cylindrical tube, which serves also as a socket-carrier for the stage. The compound microscope is here reduced to the simplest form I have met with to be a really serviceable instrument for the purpose in view; and the mechanism is of thoroughly substantial character. The stage fits in the socket-carrier by a short tube, and, for portability, is removed, and a metal cap substituted, to exclude dust from the objective; a tube cap covers the eye-piece. I commend this model to the notice of our opticians.

Beck's "International" Microscope.—In this microscope (Fig. 84, p. 1105) Messrs. Beck have added a movement to Tolles's vertical disc, by which the centre can be raised or depressed to correspond with the thickness of the slide. The stage can also be turned to the inverted position by rack-and-pinion. Whether or not these modifications are of real service I will leave others to decide.

The fine adjustment is modified from that known as Zentmayer's, and is open to the same objection, inasmuch as the delicately fitted slides have to carry the coarse adjustment, body-tube, &c.

Watson's Microscope (Crossley's form).—In this microscope (Fig. 85, p. 1106) we have an innovation in the method of obtaining radial or concentric illumination, designed by Mr. Edward Crossley, F.R.A.S., and constructed by Messrs. Watson.

The light from the lamp is projected into the hollow trunnion-axis of the microscope with the aid of a bull's-eye condenser, and by a right-angled prism, A (*vide* Diagram, Fig. 86, p. 1106), placed in the centre of this axis, is reflected forwards in the direction of the axis on which the swinging tail-piece turns. The arm of the swinging tail-piece is made in the form of a box, and carries a second similar prism, B, in the axis on which it moves, so as to intercept the rays of light coming from the first prism and reflect them in the direction of the arm or box. At the other end of the box is a third prism, C, which reflects the rays of light forward on to the mirror, D, whence they are directed to the object, E, on the stage. The dotted line represents the direction taken by the rays after reflection from the prism within the trunnion-axis.

It will thus be seen that no change in position of the microscope on its inclining axis affects the direction of the light from the lamp, and also that in all positions of the swinging tail-piece, whether above or below the stage, the illumination remains constant upon the object. Thus (apparently) the greatest facility is given for illuminating the object at any angle, and seeing which is most suitable.

I have not tested this arrangement of prisms for oblique illumination, and therefore cannot speak of it from personal experience. I should, however, expect such a design to require a general accuracy of construction in the mechanism and in the adjustment of the prisms, quite beyond the average found in our best microscopes.

The swinging tail-piece is mou[illegible] a disc after the manner of Tolles's [illegible] p. 1103), and, to provide space for [illegible]ment, the stage is carried on a bent arm so as to be free from the tail-piece. This plan greatly increases the complexity of the manufacture.

Messrs. Watson appear to have modified the "Zentmayer" fine adjustment by dispensing with the lever, and using a conical-ended

Fig. 84.

Beck's "International" Microscope.

screw, lifting the slide by the pressure of the cone-surface. Any such application of the travelling cone—though it were a good system in itself, which I think is not the case—has no beneficial influence on the radically defective method of employing the fine slides to carry the coarse adjustment, &c.

Ross's Radial Microscope (Wenham's

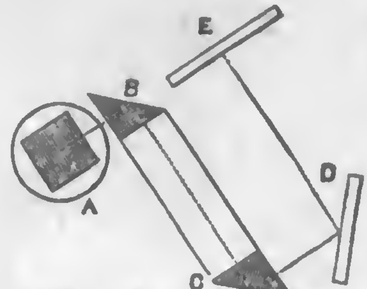
form).—We have here (Fig. 87, p. 1108) a new development in microscope construction due to Mr. F. H. Wenham. The aim has been to provide a large range of effects of oblique light both in altitude and azimuth.

The principal movements are as follows :—

Fig. 85.

Watson's Microscope (Crossley's Form.)

Fig. 86.



Crossley's Swinging Tail-piece with Prisms.

(1.) An inclination of the limb together with the body-tube, stage, sub-stage, and mirror, in a sector sliding within jaws attached to the rotating base-plate. The centre of this inclining motion is (approximately) the point where the plane of the object cuts the optic axis, *i.e.*, a point situated about the thickness of an ordinary object-slide above the centre of the surface of the stage. (2.) A lateral inclination of the limb to either side upon an axis attached to the centre of the sector; the centre line of this axis prolonged forward also intersects the optic axis in the plane of the object on the stage. (3.) A rotation of the instrument on its circular base, the optic axis being the centre of motion.

The leading principle followed in the construction of the stand is that when it is inclined backwards (as in Fig. 88, p. 1109), or laterally (as in Figs. 89, 90, and 91, p. 1109), or rotated on the base-plate, a pencil of light from a fixed source will always reach the object, all the movements, whether separate or combined, radiating from the object (or the prolongations of its axes) as a centre.

The stage rotates completely, and is a modification of Tolles's (to which I referred in my notes on his microscope with vertical disc, Fig. 82), in which the rectangular motions are effected by milled heads vertical to the surface of the stage, and entirely within the circumference. It is mounted on the Zentmayer system, and graduated near the edge, and "finders" are engraved in convenient positions; two centering screws are provided, by which exact rotation on the optic axis can be secured; and it can be easily removed, or may be replaced by a glass or metal friction-stage, &c. A simple and effective plan has been adopted of applying the iris-diaphragm, hemispherical immersion illuminator, &c., beneath the stage, where they are held by a small projecting peg and a spring-latchet.

The sub-stage can be removed entirely from the lower part of the limb by means of a chamferred sliding plate. Rectangular (centering) and rotating motions are provided.

The coarse adjustment is of the "Jackson" form, by means of a spiral pinion and diagonal rack-work.

I will deal with the fine adjustment later.

In illustration of the variety of motions obtained with this microscope, Fig. 88 shows the sector inclined at about the usual position for working with central illumination. Fig. 89 shows the lateral inclination of the limb, &c., the sector being at its highest position. Fig. 90 shows the Zentmayer swinging tail-piece clamped to the sector (as suggested by me), the limb being inclined laterally, and the sub-stage removed; this lateral inclination of the limb causes the stage to revolve upon a central horizontal axis, so as to present the object to the illuminating pencil at all obliquities in altitude, while the rotation of the stage would give illumination in all azimuths. Fig. 91 shows the sector at the lowest point, so that the microscope-body is horizontal, the tail-piece being clamped to the sector, the limb swung laterally about 45° (to the right), and the sub-stage removed; this position of the sector would be that required for measuring angles of aperture by means of the graduations on the circular base. The axis of the lateral inclining motion is also graduated, so that either the degree of inclination of the limb or that of the swinging tail-piece can be registered. In all these positions, and, indeed, in every position in which the various movements enable it to be placed, the microscope is very steady.

Since Figs. 88, 89, 90, and 91 were made, an arm has been attached to a rotating plate in the centre of the lower base-plate to carry the lamp on a pillar, as in Fig. 87.

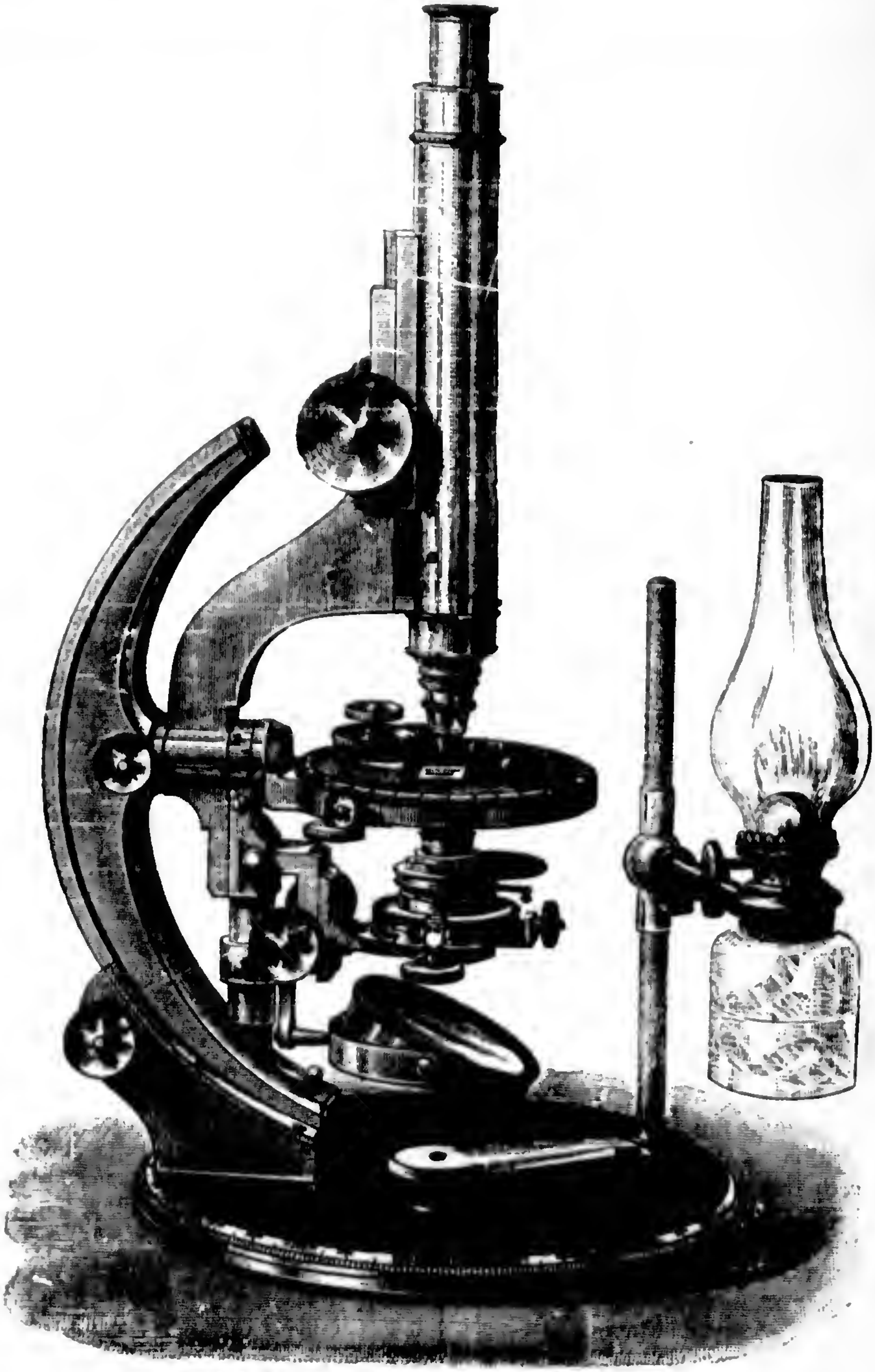
The fine adjustment shown in the four small figures consisted of a vertical chamferred slide, carrying the nose-piece only, and controlled by milled heads on either side of the nose-piece. This arrangement was subsequently replaced by an entirely new design of adjustment by Mr. Wenham, consisting of a V-slide, acted upon by two "snail"-cams, between the edges of which revolved a steel roller, forming the axis of, and controlled by, a large milled-head passing longitudinally through the slide of the coarse adjustment, and projecting slightly on either side, in a convenient position for work. The V-slide was fitted within the body-tube, and carried at its lower end the nose-piece; it was pressed downwards by a spiral-spring, against which it was moved by the revolution of the cams.

In practice, however, it was found that the steel roller actuating the cams was liable to slip when the movement had not been in use for a few days, and Messrs. Ross engaged Dr. Hugo Schrœder to design a new system, which is shown in Figs. 92 and 93 (p. 1110).

The nose-piece, A, is attached to a tube which is fitted to slide accurately in adjustable bearings in the body-tube, B. The nose-piece tube has a short projecting arm, C, by means of which it is pressed upwards by a strong spiral-spring mounted in a cylindrical box, L, outside the lower end of the body-tube. The arm, C, is moved against the spring by the differential-screw mechanism (with milled head, D), which is gimballed on a bracket, E, attached to the upper part of the body-tube.

The differential-screw mechanism consists of a steel rod, F (connected with D), which has two screw threads at the lower end, one working in a thread cut in the end of the inner tube G, and the other in the block, H, which is soldered within the sheath, J. When the milled head is turned to the left, the block, and with it the sheath, moves downwards, while the rod itself, carrying the block and sheath, moves

FIG. 87.



ROSS'S RADIAL MICROSCOPE (WINHAM'S FORM)

upwards. As the screws are cut respectively to 45 and 52 threads to the inch, the resultant motion is equivalent to the difference between the motion of the two screws, that is, to the motion of a screw of nearly 335 threads to the inch.

The end of the sheath is tipped with a small sphere, K, of polished steel, while the projecting arm of the nose-piece tube, against which the end works, has a corresponding concave bed of polished agate.

This differential-screw focussing mechanism was found to work with great delicacy when fitted with extreme care; but the difficulties of manufacture compelled Messrs. Ross to adopt a simplified form, in which a direct-acting screw with a very fine thread is substituted for the differential screw. Experience must decide the question of the durability of this later application of the fine screw; the

FIG. 88.

FIG. 89.

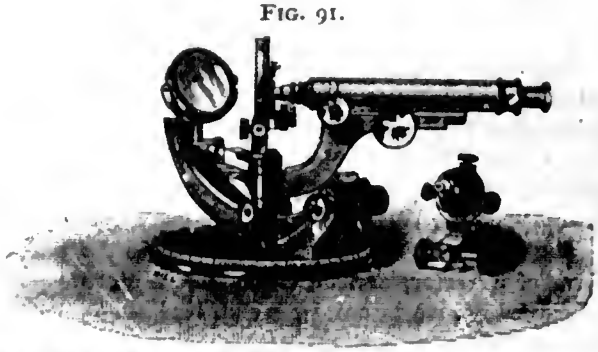
ROSS'S RADIAL MICROSCOPE (WENHAM'S FORM).

motion is now so accurate that I am inclined to believe the difficult problem of designing a really efficient and convenient fine adjustment for the "Jackson" form of microscope has met with a solution—at least by approximation. Another solution of this problem has been submitted to me recently by Messrs. Swift, and I must in fairness admit that they, too, have grappled with the difficulty with considerable success; the system is applied in the next microscope we shall examine.

The question of the utility of the great variety

FIG. 90.

FIG. 91.



ROSS'S RADIAL MICROSCOPE (WENHAM'S FORM).

of movements combined in Mr. Wenham's design naturally arises. I am not prepared to say that any one of the movements is essentially useless in practical microscopy. I understand from Dr. Dallinger, the President of the Royal Microscopical Society, that in some of his most difficult investigations in tracing the evolution of minute forms of life, no facilities hitherto devised for controlling the illumination, according to methods capable of being recorded and repeated, have proved valueless; and I believe he has tested this Radial Microscope by practice more thoroughly than any other microscopist.

In the details of construction, several modifications of Zentmayer's plan of suspending the swinging tail-piece have been introduced by Messrs. Ross, to correct the tendency to flexure and general unsteadiness in the stage and substage so painfully evident in Zentmayer's own construction; and I must admit that my objections to the system of suspension have been correspondingly modified—but no further.

Fig. 92.

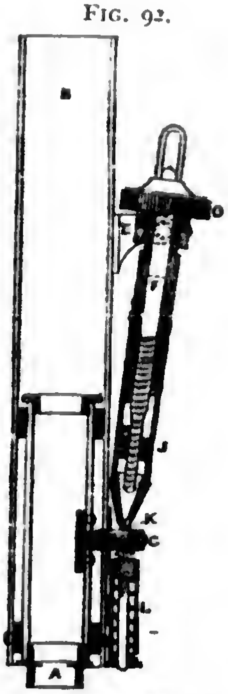


Fig. 93.

