THE MICROSCOPE

By

DR. HENRI VAN HEURCK

TRANSLATED BY

WYNNE E. BAXTER

THE MICROSCOPE.

PRINTED BY
W. E. BAXTER LIMITED,
Lewes and London.

Dr Henri Van Heurck
1892

[illegible] Anvers phot. J Malvaux Bruxelles photogravure

THE

MICROSCOPE:

ITS CONSTRUCTION AND MANAGEMENT.

INCLUDING

TECHNIQUE, PHOTO-MICROGRAPHY,

AND

THE PAST AND FUTURE OF THE MICROSCOPE.

BY

DR. HENRI VAN HEURCK,

Professor of Botany and Director at the Antwerp Botanical Gardens;
Late President of the Belgian Microscopical Society;
Hon. F.R.M.S. and New York M.S.

ENGLISH EDITION.

Re-edited and Augmented by the Author from the
Fourth French Edition, and Translated by

WYNNE E. BAXTER, F.R.M.S., F.G.S.

With Three Plates and upwards of 250 Illustrations.

LONDON:
CROSBY LOCKWOOD AND SON,
7, Stationers' Hall Court, Ludgate Hill.
New York: D. VAN NOSTRAND COMPANY,
1893.

AUTHOR'S PREFACE TO THE ENGLISH EDITION.

The Fourth Edition of this book had only just appeared when Mr. Wynne E. Baxter, a skilful English microscopist, honoured us by offering to publish an English Edition.

We cordially accepted Mr. Baxter's offer; but in the meantime the Antwerp Microscopical Exhibition has taken place, at which the best work of the most skilful manufacturers of the present day appeared. We were especially anxious that any English microscopist who might wish to read our treatise should have the advantage of the recent study which our position, as President Director of the Exhibition, has enabled us to make.

Materials accumulated to such an extent that we may now issue the present Volume, not as a translation of the Fourth Edition, but as being a really new Work—a Fifth Edition.

Thus, the instruments of several manufacturers, Messrs. Bausch and Lomb, Crouch, Koristka, Erbe, Adnet, &c., which were not mentioned in the Fourth Edition, are described in this. All the Illustrations (amounting to a considerable number), which in this Volume are numbered with a figure, followed by a letter (*e.g.*, 196, *a*, *b*, *c*, *d*, *e*), will not be found in the French Edition.

We cannot conclude this Preface without expressing the debt of gratitude we owe to Mr. Wynne E. Baxter, who has so generously not only devoted much valuable time to this translation, but undertaken the entire expense of the publication, with the sole purpose of acquainting his fellow-countrymen with a Work, which, he believes, is not devoid of merit.

But it is not only from a pecuniary point of view that we owe our acknowledgments to Mr. Baxter. "Traddutore traditore," says the Italian proverb. We may truly assert that this Book is one of those rare exceptions in which the proverb does not apply. Mr. Baxter has shown by his work that the niceties of the French language, as well as all microscopical details, are equally familiar to him, and in several cases he has even suggested improvements to us. If, therefore, there be any fault to find with any passage in the Volume, it is the Author, and not the Translator, whom the reader must blame.

ANTWERP, *November*, *1892*.

EXTRACT FROM THE FOURTH (FRENCH) EDITION.

"We were not twenty years of age when we wrote the manuscript of the First Edition of this Volume. However, it was only published some years afterwards, at the request of our friend, Arthur Chevalier, who wished to insert in it certain parts of his *Etudiant-Micrographe.*

The microscope has, indeed, always been our favourite study from boyhood, and to it we are indebted for some of the happiest hours of our life.

When we wrote the first manuscript of this Work, microscopical research was not as popular in Belgium and France as it is now. A microscope was then little more than a toy, and our Book, a humble pamphlet of 104 pages, was, indeed, the first Work by which a French reader could initiate himself into the practice of vegetable microscopy.

Four years after its publication a Second Edition was demanded; and the Third Edition, of which a considerable number of copies was printed, appeared nine years afterwards.

The constant application and length of the work necessitated by the publication of our *Synopsis des Diatomées*, has delayed the appearance of this Fourth Edition, which some of our loyal readers have for a long time past demanded.

There will not, however, be much ground for complaint at the delay. The microscope has made such rapid progress of late years, that theory forces the belief that we can expect but a few further improvements, the most important of which will be a more complete utilisation of the aperture of objectives.

As in each of our previous Editions, this Work has been entirely re-written, with the exception of a few of the old sections which have been utilised. We are, therefore, practically speaking, publishing an entirely new Work.

We have treated at some length the recent progress in microscopy. Photo-micrography, staining processes, &c., have been set forth with the fullness their importance deserves.

The same applies to the very important theory of Professor Abbe, the practical application of which has enabled the microscope in a few years to reach the state of perfection which it enjoys at the present time."

Antwerp, *2nd August, 1891.*

TRANSLATOR'S PREFACE.

The popularity of this Work on the Continent would alone be sufficient justification for an English translation; but it has, besides, intrinsic merits which will naturally commend it to readers.

There does not appear to be a work which, while maintaining its elementary character so completely, at the same time deals with so wide a range of microscopical subjects.

Again, such a book must necessarily be of interest to all who devote serious attention to microscopic work, as a means of comparing the Continental views and modes of thought with those of their own and other countries. For these and other reasons it is believed that this Volume will be acceptable as an addition to microscopical literature.

An endeavour has been made to avoid terms of expression essentially French, but at the same time to strictly adhere to the meaning of the text. Notwithstanding the trouble which the Author has taken in revising all the proofs, yet it is far too much to hope that the Work, even with that assistance, is altogether free from mistakes.

The Translator has been fortunate in securing the co-operation of several friends in carrying out his undertaking, but his acknowledgements are specially due to his son, Mr. Reginald T. Baxter (Exhibitioner and Scholar of Clare College, Cambridge), who has afforded very valuable assistance throughout the Work.

It is hoped that the addition of a somewhat voluminous Index and Vocabulary, &c., will be found useful for purposes of reference.

A further Work on the Diatomaceæ, founded on the Author's classical "Synopsis des Diatomées de Belgique," is being prepared by the Author for translation into English. It will be published uniformly with the present Volume, to which it is intended to be supplementary.

W. E. B.

170, Church Street, Stoke Newington, N.
18th November, 1892.

CONTENTS.

FRONTISPIECE.—PORTRAIT OF THE AUTHOR.

INTRODUCTION.

CHAPTER I.

CHAPTER II.

CHAPTER III.

BOOK I.

CHAPTER I.

CHAPTER II.

i. OPTICAL PARTS OF THE TUBE—(*continued*). PAGE

CHAPTER III.

BOOK II.

CHAPTER I.

CHAPTER II.

BOOK III.

CHAPTER I.

USE OF THE MICROSCOPE—(*continued*). PAGE

CHAPTER II.

CHAPTER III.

CHAPTER IV.

BOOK IV.

CHAPTER I.

1. Aqueous and Oily Media:

GENERAL RULES, &c.—(*continued*).

CHAPTER II.

BOOK V.

THE MICROSCOPE.

INTRODUCTION.

CHAPTER I.

OPTICAL NOTIONS.

Light.—General.

LIGHT is the agent which produces in us the sensation of sight.

Light is emitted by luminous bodies themselves, such as the sun and burning substances, or is reflected by bodies which have not the power of of emitting it themselves, which are called non-luminous, such as the moon.

It is admitted that the molecules of luminous bodies are in a state of exceedingly rapid vibration; and these vibrations, being communicated to the ether, which pervades all space, are thus propagated and eventually strike our retina. The number of these vibrations in the unit of time produces in us the sensation of different colours.

The straight line along which light is propagated is called a *ray*. An assemblage of rays constitutes a *beam*. The word *pencil* is also sometimes used to designate a limited quantity of rays.

Bodies through which light can be propagated are called in optics *media;* such for example are air, water, and glass. They are further called transparent, translucent, and diaphanous, according as the rays are transmitted more or less freely in contradistinction to opaque bodies, which do not allow luminous rays to be transmitted. Many bodies which at first sight appear entirely opaque still allow some rays to pass through them when they are reduced to excessively thin plates. Such is the case with gold, silver, &c.

In every medium which is homogenous, that is to say, having throughout the same composition and the same density, light is propagated in straight lines. It no longer does so when it meets an opaque body or passes from one medium into another. In this case the light is reflected, refracted, or decomposed. *Reflection* is the property by virtue of which polished bodies can send back, in certain directions, the luminous rays falling on their surfaces. *Refraction* is the change of direction which transparent bodies exercise upon light which traverses them obliquely.

We need not concern ourselves at present about the decomposition of luminous rays which apparently takes place in their passage through pieces of glass cut in a certain manner, and called prisms.

Reflection.

In microscopes of the present day the reflection of light is only made use of to illuminate the object under observation When the microscope is used without a condenser a plane mirror is employed for low and a concave mirror for high magnification.

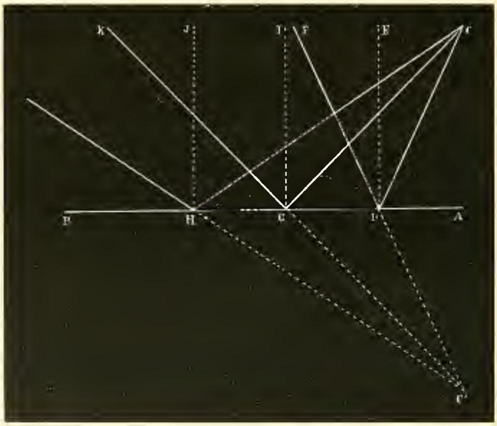


Fig. 1.

Let us examine the course taken by rays falling on a plane mirror. Let A B (fig. 1) be the mirror, C a luminous point: a ray emanating from this point and striking the mirror at D will make, with the perpendicular to the surface of the mirror at that point (which perpendicular is termed the *normal*), an angle E D F, called the angle of reflection, equal to C D E the angle of incidence.

Other rays C G, C H, emanating from the same point, make again, with the normals G I, H J, the angles of reflection I G K, J H L equal to the angles of incidence C G I, and C H J; thus, all the reflected rays seem to diverge from a point C', which has no real existence, and is called the virtual image of C. Its position as compared with that of C is symmetrical with regard to the mirror.

Fig. 2.

The law is again the same when parallel rays C, D, E (fig. 2) strike a plane mirror. In fig. 2 the angles of reflection are equal to the angles of incidence

Concave Mirrors.—There are many kinds of these, but those which are employed with microscopes are usually spherical, that is, representing a portion or segment of a sphere. Spherical mirrors have as their *centre of curvature* the centre of the sphere of which they represent a part; thus the mirror A B (fig. 3) has for *radius of curvature* the radius O A.

Fig. 3.

The point C, the middle of the mirror, bears the name of *centre of figure*, and the infinite straight line which passes through this point and the centre of curvature is *the principal axis.*

Concave mirrors possess the property of concentrating the luminous rays which they receive, at a single point which is called a *focus.*

There is a distinction between the *principal focus* and *conjugate foci.* We shall see what these two expressions signify.

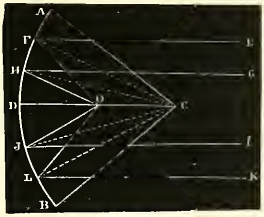


Fig. 4.

Let A B be a concave mirror, of which C is the centre of curvature. Let us consider it as composed of an infinite number of plane mirrors. The extreme tenuity of luminous rays, and the infinitely small surface on which they can be reflected, permit this supposition, which thus reduces the laws of reflection for curved mirrors to those for plane mirrors (fig. 4).

Let us suppose the luminous rays E F, G H, *I* J, K L, parallel to one another and to the principal axis, to fall on the mirror; they will make, with the normals (which will then be the radii C F, C H, C J, C L) the angles of reflection C F O, C H O, C J O, C L O, equal to the angles of incidence E F C, G H C, *I* J C, K L C, and all these rays will meet in a point O in the centre of the principal axis C D.

This, however, only holds good for mirrors which are but a small segment of a sphere when the angle A B C is but a few degrees in magnitude.

Let us now consider the triangle C F O: by the laws of geometry the angle F C O is equal to the angle C F E, being alternate angles with respect to the parallels E F, C D, intersected by the straight line C F; now we have just seen that the angle of reflection C F O is equal to the angle of incidence E F C. The angles F C O and C F O are, therefore, equal to one another since they are both equal to E F C, and, consequently, the straight lines C O and O F are equal. Since the luminous rays can approach so as nearly to coincide with the axis C D, it follows that the point O is to a very minute fraction at the middle of the straight line C D. This is the principal focus.

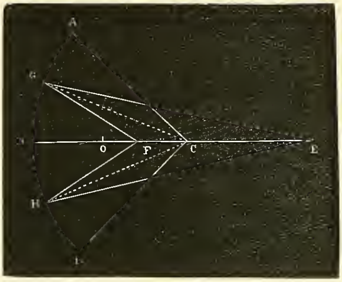


Fig. 5.

Let us now suppose that the rays falling on the mirror, instead of being parallel, proceed from a luminous point E (fig 5), situated at a certain distance from the centre C; the angles of incidence, and consequently of reflection, will be smaller than in the preceding case. The point F, where the rays re-unite, will, therefore, be found situated in front of the point O, and between that point and the centre C It is called the conjugate focus of the point E.

It is easy to see that the farther the point E is withdrawn from the centre C, the nearer the conjugate focus will approach the principal focus O until it becomes coincident with it. If, on the contrary, we draw the point E nearer, the conjugate focus will equally approach the centre. If E becomes coincident with C, the rays impinging perpendicularly will be reflected on themselves.

If the luminous point be placed between C and the principal focus, the conjugate focus will be carried over to the other side of C, so that the conjugate focus of the point F will be E.

At the principal focus a conjugate focus is found situated at infinity, the reflected rays being parallel; between the former point and the centre of figure D the focus will be *virtual* and placed behind the mirror.

After what has preceded, it will be seen that the experimental determination of the principal focus of a concave spherical mirror is very simple; it is placed so as to receive a beam of solar rays in a direction parallel to its principal axis, and, by presenting a white card before it, the distance at which the image of the sun thus obtained appears plainest, is found.

This point will be *the principal focus*, and twice its distance from the centre of the mirror will give the radius of curvature.

The words *parallel rays*, having been employed several times, it may, perhaps, be asked by what means such rays can be obtained. It should, therefore, be understood that rays which emanate from a point in the sun or stars are considered to be endowed with parallelism. Although these rays are not mathematically parallel, they can, nevertheless, be considered as such on account of the enormous distance of the bodies producing them.

Refraction.

We have previously seen what refraction is. It has only a sensible effect when the rays fall obliquely with respect to the surface of the medium considered; when they fall perpendicularly on this surface, they continue in the same course in the second medium as they did in the first.

Consider, now, a ray from one medium falling obliquely upon the surface of another; for example, from air upon glass, and call it B A (fig 6). At the point of contact A, raise the normal C A D; the ray, instead of following its course in the direction of A B produced, *is bent towards* the normal, making with it an angle E A D (of refraction) smaller than C A B, the angle of incidence.

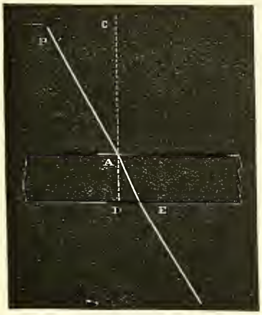


Fig. 6.

Passage of light through media with parallel surfaces.—This takes place whenever a ray emerges from a less dense medium (and consequently less refractive) and enters a denser medium. If we suppose a plate of glass to have parallel surfaces, the ray B A E produced upon emerging from the glass and re-entering the air, will be deflected from the normal the same amount that it was bent towards it in its first refraction, and it will make an angle of refraction equal to the angle of incidence in the first refraction.

If the line of its direction be now produced, the ray upon emerging from the glass will be seen to be following a direction parallel to that which it had before entering the medium. This effect takes place in consequence of the two surfaces of the plate in question being parallel; if they had not been so, the ray would have taken another direction, but never parallel to A B. This property is very important in demonstrating the properties of lenses.

It is shewn in physics that *the sines of the angles of incidence and of refraction are to one another in a ratio which is constant for the same media and for the same colours.* This ratio is called the *index of refraction*; from air into glass it is 3/2, from glass into air it is 2/3.

Critical angle, total reflection.—We have seen that a ray, passing from one media to another less dense, makes an angle of refraction greater than that of incidence. It therefore necessarily follows that for some angle of incidence, the angle of refraction will be right, and that the refracted ray will emerge parallel to the surface of the plane. The angle of incidence producing this effect is called the *critical angle.* And, indeed, for every angle greater than this, the ray is no longer refracted but is completely reflected, which phenomenon is called *total reflection*, and is made use of in a special kind of prism.

The critical angle for crown glass into air is 41°.

Passage of light in media, with non-parallel surfaces.—Among media, with non-parallel surfaces, a distinction is made between prisms and lenses. Prisms are pieces of glass with plain surfaces inclined towards each other. Knowing the laws of refraction it will be easy to deduce the course of rays in these media.

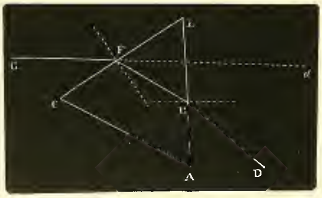


Fig. 7.

Consider a triangular prism, the transverse section of which is A B C (fig. 7), and a luminous point D: in the plane A B C a ray, starting from this point strikes the prism at E, and is refracted *towards* the normal D B A since it passes into a more refractive medium; it then takes the direction E F, and is refracted anew at the point F, where it again emerges into the air, but is deflected *from* the normal D B C.

By placing the eye at the point G the light will appear to follow a single straight line, and the point D will be seen, not at its true position, but in the direction F *d*. Prisms then, like plane mirrors, can be used to make a luminous point appear displaced.

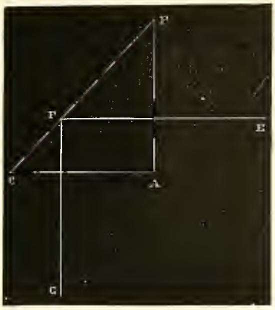


Fig. 8.

Application of prisms as reflectors.—Prisms used for this purpose are cut in the shape of a right-angled isosceles triangle as A B C (fig. 8). Consider an incident ray E F parallel to A C: the angle E F B will be equal to A C F, and like it an angle of 45°; now the critical angle of glass being only 41°, the ray E F will be reflected completely at F, and will follow the direction F G parallel to A B.

The eye placed at E will then see objects placed at G as if they were on E F produced.

Of Lenses and their properties.

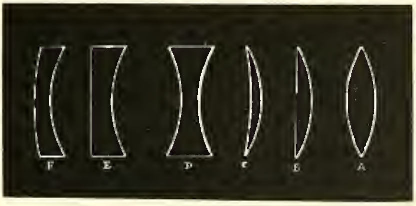


Fig. 9.

Transparent substances (in general glass) cut in such a manner that the luminous rays which traverse them, can be made to converge or diverge, are termed lenses. There are two series of lenses: the convex series, and the concave series. These series comprehend the following forms (fig. 9):—

A The bi-convex lens.
B The plano-convex lens.
C The concavo-convex lens or convergent meniscus.
D The bi-concave lens.
E The plano-concave lens.
F The concavo-convex lens or divergent meniscus.

Let us take for granted, in the first place, the same hypothesis as we did for spherical mirrors, viz.:—that lenses are formed of an infinite number of small plane surfaces, having as normals the radii drawn from these points to the centres of curvature (*see* later "Definition of the centre of curvature.")

Optical Centre.—A point, such that every luminious ray, passing through it, is, upon emerging from a lens, parallel to its direction before entering the lens, is called the Optical centre of the lens

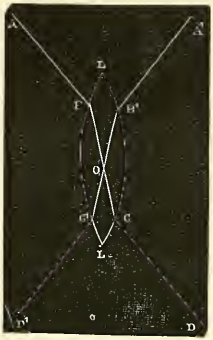


Fig. 10.

Thus in figure 10 the point O will be the optical centre of the lens L L', if the incident ray A B is parallel to the emerging ray C D: another incident ray A' B', then passing through O, so as to become the emerging ray C' D', again verifies the definition.

We have now to find the position of this point O, but in the first place let us remark that the centre of a sphere, of which this surface of a lens forms a part is called the centre of curvature of this surface of the lens.

Thus in figure 11, let A B C E be a lens, and A B C the surface to be considered. This surface has reference to a sphere A B C D, of which it forms a part. If this sphere has its centre at O, this point will be the centre of curvature of the surface A B C. It should further be noted that the centre of curvature must not be confounded with the centre of figure; this last varies according as a part of the edge of the lens is cut, so as to render it either square, polygonal, or of different forms, and the centre of figure, although it can be made to change with each new form, though not necessarily in the case quoted, will change with each form, while the centre of curvature will remain the same; we will suppose the lenses to be round like those ordinarily used in practice, and in this case also the position of maximum thickness of convergent lenses and that of minimum thickness of divergent ones usually coincide with the centre of figure. If this condition is not fulfilled the lenses are eccentric, as in the ordinary stereoscope, where they have to be so. We are here supposing that the lenses are always spherical, the centre of figure corresponding to the maximum or

Fig. 11.

minimum thickness, according as they are convergent, or divergent.

To find the optical centre of any lens, the points where the normals and the tangents are parallel must first be found, or what comes to the same thing, the points where the element of the surface is parallel in each corresponding surface.

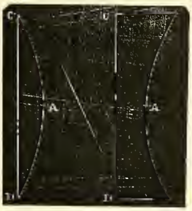


Fig. 12.

Thus, in lenses where one surface is plane this will be seen at once, for it is evident that the point A (the centre of figure of the curved surface) (fig. 12) will have its tangent parallel to C D, or its normal parallel to that of C D, or the element A will be parallel to all the elements of the surface C D, each of which amounts to the same thing.

Now every ray which enters at the point A will emerge from the surface C D parallel to the direction which it had at its entrance, since it passes through a plate with parallel surfaces: then following the definition which we have given of the optical centre, the point A will be this centre.

All the rays which emerge from it will have a direction parallel to that which they had before entering the surface C D.

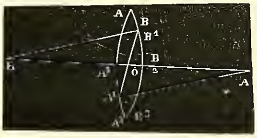


Fig. 13.

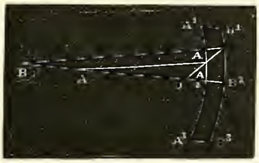


Fig. 14.

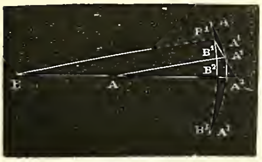


Fig. 15.

In figures 13, 14, 15, 16 below, B is the centre of curvature of the surface B1 B2 B3; A that of the surface A1 A2 A3.

If any radius B B' be drawn from the centre of curvature B to the corresponding surface, cutting it in B', and then if a radius A A', parallel to B B', be drawn from the centre of curvature A, cutting the corresponding surface A1 A2 A3 at the point A', these surfaces at the points A' and B' will have the normals B B', A A' parallel by construction.

It follows that their elements will also be parallel at these points. Therefore, if a luminous ray enter the lens at A' so inclined as to emerge at B', or inversely, it will act as if it passed through a medium with parallel surfaces; that is to say, that its deviations before

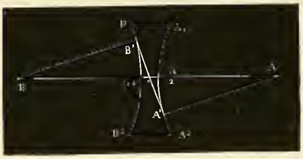


Fig. 16.

its incidence, and after its emergence, will be parallel; therefore it will pass through the optical centre O.

Further, the luminous ray which passes through A and B will not deviate from its course; it will consequently also pass through the optical centre; therefore the point of intersection of A B and A' B' will give this centre. Every straight line passing through the optical centre is called an *axis;* the *principal axis* is that axis which also passes through the centres of curvature; the others are *secondary axes.*

Every luminous ray which follows the principal axis does not deviate from its course. It is almost the same with regard to secondary axes, at least, if the lenses are not too thick, and the secondary axis does not make too great an angle with the principal axis.

If these conditions are not fulfilled the luminous ray which follows the secondary axis is slightly displaced, although remaining parallel to itself.

Determination of the foci of lenses:—A. Convex Series.—Let us take the bi-convex lens as a type of the convex series; the student who has understood the properties of this will find no difficulty in applying them to other lenses of the same series. Like the concave mirror the bi-convex lens possesses a principal focus and conjugate foci, which can be either real or virtual.

Let rays mutually parallel to the principal axis pass through a lens. These rays experience a primary deviation upon entering the glass, and are bent towards the axis A B C (Fig. 17); on again entering the air they experience another deviation towards this axis, which they intersect at the point C. Since all the parallel rays intersect at this same point, it will be the principal focus of the lens.

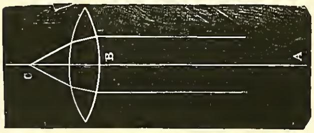


Fig. 17.

The principal focal length is the distance of the focus from the optical centre. It is this which determines the "number" given to glasses for spectacles, &c.; thus, according to the old numbering (which, however, is now replaced by numbers corresponding to the divisions of the metrical system), lens No. 5 is one whose principal focus is at a distance of five inches from the optical centre.

If luminous rays proceed from a point A (fig. 18), situated on the principal axis, and meet the lens in the form of a divergent beam, the same thing as before takes place, only the deviation being less the refracted rays are concentrated at a point C' farther off than the principal focus which is called the conjugate focus of A. If A is brought nearer, C' moves farther away; if A is withdrawn, C' draws nearer without ever becoming coincident with C, so long as the beam is not parallel.

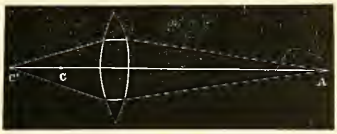


Fig 18.

Secondary foci are foci which lie on secondary axes where the incident rays are parallel to them. There focal distance is the same as for the foci which lie on the principal axis; nevertheless, after what we have seen with regard to secondary axes this is only approximately true, and is only absolutely true for ideal lenses having no thickness, but in practice it is sufficiently accurate.

If we suppose the luminous point A (fig. 19) always situated on the principal axis, but between the lens and its principal focus O, we shall have the course of the luminous rays constructed as follows: the rays which are divergent before entering the lens remain divergent upon emerging. They cannot therefore themselves form a focus, but when produced backwards they meet one another in A' on the other side of the principal focus, giving to the eye placed behind the lens the sensation of a focus. This focus is "virtual," that is to say, one appears to see it, but it does not really exist; it cannot, like real foci, be received upon a screen or ground glass. If A is brought near to the lens, A' approaches the principal focus; if A is brought near to this point, A' withdraws from it.

Fig. 19.

Formation of the images with convex lenses.—We have always assumed in what has preceded, that luminous points giving rise to the foci, were situated on the principal axis of the lens. Let us notice that the formation of foci will be always the same if these points happen to be on secondary axes, the foci being then formed at a certain point on these axes where the divergent rays intersect after passing through the lens.

This being granted, let us further remark that in order to obtain the images produced by convex lenses, the image of an object is formed by the union of the foci, produced by each of the points of this object, the demonstration of which can be simplified by making the construction only for the top and bottom. These two extreme points being found, the position of the object in the image will be determined, since the foci of all the intermediate points will arrange themselves between them.

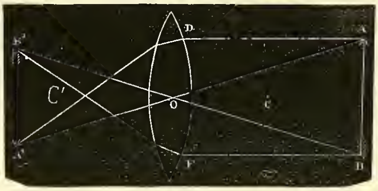


Fig. 20.

Two cases may occur: either the object may be beyond the principal focus with reference to the lens, or within it. Let us suppose first that the object A B is beyond the principal focus C (fig. 20); let O represent the optical centre and draw the secondary axes A O, B O. After what we have just seen, the focus of the point A ought to be some point on the axis A O, and that of B some point on B O. Now draw the incident rays A D and B F parallel to the principal axis. These rays will be refracted so as to pass through the second principal focus C' and they will cut the secondary axes at the points A' and B'. At the point A' the image of A will be formed and at B' that of B. In the same way it could be shewn that all the points contained between A and B would be formed by foci between A' and B', where we shall therefore have the complete image of the object A B. This image is inverted and real. If we refer to what has been said of foci we shall observe that the farther the object is from the principal focus the more the rays, emanating from each point of the object, approach to parallelism and the smaller becomes the image of an object (though large) and the nearer it approaches the principal focus (1). On the contrary, if the object is brought very close to the focus its image will be formed at a definite distance and will be greatly magnified (2).

Let us suppose in the second place that the object A B is placed between the lens and its principal focus.

Draw the secondary axes A O and B O, and the incident rays

---

(1) Principle of the camera obscura.

(2) The Principle of apparatus for Optical Projection.

A D and B E (fig. 21), these rays after being refracted emerge from the lens, diverging more and more from the secondary axes; but if these rays are produced backwards, cutting the same axes at the points A' and B', they will form there the virtual image of the points A and B; all the other rays emanating from the object A B forming foci between A' and B', we shall there have an erect and magnified virtual image of the object A B, which will be observed by an eye looking in the direction of the rays. In this lies the principle of magnifying glasses or simple microscopes as mostly used.

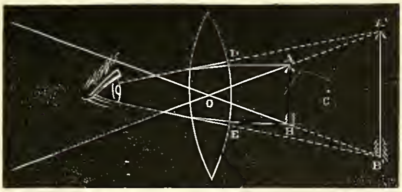


Fig. 21.

Determination of the foci of lenses.—B. Concave series.

Formation of foci.—Let us take the bi-concave lens as a type. In all lenses of this series only virtual foci are formed, whatever be the position of the luminous point, this being considered as real.

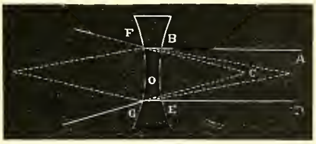


Fig. 22.

In figure 22 at the side the parallel rays A B and D E strike the lens O.

Draw the normals at the points of incidence B and E; within the lens the rays approach these while they themselves diverge; draw the normals at their points of emergence F and G; they deviate from these and still diverge, and therefore do not form any real focus, but if produced backwards they form the principal focus at C, which is at the same time virtual.

If the incident rays proceed from a point situated on the principal axis, it is evident that these rays, already divergent upon entering, diverge still more and form virtual foci, situated between the principal focus and the lens.

Production of Images—Concave lenses having only virtual foci can only produce virtual images of real objects.

Let A B (fig. 23) be an object placed before the lens O; draw the secondary axes A O and B O, the incident rays A D and B E, and erect normals; the rays approach these, while they themselves diverge; upon emerging they deviate from them, and diverge still more,

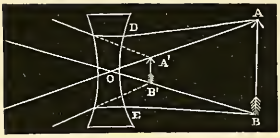


Fig. 23.

but if produced backwards they intersect the secondary axis at A' and B'; in the same way the different points situated between A and B group themselves between A' and B', where a virtual and erect image will then be formed, smaller than the object. This takes place, whatever be the distance of the object from the lens.

Spherical Aberration.

Every lens may be considered as formed of a system of prisms, or of parts of prisms (planes tangent to the lens), and having wider and wider angles. Thus a deviation is produced, which becomes more and more considerable, according as the edges of the lens are approached, and which increases more rapidly than is necessary to collect the rays to one focus.

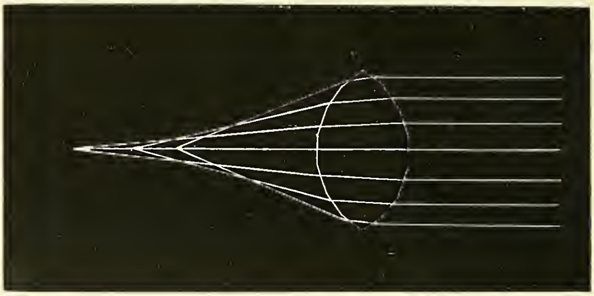


Fig. 24.

This way of regarding lenses is identical with that which we have given (page 3) for spherical mirrors, and this unequal deviation for different parts of the lens is called *spherical aberration.*

Spherical aberration is a serious defect, which the optician tries to remove as far as possible by different combinations.

Besides the theoretical figure (fig. 24) given above, we shall give another to make the effect in question more intelligible, and for greater clearness we shall exaggerate the defect.

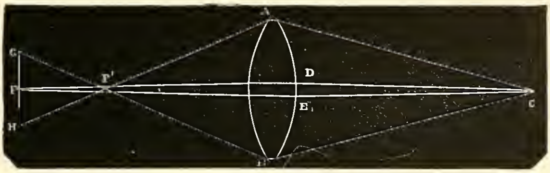


Fig 25

Let A B be a lens and C a luminous point. From this point draw the rays C A and C B so as to just graze the edges, and draw other rays C D and C E very close to the principal axis (fig. 25).

When these rays traverse the lens we find that C D and C E form their focus in F, while A C and C B form theirs in F', situated in front of F.

If from the point C, other rays be drawn between the extreme rays in the figure, their foci will be found to be between F' and F. The distance F' F will be the longitudinal spherical aberration, and G H the lateral spherical aberration of the lens. The consequence of this is that instead of having at F a single luminous point, as focus of C, we shall have a luminous centre, which will be F surrounded by a diminishing halo, having G H as its greatest diameter, and G F' H its angle of aperture. Every object placed at the point C will similarly present to the eye a central image, surrounded by a second indefinite outline resulting from spherical aberration.

This is necessarily annoying to the observer, and efforts have therefore been made to remove this defect, in the first place by providing the lenses with diaphragms, that is to say, with small disks of blackened cardboard, or brass, which cover up their edges and only allow the rays to penetrate in the middle. Diaphragms add much to the clearness of the images produced, and this increases in proportion to the smallness of the aperture, but then another inconvenience arises, namely, that the smaller the aperture the fewer are the luminous rays which it lets through, whence the object must be strongly illuminated to obtain a sufficiently intense image.

In optical instruments, in which diaphragms are employed, there are generally several apertures to be used according to the amount of light at one's disposal, and also according to the character of the objects observed.

Spherical aberration can also be considerably lessened, and sometimes even obliterated by using combinations of lenses instead of a single lens. An optician has to combine these, so that their spherical aberrations react on one another, and are thus totally or partially destroyed.

Aberration of Refrangibility—Achromatism.

Light used for the purpose of illumination, whether it comes from the sun, or from a lamp, is white.

When we observe objects without the intervention of lenses, this light appears to us simple and homogeneous. It is no longer so when a prism or a lens is interposed between these objects and the eye.

Light then is not only refracted, but also decomposed into its elements, which are violet, indigo, blue, green, yellow, orange, and red. All these colours forming the solar spectrum are unequally refrangible. We have mentioned them in their order of refrangibility. Their indices for a slightly refractive and dispersive glass vary from 1·5466, index of the violet rays, to 1·5258, the index of the red rays, while for very refractive and dispersive glasses, and still more so in certain liquids, this difference of index is tripled, or even quadrupled.

Since white light is decomposed in lenses (a phenomenon called *Dispersion*), and is at the same time refracted, it follows that the rays do not meet in a single point on the secondary axes to which they are parallel, and there form a focus.

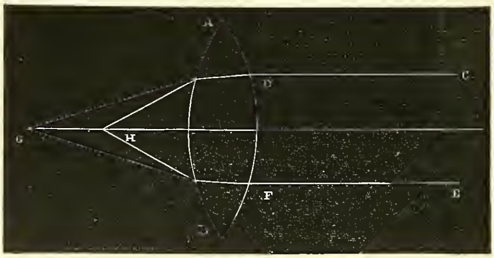


Fig. 26.

For example let two parallel rays C D and E F strike the bi-convex lens A B (fig. 26). These rays are decomposed in the lens at the same time that they are refracted, and upon emerging, each of the colours of which white light is composed, will form its own special focus. These foci will be found between G, the focus of the red rays—the least refractive, and H the focus of the violet rays—the most refractive. The distance H G is the *Chromatic Aberration*.

If now objects are observed through such a lens, it will be noticed that their outlines are not sharply defined, and that they are tinted with all the colours of the spectrum, which is naturally a great inconvenience.

It was thought for a long time that it would be impossible to remedy this defect, but in 1757, Dollond, an English optician, shewed that aberration of refrangibility was virtually nullified by the use of a system of two lenses of different composition placed in juxta-position.

To understand the effect thus obtained, it is necessary to know that the glass generally used for lenses is crown-glass (silicate of potassium and lime).

There is also another kind of glass, called flint glass, which consists of silicate of potassium and of lead, very rich in oxide of lead.

Flint glass has an index of refraction of nearly 1·63, and a dispersive power ·059, greater than crown-glass, where the figures are only 1·52 and ·036.

For a long time there existed only one kind of crown and one kind of flint-glass, and the achromatisation of objectives was therefore very incomplete. Only the red and blue rays blended together.

Researches made mostly in France and England caused the different kinds of glass to be increased in number, and consequently caused an improvement in the construction of objectives.

But the number of these kinds of glasses was still very limited, and quite insufficient to answer all the requirements of the optician.

It was then that Professor Abbe, of Iéna, commenced his researches, in conjunction with a skilful chemical specialist, Dr. Schott, and an investigation of all elementary bodies, capable of producing vitreous compounds, was systematically conducted.

This investigation, which absorbed considerable sums of money, had the most fortunate results, and since 1886, the firm of Schott and Co. (Drs. Schott, Abbe, and Zeiss) have been able to offer for sale seventy different kinds of glass, many of which are vitreous compounds, being glass only in appearance, for they do not contain silica. Silicon is replaced by boron in an entire series of flints, and by phosphorus in a series of crowns.

The new glass commonly called "Schott glass" or "Iéna glass," is now employed by opticians throughout the world.

Professor Abbe has, moreover, introduced several natural substances in the construction of objectives which defy all artificial imitation.

Such, for example, is the fluoride of calcium or "Fluorite" of the mineralogist. The index of refraction of this substance is only 1·434, that is to say, considerably less than that of any kind of glass hitherto manufactured, and its dispersion is only half as great.

If, therefore, a convex lens be made of crown glass, we assume that it is possible to calculate for a concave lens of flint a focal distance such that, when it is applied to the convex lens, it recomposes the white light dispersed by the latter without altering its converging properties. A lens thus corrected is called "*Achromatic.*"

In physics, achromatism is demonstrated by the use of two prisms: one of flint and another of crown glass. These prisms, in order to have the same dispersive power, should have their angles unequal, since with their angles equal the flint is more refractive and more dispersive; by making a ray of white light penetrate a prism of flint glass, and receiving it after dispersion through a prism of crown glass, it will be refracted while reconstructing the white light.

Achromatism is one of the most delicate branches of optics; it is an essential property for lenses of a good microscope. Although lenses which are made to achromatize one another could be placed in free juxta-position opticians prefer to cement them together with Canada balsam, which prevents the dust from penetrating them and unites them into one single achromatic system.

Simple Microscope.

The simple microscope most employed is the magnifying glass, either bi-convex or plano-convex lens, for the very simple theory of which we refer back to what we have said about the formation of images by these lenses.

But the defects, spherical aberration and aberration of refrangibility, which are very pronounced in this microscope, were soon recognised by the scientific men who employed them; they abandoned it for high powers, and sought a more perfect instrument which answered better to their requirements. At that time Wollaston invented the doublet. This instrument is, as its name indicates, composed of two lenses which act like a single one.

These two glasses are plano-convex, set in a single mount and separated by a diaphragm.

The convexity of each is turned towards the eye, and the larger lens is nearer the object.

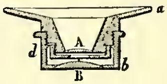


Fig. 27.

Beside achromatism and the diminution of spherical aberration obtained by using a diaphragm, the principal advantage which doublets offer, is that, as two glasses are employed, the focal distance of the lower one can be increased so that the object can be moved farther away, which is a very important consideration in microscopical dissections, where it is necessary to have between the lens and the object to be dissected sufficient room to use the hands and manage the dissecting instruments. The doublets most in use magnify from 5 to 100 times.

Fig. 28.

Compound Microscope.

The compound microscope, reduced to its simple form, consists of two glasses mounted in a tube; one which is called the *objective* is turned towards the object, and the other, the *ocular*, turned towards the observer. Let a microscope (fig. 29. next page) consist of the objective A A' and the ocular B B', and let us suppose that it is desired to observe the object C D. What will be the course of the luminous rays? First of all place the object C D a little beyond the principal focus of the lens A A'.

Draw the secondary axes to the points C and D. According to the rules of refraction, an enlarged image C' D' of the object C D will be formed, real and inverted. If now we calculate the distance between the ocular and the objective, so that the image C' D' is formed between the lens B B' and its principal focus, the rays emitted by this image will be refracted again in B B' and will form at C'' D'' a virtual image amplified and erect with respect to the image, but inverted with respect to the object.

This then undergoes two magnifications However, it is not sufficient that the real image C' D' should be formed anywhere between the ocular and its principal focus; but it must be formed at a point, such that when magnified and rendered virtual, it is to be found at such a distance as to be distinctly seen by the observer. This distance varies with different individuals. It is somewhere about 25 centimetres ($9^4/_5$ inches), a little more for long-sighted people (presbytes), and less for short-sighted people (myopes).

Either the ocular alone, or the entire microscope, must therefore be capable of being removed so as to modify the position of the image according to the condition of the observer's eyes.

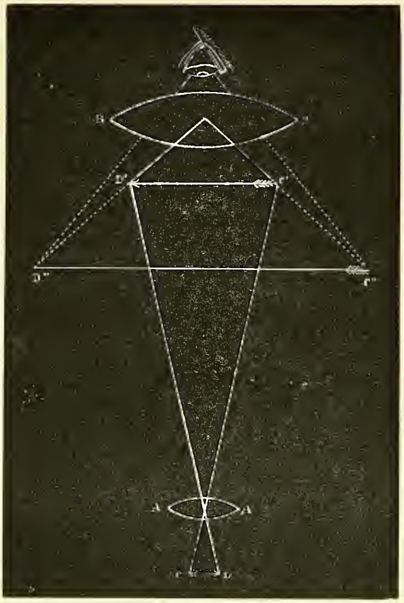


Fig. 29.

The microscopes in general use are not so simple as the one we have just described. In the first place the objective is formed most frequently of several lenses, causing an increased effect which allows their distance from the object to be greater, and also gives them other very useful qualities. In the next place between the objective and ocular, a lens, called a field glass,is interposed, which constitutes an important improvement.

In the first place it is sufficient by itself to achromatize the rays dispersed by the objective, next it collects all the rays and draws them towards the centre of the ocular, and this diminishes the spherical aberration.

The ordinary compound microscope is therefore arranged as follows:—The rays on emerging from the objective are collected by the field glass and form in the middle of the ocular tube a first real image, magnified and inverted. This image is again magnified by passing through the ocular lens, which arrives at the observer's eye, and is sent back so as to form a virtual image at a certain distance above the objective.

The whole system is moveable and can be displaced with reference to the object, so as to be able to see the image distinctly.

The second magnification adds no detail to the image and obscures it considerably if the ocular has strong amplifying power. In constructing microscopes, the aim of the manufacturer should be to give to their objectives the greatest possible magnifying power they can and only to employ medium oculars, especially as the object can always be strongly illuminated, while in the case of the image it is impossible.

CHAPTER II.

PROFESSOR ABBE'S

THEORY OF MICROSCOPIC VISION,

And its Results in connection with Practical Microscopy. (1)

Up to the present we have spoken of light which emanates from a body, as though the theory of Newton were still admissible, that is to say, as if it were still believed that a luminous beam is made up of actual physical rays, and that the meeting of such rays at a given point always produces a light, whose intensity is proportional to the quantity of the rays.

But it has been known for some time that this idea is untenable. The facts which we know through the studies of Grimaldi, Hooke, Young, Fresnel, and many other scientists, have given rise to another conception of the nature of light, namely (the hypothesis of Huyghens and Fresnel) that the radiation of light is produced by an undulatory motion of the ether. In homogeneous bodies, such as air, water, and glass, these undulations are propagated with the same velocity in all directions. The luminous rays have no real existence, considered as physical straight lines. *Only cones of luminous waves more or less narrow* (acute, if the word be preferred) *are produced* when the development of a uniform system of waves is interrupted by means of a screen pierced with holes. In the case of a sufficiently obtuse cone, moreover, the luminous rays can also be regarded as a mathematical abstraction, that is to say, as the normals to the wave surfaces.

But each point on a wave's surface should be regarded as being itself, in its turn, the centre of an undulatory movement, such that the

---

(1) Professor Abbe's theory of microscopic vision, which is summarized in this chapter, was first published in 1873. It is the practical application of this theory which has given to the construction of the microscope its present phase, and which has realized in a few years a progress beyond anything that what could have been hoped for.

We may add that we have gathered the principal elements of this chapter from our conversations and correspondence with the learned Professor, and with his skilful assistant, Dr. S. Czapski. Professor Abbe has been good enough to give us permission to announce that the following pages reflect faithfully his ideas on microscopic vision.

effect of a luminous wave, whether entire, or more or less limited, is always made up of the sum of the effects of all the parts of the wave conformably to the principles of interference.

Every point on the same wave surface *oscillates in the same time, and in the same way;* they are in that way distinguished from *independent* luminous centres, which are distributed over a surface, and whose phases are entirely independent the one of the other.

Let us endeavour to make what we have just mentioned more comprehensible by applying the preceding data to a special case.

If at O (fig. 30) we have a point luminous of itself, and if in its neighbourhood we have a system of lenses L, it is in the first place evident that we have only to consider the part of the luminous waves emanating from O, which is enclosed in the cone O A B, that is to say that part which has as base the nearest surface of the lenses, and as apex the luminous point O itself.

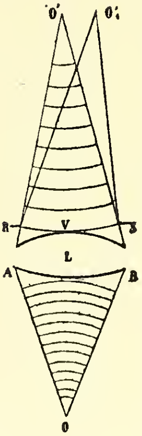


Fig. 30.

If the system of lenses in question has the property of concentrating at another point, the luminous motion which proceeds from O, then according to the undulatory theory, the system of lenses is said to transform the spherical waves proceeding from O, and concentric with respect to O, into other spherical waves, whose common centre is a point O' towards which they contract (converge being the usual expression) if it is a real focus; or whence they appear to emerge if it is a virtual focus.

Let us now assume the case of convergence of which we have just spoken, and let us see whether, under such conditions, the point O is actually reproduced at a point O'. Let us observe moreover upon what the size of this point, greater or less, depends. A little reflection suffices to make it clear, that if any one of the waves which contract towards O' be considered; (for example R V S, whose apex touches the posterior surface of the lens), then the elementary waves (which can be regarded, according to Fresnel and Huygens, as emanating from the different points on this), these elementary waves, we repeat, all arrive at a point O', and in exactly the same phase, that is to say, in the same undulatory condition.

In fact, the courses taken by the elementary waves from each of the points of a spherical wave, towards the centre of the latter, are all equal, because they are the radii of a sphere.

It is thus evident that the effects of all these waves ought to be added to the point O', and that it is at this point that *the greatest possible* luminous effect is produced.

The effect is not, however, absolutely nil at a point in the neighbourhood of O'. Consequently at a like point (O'_1) the courses taken by the elementary waves are not equal; thus these waves arrive there in slightly different phases, and so it is impossible that the luminous effect at O'_1 should be as strong as at O'.

But it will only be at a certain distance from O' that the difference of phase will be sufficiently great, in order that the waves should mutually destroy one another, and consequently produce darkness. As far as this distance the brightness will gradually diminish.

It follows from the preceding consideration that the image of a point O produced by any system of lenses can never be a point, but will always be a disc, whose brightness gradually decreases from the centre to its edge.

In continuing our research in this order of ideas, we shall consequently see that there ought always to be a second distance from O', up to which the luminous action of the elementary waves begins again to increase: and that around the disc in question, at first a *dark* ring, and then another *luminous* ring should be produced, and that this phenomenon should be repeated several times.

But the brightness of the first ring, and still more that of the outer rings, is so very small compared with that of the centre of the disc that it need only be taken into account in very rare circumstances.

Thus we shall be in a position to give an exact account of the circumstances on which the *size* of the little disc, which forms the image of a point, depends; that is to say, the circumstances which determine the resolving power of a system of lenses.

But it is of very little use to pursue further here these considerations, which are very important in the theory of astronomical instruments, and which have been likewise studied by Helmholtz, in the manner indicated above, from a microscopical point of view.

In fact, contrary to what takes place with celestial objects, those which form the subject of microscopical study are not (at least for the greater part) luminous themselves. Thus there do not exist any independent points from which the spherical waves proceed, as we have assumed above.

Objects studied with the microscope are most often illuminated indirectly by another source of light, with the aid of mirrors and lenses, and the illumination is generally effected by taking advantage of its *transparency.*

This circumstance completely alters the conditions of the formation of their image.

Let us now see then how the image is produced under these new conditions.

If opposite the lens L (fig. 31) there be a point O, which is not luminous of itself, but which only transmits rays emitted by the luminous source, M, underneath then it will be impossible to obtain by the geometrical re-union of these rays an image which corresponds with the physical image.

The reason of this impossibility is that the essential condition, on which the concentration at O depends, is not realised, and this essential condition is the identity of the vibrations propagating themselves equally in all directions.

How then is it possible to form the image of an object composed of points themselves non-luminous? This is what we are going to enquire into.

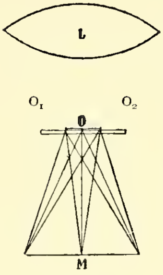


Fig. 31.

Let an object O (fig. 32) be composed of transparent and non-transparent elements in juxta position. Each of the points of the luminous source M sends out a spherical wave, which eventually strikes the object, and the undulatory theory of light tells us that secondary undulations are then formed, which proceed from all the transparent points of the object. These undulations start from different points in the same phase, or in phases which only differ by the slight difference of distance traversed from M to O, to O1, and to O2.

These secondary undulations differ then from the primary undulations, which proceed from different points of a luminous object, in the fact that they are capable of interfering with one another, which is not the case with waves proceeding from different points of an object itself luminous.

Immediately behind the object these secondary undulations produce interferences, which increase the intensity of the light in certain directions, and diminish it, or even annihilate it in other directions.

These interference effects are spoken of as *diffraction of the object.*

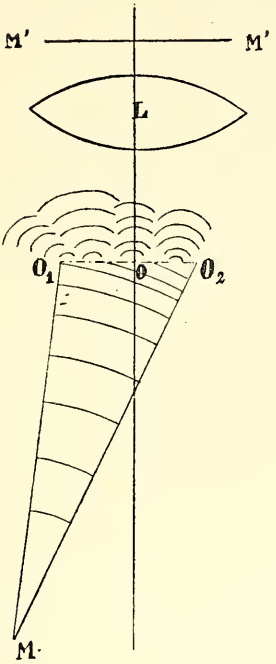


Fig. 32.

The character of this diffraction depends entirely upon the constitution of the object, that is to say, its size, its shape, its substance, and the arrangement of the elements composing it.

But as the objective receives no light, other than the oscillatory motion, which is produced by the diffraction of the object; it follows that all that appears in the microscope ought to depend upon this diffracted light, and consequently *the diffraction which an object produces is the sole effect an object has on its image.*

The effects of diffraction are observed in a characteristic way when an object is examined having *regular* structure, *e.g.*, striæ or elements arranged at equal distances, whether in a rectangular series, or in a series increasing by any angle. In all these cases the light is diffracted in a way which produces a series of maxima and minima *separated* and disposed, either in the shape of a fan or bundle (fig. 33).

The objective projects these divergent maxima and minima emitted by the object in M'M', the *focal plane* conjugate to the plane *of the luminous source M.*

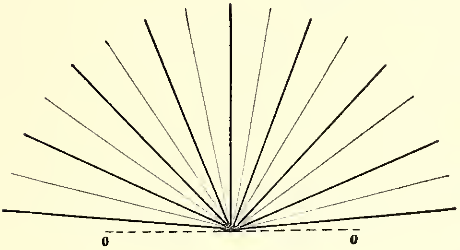


Fig. 33.

These maxima and minima can be observed by removing the ocular, and looking down the tube of the microscope; a transverse section of their different beams is then seen.

The luminous effect produced by the undulations, of which we have spoken above, and which are transmitted by the objective to the plane, conjugate to the object, *is the image of the object.* This image can be mathematically constructed in accordance with the theoretical views of undulatory optics as an effect of interference of the diffracted rays.

Hitherto we have considered the effect which an isolated luminous point, emitting monochromatic light, produces. It still remains for us to examine in the first place the effect of white or composite light, and then the action of an extended luminous source, or one composed of numerous points. Let us, to begin with, take the first of these points.

It is known that the wave length differs for each of the colours of the spectrum. It follows from this that the effect of diffraction produced by the same object for these different colours differs simply in the space, more or less considerable between the corresponding maxima or minima. This difference in the diffraction spectrum is compensated in the formation of the image, produced by interferences, by the difference of wave length, and this in such a way that the final result is the same for all the colours, and consequently the image itself, may perhaps be altogether achromatic (1).

We now come to the second of the points, which yet remains to be examined.

Every extended luminous source may be considered as formed of a number of isolated points, which act independently of one another, and consequently the final result is a simple *superposition* of the

---

(1) A few supplementary details will make what we have just stated more comprehensible. The diffraction image (that is to say, the section of diffracted beams behind the objective) is in its dimensions simply proportional to the wave lengths.

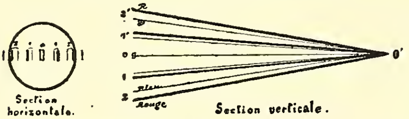


Fig. 34 and 35.

If, for example, the object consists of a simple grating of lines, then behind the objective isolated maxima are seen, and in consequence of the difference in the wave lengths, those of red colour are more distant from one another and from the middle of the field than those of blue colour; this is why the course, which the blue of the spectrum, 1 has to take to the point of the image O', is shorter than the course of the red spectrum 1 to the same point. And the one exceeds the other by such a quantity that on each side of these courses a similar *number* of waves of each species of light is produced, so that both arrive at the point O' in the same time, and in the same phase. The same applies to other spectra. If then the interference of all the red spectra produce at O' a red luminous point, then all the blue spectra equally form a blue luminous point, and so on. If on the contrary all the red waves mutually destroy one another by interference, then the same applies to the blue, green waves, &c.

elementary images produced by these different luminous points in the way described above. We have just passed in review a statement of the points of Professor Abbe's theory; it now remains for us to examine the principal consequences, which result from this theory.

General Results.

1. The image of an object *is not* a geometrical projection which produces it point for point, as would be the case if the image was formed according to the laws of geometrical optics by the reunion of luminous rays, which diverge from different points of the object.

The image has no connection with the object, *except by* that part of the diffracted rays which penetrates the objective. It follows from this that there exists no absolute likeness between the object and its image, for this likeness depends on special conditions, which we shall speak of further on, and when these conditions are not fulfilled every degree of dissimilarity can be produced.

The same object always gives *different* images if different parts of the diffracted beam enter the objective of the microscope.

Different objects can give *identical* images when only the parts of their diffraction spectra, which are identical in each of them, penetrate the objective, while the dissimilar parts of the spectra are excluded *e.g.*, by diaphragms placed at the back of the objective.

The two following assertions, which were made for the first time in Dr. Abbe's work, published in 1873, have been proved by the help of experiments made with gratings (2).

2. Mathematical analysis, based on the undulatory theory, determines the conditions for similarity and dissimilarity between the image and the object, and enunciates them as follows:—

(*a*) The image is *always exactly like* the object, as if it were a geometrical projection point for point, when *the whole of the diffracted pencil* (which the object produces by the rays which traverse it) penetrate the objective of the microscope, and when consequently no part of the pencil of sensible intensity is lost.

(*b*) When, on the other hand, the whole of the diffracted light *is not received* by the objective, then the image differs from a geometrical projection the more according as the *lost* part of the diffracted beam is more considerable, that is to say, the *greater* the

---

(2) We give in the following chapter an article where these experiments are described at length by Mr. J. W. Stephenson, after Professor Abbe. However, we have been obliged to append to the above mentioned article modifications, consequent on the new ideas entertained by Professor Abbe, and which have not hitherto been published.

number of the diffracted rays excluded, and the greater the intensity of these excluded rays, the more will the image differ from a projection of the object.

In this last case the microscopic images appear like an exact image of *another object* (which may really exist, or be capable of being artifically constructed, or may be imaginary), which will be constituted in such a manner that its *complete* diffraction spectra will be identical with that part of the spectra of the observed object, which alone is admitted into the objective.

3. From these two preceding statements result other consequences relating to the mode of action of the microscope, when account is taken of the deductions that can be drawn from optics upon the way in which different objects are diffracted.

The greater the dimensions of the elements of which an object is composed, the smaller is the angular area, over which the diffraction effects of this object extend. The smaller the elements become, the greater the angular extent of the diffraction spectrum becomes.

If the dimensions of the elements are large multiples of the wave lengths of the light, then the intensity of the diffracted light disappears at a very short angular distance from the incident beam.

Consequently from each incident ray there only proceeds one erect diffracted beam, whose angular amplitude is only a few degrees, of even only a fraction of a degree.

If on the contrary the dimensions of the elements or of some of the elements of an object are very small multiples of the wave lengths, or are even smaller than that, then the diffracted light of noticeable or even considerable intensity extends a very great distance from each incident ray.

As the wave length of a light of the same colour, entering different media, is inversely proportional to the indices of refraction of their media, it thus follows that one and the same object produces in a dense medium, (as for example, glass or oil), a diffraction spectrum proportionally less extended than in a medium of rare density (as for example in air).

When we are concerned with objects composed of very small elements, as for example, diatoms with fine striation, then the *total* diffraction spectrum can only be produced in a medium having a very great index of refraction, with a proportionally diminished wave length, while in air, and even in water, and more refractive substances, a more or less considerable *central* part of the diffraction spectrum then occupies an angular extension of 180°

The result of all the preceding is as follows:—

Objects whose parts are large compared with the wave length of the light, or even the parts of objects whose elements are considerable, will always produce an image, which will be perfectly like them, even when objectives of small aperture are employed, and that because the diffraction beams of very small angular extension which they produce, can always completely penetrate the objective. With objects of this kind, which are comparatively coarse, the action of the microscope gives a *final result,* which *entirely* obeys the rules of geometrical optics, provided that the physical conditions are fulfilled.

On the other hand, with objects which produce a large angular expansion of diffracted light, a part of the diffracted beam *is lost,* and this loss is greater according as the angle of aperture is smaller. The lost part, with axial illumination, belongs to the peripherical part of the beam; with oblique light it is an eccentric part which is lost.

The smaller the elements of an object become, the greater should be the angle of aperture (calculated for a given medium) *necessary to utilize the whole or partial diffraction spectrum of the structure,* and consequently to obtain an image of exact or approximate similarity.

The same angle of aperture, in a highly refractive medium, embraces a more extensive diffraction spectrum, and one which corresponds to a shorter wave length of the denser medium.

In fact, the angles of aperture for different media (having regard to the more or less complete absorption of the diffraction beams) vary as the sines of the half-angles, multiplied by the indices of refraction of the media, for which these angles of aperture are of service. These have then to each other the same ratio as numerical apertures.

Consequently, numerical aperture is the measure of the power which an objective possesses of showing more or less faithfully the elements of an object up to a given degree of minuteness.

Special Results relating to the Formation of the Images of Objects possessing a periodic structure.

In objects of irregular structure, the diffraction spectrum extends irregularly in the direction of each incident ray. On the other hand, with objects composed of a considerable number of identical elements disposed in regular series the spectrum assumes a regular form corresponding to them. Here each of the incident rays, each colour being considered separately, divides itself into a number of *isolated* rays (maxima of light, which are separated by dark spaces), which dispose themselves regularly about the axial ray.

In simple periodic structures (striæ at regular intervals), the rays form a plane fan of intensity, gradually decreasing on each side to zero: in double periodic structures (with elements disposed in lattice-work form), they form a beam, with a section in the form of a cross, in which the isolated rays are arranged in series in two directions. As regards the formation of the images of similar objects, the following points are ascertained:—

1. The structure of the object *is not* represented, that is to say that the lines, or the points ("beads") *are not resolved*, when only a single one of the rays of the diffraction beam, to which reference has been made above, enters the objective. To obtain the image of a striation, at least *two* diffracted rays must enter the objective, there being included in them the direct continuation of the incident ray which represents the central maximum of the diffraction spectrum: for example, there must therefore enter the objective, this direct ray plus a diffracted ray.

To obtain the image of a double periodic structure, the objective must receive at least *three* rays belonging to different lines of the spectrum.

2. As the angular distance of the successive rays of the diffraction spectrum, measured by the sines of the angle, is greater according as the striæ (or series of elements) are closer together in the object, it follows from this that each magnitude of the interval between the striæ necessitate a corresponding magnitude of the angle of aperture of the objective, in order that this latter may be able to receive two rays at the same time.

The magnitude of the angle of aperture necessary for the above differs according to the direction of the incident ray. That is to say, according as the ray passes through the centre of aperture, or passes through the edge, as is the case in oblique illumination. In this second case, the nearest diffracted ray can be twice as remote from the direct ray as in axial illumination. Here then is the reason why the same objective shows (resolves) with oblique illumination closer striæ than could be done in axial illumination.

3. The mathematical determination of the statements enumerated in the last paragraph (2) leads to a numerical formula for the *separating* power (resolving power) of a microscope:—

If the numerical aperture of an objective is represented by a, the wave length of the light employed in the observation (this wave length being calculated for air) by λ, then we shall have for δ, which is the shortest distance of an object which can be distinguished by this objective for purely axial illumination, $\delta = \frac{\lambda}{a}$; for the most oblique illumination possible, $\delta = \frac{1}{2} \frac{\lambda}{a}$.

CHAPTER III.

EXPERIMENTS ON THE APPLICATION OF DR. ABBE'S THEORY OF MICROSCOPIC VISION,

By J. W. STEPHENSON. (1)

In my opinion the very important theory of microscopic vision, which has been enunciated by Professor Abbe, has not received in this country the attention it pre-eminently deserves. This theory asserts that the microscopic images produced by certain objects of minute detail, such as diatoms, scales of insects, and other things, are not simply dioptrical images, such as the mere outline of an object, but are the result in most cases of the combination, or fusion together of the central pencil, with certain secondary images produced by the interference of those pencils of light, into which by diffraction the incident ray of light is, in passing through the object itself, decomposed. In other words, the theory asserts that the principal, or central beam of light *alone* is not sufficient truly to depict fine lines, small apertures, or other minute structural details, but that as far as resolution is concerned, two or more pencils are always necessary to produce the desired effect. These pencils may, or may not, include the principal or dioptric beam, but where the latter is excluded, the image necessarily appears on a dark field.

Further, the contention of this theory is that when, from any cause whatever (whether from angles formed by the intersection of lines, or the closeness of the lines themselves, whether from the aperture of the object glass, or when by artificial means the diffraction images as seen within the body of the microscope are made similar), the microscopic images themselves will be identical.

---

(1) This work was presented to the Royal Microscopical Society of London, in January, 1877, by our esteemed correspondent, Mr. F. W. Stephenson. As we have already stated, we have added modifications, which the recent views of Professor Abbe necessitate.

The diffraction images of a lined object in focus on the stage of the microscope may readily be seen by removing the eye-piece, and looking down the tube of the instrument. Here, with the light central, and the lines on the object parallel, the coloured spectra are distinctly visible, going off on either side at right angles to the direction of the striæ, the most refrangible rays being next to the central beam of light. The latter fact is particularly mentioned, as it has an important bearing on the limits of visibility, and on the photographic reproduction of microscopic objects.

Professor Abbe has supported his views by some very striking experiments, which appear to me to be a complete practical demonstration of the truth of his mathematical deductions.

I shall describe four or five of those experiments, which impress me as being the most important, and, therefore, the most interesting.

First Experiment.—The purport of the first experiment is to illustrate the production of *identical* microscopic images by *different* structures, when by artificial means the diffraction pencils arising therefrom are made similar in number and position, within the tube of the instrument, as previously mentioned. This experiment is made on a grating (1) formed of alternately long and short parallel lines (fig. 36) ruled with a diamond through a film of silver of extreme tenuity, deposited on the underside of a thin cover-glass, and subsequently cemented with balsam to an ordinary glass slip, the coarser lines being about 1790 to an inch (71 per millimetre), and the fine about 3580 (142 per millimetre), that is to say, twice as close together.

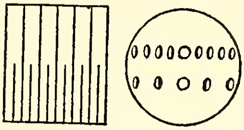


Fig. 36.

On the left: Grating used in the first experiment. — On the right: Appearance presented upon removing the eye-piece. showing central and spectral images.

This grating gives rise to two sets of diffraction spectra, when placed beneath the objective in focus in the middle of the field; the set arising from the wider portion being *exactly* half the distance apart of that arising from the narrower, such distances between the

---

(1) The gratings necessary for these experiments are provided by the firm, Carl Zeiss of Jéna, under the name of diffraction plate, and at a price of 15 frs. The plate is sold with an adapter, having a lateral grove, in which to slide a series of diaphragms, with apertures of different shapes. The adapter is screwed to the microscope by its upper part, and to its lower part is screwed an objective, having a given aperture, *e.g.*, the "a a" of Zeiss, or another of the same focus and the same aperture.

These precautions are indispensable for the success of the experiments, the size of the diaphragms having been calculated for the above-mentioned objective.

spectra being inversely proportional to the distances between the lines themselves (1).

Upon removing the eye-piece, these two rows of spectra (fig. 36) are visible, one above the other, as the eye is brought to see successively the air images at the upper end of the tube.

It is obvious, from fig. 36, that the wider grating gives spectra exactly one-half the distance apart, and therefore twice as numerous as those arising from the narrower, that the latter may be made to coincide with the former, in number and position (as required) by stopping out every alternate ray from the wider grating.

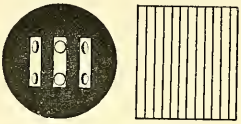


Fig. 37.

On the left: Diaphragm with three slits, shutting out certain spectral images, and making those produced by the two parts of the grating, identical.—On the right: Appearance obtained with the diaphragm. The fine lines are in normal condition, the coarse ones are doubled in number.

This is readily accomplished by placing a stop close to the back combination of the objective, so constructed that a central slit will admit the central ray only, whilst another slit on each side will admit only the second spectrum of the wider, and the first spectrum of the narrower grating (the spectra are cut off from the centre) (fig. 31).

Upon replacing the eye-piece, it will now be seen that the microscopic image of the narrower lines remains unaltered, but that the wider lines have *doubled in number* (fig 38) by an apparent prolongation of the shorter lines between them, making the two images identical, the lines in the upper part being distinguishable only from those in the lower by somewhat less brightness, which simply arises from the smaller number of real lines, through which the light can pass.

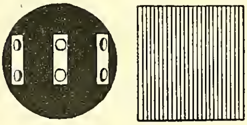


Fig. 38.

On the left: Diaphragm excluding all the spectra of the field (fig. 36), excepting the fourth of the coarse and the second of the fine grating. On the right: Effect produced by this diaphragm: the coarse lines are quadrupled, and the fine lines doubled in number.

Again, by stopping out all the spectra, except the fourth of the wider, and the second of the narrower part (by the diaphragm of fig. 38), the disposition of the spectra is again rendered

---

(1) We need not mention that this is the fundamental principle of the phenomenon of *gratings*.

When a luminous point is looked at in a dark room, through a plate ruled with fine, parallel striæ, which are very close together and alternately opaque and transparent, instead of seeing a single spot, a series of images of this spot is seen ranging along a similar (they coincide in number and position), and the microscopic images, though changed, will be still found to be identical (fig. 38) by the doubling of the narrower, and quadrupling of the coarser lines (2).

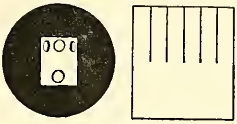


Fig. 39.

On the left: Diaphragm excluding all the spectral rays from the fine part of the grating 1, and all the spectral rays except the two adjacent to the central ray in the course part.—On the right: Effect produced: the coarse lines only are visible, the narrow lines are invisible.

Second Experiment. The object of this experiment is to shew that unless one spectrum *at least* is admitted the objective will have no power to resolve the lines.

The same grating (No. 1, fig. 36) is used as in the preceding experiment with a diaphragm having a single central slit, so adjusted (parallel to the lines of the object) that one spectrum only will be admitted on each side from the coarser grating and none whatever from the finer (fig. 39).

Whilst looking into the microscope it is seen that by the reduction of the aperture, the fine lines (all the spectral images of which have been excluded) have disappeared and are replaced by a uniform surface of silver; the coarse lines remain in their normal condition as the theory indicates.

Third Experiment.—The object of this experiment, like the first, is to illustrate the necessity of an angular aperture sufficient to admit some spectra lrays. The diaphragm has a central slit only 1-30th of an inch in size (fig. 40) which is sufficient to exclude the spectral rays of the finer as well as of the courser lines.

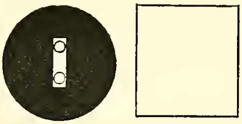


Fig. 40.

On the left: Diaphragm excluding all the spectral rays.—On the right: Effect produced: no line is visible.

The examination in the microscope shows that even as far as lines 1780 to the inch all resolving power has

---

line, perpendicular to the direction of the striæ of the grating displaying spectra. These are diffraction spectra.

The more numerous are the striæ of the grating in a given space, and consequently the more compact they are, the more dispersed and visible are the spectral images of the luminous point; the wider apart the striæ are, the more compact are the spectral images, *i.e.*, the distance between the spectral images is inversely proportional to the distance between the striæ. J. P.

(2) This appearance follows from the principle above; since the spectra which reach the eye through the diaphragm are put at quadruple the distance in the coarse part of the grating they represent the image of lines situated at a distance four times as small; those of the fine part being doubled in their distance represents to the eye the image of lines situated at distances twice as small.

To see this appearance distinctly with the "a a" objective of Zeiss (1½in.) which Dr. Abbe uses, it is necessary to employ a strong ocular No. 5 of Zeiss (No. 5 of Hartnack and Prazmowski, E of the English opticians).

Every other objective of 1 to 2 inches focus would similarly succeed with a suitable diaphragm. That which is employed with the "a a" objective of Zeiss has three slits, each 1-20th of an inch in size, and having the same distance of 1-20th of an inch between them.

departed; the double grating is replaced by a nearly uniform silver band without any trace of lines.

Only inequalities exist in the outline of the lines which grow visible, and help to render the lines apparent.

In all these experiments, where a diaphragm, perforated with a slit, has been employed, it will have been observed that the sides of the slit are parallel to the direction of the lines, but it will be found that if the diaphragm is turned so that the slit is perpendicular to the direction of the lines, all the spectra will be admitted, and perfect definition will result, proving that the position of the diaphragm relative to the striæ and not its form alone, produces the phenomena in question.

The same effects of duplication or obliteration of lines may be produced on an object such as *Lepisma saccharina*, by using higher powers and suitable diaphragms.

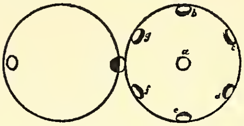


Fig. 41.

On the left: Effect produced by light of extreme obliquity on parallel lines so fine as to reach the limit of resolvibility: the illuminating ray is at the edge of the field and only the more refrangible rays of the spectral image remains in the field at the opposite edge (to the right). On the right: Appearance produced in the tube by a valve of *Pleurosigma Angulatum* (central light).

The limit of visability is a direct consequence of the demonstration of the fact that no resolution can be effected unless at least two rays are admitted. And as the admission of a secondary or spectral image is absolutely dependent on the numerical aperture of the objective, it follows that the resolving power is a *function* of the aperture. This aperture has its superior limit 180°. When the limit of resolving power with oblique light is reached, the illuminating ray is seen at the extreme end of the back lens with the spectral image on the opposite edge, as in the field (fig. 41).

The rule given by Prof. Abbe for determining the greatest number of lines per inch which can be resolved by oblique light (taking any given colour as a basis) shows that *this number is equal to twice the number of light waves in an inch multiplied by the sine of half the angle of aperture.*

As the sine of an angle can never exceed unity, the maximum of the above grating will be equal to twice the number of waves contained in an inch for the ray of greatest refrangibility which will afford sufficient light for this experiment.

With central light the maximum for a given colour will be equal to the number of waves contained in an inch. What the colour of this light is it is generally impossible to determine, as the capacity for appreciating light varies with different individuals. If, for example, we take 0·43 μ in the spectrum as being sufficiently luminous for vision, we find the maximum, as far as *seeing* it is concerned, to be 118,000 to the inch.—But as the non-luminous chemical rays remain in the field after the departure of the visible spectrum, a photographic image of lines, much closer together, might be obtained.

How little is gained in *resolving* power by an excessive angular aperture is seen, when it is considered how slowly the sines of large angles increase. In making a reduction from 180° to $128\frac{1}{3}^\circ$ in the *angle* of aperture, a diminution of only 1-10th of its sine is produced, and consequently of only 1-10th of the resolving power, with a considerable increase in the general utility of the objective; or, if reduced to $106\frac{1}{4}^\circ$, we have still on the same hypothesis by this a resolving power, capable of defining 94,400 lines to the inch.

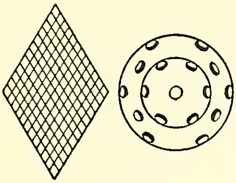


Fig. 42.

On the left: Grating crossed at 60°.—On the right: Disposition of the spectral images produced. These images form, in the little internal circle, an arrangement like that which *Pleurosigma* gives (fig. 41, on the right).

The following experiments are made with crossed gratings, and also give important results.

These gratings are produced by ruling two sets of parallel lines on silver films, the first on the underside of a thin cover glass, the second on an ordinary slide; then the two pieces of glass are cemented together by Canada balsam, so that the two sets of lines are in contact, forming an angle of 60° with each other, which produces rhombic figures on the whole surface of the grating (fig. 42).

Fourth Experiment.—The object of the first experiment, with crossed gratings, is to show that, with a certain arrangement of the light, the real lines can be made to disappear, and are replaced by a set of perfectly distinct spurious lines, parallel to a diagonal of the rhombic figure (fig. 43).

The crossed grating, examined without the ocular, with central light, gives an arrangement of the spectral images on the field (fig. 42, on the right), in which the inner circle of images is identical with that, which *Pleurosigma angulatum,* under similar circumstances, furnishes (fig. 41, on the right). The real lines are made to disappear, and a system parallel to a diagonal of a rhombus is made to appear by employing a diaphragm, with a single slit in the direction of a diagonal, and the spurious lines will appear parallel to the other diagonal, that is to say, perpendicular to the slit.

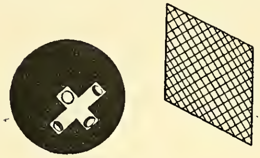


Fig. 43.

On the left: Diaphragm, with cross-shaped slit, admitting central ray, and three spectral rays; the lines joining the four images, two and two are perpendicular to one another.—On the right: Effect produced: The lines, which appear cross at right angles, to the distances, inversely proportional to those of the spectra (: : $\sqrt{3}$: 1).

If a diaphragm, perforated with a cross-shaped slit, as on the left of figure 43 admitting the central ray and three spectral images, the imaginary lines joining these four images, two and two, being perpendicular to one another, two sets of parallel lines will be obtained, the first longitudinal (on the right of figure 43), perpendicular to the long transversal branch of the cross-shaped slit; the second transversal perpendicular to the short longitudinal branch of the slit. These two sets of spurious lines will therefore cut at right-angles, although the real lines of the grating cut at 60°. This effect, evidently, follows in accordance with what we have said above, from the fact that two sets of spectral images, parallel to the diagonals of the grating, which cut at right-angles, have been admitted.

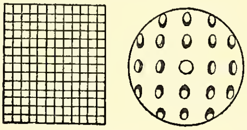


Fig. 44.

On the left: Grating crossed at right-angles. — On the right: Field observed in the tube.

Similar results will be obtained with a grating crossed at right-angles, as that of figure 44, which, examined without an ocular, will give the field as in figure 44, on the right.

By employing a diaphragm, which only allows the central and a single spectral ray to pass (fig. 45), the two systems of horizontal and vertical lines disappear, and are replaced by a single set, composed of parallel lines, and parallel to one of the diagonals of the little squares of the grating (that is to say), to that diagonal which is perpendicular to the slit. The distance between these spurious lines is to that between the real lines, as $1 : \sqrt{2}$.

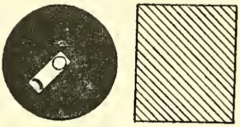


Fig. 45.

On the right: Diaphragm admitting the central ray and spectral ray. —On the left: Effect produced: a set of diagonal lines, perpendicular to the slit.

Fifth Experiment.—The object of this experiment, which is perhaps the most important of all, is to show that by admitting into the objective only one row of spectra, the structure of such an object as that under consideration is absolutely indeterminate.

In this experiment, the slit diaphragms are entirely discarded, and the crossed grating is examined with a simple circular stop, which is used merely for the purpose of so reducing the angle of aperture that the first row of spectra only shall be admitted.

The illumination is central, and, upon examination, without an ocular, seven pencils of light are seen in the field; the first, in the centre, and which is brilliant, is the dioptric pencil; the six others, equi-distant around the margin, are the spectral rays (see the inner circle drawn in the field of fig. 42.)

Let it now be clearly borne in mind that we are about to examine a structure, which we *know to be entirely composed of distinct rhombic markings.*

On replacing the eye-piece for this purpose, we see *hexagonal* markings over the entire field, as in *Pleurosigma angulatum*, and this effect has been produced simply by so reducing the aperture relatively to the fineness of the object, that the first spectra only are admitted.

From this microscopic image, we can infer nothing as to the real structure of the object under examination; we know it to be rhombic, but it appears to be hexagonal.

But the central ray, and the six coloured spectra, which have produced this result, are identical in aspect with that presented by a single valve of *Pleurosigma angulatum*, with central light. (Compare the whole field, fig. 42, with the inner ring, which is there drawn).

This diatom, with central light under the highest powers, and with the largest apertures, necessarily presents the same spectral appearance, in consequence of the fineness of the striæ, or holes (whichever they may be), the dispersion being too great to admit the second row of spectra, *unless one of the objectives, lately constructed, and having an aperture from* 1·5 *to* 1·6 *is employed.*

It has now been proved that, with the means employed, no definite inference could be drawn of the real structure of the artificial object, and it is equally certain that the demonstration will apply with equal force to the valve of *Pleurosigma Angulatum*, the hexagonal markings of which may, to use the words of Professor Abbe, arise from "two sets of lines, or three sets of lines, or isolated apertures of *any* shape in the object itself" (1).

---

(1) Professor Abbe admits that if optics do not permit of the determination of the nature of certain delicate structures, on the other hand, the method that we have adopted in our works (determination of the nature of fine structures by the study of diatom valves having analogous but much coarser structures), this method, we say, of forming a conclusion by analogy, is the safest means of arriving at the truth. H. V. H.

If it were possible to admit the second row of spectra, a nearer approach to a knowledge of the true structure would be obtained; as the larger the number of diffracted rays admitted, the greater the similarity between the image and the object, the keystone of the theory being that "*the interference of ALL the diffracted pencils, which come from the object, produces a copy of the real structure,*" as in a dioptrical image; but it is impossible to admit all the rays, as has been abundantly shown, by the great dispersive power of many fine structures.

Further illustrations of the formation of hexagonal markings may be found on the same diatom.

On bringing into focus, with an objective of about ·8 numerical aperture, a good specimen of *Pleurosigma Angulatum*, flat and having distinct-looking lines, and using a broad beam of central light, the six diffraction spectra, before alluded to, may be distinctly seen (without an ocular) within the margin of the back lens of the objective (fig. 41). Any two adjacent spectra, combined with the central cone of light, will form an equilateral triangle (*a*, *b*, *c*, for example), and produce the well-known hexagonal markings, that is to say, three sets of lines crossed at 60°, but, as any other pencils forming an equilateral triangle will also produce hexagonal markings, a *new* set on a dark field may be formed by excluding the central, and three alternate rays of the six spectral rays. We will take, for example, the three rays, *b*, *d*, *f*, (or *a*, *c*, *e*, *g*); the sides of this triangle being longer than those of the common figure in the proportion of $\sqrt{3} : 1$, the new hexagons will be *three times* as numerous as the first ones, having their sides at a different angle to the median line. The three pencils producing the interference in this case are, as we have said, *b*, *d*, *f*, or *c*, *e*, *g*, and not only is this effect seen to be capable of production, but it follows from the theory that there must be visible three other sets of lines bisecting the angles between the common lines, and corresponding to the combinations of the spectra *g*, *c*, or *f*, *d*—*b*, *f*, or *c*, *e*—*b*, *d*, or *g*, *e*. All these phenomena can be produced by excluding suitable rays. It is easy to get the lines bisecting the angles of the common rows one after the other, and of these, one set parallel to the axis of the frustule. For this purpose, oblique light must be used, and the central beam, and one of the peripheral rays must be stopped out, leaving, for instance, *b* and *f*, or *c* and *e*, (*i.e.*), two spectra parallel to the median lines (1).

---

(1) The firm of Carl Zeiss has constructed lately a special apparatus for the demonstration of these experiments even by projection on a screen.

THE MICROSCOPE.

BOOK I.

CHAPTER I.

GENERALLY.

THE invention of the microscope is ascribed to Zaccharias Janssen, of Middleburg (Holland), in about the year 1590, and is the instrument which enables us to study objects too minute to be seen distinctly with the naked eye. It is composed of different parts, each of which has a special and clearly-settled use. The microscope is an apparatus which must be manipulated with care, if it is desired that the best results be obtained from it. To commence with, therefore, we will examine the various parts of which it is composed, both those which are essential, and those which are accessory.

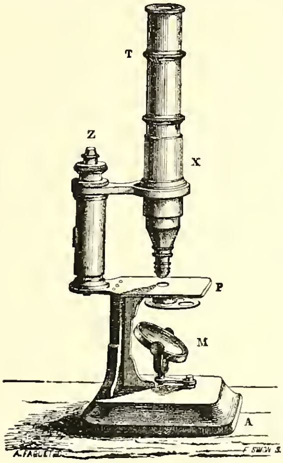


Fig. 46.

Microscope.—The *foot* A of the microscope is that part of the instrument by which it rests on the table; it is attached to a single or double pillar, or to a bar, which supports the microscope proper; the name of foot is also often given to the entire arrangement, which we have just described. In first-class instruments, the microscope is always jointed at the foot, so that it may be inclined at any angle.