Schroeder's Fine Adjustment.

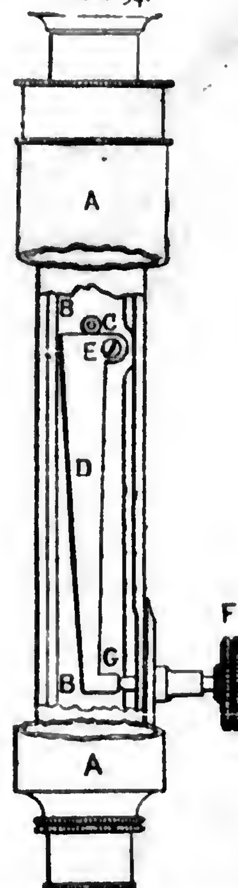
Swift's Microscope (Wale's form).—In this microscope (Fig. 95, p. 1111) Messrs. Swift have adopted a form of inclining limb devised by Mr. George Wale, of the United States, by which great stability in all positions of inclination is secured.

The limb is curved in the lower part in the form of a sector, and on either side a deep V-shaped groove is cut, by which it slides on corresponding projections at the upper ends of the base support; the clamp-screw at the side serves to regulate the tension, or to fix the position. By this arrangement, the centre of gravity suffers very little displacement by the inclination of the limb, and the steadiness is well maintained.

The curve of the limb allows complete rotation of the mechanical stage. The centering and rotating substage is furnished with rack movement, on which it is applied by a dovetailed slide. The mirror, with gimbal, two arms, and rotating socket slides on the tail-piece, which is hinged to swing laterally on the end of the limb.

To this instrument Messrs. Swift have applied a new arrangement of fine adjustment

Fig. 94.



Swift's Fine Adjustment.

which they have patented. The mechanism is shown in Fig. 94, where A A is the body-tube (the middle part cut away to show the action) connected with a chamferred slide at either end at the back, fitted to move accurately and lightly on the front of the coarse adjustment slide, B B, of the usual "Jackson" form, a spiral-spring above and at the back pressing it downwards. A long lever, D, is attached to the plate, B B, to pivot at E; by the action of the milled-head, F, on the lower end, G, of the lever, the lifting stud, C, connected with the chamferred slide behind the bod-tube, B B, is raised very slowly through a focussing range of about 1-10 inch; the

FIG. 95.

SWIFT'S MICROSCOPE (WALE'S FORM).

reverse action of the screw allows the spiral-spring above to press the slide downwards.

By this very simple mechanism, the fine adjustment is applied on the front of the coarse adjustment, and acts on the whole body-tube, and not merely on the nose-piece, so that the magnification is not altered by change in the focal adjustment. It is obvious that the slowness of the motion is here controlled by three factors: (1) the length of the lever, D, (2) the distance of the lifting-stud, C, from the pivot or fulcrum, E, and the pitch of the screw-thread on F. I am informed that Messrs. Swift anticipate being able to adapt this system of focussing to all their better class of instruments. My trials of this fine

FIG. 96.

SWIFT'S PORTABLE MICROSCOPE.

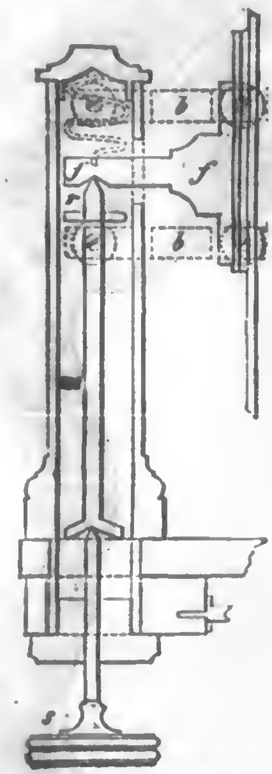
adjustment, using a 1-12 inch homogeneous-immersion objective of the highest aperture hitherto constructed (1·5 N.A.) have led me to a decidedly favourable opinion of the mechanism.

Swift's Portable Microscope.—Of the many designs of portable microscopes, this little instrument (Fig. 96) is the most complete I have seen, and the workmanship (due, I believe, to Mr. Mansel Swift) is excellent. We have here a compound body with draw-tube fitting with inclining movement on a pillar with tripod base, four eye-pieces, four objectives (including 1-16 inch "immersion,") achromatic condenser with diaphragms, stops, &c., polarizer, analyzer, mirror with gimbal and sliding-rod, the whole fitting in a box of miniature dimensions.

Seibert and Krafft's Fine Adjustment.—For small microscopes the form of fine adjustment shown in Fig. 97 has been much employed in Germany for low-priced microscopes.

The focussing screw, *s*, acts upon the funnel-shaped head of the pivot, *m*, the upper end of which acts in a similar manner upon *ff*, the solid bar attached to the body-tube. The ring, *r*, which serves as a guide-piece, lies loose in the hollow pillar, and, as a rule, does not touch the pivot; its function is merely to prevent the point of the pivot from slipping out of the

FIG. 97.



SEIBERT AND KRAFFT'S FINE ADJUSTMENT.

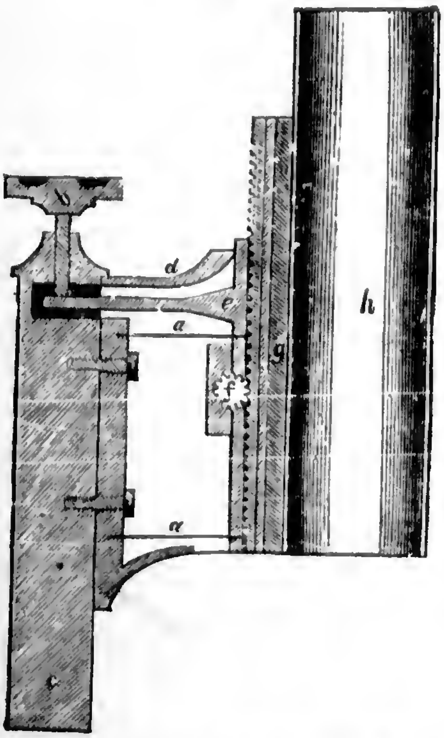
notch in *ff*. The cross-bars, *bb* (two on each side), are attached by screws to the hollow pillar, and the body-tube is held between the points of four screws near the front ends of the bars. The focussing motion is communicated to the solid bar, *ff*, by the screw, *s*, acting against the pressure of the spiral spring shown above by dotted line, the friction being limited to the eight screws of the four cross-bars. The movement is similar to that of an ordinary parallel ruler with connecting bars, the hollow pillar being the stationary side.

In later constructions the four bars have been advantageously replaced by two broad plates.

Bausch and Lomb's Fine Adjustment.—This focussing system (Fig. 98) is probably the simplest that has ever been applied to the compound microscope, and seems to have been suggested by the last we examined.

The focussing screw, *b*, acts upon the angle-piece, *e*, which is connected by rack-work, *f* and *g*, with the body-tube, *h*; *e* is an angle-piece suspended on the pillar, *c*, by the two parallel springs, *a a*. The pressure of the screw, *b*, on *e*, depresses the body-tube, the springs, *a a*, allowing a motion of about 1-10 inch. By the reverse motion of the screw, the springs come back to the normal level as shown.

Fig. 98.



Bausch and Lomb's Fine Adjustment.

A defect in this system seems to have passed hitherto unnoticed. If a high power were in focus with the mechanism nearly in the position shown, a very slight pressure would cause the springs to bend, and thus the objective might break the cover-glass.

Messrs. Beck, Ross, and others appear to have adopted this system for small microscopes, and Messrs. Swift have reversed the movement (to avoid the danger I have noted) by converting the horizontal portion of *e* into a lever suspended on a fulcrum slightly to right of the upper *a*, by which the motion is made slower.

Riddell's Binocular Microscope.—Although personally I do not favour binocular microscopes, yet I think it will be of interest to briefly note upon the chief modern developments in that direction.

Prof. J. L. Riddell, of New Orleans, was the original inventor of the binocular compound microscope with one objective. A copy of his original instrument was recently sent to England, which is shown in Fig. 99 (p. 1114). The arrangement of the binocular prisms is shown in section in Fig. 100 (p. 1115).

The pencil of rays emerging from the objective, *l*, is divided in two, each half passing respectively into the right and left prisms; the path of the rays is *a*, *b*, *c*, *d*, the object is at *o*.

To facilitate the perfect coalescence of the images in the field of view for every width of eyes, Professor Riddell provided (1) a means of regulating the inclination of the prisms by mounting them in hinged frames, so that, while their lower terminal edges remain always in parallel contact, the inclination of the internal reflecting surfaces can be varied by the action of a milled head in front of the prism box; (2) the lower ends of the binocular tubes are connected by travelling sockets, moving on one and the same axis, on which are cut corresponding right and left-handed screws, so that the width of the tubes may correspond with that of the prisms; and (3) the upper ends of the tubes are connected by racks, one acting above and the other below the same pinion, so that right and left-handed movements are communicated by turning the pinion.

Professor Riddell found that, in many cases, it was advantageous to employ two small concave mirrors rather than one large mirror, so as to equalise the illumination in both fields.

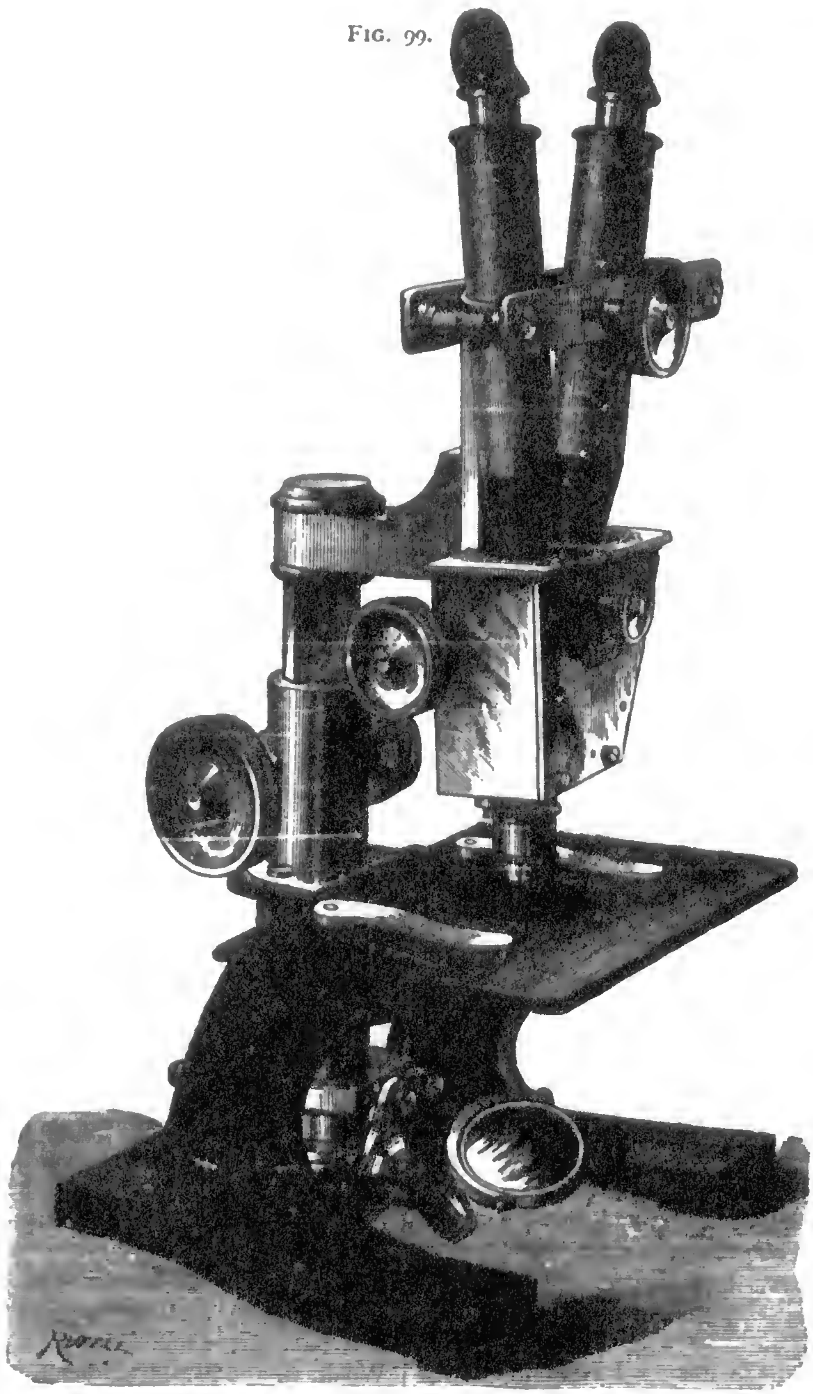
To obviate the inconvenience of using the instrument always in the vertical position, small right-angled prisms are so mounted in brass caps as to be slipped at pleasure over the eye-pieces. The combination of the binocular prisms with the eye-piece prisms inverts the image in *both* planes, so that the movement upon the stage is seen through the instrument without inversion.

This system of binocular seems to have excited much curiosity at the date of its first publication in England (1854), and Mr. Wenham, and Messrs. Nachet, of Paris, were soon in the field with a number of binocular arrangements. One of the devices of the latter firm was converted into a binocular erecting eye-piece for the microscope and telescope by Tolles, of Boston, and for moderate magnification I am informed that it is a useful appliance. Mr. Wenham's original contrivance has gone through many modifications, culminating in the system shown in the next Figure.

Wenham's Binocular Microscope.—The most popular form of binocular microscope was planned by Mr. Wenham about 1862; the action is shown in Fig. 101 (p. 1115).

The prism, P, is so arranged as to take up exactly half the pencil of rays emerging from the objective, O, and after undergoing two total reflexions at the internal faces of the prism, these rays pass across the optic axis in the direction L (the left eye), while the other half of the pencil of rays passes in the direc-

FIG. 99.



RIDDELL'S BINOCULAR MICROSCOPE (1853-4).

tion R (the right eye). This form of binocular appears to have practically superseded all others. The deflection of half the pencil across the axis, so that the right eye receives the left half and the left eye the right half of the original pencil of rays, has been said to be the cause of stereoscopic (true projection) vision; whilst in other binocular systems, where no crossing of the axes takes place and where, consequently, the right eye views, the image formed by the right half of the objective, and the left eye that formed by the left half) pseudoscopic vision is said to obtain.

FIG 100.

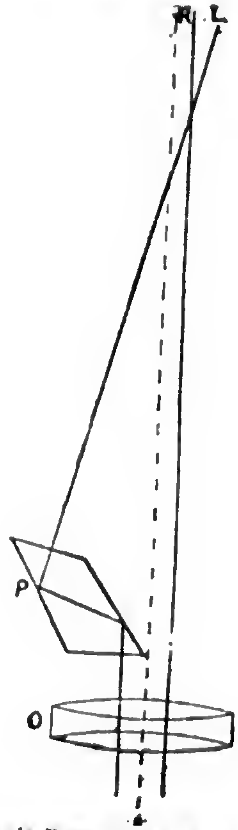
RIDDELL'S BINOCULAR PRISMS.