The microscope proper is composed of a tube, terminated at its two extremities by a combination of lenses. This entire arrangement can be made more or less to approach or recede from a small table, which is called the *stage*, and on which the object is placed for examination. The stage is perforated with an opening, through which the light, coming from beneath can pass, and illuminate the object.

Let us examine these different parts more in detail. The *tube* (fig. 45 T) is made of brass, having its inside blackened. It is open at the upper end, so as to receive another shorter brass tube, which is fitted into it with a sliding motion. This shorter tube carries a lens at each end of it, and is called the *ocular*. The lower end of the tube is provided with a spiral groove, by which means a system of lenses, called *the objective*, can be adapted to it.

The tube is usually composed of two pieces, the one sliding into the other, so that it can be lengthened or shortened for different magnifications. In good instruments, the inner tube is divided into inches and lines or millimetres (1), so as to indicate exactly the actual length of the total tube used.

All microscopes have not the same length of tube, and a distinction is made between the *English length*, which is adopted by all English and American makers, and which is ten English inches (say 255 millimetres), and the *Continental length*, which is from sixteen to eighteen centimetres (say from $6^3/_{10}$ to $7^1/_{12}$ inches), but by drawing out the tube, the length can usually be increased to 20—22 centimetres ($7^4/_5$—$8^3/_5$ inches).

The length of the tube is a matter to be taken into consideration when the microscope is being used. Unless the objective is furnished with a long correction (we shall see later on what this is), which always is the case with English, but seldom with Continental objectives, no objective will give a good image, except when employed with the length of tube, for which it was constructed. To bring the tube nearer to, or farther from the stage, it is made to slide, by giving it a spiral movement in the tube X, which is carried on the arm of the slow movement Z. We have thus, by a sliding movement, what is called the *rough adjustment*. In instruments of superior quality, the rough adjustment is effected by turning a milled head, attached to a pinion, which acts on a rack fixed to the tube.

The rough adjustment serves to bring the object more or less into view, that is to say, it moves the tube, so that the distance of the object from the tube (containing the optical part) is such that the details are seen clearly. In addition to this adjustment, every

---

(1) One millimetre=·0394 of an inch, or roughly 1-25th of an inch; one inch=25½ millimetres.

complete microscope possesses a *fine adjustment* as well, which is effected by turning the milled head Z, controlling a micrometrical screw. By means of the micrometrical screw, the tube can be moved a very little distance indeed (*e.g.*) one hundredth of a millimetre, and even a much smaller in certain instruments.

The *stage* P is a small solid table of metal, perforated with an opening opposite the tube. The glass slip, which bears the object for examination, is placed on this stage, and the former can be fixed with two brass springs, which are called *clips*. Later on, we shall have to return to the parts of the stage.

The *mirror* M, which will be found under the stage, enables the object to be illuminated by transmitted light. The light reaches the object, either slightly concentrated when the plane mirror is employed, or strongly concentrated when the concave mirror is used.

Such are the essential parts of which the microscope is composed. We now pass on to describe these principal constituent parts in greater detail.

CHAPTER II.

DETAILED EXAMINATION OF THE PARTS OF A MICROSCOPE.

I. THE OPTICAL PARTS OF THE TUBE.

I. THE OBJECTIVES.

General Remarks.

The objective is the most important part of the microscope for the more perfect the objective, the better will be the results obtained by the instrument.

Objectives of the present day are all achromatic, that is to say, formed by combination of lenses made of flint and crown glass, and even of various other substances, and so combined, that the red and blue rays, which become separated when white light passes through the lenses, are once more reunited in the same plane.

When the objective is not achromatised, these rays remain separated; the image of the object under examination is then surrounded by a blue and red border, and does not present any clearness.

It is only since 1885, thanks to the fact that new combinations (glass and pseudo-glass) can be employed in the construction of lenses, that objectives can be obtained, in which the three principal rays of the spectrum are reunited on the same plane. In this way, objectives of extreme perfection are obtained, to which the name of *apochromatic objectives* is given. They are, unfortunately, extremely expensive, on account of the difficulty of their construction.

Formerly, objectives were formed of a single lens only, more or less convergent according to the magnification desired.

Charles Chevalier, who, in 1823, constructed the first achromatic lenses with short focus, conceived the idea of superposing several of them. He could, in this way, distribute the curvature of a single lens over several lenses. The effect of this was first to render the construction of objectives easier, since each lens in the Chevalier objective was a great deal larger than in the ordinary one; and secondly, the image for a given magnification became much brighter and more distinct.

Moreover, Charles Chevalier achromatised each of the lenses of his objectives separately; each of them therefore could, if desired, be employed singly.

The combination forming an objective, actually gives an achromatised image, but the composition of the crown and flint glass in each lens varies. An image is thus obtained, showing the details of the object much better, and having, what is called, greater aperture, but the lenses should remain combined and be employed united, as the manufacturer supplies them.

Objectives are divided into those whose lenses are fixed in their mounting, and those with correction collars, which have previously been mentioned.

1. **Objectives fixed in their Mounting.**—Objectives fixed in their mounting, are those whose lenses are fixed by the manufacturers at a determined and invariable distance. Such an objective can only be employed for a fixed length of tube.

2. **Objectives with Correction Collars.**—In 1829, Amici first noticed that high-power objectives, which give a perfectly clear image when objects, not covered with a glass, were examined, did not give so good a one when the object was covered, and that the clearness of the image increased and diminished, according to the thickness of the cover-glass. To remedy this defect, which resulted from spherical aberration, Amici constructed his objectives in such a manner that they could all be used with cover-glasses of a definite thickness.

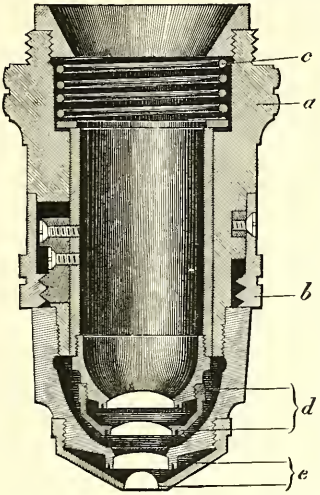


Fig. 47.

In 1837, the celebrated English optician Ross, though ignorant of the discovery of Amici, made the same observation, and to remedy the defect, he invented correction objectives.

In this kind of objective, the two upper lenses (fig. 47, *d*) occupy an invariable position with regard to one another. They are fixed in a moveable tube, and can be made to recede from, or approach, the lower part, which is fixed, and carries the single or double frontal (fig. 47, *e*). By turning the ring *a*, the upper lenses rise or fall, and a coiled spiral spring *c* regulates the small inequalities of the screw, and above all prevents the "back lash," which is always produced when the sense of motion is changed. The firm of Carl Zeiss engrave on their correction objectives a very practical series of figures. This series of figures, which extends from ten to twenty-five (or less) indicates at once the position to be taken for any given thickness of cover-glass. If we have, for example, to study a preparation covered with a cover-glass 1½ tenths of a millimetre thick, the division 15 is placed against the index, and we shall have the best position of the lenses in which to study the preparation in question with axial light.

Objectives may be divided into two classes, dry and immersion.

3. **Dry Objectives.**—Dry objectives are those where the object (or rather the slip which covers it) remains at a certain distance (which may be extremely small) from the objective, or where the air intervenes between them continuously.

4. **Immersion Objectives.** — Immersion objectives, on the other hand, are put in conjunction with the cover-glass by means of a drop of liquid. Distilled water is the liquid interposed in ordinary immersion objectives; in objectives called *homogeneous*, cedar oil is used, either pure or previously thickened by the oxidizing action of the air and by then adding olive oil.

By the interposition of this liquid, a great number of luminous rays are recovered, which were previously lost in their successive passages from the cover-glass into air, and from that again into the glass of the objective.

The cedar oil has the same index of refraction (1·515) as crown-glass, which is used in the construction of the lens nearest the object, and which is called the *frontal.* There is, therefore, in that medium no loss of light by refraction, although there is still a little in the case of water, whose index is only 1·336.

Immersion objectives give a clearer, brighter, and more detailed image than dry objectives. They have, at the same time, a greater frontal distance for the same amplification; that is to say, the frontal remains at a greater distance from the cover-glass, and consequently work becomes easier.

It was at once thought that homogeneous objectives realized the limit that could possibly be reached in the construction of objectives.

But this was not so, for of late the firm of Zeiss have effected an extremely important advance in microscopical optics, first by the construction of apochromatic objectives, and also by the manufacture of a special objective, whose frontal is no longer of crown but of very dense flint-glass.

5. **Apochromatic Objectives.**—Apochromatic lenses were first offered for sale in 1886 (1) by the firm of Zeiss, and were the result of the researches of Professor Abbe.

From an optical point of view, apochromatic objectives differ from all systems of lenses hitherto used for the microscope, in that they simultaneously realize two conditions relating to the union of the rays of the spectrum in one focus. The first is the convergence of *three* different rays of the spectrum to a single point on the axis, *i.e.*, in the suppression of the spectrum called *secondary*, which existed in all achromatic systems in use up to that time. The second condition is the correction of spherical abberration for *two* rays of different colours, while, up to that time, correction had only been made for a single ray (viz., for that whose colour was the clearest).

All optical systems constructed up till then (the microscope, as well as other instruments) give a *clear* image only for the rays of a single colour (intermediate between yellow and green for ocular instruments, and intermediate between blue and violet for photography).

For all other colours they give images more and more obscured, surrounding the clearest image with a coloured border, or rather, forming a general mist, which envelopes the whole field. Apochromatic objectives give, on the contrary, for all the rays of the spectrum images of an approximately uniform clearness. Therefore with white (compound) light, or even when only some portions of the spectrum intervene (whether when using monochromatic light, or when photographing) objects can be observed and the image is always uniformly clear.

Further, in the old systems the correction of chromatic aberration is only good for a single zone of the objective; it becomes worse and worse towards the edge and towards the centre of the lens; in apochromatic systems, on the contrary, chromatic correction is effected for all the zones of the objective alike. For instance, if the Abbe test be used, the appearance of a coloured outline cannot

---

(1) *See* H. Van Heurck, Journal de Micrographie 1886, page 91.

be noticed with a very oblique illumination any more than when a moiety or the centre of the lens is illuminated.

Thus, in the ordinary achromatic systems, even for the zone of the objective where the chromatic correction is the best, the rays of only two colours cut the axis in a single point; the images of different colours, therefore, only coincide two and two, and present a very marked *difference of focus* between them. In the systems we are considering, the rays of different colours cut the axis three and three in the same point, so that the space over which the different foci of all the rays of the spectrum (from the optical rays to the extreme chemical rays) extend is from seven to ten times smaller, and can consequently be considered as practically reduced to zero, and this takes place in an identical manner for each zone of the objective.

The images of the different colours, already very clear in themselves, are then made to exactly coincide, and to act simultaneously so as to produce one and the same effect.

The practical advantages of these improvements are therefore manifest. The concentration of a much greater light for ordinary ocular observation, or for any other use, with any kind of illumination (central or oblique, white light, or monochromatic) assures an advantage, to these systems over all others hitherto constructed, as much on account of the importance of their effects, as the number of applications of which they are susceptible.

The natural colours of objects, even to their faintest tints, are faithfully reproduced in the image. They are almost as distinct at the sides as in the middle of the field. It is only on account of the inevitable curvature of the field that the marginal parts have not quite the same focus as the central parts, which should be focused one after the other by means of the micrometrical screw.

These objectives admit of the use of very strong oculars without any loss of clearness and brightness in the image. High magnifications are therefore obtained with a relatively long focal distance and each of the objectives consequently furnishes a very wide range of different amplifications.

6. Objectives with very wide Aperture.—If the crown-glass of the frontal be replaced by a substance of greater refractive index the aperture of the objective is considerably increased. About 25 years ago, we made experiments in this direction, and we gave an account of them in 1869 (1)

---

(1) *See* Second Edition of Le Microscope par le Dr. Henri Van Heurck, 1869.

But, notwithstanding results beyond our expectation, we were obliged to interrupt our researches from want of leisure and a sufficiently perfect plant to bring these experiments to perfection.

But what an amateur could only sketch, the firm of Zeiss has brought to perfection, and, in fact, has much surpassed what we could have believed possible.

The objective, which they have constructed, possesses a numerical aperture of 1·63, the frontal lens is made of flint-glass, having an index of 1·72, and it is immersed in monobromide of naphthaline, whose index is 1·65.

In comparing these different figures, the objective will be seen to vary considerably from the *homogeneous* type.

We shall describe this admirable objective when speaking of the apparatus of the Zeiss firm.

Moreover, this objective is not the last word, so to speak, of the science, for Messrs. Zeiss anticipate the possibility of effecting before long some steps in advance in the same direction.

7. Objectives are usually adapted to the tube by means ot a screw-thread, but, unfortunately, these differ.—There is the *French screw-thread* used by Nachet, the *German thread* adapted by German makers, and lastly, there is the *English thread* (*Society's Screw*) employed by the English and American makers, and also by Zeiss. The English thread, which was designed by the Royal Microscopical Society of London, is very superior to the others, because in the construction of objectives it allows the use of lenses of a greater diameter. Let us add, however, that good Continental makers like Nachet, Reichert, and Hartnack, now furnish their best instruments with the English screw-thread. In these instruments it is only necessary to remove the small piece which forms the end of the tube, and which is called the *cone* to enable objectives furnished with the English thread to be adapted.

The English thread is however not all that we have to say on this matter. In America the *American thread* is also employed, which is considerably greater and admits of the use of lenses with a much larger diameter, and thus offers certain advantages. In the first place, the larger the lens the easier it is to make, and consequently the real curvatures approach closer to the calculated curvatures; then the larger the lens, the more luminous rays it admits—and this, especially in photography, is not to be despised. Moreover, the first and second points which we have just enumerated allow of the use of more powerful oculars with a given objective.

Formerly, objectives were classified by numbers or letters—an altogether arbitrary classification, which differed with each maker. Now, nearly all the good makers classify their objectives according to the focus, or focal distance.

8. Many factors require to be taken into consideration when examining objectives, viz.:—*Focal distance*, *frontal distance* and the *angle of aperture.*

Focal distance.—The place, where all the rays, received by a lens, are united into a single point, is called the focus of the lens, and the distance of this point from the lens is called the focal distance.

In ordinary microscopical objectives, constructed with two, three, or four lenses, these united lenses play the part of a single simple lens.

In reality, the focal distance of such a combination is shorter than that of a simple objective, which will give the same magnification. They can nevertheless be compared, and American and English opticians as well as some German makers number their objectives according to their focal value.

The simplest procedure for measuring the focal distance of an objective is that indicated by Prof. Harting, as follows:—The micrometer (divided into hundredths of a millimetre for an objective of high power, or into tenths of a millimetre for one of a low power), is placed on the stage. The objective, whose focal distance is to be determined, is screwed into the tube of the instrument, and the ocular is taken out and replaced by finely ground-glass.

The microscope is illuminated by solar rays, and adjusted so that the lines of the micrometer appear with their maximum clearness on the ground-glass.

The breadth of the image of a micrometrical division is measured by means of a compass or rule (for greater exactness, a certain number of divisions may be taken, and the average breadth calculated), and then the exact distance of the surface of the micrometer from the surface of the ground glass must be measured. The focal distance is then found by means of the formula:—

$$a = \frac{b\,h}{d}$$

It follows from this formula that the exact focal distance f will be

$$f = \frac{a\,b}{a+b}$$

In these formulæ:

a represents the distance of the micrometer from the objective;

h the real size of a division of the micrometer;

d the size of a division of the micrometer in the image;

b the distance of the micrometer from the image;

Frontal distance.—The focal distance must not be confounded with the frontal distance, for the latter is the space between the objective and the cover-glass when the preparation is in focus, that is when it can be seen with the greatest precision.

Frontal distance is an important factor in estimating the value of an objective. If the frontal distance is too small, it is necessary to use cover-glasses which are very thin, and therefore difficult to manage, and, moreover, many ready-made preparations cannot be studied by such objectives.

We must, therefore, now examine the optical qualities which an objective should possess, and this we will do in the following paragraph.

Optical qualities of a good objective.—Objectives ought to give images whose outlines are clear, well-defined, and showing the details well, and the image formed at the margins of the objectives should be as good as that in the central part.

These qualities depend on the angle of aperture, and on good correction for chromatic and spherical aberration.

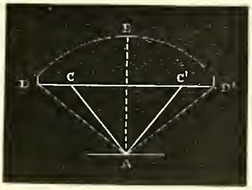


Fig. 48.

The angle formed by the two extreme rays, emanating from the object, and utilized by the objective, is called the *angle of aperture* (fig. 48).

The greater the angle (fig. 48) C A C' and D A D', and the more detail in the image which the objective shows, but, in proportion as this angle augments, so will the frontal lens of the objective approach the cover-glass, and the part of the object shown at any time approximate to a mathematical plane. It is necessary that the angle of aperture of an objective be made proportional to its power; it would be absurd to give a very great angle to a low power, for it would thus be made to give details, which the eye could not distinguish, because they would be too closely compacted together.

The angle of aperture of a dry objective is completely different from that of an immersion objective, and as the angular measure of aperture was subject to various interpretations, Professor Abbe thought of the happy idea of replacing this measure by another, which is called *Numerical Aperture.*

This quantity is represented by the expression:

$$O = n \sin u$$

where n represents the index of refraction of the surrounding medium, air, water, or oil, and u the half-angle of incidence of the extreme rays.

Thus, says Dr. J. Pelletan [1], a dry objective, which has 180° as its extreme angle of aperture, will have 1 as its Numerical Aperture. For in the formula $O = n \sin u$, the index n of air is 1, and the angle u is the half of 180°, that is to say 90°, the sine of which is 1. The numerical formula therefore becomes $O = 1 \times 1 = 1$.

It is thus seen that a water immersion objective of only 97° of angular aperture corresponds in optical power to this dry objective of 180° maximum angular aperture, and whose numerical aperture = 1. For the sine of $48\frac{1}{2}°$ (the half of 97°) is roughly ·752, which, multiplied by 1·33, the index of water, gives 1 as the value of its numerical aperture.

And the same optical effects would be produced by a homogenous oil immersion objective which has an angular aperture of only 82°, for in the formula $O = n \sin u$ the index n of cedar oil used is 1·52, and $\sin u$ or $\sin 41°$ is practically ·658. Therefore, $O = 1{\cdot}52 \times {\cdot}658 = 1$.

It will similarly be seen that a water immersion objective of only 85° angular aperture corresponds to a dry objective, having an angular aperture of 128° (in air), because each has the same numerical aperture, viz., ·90. Practically, the formula gives for the numerical aperture of the first: $O = 1 \times \sin 64° = 1 \times {\cdot}90 = {\cdot}90$; and for that of the second: $O = 1{\cdot}33 \times \sin 42\frac{1}{2}° = 1{\cdot}33 \times {\cdot}68 = {\cdot}90$.

Again in the same way, a homogeneous immersion objective ($n = 1{\cdot}52$), having an aperture of only 92°, corresponds to a water immersion objective ($n = 1{\cdot}33$) of angular aperture 112°, for each has 1·10 as its numerical aperture, as is easily seen from the above mode of calculation.

It will now be observed that if, as we have seen above, a water immersion objective, whose angular aperture is 97° and whose numerical aperture is 1, and a homogeneous objective of 82° angular aperture, whose numerical aperture is also equal to 1, correspond to a dry objective of 180° angular aperture, whose numerical aperture is equal to 1, then all water immersion objectives, which have an angular aperture greater than 97°, and all homogenous objectives, whose

---

(1) Les Diatomées, page 150.

angular apertures are greater than 82°, correspond to dry objectives, whose angular apertures would be greater than 180°.

Now, this result appears absurd. It is difficult to comprehend an objective whose angular aperture would be greater than 180°; indeed it is a thing which cannot be realized in practice with dry objectives. These are the very same considerations which have excited long and animated discussions among microscopists on what is called the aperture question. And one of the reasons which led Professor Abbe to abandon the idea of angular aperture, and adopt numerical aperture in its stead, which is applicable to all cases, was the fact that it has no meaning after a certain limit.

Numerical aperture is estimated in practice by means of a very small and very simple apparatus, called *Abbe's Apertometer* (fig. 49).

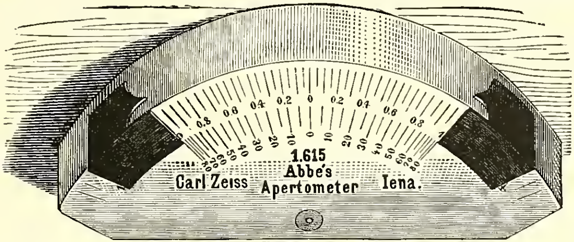


Fig. 49.

The apertometer, an apparatus placed on the stage of the microscope, consists of a thick semi-circular disk of flint-glass, 90 mill. (3·546 inches) in diameter. The diametral edge is bevelled so as to give the effect of a reflecting prism, and so send the light horizontally into the axis of the microscope.

The objective which is being examined is made to focus the central point of the upper surface of the disk. The limits of aperture are determined by the two indicators, which slide on the circumference of the disk, the image of which being projected by the objective into the tube of the microscope, is focussed by means of an accessory objective, which is screwed to the lower end of the draw-tube; the focus is then obtained by moving the draw-tube up and down.

The indicators, focussed as just mentioned, are then moved to and fro along the surface of the disk, and when their image is on the point of disappearing from the field, their position is read on the two concentric scales drawn on the disk. One of these scales gives the angle of aperture of the objective, the other indicates its numerical aperture.

The possession of an apertometer is of great service to those manufacturers and microscopists, who are constantly comparing objectives, but evidently the student, who has only a few objectives at his command (as is usually the case) has no need of this ingenious apparatus, and can estimate accurately enough the aperture of his objectives by examining certain diatoms.

Indeed, diatoms have markings and striæ at regular intervals on their silicious frustules, which vary only to a very small extent in the same form.

Now the power of resolving a certain number of lines or striæ within a given space, depends upon the numerical aperture of the objective.

The aperture of an objective can therefore be estimated accurately enough for all practical purposes by making an examination of certain diatoms.

The Royal Microscopical Society of London has published a table, which indicates the number of lines which a well-constructed microscope of given aperture should theoretically be able to resolve.

We give here an extract from this table for the most usual numerical apertures of good objectives. We have reduced to a millimetre, the number indicated for the English inch (=25·5 mm.).

Numerical Aperture.	Maximum number of lines which an objective can resolve in a millimetre.			Corresponding diatom for white light and mean number of striæ.	Corresponding number of the groups in Nobert's tests.	
	In white light.	In blue mono-chromatic light.	By photo-graphy.		Test of 30 groups.	Test of 19 groups.
1·63	6000		10000	Amphipleura in beads (5000 to 5100)		
1·40	5292	5737	6972			
1·30	4915	5327	6474			
1·25	4726	5722	6225			
1·20	4536	4917	5976			19th (4430)
1·15	4347	4112	5727			18th (4209)
1·00	3780	4098	4980	Amphipleura pellucida (3700)		16th (3766)
·95	3591	3893	4731	Vanheurckia crassinervis (3500)	30th (3544)	15th (3591)
·80	3024	3278	3984	Vanheurckia rhomboides (2800)	25th (3000)	13th (3100)
·60	2268	2458	2988	Pleurosigma angulatum (2000)	16th (2264)	9th (2215)
·40	1512	1639	1991	Pleurosigma Balticum (1500)	9th (1490)	6th (1550)
·30	1134	1229	1494	Navicula elliptica (1100)	7th (1091)	4th (1108)
·20	756	819	995	Navicula viridis (700)	4th (707)	2nd (665 lns.)

We give at the same time the diatom which corresponds to this number, and also the group in the Nobert test. It should always be borne in mind that the number indicated is the theoretical figure, and it would be futile to expect to realize it in practice; but if the objective is well-constructed, the resolution of the diatom or the corresponding group of Nobert, can be effected by employing monochromatic blue light.

This list can be completed in like manner for objectives, which could not possibly be produced at present. Let us note, however, that it is scarcely credible that a numerical aperture of 2·0 can be exceeded, or even that that aperture can be attained.

To go as far as 2·5, it would be necessary that the frontal lens be made of Diamond, or of Realgar, which, indeed, is quite possible. But it would also be essential that the cover and slide of the preparation have the same refractive index, which, is very hypothetical, unless that can be made artificially of large plates of diamond. Moreover, the immersion liquid must have the same index, which is even still more problematical.

Be that as it may, we have added the last two apertures simply by way of curiosity, and for the purpose of showing how little difference—compared with what we already have—these fabulous objectives would produce.

In the following list the resolutions are calculated only for axial light; for oblique light, the figures ought to be about doubled:—

Numerical aperture.	Maximum number of striæ which the objective can resolve per millimetre in axial light.		
	In white light $\frac{a}{\cdot 53}$	In blue monochromatic light $\frac{a}{\cdot 49}$	By photography. $\frac{a}{\cdot 40}$
1·70	3210	3470	4250
1·75	3300	3571	4375
1·80	3390	3673	4500
1·85	3490	3775	4625
1·90	3585	3800	4750
2·00	3775	4080	5000
2.5 (Diamond and Realgar)	4717	5100	6250

The Nobert test, which we have cited above and of which we shall speak again later on, consists of a series of groups of lines ruled by a diamond on a glass slip. In each successive group the lines become more delicate and closer together. There are two kinds of Nobert tests in existence, the first consists of thirty groups; the first of which shews 443 lines per millimetre, and its last shews 3,544. The second Nobert Test, which was the last to be submitted to microscopists, shews 443 lines per millimetre in the first group, and 4,430 lines in the nineteenth, or last group.

These tests bear the name of the skilful optician who used to construct them, and who died about five years ago, having kept secret to the last the process which he employed.

The instrument used by Nobert belongs, at present, to Mr. Crisp, the eminent treasurer of the Royal Microscopical Society of London.

Fasolt, in America, it is said, makes tests analagous to those of Nobert, but we have no personal knowledge of them.

The power of exhibiting detail, as we have just seen, depends on the angle of aperture, and is called the *resolving power* of the objective.

An objective, whose aberrations are well-corrected, will define well the outlines of the objects which it shows, and it is then said to have good *defining power.*

A wide angled objective, we have previously seen, always has a very small frontal distance, and only grasps a mathematical plane, but objectives having a certain *penetrating power*, that is the power of grasping several planes at one time, and having greater frontal distance, are preferred for histological studies. These objectives have smaller angular aperture, and are theoretically inferior.

Professor Abbe has satisfactorily established the fact that a certain relation must exist between magnification and angular aperture, and he has published a long paper on this subject in the journal of the R.M.S. of London (1).

9. On the number of Objectives.—It is absolutely useless, even for anyone who desires to apply himself to the most serious microscopical studies, to have very numerous objectives unless indeed he wishes to devote himself to studies of comparison.

The following series amply suffices:—

An objective of 2 inches (48 mm.) whose initial magnifying power is 5
" " 1 inch (24 mm.) " " " 10
" " $\frac{1}{2}$ " (12 mm.) " " " 21
" " $\frac{1}{4}$ " (6 mm.) " " " 41
" " 1-10th (2·5 mm.) " " " 100

The $\frac{1}{4}$ of an inch can always be replaced by a 1-6th, and the 1-10th by a 1-12th of an inch.

---

(1) On the Relation of Aperture and Power in the Microscope, J.R.M.S., 1883, page 790.

It must be well understood that the objectives should be of the best quality, and that the 1-10th and the 1-12th should be immersion.

The last objective ought, indeed, to be apochromatic and of homogeneous immersion, if it is to be used for all researches.

The entire series, on the other hand, would not be required, and the two inches and the 1-12th inch could be suppressed if it is only required for certain researches. The last objective can then be a 1-12th inch water immersion.

Let us recapitulate the preceding data:—

1. *Complete and perfect series.*

Objective of 2 inches;
„ of 1 inch apochromatic;
„ of $\frac{1}{2}$ inch;
„ of $\frac{1}{4}$ or $\frac{1}{6}$th inch apochromatic;
„ of $\frac{1}{8}$th or 1-12th inch, homogeneous apochromatic;

2. *Incomplete series, but sufficient for the greater number of researches.*

Objective of $\frac{1}{3}$rd inch, or $\frac{1}{2}$ inch;
„ of $\frac{1}{6}$th inch;
„ of 1-12th inch homogeneous immersion;

3. *Series very incomplete, but sufficient for many ordinary researches.*

An objective of 1 inch, and an objective of $\frac{1}{6}$th of an inch.

Tests.

1.—Ordinary Tests.

Certain objects, whose details are well-known and which serve as standards to estimate the value of objectives, are called *Tests.*

It is by examining the principal tests in every possible illumination that the young microscopist will become initiated into all the resources of his microscope, and being perfectly aware by the published designs what details the object should show, he will work on until he is able to bring these details clearly into view.

The number of tests described by authors is considerable, but they may be limited to the six following:—

Pygidium of a flea;
Podura plumbea;
Pleurosigma angulatum;
Surirella Gemma;
Van Heurckia rhomboides and var crassinervis;
Amphipleura pellucida;

If to the above a Nobert test can be added, these will be sufficient for every experiment.

We will now examine these tests in detail :—

Pygidium of a Flea.—The Pygidium of a flea is an excellent test to judge of the defining power of an objective. We have employed it for this purpose for more than 25 years, and we are very satisfied with the results that it has given. This test should always be prepared by the student for himself, for we have never yet met with a good specimen produced by a professional mounter.

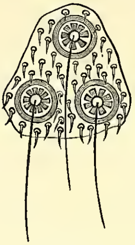


Fig 50.

The Pygidium of a flea (fig. 50) is composed of two lobes, and displays thirty-two to thirty-eight long and stiff hairs, implanted in the centre of as many areolæ, and each is surrounded by a row of small cuneiform elevations. The spaces between the areolæ are covered with small spines.

An excellent objective ought to show these areolæ clearly defined in all their parts, and the elevations ought to appear cuneiform, and not round as they are drawn by Dujardin. Moreover, the colour of the object ought to be a very clear brownish yellow, without the slightest appearance of milkiness.

Podura.—Under the name of *Podura* is included the scales of *Podura plumbea* (*Lepidocyrtis curvicollis*). This object, which is almost unknown to continental microscopists, is the favourite test with English observers.

The scales show markings, which have been compared, with much justice, to notes of exclamation. When the objective is good, and the correction is suitable to the thickness of the cover-glass used, these markings are clearly defined and traversed by a long luminous band.

The *Podura* is a test of definition for objectives of less than ¼-inch, the illumination ought to be quite axial, and the condenser achromatic, and used with a moderately large opening in the diaphragm.

The *Podura* has been very specially studied by the late Mr. Richard Beck (¹), and we have to thank Messrs. R. and J. Beck for the reproduction of Plate VII (fig. 51), which represents the different aspects, which these scales assume under different conditions

---

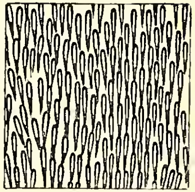
(¹) A Treatise on Achromatic Microscopes, by Richard Beck, London, 1865.

PLATE VII.

FIG 1

FIG 2

FIG 3



PODURA SCALE, AS A TEST.

Each Square = 001 of an Inch, X,1,300

FIG 4

FIG 5

FIG. 6.

Fig 51.

In fig. 1 is seen the appearance of the markings where the focussing of the object is perfect, and when the correction adjustment of the objective leaves nothing to be desired.

In fig. 2 the correction of the objective is equally perfect, but the object is found to be either a little over or under-focused. In fig. 3 the correction is perfect, but the focussing is very slightly faulty. In figs. 4 and 5 is seen the appearance produced by over or under focussing the objective, combined with an imperfect adjustment of the correction collar, and lastly, in fig. 6, the focussing is perfect, but the correction of the objective is bad.

The *Podura* also enables the chromatic corrections of the objective to be well judged of; all achromatic objectives show these notes of exclamation strongly coloured, only apochromatics display but a slight trace of colour.

Pleurosigma angulatum.—When examined under objectives without sufficient numerical aperture, the *Pleurosigma* displays valves of a brownish yellow, without any appearance of marks or designs. When the aperture becomes moderate (*e.g.*, about ·6), no mark can yet be seen in axial light with the use of a diaphragm; but if it is illuminated, either obliquely, or what is still better, by means of a large converging cone of light, produced by a condenser used with a diaphragm with a sufficiently large aperture, then on the valve will be seen three series of lines crossing one another, at an angle of 60° (fig. 52).

With immersion objectives and objectives of large aperture, the valve can be seen covered with perfectly round points. The nature of these points, which have been called beads, has been for a long time doubtful. It was generally believed, and some microscopists still believe, that these are hemispheres in relief. Others say that they are depressions. Finally, we have detailed, in our *Synopsis des Diatomées*, the grounds which made us admit that they are cavities in the middle plate of the valve.

Under certain conditions of illumination, and especially with the new objective of 1·60 numerical aperture, instead of round points, hexagonals are seen (figs. 53 and 54). It was thought that this was simply an optical illusion, but we demonstrated in December, 1889, that these hexagonals really represented the form of the openings of the lattice work, or middle plate of the valve. The appearance of round points is produced by focussing the upper part of the openings

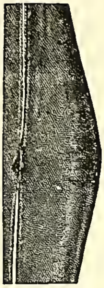


Fig. 52.

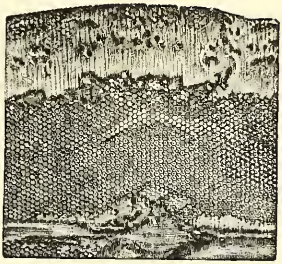


Fig. 53.

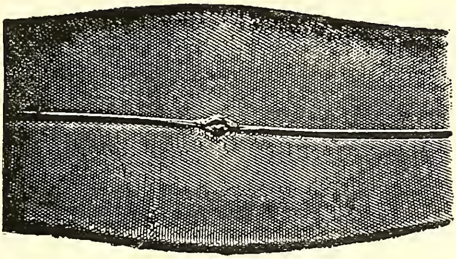


Fig. 54.
Pleurosigma angulatum photographed with electric light.

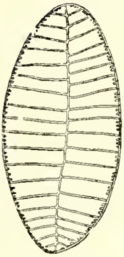


Fig. 55.

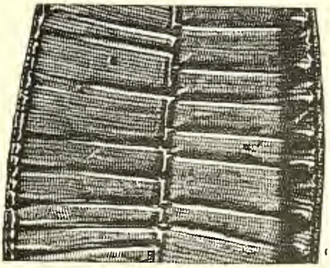


Fig. 56.

where species of domes are formed by the upper bed of the valve, which closes the openings of the middle plate.

Surirella Gemma.—The diatom of this name shows very easily the appearance of the lines transverse to its longer axis (fig. 55). It is a more difficult matter to make the longitudinal lines visible, and lastly, it is exceedingly difficult to resolve very clearly the square beads, which cover the valve in slightly sinuous lines (fig. 56). To be very successful in doing this, it is necessary to employ a good immersion objective, and either an oblique illumination, or better still, a large luminous cone of light produced by a condenser of sufficient aperture.

The transverse striæ, which ought to be resolved in beads, are about 2,000 per millimetre in number.

The Surirella is an excellent test to ascertain if the chromatic and spherical aberrations have been well corrected in objectives of the highest power. With this object the test is examined with the condenser open fully, as is done for bacteria. Under these conditions of illumination one can estimate clearly and easily any defects of correction which produce a diffused and coloured image. Let us note, moreover, that the best apochromatics alone can give an uncoloured image.

Van Heurckia rhomboides.—The genus Van Heurckia, created by the eminent diatomographer, A. de Brébisson, includes a small number of forms very difficult to resolve.

Two amongst them are the celebrated tests: *Van Heurckia rhomboides* (fig. 58), and its variety *crassinervis* (fig. 57).

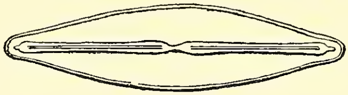


Fig. 57.

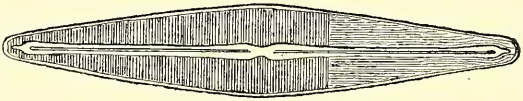


Fig. 58.

These two forms, which are rhomboidal lanceolate, have longitudinal and transverse lines, which cross one another at right-angles, the longitudinal lines are much more robust, and more easy to resolve than the transverse ones, which in the *rhomboides* are 2,800 per per millimetre in number, and in *crassinervis* about 3,500.

Van Heurckia rhomboides can be easily resolved into delicate beads by means of an immersion objective having a numerical aperture of 1·15 to 1·20. *V. crassinervis* (*Frustulia Saxonica Rabh.*) is much more difficult to resolve.

Amphipleura pellucida.—This diatom, which is the most difficult to resolve of all those employed as tests, has lanceolate valves and a raphé (median line), terminated by two very elongated nodules. The middle nodule is absent; with much pains, a few traces of it can be found.

The *Amphipleura* (fig. 59) has transverse striæ which are excessively difficult to see; they are very fine, and number about 3,700 to the millimetre.

Fig. 59.

The resolution of these striæ into beads is the greatest difficulty of the microscopist. They were made visible by us in the first place by means of a 1-12th homogeneous of Zeiss, on a silvered preparation, made by the late Dr. A. Y. Moore. We were able to make a photograph of it in 1884.

In 1887, we succeeded in photographing by transparency the *Amphipleura* resolved into longitudinal lines, and into beads. The negative was made with a Zeiss' ⅛th apochromatic homogeneous objective (N. A. 1·40), and one of our own preparations in the yellow medium and monochromatic solar illumination.

This photograph was reproduced in the "Bulletins de la Societé Belge de Microscopie," for 30th April, 1887.

Lastly, in October, 1889, Zeiss' apochromatic objective of N.A. 1·63 enabled us to photograph the *Amphipleura* perfectly resolved into beads over the whole surface of the valve.

It is not difficult to make the longitudinal lines of the valves of the *Amphipleura* appear, but these lines are parallel to the edge of the valves. The real lines are parallel to the raphé, or middle rib, and are *undulated throughout their entire length*, which arises from the beads not being exactly placed one above another.

The phototype plate, which we give opposite page 64, shows the appearance which the principal tests present when they are examined under the Zeiss' objective of N.A. 1·63, with monochromatic solar illumination.

The *Amphipleura pellucida Kütz.* is represented in the first three figures. The resolution into lines, or striæ, is seen in fig. 3, with a magnification of 2,000 diameters. The beads are seen in fig 2, and fig 1 with magnifications of 2,000 and 3,000 diameters respectively.

Fig. 4. Fragment of a valve of *Amphipleura Lindheimeri Grun.* A species only distinguished from *Amphipleura pellucida Kütz.* by its size being often much larger, and by its striation being coarser. The "beads," or openings of the lattice work, are seen to be square. Magnification 2,500 diameters.

Fig. 5. *Pleurosigma angulatum W. Sm.* Focussed exactly on the hexagonal openings in the lattice work. About 10,000 diameters.

Fig. 6. *Pleurosigma angulatum W. Sm.* Focussed on the upper surface of the valve. The upper part of the small domes can be seen, and between them the points formed by the imperfect focussing of the sides, or walls of the hexagons.

Fig. 8. *Surirella Gemma Ehr.* magnified 1,000 diameters.

Fig. 9. *Van Heurckia crassinervis Breb.* magnified 2,000 diameters.

All these photographs were made with Zeiss' 1-10th inch of N. A. 1·63.

Monochromatic solar light.

Special compensating eye-piece 12.—Condenser 1·6.

Preparations in a medium of 2·4.

Covers and slides in flints of 1·72.

Fig. 7 shows the 19th group of Nobert's test (4,443 lines to the millimetre): this photograph was made with a 1-12th inch apochromatic of N. A. 1·4 of M. Carl Reichert, of Vienna.

2.—Nobert's Test.

A skilful German optician, the late J. A. Nobert, living at Barth, in Pomerania, thought of the idea of tracing on glass, series of lines, nearer and nearer to one another. The tests, or proof tables, as Nobert called them, are truly wonderful, and nothing was known up to his death of the process employed by this maker in tracing lines so fine, and so close.

Nobert produced two series of tests. The first and oldest series contained thirty groups of lines, and cost £4 16s. od. We give below, according to Prof. Harting, the number of lines in each group :—

Group No. 1 contains 443 lines to the millimetre.
,, 5 ,, 806 ,, ,,
,, 10 ,, 1612 ,, ,,
,, 15 ,, 2215 ,, ,,
,, 20 ,, 2653 ,, ,,
,, 25 ,, 3098 ,, ,,
,, 30 ,, 3544 ,, ,,

This test has the appearance of an ordinary microscopical preparation. The lines are traced on the centre of a cover-glass, which is fixed to an object slip like an ordinary preparation.

Of course, the lines become more and more difficult to resolve as the number of the group increases.

The construction of objectives having improved, M. Nobert produced a new test, having only nineteen groups but in this the 19th group is much more difficult to resolve than the thirtieth of the first series.

The following gives the distance and number of lines of these nineteen groups:—

Groups.	In a Paris line according to Nobert. [Paris line = ·0888 inch].	In a millimetre according to Harting, III. 374. [Millimetre = ·0394 inch].	Number of lines in each group.
1	1/1000	443	7
2	1/1500	665	10
3	2000	886	13
4	2500	1108	15
5	3000	1329	17
6	3500	1550	20
7	4000	1772	23
8	4500	1994	25
9	5000	2215	27
10	5500	2437	30
11	6000	2658	34
12	6500	2880	37
13	7000	3100	40
14	7500	3323	43
15	8000	3544	45
16	8500	3766	48
17	9000	3987	51
18	9500	4209	54
19	10000	4430	57

Certain authors have stated that Nobert's tests are of very little use to microscopists; they say that the tests differ from one another, on account of the varying pressure of the diamond used in making them, the nature of the glass, &c., and that, moreover, they will never be of use to recognize a good objective, because they cannot be examined in very oblique light.

We expressly contest all these points, and we are pursuaded that these statements arise from an insufficient study of the test, and that its only fault is its costliness.

In the first place it can be used equally well in central and in oblique light; then the test is very far from being as variable as it is stated to be; diatoms are infinitely more so, and the difficulty of resolving them is affected by a number of circumstances (*e.g.*), age, locality, &c., as all know who have made a special study of these very interesting beings.

We possess both the tests, and have used them daily for a long time. Although these two series of groups date from very different periods, they are nevertheless perfectly comparable with one another; and a given objective, which enables us to resolve a certain group with one test, resolves the equivalent group of the other test, neither more nor less.

The late Colonel Dr. Woodward has produced a series of admirable photographs of the nineteen groups, which were made by him for the Exhibition of Philadelphia. This eminent microscopist had the kindness to send us these photographs, and what we observe is in every respect identical with the images obtained by Dr. Woodward.

These photographs were accompanied by a leaflet, entitled *Memorandum on the Nineteen-band Test-plate of Nobert.* This eminent savant, who dedicated all his time to the elucidation of the most difficult points in microscopy, and whose competence cannot be here called into question, expresses himself in the following manner in this memorandum; we happily agree with him on all these points:—

"The plate of Nobert, which we are about to describe, offers an admirable means of measuring the defining power of the best objectives. It appears better adapted for this purpose than diatoms, which are so generally employed, because in the latter the individual specimens of the same species vary considerably in the fineness of their lines. Although it cannot be supposed that Nobert has always attained just the same degree of precision, an examination of a good number of plates demonstrates that the deviations from the requisite precision are so slight that *they are practically inappreciable.*"

3.—Test and Proof-plate of Möller.

Möller, of Wedel (Holstein), a skilful preparer, manufactures very valuable tests. The ordinary graduated test consists of twenty diatoms placed in a line, more and more difficult to resolve.

This test can replace the test of Nobert up to a certain point. Ed. Thum, the skilful diatom-mounter (35, Bruder Strasse, Leipzig) furnishes similar tests.

We cannot too strongly recommend microscopists to obtain at least this graduated test, which will render them the greatest service in appreciating the relative value of different objectives.

We give below the number of striæ in the diatoms in Möller's test, as well as those in some other diatoms often employed:—

Number of striæ in the diatoms of Möller's Test, together with the corresponding groups of Nobert.

	Number of striæ of different specimens.	Möller's Test.		Nobert's Test, in 19 groups.
		No.	Number of transverse striæ (1).	
Lepisma saccharina (large)	400 per mill.			
,, ,, (small)	700 to 900		per mill.	
Pinnularia nobilis	400 to 600	2	455	1st = 443 per mill.
Hipparchia Janira	1000 to 1200			
Navicula Lyra var		3	640	2nd = 665 ,,
,, ,, ...		4	988	
Pinnularia interrupta var		5	1055	4th = 1108 ,,
Stauroneis Phœnicenteron		6	1330	5th = 1329 ,,
Grammatophora marina		7	1429	
Pleurosigma balticum	1400 to 1500	8	1300	
,, acuminatum........		9	1734	
Nitzschia amphioxys		10	1736	
Pleurosigma angulatum..........	2200 to 2300	11	1738	7th = 1772 ,,
Grammatophora subtilissima	variable	12	2429	
Surirella Gemma.................	,,	13	2153	
Nitzchia sigmoidea	3000 to 3100	14	2531	
Pleurosigma Fasciola............		15	2225	9th = 2215 ,,
Surirella Gemma (long)..........	3000 to 3200	16	2650	11th = 2658 ,,
Cymatopleura elliptica		17	2531	
Vanheurckia viridula (medium) ..	2700			
,, rhomboides	3000			
,, crassinervis				
(Frustulia saxonica)	3400 to 3500	18	3193	13th = 3101 ,,
Nitzschia curvula		19	3334	14th = 3323 ,,
Amphipleura pellucida	3700	20	3614	Between the 15th and 16th groups.

4.—Photographic Test of the Author.

For some years we have employed, as a test, a detail in the structure of the *Pleurosigma*, which we have only made known to one or two friends up to the present time.

If the median nodule of the *Pleurosigma* be carefully examined, there will be seen at each extremity, a small ball, which is terminated by an excessively delicate thread, and lost in the raphé.

---

(1) After Morley in Monthly Mic. Jour., vol. xiii., page 241.

It is probable that this thread is a caniliculum, and that what seems to be a small ball is its opening. Thus the whole appearance is similar to that which presents itself in large naviculæ.

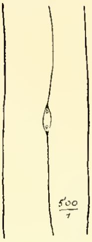


Fig. 60.

Whatever this detail which we are describing, and which is seen most clearly in *Pleurosigma Balticum* (fig 60) may be, it is of extreme delicacy, and in many cases is very useful.

We have often used it as a standard test for realizing the defining power of wide angled objectives, but it is used with great advantage in photography.

Moreover, since the detail is much more delicate than any diatom striæ whatsoever, it is rendered invisible by the slightest difference in focussing.

It can, therefore, be used in photo-micrography,

1st, to estimate the defining power of objectives,

2nd, to prove if an objective has a chemical focus. In this case, after the object has been carefully focussed on the ground-glass, it is photographed first in blue monochromatic light, then in white light; if it has no chemical focus, the image ought to be just as clear in the two negatives. This experiment enables us to prove that the objective 1·6 N.A. of Zeiss has not a chemical focus which an English microscopist supposed that he had found in it.

3rd. Lastly, the correct adjustment of magnifying glasses, used for focussing, can be verified, which is of the greatest importance. For this purpose, an apochromatic objective of high power must be used. If the lens is properly adjusted, the object should appear as clear in the negative as when sharply focussed on the ground glass.

5.—Professor Abbe's Test.

Professor Abbe's Test is a very simple piece of apparatus of very moderate price, and is absolutely indispensable to every microscopist who desires to do serious work. Indeed, this small piece of apparatus enables it to be possible to determine :—

1st. Whether the chromatic and spherical aberrations of the objective are well corrected.

2nd. What is the best thickness of cover glass for any objective (without collar correction), employed for any given length of tube; and inversely, what is the best length of tube for a given thickness of cover-glass, with the same object-glass.

3rd. What is the best position of the correction collar (for an objective possessing one) in each of the two preceding cases.

All these problems are very easily solved with the Abbe test.

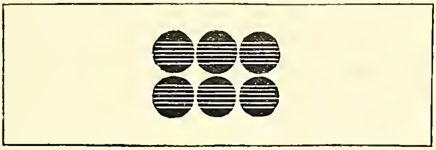


Fig. 61.

Fig. 62.

This test consists simply of an ordinary glass slip having fixed to its surface (fig. 61) six cover-glasses, of thicknesses ·09, ·11, ·14, ·17, ·20, and ·23 mm. respectively, or in other words, 1-10th, 1-9th, 1-6th, 1 5th, and 1-4th of a millimetre.

The lower surface of each (which is fastened to a glass slip by means of Canada balsam) is silvered, and in this silver film is traced a series of six bands, composed of fine and very close lines (fig. 62.)

The mode of employing this apparatus is very simple and is carried out in the manner described below; it can only be effected with a microscope possessing an Abbe condenser or a similar piece of apparatus.

We begin by sharply focussing a group of lines on the plate, and when that is done the diaphragm is drawn away from the axis in a direction parallel to the lines, and light is rendered so oblique as to allow the luminous cone to pass by the marginal zone of the objective.

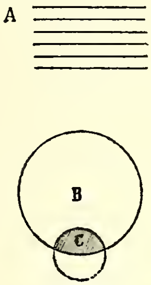


Fig. 63.

Thus, for example, if the lines appear to lie in the direction A (fig. 63), the diaphragm is so placed that on looking into the tube after the ocular has been withdrawn, one can see the opening of the diaphragm in the position C in the circle B representing the opening of the objective.

If an immersion objective, whose aperture exceeds 1·0, be used, the glass slip should first be connected with the sub-stage condenser by means of a drop of water, glycerine, or cedar oil, in order that the luminous rays may not reach the marginal zone of the aperture of the objective.

These preliminary arrangements having been made, we can now begin to make our test.

If the objective has a correction collar it should be turned until the position is found in which the delimitation of the lines *when examined in the middle of the field* appears as clear as possible, that is to say, when the lines show neither nebulosity nor any want of distinctness.

The nebulosity (or milkiness as it is often called) shows that the correction has been exceeded; if on the other hand there is under-correction, the edges do not become milky, but they are indistinct and diffuse. If in the latter case, the objective is adjusted so as to obtain as clear an image as is possible, this clearness will not continue when the diaphragm is brought back into such a position as to substitute axial for oblique light; indeed, to obtain a clear image the focussing must be changed.

If the objective has no correction collar the best thickness of cover-glass for a given length of tube can be found in the same way, and inversely the length of tube which is most suitable for a given thickness of cover-glass can be similarly determined.

The above method gives very sure results; but naturally it requires a little experience to appreciate such nice differences as the above.

II. THE OCULARS.

It is the object of the ocular to magnify the image produced by the objective and to render it plainer and clearer.

Microscopists make use of various kinds of oculars, the most useful forms of which are: Huygens' ocular, Ramsden's ocular, the Orthoscopic ocular, the compensating ocular, and the projection ocular.

Huygens' Ocular.—This is the ocular which usually accompanies microscopes. It consists of two plano-convex glasses, having their convexities turned towards the objective and fixed at the extremities of a tube. The smallest of the glasses, which really magnifies the image, is nearest the eye, and is called the *eye-glass*. The lower one is called the *field-glass* or *collecting glass;* it diminishes the magnification of the eye-glass, but renders the image clearer. A diaphragm is placed very near the focus of the eye-glass.

Microscopes are provided with a series of Huygens' oculars. On the Continent they are generally numbered from 1 to 5; in England they are either marked 1, 2, &c., or A, B, &c. up to F; in America they often designate oculars by their magnifying power, and speak of them as oculars of an inch, ½ inch, &c. The magnification of Huygens' oculars, ranges from 2·5 to 15. When it exceeds six and seven times, these oculars loose in clearness enormously and become very inconvenient, because the eye has to be put very close to the upper lens or eye-glass.

Ramsden's Ocular.—In this ocular there are again two plano-convex lenses, but the convexities are turned towards each other and the lenses are nearer to one another. This ocular acts as a magnifying glass and is used almost exclusively for microscopic measurements, because the extreme divisions of the micrometric scale are not distorted as is the case with Huygens' ocular.

Orthoscopic Ocular.—This ocular is nearly always used for photo-micrography—formerly introduced to assist the ocular; but this is a process which will, we believe, be abandoned at no very distant date, and be replaced exclusively by the use of the projection or compensating ocular.

In this ocular the eye-glass is achromatised and is concavo-convex; the field-glass is bi-convex.

Compensating Ocular.—This ocular was invented by Prof. Abbe and has only been a commercial article since 1886.

It consists of a plano-convex lens placed above a bi-convex lens. The lenses are brought close together so as almost to touch, and no diaphragm is placed between them. The upper lens is simple, the bi-convex lens on the other hand is complex; a series of diaphragms is placed under the latter. Such are the oculars 8, 12, 18, and 27.

In the weak ocular it is, on the other hand, the upper lens which is achromatised.

In the two very low numbers 1 and 2, both lenses are simple.

In numbers 1, 2, and 4, a diaphragm is placed between the two lenses. The weakest eye-pieces, numbers 1 and 2, which are called, *searcher oculars*, are only intended for a general examination of the preparation.

The others are the *working oculars.*

These oculars are constructed for the purpose of correcting certain defects inherent in apochromatic objectives, and which cannot be eliminated in the construction of the objective itself. They give a perfect image with apochromatic and other wide-angled objectives, but they are not suitable for ordinary small-angled objectives.

The number of these oculars indicate also the magnification which they give with any objective for the length of tube indicated.

Thus the ocular 4 amplifies the image given by the objective four times. Supposing we have to work with a 1-10th of an inch whose initial magnifying power is 100: we should then have 100 × 4 = 400 as the total magnifying power.

These oculars are also mounted, so that they can be interchanged without alteration of focus, and all (except No. 27) permit the use of the camera lucida with ease.

Projection Oculars.—These oculars, which are also due to Professor Abbe, are designed to project the image presented by the objective on to a screen; they are therefore eminently suitable for photo-micrography and will ultimately, it is believed, be exclusively used by all photo-micrographers.

They are indeed very convenient and give remarkably clear and pure images.

These oculars are composed of a small achromatized bi-convex projecting glass and of a plano-convex collecting lens or field glass, having its curved surface turned towards the objective. A small diaphragm limits the field of the image, and the projecting glass which is moveable can be adjusted as desired.

The entire system is carefully corrected chromatically, and with special care for secondary chromatic aberrations and for the difference of focus between the chemical and optical rays.

The image projected on a screen, or on a sensative plate, preserves exactly the same arrangement of all its parts as in ordinary observation. Moreover, the preparation having been arranged as desired, all the subsequent operations consist in replacing the ordinary ocular by a projection ocular, and in screwing up or down the projection system till the edge of the diaphragm is shewn with maximum clearness on the screen or on the ground glass of the photographic camera. The shorter the distance between the screen (or ground glass) and the microscope, the farther should the projection system be withdrawn from the diaphragm; the projection system ought then to stand out much farther from the tube.

As soon as the image is quite clear, the ordinary photographic operations may commence. One point, however, must be observed during the preliminary operation, viz.:—That throughout the operations the tube of the microscope should be kept at exactly the same length, that length naturally being that for which the objective is constructed.

Projection oculars hitherto have been constructed by Messrs. Zeiss, Reichert, Powell and Lealand, and some other makers; the first two makers make different oculars for the Continental tube and the English tube.

The oculars for the Continental tube (of 160 millimetres) have an amplification of two and four times. Those of the English tube (of 250 millimetres) are marked 3 and 6.

These figures at once indicate the number of times the initial magnification of the objective is multiplied by the ocular, or in other words, the proportion by which the focal length of the *whole* microscope is *diminished.*

Thus the ocular No. 2 diminishes the focal length of any objective just one-half; consequently an objective of 3 m/m ($^1/_8$ inch) projects *with* this ocular, at a given distance, an image whose size is absolutely identical with that which an objective, whose focus is 1·50 m/m ($^1/_{16}$ inch), will give *without* an ocular at the same distance.

The linear magnification of a projected image is the distance between the image and the posterior focus of the lens system divided by the focal length of the system. The posterior focus of the lens system corresponds in the microscope exactly to the upper side of the ocular.

It follows from the preceding data that the amount of amplification of an image is obtained for any distance between ocular and screen by dividing this distance (expressed in millimetres) by the focal length of the objective used and multiplying the quotient obtained by the number of the ocular.

Thus the objective of three millimetres ($^1/_8$ inch) will give with No. 2 projection ocular at a distance of 150 centimeters an amplification of 1000 times:

$$\frac{1500}{3} \times 2 = 1000$$

However, this rule only applies to long distances; with short distances the results which the calculation gives are too high.

The diameter of the image on the screen or on the photographic plate permits about

$^1/_5$ of the distance from the image with oculars 2 and 3.
$^1/_3$,, ,, ,, ,, ,, 4 ,, 6.

The image can be taken to as *great* a distance from the ocular as may be desired. The minimum distance between ocular and image may be 40 centimeters with Nos. 2 and 4, and 25 centimeters with Nos. 3 and 6.

Weak oculars are preferable for projections made during lectures or demonstrations as well as for photography with small magnification or with a long camera. On the other hand the strong oculars 3 and 6 will be preferable when it is desirable to photograph with a short length of camera.

II.—THE STAGE.

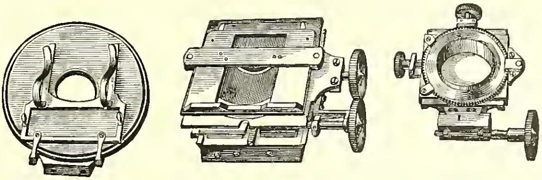
The stage should be large enough to allow the two hands to rest on it, and sufficiently thick to resist the pressure of the fingers. Generally it is made of blackened sheet brass, sometimes it is covered with ebonite or with a plate of black glass to prevent its being injured by reagents.

There are usually two clips on the stage for the purpose of holding the preparation in position.

In some instruments the stage—then called a rotating stage—can turn right round on its axis, carrying with it the part of the preparation in view; the result of this is that every part of the object is illuminated in turn, while the mirror remains stationary. This piece of apparatus is expensive, and is now very little used owing to the universal practice of employing condensers instead. However, it is found to be very useful when the object has to be placed in a particular position in order to facilitate the drawing of it by the camera lucida.

In first-class English instruments only the moveable part of the stage turns. This arrangement is more convenient than the rotary stage, but it needs to be constructed with great accuracy, which naturally is expensive.

Mechanical stage.—Large English instruments, and also those of M. Nachet, have stages with moveable carriers, that is to say they consist of several superposed pieces, rendered moveable by means of milled heads, which enable all the parts of the object to be taken in turn across the field of the microscope, and also allow the object, when once found, to be kept in view and in the most advantageous position, either for making a drawing of it or for micrometrical measurement.



English stages and sub-stages.
Fig. 64.

M. Reichert manufactures a very convenient form of mechanical stage, which can be removed at pleasure, but this apparatus is not quite the same as the English mechanical stage.

A similar apparatus is also made by M. C. Zeiss (fig. 65), the engraving of which sufficiently explains its construction. As may be seen, it is a simple stage placed on that of the microscope, and fixed to the slow movement pillar by means of the plate B and the screw K, the end of which is lodged in a small hole drilled into the pillar when the stage is first applied.

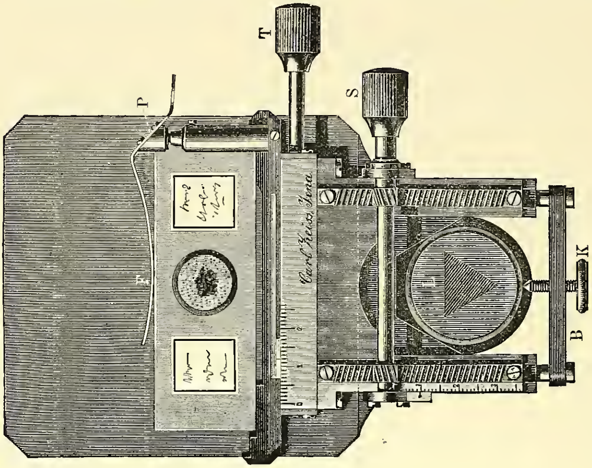


Fig. 65.

III.—THE MOVEMENTS.

We have already indicated the two movements which every first-class microscope should possess. For the rapid movement, the rack and pinion is very superior to the sliding movement, and by it alone can the perfect centering of the tube in relation to the illuminating apparatus be maintained.

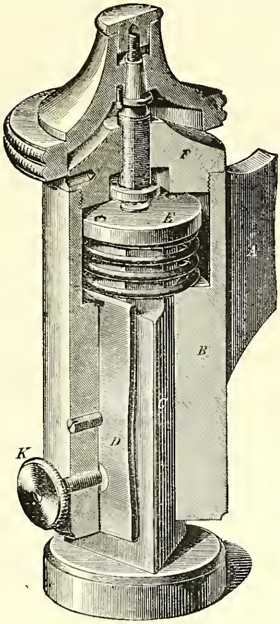


Fig. 66.

The slow movement of microscopes is generally produced by two round or triangular tubes, the one fitting into the other, which tend to part from one another under the pressure of a spiral spring. A screw of very fine pitch bearing a milled head enables the space between them to be varied to any desired extent. By examining figure 66 at the side it will be understood that by means of this movement the outside tube, which carries the microscope tube, is displaced, and the objective approaches or recedes from the object.

In some large instruments the slow movement is extremely accurate and delicate, nor could it indeed be too much so, because the slow movement serves to accommodate the observer's eye, and upon the delicacy of this micrometric movement depends the power of producing the finest *optical planes* in an object, and consequently the power which enables us, in a greater or less degreee, to appreciate the structure of the object under examination.

In the microscope constructed according to our specifications by Messrs. Watson and Sons, which we shall describe further on, the slow movement is communicated to the tube by a lever, and this slow movement, which has absolutely no back lash, is of such precision that each of the divisions of the milled head corresponds to 1/1300 of a millimetre.

IV.—ILLUMINATING APPARATUS.

I.—ILLUMINATION BY TRANSMITTED LIGHT.

The apparatus employed in microscopes for illuminating objects by transmitted light are *mirrors* and *condensers.* The illumination is modified by *diaphragms.*

1. **Mirrors.**—Every microscope is furnished with a mirror; in good instruments the mirror is double, being plane on one side, and concave on the other; the mirrors of English instruments are much larger than those of continental instruments, and consequently give more light, which is often advantageous.

It was formerly believed that by means of a plane mirror parallel rays were obtained, and that the concave mirror produced convergent light. This is not so: the plane mirror also gives convergent light, for since all luminous sources at the service of the microscopist for ordinary work give divergent rays, it follows that the rays converge by reflection from the mirror. It may therefore be asked how it is that the plane mirror gives a less intense illumination than the concave mirror. Mr. Giltay (¹) explains this in a very simple manner. He says that if P Q be an opening of finite dimensions, through which rays from a luminous source can alone be admitted (*e.g.*, a window), then the point O will receive no light reflected from the ends A and E of the plane mirror because the incident rays must have travelled along the lines A'A and E'E, which do not pass through P Q. Finally the figure shews that light can pass through P Q which will strike the concave mirror at points *a* and *e* situated outside B and D and be reflected into O, which demonstrates that the useful surface of a concave mirror is greater than that of a flat mirror.

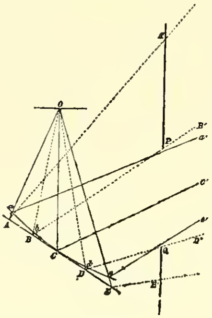


Fig. 67.

The entire difference between the two mirrors consists simply in the fact that the concave mirror can receive and reflect on a given point a greater number of rays proceeding from a circumscribed luminous source than can a flat mirror.

A well-mounted mirror should be capable of being raised and lowered so that the different sections of the luminous cone which falls on the

---

(¹) E. Giltay. Inleiding tot het gebruik van den microscoop. Leiden. 1885.

object can be utilized; it should also have the means of projecting the luminous cone at every possible angle so as to give what is called "*oblique illumination;*" this latter property is obtained by mounting the mirror on a jointed arm.

2. **Diaphragms.**—Diaphragms are pieces of copper, pierced with an opening. These are placed so as to intercept more or less of the luminous beam reflected from the mirror.

There are two kinds of diaphragms: 1st, those which cut off a part of the peripheral rays of the beam of light reflected by the mirror; 2nd, those which intercept a part of the central rays.

In the first case, either a plate is employed, pierced with apertures of different diameters and fixed so that each of these apertures can be brought immediately under the stage opening, or a tube is used carrying in its upper extremity some brass discs pierced with holes of different sizes and capable of being adjusted at different distances from the stage.

Fig. 68.

This second method, which admits of a finer graduation of light is preferable.

Some time ago a third kind of diaphragm was introduced, called the *Iris* or *Contraction Diaphragm.*

The invention of this diaphragm seems to have been made by Ch. Chevalier. We recollect seeing some twenty years ago, in the collection of Dr. Arthur Chevalier, a model constructed by his father, and called by him an *artificial pupil.* It consisted of a large number of small metallic plates partially overlapping one another and so arranged that by means of a knob placed on the frame which held them, the opening could be increased or diminished, while at the same time it remained perfectly circular.

Charles Chevalier, so far as we know, never applied his "pupil" to one of his instruments. It remained merely a model, and like many of the ideas of this indefatigable inventor, was never practically applied.

The Iris-diaphragm is superior to all others; by its means light can be graduated quickly and with exactness.

It is often useful to cut off a part of the central rays of the luminous beam in order to reveal very delicate details; to effect this a glass plate, whose centre is covered with a small black disc, may be placed over a diaphragm with a large opening, or, still better (as is generally done), a similar disc may be fixed in the centre of a diaphragm by means of three thin brass strips.

Diaphragms are placed below and very close to the stage, when they are used without a condenser. When, however, this latter apparatus is employed the diaphragm is usually placed beneath the lower lens. For certain oblique illuminations it may be placed above the upper lens, but this often occasions inconvenience—as for instance, when an immersion condenser is employed.

3. **Condensers.**—The condenser consists of a system of lenses which is placed between the mirror and the stage, and allows a bright cone, containing many more rays than that which the mirror alone produces, to be thrown upon the object.

The first true condenser was invented by Dujardin, and soon afterwards was brought to great perfection in England. For a long time condensers remained almost unknown on the Continent, but as early as 1858 the late M. Nachet, (the first optician of that name, who was a pupil of Ch. Chevalier and set up for himself) had invented a condenser, the optical formula of which closely resembles that of Prof. Abbe's condenser, but unlike the latter it was achromatic. The late M. Villot, Inspector-General of the Imperial Museums at Paris, acquainted us with this condenser in 1865, by forwarding to us an exact plan of the arrangement of the lenses, and of their curvatures. The letter of this microscopist enables us to fix the date. A little later, the collections of M. Mouchet, which we acquired at his death, put us in possession of one of these early condensers, which are constructed very similarly to those of M. Villot. Although out of date, and of an aperture very inferior to that which the firm of Nachet provides to-day (fig. 69), we greatly appreciate this old condenser, and still find it occasionally useful.

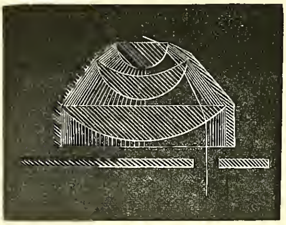


Fig. 69.

It was not until after Prof. Abbe had in 1873 announced the condenser which bears his name, that Continental microscopists began to appreciate the value of these instruments. Now every good microscope possesses an Abbe condenser, and we are persuaded that in addition to this the achromatic condensers which the English employ will also be ultimately employed on the Continent.

The number of condensers used is considerable, and every possible form exists in England. We shall content ourselves by describing here the Abbe condenser and those of Messrs. Powell and Lealand, which are really the best kinds in existence

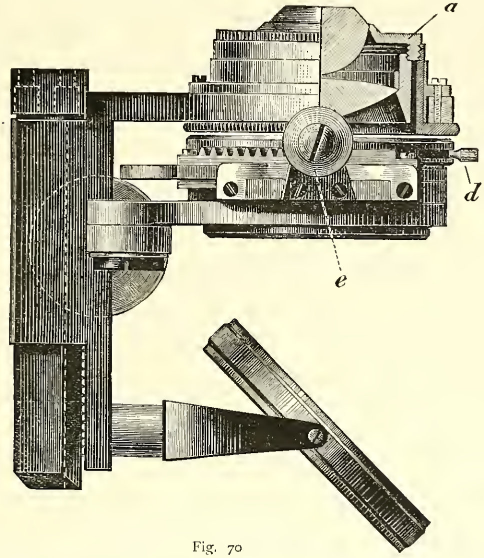


Fig. 70

The Abbe Condenser.—This apparatus (fig. 70), which is at the present time manufactured by the firm of Zeiss and all good makers, mainly consists of a condenser or system of wide-angled lenses, of a diaphragm carrier capable of holding discs with various apertures, and of a plano-concave mirror. These three parts are placed on a single mount, which can be adapted to the microscope by means of a groove under the stage, in which the ordinary mirror is usually placed.

The flat surface of the upper lens of the condenser should be brought very nearly to the level of the stage, till it almost touches the under surface of the glass slip. The whole apparatus can be raised or lowered at will by means of a rack and pinion, and thus the rays can be focussed on the plane in which the object under examination lies.

To insert or change a diaphragm, the carrier is drawn to the right, which makes it turn on an axis; the diaphragm is then inserted, and the carrier is returned to its original position by a movement in the opposite direction. The rack adjusted to the carrier enables the opening to be withdrawn from the optic axis in the first place, and then while thus in an eccentric position to be turned about this axis. In this latter movement, the bar which carries the pinion, acts as a lever only. By the first movement, just described, all degrees of *oblique* illumination are obtained, and by the second, incident *direction* of the luminous rays is changed at pleasure.

While the rack is being rotated the catch of a small spring point shows that the position of the diaphragm is centred so as to give *direct* or *axial* illumination.

For observations by *transmitted light* stops with central apertures are used, and the size of the opening chosen depends on the focal distance of the objective, the nature of the preparation and the intensity of the source of light employed.

If desirous of examining preparations whose elements are rendered visible, not by the unequal absorption of the light, but rather by differences of refraction, the observer is generally recommended to use *the smallest possible* stop, which will give sufficient light. On the other hand, when examining some *stained* preparations, especially bacteria, bacilli, &c., stops of large apertures, or even the condenser without any diaphragm, can be advantageously employed.

When wishing to make observations on a *dark ground*, annular diaphragms (which are wheel-shaped) are used; they are placed like the others in the diaphragm carrier, but always in a central position. In this case, a reduction in the aperture of the objective also is necessary, or at least advantageous, for all powers except the lowest.

This reduction is effected by means of special diaphragms, which are placed above the upper lens of the objective, or screwed between the cone and the lenses when these parts can be separated.

In the case of *dark ground* illumination the useful rays are those which pass through the object. Consequently this mode of examination is unsuitable for the examination of opaque objects.

Objectives with correction collars cannot be used with this kind of illumination, because in their case the interception of the marginal zone is not easily effected by the aid of a diaphragm.

When wishing to obtain with immersion objectives, an illumination *as oblique as possible*, or an illumination *on a dark ground*, with high powers, it is advantageous to put a drop of water on the flat surface of the upper lens of the condenser, so that the space between this lens and the glass slip is occupied by a medium, more refractive than air. By this means rays are rendered useful for observation, which, otherwise, would not be able to reach the preparation by reason of the total reflection, which they would undergo in the space of air intervening. The condenser is then called an immersion condenser.

When a wide-angled condenser is used with oblique illumination and an objective, whose numerical aperture exceeds 1·33, the upper lens of the condenser must be connected with the glass slip with a *drop of cedar oil*, and not with a drop of water.

For observations with *polarised light*, the polarising Nicol Prism, by means of a special mounting, is placed in the diaphragm carrier and an *ordinary diaphragm is placed over it.* The other operations are carried out as before mentioned. Polarised light, in addition to ordinary light, can be used with oblique as well as with axial illumination.

Films of selenite or of mica are placed above the Nicol Prism on the diaphragm carrier, and a diaphragm is placed over them as before. For all observations with the condenser it is the rule to use a flat mirror; however, with very low objectives, the flat mirror does not generally allow the field to be regularly illuminated, and the concave mirror is then used. It is only for this reason that it forms part of the apparatus.

In all the above cases when once the mirror is conveniently arranged for illumination, it is unnecessary to re-adjust it when changing the diaphragms.

If observations be made with lamp-light, the use of either a bulls-eye condensing lens, the largest possible, or a glass sphere filled with water, is highly recommended, to obtain a uniform illumination, for otherwise the flame would have to be brought too close to the microscope. The lens or glass sphere is arranged between the lamp and the microscope in such a position that the image of the flame is projected on to the mirror.

At the present time the firm of Zeiss divides this condenser into three optical parts. The first has a numerical aperture of 1·2, the second of 1·4, and the third, which only dates from 1889, of 1·6, and is designed on purpose for their new objective of N. A. 1·6.

These three optical parts can be interchanged at will.

Messrs. Zeiss just recently have introduced an achromatic condenser, which which can be placed above the mechanical part instead of the previous ones.

This condenser has a numerical aperture of 1·0, and is designed especially for photo-micrography, but it is also of the greatest service in ordinary observations.

On account of the extreme ingenuity with which the mechanical part of the Abbe condenser is made and of the enormous aperture which it gives to the optical part, this piece of apparatus is of inestimable value, and can scarcely be equalled for serious work. It is always a special advantage in photography that the chromatic optical part should be replaced by an achromatic system.

Messrs. Powell and Lealand's Condensers.—Except as regards the enormous aperture of 1·6 lately obtained by the Abbe condenser, Messrs. Powell and Lealand's condensers effect all that is possible with any other condensers, and moreover they are made with unsurpassed perfection, the *achromatic oil condensers* especially.

This firm constructs five condensers, which we intend duly to examine in order.

Chromatic Oil Condenser.—This little piece of apparatus, as ingenious as it is cheap, is perfectly suited to the resolution of diatoms with oblique light.

The optical part consists of two lenses placed one above the other and so mounted as not to admit of being unscrewed. The mechanical part consists of a tube which can be fitted to the substage carrying the optical part above it. By means of a small cogged arm, which is pushed to one side, a central opening, giving axial illumination at first and then a marginal opening, giving feeble oblique light, are successively disclosed. By pushing the arm one cog more very oblique light is obtained, and finally when the last cog is reached two marginal openings, mutually at right angles, are disclosed.

The condenser is used dry, as a water, or as an oil immersion, and in the last case it has a numerical aperture of 1·35.

By replacing the optical part, already described, by another, the upper lens of which has the middle part truncated and set on end, a N. A. of 1·4 is obtained.

This little piece of apparatus can be used not only for diatoms, but in all cases when the Abbe condenser is employed except when very great axial aperture is required.

Achromatic Condenser.—The Achromatic Condenser of Messrs.

Powell and Lealand, has an aperture of 170°; in England it enjoys an immense reputation, and of late by its means the most important discoveries of Beale, Dallinger, &c., were made.

The optical part of this condenser consists of three lenses placed at fixed heights above the diaphragms. These form a double series, placed one above the other. The upper series has openings of increasing size, like ordinary rotating diaphragms. The second series is fitted with circular diaphragms having openings of various forms. The two series can be turned either together or singly, as desired.

Apochromatic Dry Condenser.—This condenser has been constructed within the last few months; the corrections for chromatic and spherical aberrations are as perfect as possible; its N.A. is 0·95. This condenser is specially made for use in photo-micrography. The optical part is screwed into the same mounting as the previous one.

Achromatic Oil Condenser.—More perfect than the preceding, the optical part can be used dry, as a water and as an oil immersion, when it has a N. A. of 1·35.

The optical part consists of four very large lenses placed one above the other and very close together.

The mechanical part consists of a tube in which a cell, with eccentric movement, receives the diaphragm plates, which are introduced under the lower lens.

Whenever the diaphragm is changed, the entire condenser has to be lowered, which is very inconvenient. This inconvenience does not exist in the Apochromatic Condenser.

Apochromatic Immersion Condenser.—This is the most perfect condenser which exists at present. Messrs. Powell and Lealand do not mention it in their catalogue, and we believe that they only make it by special order. Being very difficult to make, it is naturally costly, the price being £12.

The optical part, which has a N. A. of 1·40, is formed of four lenses placed one above the other, and

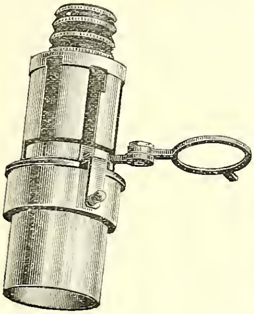


Fig. 71.

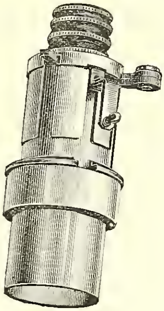


Fig. 72.

Fig. 73.

the whole is made apochromatic. The mechanical part admits of every conceivable kind of illumination. It consists of a tube, the lower part of which fits into the substage and the upper part holds the optical part (figs. 71 and 72).

In this tube slides another tube having, like the last mentioned condenser, a ring with an eccentric movement. But since this second tube can be raised or lowered, at will, it is unnecessary to displace the condenser in order to change the diaphragms, and, moreover, the movement of the inner tube allows the diaphragm to be taken a considerable distance from the lenses. The adjustment of diaphragms in a tube (without a condenser) is thus rendered possible, and the illumination can be graduated with the nicest delicacy, while at the same time, by changing the diaphragms, every conceivable kind of illumination can be obtained.

Rules for using a Condenser.—Professor Abbe's condenser is mounted in a holder which fits a spring jacket on the microscope, except in instruments quite recently constructed. This has its advantages for ordinary observations, but then, on the other hand, certain researches *with flame images* cannot be conducted, researches which aim at the solution of the most difficult problems in microscopy; for example, the discovery of the ultimate nature of the diatom valve, the flagellum of bacteria, &c. The following rules apply to any kind of condenser whatsoever, which can be axially raised and lowered.

The object is first placed on the stage and focussed as accurately as possible, then by properly adjusting the flat mirror the image of the luminous source is directed to fall on the middle of the field, and the condenser is racked up or down to allow the image to be distinctly seen with maximum clearness. This is called observation in the image of the flame, because this illumination, in which focussing is most frequently conducted, allows details to be observed which are invisible in every other kind of illumination.

This illumination, however, is sometimes disagreeable, and in observations which do not require great precision the condenser is lowered until the field of the microscope is uniformly illuminated. If the light is too bright, it is modified by means of a blue or neutral tinted glass.

If daylight be employed the object is focussed as before, and then the mirror is directed towards a distant object, which is also focussed so that the image coincides with that of the object. The mirror is then shifted without changing the condenser, and is directed towards a white cloud or a wall, on which light falls, or some other luminous source.

With daylight, as with artificial illumination, a suitable diaphragm must be used, viz.: one with which the object can be seen clearly, without being overpowered with light. Should oblique illumination be required instead of a diaphragm with a central opening, a diaphragm with either an annular or an eccentric opening should be used. In the last two cases the condenser must be raised considerably to obtain a suitable light.

The following, is the last method here given of illumination, and is one by which any objective can be turned to good account.

The mirror is turned aside from the axis, and the microscope is so inclined that the image of the luminous source is shewn direct in the same way as when it is reflected by means of a mirror. All the other operations are carried out as with a reflector.

II.—ILLUMINATION OF OPAQUE OBJECTS.

Illumination of opaque objects is effected: 1st, with the mirror; 2nd, with condensing lenses; 3rd, with Leiberkuhn's speculum; and 4th, with the "vertical illuminator."

1. **Mirror.**—Some English and American microscopes are so constructed that the object when placed with the stage, forms as it were, a centre, around which all the parts of the instrument can rotate. Such, among others, is the beautiful "Wenham Radial," made by Ross, in which these movements are carried out in the most complete and precise manner. In this and other similar instruments, such as the Ross-Zentmayer, &c., the mirror can be brought above the stage. No other accessory apparatus is therefore required for illuminating opaque objects, provided that they are examined with objectives, whose frontal distances are sufficient to allow the light to reach the object. This latter provision applies equally to condensing lenses.

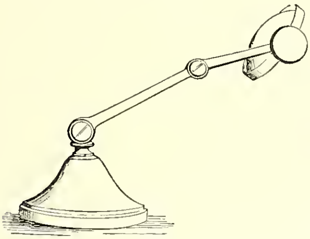


Fig 74.

2. Condensing Lenses.— Condensing lenses are simply plano-convex magnifying glasses of considerable size, supported on a foot; they can be made to assume any position, by means of their many joints (fig. 74). These magnifying glasses when placed between the microscope and the luminous source can be made to concentrate a pencil of condensed rays upon the object.

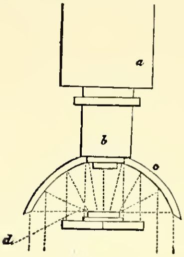


Fig. 75.

3. The Speculum of Lieberkuhn.—This apparatus is but seldom used. It is simply a concave mirror made either of silver or of silvered glass, and so constructed as to concentrate a beam of condensed rays on to the object (fig. 75). The mirror of the microscope acts as a luminous source, so that there must be an open space around the object, to allow the rays reflected from the mirror to reach the Lieberkuhn. A special Lieberkuhn is necessary for each objective.

4. Vertical Illuminator.—This little piece of apparatus, invented by my friend, Professor H. L. Smith, is ingenious and moreover inexpensive.

The vertical illuminator consists of a small cylindrical brass tube, which can be screwed on to the microscope above the objective, and encloses a bar having a disc fitted into its end, which can be rotated about its axis (fig. 76). This tube has a small opening in its side, through which a pencil of light is thrown on to the disc, when inclined at an angle of 45°. This pencil is reflected down through the objective, which condenses it on to the object, and is then reflected back to the eye of the observer. This apparatus can be used with any objectives, and gives particularly excellent results with high powers. It renders the resolution of very difficult details possible, and it was by its aid that we first succeeded in photographing the beads of the *Amphipleura*. The valves were silvered underneath, thus producing an opaque object.

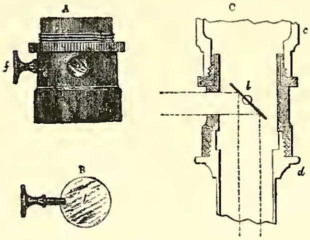


Fig. 76.