Brücke's Lens.—The revival of the Galilean microscope by Brücke (about 1852) has led to such useful combinations for dissecting purposes, that I cannot omit to notice the instrument.

Brücke proposed to use achromatic doublets in combination with a concave eye-lens, for moderate magnifications, where simple lenses or ordinary doublets or triplets had previously been employed. Fig. 102 shows the form issued by Nachet, in which the eye-lens is mounted in a draw-tube, so that different magnifications can be obtained; the mounting is applicable to any form of simple microscope or lens-carrier. Zeiss has also worked out excellent combinations of this form in fixed settings, and supplies a small stand designed expressly for them. Our opticians appear to have wholly neglected this most useful little dissecting microscope.

A Japanese Microscope.—This microscope (Fig. 103, p. 1116) was manufactured at Tokio, Japan. The design is evidently copied from a modification of Culpeper and Scarlet's microscope (Fig. 47). The novel points seem to be (1) the arrangement of a groove on the stage in which the object-slide is placed, so that different parts can be viewed by lateral move-

FIG. 101.



WENHAM'S BINOCULAR MICROSCOPE.

ment—a modification of the rotating multiple stage of Chérubin d'Orléans, to which I have referred; (2) the whole construction is of a vibratory or tremulous character, suggestive of

FIG 102.

BRUCKE'S LENS (AS MADE BY NACHET).

a total misapprehension of the real purposes of a microscope; the body-tube rocks in its socket, and the upper base turns and rocks on the lower one, and if the instrument is touched and released, it quivers throughout, and slowly settles down into stillness—provided one does not breathe upon it.

We have now passed in rapid review some of the best types of microscopes designed since the first application of achromatism. The number might be greatly increased, had we time and space, for in addition to the more important type-models I have described, every optician I have mentioned (and many others I have not mentioned) has brought out forms of less and less complete design, to meet the

FIG. 103.

A JAPANESE MICROSCOPE.

demands of students and others to whom economy of outlay was almost the first consideration. The designs of these less complete instruments are of inferior interest, because we know that the principal criterion by which they are to be estimated is the expense. As a rule, however, those opticians who have devised and made the best class of microscopes, have also devised and made the most serviceable forms of lower class.

Then, again, numerous designs have been produced for special purposes. We have microscopes for the observation of chemical processes and the fusion of metals, &c., where the instrument has to be protected from the action of acids, gases, heat, &c. Petrological microscopes, where polarising and goniometrical appliances are chiefly embodied (of these I remark, in passing, that M. Nachet has made a specialty, and his instruments are probably the most complete of the kind). Then we have microscopes for recording the growth of plants; for viewing objects at the bottom of an aquarium, by means of an aquatic nose-piece; for observing the circulation of the blood in the frœnum of the tongue, &c.; for counting the threads of silk, wool, linen, &c.; for measuring lengths to an accuracy of 1-100,000 inch or higher; for viewing the walls of the stomach and other internal parts of the body by means of an electric light; for class demonstrations; for field work; for examining large specimens of minerals, &c., for which Marten's Ball-jointed microscope was specially designed, with ball-and-socket movements to the body-tube carriers; and we have several instruments that were designed expressly to compete for the medals offered by the Society of Arts, in 1855, for School Microscopes and Students' Microscopes. The best known models for these and many other purposes are exhibited here, and with due time at my disposal we might pass them all in review.

With reference to accessory apparatus originated or improved in conjunction with the achromatic microscope, I may note that the Huyghenian and Ramsden forms of eye-pieces, as applied to the telescope (or the former slightly modified), have come into use; that Orthoscopic or Aplanatic eye-pieces, and "Holosteric" or solid eye-pieces, have been occasionally applied; partially achromatised (Kellner), and in some cases wholly achromatised (Schrœder) eye-pieces have been tried, but with by no means the amount of advance in optical power that was expected by Lalande, Brewster, and others. Amplifiers have been tried, beginning with Selligue; and latterly they have been achromatised by Tolles and Zeiss specially for photo-micrography.

The greatest improvement amongst the different kinds of apparatus contrived for illumination has been the achromatic condenser as made by Powell and Lealand, which has a series of stops and graduated diaphragms for regulating the light. Other opticians have contrived more or less elaborated forms of sub-stage condenser, in some cases combining a number of appliances in one piece of apparatus; my impression is that, in many of them, too much is attempted, and hence essential points are somewhat neglected. More recently, Powell and Lealand have been working out an achromatic condenser to correspond as nearly as possible with the highest apertures of our objectives; the successful production of this apparatus is waited for with much interest by Dr. Dallinger and others, including myself.

Then we have had many devices for oblique illumination, such as Amici's prism, and Dujardin's prism, variously applied; the "Vertical Illuminator," in which the objective is made to act as a condenser to the object; Reid's "Kettle Drum;" Woodward's Prism: the Hemispherical Lens; Wenham's Semi-disc; the "Diatomoscope;" double-prisms; mirrors arranged to rack close to the base of the slide; silvered glass slips to place beneath the slide to be illuminated from above; prisms cemented on the face of the slide, so as to transmit rays to be totally reflected from the internal surface of the base of the slide; Catoptric and Cata-dioptric Illuminators of almost impossible complexityof action; an Immersion Stage Illuminator; a multiple plane-faced prism and lens; a semi-cylinder Illuminator, and a host of others, the great majority of which have had their day, and are now rapidly being forgotten.

For dark-ground illumination we have had Spot lenses, Amici's Inverted Cone, Shadbolt's Annular and Sphæro-annular Condensers, Wenham's Parabolic Reflecting Mirror, the Wenham-Shadbolt Paraboloid, Wenham's Immersion Paraboloid, Wenham's Reflex Illuminator, and a few other similar contrivances, of which the Spot-lenses and the Wenham-Shadbolt Paraboloid still survive. For "opaque" illumination we have the Lieberkühn, the Selligue Prism, the Parabolic Side Reflector, and a few minor variations of little importance.

Special devices have been contrived to furnish monochromatic light of any primary colour.

Of diaphragms we have had circular, square, oblong, triangular, indeed almost every imaginable shape, tried singly or in series, sometimes combined by means of superposed slides or by rotating plates. In one or two non-achromatic Immersion Illuminators we have had a small circular diaphragm made to move from the axis to the margin of a combination of lenses of high aperture. Rotating calotte diaphragms have been adapted by Zeiss and Swift. We have also iris-diaphragms, combined with condensers or alone, or again used at the nose-piece to reduce apertures. I don't think they have yet been applied to the eye-piece to cut down the field, but this will come, as an "important" modification, doubtless, of other and better methods.

Then we have double, triple, quadruple, and sextuple nose-pieces, first sliding, then rotating, some set at an angle, then curved, then mounted on a calotte, and, for lightness, the best have been made of aluminium. These devices should not be employed on high-class microscopes focussing by the nose-piece, as they are very apt to strain the sensitive mechanism.

Of changing nose-pieces, we have, first, Chevalier's double stud projecting from a ring, slipping into corresponding slots in the face of the socket, and held by a slight rotation; then the Geneva Optical and Physical Company's changing nose-piece, where the objectives have rings with shallow flanges slipping under a spring catch—a method also adopted by M. Nachet, and by M. Bertrand; then we have Mr. Nelson's arrangement, where three short segments of the internal thread of the nose-piece are cut away, and corresponding segments are removed from the screw-threads of the objectives, so that they may be pushed in the nose-piece, and slightly turned, which plan has brought upon us a mass of modifications, suggestive that we should pass the remainder of our natural lives in mastering their construction and use—many of them more troublesome to use than the screw-system they are intended to supersede.

We have more than twenty different arrangements for carrying bull's-eye condensers, as many lamps of special design for use with the microscope, of which Dr. Dallinger's, with its adjustable screens, &c., is designed for the "fine art" of microscopy; while Mr. Nelson's is less complex, but still thoroughly practical.

Then we have screw stage-micrometers, and simple ruled stage-micrometers, and others of various designs, to measure blood corpuscles with or without the aid of photography; screw eye-piece micrometers of both the Huyghenian and Ramsden forms, to be carried preferably on a separate stand, and not in the body-tube, where extreme accuracy is required, as suggested by Mr. Nelson—in some cases, to avoid errors due to unequal magnification of the centre and the margin of the eye-lens, a lateral motion has been added to the eye-lens, so that the measurements are always determined by the image seen in the axis only; Jackson's eye-piece micrometer (a simple and practical device); Hartmack's eye-piece micrometer, with oblique scale; eye-pieces with crossed wires, and with parallel vertical wires for readily estimating comparative dimensions, and others with fine ruled squares of known dimensions, which were generally applied by Andrew Ross and Hugh Powell to the Ramsden eye-piece, at the focus of the combination.

We have Cameræ Lucidæ, such as Wollaston's, dividing the pupil of the eye; Soemmering's steel disc, conveying the image from the microscope to the centre of the pupil, the outer zone of the eye viewing the pencil and paper directly; Beale's neutral tint reflector; many forms devised by Nachet, the best of which has a film of gold on the final reflecting surface through which the microscope image is seen tinged with green colour due to the gold; Zeiss's or Abbe's, which are similar in action to Nachet's; Nobert's, Chevalier's, Beck's, and the best of all that I have tried—Schroeder's, which is a modification of the principle utilised in Wenham's high-power binocular prism.

We have frog plates; animalcule cages or "live" boxes; compressoria; vivisection troughs for showing the circulation of the blood in the lung of the frog; hot stages and reservoirs with multitudinous devices for maintaining an even temperature; stages with electrical appliances for viewing minute vacuum tubes, &c.; safety stages of several designs, the earliest (intended as such) probably by Powell, which is seen on a large microscope he made for Stonyhurst College in 1842, and the simplest form is that recently devised by Prof. Charles Stewart, Curator of the College of Surgeons, in which the slide is held by two india-rubber bands stretched across a light wood frame, useful for class demonstrations. And we have polarisers and analysers of various designs; some of the former give a much larger field than Nicol's prism, and permit the combination with a condenser, as in Hartnack's form; of the latter, some rotate at the nose-piece in the body-tube, or, again, over the eye-piece combination with a graduated goniometrical disc and pointer, as in Hartnack's. Double-image prisms have been devised by Prazmowski and by Abbe. For carrying selenites we have many systems of convenient rotation; and in one instance we have clock-work applied to keep the rotation of one or more plates going, to amuse the ladies when we exhibit sections of the "North Pole," &c., at *soirées*.

Of curiosities among achromatic microscopes, we have here the first Engiscope made for Dr. Goring, an unwieldy instrument, capable of knocking me down if I were to release the ball-and-socket joint without due care. The working microscope of the late Prof. Schwann (of "Cell-theory" fame) of Louvain. The original microscope of Cornelius Varley, for which the Society of Arts awarded him a medal. The original model of the Oberhaeuser Dissecting Microscope, with a telescopic erecting eye-piece applied. The original model of Amici's Horizontal Dioptric Microscope. The working microscope by Amici that formerly belonged to the distinguished Italian, Professor Alessandrini, of Bologna. Wenham's original Binocular Microscope. A copy of Riddell's original Binocular Microscope. Then we have "Jumbo," the largest microscope known; and the "Midget," the smallest working model known; and a prettily-made "drum" microscope, by Alfred Nachet as a lad; and three binocular microscopes, consisting of achromatic objectives sawn through to form binoculars—a sort of quintessence of absurdity for modern binoculars. Then we have some of Tully's early objectives; some of Chevalier's; Amici's, including early oil-immersions, and a ruby-fronted immersion; Wenham's, with his first binocular prism applied almost in contact with the posterior combination; the famous 1-6 inch immersion of Tolles, about which part of the aperture controversy turned; and a 1-4 inch, also by Tolles, with a tiny prism behind the front lens for projecting light upon opaque objects through the front lens.

You will naturally expect me to say something of the progress that has been made in the construction of objectives.

The Selligue objectives I have examined were by no means good, from our present stand-point of excellence; those of Chevalier were unquestionably better; and those of Tully better still. The best I have seen of Tully's were small doublet fronts with larger triplets above. The earliest of Oberhaeuser's were apparently copied from Chevalier's. It is said that Lister's discovery of aplanatic foci led immediately to great improvement in objectives; in proof of this, however, I have only met vague assertive evidence. The English optician who did more than all the others together to improve objectives was the late Hugh Powell, and he repeatedly affirmed to me that every advance he himself had made, since the days of Tully's first efforts, had been arrived at by sheer experiment, without a single hint of any value from any theorist whatsoever. It is also certain that Oberhaeuser, Hartnack, Nachet, senior, knew nothing of Lister's investigations, and yet, as late as 1863, objectives made by them were only slightly inferior to Powell's, and were quite on a par with objectives of any other English maker. Whence I infer that Lister's influence has been much exaggerated.

By sheer experiment it appears to me that the great bulk (if not the whole) of the improvement in England was made down to 1868, when Powell undertook the experiment with the immersion system, in consequence of my showing him certain immersion objectives by Hartnack. In Paris, the frequent visits of Amici from 1824 onwards kept certain of the opticians *au courant* of his incessant experiments, and I have been informed, on reliable authority, that the first immersion lenses he made (about 1840) were designed to be used with certain oils which were regarded as practically equal to glass in refraction, thus really constructing homogeneous-immersion objectives, though without any conception of the possibility of apertures greater than would correspond to the maximum air apertures. Exception was taken by the amateurs of that day to the use of oil, on the ground that their slides were injured by it, and hence Amici gave up the oil-immersion system and adopted water as the immersion fluid. In 1855, he showed a number of water-immersion objectives in Paris, and Nachet, senior, and Hartnack worked out some on the same type. In 1862, Prazmowski joined Hartnack, and the production of immersion objectives made great progress, thanks to Prazmowski's combination of theory and practice, so that, at the Exhibition of 1867, the objectives exhibited by Hartnack were notably in advance of those of his rivals. From 1867, until quite recently, the Paris opticians made but very slow progress with their immersion objectives. In England, on the contrary, no sooner had Powell and Lealand started with the immersion system, than their objectives immediately became the best in the field. Wales, in America, and Spencer turned out high-class immersion objectives as early as 1869-70, and then Tolles engaged upon them with more concentration of effort (for previously he had only made them at intervals), and soon produced "optical curiosities" in which he claimed (1872-3) to have increased the apertures beyond the maximum possible with dry objectives. Meanwhile, Zeiss had been working at immersion objectives, and in his catalogue of 1874 he distinctly claimed apertures of "104° to 108° in a film of water, whereas such an angle of even about 96° would correspond to an angle of 180° in air."

A great controversy took place between Tolles and Wenham on the aperture question, on which I will not enter except so far as to state that, in support of his claims, Tolles published, or caused to be published on his behalf, certain computations relating to the apertures of his immersion objectives. During this controversy, Tolles produced a number of objectives having an extra front lens, which were of special excellence. Amongst them was a certain 1-6 inch that he made for Mr. Frank Crisp, and the aperture of which was the subject of endless published letters, &c.

In 1878 Zeiss produced, under the instructions of Dr. Abbe, oil immersion-objectives, which were afterwards termed "homogeneous" immersion, and was immediately followed in England and America by the best opticians. When Zeiss's oil immersions were first issued, Dr. Abbe stated that the idea of the system had been suggested to him by Mr. J. W. Stephenson, the Treasurer of the Royal Microscopical Society. Of course, I cannot for a moment dispute Dr. Abbe's statement as to the origin of the idea so far as he was concerned; but his testimony related only to the communications as between Mr. Stephenson and himself, leaving wholly untouched the question of Mr. Stephenson's originality. In my opinion the origin of the homogeneous-immersion formula is largely due to Mr. R. B. Tolles, and I think this can be substantiated by the now generally admitted criterion—the priority of publication.

In Vol. X. (1874) of the "Monthly Microscopical Journal," pp. 124-5, Mr. R. Keith published the elements furnished by Mr. Tolles, from which he had computed the aperture of a certain 1-10 inch objective, about which a part of the aperture controversy had turned. Photographs of the computation, *in extenso*, were forwarded to the editor of the journal and to me, for distribution among those interested in the subject; with reference to the copies of the computation sent to the editor of the journal, a note was appended to Mr. Keith's paper stating that they were to be obtained by communicating with the editor.

That computation distinctly traced the rays of light from the posterior focus to the radiant at the front of the objective, and the immersion medium connecting the front lens with the radiant was assumed to be fluid balsam, of the same refractive index as the substance of the front lens, and consequently was homogeneous with it. Clearly this was a published formula for homogeneous-immersion. That the idea of the influence of more highly refractive medium was distinctly in the minds of Mr. Tolles and his friends, was proved incontestably by the statement of Dr. J. J. Woodward, in a paper accompanying that of Mr. Keith, as follows:—

"Mr. Keith further states that he has computed the spherical aberration of the combination, adjusted as above [*i.e.*, at the position of the correction-adjustment for maximum aperture], and finds it practically *nil*. This being the case, the objective ought to perform well when adjusted to the point of maximum aperture, if *balsam* be used as the immersion fluid in lieu of water. . . . . . Accordingly, in company with Mr. Keith, I tested the objective in this way on *Grammatophora subtilissima* by lamplight, and we both thought the definition unmistakably better than with water immersion." ("Month. Micr. Journ.," *loc. cit.*, p. 127).

It should be distinctly held in view that the publication of Mr. Tolles's formula took place in 1874, and from that formula any other competent optician might have constructed similar objectives. I think the formula could not be more accurately designated than by the title "homogeneous-immersion formula," though that expression was not employed till some seven years later.

The Zeiss oil-immersion objectives, made to a formula of Dr. Abbe, which he stated was the outcome of a suggestion by Mr. Stephenson, were not issued till 1878, and the formula has not yet been published.

If priority of publication of the formula on which homogeneous-immersion lenses could be produced carries with it the title of inventor, then Mr. R. B. Tolles stands alone as the inventor; but he not only published the formula, he constructed objectives on it. It would not do to say that Mr. Stephenson's suggestion was made with a view to obtaining apertures greater than correspond to the maximum for dry objectives. That might be quite true of Mr. Stephenson in 1878; but it was quite as certainly true of Mr. Tolles in 1874, at a date when Mr. Stephenson denied the possibility of any such apertures.

I have stated the claims of the late R. B. Tolles as against those of Mr. Stephenson under a consciousness of grave responsibility. The future of the microscope will probably be so much involved in the successful development of the homogeneous-immersion formulæ, that the merits of the originators of the system will have more and more substantial recognition. Amici led the way, as I have said, by the application of the immersion system to modern achromatic compound microscopes. He made objectives for use with oil-immersion and then with water-immersion, but, so far as I know, Amici merely aimed at getting more and more perfect correction of the aberrations, without any definite conception of the possible extension of apertures beyond those of dry objectives. The merit of Tolles was that he first published a formula by which the possible attainment of such apertures was demonstrated theoretically, and he supported his case by the practical construction of such objectives. His formula was strictly for ***homogeneous-immersion***, and his 1-10 inch objective, by the testimony of Dr. Woodward and Mr. Keith, constructed on that formula, gave its best results when used with homogeneous-immersion. It would be strange, indeed, if, when the history of the evolution of the homogeneous-immersion system comes to be written definitely, the whole credit of its invention should be given to Mr. Stephenson, in the face of the fact, to which I have already adverted, that at the date of the publication of Tolles's formula, Mr. Stephenson denied the validity of that formula by denying the possibility of the existence of the aperture computed, a denial which he appears to have persisted in until about the date of the publication, in English, of Dr. Abbe's admission that such apertures were possible. Mr. Stephenson's conversion from the wrong to the right side of the controversy was, of course, a valuable factor in support of the position of Tolles, whether it coincided accurately with Dr. Abbe's admission of the validity of Tolles's argument or not.

In conclusion, permit me to say that no expressions that I can employ will adequately convey my appreciation of the services rendered by Dr. E. Abbe, of Jena University, by the publication of his researches on the "Theory of Microscopical Vision." Dr. Abbe has revolutionised the old empirical views as to the value of high apertures, demonstrating that high amplifications, unless accompanied by proportionately high apertures, produce necessarily untrue images of minute structure. He has also introduced a practically perfect system of estimating apertures, known as the "Numerical aperture notation," by which not only can an accurate comparison be made of the relative apertures of any series of objectives, whether dry or immersion, but their resolving power under the various conditions of the kind of light employed, their penetrating power, and their illuminating power can now be estimated with mathematical exactness.

Dr. Abbe's services in connection with the practical production of objectives on the homogeneous-immersion system by Mr. Zeiss must also be recognised emphatically. It is known, too, that he has long been engaged on a problem of the highest importance for the progress of all optical instruments—the production of new kinds of glass, by which he anticipates greatly reducing the secondary spectra. Within a few days only we have had news of a most promising character regarding his success. I need hardly say that if this problem reaches a practical solution, microscopy will have a new start.

When I go back in memory to the condition of the microscope in my early days, and pass in review the progress I have witnessed in the construction of the instrument both optically and mechanically, in view of the great strides made in my time and of the possible improvement foreshadowed by Dr. Abbe's latest researches in the combinations of new kinds of glass, I am led most strongly to the conclusion that microscopy has before it the prospect of a glorious future.

For the use of the wood-cuts Figs. 79-83, 86, 92, 93, 97-100, 102, and 103, my acknowledgements are due to the Royal Microscopical Society.

ELEMENTARY LECTURES.

ELECTRICITY.

By Professor George Forbes.

Lecture VI.—Delivered May 22nd, 1886.

Practical Applications of Electricity.

At the conclusion of my last lecture I stated that I proposed to make an alteration in the programme. I had originally intended that my last lecture should have been upon the subject of electrical measurement, showing how a system of electrical units has been evolved, each one dependent upon the other. This would have been a very interesting field, and is a most important matter, and I should have been glad to include it in the course of lectures; but the course was started with a special object in view, that of passing in review all the fundamental principles and laws of electricity which regulate these numerous applications which we meet with every day, and to enable those who are not practical electricians to be able to understand what they meet with in the course of their daily life, in the numerous applications of electricity. For this reason I announced last week that I intended to change the subject of this lecture, and to review in a sketchy manner some of the more important practical applications of those general laws, principles, and discoveries which we have been examining for the last five lectures, and to show how these things are applied in actual practice. To-day I shall deal with some of the more important applications.

Among these applications I think you will all agree with me that the most important at the present time is the great facility which we have acquired of creating almost unlimited quantities of electricity by means of the transformation from mechanical power into electricity. This is the result of the dynamo machine. After that I propose to say something about another application, which has had a great deal to do with the development of civilisation in its present form, and that is the invention of the electric telegraph. And, in conclusion, I propose to speak of the still later invention, but one which has attained such a vast application in the short period of its existence, namely, the telephone.

In the development of invention applied to the progress of civilisation, there are two essentially different parts to be carried out. First, there is the grand field of discovery, and in this field of discovery in electrical science no name stands higher than that of our celebrated countryman, Faraday, whose name has been so often mentioned in these lectures. And, secondly, there is the work of the practical inventor, who realises the tools which have been put into his hand by the philosopher, and who applies these tools to evolve practical ideas, and turn out inventions which assist the progress of civilisation. I am first going to speak to you about the manner of construction of the dynamo machine, and all that I can hope, in this sketchy review of the subject, is to be able to tell you enough about it so that, when you see a dynamo machine running, you may be able to appreciate the object and purpose of the several parts of that machine, and be able to judge to some extent how far these different parts seem to be suitable to fulfil their offices.

In my last lecture, I showed you the action of this little machine which is due to Faraday, consisting of a coil of wire which is capable of rotation round one of its diameters. In doing so, it cuts the earth's lines of force—that

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FRIDAY, NOVEMBER 2, 1888.

All communications for the Society should be addressed to the Secretary, John-street, Adelphi, London, W.C.

Proceedings of the Society.

CANTOR LECTURES.

THE MODERN MICROSCOPE.

By John Mayall, Jun.

Lecture I.—Delivered February, 27, 1888.

Before proceeding with the subject-proper I have engaged to treat of in these lectures, I think it will be *à propos* that I should ask your attention to sundry points of historical interest, which will serve partly to supplement and partly to correct certain data and criticisms made thereon in my previous Cantor Lectures on the Microscope.* The matters I wish to refer to in this connection are generally such as have come to my notice within the last two years only, and this I trust will be considered a sufficient reason for dwelling upon them now.

I formerly stated that there was considerable difficulty in fixing the precise origin of the microscope, both as regards the actual date, and as to the particular form of the construction of the earliest models, but that the date was probably within the two decades comprised between 1590 and 1610.

If, however, we may consider the simple hand-magnifier as a microscope—and there is, I think, a general concurrence of opinion that we are entitled to do so—then I am able to establish the existence of microscopes in the early years of the 16th century by graphic evidence of a specially interesting kind, evidence that appears to have wholly escaped the notice of writers on the microscope hitherto. I refer to the portrait of Pope Leo X., painted by Raphael between 1513 and 1520, which is in the Palazzo Pitti, Florence, and in which the Pope is shown holding a hand-magnifier, evidently intended for the examination of miniatures, &c., in an open volume upon the table. Fig. 1 (p. 1150) is reproduced from an engraving of this portrait.

As it is hardly to be supposed that this hand-magnifier was the first ever constructed, we may infer with some probability that simple microscopes of this form may have been known in the 15th century, or even earlier. The construction of such an instrument would necessarily acquaint the optician with the dependence of the magnifying power on the curvatures of the lens surfaces, which would assuredly lead to the production of lenses of different power for various purposes; so that the evolution of the microscope may have been practically contemporaneous with the construction of the earliest spectacles—may, in fact, have been brought about through the experimental efforts to produce convex spectacle glasses suitable for different sights.

With this anterior evidence before us, demonstrating the existence of hand magnifiers so early, we need no longer perplex ourselves with endeavouring to interpret the vague passages in Fracastoro's "Homocentrica" which certain writers* have cited as evidence that he must have known the use of lenses combined as in telescopes, whilst others† think the matter doubtful.

Galileo's Microscopes.—The very early connection of Galileo's name with the evolution of the microscope is a fact of so much historical

* See *Journal*, vol. xxxiv. (1886), pp. [illegible], 1007-1021, 1031-1048, 1055-1071, and 1095-1121.

* Notably Tiraboschi, "Storia della Letteratura Italiana," Firenze, nuova ed., 18[illegible], vol. vii., pp. 475-6; Ginguené "Histoire Littéraire d'Italie," 2ième ed., Paris, 1824, vol. vii., p. [illegible]: also in his article on Fracastoro in the "Biographie Universelle:" and Libri, "Histoire des Sciences Mathématiques en Italie," Paris, 1840, vol. iii., p. 101.

† In Drinkwater's "Life of Galileo" (Penny Cyclopædia), it is stated that Fracastoro's "expressions, though they seem to refer to actual experiment, yet fall short of the meaning with which it has been attempted to invest them." Fracastoro's knowledge of the employment of lenses is based on the following passage, and another more vague, from his "Homocentrica," sec. ii., cap. 8 (p. 18 of the original edition, Venetiis, 1538, 4to), "per duo specilla ocularia si quis perspiciat altero alteri superposito, maiora multo et propinquiora uidebit omnia," which Drinkwater translates "if anyone looks through two eyeglasses, *one placed upon the other*, he will see everything much larger and nearer." Drinkwater adds: "It should seem that this passage (as Delambre has already remarked) rather refers to the close application of one glass upon another, and it may fairly be doubted whether anything analogous to the composition of the telescope was in the writer's thoughts." Arago, in his "Astronomie populaire" (Paris, 1854, vol. i., pp. 175-6, and Smyth and Grant's translation, London, 1855, vol. i., p. 113), cites the two passages from Fracastoro, and leaves the reader to decide how far they may be fairly taken to prove the possibility of Fracastoro having employed telescopes.

FIG. 1.

POPE LEO X. (FROM AN ENGRAVING OF RAPHAEL'S PAINTING IN THE PALAZZO PITTI, FLORENCE) WITH HAND MAGNIFYING GLASS. (1513—1520).

interest that any instruments bearing traditional association with him must be referred to here.

In the Museo di Fisica, Florence, are two small microscopes, which the Curator, Prof. Meucci, informed me have been handed down from generation to generation, since the dissolution of the famous Accademia del Cimento in 1667, together with other instruments, and with the tradition of being constructed by

FIG. 2.

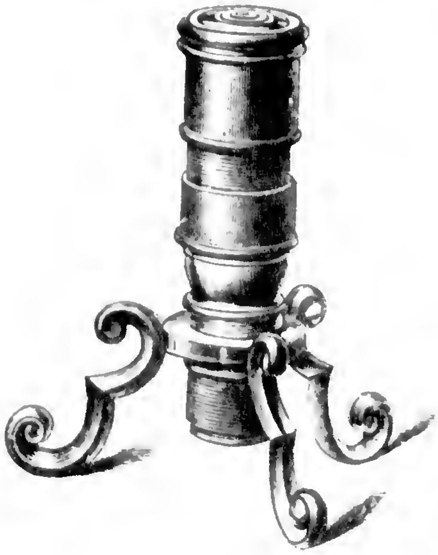
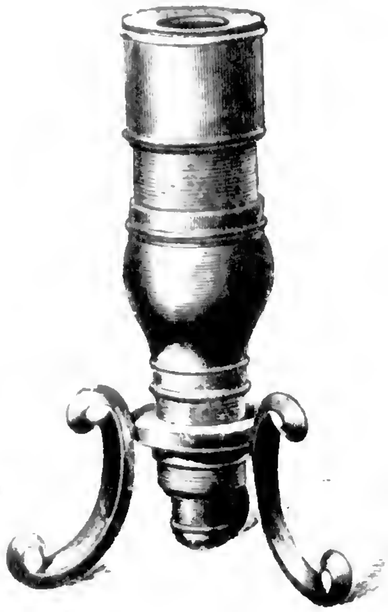


FIG. 3.



GALILEO'S MICROSCOPES.

FIG. 4.

CAMPANI'S MICROSCOPE (1686?).

Galileo. By the courtesy of Professor Meucci, I was enabled to secure photographs* of these microscopes, which are here reproduced in Figs. 2 and 3.

When I was permitted to examine these instruments some two years ago, and again about a year ago, I could not evade the suspicion that, if the tradition were critically examined, it might be extremely difficult, if not impossible, to track them to the days of Galileo. The construction of these two microscopes seemed to me so far superior to that of most of the optical instruments made within 20 or 30 years of the death of Galileo (1642), including Galileo's own telescope, that I could not avoid being sceptical as to their alleged origin. I note also the great similarity of design between these microscopes and that of Campani, Fig. 4, which I reproduce from my previous Cantor lectures. This form of Campani's microscope appears to have been first

* At the delivery of this lecture transparencies from the original negatives were projected on the screen by the oxy-hydrogen lantern, which enabled me to point out sundry details of the constuction which it has not been possible to show in the woodcuts given herewith.

published in 1686,* and as the original figure has escaped the attention of writers on the microscope hitherto, I here give a photo-zincograph of it (Fig. 5), which will also serve to illustrate what was then considered the proper mode of employing it.