CHAPTER III.

ACCESSORY APPARATUS.

In the preceding chapter we have examined the essential parts of the microscope. We have still to describe various accessory pieces of apparatus, by which certain very important researches can be made, and which in many cases are quite indispensable.

By means of these pieces of apparatus, the sizes of objects can be measured, drawings of them can be made (with the camera lucida), and their nature be more perfectly understood (with the polariscope and spectroscope). With others, an object, once found, can afterwards be quickly found again; others facilitate work (*e.g.*, the dissection eye piece and the reversing prism), or allow the objectives to be quickly changed (*e.g.*, revolving nose pieces and adapters). These we propose to examine in due order.

Micrometers.—Microscopical measurements are made by means of micrometers. There are two kinds of micrometers, viz.: the eye piece and stage micrometer.

Eye piece Micrometers.—The microscopist uses the eye piece micrometer to measure the actual size of the object he is studying. Several kinds are made, but they all depend upon the same principle, as follows: in the focus of the eye-glass is placed a fixed scale, whose graduations are accurately known, so that the size of the image may be numerically expressed in terms of the divisions of the scale.

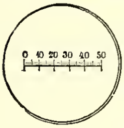


Fig. 77.

The eye piece micrometer as generally used consists of an ordinary ocular containing a glass disc, on which are traced equidistant lines, generally $^{1}/_{100}$ of a centimeter apart (fig. 77). This glass disc is fixed by most opticians, but it is sometimes made moveable, always remaining, however, in the same plane; this last model adopted by Hartnack and Bénèche (fig. 78), is more expensive than the ordinary eye piece micrometer, but then, on the other hand, the

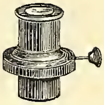


Fig. 78.

edge of the object can be made to coincide with one of the divisions of the scale.

The eye piece micrometer, which we have just described, is quite accurate enough, but sometimes a much more precise and, at the same time, more convenient micrometer is employed, viz., Ramsden's micrometer, a micrometer with parallel threads, which is used also for astronomical observations.

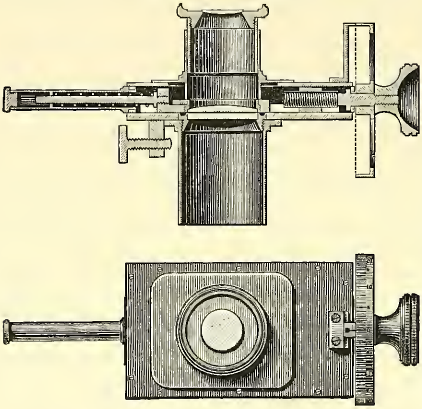


Fig. 79.

An instrument of this kind is manufactured by the firm of Carl Zeiss, composed of a positive ocular mounted above a brass plate, which is divided into equal parts by notches; in the middle of the plate is found a spider's thread, dividing the field of the microscope into two equal parts. Underneath this fixed plate there is a brass framework, which can be moved in the same plane, and has fixed to it a second spider's thread placed parallel to the first one. This frame is constructed so that the thread which it contains can be made to coincide with the first thread, and be withdrawn from it any required distance. This latter motion is produced by turning a milled head at the side of the ocular, carrying a cylinder divided into a hundred divisions, which pass successively in front of a fixed index.

The distance between the notches seen in the field is such that whenever the cylinder arrives just halfway between two successive notches, the thread registers 0 (Zero). The object is placed so that the threads touch it on both sides; the number of notches which the moving thread has passed, multiplied by 100, and added to the number registered by the cylinder, gives the relative size of the object.

With this micrometer excessively small objects can be measured; it consequently provides very valuable means of measuring the number of the striæ on a diatom in a given space.

For the parallel thread micrometer, and also for the ordinary eye piece micrometer, the actual length represented by a division must be previously ascertained, always keeping the tube of the microscope of constant length. We shall show how this is done in the chapter treating on the measurement of microscopical objects.

Stage Micrometer.—The stage micrometer consists of a glass slip, on which very fine lines at equal distances are engraved. The first micrometers of any use appear to have been made by Lebaillif. We happen to possess the ingenious machine made by this scientist, fifty years ago, for tracing the lines, and it fulfilled its object admirably. Lebaillif went so far as to divide the millimetre into 500 parts. By means of the improvements which have been added to this instrument the size of a division has been greatly reduced.

The micrometer usually employed has on it one millimetre divided into 100 parts, and is the scale by which the value of a division in the eye piece micrometer is established.

2. **Camera Lucida.**—It is the object of the camera lucida to project the image of an object seen in the microscope, on to a sheet of paper in such a way that a person inexperienced in drawing may yet be able to sketch the outline without difficulty.

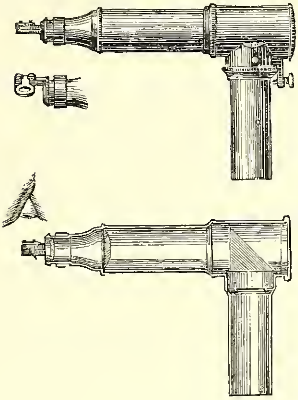


Fig. 80.

Though it often assumes different forms, the camera lucida usually consists of a prism, placed in front of the ocular.

That of Oberhauser is such a piece of apparatus, and is very convenient. It consists of a prism, smaller than the pupil, and is permanently fixed in front of a special ocular. Above this prism is annexed a ring of blackened brass, close to which the eye is applied. Both the paper and the image reflected by the prism can then be seen at the same time.

The ocular fits into an elbow-piece enclosing a rectangular prism at the joint of the elbow. The whole is fixed to the microscope when vertical, which is thus transformed into a horizontal microscope

The eye piece camera lucida can be removed when desired, and the rest of the instrument used as an ordinary horizontal microscope.

In figure 80 we give the form of Oberhauser's camera lucida.

The apparatus above is very useful for low or medium magnifications, but it is not easy to manage it with high magnifications, because such a great deal of light is absorbed by the two prisms.

A camera lucida which can be used as easily with high as with low magnifications is that due to Arthur Chevalier, and projects the image given by a vertical microscope, and on a horizontal surface.

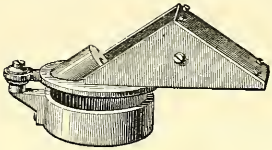


Fig. 81.

It consists (fig. 81) of a small steel mirror, at a certain distance from which is placed a prism, having its hypoteneuse silvered.

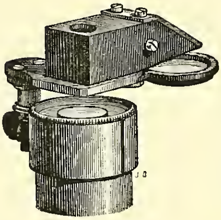


Fig. 82.

Nachet's camera lucida is quite as serviceable (fig. 82), and consists of a rhomboidal prism, having one of its oblique surfaces opposite the eye-piece, to which a second very small prism is annexed. The whole is enclosed in a small brass case, whose distance from the eye-glass can be adjusted as required.

In the camera lucida, now manufactured by the skilful Parisian maker, the small prism is done away with, and the reflection is effected by a very thin coating of gold. So thin indeed is this coating that the object may be seen perfectly through it, while at the same time its reflecting power is sufficient to show the sketch clearly.

Mons. Nachet also constructs a camera lucida, which can be adapted

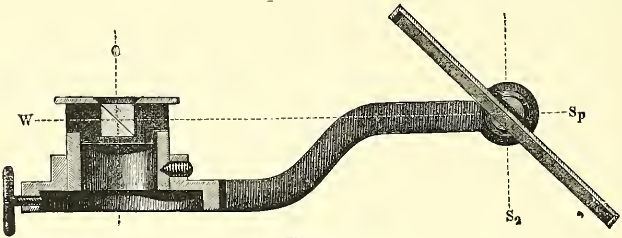


Fig. 83.

to the inclined microscope. It is a convenient form and we almost always use it for making our drawings with.

Professor Abbe has lately invented a camera lucida which can be highly recommended. In this apparatus, represented in figure 83, the paper is seen by means of a double reflection, produced first by the flat mirror *Sp*, and then by the silvered surface of a small prism. The microscopical image can be seen directly through an opening cut in the silver on the prism. In consequence of the concentricity of the luminous beams proceeding on the one hand from the microscope, and on the other from the surface of the paper, which reach the eye simultaneously, the point of the pencil can easily be held so as to coincide with the image, and a sketch thus be made on a horizontal plane without any marked deformity.

The intensity of the light reflected by the paper is regulated by means of two smoke-tinted glasses, which are placed in a groove adapted to the mounting of the prism.

Figure 84 below shows how a microscope, which can be inclined, is arranged for adapting the camera lucida. When this apparatus is used, the light of the microscope must be so regulated that it is of an intensity as nearly as possible equal to that from the paper on which the drawing is being made; when the light from the paper is more intense than that of the microscope it is impossible to distinguish the point of the pencil sufficiently well. In this case the light from the paper must be reduced by means of a screen.

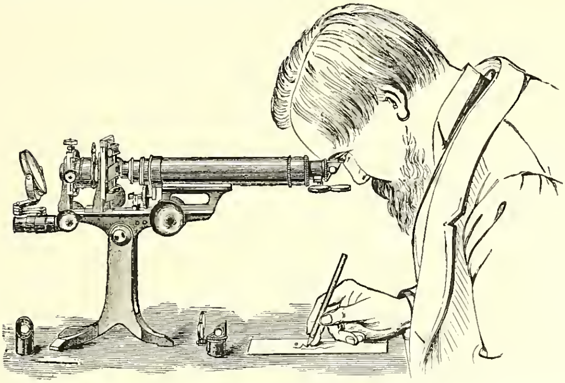


Fig. 84.

3.—**Polarizing Apparatus.**—Polarisation is a modification of light, in which the vibrations do not take place at all angles as is the case in natural light. Polarized rays when once reflected or refracted cannot be reflected or refracted again in certain fixed directions.

When any drawing is examined through a crystal of Iceland Spar a double image is observed, which is produced by the incident ray being twice refracted. One of these rays obeys the ordinary laws of refraction and is called the *ordinary ray;* the other which does not obey them is called the *extraordinary ray.*

Substances, which possess the property of refracting a ray twice, are said to be endowed with double refraction.

An apparatus in which Iceland spar is used, called a *Nicol prism,* is most frequently used for polarising light in the microscope.

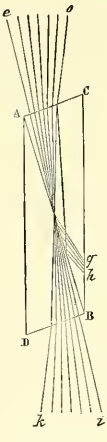


Fig. 85.

The Nicol prism is a parallelopiped of Iceland spar, whose length is equal to 3·7 times its thickness. This parallelopiped is cut in two along the diagonal A B (fig. 85) joining the corners of its obtuse angles. The planes of section are carefully polished and then cemented together with Canada balsam. Now the index of refraction of this resin (1·549) lies somewhere between the ordinary index of spar (1·658) and the minimum of its extraordinary index (1·483).

The critical angle for the ordinary ray in Canada balsam being 69·5, every ordinary ray which strikes at a greater angle undergoes total reflection.

Let *o* be a ray which strikes the surface A C obliquely. It will undergo refraction which will change its direction. Let us suppose that it now makes an angle 20·5° with the plane of section A B, this ray will be the limit of the field in which ordinary rays do not occur since all such rays striking the film of balsam at a greater angle will undergo total reflection. Thus all the rays between the limits *o* and *Ae* which are ordinarily refracted in the spar, will be reflected so as to form a luminous cone *hg* which will be lost on the blackened surface of the prism C B. On the other hand the extraordinary rays, since their index is less than that of balsam, will be transmitted through the cement and will spread themselves when they emerge in the space *ik.*

The light, thus polarised by means of the Nicol Prism, called the *polariser,* and placed under the stage in the place of the diaphragms, passes through the object and is received by the objective above, at a variable distance after which it meets a second Nicol Prism, called *the analyser*, which enables us to observe that the light has been polarised.

Whenever the analyser and polariser are so placed that their surfaces are parallel, the field is illuminated; but if they be turned so as to be inclined an angle of 90° the field will appear dark.

Polarisation is the more complete as the field appears either darker or brighter.

Many substances produce characteristic effects on polarised light by which they can either be recognised or even their structure be determined by them; some appear to be simply lighted in the dark field of the instrument, others at the same time are clothed with the most vivid colours.

Besides being of great importance to the scientist, polarisation in certain cases brings before the amateur one of the most beautiful sights under his control; moreover, there is scarcely an instrument that can be called in any way complete without a polarising apparatus.

Substances which produce any effect on polarised light are called *anisotropes*; those on the other hand which leave the field obscure are called inactive substances or *isotropes*.

By placing thin films of selenite or mica above the polariser the sensitiveness of the polarising apparatus can be greatly increased.

The polarising apparatus, usually fitted to microscopes, consists of two Nicol Prisms, one of which is placed under the stage of the microscope, and the other is adapted to the lower end of the body tube immediately above the objective. By means of a milled head or projecting collar the tube containing the prism can be rotated.

Some makers place the analyser above the ocular, but this arrangement has the disadvantage of considerably limiting the field of vision. M. Harting recommends a position between the two preceding ones, and accordingly places the analyser at the lower end of the ocular tube.

Messrs. Hartnack and Prazmowski have invented a new kind of polarising apparatus, which they have patented. This apparatus differs from the Nicol Prism, in that the Iceland spar prism is of a particular shape, the analyser is placed between the eye and the ocular without limiting the field of vision. For a complete description of these prisms, the *Annales de la Société phytologique et micrographique de Belgique* for the year 1867 should be consulted.

Sometimes English condensers are provided with a polariser, which can be removed at will (*e.g.*, those of Messrs. Swift); that which Messrs. Ross and Co. adapt to their microscopes is also very good, and is called *Darker's revolving selenite stage.*

Darker's Revolving Selenite Stage.—This apparatus, which is adapted to the sub- or accessory stage, consists of a tube enclosing three metal frames, each of which contains a layer of selenite, which can severally illuminate the polarised field with a different colour.

Each frame can be rotated separately, and moreover, by means of a little lever, can be withdrawn from the axis of the instrument. In this way one or more of the films can be used simultaneously. The Nicol Prism is screwed on below this apparatus.

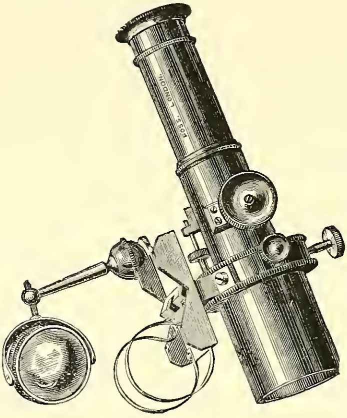


Fig. 86.

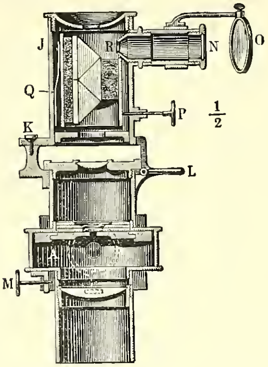


Fig. 87.

4. Spectroscope.—Mr. H. C. Sorby has invented a spectroscope, which can be fitted to a microscope like an ordinary ocular.

This instrument (fig. 86) consists of a tube containing a series of superposed prisms placed above an ordinary achromatic ocular, the lenses of which can be made to approach or recede from one another.

Between these lenses is placed a diaphragm with a slit, the size of which can be increased or diminished as desired by means of a projecting knob at the end of the tube, and to one side of this slit a small prism is placed. This produces the spectrum of light which is used in all subsequent observations, and is further reflected by a lateral mirror. In this way the eye receives simultaneously the normal spectrum and that of the object which is being studied. This is indeed a serviceable instrument, but naturally it requires a little preliminary practice on the part of the manipulator.

The firm of Zeiss manufactures a spectroscope depending on the same principles, only it is much more convenient and complete; and we are constantly using it and are satisfied with it (figs. 87 and 88).

As well as in Sorby's apparatus the lens in this case can focus on the slit. This can be made wider or narrower by means of a symmetrical movement of two plates, produced by turning the screw F, and its extension is sufficient for examining the whole visual field.

The length of the slit can be reduced by turning H, so that by properly using the comparison prism, the opening may be completely filled by the image of the object. The apparatus under observation is fitted with a comparison prism, having a lateral support, with a spring for fixing the comparison objects and illuminating mirror. All these parts, as well as the ocular, are put together in a circular frame. An Amici prism of strong dispersive power is placed above the ocular, and may be moved about the pivot K, so that it can be withdrawn from the optical axis altogether and be accordingly focussed. The axial position of the prism is indicated and maintained by the spring catch L. A small lateral tube adapted to the mounting of the prism together with a mirror projects onto the spectrum the image of a scale, whose divisions give in fractions of a micromillimetre the wave lengths of the light in that part of the spectrum on which they are projected. The scale is made to coincide with the spectrum by means of the screw P.

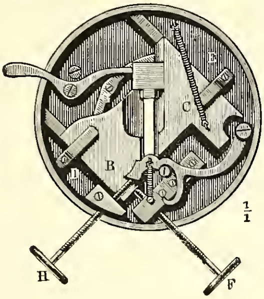


Fig. 88.

5. **Finders.**—A finder is a piece of apparatus with which an object difficult to find ordinarily under the microscope can subsequently be found immediately, *e.g.*, a particular diatom frustule in a preparation which contains many other frustules. Finders are thus of great service, especially to the diatomist.

In certain English microscopes, as well as in the large model of M. Nachet the moveable stage itself acts as a finder, which is much more convenient. Before examination, the preparation is placed in a fixed position by bringing it in contact with the two brass knobs which are set square.

The different parts of the preparation are then made to pass successively across the field of view, and whenever an object of interest appears a note can be taken of the two figures denoted by the indices on the verniers placed at the two adjacent sides of the stage, so that afterwards the same object can be found again by making the verniers register the same figures.

When the stage is not graduated the Maltwood finder can be used instead.

It is a micro-photograph of a series of 2,500 numbers arranged as shewn in figure 89, which represents but a portion of one.

When on a slide an object is seen which we may subsequently wish to find again, the object is replaced by the Maltwood finder, and the two numbers of the square which is seen in the field are read off and noted down on the slide. If subsequently we wish to again observe the object, the finder is placed on the stage and moved about until the numbers noted on the slide appear in the field. Then it is removed and the preparation is placed on the stage in the same position, and the object sought for is found.

10 8	11 8	12 8	13 8	14 8
10 9	11 9	12 9	13 9	14 9
10 10	11 10	12 10	13 10	14 10
10 11	11 11	12 11	13 11	14 11
10 12	11 12	12 12	13 12	14 12
10 13	11 13	12 13	13 13	14 13
10 14	11 14	12 14	13 14	14 14

Fig. 89.

Finally, if the microscope have no mechanical stage another method can be adopted. Two crosses opposite one another, are first marked on either side of the stage and as indicated in figure 90. When an object is met with in a preparation which we wish to find again subsequently, two crosses similar and coincident with those on the stage are marked on the object-slip with a writing diamond, so as to coincide with the crosses on the stage. The object may then be found anytime afterwards by making the crosses on the preparation coincide with those marked on the stage.

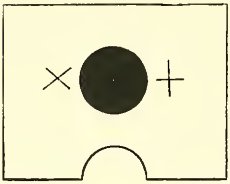


Fig. 90.

The learned Hungarian diatomographer, Dr. Jos. Pantocsek, of Tavarnok, has invented a very simple and effective finder.

On the stage are traced a series of horizontal and vertical lines, one millimetre apart, the two last of which form the o of the scale, and cross one another exactly in the centre of the stage opening. The lines are numbered from o up to 40 (fig. 90*a*).

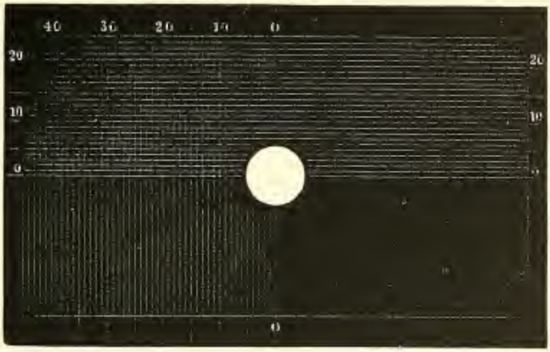


Fig. 90*a*.

In order to find again an object which has been seen in the field, the number merely of the two lines (one horizontal and the other vertical), which coincide respectively with the left hand and upper edges of the slide have to be noted; whenever the slide is placed on these co-ordinate lines the object will be seen in the field.

Under the name of *diatom finder*, Mr. May, of Philadelphia, has invented a small and very simple apparatus, which we have used frequently during the last twelve years.

It consists of one tube fitting into the other. The inner tube has at its upper extremity a standard English objective screw, and is screwed to the end of the microscope tube after the object in question has been brought into the centre of the field.

The outer tube, moveable about the first, carries at its lower extremity a diamond point placed in a slightly eccentric position.

The microscope tube is lowered until it rests by its own weight on the cover of the preparation; it is then rotated on its axis, and in this way a small circle is drawn round the object to be found again.

The size of the circle depends on the eccentricity given by the small shank which holds the diamond.

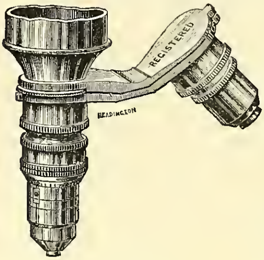


Fig. 91.

6. Rotating Nose-piece. — Under the name of *revolver* M. Nachet has invented a piece of apparatus which in England is called *Brooke's double nose-piece*, and which allows the objective to be changed in a moment.

Figure 91 represents such a rotating nose-piece. Rotating nose-pieces are also made so as to carry as many as five objectives; we happen to have one of these, which was made for us by Messrs. Seibert and Krafft, of Wetzlar, the centering of which is extremely accurate.

Adapters.—The adapter is quite a new piece of apparatus, and has only come into use since 1878; it is intended to facilitate the changing of objectives and save the time which would otherwise be lost in screwing and unscrewing. Most probably the first adapter was invented by Ch. Chevalier, who secured his objective by means of a bayonet, a method of great simplicity, rapidity, and preciseness.

The earliest adapter as used at the present day was invented by Professor Thury, of Geneva, and has been called "Pince Suisse." In this system the objectives are previously screwed on to a ring, and instead of the usual cone and screw-jacket the tube of the microscope is terminated by branches, a kind of pincers, whose two arms are held tight by a spring, but by slightly pressing these can be separated again. The ring is slipped into the pincers by pressing lightly the lower branch, and the objective is held tight in its place, by the spring. A steel rim, soldered to the upper branch of the pincers, and which moves easily in the opening of the ring, ensures the centering of the objective.

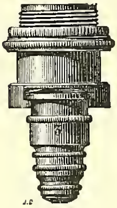


Fig. 92.

After having used this adapter for several years we can warmly recommend it. It only requires a moment to replace one objective by another, and a better centering is obtained than with a screw.

M. Nachet has constructed an adapter which is a slight modification of the preceding one, which

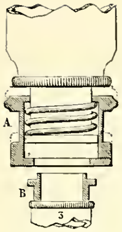


Fig. 93

gives equally excellent results. It is represented in figures 92 and 93.

We think it is unnecessary to mention the numerous systems of adapters which have been suggested in England and America, all of which are more or less like the swiss-pincers, or the bayonet of Ch. Chevalier, but we ought to fully describe an adapter which has recently been invented by Dr. Roderick Zeiss, and called by him the "*sliding objective changer.*"

This little piece of apparatus, the most convenient and precise of any hitherto made, possesses a mechanism by which each objective can be easily centred by the observer himself; it admits of the use of any number of objectives (figs. 94 and 95). The constituent parts are:—

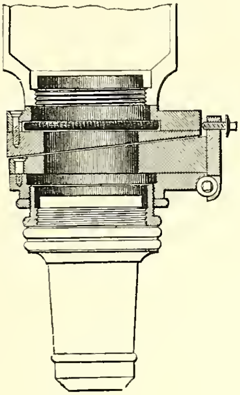


Fig. 94.

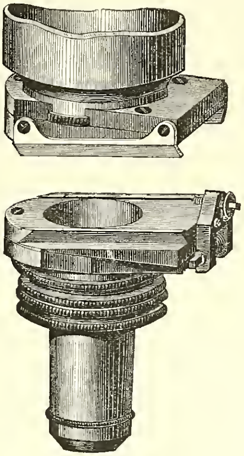


Fig. 95.

a. Tube Slide.—This part is fixed to the tube in the same way as an ordinary nose-piece; it is screwed firmly to the tube, the slide opening towards the front.

The direction of the sliding motion is not perpendicular to the optic axis, but inclined at a small angle to it.

b. Objective Slide.—This slide has the same angle of inclination to the optic axis as the preceding. It follows that when the objective is taken off it rises a little, and no damage is done to the ring of varnish enclosing the mounted preparation.. A screw stop turned by means of a watch key is adapted to the end of this fitting, which stops and fixes it in any required position, to which position it can be brought back again after being removed. This screw acts as a centering adjustment in the direction of the slide. An endless screw, turned by means of the same key, controls the centering in a direction at right angles to the slide.

Objectives whose settings are so matched that they are approximately in focus when changed can be focussed accurately by means of a mechanism *ad hoc*, which contains the piece intended to receive them and which is fixed once for all in their proper position by means of a clamping screw. The slides employed to carry the objectives slip with great accuracy into the slide of the other piece, and can be purchased in such numbers as may be required from time to time.

After carefully centering the objective the same part of the object returns exactly to the middle of the field with each change of objective; it, moreover, remains as nearly as possible in focus, so that it usually only requires to be slightly adjusted by the micrometer screw.

7. **Dissecting Eye-piece and Reversing Prism.**—Under the name of dissecting ocular, a special ocular is referred to, the object of which is to correct the image which, as is well known, is always seen reversed.

This ocular consists of two oculars placed one at each end of a brass tube. It is, really, nothing more than the terrestrial ocular adapted to astronomical telescopes.

By drawing out this tube more or less, a pancratic microscope is obtained; that is to say, one whose amplifying power is proportional to its distance from the objective. Thus, with the dissection eye-piece adapted to M. Hartnack's microscope, the magnifying power varies from 6 to 50 diameters with objective No. 2, and from 30 to 110 diameters with No. 4.

The dissecting ocular is an excellent accessory when a compound microscope is used for making dissections, or for picking or sorting diatoms; without it, it is very difficult to direct the needles conveniently, because every movement has to be made in an opposite direction to that in which they are seen to move.

To achieve the same object, the late A. Chevalier manufactured a *reversing prism*, which was placed on the ocular. We highly value this last piece of apparatus, as its use is very convenient for making a series of dissections which do not require a constant change of amplification.

Arthur Chevalier's reversing prism possesses the advantage of being immediately applicable to any ocular, but it diminishes the field of vision. To remedy this inconvenience, M. Nachet constructs a special ocular (fig. 96), which encloses a prism with four surfaces, whose angles are calculated in such a way that the rays forming the image are reflected by it three times before they reach the eye, and reverses on the retina the image produced by the object; now, as the image given by the object is reversed as regards the ocular, that which is produced by the prism is rectified or erected as regards the object itself.

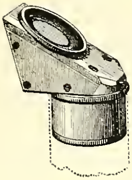


Fig. 96.

8. Binocular Microscope and Stereoscopic Microscope.—The microscope need not necessarily be used with only one eye; for a long time past microscopes have been constructed so that both eyes can be employed. These are called *binocular microscopes*, and some of these pieces of apparatus which convey a sensation of objects in relief are called *stereoscopic microscopes.*

Binocular microscopes do not give such perfect images as monocular microscopes; on the other hand, their use is less fatiguing. Stereoscopic microscopes—it is with reference to those of Wenham that we now speak—can only be used with objectives of low power and small numerical aperture.

The special binocular microscopes, such as are constructed and much used in England, are almost unknown to continental observers. This instrument cannot certainly be made use of for the study of the fine structures of diatoms; but for the study of elementary histology, entomology, &c., it is both very convenient and pleasant. It is also excellently suited to the study of the *form* of diatoms, and we venture, indeed, to assert that he who has never examined a diatom with a stereoscopic binocular will not possess so clear an idea of one as he who is acquainted with this instrument.

In Wenham's binocular microscope, the image, as it emerges from the objective, meets, over a moiety of the opening of the latter, a small prism, which doubly reflects, and consequently sends into the left-hand tube the image given by the right-hand half of the opening of the objective, while that emanating from the left part of the objective reaches the ocular directly and without deviation.

Abbe's Stereoscopic Ocular.—If Wenham's microscope, of which we have just spoken, is little known on the continent, on the other hand, Abbe's stereoscopic ocular, which can be adapted to every continental microscope, has begun to be known.

Prof. Abbe's apparatus is adapted to the microscope tube in the place of the ordinary ocular (fig. 97). The luminous pencil emerging from the objective reaches a thin stratum of air, situated between two prisms, where it is bisected; divided into two parts, one part crosses the upper prism and proceeds to the ocular, which is directly above it, the other part is reflected against another prism, placed at the end of a second tube, which makes an angle of 14° with the principal tube. This latter prism transmits the reflected part to the right eye of the observer through a second ocular.

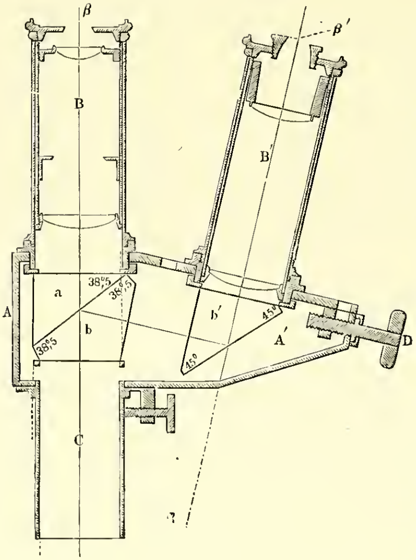


Fig. 97.

The two oculars differ, although they finally produce equal magnification; the second is calculated so as to compensate for the longer path which the luminous pencil striking it, has to traverse before reaching the eye.

The second ocular can also be so adjusted that the distance between the two oculars suits the observer's eyes.

Above the oculars are two adjustable semicircular diaphragms; these diaphragms, by bisecting the pencil, produce a sensation of objects in relief. By taking them off, simple binocular vision is obtained, which is useful in many cases, and which some people find less fatiguing than monocular vision.

The apparatus can be used with any objective. The loss of light caused by the prisms is insignificant.

9. Dr. H. Van Heurck's Comparing Ocular.—To scrupulously compare two diatoms, by examining them in succession under the same microscope, is absolutely impossible. The difficulty can be bridged over by drawing the two forms, and then comparing the drawings; but although this is the best way of studying diatoms, it is a proceeding which takes up so much time that recourse cannot always be had to it.

In order to proceed with greater expedition, we conceived the plan some time ago of using two microscopes at the same time which gave the same magnification, which were brought close together, so that each of them corresponded to one of the eyes. After some attempts one can manage, by a proceeding similar to what is called "double vision," to superpose the images; however, this cannot be effected without some fatigue, and it is impossible to continue the work many hours together as one is often obliged to do.

Having seen in the Journal of the Royal Microscopical Society for June, 1886, a description of the comparer which M. Inostranzeff was employing to compare the colour of minerals, it occurred to us to construct and try a similar apparatus. We recognised the fact that the instrument was very practical, but it was insufficient for diatoms; in the first place the field was partially cut, thus where the prisms join there remained a black band which precluded a perfect comparison, and, lastly, we prefer (for reasons given later on) that the juxtaposition of the diatoms should be made not longitudinally but along half the breadth of the valve.

M. Carl Reichert, of Vienna, constructed an apparatus according to our specifications which works perfectly. Instead of the two prisms being juxtaposed along one of their edges, as is the case with the instrument of M. Inostranzeff, we use instead two prisms of considerable height, but of limited breadth, juxtaposed along one of the triangular surfaces (fig. 98). The two images are juxtaposed in the direction of the height; the carrier of the two prisms is

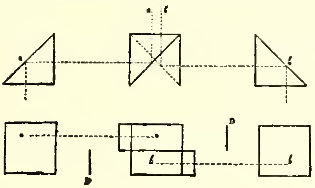


Fig. 98.

moveable, and can be turned on its axis and fixed in any position whatever. By turning it slightly the line of separation between the two prisms can be made to disappear completely, and indeed so completely that a perfect diatom valve can be constructed with the two half valves, which belong severally to one of the fields.

It was in this way that we were able to photograph a valve of *Actinoptychus splendens*, made by the aid of the Comparer, by bringing two half valves into juxtaposition. The photograph has to be examined very carefully to find out where the valves join.

Comparisons can, therefore, be made as completely as possible, and the images are so clear that even high powers can be used.

Diaphragms D D cut off in each part of the tube the light coming from the opposite side, which would otherwise be prejudicial.

10. **Dr. H. Van Heurck's Transformer.**—It is well known that objectives are constructed for a given length of tube. During our researches, especially those in photo-micrography, we have frequently been annoyed by this fact, and consequently we have endeavoured to remedy it. The small piece of apparatus which we have called a *transformer* is the result. It consists simply of a *perfectly achromatic* lens, which is either concave or convex, and has a focal length of exactly twenty inches. This lens is screwed on just above the objective, or what is better, at the lower end of the draw tube, so that it can, within certain limits, be taken nearer to or farther from the objective, and can also be turned on its axis so as to obtain the clearest image.

The concave lens transforms the Continental objective into an English one, the convex lens on the other hand transforms the English objective.

It can easily be understood how useful is such a transformer, which only costs a few francs, while at the same time such expensive objectives, as all the apochromatics of 1·4 and 1·6 N. A., lose nothing by the use of this accessory.

We have made experiments with simple lenses, but the firm of Zeiss have been good enough at once to construct for us achromatic lenses of the focal length and form desired.

Messrs. Bausch & Lomb's Cover-glass Gauge.—The principal object of this ingenious little instrument, represented by figure 98*a*, the price of which is only the small sum of three dollars (12s.), is to measure the thickness of cover-glasses. Its second object is to introduce a new system of cover-glass correction by means of a draw tube;

in devising it, the object has been to provide a mechanical means for obtaining the best optical results without any possibility of doubt, and it accomplishes its purpose perfectly.

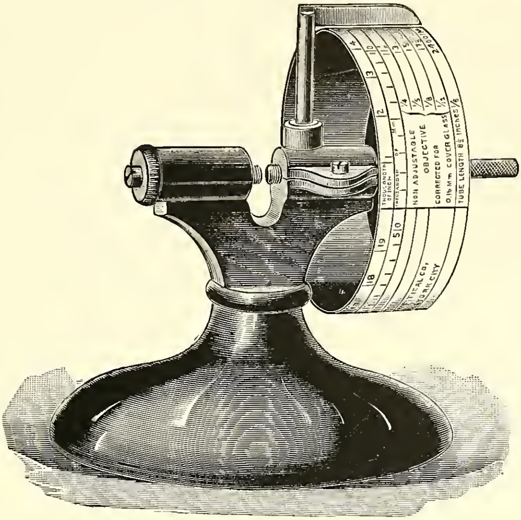


Fig. 98*a*.

This instrument is provided with a stand of japanned iron; cut horizontally through the top is a thread $^1/_{50}$ inch pitch and $^3/_{16}$ inch outside diameter. A recess is cut in the top below the line of the screw and at right angles to it, for placing the covers. The one-half of the top of the stand which receives the micrometer screw is slotted longitudinally to the depth of the screw, and is provided with a set screw to take up wear, the other half has the fixed screw, adjustable however for final adjustment. The end of the micrometer screw is milled, but of a smaller diameter, so that no force can be exerted so as to endanger the cover-glass. Fixed on the screw between two nuts is a brass drum with a half-inch face. A knife-edge index finger is fixed to the top of the stand and projects over the top of the drum.

To the outside diameter of the drum is fixed a strip of glazed paper provided with a series of divisions. The first gives the thickness of cover-glass in one-thousandth inches, the second one-hundredth millimetre. The third indicates the proper tube length with various thickness of cover glass with a non-adjustable $\frac{1}{4}$ corrected under a tube length of $8\frac{1}{2}$ inches and cover thickness of 0·16 mm.; the fourth gives the tube length of a 1-5 inch objective under the same conditions; the fifth for a 1-8, and the sixth for a 1-12 for the same conditions of tube length and cover; the seventh is for a 1-6 with the same cover and tube length of 160.0 mm.

In objectives provided with cover correction the graduation is so arranged as to read to 1-100 mm. No matter what the power of objective, or whether dry or water immersion, the number gives proper correction for a thickness corresponding to it.

Artificial Illumination of the Microscope.—1. Lamps.—The microscopist is not always free to employ his time as he pleases; more often than not he is compelled to defer till the evening observations which he could more easily carry out during the day. Fortunately, however, there are but few observations which he cannot make by artificial light; the study of diatoms and the resolution of tests are made better by the light of a lamp than by day-light.

An oil-lamp can be used for these observations, but a petroleum lamp is preferable because the light is whiter. Gas can likewise be used.

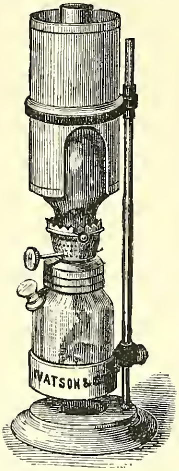


Fig. 99.

An ordinary petroleum lamp is sufficient for most researches. English makers have, however, designed different kinds of lamps, which certainly possess some advantages. Some are sold, costing as much as £6, and even more.

It is essential to have a lamp giving a good white light, which depends upon the way in which the burner is constructed, and it must be one which can be used either with the edge or flat of the flame at will, while as much as possible of the unused radiant is shaded from the eyes. The lamp, in figure 99, of Messrs. Watson and Son, perfectly fulfils these conditions at a moderate cost.

The same makers sell a more complete lamp, furnished with a silvered reflector, a condensing lens, tinted glass, &c. But these luxuries are often unnecessary.

But at the present time there is an illumination which is superior to that afforded by petroleum, viz., electrical incandescent illumination.

2. Electrical Illumination.—In February, 1882,(¹) we published the result of our researches on the use of electrical illumination.

Since the month of November, 1881, when we determined to employ the incandescent lamps, which had recently been invented, we have always worked with electrical illumination, and it would be very annoying if we had to forego it.

Electrical incandescent illumination is superior to any other kind of illumination. It possesses the softness of that given by good petroleum lamps, and resolves delicate details almost as completely as monochromatic light. The delicate striæ of *Amphipleura* and the 19th group of Nobert's test can be seen with perfect clearness.

Professor Abbe, whom we made acquainted with the result of our researches, has given us the following theoretical explanation of it. He attributes it to two causes.

1. The greater whiteness of the light. Therefore the light includes more blue and violet rays. Now, as it has been shewn by measurements, made by Professor Abbe in different monochromatic illuminations, that the separating power of any given objective increases as the length of the wave of light employed diminishes, it follows that the electric light ought to show delicate detail more easily than does the yellowish light of gas or of lamps.

2. The specific intensity of electric light being far more considerable than that of any other artificial light, sufficient illumination is obtained with a much more restricted luminous pencil than that which must be used to obtain the same luminous intensity with gaslight, or with diffused daylight. Rays which are much more oblique can, therefore, be used.

When we first used the electric light, we placed the lamp, which was of rather large dimensions, in a box, in the lid of which was an opening, which had glass fitted into it. The microscope was placed on the box, the mirror having previously been moved to one side of the axis, or taken off. The light of the lamp was then centered by means of a plano-convex lens, and was directed onto the condenser of the microscope. By manipulating the latter, the illumination was modified.

The lamps used in this arrangement required a considerable electromotive force, but shortly afterwards Mr. Swan placed at our disposal some much smaller lamps, which only required about 7 volts.

Mr. Stearn (Mr. Swan's colleague and director of the Swan Company) made still further improvements, and invented some new lamps specially

---

(¹) Consult: "La lumiere électrique appliquée aux recherches de la micrographie et de la photo-micrographie par le Dr. Henri Van Heurck. 2e Edition. Anvers 1883."

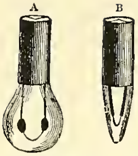


Fig. 100.

designed for microscopic illumination. These lamps (fig. 100) are of two kinds. Some (A) give a brighter light than the rest, and are intended for experiments in polarisation and photo-micrography; others (B) have a very short thread, and are suitable for ordinary illumination. They only require an electro-motive force of $3\frac{1}{2}$ volts and a current of $1\frac{1}{4}$ amperes which may be supplied by two accumulators, or two Bunsen cells. Their illuminating power is roughly equivalent to one candle, but if

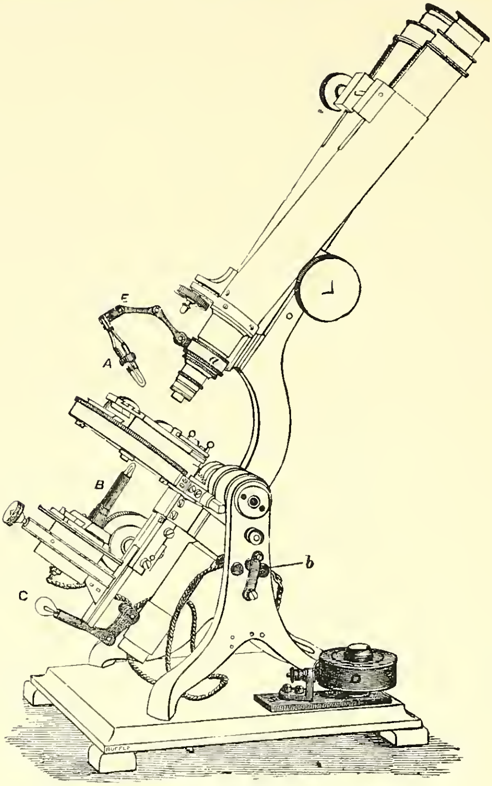


Fig. 101.
Microscope arranged for illumination with three incandescent lamps.

necessary they can be raised to a candle power of 2½ for some minutes.

Messrs. Mawson and Swan have designed a special microscope for the use of Mr. Stearn's lamps, which we will now describe.

The entire microscope (fig. 101) is mounted on a metal stand, the lamps are fixed permanently to the instrument, the different metal parts serving as conductors. There are three lamps attached to the microscope. The first A can be used to illuminate opaque bodies, and is attached above the objectives by a collar *a*, which allows the lamp to be rotated, while the jointed arm E allows it to be withdrawn from or brought near to the object for the purposes of illumination.

The second lamp B is placed on the sub-stage; by sliding it in a groove it can be pushed sideways so as to give oblique illumination.

Lastly, the third lamp C, whose illuminating power is greater than the previous ones, is attached to a jointed arm in the place of the mirror. This lamp is used in experiments in polarisation and photo-micrography, as well as for the illumination of condensers.

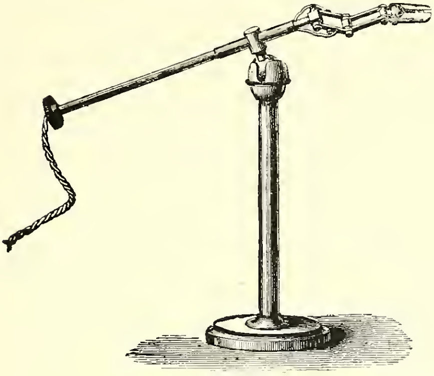


Fig. 102.—Lamp-carrier on stand.

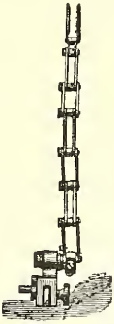


Fig. 103.—Lamp-carrier for fixing on stage.

The resistance produced by a coil of steel-wire allows the power of the electric current to be controlled, and a commutator *b* allows the current to pass in any of three directions to either of the three lamps.

Lastly, by means of the stands in figures 102 and 103 the electric light can be adapted with more or less ease to any microscope not specially arranged for this work.

The photophore of M. Trouvé is also a very convenient piece of apparatus for electric lighting. As a matter of fact it is simply the apparatus that we devised in 1881 for illuminating the microscope. The photophore consists of a nickel brass tube (all the parts of the apparatus are similarly nickeled), in the middle of which is placed the lamp, which is of a special form with a straight filament. At the back of the tube there is a reflecting mirror of silvered glass, and in the front of a second tube, sliding in the first, is a condensing lens. With this second tube, the space between the lens and the lamp can be regulated, and consequently a pencil of convergent, divergent, or parallel rays can be obtained as desired. The condensing lens being moveable in its mounting, can be turned so that the convex face is in front or behind.

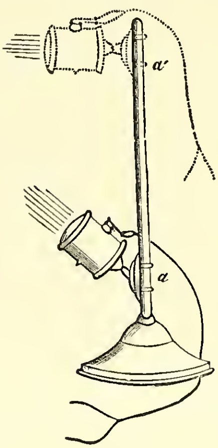


Fig. 104.

The photophore (fig. 104) is screwed on to a very heavy foot, carrying a split tube, 20 centimeters ($7^4/_5$ inches) in height, which acts as a spring, over which slides with very little friction, a second tube, which can be fixed at any height. This second tube carries two fastenings, *a*, *a′*, one placed at the upper and the other at the lower end; each of these fastenings consists of a steel ball with a rod furnished with a screw thread. The ball is held tight between two concave metal plates, the first of which, having a hole in the middle, allows the threaded rod to pass through. The photophore screwed on this rod can then, in consequence of the movements of the ball, be placed in any position that may be desired.

Lately, our learned correspondent, Dr. Engelmann, professor of biology at the University of Utrecht, and one of the most zealous promoters of electric lighting in microscopy, has had a small and very simple apparatus constructed for him, which acts very well, and at the same time fulfils the purpose of a rheostat or light regulator.

This apparatus (fig. 105), is composed of a brass foot M, carrying a rheostat R, and a lamp carrier S.

As will be seen the positive current enters by the pillar *a*, whence it passes to the upper part of the rheostat, through it, and, by means of the brass foot, is carried direct to the lamp. From the lamp the current returns by a fine copper thread to the pillar *b*, and thence to the negative pole of the electric current.

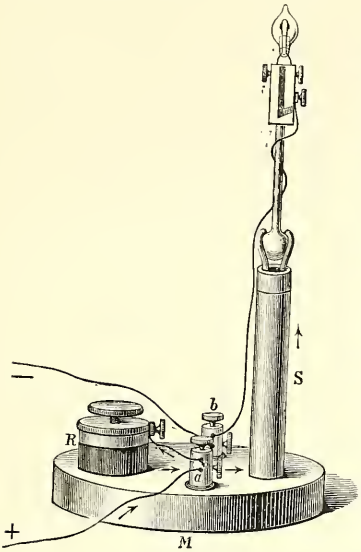


Fig. 105.

The lamp can be raised to different heights by means of the two brass tubes S, which slide in one another, and can also be placed in every possible position by means of a ball and socket as seen in the plate.

With regard to the rheostat itself, it is composed of a brass cylinder insulated at its foot by a foundation of ebonite or serpentine. This cylinder contains a pile of thin discs formed of a mixture of graphite and gelatine. The resistance of these plates depend upon the relative proportions of the two constituent parts.

By means of an adjusting screw which terminates just above the rheostat, and which by means of a brass disc tightens or loosens the resistance plates, the intensity of the current can be regulated with mathematical precision.

This apparatus being rather feeble for many kinds of research, M. Kagenaar, engineer of the University of Utrecht, has made a more perfect one in accordance with our instructions, the construction of which Professor Engelmann has kindly superintended.

This new apparatus is composed of a small brass table, 20 centimetres (8 inches) in length and 10 centimetres (4 inches) in breadth. This table carries at one end the small rheostat lamp-carrier described above, and on it a corresponding horizontal rheostat placed lengthways. The essential part of this latter apparatus is a long tube of serpentine enclosing 120 graphite discs. When the discs are tightly pressed the resistance attains nearly ¼ ohm, and by slowly loosening the regulating screw, this resistance can attain 800 or 1000 ohms. The apparatus can therefore, theoretically, be used for very small lamps as well as for very powerful ones; indeed, by employing 16 Reynier's large-sized accumulators of 12 plates, we have found no difficulty in using successively lamps of 2 volts and ·5 amperes up to 12 volts and 4 amperes heated to a white heat.

The two small pieces of apparatus fixed on to the brass tablet can be taken off from it if desired, and the lamp carrier can also be turned about its axis and fixed in all azimuths.

We believe that it would be impossible to produce an apparatus more complete, more powerful, and at the same time more compact than that we have just described.

After having described the illuminating apparatus it still remains to examine the electrical sources to which the microscopist can have recourse.

Two or three Bunsen cells are quite sufficient for the small lamps. The vapours given off by these batteries make them unsuited for use in a laboratory, and we do not advise their introduction into the work-room.

The bichromate batteries provided with a windlass are more manageable, although they also emit unwholesome vapours.

Indeed, we cannot advise any but the small portable battery of Trouvé or the Radiguet battery.

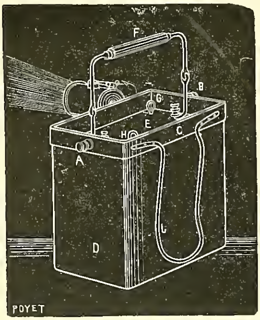


Fig. 106.

The portable battery of Trouvé (fig. 106) consists of a small ebonite tank D, measuring 15 centimetres (6 inches) in length by 10 (4 inches) in breadth and 18 (7 inches) in height, divided into six compartments, each being two-thirds the height of the tank, intended to form as many elements.

At the bottom, these compartments communicate with one another by a very small opening.

The active elements attached at the bottom to the cover E, are arranged in six ranks, each of which corresponds to one of the cells of the ebonite tank; each of the ranks constituting an element is formed of two zinc rods placed between three carbon rods. The six elements are coupled together by connections disposed symmetrically and neatly on the top of its cover, which also carries two terminals for establishing the current.

The battery does not emit any odour, and will feed the photophore lamp for two hours.

When the battery is exhausted the two milled heads A, B are unscrewed, the rim which they keep in position is removed; then the handle F is taken hold of, and by raising it the cover and the elements are removed at the same time; the exhausted liquid is thrown away, and the tank is washed with water; 800 grammes (1¾lbs. avoirdupois) of new liquid previously prepared is then poured in, and the cover, rim and the two milled heads are returned to their original position, and the battery is again in working order.

The liquid for this battery is thus prepared: into a large stone vase is placed 1 kilo (2 1-5th lbs.) of bichromate of potash, 8 litres (7 quarts) of water is added, and then 2 litres (3½ pints) of sulphuric acid (commercial), which is poured in very slowly in a narrow stream, while constantly stirring it by means of a glass rod. The liquid gets very warm during the operation, and it must be left to cool before being employed.

With the quantity which we have just mentioned the battery can be charged 12 times.

The small Trouvé battery is an excellent one for the microscopist who only desires to use electric light on special occasions. But if he desires to have it permanently at his command he would do better to use either the Trouvé windlass battery or the Radiguet battery.

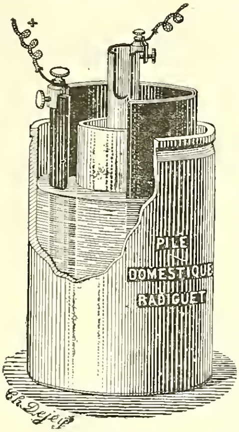


Fig. 107.

The Radiguet battery [1] is a modification ot the Poggendorf battery, and is a very great improvement upon it. It has all the advantages and the energy of a Bunsen battery, without any of its inconveniences.

Each element of the Radiguet battery is composed of an impervious stone jar, a carbon cylinder, a porous cell, and a support which amalgamates with its cistern-reservoir. These different parts are placed one within the other as seen in figure 107.

It is the combined effect of the amalgam support and its cistern, wherein the novelty of the battery lies.

---

(1) Radiguet, maker of Scientific Apparatus, 15, Boulevard des Filles-du-Calvaire, Paris.

M. Radiguet had noticed that when the mercury contained traces of zinc, or when it was in contact with red copper, the electrical current had a tendency to distribute the mercury over the entire surface of the copper. This observation induced the skilful electrician to construct the amalgam support.

As seen in figure 108, this support is composed of a zinced copper tube, to which is attached a kind of basket to receive zinc, which may be granulated, or, better still, in the form of round shot, which have been cast either at the foundry or by one's self; M. Radiguet also supplies them by the kilo at a low price.

Underneath this basket is a porcelain cistern containing the amalgam by which the the zinc is kept constantly amalgamated. This cistern is connected by a copper bolt to two metallic feet, attached to the bottom of the basket.

Such is the apparatus that we are going to put in working order, and for that purpose we pour into the outer jar an acid solution of bichromate of soda, and into the porous jar some pure water; the battery will then begin to work at the end of a few hours. If we wish to to make it work immediately we only have to pour a few grammes of sulphuric acid into the water, as thus we anticipate by dialysis what otherwise takes place gradually.

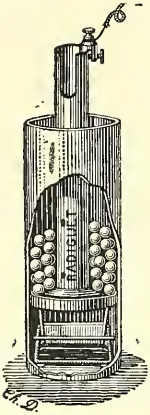


Fig. 108.

The battery works on an average for eight days, at the end of which time the acidulated water in the porous vase must be changed. This is not a difficult operation, and can be easily effected in a few minutes, without taking the battery to pieces or deranging it in any way. This is carried out by means of a very ingenious apparatus, which is patented under the name of the Radiguet siphon (fig. 109).

This siphon has an advantage over all others because it is set in operation by blowing and not by suction; it is emptied in the same way. These two operations are effected by means of an india-rubber ball.

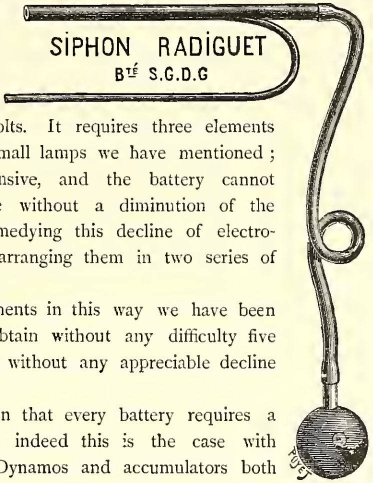
To fill, it is sufficient to press the ball slowly once or twice; to empty, it is also pressed, but this time sharply.

The large tube of the siphon encloses a narrow tube, which is a continuation of the straight outer tube, and the diameter of the lower end of the large tube is much smaller than that of its average section. It follows then that when air is blown in slowly the pressure increases in the large tube, drives back the liquid into the straight branch, and the siphon is found to be full. A rapid pressure on the other hand drives back the liquid completely, and the siphon no longer works.

The inner jar should be in this way emptied once a week. The outside liquid need only be changed monthly, or perhaps not so often. This operation can also be carried out by means of the siphon.

The battery is therefore always charged, and it is only necessary to take it to pieces now and then to thoroughly clean it.

Fig. 109.



The electro-motive force of the battery is about two volts. It requires three elements to give a white light in the small lamps we have mentioned; however, they are too expensive, and the battery cannot last for any length of time without a diminution of the light. The best means of remedying this decline of electromotive force is obtained by arranging them in two series of three elements each.

By arranging the six elements in this way we have been able for a whole week to obtain without any difficulty five hours' illumination at a sitting without any appreciable decline of the light.

Let us add in conclusion that every battery requires a certain amount of care, and indeed this is the case with every source of electricity. Dynamos and accumulators both require constant attention and electrical illumination by canalisation should be the microscopist's ideal. Let us hope that, at any rate in all large towns, this desideratum will be realised in a very short time hence. At Antwerp proposals have been made by the eminent electrician Van Rysselberghe, and the Municipal administration have accepted them; the public will therefore in a few months have electric light at their disposal.

BOOK II.

SIMPLE MICROSCOPES AND PROJECTION MICROSCOPES.

CHAPTER I.

SIMPLE MICROSCOPES.

The simple microscope, which had to serve for all serious study until the means of rendering the compound microscope achromatic was discovered, is essentially composed of a magnifying glass, mounted on a moveable screw, under which the rays are reflected from a mirror on a plate of glass, or brass, attached to the stage.

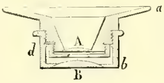


Fig. 110.

At the present day the simple microscope is never used, except for microscopical dissections, which do not require a greater magnification than 15 to 60 diameters.

* Fig. 111.

Formerly biconvex lenses were used. But now, doublets are generally employed, conceived in the first place by Wollaston. Charles Chevalier followed up Wollaston, and made the doublets which are still in use. Chevalier's doublet is a combination of two plano-convex lenses of the same focal length, having their convexities turned towards the eye (figs. 110 and 111).

A small diaphragm intended to correct spherical aberration is placed between the two lenses, which are of unequal size, but nevertheless of the same focal length. The advantage of doublets over biconvex lenses is that for the same magnification the former gives an image which is much clearer and more free from spherical aberration.

Many opticians devote themselves specially to the manufacture of simple microscopes, but the firm of Chevalier enjoy the greatest reputation.

The firm of A. Chevalier make a number of models of simple

---

* Figure 110 represents the doublet mounted, and figure 111 shows the arrangement of the glasses: A, upper glass; B, lower glass; O, intermediate diaphragm.

microscopes. One of these (fig. 112) costs £2, accompanied by a doublet magnifying forty times. Another model, better finished (fig. 113), has two doublets, and costs £4. It consists of a heavy foot, rigidly connected with the stage, and carrying a reflecting mirror. The doublet is carried on an arm, which can be moved from front to back by means of a rack, and which can also be turned about its axis so as to describe a complete circle, by which means it can pass over all parts of the stage.

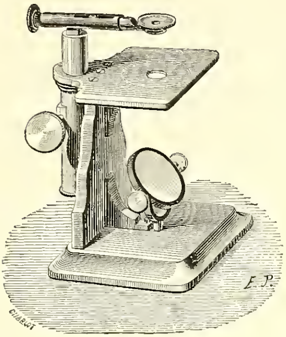


Fig. 112.

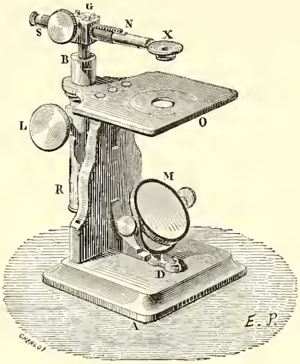


Fig. 113.

Lastly, a more carefully finished model (fig. 114) provided with a square pillar, costs at present £5 4s. Chevalier sells his doublets separately. Their price varies as follows: Doublets magnifying, 12 to 120 times, 8s.; the same 130 to 240 times, 15s.; the same, 480 times, 16s.; the same, 500 times, £1.

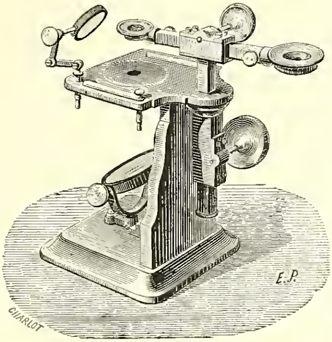


Fig. 114.

M. Nachet also manufactures simple microscopes. One of these instruments, having a rack with two milled heads for focussing, and a stage carrying two side rests for the convenience of the hands during important dissections, costs £2 8s. with two doublets (fig. 115).

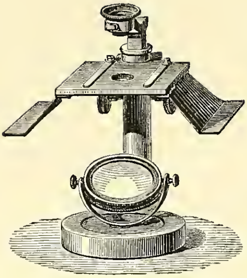


Fig. 115.

Lastly, a binocular apparatus for dissection (fig. 116), which we examined a little time ago, and by means of which dissections can be seen very vividly in relief, also costs £2 8s.

This optician also sells the doublets separately. The price is 5s. for those of 20 to 5 millimetres, focal length, and 8s. for those of 5 to 2 millimetres.

The firm of Carl Zeiss, of Iéna, also justly merit their reputation for simple microscopes; and, some years ago they invented a combination which has been adopted by a great many observers, and cannot be too strongly ecommended. This combination consists of an objective composed of three achromatic lenses screwed to the lower end of a tube, on the upper end of which is a concave achromatic ocular.

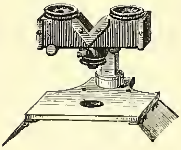


Fig. 116.

These lenses can be used either singly—in which case they magnify 15, 20, or 30 times respectively—or the ocular may be used with either one, two, or three lenses at a time, giving respectively magnifications of 40, 60, and 100 times. The focal distance is very large, being 9 millimetres for the highest power, and 30 millimetres for the lowest.

This excellent combination, which can be applied to any simple microscope, only costs 30 shillings.

M. Nachet manufactures a similar combination for £1 8s.

In America, Messrs. Bausch and Lomb, of Rochester, make a very ingenious simple microscope, called *the compact dissecting and mounting microscope* (fig. 116a), which appears to be very generally used in the United States.

The base of the instrument, which is of cast iron, is varnished, and is sufficiently large and heavy to insure the perfect stability of the instrument. On one side of it rises a brass pillar, jointed at the base by means of a hinge, and at the stage by means of another hinge.

The pillar contains a triangular rod of polished cast iron, carrying at the side a rack which can be raised or lowered by means of a pinion.

At the upper end of this rod a ring, for carrying the lenses, can be adjusted with a sliding motion.

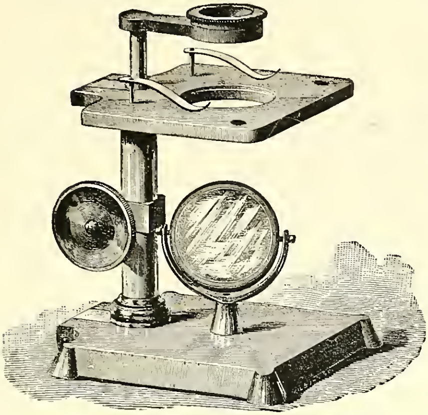


Fig. 116*a*.

Inside this ring is a screw thread by which any objective furnished with the English thread can be screwed.

Two lenses having respectively 2-inch and 1-inch focus are mounted in ebonite rings, and can be placed one above the other so as to give magnifications of from five to twenty-five times.

By means of the ingenious system of hinges, which allows the different parts of the microscope to fall back on themselves, like the leaves of a portfolio, the instrument only occupies a small space. The box containing it, with the various accessories, is only 15 centimetres (six inches) long by 12 centimetres (4½ inches) broad and 6½ centimetres (2½ inches) high.

The price of the instrument is $12 (£2 10s).

CHAPTER II.

PROJECTION MICROSCOPES.

SOLAR MICROSCOPE; GAS MICROSCOPE; PHOTO-ELECTRIC MICROSCOPE.

The difficulty of exhibiting a series of microscopical objects to a large number of people and the loss of time which this necessarily involves have for a long time suggested some special apparatus by which these inconveniences might be avoided. Such is the origin of projection microscopes.

These instruments depend on the same principle as the magic lantern; the rays, coming from a luminous source, fall upon a convex lens (or a combination of lenses producing the same effect) which concentrates them on the object: thence these rays reach an objective which is placed at a distance rather greater than its principal focal length. By such an arrangement a real and greatly magnified image of the object is formed which may be received on a screen at any distance.

The names of many projection microscopes which are practically the same instruments, vary according to the illuminating apparatus used. Such are the solar microscope, the photo-electric microscope, and the gas microscope.

All these instruments require a completely darkened room, or hall, so that no light, except that furnished by the instrument, can meet the spectators' eyes and so diminish the intensity of the image received on a tightly-stretched screen, which should be made either of strong white paper or a scrupulously white sheet. When the spectators and the instrument are on opposite sides of the sheet the latter must then either be wetted immediately before the experiments, or, better still, sized with two coatings of gelatine. The object of the sizing is to fill up the interstices found between the threads of the sheeting.

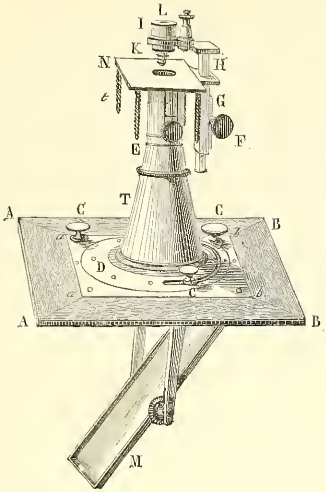


Fig. 117.

The oldest instrument of this kind is the solar microscope, and its invention is generally attributed to Lieberkuhn. However, the researches of M. Harting prove irrefutably that this apparatus is due to Père Kircher, and that Lieberkuhn, who made known the instrument in England, and to whom the invention is attributed, only imitated an instrument constructed by Fahrenheit, who then lived at Amsterdam. It was in this city that Lieberkuhn saw the instrument in the hands of George Clifford and Henri de Raad.

The solar microscope has undergone very important modification at the hands of Charles Chevalier; the model as conceived by this eminent optician (fig. 117) we shall now describe.

A A B B, is a wooden slab or panel of a shutter having a circular opening cut in it, which must be situated just opposite the tube of the instrument, T.

a a b b, is a brass slab, which is fixed to the above with a screw-knob, a plane reflecting mirror M can be rotated by means of the knob C, which turns the disc D by acting on a rack and pinion.

A second knob C gives the mirror a vertical movement.

To give the vertical movement of the apparatus all possible exactness and rigidity, Charles Chevalier placed on the side of the instrument a rack and pinion.

T is the usual conical tube which carries the large condensing lens at the widened end; the top of the cone ends in a tube E which receives another tube *t*, the end of which is furnished, near the object slip, with a second condensing lens which is usually called the *focus.*

Charles Chevalier rendered this lens moveable by means of a rack and pinion. The focus of the lens can thus be altered (*i.e.*, the object can be placed more or less near its focus) which is an important feature, because some objects require but little light, while others would be consumed or altered in character immediately if they were placed exactly in the focus of the condenser. At E the tube is moveable, which allows the illumination to be regulated.

The stage N is made of two plates whose distance apart can be modified at pleasure by means of spiral springs. Formerly preparations of a particular shape could alone be used; by means of the arrangement of Charles Chevalier every kind of object can be examined under the instrument, especially transparent troughs having their opposite sides parallel.

Let us now observe the construction of the magnifying system. H is a square rod which can slide in the tube G by turning the milled head F; at one end of H and fixed at right angles to it is the piece I, which holds three achromatic lenses K, and in some cases the concave lens L, which we shall mention again later. Close to L is an adjustment screw for exact focussing.

Charles Chevalier has also applied the adjustment screw to the solar microscope in the case of all slow movements. Moreover, when in 1823 he succeeded in making achromatic lenses, he also adapted these to the solar microscope.

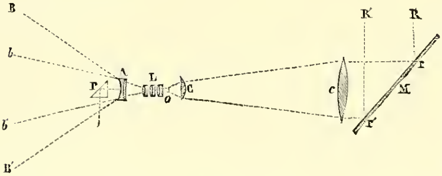


Fig. 118.

Before showing how the solar microscope should be used, let us first explain briefly the theory of the instrument.

M (fig. 118) represents the mirror, *c* the large condenser, C the *focus*, L the three achromatic lenses, A the concave achromatic lens. P is a rectangular prism, which may be introduced if required. R R' represents the solar rays reflected at *r r'* by the mirror M, refracted by the condenser *c*, and again by the lens C, which concentrates them on the object *o*. The rays which pass through the object are received and refracted again by the lenses L, and after crossing each other, form on the screen in front of the instrument an inverted image of the object, the size of which depends on the distance of the screen from the objective.

We have mentioned that a plano-concave achromatic lens A is made use of (fig. 118); and the advantages obtained from it are as follows:—

It often happens that the room where the experiments are being made is not long enough to give the magnification desired.

By placing before the lenses the concave achromatic glass mentioned above, this inconvenience is avoided, because the image produced is much greater than if the lens was not employed. Moreover, the figure will render this effect quite intelligible; for the rays B B' will project a larger image on a screen at a given distance than will the less divergent rays *b b'*. The concave lens can be removed if necessary.

By means of the figure, the effect of the prism P is also clear. It allows the image to be carried forward either sideways, or on the floor, or on the ceiling.

We will now show how the solar microscope is used.

The workroom should, if possible, have but one window, and that facing the south. This window should be made perfectly light-tight by means of shutters; then one of the panes should be removed and replaced by a wooden panel having a circular opening large enough to admit the mirror of the instrument. The plate *a a*, *b b*, is fixed to the panel, and held in position by means of the screw knobs, which should be screwed into some nuts placed in the panel for that purpose.

The mirror M, and the large condenser will then be outside the window.

The objective carrier L is then removed, and the mirror M is so adjusted by means of the knobs *c c*, that the sun is reflected by it on to the condenser. Then the fine adjustment of the *focus* is made use of, until a perfectly clear disc is projected on the screen. The objective carrier has now only to be replaced, and the preparation slipped between the two spring plates of the stage. The object is then focussed by adjusting the lenses by means of the knob F.

It is now understood that the *focus* is intended to regulate the light, and that with it the object can be illuminated slightly or strongly by making the focus of the luminous rays approach the latter, or by placing the object actually in the focus. Delicate objects, live objects, &c., should not, therefore, be placed in the focus of the luminous rays, but rather close to it. However, after a little practice one will soon become acquainted with all such necessary precautions. The light must also be carefully watched, because the motion of the earth is always altering the position of the reflector.

An intimate acquaintance with the objects observed will afford the secret of illumination, and it will be soon discovered when the circulation of the blood of a living animal has to be observed, that if it be placed in the focus of the solar rays, life, and therefore the phenomenon will cease; at other times this concentration of heat is necessary, *e.g.*, when we wish to crystalise solutions of salts. It is, therefore, important to know how to regulate the light by the *focus*. The tube E, which slides into the tube T, may also be used. The image produced by the microscope is received on a screen which should be tightly stretched and parallel to the axis of the microscope. The nearer the screen is, the smaller proportionally will be the image. However, the screen cannot be removed to any distance, because the light will become insufficient. Some white paper carefully stretched over a frame will form one of the best screens. Vegetable paper can also be employed, or the image may be projected on a wall, if very white and smooth.

By going behind the screen, when it is made of thin paper, the objects can be distinctly seen and drawn. When the wonderful effects of the solar microscope are displayed to a large number of spectators, it is placed behind the screen, so that they may see the object without their attention being distracted.

To obviate the inconveniences of solar light with special reference to scientific demonstrations, recourse is had to oxy-hydrogen or the electric light. In this case, either the gas or photo-electric microscope is employed, each of which, as previously stated, is simply the solar instrument having a different luminous source.

The gas microscope, which was first used by Mr. Cooper, of London, was introduced into France by Mr. Warwick, but the apparatus was dangerous; Charles Chevalier and Galy-Cazalat modified it so as to make it manageable.

Notwithstanding the utility of the instrument, it can be easily understood that its use is restricted.

The photo-electric microscope was first constructed by Charles Chevalier in accordance with the views of Messrs. Donné and Foucault. The instrument has been made more perfect in form and illumination by Mons. Duboscq, the optician, who has made an apparatus which can be worked quite conveniently. Like the gas microscope, the use of the photo-electric microscope is also restricted; but for regularity of effects and brilliancy of illumination, oxy-hydrogen gas should certainly be preferred.

When a large audience has to be addressed, very delicate objects cannot perhaps be seen at a certain distance; the object itself under these circumstances can be shewn either by a photograph or by a good drawing traced on glass.

Demonstrations with the oxy-hydrogen gas microscope are very instructive. We have made use of them for our classes with great success for more than 20 years, and we have devised a very simple apparatus, easy to manage and one which works with the greatest regularity. For several years our apparatus has been used at the Higher School of Pharmacy at Paris in the classes for materia medica given by Professor Planchon, who praises it very much. More recently the same apparatus has been adopted by the Industrial School of Antwerp, and also by the School of Medicine at Nantes.

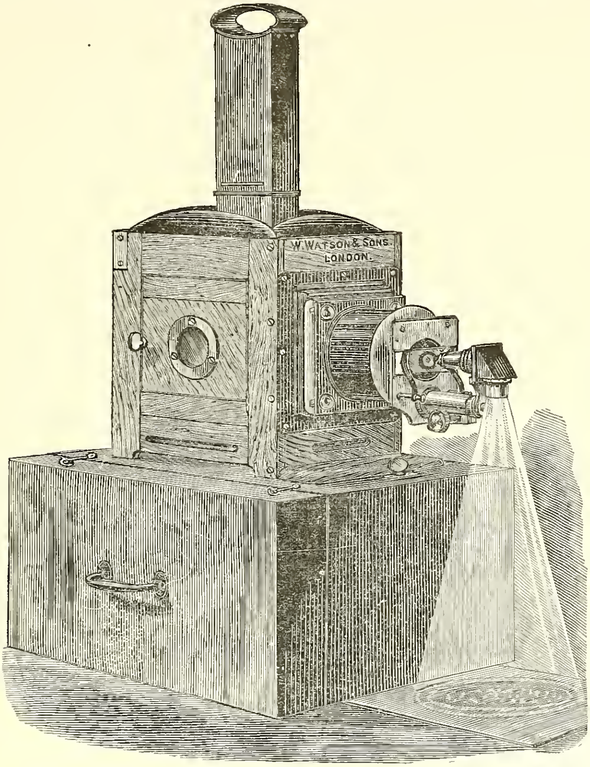


Fig. 119.

In this apparatus the luminous source is a cylinder of lime rendered incandescent by a jet of oxygen and hydrogen gas, which may be introduced either separately or mixed as desired. The condenser is three and a half inches in diameter, and the curvatures of the lenses are calculated so as to make use of all the rays emitted from the luminous source.

The microscope, which is furnished with a coarse and fine adjustment is placed in front of the condenser. The objective used is Ross's 2-3rds inch, having an achromatic magnifying glass in front of it.

The microscope can be instantly replaced by a special objective by which drawings and photographs can be projected on to the screen.

One of the most valuable properties of this apparatus is that only a distance of from 2 to 3 metres (6ft. 6in. to 9ft. 10in.) is required between the instrument and the screen. The apparatus for photographs notably supplies an image of 2½ metres (8ft. 2in.) in diameter at a distance of 3 metres (9ft. 10in.).

Oxygen can be produced in about 20 minutes by means of special retorts made of sheet iron, which are not liable to explosion.

Messrs. Watson and Son also make a very simple microscope, which can be adapted to any projection lantern. This apparatus, which is represented in figure 119, can of course be used for low powers only.

Let us further notice before concluding, that by means of Professor Abbe's projection oculars any microscope whatever can be transformed into a projection microscope. For this purpose it is only necessary to incline it horizontally, to place a luminous source behind the condenser, and to receive the rays emanating from the ocular on an appropriate screen.

BOOK III.

CHAPTER I.

USE OF THE MICROSCOPE.

1.—Situation and Arrangement of the Work Room.

The aspect of the work room is by no means a matter of indifference. The best room is one in which the windows face the north or west, or better still north-west. However, if this is impossible, the difficulty can always be met; a worker in a room facing the south will make better observations by screening the windows with a white blind, which will protect him from the direct solar rays. The same applies to windows facing the west. This last aspect is particularly suitable for experiments with microscopic photography and also for studies with monochromatic light where the sun is necessary.

A large and very solid table is the most indispensable piece of furniture. It should be placed near the window, and should have at each end as many drawers as possible, so arranged that an observer, when sitting, can open them without moving. The drawers should have a certain number of compartments to receive all the accessory apparatus and tools in ordinary use.

For some years past we have employed a special table, which appears to have been used in the first place by Mr. Amrhein, of Vienna. This table, the general fitting up of which is similar to that of the table we are about to describe, differs from it in having a glazed frame, which covers it up entirely, and is opened in front and at the top. In our model the hind part can also be partially opened, in order that the light shall not have a second glass plate to traverse during observations by daylight.

Such a table is of inestimable value for ordinary work. In less than a minute the observer can open it and recommence the work previously interrupted. The instruments and all the implements are found in exactly their previous position under cover from dust.

When electric light is used, as we do, for illumination, the knob of the commutator has only to be pushed to find the object again, just as it was before in the same position, and similarly illuminated, &c. A complicated drawing can thus be easily accomplished though it may have been interrupted and recommenced many times.

In default of such a table, the microscopes must, after each sitting, be covered over with a glass globe, as the instruments will become damaged if they are taken out of their cases too often and then returned again after each sitting.

2.—Choice of Light.

As far as possible work should be carried on by daylight. If, from unavoidable circumstances, observations can only be made at night, a steady white flame should be used. In the absence of electric light, oil lamps are the best and most economical. For histological work, if the light be too intense, a small ground glass may be placed to advantage on the diaphragm to soften down the light. This can also be accomplished by interposing a blue glass, chosen so that the colour of the glass is complimentary of that of the flame, in which case a white light is obtained.

During the daytime, sunlight reflected from white clouds, or by a wall of the same colour, should be preferred. The blue colour of the sky does not permit the observation of very delicate details.

Direct sunlight can never be used in ordinary observations. The softest possible light should be chosen, which should be further moderated by the use of diaphragms, never losing sight of the fact that the smallest diaphragm openings are reserved for the highest powers. First-class instruments allow the light to be modified by raising or lowering the diaphragms; this is an excellent arrangement, and admits of a perfect gradation of illumination.

Complete instruments have two mirrors: the plane is used for low powers; the concave, which concentrates a larger quantity of light, is employed for high powers.

Several systems of illumination, already mentioned above, may also be placed in the luminous path. It is hardly necessary to say that the plane mirror should be employed when an apparatus for concentrating the rays is used, and that a rectangular prism which has only one reflecting surface is preferable.

Oblique illumination is a method which possesses great advantages.

It should be employed when we wish to discern clearly the composition of the surfaces of very delicate objects; as for example, certain diatoms, the striæ of which are of extreme tenuity. It is obtained by placing the mirror on one side at different angles to the stage.

For some time past certain English microscopists have credited oblique illumination with every kind of defect. They declare that results given by this illumination are misleading and unreliable, and that only axial illumination (so-called) given by a condenser with a moderately sized stop is admissable. Several eminent microscopists who have materially advanced the science, *e.g.*, Hon. J. D. Cox, of Cincinnati, have done justice to these absurdities. Professor Abbe in his turn has demonstrated that this professedly axial illumination is in reality a combination of axial and oblique light, and that there is no theoretical reason for attributing to the former any advantages whatever. The time has not, therefore, arrived when microscopists can abandon oblique illumination, as the most powerful means of investigation at their disposal, for any objective whatsoever can shew, with oblique illumination, nearly twice as many lines as can be seen with really axial illumination. When used injudiciously, oblique illumination may sometimes give illusory results, but an experienced observer will never be misled by them. By simply changing the direction of the oblique illumination one can make sure whether a line or striæ really exists.

When opaque objects are examined they should be placed on a slip of a dark colour if they are light, and on a slip of a light colour if they are dark. Then, as ordinary daylight or lamp light is not sufficiently intense, the rays are concentrated in a bundle on to the object by interposing between the light and the instrument a plano-convex lens, the plane side being turned towards the preparation. This lens is always mounted on a single foot in large instruments, and it is important to place it so that its focus falls almost on the object.

For the same purpose the Lieberkuhn mirror can also be used to advantage.

Certain objects, however, have to be examined by polarised light. For this purpose, the lower prism must be placed underneath the object, and the cone, at the lower extremity of the tube of the instrument, must be replaced by a piece containing the analyser to which the objectives are then screwed. After having placed a condensing lens above the prism, the polariser can be adjusted until the outline of the objects under observation are clearly focussed.

In certain pieces of polarising apparatus the polariser is mounted above the ocular. These are generally accompanied by a graduated circle and are used for the purpose of measuring angles. They are employed especially in microscopes intended for mineralogy.

Monochromatic Light.—For some time microscopists, especially those who are engaged in studying diatoms, have used a special kind of illumination, for the examination of striæ which it is difficult to see. They employ monochromatic light, that is to say, they only make use of one of the rays of the spectrum. The blue ray is preferred as by it the best effect can be obtained. Monochromatic light can be produced in several ways: either by decomposing white light by a prism, or sifting the light through a bath containing a solution of ammoniacal sulphate of copper. A stage is fixed in the window on which is mounted a solar microscope, of which the objectives and focus are removed; a ray of light is introduced into the room, which, by means of the mirror of the solar microscope, is made to strike the mirror of the working microscope. The bath is placed quite close to the solar microscope, and the solution employed should be of a sufficiently deep blue colour. This method of operation was employed for a long time, but since possessing the excellent condenser of Professor Abbe, we have not required so complicated an arrangement. We have been content with making the diaphragm as eccentric as possible, and with receiving the solar rays on the plane mirror, after having passed them through three, four, or five plates of deep blue glass, placed a few centimetres in front of the microscope. The number of blue glasses should be proportional to the intensity of the solar light, and any superfluous light is avoided by a cardboard screen.

By working in this way, and by using objectives as perfect as those that we now possess, the resolution of the most difficult tests, such as *Amphipleura*, even in balsam, and that of the last groups of Nobert's tests, can be easily obtained in oblique illumination.

3.—Magnification.

It is a general error with persons who are unacquainted with microscopical observations, that much more can be seen when considerable magnification is employed. This is an entirely erroneous idea; the greater number of observations, especially those of vegetable anatomy, being made with magnifications of from 50 to 200 diameters. In studying diatoms we usually employ a magnification of from 400 to 1,000 times, given by a dry apochromatic objective of ·95 N.A. for ordinary work, and one with an aperture of 1·4 for profound study. The compensating oculars 4, 8 and 12 are those we usually employ. The highest powers are rarely employed, and then to investigate only the smallest forms or to elucidate details. Whatever observation be made, the general appearance of the object should always be first studied under a low power. Stronger powers may gradually be employed, but then only when the necessity for it has shown itself.

4.—Hygienic Rules for Microscopical Research.