In the matter of construction the advantage is clearly with the "Galileo" microscopes; the tripod, screw-socket, and the body-tube being of substantial metal, the focussing-screw gives a fairly accurate movement, whereas in the Campani instrument the lower portion, though of brass, is very slightly made, and, as the body-tube is of wood, the focussing-screw on the exterior must always have been an inferior arrangement.

I am aware of the difficulties incident to any estimation of the date of these "Galileo" microscopes based merely on what one may consider primitiveness of design, for experience

Fig. 5.

Novum Microscopium Dn: Iosephi Campani, ejusque usus.

has long informed me that some of the rudest designs have been re-invented over and over again, even in this century. But in these "Galileo" microscopes, neither the design nor the execution appear to me "primitive;" on the contrary, they evince, in my opinion, far too much knowledge of the requirements of microscopes for the date assigned to them *ante* (1642). As the Museo di Fisica contains a large number of optical instruments constructed in the 17th century, comparisons can be readily made, which I did on the two occasions mentioned, and my conclusion was, that these microscopes represent a later date

* "Acta Eruditorum," Tab. x. (pp. 371-2). This date (1686) must cancel my former conjecture as to the possible earlier date of the construction. In the Dresden Museum of Physical Instruments is a microscope of this orm, bearing Campani's name, and the date 16.0.

of construction, the design and workmanship being altogether superior to the optical instruments the construction of which dates back to Galileo's time.

By way of illustration of the simplicity of some of the early microscopes, I give a reproduction in Fig. 6 of an instrument

FIG. 6.

CAMPANI'S MICROSCOPE (1673?).

in the Museo di Fisica, standing near the so-called "Galileo" microscopes, which, from its similarity to a microscope in the Conservatoire des Arts et Métiers, Paris, bearing the inscription, "Giuseppe Campani, in Roma, 1673," I should confidently assign to Campani. The "Galileo" microscopes clearly represent a higher grade of mechanical design and construction.

Schott's Microscopes.—I formerly reproduced certain curious figures of microscopes from Gaspar Schott's "Magia Universalis" (1657), expressing myself against the probability of their having ever been constructed as shown. A suggestion has been made by Mr. Frank Crisp, Secretary of the Royal Microscopical Society, by which the anomalous appearance of the instruments may be explained, and as the suggestion appears to me highly probable, I venture to bring it to your notice. To render the matter readily intelligible I reproduce the figures again. (Figs. 7, 8, and 9, p. 1154.)

It is obvious that we estimate the size of the microscopes by comparison with the size of the observer figured with them. Mr. Crisp suggests, then, that the draughtsman, knowing probably nothing of the subject, instead of figuring an eye only directed to the instruments, represented the full-length figure of the observer, whence we estimate the microscopes to be of prodigious size. This explanation is supported by a comparison with Figs. 10, 11, and 12, (p. 1154) from Traber's "Nervus Opticus" (Viennæ Austriæ, 1675, fol., Pl. IV.), in which references are made to Schott's work.

This explanation seems to me the more acceptable from the fact that in describing Divini's microscope (Fig. 9), Schott states that it had a tripod support—"*super tripedale fulcrum*"—which his draughtsman has converted into the fanciful picture of an enormous cylindrical tube, with the observer standing on a sort of embankment to look into it; whereas Traber's figure (my Fig. 12) plainly shows the support, and the instrument appears of reasonable dimensions. Moreover, Schott distinctly states that Fig. 13, p. 1155 (Descartes' lens) was taken from Kircher's "Ars Magna Lucis et Umbræ" (Romæ, 1646, fol.), and on reference to that work we find an eye only directed to the lens (see my Fig. 14, p. 1155, reproduced from Kircher's work); and we note, further, that the insect figured by Kircher on the end of a pointed rod was converted by Schott's draughtsman into a candle flame!

Hooke's Microscope.—The application of the field-lens to the eye-lens in compound microscopes (described by Hooke in his "Micrographia," 1665) appeared to me the most important item of Hooke's improvements in microscopes; but further research has convinced me that he was preceded by Monconys in this application.

Moncony's Microscope.—In the "Journal des Voyages de Monsieur de Monconys" (Lyon, 1665, 4to, 1ère partie, p. 128) we find a description of his microscope, which I here give in translation:—

Distance from the object to the first lens, *one inch and a-half.*

The focus of the first lens, *one inch.*

Distance from the first lens to the second, *fifteen inches.*

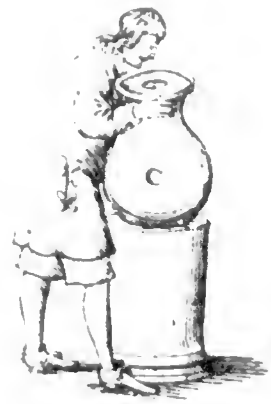
Focus of the second lens, *one inch and a-half.*

Distance from the second to the third, *one inch and eight lines.*

FIG. 7.

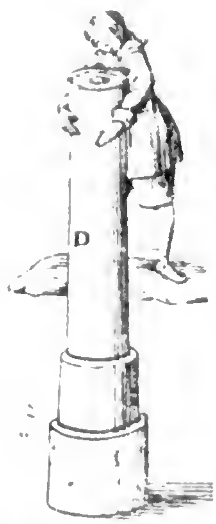
MICROSCOPE FROM SCHOTT'S "MAGIA UNIVERSALIS" (1657).

FIG. 8.



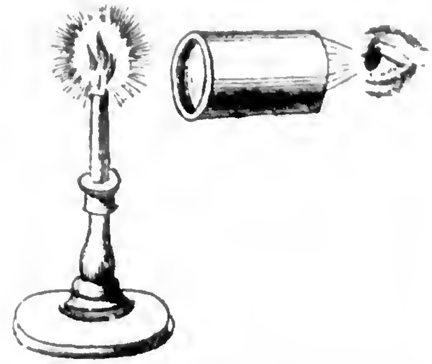
MICROSCOPE FROM SCHOTT'S "MAGIA UNIVERSALIS" (1657).

FIG. 9.



"DIVINI'S" MICROSCOPE, FROM SCHOTT'S "MAGIA UNIVERSALIS" (1657).

FIG. 10.

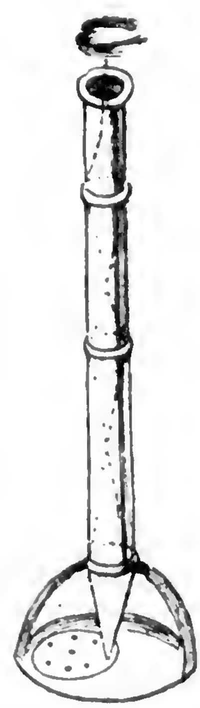


MICROSCOPE FROM TRABER'S "NERVUS OPTICUS" (1675).

FIG. 11.

MICROSCOPE FROM TRABER'S "NERVUS OPTICUS" (1675).

FIG. 12.

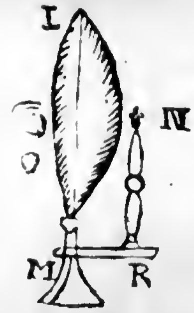


"DIVINI'S" MICROSCOPE, FROM TRABER'S "NERVUS OPTICUS" (1675).

FIG. 13.

DESCARTES' LENS, FROM SCHOTT'S "MAGIA UNIVERSALIS" (1657).

FIG. 14.



DESCARTES' LENS, FROM KIRCHER'S "ARS MAGNA, &C.," (1646).

Focus of the third lens, *one inch and eight lines*.
Distance from the eye to the third lens, *[illegible]*.

It is evident that a compound microscope having a field-lens could be constructed from these data. Monconys died in [illegible], and from a note on p. 117 (*loc. cit.*) it appears that he had the instrument made, in [illegible], by the "son-in-law of Viselius."

In support of Monconys's claim to have first devised a microscope with a field-lens, I may note the testimony of Honorato Fabri, who states in his "Synopsis Optica" (Lugduni, 1667, 4to.), p. 153, that the first instrument known to him of this construction was made at Augsburg to the design of Monconys.

Wherever Monconys travelled he was alert in searching for microscopes and telescopes. In visiting Italy he met Toricelli, Kircher, Divini, and others connected with scientific pursuits, and coming to England in May, 1663, he mentions (*loc. cit.*, 2me *partie*, p. 11) that he visited "Riues en Longenker" (Reeves, of Long-acre), "who makes excellent microscopes," and that a few days later he called again, and was shown a "lanterne sourde" (dark-lantern = "magic-lantern"), having a "hemisphere of crystal of about three inches diameter, which projects to a great distance the images of objects which he places between the light and the crystal lens, by means of a sheet of glass on which they are painted" (*ib.*, pp. 17-18). Other visits to Reeves are mentioned, and on the 3rd of June he called on Boyle and saw "two excellent microscopes, which surpassed his own in size but not in clearness." The next day he again saw Boyle, who explained that in order to examine perfectly the eye of an ox or other animal, he froze it, and then easily cut sections of it, which is the earliest reference I have met with to section-cutting by the freezing process. He mentions also seeing, at Christopher Wren's house in Whitehall, "drawings of a flea . . . . and of a fly's wing made by the microscope."

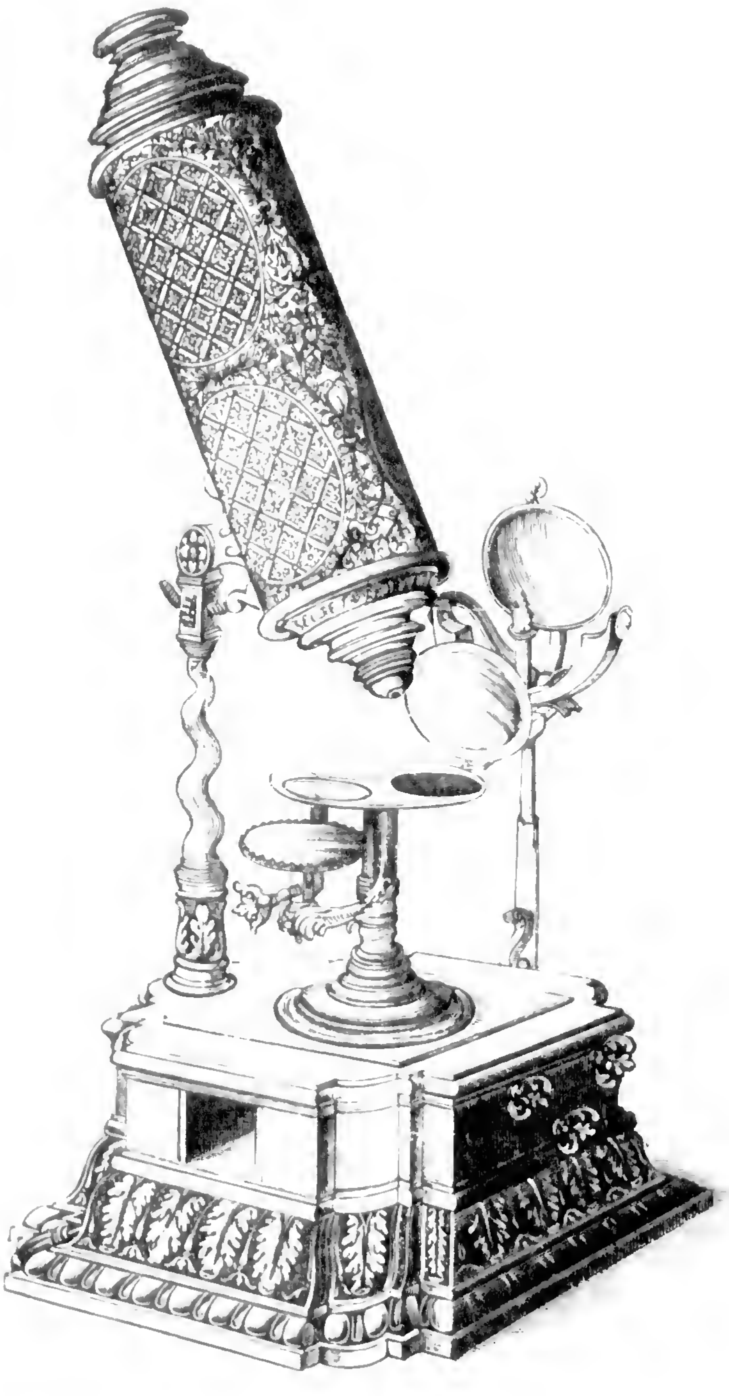
At La Haye, Holland, in August, 1663, he called on Isaac Voss ("Vossius"), and saw his microscope, consisting of "a hemispherical lens mounted in a wood cell, to slide behind a small black tablet, or screen, concaved on the side applied to the eye, and pierced in the middle by a very small hole" (*ib.*, p. 153).

Hertel's Microscope.—The first application of a mirror to the microscope is a point of particular interest in the history of the instrument, and as I have not met with any earlier reference to it than that in Hertel's "*Anweisung zum Glas-Schleifen* (Halle, 1716, sm. 8vo.), Tab. XVIII., I here give a woodcut from his original figure (Fig. 15, p. 1156).

The mirror seems to have been plane ("ein runder plan-spiegel," *loc. cit.*, p. 141). The instrument is otherwise remarkable, (1) for the arrangement of the moveable stage on a special pillar support; (2) for the illuminating arrangement, consisting of a concave metal mirror reflecting the light through a condenser upon the object; (3) for the curious hinge and screw-sector mechanism for inclining the body-tube; and (4) for its generally ornate character, which point probably received attention that would have been more usefully bestowed in making the essential parts of the instrument more substantial.

Lieberkühn's Microscope.—The "Lieberkühn" has become so essential a part of every microscope since its practical development by Dr. N. Lieberkühn, about 1735 (though, as I formerly showed, Descartes had figured an appliance embodying the same principle in his "Dioptrique," published anonymously with his "Discours de la Méthode," in [illegible]), that the first figure of

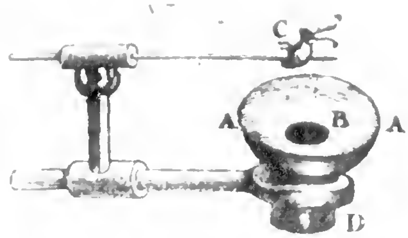
FIG. 18.



HERTEL'S MICROSCOPE (1716)).

the device cannot fail to be viewed with interest by every microscopist. Fig. 16 is

Fig. 16.



LIEBERKUHN'S MICROSCOPE (1739).

reproduced from the earliest drawing I have found of Lieberkuhn's microscope, in P. Van Musschenbroeck's "Essai de Physique,"* tome ii., pl. xxiv., fig. 10. The description of the instrument and its employment is thus translated:—

"There has also been recently discovered a good way of strongly illuminating large opaque objects, so that they may be examined by every kind of microscope, even by means of the smallest kinds. AA is a small spherical concave mirror of fine silver, well ground and polished, whence the light is reflected to a focus on the object C, so that it is strongly illuminated at the back. The mirror is pierced in the middle, B, and the microscope lens or object glass is then inserted and adjusted either forward or backward; the eye is placed at D, and the object is seen very clearly." (Loc. cit., p. 515.)