It is often said that microscopical research is injurious to the eyesight. There is absolutely no foundation for such a statement. Without referring to Leuwenhoeck, who made observations even at the age of 90, and our friend the late M. Adan, who did much work at 85 by means of simple microscopes, which were both rude and fatiguing, we may cite Schacht and Harting, who have both assured us that their sight has not suffered by the continuous observations to which they devoted themselves. We have personally used the microscope daily from childhood; we have often extended far into the night observations which we commenced in the morning, and that sometimes for many days; on one occasion we even continued for nearly two months without interruption. We have spent, and still often spend, several hours in examining delicate details in bright solar light, subdued by the ammoniac copper bath or blue glass. With the exception perhaps of very slight shortsightedness our researches have in no way injured our sight. Moreover with proper precaution microscopical researches can never cause injury; on the other hand, they may cause real danger if recklessly conducted. Mandl cites the case of a microscopist who almost lost his sight through having made all his observations in a dark room in which light was only admitted through a small opening opposite the mirror. One of the most illustrious algologists of our time, the late A. de Brébisson, also wrote us that having spent the winter in making prolonged and fatiguing observations with very brilliant artificial light for the purpose of counting the striæ of diatoms, a violent congestion ensued, which forced him to suspend all work for nearly a whole year. But no such trouble need be feared by anyone who will take heed of the following advice:

1. Do not make observations directly after a meal.

2. Let the field of the microscope be comfortably illuminated. Always avoid brilliant illumination, and on no account use solar light for ordinary observations.

It is only during experiments with polarized light, photo-micrography and with monochromatic light, that solar light can really be employed to advantage.

3. As soon as your eyes feel at all fatigued suspend your observations at once. This is of the greatest importance.

4. An excellent hygienic rule, which has greatly assisted us during the last six years, is to wash the eyes thoroughly every morning with warm water. We use a litre ($1\frac{3}{4}$ pints) of water for this daily ablution. The warm water thus employed produces at first a very slight congestion, followed immediately by an excellent reaction. We cannot too strongly recommend this washing which rests the eyes. Cold water on the other hand gives a momentary calm, followed afterwards by a congestion of the visual organ.

The eyes, like other organs, must naturally be used with discretion. However, it is unnecessary to lay further stress on the advice given. The man of science and the simple amateur will appreciate its importance at once.

There is still one question that remains to be answered: How must the microscope be arranged to prevent fatigue?

If the reader simply wishes to study preparations in which the object is already covered with a cover-glass, there is no better position for the microscope than an inclined one. It prevents the passive congestion of the head, which is produced by the compression of the blood vessels of the neck, and it prevents flying flies (*muscæ volitantes*) from annoying the observer by continually appearing in the axis of vision.

But if objects mounted in liquid have to be studied, or if dissections have to be made, or re-agents have to be used, then the inclined position is no longer convenient. The microscope should evidently rest in a vertical position. However, these inconveniencies can be remedied either by fixing a rectangular prism at right angles to the microscope, as we have done for more than 20 years, when using one of the large English instruments, or by placing on the ocular an isosceles prism as our late friend Harting did, who was much annoyed by flying flies.

Professor Abbe declares in one of his works that a well-constructed prism does not affect the image. We agree entirely with this opinion. Our rectangular prism, which has the advantage of ensuring free play to the chest, does not in any way affect the appearance of the most delicate microscopical details, as for example the beads of the *Amphipleura*.

5.—Example of a Microscopical Observation.

We feel confident that we have now explained the management of the microscope in sufficient detail; however, being anxious to facilitate the observations of persons who are not yet accustomed to the use of this instrument, and who are eager to profit by it in every possible way, we believe it will be useful to give an example of the application of the rules mentioned above.

Let us suppose then a beginner wishes to observe all the striæ on a *Surirella gemma*, which is one of the most difficult tests. If by following our advice he succeeds in accomplishing this, he may be quite sure that the microscope has no secrets which he cannot discover.

Let us take a good ordinary microscope, without a condenser, but provided with a jointed mirror, and place it a few feet from the window, on a very solid table, the height of which should be such that when sitting the observer can conveniently look down the tube of the microscope in a vertical position. We shall proceed in this case with every precaution, but later on with practice, the student will accomplish this with less labour.

With this purpose in view let us first try an objective of about half-an-inch; when it has been screwed to the tube which is furnished with an ocular of medium power, a medium sized diaphragm is inserted.

Attention must now be paid to the illumination. The reflecting mirror placed in the axis of the tube is inclined, so as to reflect the light through the opening of the diaphragm. We must now experiment until we get a soft white light; as long as it is not so, you may be sure that the inclination of the reflector is defective.

You next place the preparation on the stage having a glass over the object, then you rack down the tube just opposite the preparation, and carefully avoid touching it for fear of injuring it; then holding it in position with the fingers or clips, you gently raise the tube of the microscope until you see the *Surirella* more or less in focus, you then move the fine adjustment right and left until one of the diatoms in the centre of the field appears quite clear in the form of an eliptical body, divided by a median line, having twelve or sixteen transverse lines on each side.

But this is but the beginning of what we are to see; secure the preparation well by means of the clips, so that it cannot get deranged, and take a higher power objective, one-sixth inch for instance, ; you then raise the tube to such a height that the first objective can be taken off and the one-sixth inch substituted for it ; this done, you substitute for the medium diaphragm that which has the smallest opening, and then you lower the tube until it is near the preparation, and raise it again directly until the object appears confused; then by turning the fine adjustment milled head to the right or left, you ought to see with the greatest clearness what you saw before, very clear indeed, considerably enlarged, but without any further detail.

Axial light having thus proved insufficient, let us see what can be done with oblique light.

First remove both the diaphragm and the sub-stage which holds it, so as completely to disengage the real stage of the microscope underneath; then incline the shank of the reflector to the right or left, so as to turn it aside from the axis of the microscope, at the same time keeping sufficient light to illuminate the object; try every possible inclination of the mirror until at last you notice between the transverse lines spoken of above, and parallel to them, other small lines, which will appear very fine, and extremely close together. An experienced eye can, after a very short time, decipher these fine longitudinal lines even with a one-sixth inch; but to see them clearly and conveniently, an immersion objective must be used.

Let us take, then, a water immersion objective. Do not displace either the preparation or the mirror; just raise the tube, and take off the one-sixth; then having substituted the new objective, take a small drop of clean distilled water, and by means of a glass rod, place it on the lower or frontal lens, without touching the latter for fear of scratching it; then screw the objective to the tube; place another drop of water on the preparation, and lower the tube until the two drops intermix: by proceeding in this way all air bubbles are avoided, which may seriously hinder observation. Now substitute a low ocular for the one you have used hitherto.

The tube must in this case be moved with the greatest care; the danger is still greater, because the water makes it difficult to distinguish the space between the objective and the preparation; the best way to avoid breaking anything is to proceed cautiously, by moving the preparation gently with one hand, while with the other the fine adjustment screw is turned from left to right or from right to left with extreme delicacy until the *Surirella* is seen clearly; if you lower the tube too much, the resistance of the preparation, which is immoveable, tells you that you are moving the adjustment screw in the wrong direction, and that you should raise the tube again by turning the fine adjustment screw from right to left. Then you displace the mirror underneath from the axis of the tube until you clearly see the longitudinal undulating lines of the object of your researches.

However, it may happen that you are not yet quite satisfied. In such a case your only resource now is in the correction collar; to use this you take hold of the moveable milled collar on the mounting of the objective, which is capable of correcting the effect of the glass slip or cover glass; you move this from right to left or from left to right until you can see the lines or striæ with the greatest clearness. It is generally necessary, when oblique light is used to bring the lenses of the objective closer to one another, which can be effected by turning (in French objectives) the correction collar from right to left; if, on the other hand, direct light is used, we must turn the collar in the opposite direction, viz., from left to right.

It is important to remark that to avoid pressing on the preparation and breaking it, and to keep the object in focus, it is necessary to move the fine adjustment either from left to right or from right to left, while the correction collar is being moved in one direction.

Such are the operations that a beginner should practise when in possession of a microscope, which is sufficiently good to render all ordinary research possible.

If instead of this apparatus he has a first-class microscope furnished with an Abbe condenser and a homogeneous objective of large numerical aperture, *e.g.*, an apochromatic objective of N.A. 1·4, the operation is much simplified. The ultimate observation should show not undulating lines, but clear isolated points (usually called "beads"); this can be easily effected with the condenser if used in accordance with the rules given on page 86 of this work.

When the work is finished, you have only to raise the tube, to wipe the preparation, and in particular to dry the lens with the greatest care with a well used cambric handkerchief, or with a piece of very clean chamois leather. These details will appear very unnecessary to experts; but it is not for them that they have been inserted; they know quite enough about it, and perhaps more than we do. It has been our sole purpose to acquaint those who are inexperienced in managing a microscope, with some of its most intimate secrets. After a few days' experience, if our advice be thoroughly followed, beginners will be considered to be quite expert, and then they will feel indebted to us, we dare to believe, for the information which we have felt a duty and pleasure in giving them.

Choice of a Microscope.

In choosing a microscope several points have to be considered, the nature of the researches for which the instrument is intended, and the price one is willing to give for it, being the most important.

It is of little use for a beginner to obtain a large and complete microscope at once, but it is still worse to buy a small instrument of inferior quality to commence with. In a very short time it would have to be replaced by another, and then the money spent upon the first would be regretted as an entire loss.

The most reasonable course is to buy in the first instance a stand which will meet every requirement that can be anticipated. If to such a stand two objectives be added, for instance an $\frac{1}{2}$ inch and $\frac{1}{6}$ inch, the student can commence practice with these, and he may add to his apparatus at a subsequent date.

We warn everyone against making this purchase carelessly or at first sight. Only instruments marked with the name of well-known makers should be accepted, and if the manufacturer himself be not directly communicated with, at least no microscope should be purchased of any agents but well-known firms in whom every confidence can be placed.

Germany, England, Austria, the United States, France, and Italy possess eminent makers; we shall just review the principal firms in these different countries by describing the models which appear to us to be most appropriate for serious research. For a definite choice, the purchaser must consult his own tastes, preferences, and especially the resources of his purse.

BAUSCH & LOMB OPTICAL COMPANY (North St., Paul Street, Rochester, N.Y., and 50, Maiden Lane, New York).—Messrs. Bausch and Lomb are old-established makers, and their justly celebrated instruments hold the first position in the United States. The instruments of these makers are of perfect workmanship and rare elegance. By a happy mixture of colours, due to the judicious use of coloured varnishes, bronze, brass, silver, nickel, &c., their appearance is very charming. No other microscopes that we know are so attractive to the eye, or produce so pleasing an effect.

Messrs. Bausch and Lomb make two kinds of microscopes: a special kind, which they call the American, and the Continental.

Figure 119*a* is a representative of the "Universal Microscope," which is the original model of the American kind.

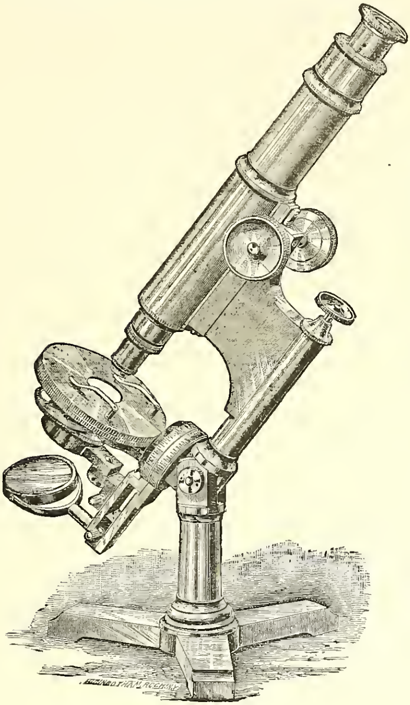


Fig. 119*a*.

The instrument rests on a foot having three legs, terminating in india-rubber pads. The body, properly so called, is carried on a pillar, and the joint allows every inclination that may be desired.

Both the bar of the mirror and that carrying the sub-stage can rotate about the optical axis of the instrument. The upper part of each bar terminates in a circular fitting, which is silver-plated and is divided into degrees.

The mounting of the mirror slides in a hollow groove in the bar, and can consequently be raised or lowered, while the rotation of the bar gives it every possible inclination.

The sub-stage, carried on an inner bar, is raised or lowered by a rack and pinion; it holds, when desired, an Abbe condenser, furnished with an Iris diaphragm, and can be turned on its axis so as to assume different oblique positions.

The stage has a mirror, rotating about its axis, which works very smoothly, and is furnished with two clips. When desired, the latter can be removed, and a glass stage and slide carrier placed upon the stage proper.

The tube is moved by a rack and pinion, which works very smoothly and with great precision. It has a double draw tube; its length, when closed, is 17 centimetres (6½ in.), and when fully drawn out, 30 centimetres (11¾ in.). The draw tubes, which are nickeled, slide in a cloth sheath, and consequently their movements are very smooth. The innermost tube is divided into millimetres. At the lower end of the tube is the American screw thread, but a nose-piece, which can be screwed into it, allows the objective with the English screw to be adapted.

The slow movement adopted by these makers is quite special, and has been patented under the title of "*frictionless fine adjustment.*"

The essential parts consist of two strong steel springs placed parallel to one another, and fixed at each end. A milled head acts on the end of a lever, which in its turn raises a piece of apparatus, which carries the coarse adjustment.

The lever is free at its two ends, and turns on a pivot freely round an axis.

The slow movement thus obtained works very smoothly and with great precision; it has however the inconvenience of constraining the tube to move in a small circular arc, which is also noticeable in microscopes furnished with the parallelogram slow movement as made by Messrs. Seibert, Reichert, Leitz, &c. Nevertheless, this is only apparent when the milled head of the micrometer screw is moved several times round.

When desired, the makers furnish their instruments with the differential screw, at a fixed price.

The instrument above described is, as we have said, the model type, but there are various modifications of it.

In its simplest form it is called the *Investigator Microscope.* It has then only one moveable bar, which carries both the sub-stage, formed of a simple tube, and the mirror. The price of this stand is \$45 (£9). The Universal Microscope, previously described, without Abbe condenser and glass stage, costs \$55 (£11).

When the Universal Microscope is in all respects as described above, the the makers call it the *Bacteriological Microscope*, and it is sold for \$75 (£15).

When of a very large size, and mounted between two pillars, with a perfect sub-stage, the instrument is called the *Professional Microscope*, and costs \$135 (£27).

Lastly, the instrument appears in the form of Wenham's Radial, which will be described hereafter. It then costs \$95 (£19), and is sold as the *American Concentric Microscope* (fig. 119*b*).

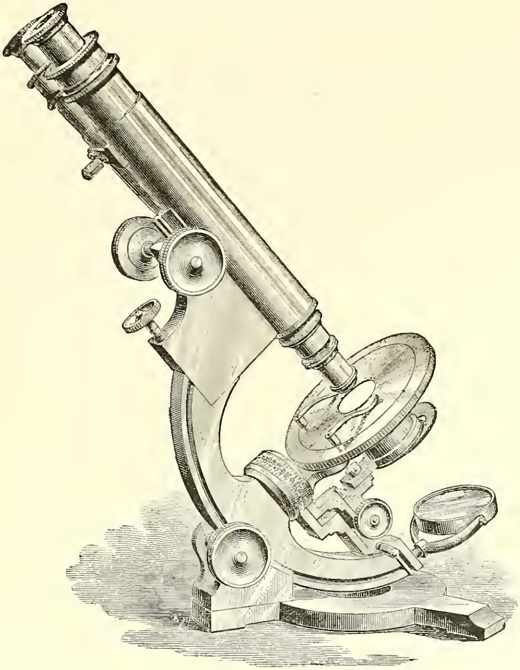


Fig. 119*b*.

It will be noticed that all these forms are in reality the same instrument, and only differ in special adaptations to various branches of study.

Messrs. Bausch and Lomb's *Continental Type* are very similar to the continental instruments of Messrs. Zeiss, Reichert, Leitz, &c.

In the *Large Continental Microscope* (fig. 119*c*) the makers have taken as their model the most perfect instruments of well-known manufacturers which we shall describe in their turn. The only difference that we notice at first sight is that here the mirror is moveable round the axis.

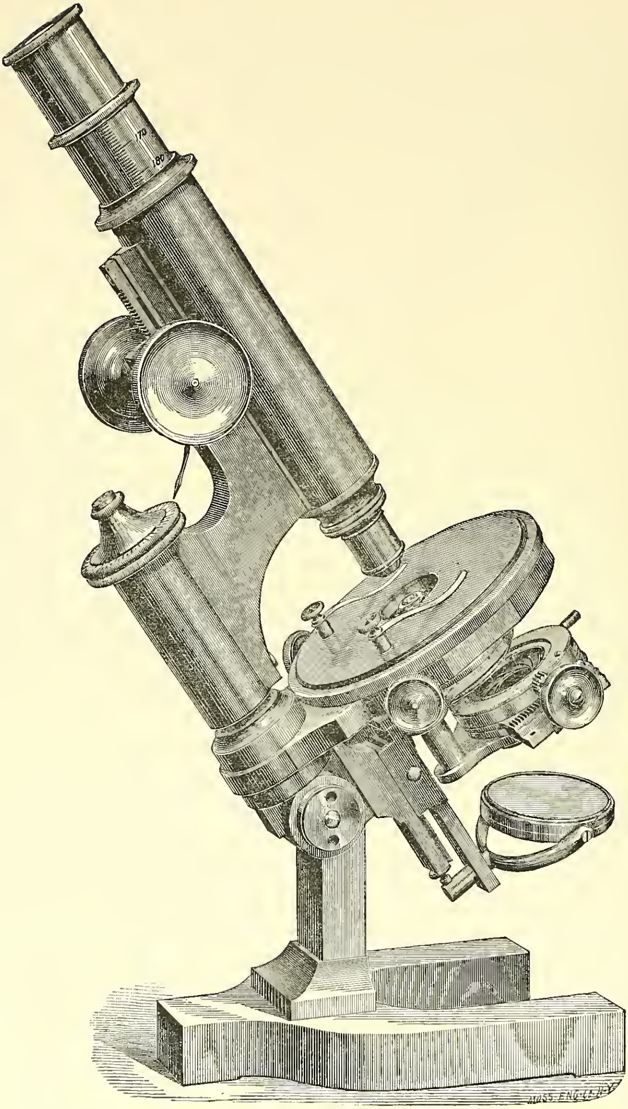


Fig. 119c.

In consequence of the provisions of the McKinley tariff, Continental instruments will find great difficulty in reaching the American

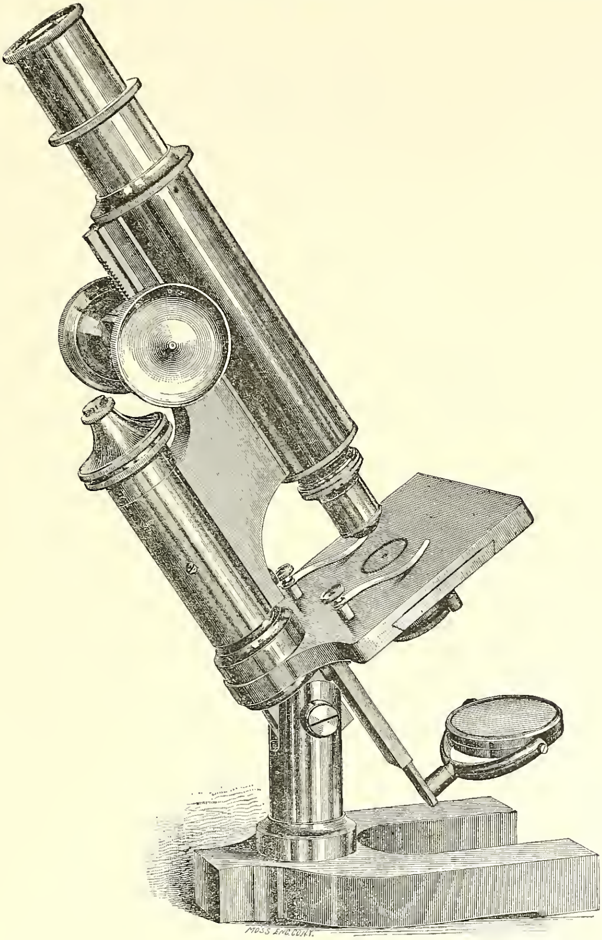


Fig. 119*d*.

markets; it is therefore probable that Messrs. Bausch and Lomb have endeavoured to furnish the microscopists of their own country with a type of instrument which appears to them to be popular. As the price of Messrs. Bausch and Lomb's apparatus is only $90 (£18), it is probable that this model is destined to have a great sale in the United States.

The *Medium Continental Microscope* (fig. 119*d*) is a very inferior model and costs $25 (£5). It is similar to those which can be obtained on the Continent at the same price.

Objectives.

Messrs. Bausch and Lomb's objectives are very numerous. Besides their special ones (the 2-3rds, 1-6th, and 1-12th homogeneous) for the Continental tube, they also make three different series for the English length, which they call the student's series, professional series, and first-class series.

The specimens which we have examined belong to the professional series, and are as follows:—2 in., ¾ in., and the 1-12 in.

These three objectives may be counted among the best that we have hitherto examined. The images are very clear, and chromatic correction is so well effected that practically no trace of colour can be found. In this respect the objectives considerably surpass those of the most celebrated Continental firms.

2 inch (N. A. = ·15) and ¾ inch (N. A. = ·35), are two objectives intended for preliminary work, and give excellent images.

1-12th inch (N.A. = 1·18) is mounted with correction collar and has a considerable frontal distance. With central illumination, the *Pleurosigma* and the *Bacillus tuberculosis* give very fine and pure images; with oblique light the *Amphipleura* is resolved with the greatest clearness. The objective suffices for every-day research, even the most delicate.

The following abridged table gives the principal objectives of these makers:—

Students' Series.

						£	s.	d.
4	inches	angle of aperture	6°	Price	$6	1	4	0
2	,,	,,	12°	,,	$6	1	4	0
1	inch	,,	20°	,,	$6	1	4	0
¾	,,	,,	27°	,,	$8	1	12	0
½	,,	,,	42°	,,	$9	1	16	0
¼	,,	,,	75°	,,	$14	2	16	0
1/5	,,	,,	75°	,,	$15	3	0	0
1/8	,,	,,	115°	,,	$18	3	12	0
1/12	,,	,,	130°	,,	$24	4	16	0

Professional Series.

							£	s.	d.	
4	inches	angle of aperture		10°	Price	$13	2	12	0	
2	,,	,,		15°	,,	$13	2	12	0	
1½	,,	,,		24°	,,	$15	3	0	0	
1	inch	,,		36°	,,	$15	3	0	0	
¾	,,	,,		40°	,,	$15	3	0	0	
½	,,	,,		65°	,,	$18	3	12	0	
1/5	,,	,,		130°	,,	$28	5	12	0	correction
1/8	,,	,,		135°	,,	$30	6	0	0	,,
1/10	,,	water immersion		170°	,,	$28	5	12	0	,,
1/16	,,	,,		175°	,,	$35	7	0	0	,,
1/10	,,	homogeneous immersion	N. A.	1·18	,,	$50	10	0	0	,,
1/12	,,	,,	,,	,,	,,	$55	11	0	0	,,
1/16	,,	,,	,,	,,	,,	$65	13	0	0	,,

First-class Series.

4	inches	angle of aperture	12°	Price	$18	3	12	0	
2	,,	,,	22°	,,	$18	3	12	0	
1	inch	,,	45°	,,	$25	5	0	0	
½	,,	,,	98°	,,	$30	6	0	0	correction
1/6	,,	,,	140°	,,	$40	8	0	0	,,
1/8	,,	homogeneous		,,	$75	15	0	0	,,
1/10	,,	,,		,,	$80	16	0	0	,,
1/12	,,	,,		,,	$90	18	0	0	,,
1/16	,,	,,		,,	$125	25	0	0	,,
1/25	,,	,,		,,	$200	40	0	0	,,

An apochromatic series is in course of construction, but we have not as yet received any information concerning them.

They also manufacture a very rational series of oculars; it consists of 2 inch, 1¾ inch, 1½ inch, 1 inch and ½ inch. Each costs $4 (16s.). The makers also manufacture continental, periscopic and holosteric oculars.

MESSRS. R. & J. BECK (of 68, Cornhill, London, E.C.), is one of the best firms in England, and their instruments are highly valued.

Their large model, No. 1 (fig. 120), called *The International*, can be inclined and is binocular.

The rapid movement is given by a rack and pinion by means of the milled head K, and the slow movement is produced by the interposition of a lever on which the milled head L acts.

The body of the microscope is supported on two pillars fixed to a horizontal circular graduated plate B, which can be turned on a fitting, having three projecting feet in the form of a tripod A, to give stability to the instrument.

The stage is of an entirely special construction. Attached to the end of a disc R, and capable of moving on a pivot round a central point, it can be turned so as to assume different inclinations; it can even be turned completely round so that an object

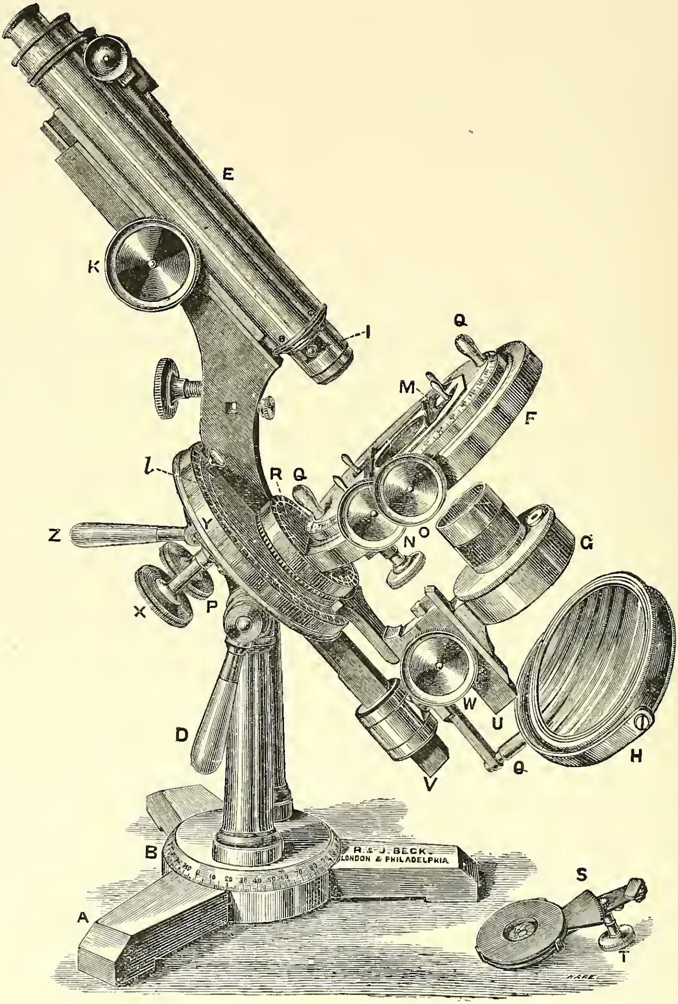

E
K
I
Q
M
F
l
R
Q
Z
Y
N
O
G
X
P
W
U
D
H
V
Q
B
R. & J. BECK.
LONDON & PHILADELPHIA
A
S
T

Fig. 120.

can be examined with any obliquity of light without fear of its thickness proving a hindrance. The mechanical stage can be given vertical and horizontal movements by means of the milled heads N and O; the side of the stage is divided into 360 degrees to serve as a goniometer.

An Iris diaphragm, which can be taken off the stage while it is being rotated, has its opening regulated by a rack and pinion and milled head T.

The sub-stage G, to which can be adapted all the apparatus for illumination usually employed, can be turned about the optic axis when oblique light is employed by means of the piece *l*, which is rotated by means of the milled head X and works in a large graduated ring Y.

Upon this ring, whose movements in the optic axis are regulated by the lever Z, the greater part of the angular movements of the microscope will be found to depend.

A triangular bar V carries concave and flat mirrors, which can be moved in all directions and are independent of the movements of other illuminating apparatus.

The price of this beautiful binocular stand, together with two pairs of oculars, forceps, &c., is £50. In the monocular form it only costs £43.

The second grand model of these makers (fig. 121) is in the same way supported on two pillars, and provided also with a revolving plate.

Its stage can be rotated about its axis by means of a rack and pinion, and is graduated for the measurement of angles; it carries a mechanical stage, moving very precisely. The stage can be rotated the entire revolution, the limb being designed to clear the milled heads.

The sub-stage can be removed when desired, and can be racked up and down by turning the milled head. The condensers and other illuminating apparatus, when axial, are centred by means of two screws acting on a spring. The mirror, which is concave one side and flat on the other, is jointed and mounted on a circular fitting, which slides on a triangular bar. The coarse adjustment is made by a rack and pinion, and the fine adjustment by a lever.

The whole microscope can move between the two pillars, and can be set at any inclination. This stand, together with two pairs of oculars and several accessories, costs £35 when it is binocular, and £28 when only mounted with the monocular tube.

The instrument No. 3 (fig. 122) only differs from the preceeding one in its smaller dimensions and its support, which consists of a

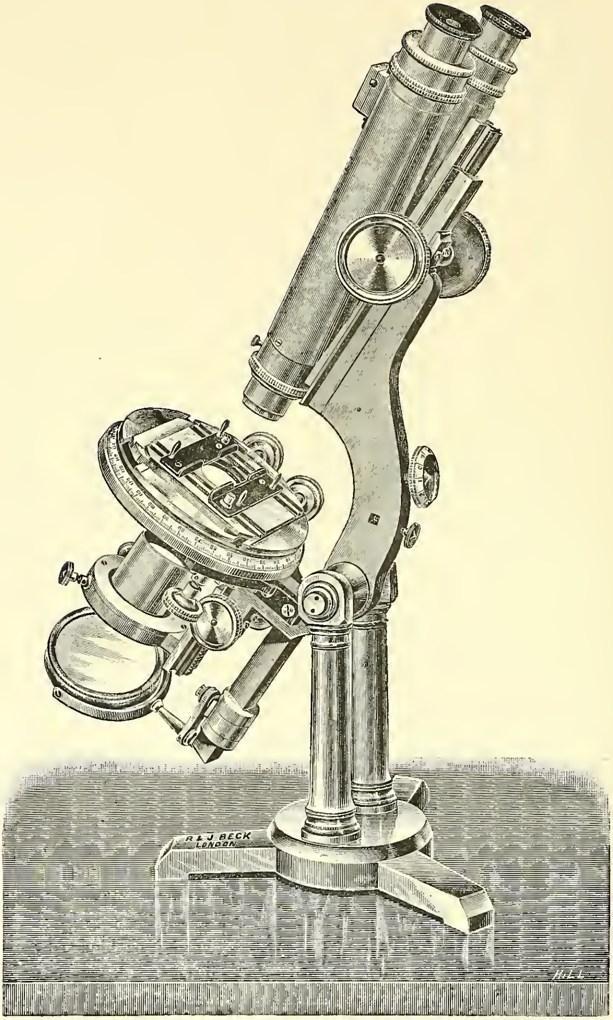


Fig. 121.

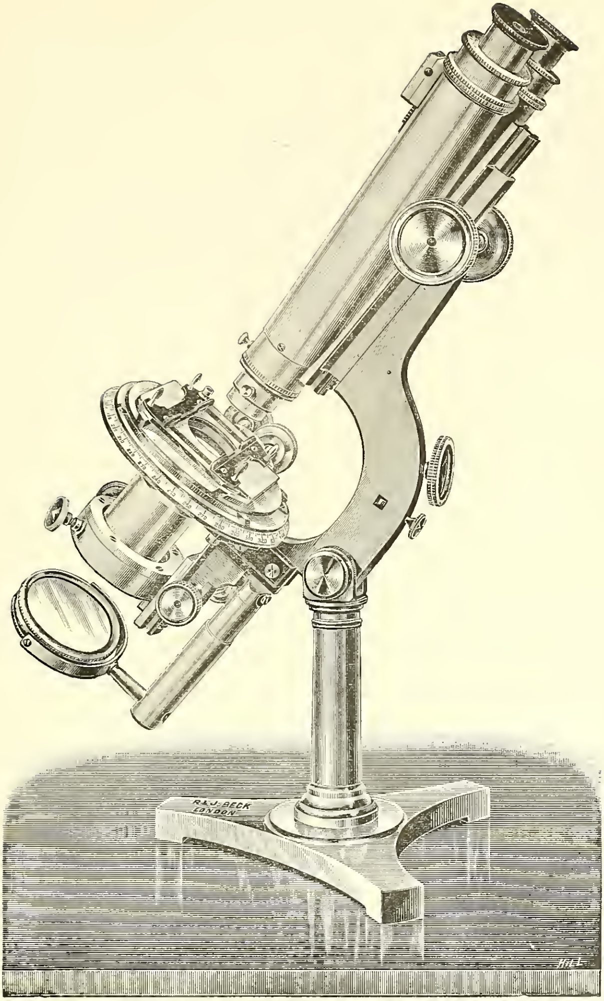


Fig. 122.

single pillar, on which the microscope can be set at any inclination that may be desired.

All the other parts of the instruments are almost identical to those of the model just described, except that the mirror is fixed to a tube sliding over a cylinder, and can thus be used for oblique light.

The binocular instrument is sold for £30 and the monocular for £25.

The same opticians make a large number of other microscopes, amongst which we shall specify the model called the *Binocular National Microscope* (fig. 123), and which is remarkable for its moderate price.

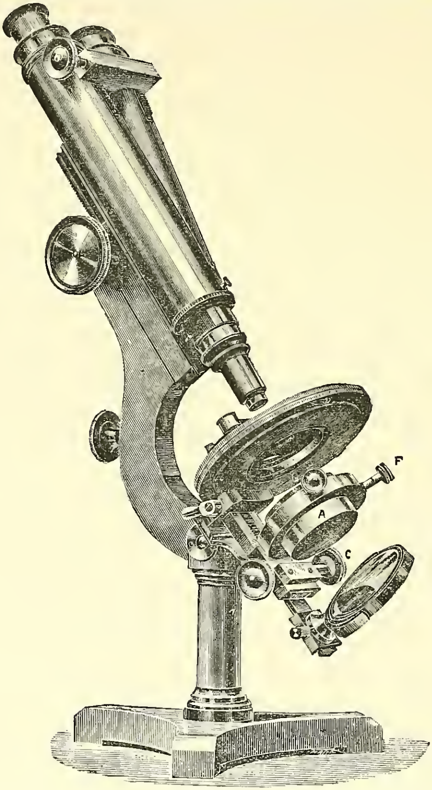


Fig. 123.

The entire instrument is moveable on its axis, and can assume any inclination.

The stage rotates and has a mechanical stage; the sub-stage can be centred by means of two lateral milled heads, and its height regulated by a rack and pinion. The mirror is jointed. The binocular tubes have an optional regulator for the distance between the eyes, and the adjustments, coarse and fine, are carried out in the same manner as in the large models of these makers.

With five objectives, a triple nose-piece, plane and concave mirror, three pairs of oculars, achromatic condenser, Wenham's parabolic reflector, polarizing apparatus, Wollaston's camera lucida, micrometer, bull's eye on stand for illuminating opaque objects, glass slips, cover glasses, forceps, &c., the instrument packed in a mahogany case, is delivered for £38 13s., but monocular it is £35 2s. 6d.

We give in the table below the price of the different objectives made by this firm :—

Focus.		Angle of Aperture.	Price.			
				£	s.	d.
4	inches.	9°	.. ..	1	10	0
3	„	7°	.. ..	1	10	0
3	„	12°	.. ..	2	10	0
2	„	10°	.. ..	1	10	0
2	„	17°	.. ..	2	10	0
1 1/2	inch.	23°	.. ..	2	10	0
2/3	„	25°	.. ..	2	0	0
2/3	„	32°	.. ..	2	10	0
1/2	„	45°	.. ..	2	10	0
4/10	„	65°	with correction collar	4	0	0
4/10	„	95°	„	5	0	0
1/4	„	75°	„	3	10	0
1/5	„	120°	„	4	10	0
1/8	„	130°	„	5	0	0
1/10	„	180°	water immersion with correction collars	5	5	0
1/15	„	180°	„	8	0	0
1/20	„	180°	„	10	0	0
1/40	„	160°	with correction collar	20	0	0
Homogeneous Immersion Objectives.						
		Numerical Aperture.				
1/12	„	1.25	.. ..	5	10	0
1/16	„	1.25	.. ..	9	0	0
1/20	„	1.25	.. ..	12	0	0

We have had occasion to examine a series of objectives by these makers quite recently (April, 1891). The following is the result of our observations :—

4-10th inch of 65°, good objective, resolved the *Pleurosigma* feebly in oblique light; the pygidium was quite passable in axial illumination.

4-10th of 95°. This objective enjoys a great reputation, which is thoroughly justified. It is in fact one of the best, if not the best, of the objectives giving this magnification that we have ever seen.

The frontal distance is considerable, but nevertheless, the pygidium presents a very beautiful image with axial illumination, and the *Pleurosigma* and the 6th group of Nobert is resolved by it very fairly.

With oblique illumination the *Pleurosigma* and the 10th group of Nobert are perfectly resolved. Considering its great frontal distance, this is, on the whole, one of the best objectives that can be desired both for histological work and the brief study of diatoms.

1-4th inch. A good objective for histological studies, inferior to the previous one for diatoms. The frontal distance is very considerable.

With axial illumination it gives a very good image of pygidium and of Podura, and it will resolve the 7th group of Nobert.

With oblique illumination the *Pleurosigma* is seen well, as also the 10th group of Nobert.

1-12th inch homogeneous immersion.—It resolves the 9th group of Nobert with axial, and the 13th with oblique illumination. The *Amphipleura*, in the yellow medium, is passably resolved. The frontal distance is very small.

L. BÉNÈCHE (of 55, Grossbeerenstrasse, Berlin).—L. Bénèche is one of the oldest and most zealous makers in Germany, and many distinguished savants have justly complimented him on his work. Messrs. Dippell and Harting speak very favourably of this maker. Schacht values the Bénèche objectives highly, and we remember seeing in about 1862, during a visit at Bonn to our late learned friend, some microscopes made by Bénèche which left nothing to be desired at that time.

This manufacturer makes at the present time several models of microscopes, the principal of which we propose to describe.

The Grand Model (A). This microscope can be inclined, mounted on a horse-shoe foot, and furnished with a rotating stage; the coarse adjustment is made by means of a rack and pinion, and the fine adjustment by means of a micrometer screw with a graduated head. This microscope is furnished with a jointed mirror and an Abbe illuminating apparatus having a numerical aperture of 1·4 and an iris diaphragm.

The alteration of the condenser to enable the use of tube diaphragms is effected by a sliding groove. It is furnished with a nosepiece for four objectives, a micrometer eye piece, a drawing apparatus after Oberhäuser, Nos. 2, 4, 5, 7 ordinary objectives, 1-12th homo-

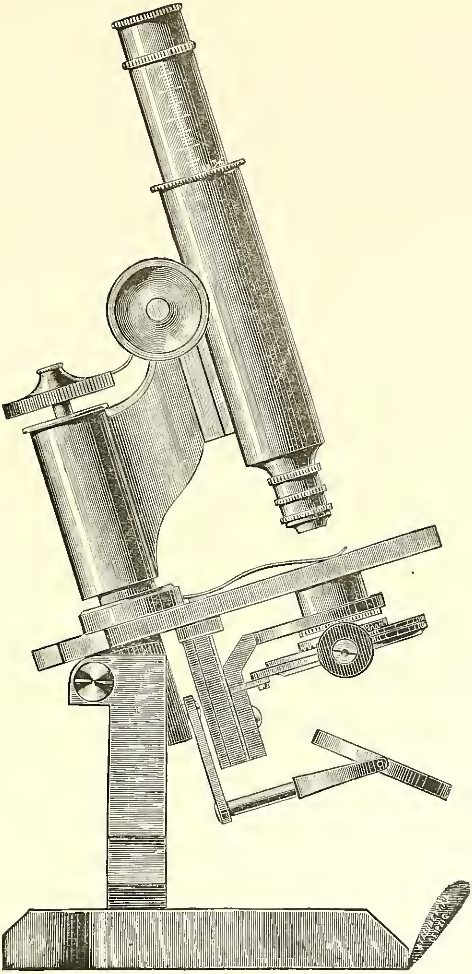


Fig. 124.

geneous immersion objective, A, B and C compensating oculars, giving magnifications from 30 to 1,500 diameters. The price of the whole is £34 6s. 8d..

The Model (A) has a rack and pinion and a micrometer screw for focussing; the mirror is jointed. It is also furnished with an Abbe condenser, but one of only 1·20 N.A. The instrument is sold with a nose-piece for three objectives, oculars 2, 3, and 4, ordinary objectives 2, 4, and 7, and an homogeneous objective. It magnifies from 30 to 1,100 diameters. It costs £16 14s. 6d. (fig. 124).

A third model, lettered B (fig. 125) has a rotating stage, and can be inclined at any angle. It has a horse-shoe foot; the mirror is jointed; the diaphragm tube can be raised without moving the cover glass. The coarse adjustment is made by sliding this tube, and the fine adjustment by a micrometer screw. Furnished with five oculars, a moveable micrometer eye-piece, Oberhaüser's camera lucida, as well as 2, 4, 5, and 7 ordinary objectives, and a water immersion No. 10, the price is £22.

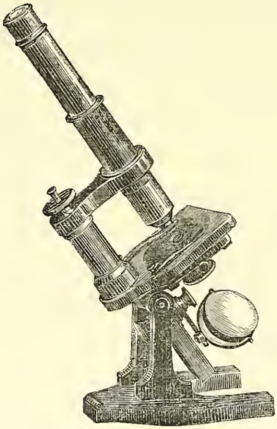


Fig. 125.