Fig. 17 is engraved from one of the earliest forms I have met with of Lieberkuhn's microscope.

Fig. 17.

LIEBERKUHN'S MICROSCOPE.

Having disposed of the more important items relating to the early history of the microscope to which I wished to direct your attention, I come to the distinctly modern microscopes. I premise that it would probably be found a convenient arrangement to divide microscopes into two great classes, Ancient and Modern; the former term to include all microscopes made anterior to the general introduction of achromatism (1824), whilst the latter term would designate all microscopes constructed subsequently.

The application of achromatism to the microscope produced great changes in the construction of the instrument. The increase of the apertures of the objectives, involving, as it did, the decrease of the depth of the focal plane, immediately betrayed many imperfections in the design and construction of the focussing arrangements that had previously been either unnoticed or regarded as unimportant.

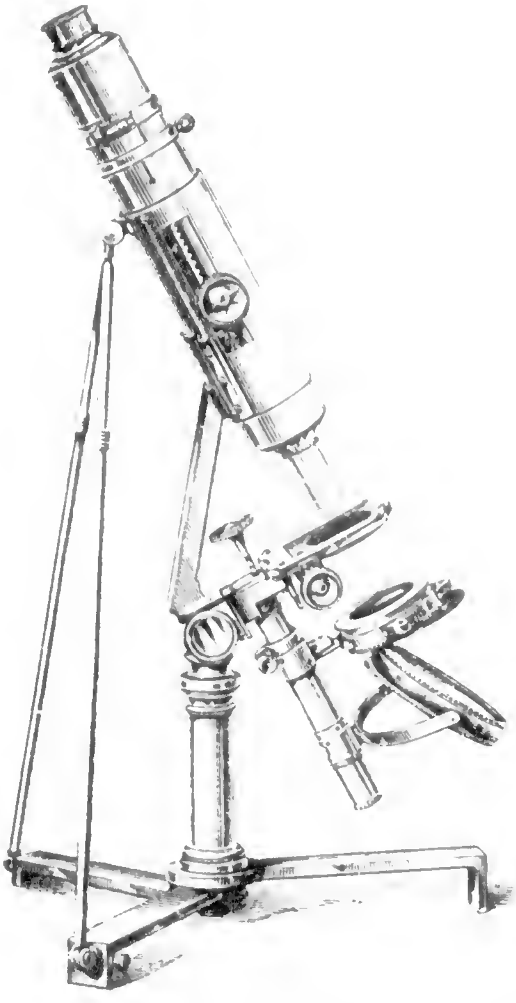
I formerly gave a figure of the earliest form of achromatic microscope made in France—Selligue's. I am now able to place before you one of the earliest known English models—Tulley's (Fig. 18, p. 1158). The former had no very distinctive claims to originality of design, but was only slightly modified from what was at that period one of the best English microscopes made by Adams, or Jones, or Dollond. In the instruments I have seen bearing Selligue's name, the objectives (and possibly the oculars) were made by Vincent Chevalier (who worked to Selligue's instructions), while the brass-work was made by himself. In the Tulley microscope here shown, struts are applied, connecting the case with the body-tube, the stage has mechanical movements, one movement being lateral in arc, but no special fine-adjustment was applied, probably because the first achromatic objectives made by Tulley were low powers of such moderate apertures that the ordinary rack to the body-tube was found sufficiently sensitive as a focal adjustment. The substage is provided with a rotating disc of graduated diaphragms; the draw-tube is graduated, evidently for the purpose of registering various magnifications, and an erecting combination is applied, whence it would appear that the intention was to work at dissections.

A glance through the instrument shows at once a great increase of light, due to the

* Two vols. 4to, Leyden, 17—.

achromatic objective, when compared with a single lens object-glass of equal power, for the latter could give a tolerable image only when a very small diaphragm was applied, whereas the former permits the full diameter of the combination to be utilised.

FIG. 18.

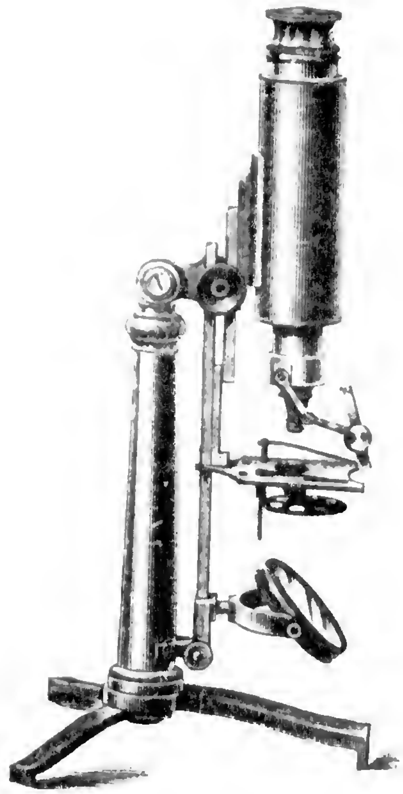


TULLEY'S ACHROMATIC MICROSCOPE.

beneath the stage. The conical dark-chamber in the form of a diaphragm fitting beneath the stage was known and employed early in the last century by Culpeper and others; whilst graduated diaphragms were used with Wilson's "screw-barrel" microscope (170-), and even earlier, as I formerly showed with Musschenbroek's microscope, in which several apertures were cut in a small plate moving in arc across the optic axis of the object-glass.

I am not able to prove that Chevalier was the first to apply the disc of diaphragms to

FIG. 19.



C. CHEVALIER'S ACHROMATIC MICROSCOPE.

In further illustration of the early forms of achromatic microscopes I give a figure of one of Charles Chevalier's instruments (Fig. 19)—his influence on the development of the achromatic microscope, as evidenced by the high reputation he acquired by his subsequent invention of the "Microscope Universelle," entitling him to special notice in this connection. The early date of its construction may be inferred from the fact that it is almost exactly similar to Selligue's (1824).

We have here also a revolving disc of graduated diaphragms, which is applied below a truncated conical dark-chamber the microscope, but the method he employed in the application seems to have favourably impressed his contemporaries, for we find that Amici adopted it immediately, and the system has held its ground to the present day, and is still much in vogue for regulating the light, whether used alone, or combined with a condenser. For low-power work the "Iris" diaphragm will probably supersede it; but where extremely delicate changes of light are required, as in critical work with achromatic condensers of high aperture, the perfection of centering obtained with the disc is a great desideratum. The more recent system, " employment of a diaphragm-carrier pivoting out of the axis, as in Abbe's condenser, by which the range of different apertures can be increased to any extent, is a substantial advance, and has been adopted in the latest form of Powell and Lealand's apochromatic condenser.

Miscellaneous.

BARCELONA EXHIBITION.

By BENNETT H. BROUGH,
Assoc.R.S.M., F.G.S., F.I.C.

A general report on the Barcelona Exhibition, by the Secretary of the Society, appeared in the *Journal* of October 12th. This I have been asked to supplement with some notes on the mining exhibits, which are amongst the most interesting and important of those in the exhibition.

Among the mining countries of the world, Spain occupies a prominent position. At the present time it is the chief producer of quicksilver, and until quite recently was also the chief producer of lead; the copper mines of Huelva are the most important in Europe; the iron mines of Bilbao are celebrated for the quantity of the ores, and for the quality of the metal produced from them; its coalfields are extensive, and ores of zinc and of other metals occur in great abundance. It was, therefore, to be expected that in a Spanish exhibition the exhibits relating to mining would be of the greatest interest, and at Barcelona they justly occupy a prominent position.

Thanks to the aid of the Spanish Government, with its corps of trained mining engineers, the rich mineral resources of the kingdom are fully shown. It is therefore possible for attention to be directed to those deposits that await further development, and that promise to open up a lucrative field for foreign capital. Indeed, this field seems to be inexhaustible, for although Spanish mining is so ancient as to have been carried on by the Romans, fresh discoveries of workable deposits are of frequent occurrence. The great antiquity of Spanish mining is well shown by the interesting collection of archæological objects found in the Rio Tinto mines. From there, too, has been brought a Roman mine-door in excellent preservation, whilst another, equally well preserved, is shown from the San Jose mine at Mazarron. An interesting prehistoric object is a human skull impregnated with carbonate of copper, found in the El Milagro mine at Onis.

The geological structure of Spain is clearly elucidated by the exhibit of the Geological Survey, who show, arranged in stratigraphical order, an exhaustive collection of Spanish rocks and fossils, as well as a collection of all the geological maps of Spain yet published. The National Corps of Mining Engineers exhibit specimens of Spanish minerals and ores from almost every known locality, admirably arranged according to the mining districts. Altogether there are 3,000 specimens, supplemented by 100 plans and photographs. This exhibit forms one of the most instructive mineralogical collections ever brought together, and gives a good picture of the mineral wealth of a country naturally very rich, and now rapidly developing under the influence of improved means of communication. Among the specimens from the Barcelona mining district, a prominent place is given to some splendid specimens of rock-salt of various colours from the Cardona mine, an absolute mountain of salt, some 500 feet in height, and three miles in circumference. A collection of minerals of scientific, rather than economic, interest is shown by the Madrid School of Mines. It numbers 112 specimens, including many of great rarity. The school also shows a collection of 95 specimens of marble, another of Spanish mining and metallurgical tools, and, lastly, a number of interesting models, including one of the winding engines of the Magdalena pit of the Villanueva del Rio Colliery, and another of the machinery for transporting and shipping iron ore employed by the Orconera Company at Bilbao.

The installation of the Almaden mines in the central nave of the Palace of Industry enables an accurate idea to be formed of the present state of these wonderful mines, where the lode sometimes attains a thickness of ten yards, and where no diminution of richness threatens the duration of the workings. Three collections, one of minerals including huge masses of solid cinnabar, one of rocks, and one of metallurgical specimens, serve to explain the nature of the occurrence of the ore and its metallurgical treatment, whilst numerous plans and photographs enable all the operations to be thoroughly understood. Two wooden models represent, on a scale of 1-25th, a pair

W. J. LINTON, "Wood Engraving." Two Lectures.
February 11, 18.

WALTER CRANE, "The Decoration and Illustration of Books." Three Lectures.
March 4, 11, 18.

C. V. BOYS, F.R.S., "Instruments for the Measurement of Radiant Heat." Four Lectures.
March 25; April 1, 8, 15.

H. GRAHAM HARRIS, M.Inst.C.E., "Heat Engines other than Steam." Four Lectures.
May 6, 13, 20, 27.

JUVENILE LECTURES.

Two Juvenile Lectures, entitled "How Chemists Work—an example to Boys and Girls," by HENRY E. ARMSTRONG, Ph.D., F.R.S., will be given on Wednesday evenings, January 2 and 9, 1889, at Seven o'clock.

Proceedings of the Society.

CANTOR LECTURES.

THE MODERN MICROSCOPE.

BY JOHN MAYALL, JUN.

Lecture II.—Delivered March 5, 1888.

It would demand far more time than is placed at my disposal were I to endeavour to illustrate fully the immense variety of modifications in the mechanical and optical construction of the microscope made since the application of achromatism. I must, therefore, limit myself to a rapid outline of those points which have seemed to me most essential.

In the mechanism of the achromatic microscope, no part has had more serious attention, from those who have sought to improve the instrument, than the fine-adjustment. I quite agree with those microscopists who have said that the crucial point of excellence in the highest class of microscope is the fine-adjustment. No elaboration of variety of movements, no monumental solidity of general form, will avail, unless combined with a good fine-adjustment. No microscope should be considered as ranking in the first class unless the fine-adjustment bears critical testing.

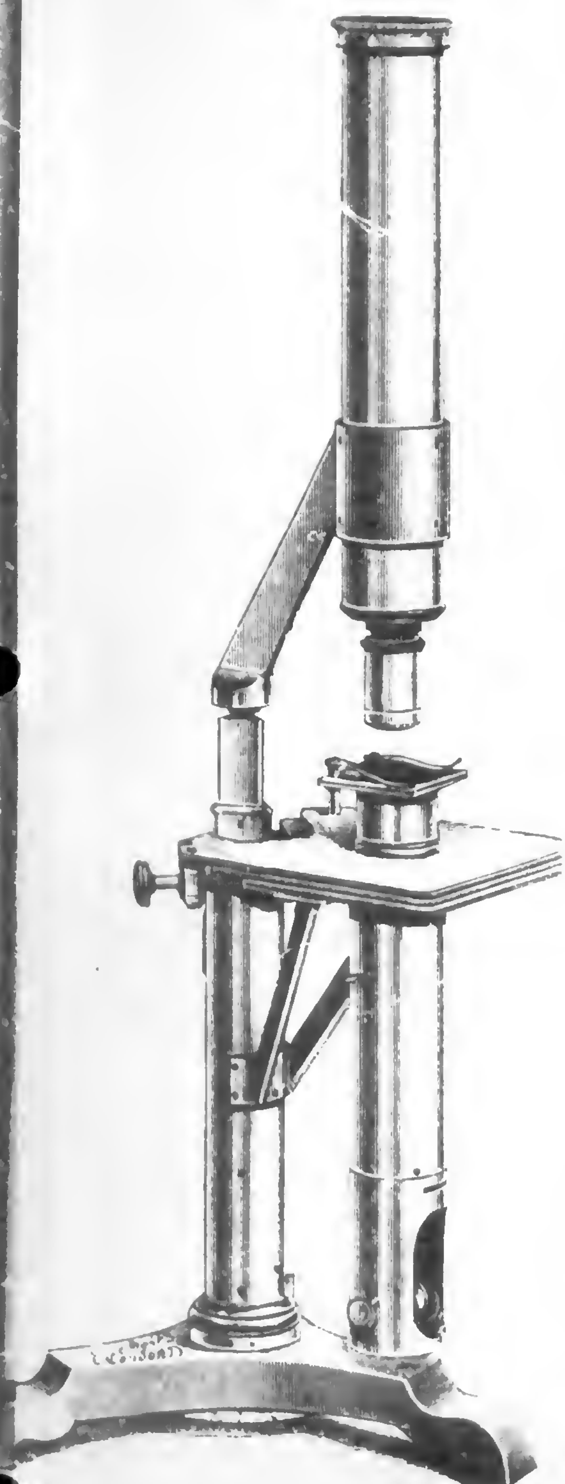
In estimating the merits of the vast series of microscopes of different designs constructed since the application of achromatism, allowance must be made for the fact that in the early days the mechanism—in England, at least—was decidedly in advance of the optical construction, so that during nearly thirty years—or up to about the year 18[illegible]—what we should now term critical testing was hardly possible. A great number of microscopes, however, were produced, by Pritchard, Smith (afterwards Smith and Beck), Andrew Ross, and Hugh Powell (afterwards Powell and Lealand), previous to 1850, that were more than equal to any contemporaneous microscopy required of them.

Of Pritchard's share in perfecting the microscope I cannot speak favourably. Beyond aiming generally at supplying good average workmanship, with a strong tendency in favour of mechanism by which the microscope could be raised or lowered, or turned about in very puzzling directions, with clamping screw-collars that seem designed to battle the ingenuity of the microscopist by the complexity of their action; or, again, in the application of candle-holders with eye-shades, and condensers with single, double, or triple arms, plaster mirrors, bottle holders, &c., &c., most of which movements and appliances served no practical purpose beyond making the instrument more costly, I am not aware that he is entitled to much credit for originality. He was, however, one of the first opticians in England to recognise the merits of C. Chevalier's early achromatic object-glasses, with which he furnished many of the microscopes bearing his own name.

Pritchard's name was so intimately associated with that of Dr. Goring, the inventor of the "Operative Aplanatic Engiscope," that this seems a fitting occasion to mention the instrument, which was elaborately figured in their joint production entitled "Microscopic Illustrations" (London, 1838, 8vo.). It may be briefly described as a large microscope, not differing essentially from many constructed during the previous forty years by Adams, Dollond, or Jones; but instead of the usual inclining-hinge or cradle-joint, Goring applied a ball-joint on the top of the pillar, by which he combined in one piece of mechanism the variety of movements which Pritchard previously obtained in a more complex manner. In the ball-joint Goring was clearly preceded by B. Martin in the instrument I formerly figured from his "Micrographia" (17[illegible]). In most of the other arrangements there was li[illegible] or no originality. The ball-joint as thus employed, when judged on its merits as a practical appliance, must be condemned, especially in connection with so large a microscope.

Andrew Ross seems never to have wearied of experimenting with different systems of fine-adjustment, and he must be credited with the successful evolution of the long-lever system acting on the nose-piece, which obtains in the highest class microscope of the present day—I refer to Powell and Lealand's. I have here microscopes by him embodying all the leading designs of fine-adjustments, constructed anterior to that system known as Zentmayer's (1876).

FIG. 20.

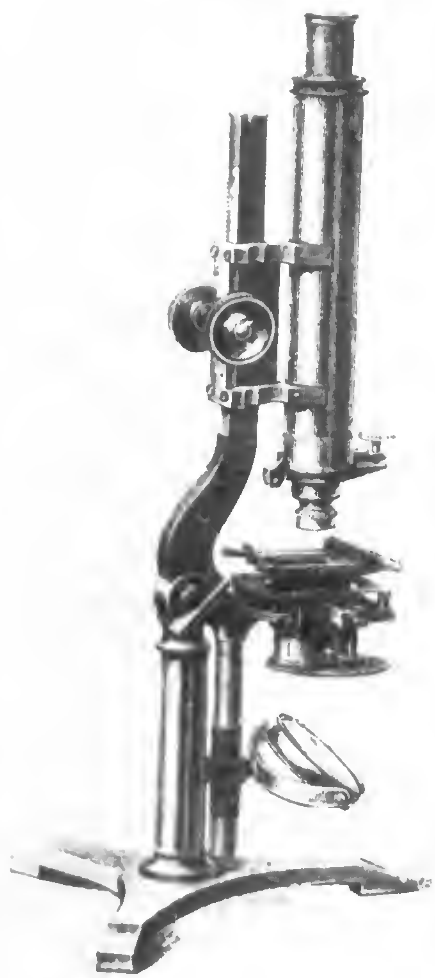


ROSS'S ACHROMATIC MICROSCOPE (EARLY FORM).

The earliest microscope I have seen by Ross is shown in Fig. 20; it has no inclining movement. The fine-adjustment consists of a long screw passing up the pillar and acting on a triangular sheath, within which the stem is applied to move with rack and pinion, the top of the stem being hollow, to receive either the cross-arm support for the single lens, or the limb of the compound body. The screw is actuated by a large graduated milled head beneath the tripod. The stage is supported by extra bracket-pieces on either side, intended primarily to avoid the flexure due to the pressure of the observer's hands in making dissections, and rectangular mechanical movements are applied, acting diagonally on either side of the stem by rather fine screws, so that the motions are very slow. The last point seems to me one in which the mechanism of the more modern microscopes has not met the requirements for high class work, for in the great majority of instruments the mechanical stage-movements act far too rapidly. This defect holds specially with the mechanism first devised, I believe, in France, but subsequently improved by Tolles, of Boston, and Wenham (the inventor of the binocular system known as the "Wenham"), in which the actuating milled-head pinions are placed vertically to the surface of the stage, by which the movements are confined within the circumference of the stage. By this modification a complete rotation of the object is effected with microscopes of the "Jackson" form; whereas, by the older system, in which the pinions project horizontally beyond the stage, the rotation is from one side of the limb to the other only, *i.e.*, is limited by the limb.

Ross seems to have modified the microscope above-figured by converting the pillar into a tail-piece, retaining the focussing-screw at the lower end; and at the upper end, near the pinion, he applied a cradle-joint to incline on a pillar and tripod. Then (apparently in rivalry with James Smith) he adopted a complicated system, consisting of a hinged stirrup-piece encircling the sheath of the body-tube stem, lifting up this sheath by a fine screw at the back. He applied a similar mechanism to act on the nose-piece only, which is known as Jackson's system, as shown in Fig. 21, which figure is interesting also as proving that he worked out a form of "Jackson" limb supporting the body-tube. He tried various modifications of this fine-adjustment, and also

FIG. 21.



A. Ro[illegible] Micros[illegible].

of the (probably an[illegible]) system of a screw-cone acting on the nose-piece. I have met with one curious experimental device of his, in which he fitted a long screw at the back of the body-tube, the thread of which served as a rack to the pinion for the coarse-adjustment, whilst the turning of the screw itself, engaged in the teeth of the pinion, gave the slow motion, thus combining in one piece of mechanism both fine- and coarse-adjustments. He then appears to have followed the lead of Hugh Powell in applying the fine-adjustment to the stage, stimulated, doubtless, by the fact that the Society of Arts had awarded Powell a medal for a very elaborate form of this mechanism. From that period (about 1841) he seems to have definitely worked at the long-lever system applied to the nose-piece by means of what is known as the cross-arm supporting the body-tube on the stem, which he brought to great perfection, a perfection excelled only, so far as my experience informs me, by Powell and Lealand.

The encouragement given to the construction of microscopes by the Society of Arts, in awarding medals for special points of excellence, is a fact of so much interest that I here give a figure of Hugh Powell's microscope (Fig. 22, p. 1167), bearing the date 1841, and embodying the fine-adjustment applied to the stage.

As a piece of mechanism this fine-adjustment is extremely good, the motion is very delicate; but the application to the stage cannot be commended from our present point of view. The requirements of modern microscopy are not met adequately by the movement of the object between the objective and the condenser with every touch of the focal adjustment. With such an arrangement the difficulties of the manipulation generally are so great as to be practically intolerable. We have now become so accustomed to the use of exactly centered and focussed illumination, remaining constant upon the object, by means of substage mechanism, allowing modifications in the light to be rapidly made to suit the different objectives in use, that we could hardly test such a microscope as this in a manner to fairly estimate its mechanical excellence.

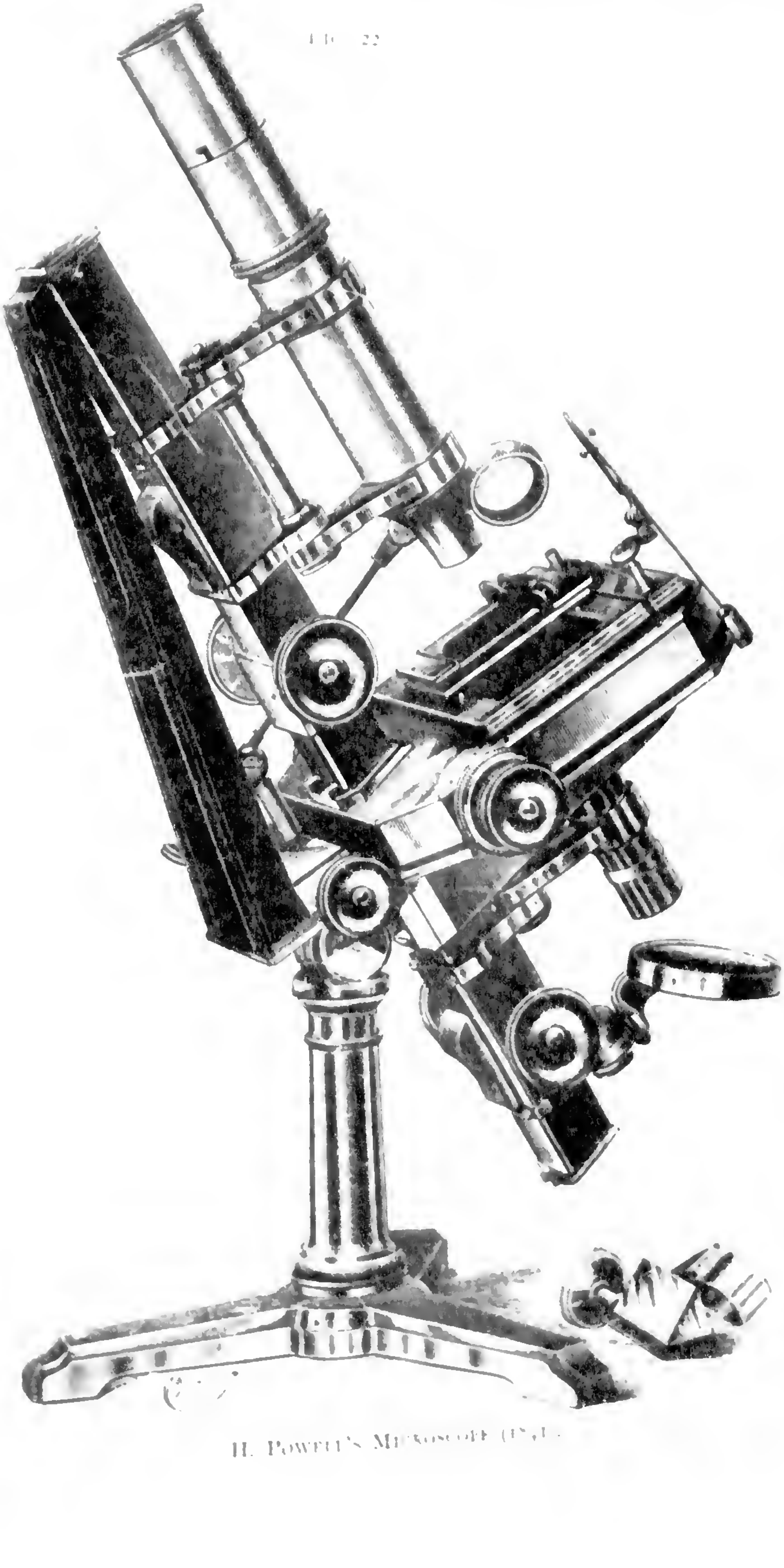
Another microscope of special interest is shown in Fig. 23 (p. 1168); it is the first model made by Smith and Beck embodying the "Jackson" limb and fine-adjustment. This system of fine-adjustment is now generally admitted to be defective; the position so near the nose-piece is not favourable for really critical work with our modern objectives of large aperture. The modification of it I formerly noted upon, devised by Dr. Hugo Schroeder, in which the actuating milled head is brought away from the nose-piece to near the eye-piece, and in which slowness of motion was obtained by the employment of a differential-screw, does not seem to have stood the test of experience, for

I observe that the makers (Ross & Co.) have given up the differential-screw in favour of a direct-action screw of fine pitch; and according to the experience of microscopists who have used the later system it still leaves much to be desired.

Of other systems of fine-adjustment that have come under my notice I may briefly note:—

1. The Zentmayer plan of making the fine-adjustment slide carry the coarse-adjustment with all its weight of body-tube, eye-piece,

FIG. 22.



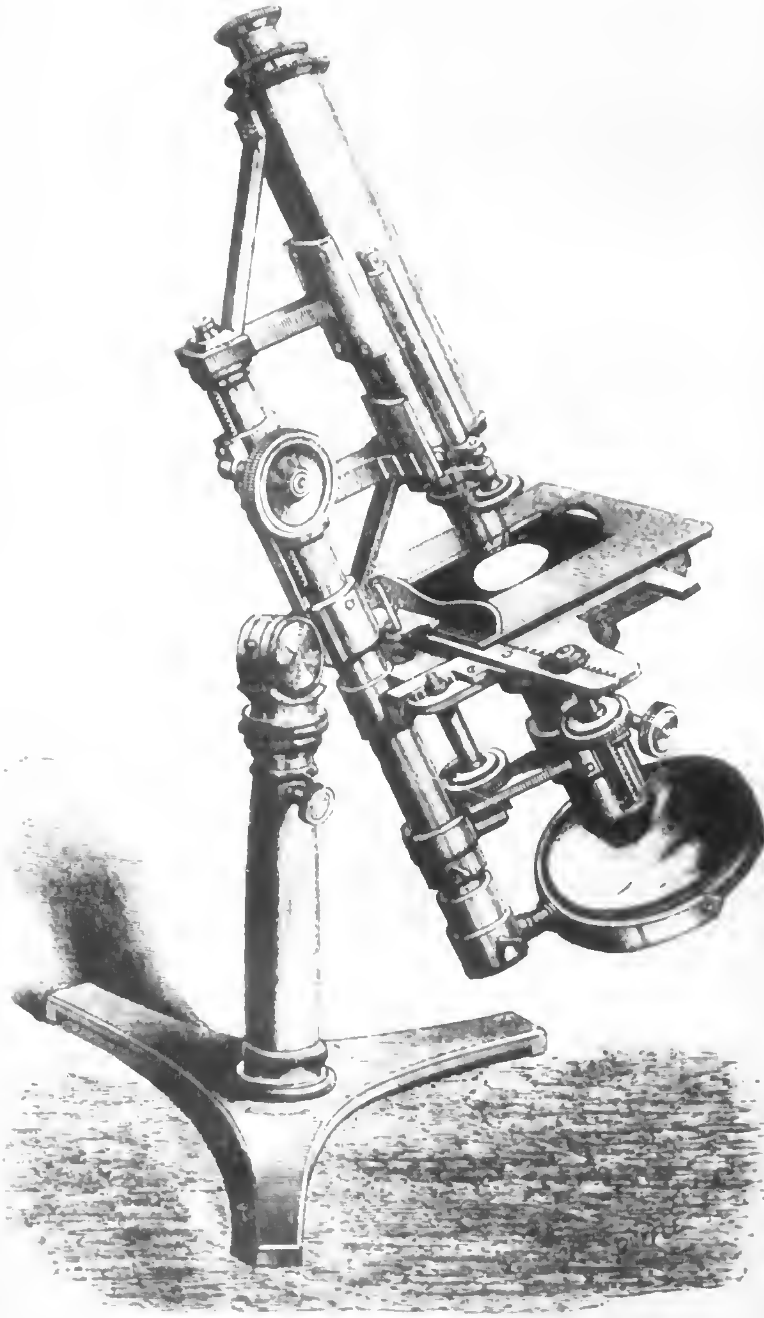
H. POWELL'S MICROSCOPE (1884).

objective, milled heads, &c., has long seemed to me defective, whether actuated by a lever and screw, or by a screw-cone.

2. Swift's long-lever actuating the body-tube, which I formerly commended, is well-spoken of by those who have worked with it continuously, and is probably the best fine-adjustment yet applied to the "Jackson" microscope.

3. Seibert and Krafft's parallel-bar suspension of the body-tube, and the analogous system, devised by Bausch and Lomb, in which broad parallel spring-plates carry the body-tube, have been largely employed for "economical" microscopes; perhaps, indeed, no better systems have ever been employed for such microscopes. I note, too, that in the latter form Messrs. Swift have applied a lever, by which the focussing is rendered more sensitive.

Fig. 23.



SMITH AND BECK'S MICROSCOPE.
(JACKSON'S FIRST FORM.)

3. The differential-screw, as proposed by Rev. James Campbell, has met with much approval from Mr. E. M. Nelson, and is regarded by him as decidedly superior to the usual "Continental" fine-adjustment, as employed by Hartnack, Nachet, Zeiss, Leitz, or Reichert. Personally I have not found the differential-screw mechanism sufficiently well made to impress me favourably.

4. Various systems of fine-adjustment by tilting the stage, which are mostly revivals of what were generally regarded as obsolete forms, have been brought forward with more or less pretension recently, and I should hope I need not criticise them.

Regarding the utility or otherwise of a racking and centering substage, I shall only say that, in my opinion, every microscope with which it is intended to do serious work should have such a substage; and if the opticians would supply an adapter fitted with a pivoting diaphragm-carrier, or even a disc of apertures, so that objectives could be conveniently used as condensers, they would add much to the interest of popular microscopy. As it is, I fear the great majority of possessors of microscopes are not aware of the immense advantages attendant upon the use of condensers, achromatic condensers being, of course, far preferable, for it is with them alone that it is really practicable to observe objects projected, as it were, in the image of the source of light focussed by the condenser.

It is, without doubt, highly desirable to have a series of achromatic condensers, of different foci, to suit the field of view of objectives of different power. It appears not to be generally known that distancing the lamp from the microscope will give a considerable range of size of luminous field, with one and the same condenser.

As to the general form of microscope that I most approve for high-class work, I have never seen any instrument to compare favourably with that of Powell and Lealand. I do not hold with certain microscopists—notably Mr. E. M. Nelson—in considering the tripod base, as made by Powell and Lealand, the only really good form. I think the projection of the feet beyond the vertical plane of the tail-piece, thus restricting the free use of the mirror-arms, when the instrument is vertical, or only slightly inclined, is inconvenient. But this is only a minor point, which I mention because I think too much stress has been put upon the merits of this or that particular form of construction of the base, regardless of the fact that the *essential* matters are the absolute steadiness of the instrument combined with the utmost freedom for the manipulations—which matters, so far as they are dependent on the form of the base, admit of many varieties of design.

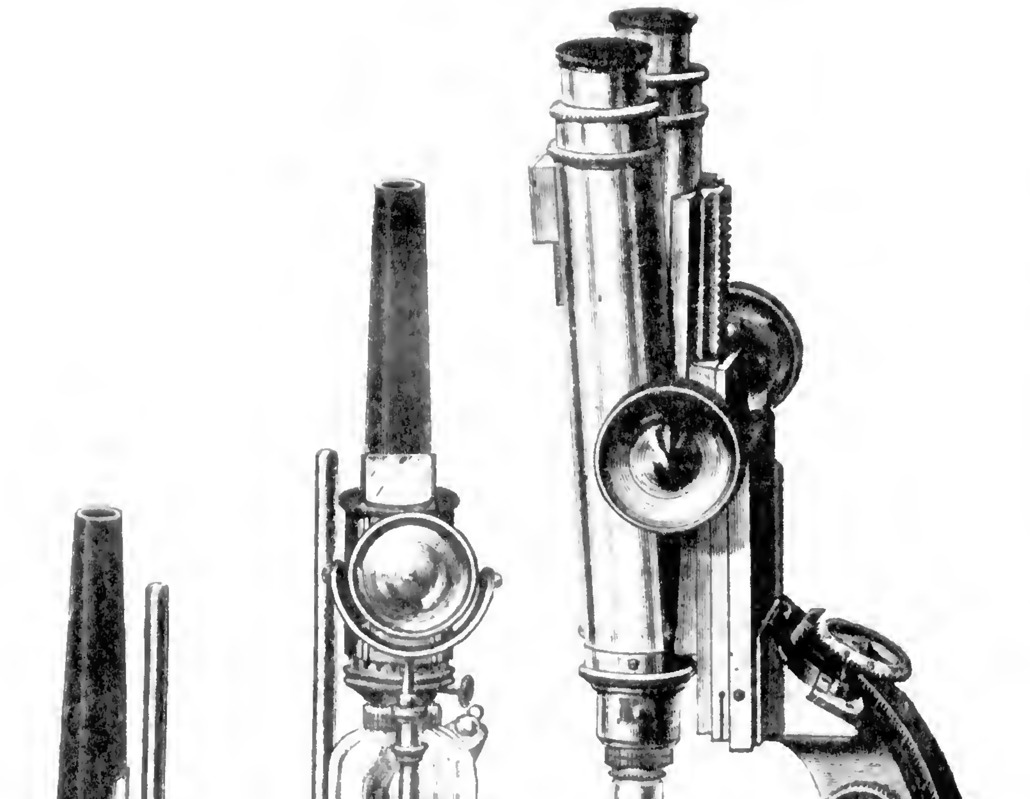
One ambitious form of microscope has been recently brought prominently forward, which is shown in Fig. 24 (p. 1170). We have here an elaboration of mechanical movements and illuminating arrangements, the complexity of which almost defies comprehension. I had intended to deal with it critically, but have been forced to give it up in despair of rendering myself intelligible. Can anyone other than the inventor approve of such a design as a practical microscope for high-class work?

Regarding the best form of student's microscope, the choice seems, upon a cursory examination, to be almost unlimited. But if the student is to be advised to train his hand and eye in the critical estimation of optical images produced by the microscope — to become, in short, an expert in the use of the microscope—then the range of choice is cut down to very moderate limits. He *must* have an instrument provided (1) with a centering sub-stage, without which critical microscopy is impossible, for an achromatic condenser is an *absolute necessity*, and such a condenser *cannot* be properly used without centering arrangements; (2) he must have a fairly good fine-adjustment, otherwise the waste of time in manipulating will be enormous, if, indeed, he ever succeeds in getting the *best* work out of his optical appliances.

I do not attempt to guide the selection of a student's microscope by mentioning that of any particular optician. Efficient instruments of this class can be supplied readily by most of our opticians, probably more satisfactorily than they can be obtained from any foreign opticians. This seems to me merely a question of demand and supply. If the student insists, however, upon having the lowest priced instrument regardless of mechanical efficiency, he will doubtless obtain what he seeks among the importers of low-class microscopes from France or Germany—microscopes made to suit the price demanded without reference to their efficiency as working instruments.

As to the objectives, oculars, and condensers that should be in the hands of a student, they should be the best his means will allow him to obtain. The advantage, from every point of view, due to Professor Abbe's recent introduction of apochromatic objectives and compensating eye-pieces can hardly be overrated; on this point the proofs are beyond all possibility of doubt. I do not venture to affirm that we have thus reached the highest attainable point of excellence with our optical appliances; but the practical evidence of advance furnished by a careful comparison between the new "apochromatic" system of Abbe and the ordinary "achro-

FIG. 24.

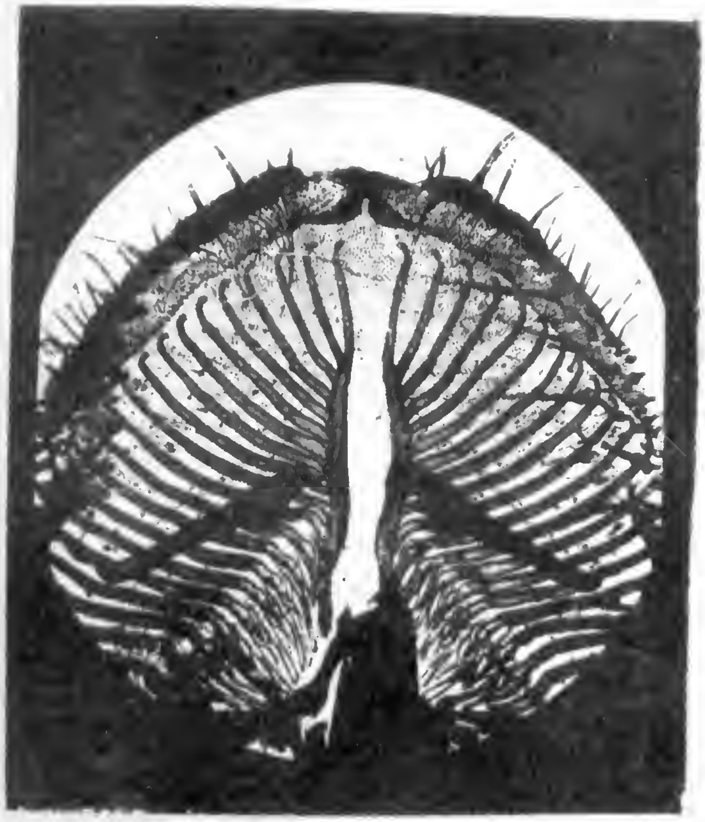


A MODERN MICROSCOPE.

matic" system, leaves no room for uncertainty as to the absolute superiority of the new system.

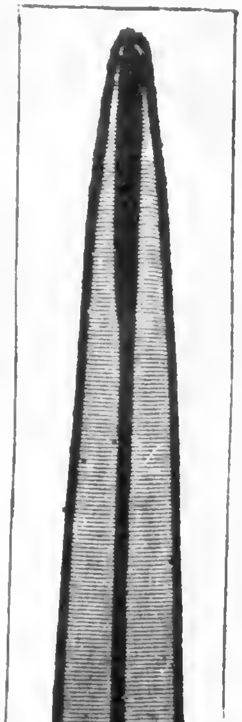
The apochromatic objectives are the direct outcome of the new kinds of optical glass due to the theoretical and experimental researches of Professor Abbe and Dr. Schott, which have been promoted to a considerable extent by the German Government. The compensating eye-pieces are the development of certain theoretical views long entertained by Professor Abbe, as to the possibility of correcting, by specially-constructed eye-pieces, defects in the image projected by the objective which cannot be corrected in the construction of the objective. They are, therefore, useful in improving the definition of many achromatic objectives of ordinary construction, and the student must hence be advised to obtain them.

At the close of my previous Cantor Lectures, I expressed my strong conviction that the new glass would lead to immediate improvement in the optical power of the microscope—would, in fact, give microscopy a new start. The results



PROBOSCIS OF BLOW-FLY × 70 DIAMETERS.

FIG. 26.



AMPHIPLEURA PELLUCIDA × 1860 DIAMETERS.

obtained by Zeiss, under the direction of Professor Abbe, are such as must raise our expectations of still further progress. On this matter I speak with special information, since I have had the privilege of minutely inspecting the optical and mechanical workshops of Zeiss, in Jena, under the guidance of Professor Abbe and Dr. Roderich Zeiss, and can therefore testify to the thoroughness of the arrangements to insure quality and accuracy of workmanship — a thoroughness that must necessarily lead to still greater technical perfection of work, a point in which Professor Abbe frankly admitted certain English and American opticians had hitherto held the lead.

It is gratifying, also, to know that our opticians have not been dilatory in recognising the utility of the new optical glass, and in thus pressing forward the improvements initiated by Professor Abbe; for it would hardly correspond with the traditions our opticians have created were they to neglect the practical improvement of the microscope, from whatever quarter the initiation might come. In this matter there can be no kind of jealousy to mar the loyal acknowledgment by all microscopists and opticians of the great services rendered to microscopical science by Professor Abbe.

In conclusion, it has seemed to me that graphic evidence of what the new apochromatic objectives will do in the hands of a skilled manipulator with the microscope is the best evidence I can give of their excellence. I therefore reproduce in photozincography two photographs recently made by Mr. E. M. Nelson, giving his data of their production.

Fig. 25 (p. 1171), *Proboscis of Blow-fly*, × 70 diameters with Zeiss's 24mm. (= one inch) apochromatic objective, ·3 N.A. Illumination, solid cone of light from Nelson's low-power condenser of 30° aperture, image of lime (oxyhydrogen) being focussed on the object. Full aperture of objective and condenser, using Zeiss's × 3 projection eye-piece. Slow isochromatic plate, exposure five seconds. Powell and Lealand's No. 1 Microscope.

Fig. 26 (p. 1171), *Amphipleura pellucida*, × 1,860 diameters with Zeiss's 3mm. (= ⅛-inch) apochromatic objective, 1·428 N.A. Illumination, Powell and Lealand's oil-immersion condenser, 1·4 N.A., and slot; oxyhydrogen light, using Zeiss's × 3 projection eye-piece. Camera 5 ft. 6 in. long. Slow isochromatic plate, exposure one hour. Powell and Lealand's No. 1 Microscope.

Miscellaneous.

SUBSOIL MAPS.

The interest which the Society of Arts has taken in geology has always been on the side of its direct bearings on agriculture. Long before the study of stratigraphical geology had commenced, it had offered a premium for a "map of the soils" of England. [See *ante*, p. 393]. At the recent International Geological Congress there were distributed copies of an extract (196 pp. woodcuts and two plates) of the Bulletin de la Société Belge de geologie, de paléontologie et d'hydrologie, giving an account of a new portable boring apparatus and the manner of working it, with an illustration from one of the sheets of the Belgian Geological Survey showing the application of its use. [May 29, 1888, by MM. E. van den Broeck and A. Rutot, Conservators at the Royal Museum of Natural History of Belgium.] From this it appears it has been in use by some members of the Belgian Geological Survey for over seven years, though it is little known in this country. Messrs. Clement Reid and A. Strahan, of her Majesty's Geological Survey, have, however, employed it in the re-survey of the Isle of Wight, the map of which has just been completed, and they have found the rapidity and ease with which it can be used of great service. With it they have been enabled to settle the uncertain points of the geology of the north part of the island, resulting in an entire re-mapping. It has also been employed in the re-survey of Norfolk. Its use for subsoil mapping is very apparent. The old boring apparatus was a cumbersome affair, requiring time for its erection and many men to work it. For deep borings, hard rocks, and for cases where a "core" is needed, it will, in some form, continue to be employed. But the new borer is not intended for deep borings; it is designed for the more rapid and more exact examination of the distribution of soils to the depth of a few yards. It requires but two men, and being easily portable, many borings near to one another can be taken in a short space of time, and the varying limits of different subsoils can be thus ascertained with an accuracy that has not before been attained. The actual borer is fashioned like the end of a worm-augur not quite three inches in diameter, and having ten turns in it. The upper end is arranged to be joined on to a "connecting rod," to which a cross handle for rotation is attached. When it is withdrawn it is found that although no "core" is brought up, the "worms of the screw" of the augur bring up, closely compacted, a sample of the soil it has reached. By means of a series of connecting rods a depth of many yards can be readily bored.

General Notes.

Consular Reports.—A correspondent writes, *à propos* of the letters now appearing in some of the newspapers on foreign international exhibitions, drawing attention once more to the neglect with which manufacturers and traders treat the information with which they are supplied by British Consuls. He gives, as an instance, the fact that, not long ago, the United States Consul at an important Spanish town wrote a report on stoves, the result of which was that he had over thirty applications for further information from various firms in the States, and that a good many applications were made to the British Consul of the town. This gentleman supplied a great deal of information to a firm in England, who were informed that if they sent some stoves out at once they would be in time to anticipate the supply from America. The firm in question, however, did not care to take the trouble, and the result has been that a large business which the natives were ready and probably would have preferred to carry on with England, has gone into American hands. In many cases consuls are blamed for not assisting English trade; but this appears to be an instance in which the assistance offered by the consul was disregarded by the parties interested in this country.