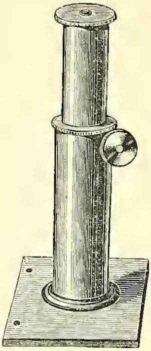


Fig. 126.

L. Bénèche also makes a microscope for demonstrations, which is represented in figure 126, and is intended to be handed from one to another in a class. It is furnished with a rack and pinion, and gives a magnification of 125 diameters. Its price is £1 15s.

We have seen four recent objectives of this maker (September, 1891). The following are the results which they gave :

No. 4 (¼ inch N.A. ·40). Very good objective for histological study, bearing well the use of strong oculars.

No. 7 (1-6th inch N.A. ·75). In axial illumination the image of the pygidium is pure and clear ; that of the Podura is good, and the objective also shows Nobert's 6th group. In oblique illumination the *Pleurosigma Angulatum* is seen in hexagons perfectly and Nobert's 8th group.

No. 9 (1-12th inch N.A. ·75). In axial illumination, the image of the Podura is excellent ; in oblique illumination Nobert's 10th group is clearly resolved.

No. 10 (1·15th N.A. 1·20). Water immersion. Axial illumination : the image of the Podura is very good and very pure ; the *Pleurosigma* is seen in hexagons very clearly, and broken edges are perfectly clear and with detail ; the *Bacillus Tuberculosis* is very clear. In oblique illumination the *Amphipleura* in the yellow medium is resolved, but the image leaves much to be desired.

M. L. Bénèche marks his objectives, when sold separately, at the following prices :—

					£	s.	d.
System No.	1	(angle of aperture 20°)	.. ..	Price	0	12	0
,,	2	(,, ,, 25°)	.. ..	,,	0	18	0
,,	3	(,, ,, 30°)	.. ..	,,	1	1	0
,,	4	(,, ,, 34°)	.. ..	,,	1	4	0
,,	5	(,, ,, 50°)	.. ..	,,	1	4	0
,,	6	(,, ,, 60°)	.. ..	,,	1	7	6
,,	7	(,, ,, 95°)	.. ..	,,	1	7	6
,,	8	(,, ,, 100°)	.. ..	,,	1	7	6
,,	9	(,, ,, 120°)	.. ..	,,	2	5	0
,,	10	(,, ,, 130°)	immersion without correction	,,	3	0	0
,,	10	(,, ,, 130°)	immersion with correction	,,	4	10	0
,,	11	(,, ,, 150°)	,,	,,	6	15	0
,,	12	(,, ,, 170°)	,,	,,	5	0	0
,,	1/12	(,, ,, 145°)	homogeneous immersion	,,	5	0	0
,,	1/18	(,, ,, 160°)	,,	,,	10	0	0
,,	1/24	(,, ,, 180°)	,,	,,	15	0	0

BÉZU, HAUSER & CO. (Rue Bonaparte, Paris.)—These makers, who were formerly foremen in the firm of Hartnack and Prazmowski, took over their business at the death of Prazmowski.

They have a considerable number of models.

The original large model, called the Hartnack model, which dates 40 back years, is a well-known instrument, and has been figured by all authors. We give a representation of it in figure 128.

Their new large model, No. VII., differs from the preceding in being constructed more solidly, and furnished with an Abbe condenser.

The latter is mounted on an eccentric piece, by which it can be placed on one side, out of the optic axis.

The instrument is made to incline, and furnished with a rack and pinion for rapid movement, and a very precise adjustment screw. The stage is rotary.

Furnished with Nos. 2, 4, 5 and 7 dry objectives, and No. 9 immersion with correction collar, and with five oculars, the price is £34 15s..

A small and excellent model, No. VIII. A. bis. (fig. 127), having a rack and pinion for rapid movement, and an adjustment screw for slow movement, costs £16 4s.

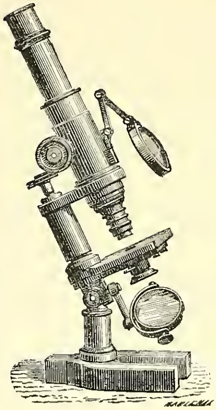


Fig. 127.

At this price is included Nos. 4, 5, 7 and 9, dry objectives, and Nos. 2, 3, 4, and 5 oculars, the first being a micrometer ocular.

We have obtained excellent results on examining the objectives of these makers.

Those given by the principal are as follows:—

No. 6, dry; aperture = ·80. Good objective, well achromatised with pure images.

No. 9, water; aperture = 1·20. This objective, whose actual focus is 1-12th inch, is one of the best water objectives which we have at present examined. It resolves most completely for it has shewn us *Amphipleura* dry perfectly; it has another and extremely rare advantage in that it gives excessively flat images. The *Amphipleura* shows its striæ from one end of the frustule to the other with a clearness which leaves nothing to be desired.

Nos. 10 and 13 have each an aperture of 1·10; their resolving power is, therefore, rather less than the preceding. The field is quite flat; the *Amphipleura* is perfectly resolved, but the image is not quite so fine as with No. 9.

Homogeneous.—We have examined two 1-12th inch; one of an aperture of 1·10 has a very large frontal distance, but has comparatively a small resolving power. The other has a shorter frontal distance, its numerical aperture is 1·25; the images are of great purity and the resolving power of the objective is considerable.

The following are the prices of these objectives:—

Dry Objectives.

No.					£	s.	d.
No. 4	(1/2 inch)	angular aperture	80°	.. .. .. Price	1	4	0
,, 5	(1/4 inch)	,, ,,	120°	.. .. .. ,,	1	8	0
,, 6	(1/5 inch)	,, ,,	120°	.. .. .. ,,	1	12	0
,, 7	(1/6 inch)	,, ,,	140°	.. .. .. ,,	1	12	0
,, 8	(1/9 inch)	,, ,,	150°	.. .. .. ,,	2	0	0
,, 9	(1/11 inch)	,, ,,	160°	.. .. .. ,,	3	0	0

Water Immersion Objectives.

No. 9	(1/12 inch)	aperture	120°	.. .. .. Price	6	0	0
,, 10	(1/16 ,,)	,,	,,	.. .. .. ,,	8	0	0
,, 13	(1/25 ,,)	,,	,,	.. .. .. ,,	14	0	0
,, 15	(1/33 ,,)	,,	,,	.. .. .. ,,	18	0	0
,, 18	(1/50 ,,)	,,	,,	.. .. .. ,,	4	02	0

Homogeneous Immersion Objectives.

No. 9	(1/12 inch)	aperture	120°	.. .. .. Price	6	0	0
,, 11	(1/18 ,,)	,,	,,	.. .. .. ,,	10	0	0

Dr. ARTHUR CHEVALIER (Palais Royal, Paris).—We only mention the firm of Chevalier as being historically noted in optics.

Our excellent friend, Dr. Arthur Chevalier, died shortly after the war of 1870-71, when, after a desperate struggle, he succeeded in resuscitating, financially speaking, the firm which his father, a man of research, and an inventor, but not a man of business, had left in difficulty. The most hopeful future offered itself to him, but, alas, neither he nor his have obtained any profit from it. Madame A. Chevalier and her two daughters followed him to the grave at an interval of a few years.

Only strangers inherited the result of the difficult work of poor Arthur, and the house put up to sale was bought for £6,000 by M. Avisard, who is still its present proprietor.

We have not examined the instruments of this firm since M. Avisard took possession. The stands are still such as we described them in 1878, but we do not know if the objectives have undergone any improvement.

Arthur Chevalier was a high-minded man and well read, not only in microscopy, but also in all natural and medical science. If fortune had smiled on him at an opportune moment, and had he lived for a few years longer, he would probably have effected a substantial progress in microscopy.

HENRY CROUCH (66, Barbican, London) is a well-known maker whom we mentioned favourably in the third edition of this work. His large instruments, which we had occasion to examine carefully fifteen years ago, were well-made and finished.

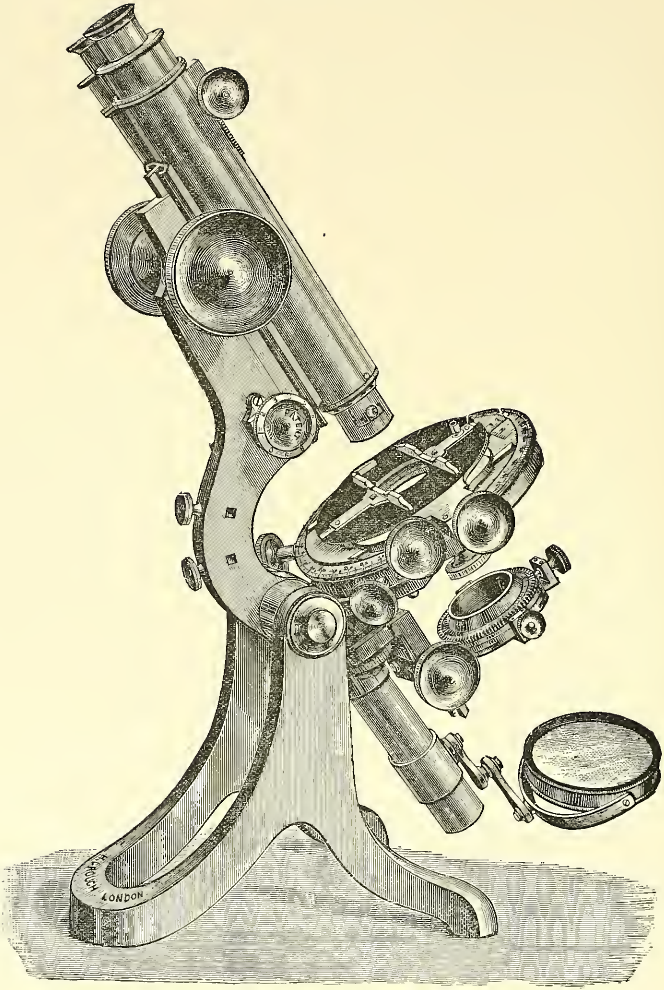


Fig. 127*a*.

The best instrument of this maker is called the *Grand Model* (fig. 127*a*), and is sold either as a binocular or monocular. In the first case the price is £42, and in the second £34.

The rapid movement is produced by a smoothly-working rack and pinion, with inclined teeth; the very sensitive slow movement is of a special patented pattern, with the details of which we are not acquainted.

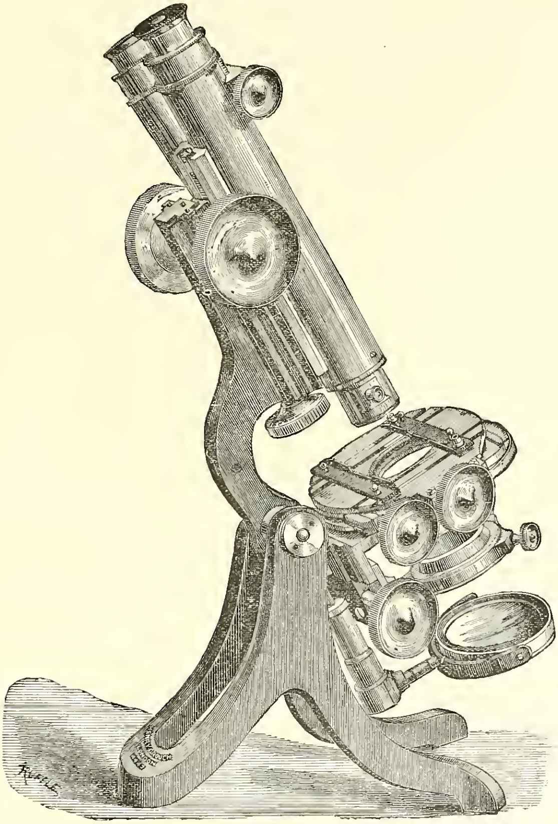


Fig. 127*b*.

The stage has rectangular adjustments, controlled by separate milled heads, and fitted with verniers. It is round and its edges are graduated. By means of lateral milled heads each objective can be centred.

The sub-stage is furnished with screws at right angles for centering, and with a rack and pinion for focussing the condensers.

The mirror, plane on one side and concave on the other, is three inches in diameter, and mounted with a double joint.

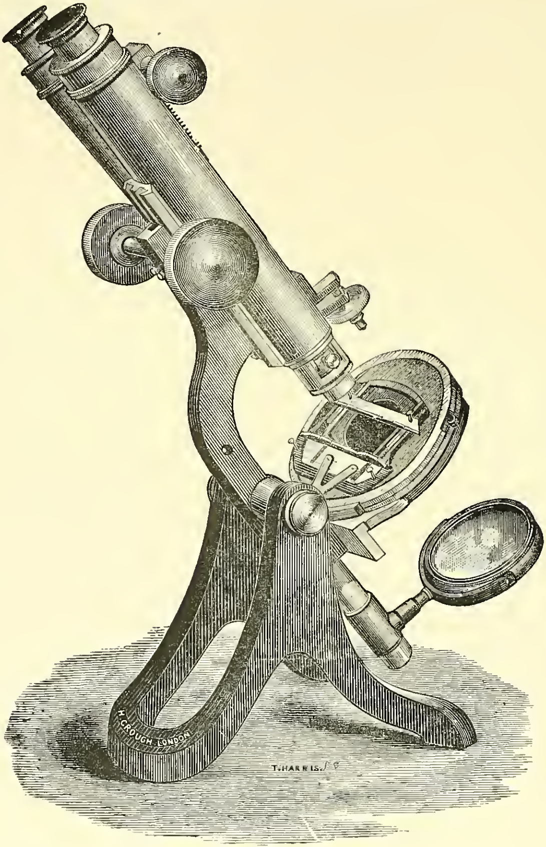


Fig. 127*c*.

Some parts of the instrument are made of brass, and others of polished bronze, thereby producing a very pleasing contrast.

The instrument called the *Premier Microscope* (fig. 127*b*) is of a much simpler character, and rather smaller in size; it only costs £17 17s. when binocular, and at this price are included objectives of 1 inch and $\frac{1}{4}$ inch, a pair of oculars, a stand condenser, and a mahogany case.

The rapid and slow movements are the same as those of the previously described instrument.

The sub-stage is furnished with a screw for centering, an adjustment for raising it, and it can also be turned aside by an eccentric hinge. We do not approve of this form of hingeing, because it does not allow a fixed centering to be maintained.

Mr. Crouch also makes a large number of other microscopes, more or less expensive, and more or less to be recommended, which we are unable to describe here; we must content ourselves with mentioning the student's model (fig. 127*c*).

This microscope, which was highly commended by the late Dr. Carpenter, is binocular; it has a stage, with rotary movement, and is furnished with a glass slide carrier.

The diaphragm has various sized apertures, and the mirror allows oblique illumination. It is accompanied by an objective of 1 inch and another of $\frac{1}{4}$ inch, and the price is only £12 15s.

"After considerable use of this instrument," says the late Dr. Carpenter, "I can strongly recommend it to such as desire to possess a binocular at once cheap, good and portable."

Mr. H. Crouch makes two series of objectives: one, called the "Best Series," is unknown to us; the other, called "Second Series of small angular aperture," contains objectives intended for the Continental tube. We have had occasion to examine some recent specimens, which we found very good for ordinary work, and gave the following results:—

1 inch and 2-3rd inch.—These objectives have large frontal distances, give very good definition, and are especially suited for elementary research in the histological laboratory.

1-6th inch.—Very good objective, similar to Zeiss' D. The image of the pygidium is very much as it should be; with axial illumination Nobert's 6th group is well resolved. With oblique illumination Nobert's 9th group and the *Pleurosigma Angulatum* are seen very well.

1-12th homogeneous (N.A. 1·25).—The *Bacillus Tuberculosis* and the *Podura* give very clear images, with axial illumination, which also shews

Nobert's 16th group quite as well. Oblique illumination shews Nobert's 18th group very passably, as well as the large *Amphipleura* (No. 33) of Möller's test.

The following are the prices of the different objectives in Mr. Crouch's "Usual Series"·—

3 inches	10°	£1	0	0
2 ,,	12°	1	0	0
1 ,,	20°	1	5	0
2/3 inch	25°	1	5	0
1/2 ,,	40°	1	10	0
1/4 ,,	105°	2	2	0
1/5 ,,	110°	2	2	0
1/6 ,,	110°	2	2	0
1/8 ,,	120°	2	10	0
1/10 ,,	120°	2	15	0
1/15 ,,	120°	4	10	0
1/12 ,, homogeneous	1.25° N.A.	5	0	0

GEBRUDER FROMME (iii., 21, Hainburgerstrasse, Vienna.)—We mention this firm as being the makers of a small and very ingenious microscope, constructed after the specifications of a skilful amateur diatomophile, M. Anton Amrhein, Jr., of Vienna.

The microscope is cylindrical, and has only a rack and pinion movement, which is, however, sufficient for the use for which it is intended, viz.: the immediate examination of collections made during excursions.

The microscope has at its side a tongue, which fits into a groove at the upper end of a stick.

At the bottom of this stick is a strong steel point, by means of which it can be easily driven into the ground. Thus the microscope is at a convenient height for observation, and one's hands free for work.

The price of this little apparatus is £1.

Dr. E. HARTNACK (of Potsdam, near Berlin).—This celebrated maker who succeeded his uncle Oberhaüser, and was so long established in Paris, removed into Germany in 1870, and established himself at Potsdam, his native town.

M. Hartnack is always in touch with the most recent progress in microscopy, and is universally regarded as one of the best makers of the day.

The large model of this maker (fig. 128) is well known. It has been devised in its entirety by M. Hartnack, and forms the type of what is called the *Continental Model.* This microscope was used twenty years ago by a large number of serious microscopists. It has at the present time undergone modifications of increasing importance, but nevertheless it is a model which is remarkable for its stability and for its general construction, by which every desirable improvement can be added to it.

The foot, which is of horse-shoe form, is very heavy ; to it is fixed two vertical pillars, between which the instrument is suspended.

The mirror, jointed for use with oblique light, can be raised or lowered.

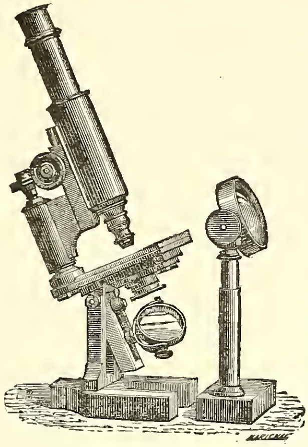


Fig. 128.

The stage is rotary and covered with black glass to prevent injury when acids are used.

The diaphragm holder has a very large opening, in which condensers, polarising apparatus, &c., can be adapted as desired.

The tube is moved by rack and pinion, and the slow movement is very precise.

A model still better known is the *Small Horse-shoe Microscope, called No. 8.* The instrument is composed of a very heavy foot of brass, of horse-shoe form, which supports a cylindrical pillar, to which is attached the stage and the rest of the instrument. The mirror is fixed to a stem to allow it to be moved obliquely.

This stage is very thick, solid, and stationary. Underneath it are two grooves, in which slides a piece of apparatus, having in its centre a tube, in which diaphragms, as well as polarising or illuminating apparatus can be inserted.

A milled head, which forms the lower end of the small tube, allows it to be raised or lowered as desired under the stage. The whole can be removed when oblique light is used.

The rapid movement is given to the instrument with the hand by sliding the body of the microscope in a tube ; the slow movement is made by means of a micrometer screw, of which we have already spoken.

This instrument, accompanied with objectives Nos. 4, 7 and 9, the last of which is immersion provided with correction collar, and oculars 2, 3 and 4, the first of which is a micrometer, is sold for £16 12s.

Microscope No. 4 (fig. 129), differs from the preceding in having a larger stage covered with vulcanite, and by the addition of an Abbe condenser of N.A. 1·25, which can be raised axially by a micrometer screw.

This condenser is furnished with an Iris diaphragm.

The stand of this instrument costs £6 15s.; when accompanied by objectives 4, 7 and I. (homogeneous immersion), together with three oculars, besides being jointed for placing in an inclined position, the price is increased to £18 5s..

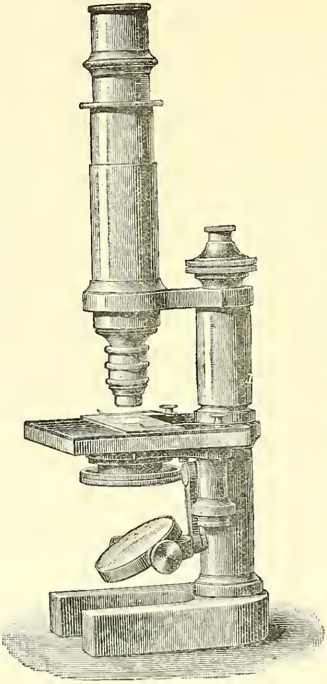


Fig. 129.

The New Microscope, No. 5 (fig. 130) is distinguished from all others of this maker by the simple action of the condenser.

Under the stage is a circular mounting, carrying the Abbe condenser of N.A. 1·40, capable of being centred and furnished with an Iris diaphragm.

The latter slides in a groove and can, in addition, be turned on its axis. The combination of these two movements allows oblique illumination in all directions.

The condenser can, by means of a rack and pinion, be moved towards or away from the stage, which is very large.

The mirror is double, very large, jointed and capable of being placed in all positions.

The slow movement is very precise and very even, the rapid movement is made by rack and pinion.

The whole instrument can be inclined, and can, moveover, be increased in height as required by means of a stem, which is inclosed in the pillar of the microscope.

The price of this stand, furnished with all these improvements, is £12; in a simple form it only costs £9 16s.

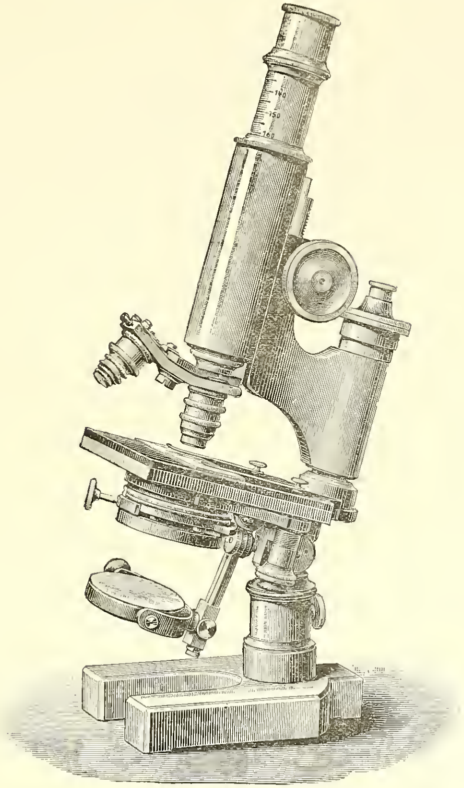


Fig. 130.

Dr. E. Hartnack's objectives preserve their old reputation, and are counted amongst the best there are.

No. 2 is intended for feeble magnification; its power varies from 25 to 40 diameters.

No. 4 is an excellent objective. It is very clear, and its powers of definition and penetration are very remarkable. The magnifications vary from 60 to 180 diameters.

No. 5 is also very good, and its focus is also sufficiently great to allow moderately thick cover glasses to be used. It gives a series of magnifications, varying from 120 to 360 diameters.

No. 6 (1-6th inch), is one of the best objectives that we know. While having a frontal distance sufficient for all kinds of work, the objective has an aperture of ·86, and the chromatic and spherical corrections leave nothing to be desired. It resolves perfectly *Vanheurckia rhomboides.*

Nos. 7, 8 and 9 deserve the same praise, and are nearly as good in all respects as the previous ones. No. 9 has a numerical aperture of ·95. The water immersion objectives have an aperture of about 1·15; all are very good, and show sufficiently well the *Amphipleura.*

The homogeneous objectives have a similar numerical aperture, the images are very good. We, however, find that No. 3 (1-24th inch), while showing bacteria well, in the case of diatoms leave something to be desired.

E. Hartnack makes his homogeneous objectives with correction collars when their maximum effect is desired. He finds, as we do, that the correction is *absolutely* necessary for the study of diatoms.

A short time ago E. Hartnack completely changed the formulæ of his objectives. We have received two objectives of the new construction, No. 1 (1-12th inch) homogeneous, and No. X, water immersion. Each has a numerical aperture of 1·27, which has never before been attained by any maker on the Continent for a water immersion objective. These two objectives are admirable, they resolve all known tests; the homogeneous objective gives a rather brighter image than the water objective.

Since these lines were written, Dr. Hartnack has again modified these objectives. We have just received from the maker (May, 1891) a series of objectives quite recently constructed.

The following is the result of the trials to which we have submitted them :—

No. 5 (focus 1-5th inch) N.A. ·90.—Good objective, the image of the pygidium is clear, and *Pleurosigma* is resolved with axial illumination.

Nos. 6, 7, 8 and 9.—These objectives, which are respectively about 1-6th, 1-7th, 1-10th and 1-12th inch, have each a numerical aperture of ·95.

They therefore only differ in their magnifying power.

All of them give a good image of the pygidium which is quite clear and pure, and they resolve *Pleurosigma* perfectly with axial light as well as the 10th group of Nobert. With oblique light the 10th group of Nobert's test can be seen when mounted in the yellow medium.

The *Homogeneous* No. 1 is 1-12th inch focus, and of N.A. 1·30. The images are pure and clear, and the frontal distance is very considerable.

The *Podura* gives a good image, slightly coloured. The *Amphipleura* shows its striæ finely resolved. Nobert's test dry shows the 12th group in axial, and the 19th in oblique illumination.

Apochromatic Objectives.—There are two apochromatic objectives, the first has a focus of 1-12th, and the second 1-18th, each has an aperture of 1·35.

The images are good and absolutely without colour, the *Podura* is of a fine black. With axial illumination, the two objectives show very well the 12th group of Nobert and the 19th with oblique illumination.

The frontal distance of the two objectives is considerable, and both have good definition, though we found the 1-12th considerably superior to the 1-18th. With the first, the resolution of the *Amphipleura* is finer, and the tendency to resolve into beads is greater.

The following table summarises the principal particulars relating to the objectives of Dr. Hartnack:—

Number,	Equivalent Focus.	Numerical Aperture.	Price.
1.—Achromatic Objectives.			
			£ s. d.
1	35· mm.	——	0 16 0
2	25· ,,	——	0 16 0
3	15· ,,	——	1 4 0
4	10· ,,	·5	1 4 0
5	5· ,,	·9	1 8 0
6	3·75 ,,	·95	1 12 0
7	3·4 ,,	·95	1 12 0
8	2·3 ,,	·95	2 0 0
9	2· ,,	·95	3 0 0
9 water immersion ..	2·2 ,,	·95	6 0 0
10 ,, ,, ...	1·6 ,,	1·25	8 0 0
11 ,, ,, ...	1·4 ,,	1·25	10 0 0
12 ,, ,, ...	1·3 ,,	1·25	12 0 0
I. homogeneous immersion	2·0 ,,	1·3	7 10 0
II. ,, ,,	1·5 ,,	1·3	10 0 0
2.- Apochromatic Homogeneous Immersion Objectives.			
	2·0 mm.	1·35	12 10 0
	1·33 ,,	1·35	15 0 0

F. KORISTKA (47, Rue S. Vittore Grande, Milan.)—F. Koristka is a new maker, who has only been established about ten years. His name is still little known out of his own country, but in Italy his reputation is firmly established. At the present time his instruments are in fact used in all the scientific establishments of his country, and justly so, for if the excellent quality of his objectives is unsurpassed, the brass work of his stands is as carefully turned out. All the different parts of his apparatus are elegantly finished and work admirably, of which we have personally assured ourselves.

This manufacturer makes a very considerable number of models, the greater part of which resemble Zeiss' stands; consequently, we will merely mention the large instruments. No. I., I*a*, and II., each of which are furnished with an Abbe condenser, and are moved by rack and pinion. In addition, No. I. has its upper stage rotary, No. I*a* a rotary stage only, while No. II. is similar to No. I., without the upper rotary stage. However, we will describe in greater detail three stands which are deserving of being specially recommended to workers.

We have, first, the *Medium Petrological Stand* (fig. 130*b*). This model, which is very commonly to be found in the natural history laboratories of Italy, can be used not only for petrological research, but also for the most delicate research in botany, animal histology, &c.

The instrument can be inclined, and is furnished with an Abbe condenser, the Iris diaphragm of which is arranged to receive the polariser. This diaphragm carries besides a small projecting notch which, from 90° to 90°, strikes against a spring so as to indicate the principal positions.

The stage is furnished with a circular scale in divisions, and a vernier, enabling readings of 10′ to be made.

The tube of the microscope carries a stereoscopic ocular with the four quartz of Bertrand. There is also an ocular for the observation of axial images, Mohl's tablets, and Klein's quartz.

The lower end of the tube is furnished with an apparatus for centering the objectives.

This stand as we have described it, together with an analyser, having a circle divided into degrees, costs £20 16s.

The complete apparatus, enclosed in a box, costs £34, when, in addition to the accessories already enumerated, it is furnished with three objectives, one of them being 1-12th inch homogeneous immersion, three oculars, one of which has a micrometer, and a triple nose-piece.

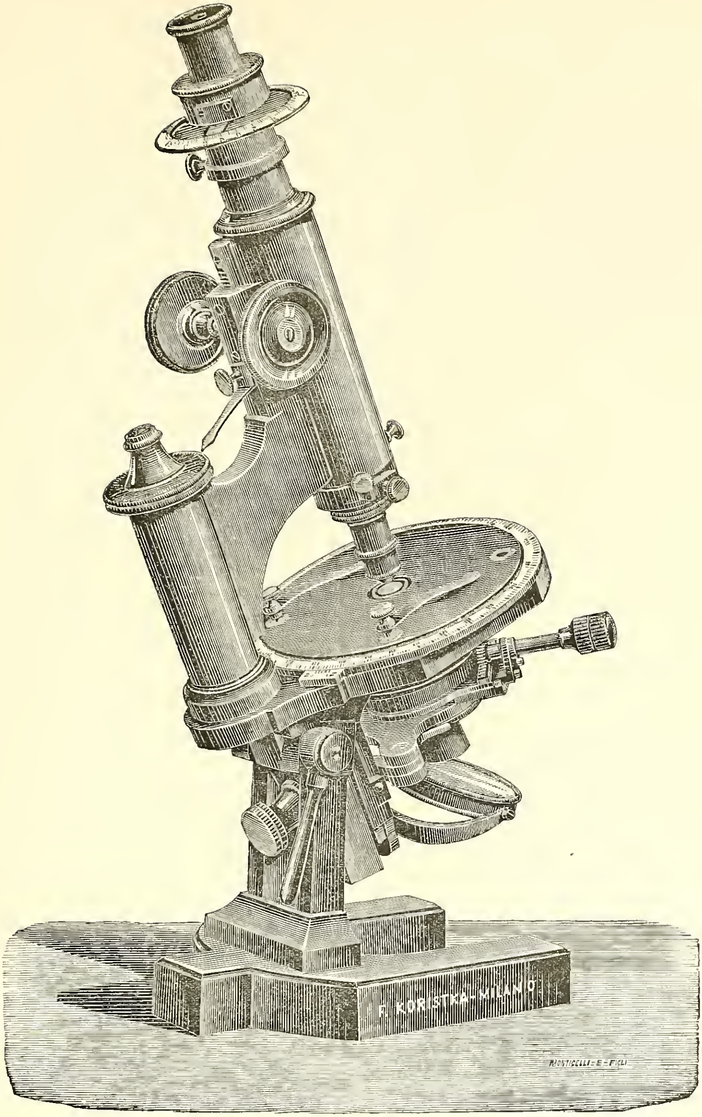


Fig. 130*b*.

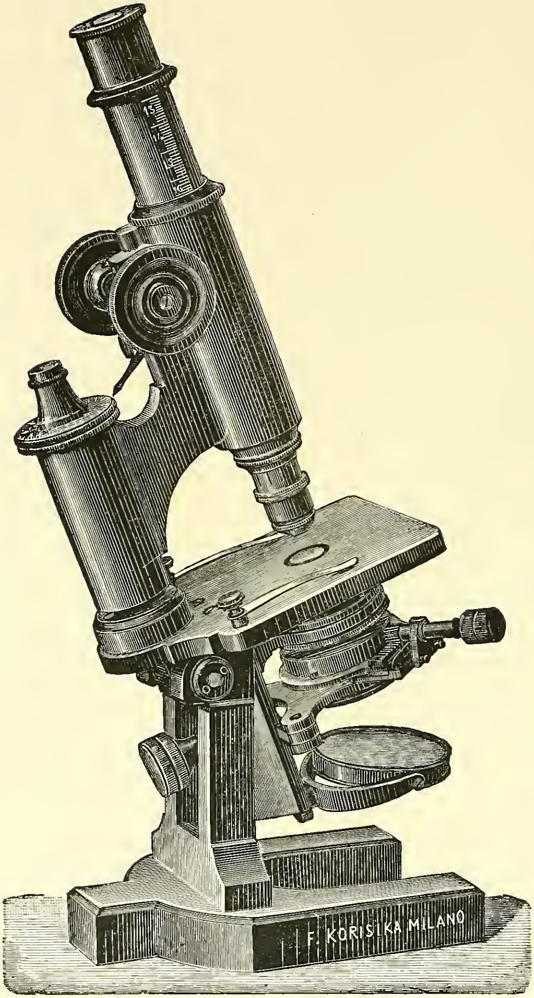


Fig. 130*c*.

Model No. III. (fig. 130*c*), which is still sufficient for delicate

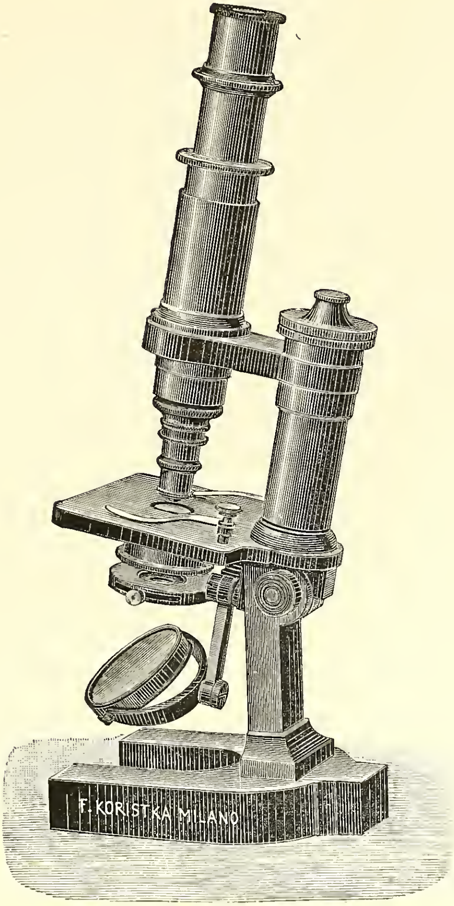


Fig. 130*d*.

microscopic research, can be inclined, the rapid movement being by rack and pinion, and furnished with an Abbe condenser, which can be raised and lowered by means of the milled head, which is seen between the two pillars which support the stage. This stand costs £9, with an Abbe condenser and ordinary diaphragms, and £9 16s. with an Iris diaphragm.

Model VI. (fig. 130*d*), very elegant and carefully furnished, only costs £5 4s. It can be inclined. The rapid movement is by sliding. It is furnished with a very precise micrometer screw and a simplified Abbe condenser, and is sufficient for all ordinary research.

As we have previously stated, this maker's objectives may be classed among the best. We have had occasion to examine an almost complete set of the date of December, 1891, and the following is the result of our examination:—

Achromatic Objectives.

No. 0 (focus 38mm. = about 1½ inch) N.A. ·12.
No. 1 („ 30mm.) N.A. ·15.
No. 2 („ 20mm.) N.A. ·20 ; and
No. 3 („ 15·5mm., or ⅗ inch) N.A. ·28 are four low powers, formed by the combination of two achromatic lenses. All four give clear and pure images, bear oculars of relatively high magnifying power, and are very useful as searchers or for observations in elementary histology.

No. 4 (focus 12mm., or ½ inch) N.A. ·44 is the first ternary combination. The images are very good, and the *Pleurosigma balticum*, as well as Nobert's 4th group, can be resolved in oblique light.

No. 5* (focus 8·5mm., or ⅓ inch) N.A. ·77, resolves Nobert's 7th group in oblique light, and gives good images in axial light.

No. 6 (focus 6mm., or ¼ inch) N.A. ·50 shows feebly the *Pleurosigma angulatum* in axial, and clearly in oblique, illumination.

No. 6* (focus ¼ inch) N.A. ·80 gives a good image of the *Pleurosigma angulatum* in axial illumination ; in oblique illumination Nobert's 10th group is seen very well.

No. 7* (focus 4mm. or 1-6th inch) N.A. ·85, and No. 8* (focus 2·8mm. or 1-8th inch) N.A. ·88, are two excellent objectives, which only differ in their magnifying power. Both with axial illumination resolve perfectly Nobert's 8th group, and give a good image of the Podura and pygidium. With oblique illumination Nobert's 11th group and the large form of *Vanheurckia rhomboides* in Möller's test are resolved with clearness.

1-12th homogeneous immersion N.A. 1·30 is a very good objective. With axial illumination the *Bacillus tuberculosis* is very good, and Nobert's 12th group is well resolved. In oblique illumination the *Amphipleura* of Möller's test, as well as Nobert's 19th group, are seen perfectly.

1-15th semi-apochromatic, homogeneous immersion differs only from the previous one in its magnifying power being somewhat larger and the purity of the images observed being considerably greater.

Apochromatic Objectives.

16mm. (2-3rd inch N.A. ·30).—The images are clear and pure. Nobert's 3rd group can be resolved with axial illumination.

8mm. (1-3rd inch N.A. ·60).—The pygidium of a flea and the Podura are seen with admirable clearness with ocular No. 18; with axial illumination Nobert's 7th group can be resolved. With feeble oblique illumination the image of the *Pleurosigma* is very good.

3mm. (1-8th inch N.A. ·95).—The images of the pygidium of the flea and of the Podura are admirable in axial illumination, which also enables the resolution of the *Pleurosigma angulatum* and Nobert's 8th group. In oblique illumination Nobert's 12th group and Möller's *Vanheurckia rhomboides* are resolved.

3mm. homogeneous (1-8th inch N.A. 1·30) and 2mm. (1-12th inch N.A. 1·30) are two excellent objectives, which do not essentially differ except in their magnifying power. The images are pure and colourless, the *Surirella* and the *Podura* show that their aberrations are well corrected. With oblique light all the tests are perfectly resolved, but we find that the images given by the 3mm. are finer than those by the 2mm.

2mm. (1-12th inch N.A. 1.40). The images are clear and brilliant; the definition of *Bacteria* are very fine, and all the known tests are shown in an irreproachable manner. We consider this objective as beyond comparison.

The following is a summary of the principal points concerning the Koristka's objective:—

No. of Objective.	Numerical Aperture.	Equivalent Focus.	Price, with Fixed Mounting.
		Achromatic Objectives.	
			£ s. d.
a	—	40 mm.	0 10 0
b	—	32 ,,	0 10 0
c	—	25 ,,	0 10 0
1*	—	28-50 ,,	1 16 0
0	·12	38 ,,	1 0 0
1	·15	30 ,,	1 0 0
2	·20	20 ,,	1 4 0
3	·28	15·5 ,,	1 4 0
4	·44	12 ,,	1 8 0
5*	·70	8·5 ,,	1 12 0
6	·50	6 ,,	1 8 0
6*	·80	6 ,,	1 12 0
7	·70	4 ,,	1 12 0
7*	·85	4 ,,	1 16 0
8	·75	2·8 ,,	1 16 0
8*	·88	2·8 ,,	2 4 0
9*	·88	2·1 ,,	2 8 0
1-10th Water	1·10 to 1·17	2·1 ,,	3 0 0
1-15th ,,	,,	1·7 ,,	5 4 0*
1-12th Homogeneous	1·25 to 1·30	2·1 ,,	5 4 0
1-16th ,,	,,	1·6 ,,	7 13 0
1-15th ,, semi-apochromatic	1·30	2·1 ,,	8 0 0
		Apochromatic Objectives.	
Dry	·30	16 ,,	4 0 0
,,	·60	8 ,,	7 12 0
,,	·95	4 ,,	8 0 0*
Homogeneous	1·30	2 ,,	16 0 0
,,	1·40	2 ,,	22 0 0
Dry	·95	3 ,,	8 0 0*
Homogeneous	1·30	3 ,,	16 0 0
			*with collar adjustment.

The semi-apochromatic 1-16th is accompanied with two compensating oculars, which are included in the price of £8. The price of Huygen's oculars is 7s. 6d. Compensating oculars vary from 16s. to £1 4s.

E. LEITZ (of Wetzlar), who has taken the workshops of Kellner, manufactures microscopes of good quality and at a reasonable price.

One of these instruments (fig. 131), called in the catalogue the *Large Inclining Microscope (Stativ I.)* has two circular revolving stages, which can be easily substituted for one another.

One is without accessories, while the other, of new construction, is furnished with a carrier, the movement of which in one direction is made by a horizontal screw, and in the other by means of a vertical friction pinion. Its movement can be registered by two scales. The preparation when fixed on the stage by two spring clips is only just above the lens of the Abbe condenser, with which the instrument is furnished, and thus enables the total illuminating effect to be preserved. The condenser is provided with an Iris diaphragm, and can be racked

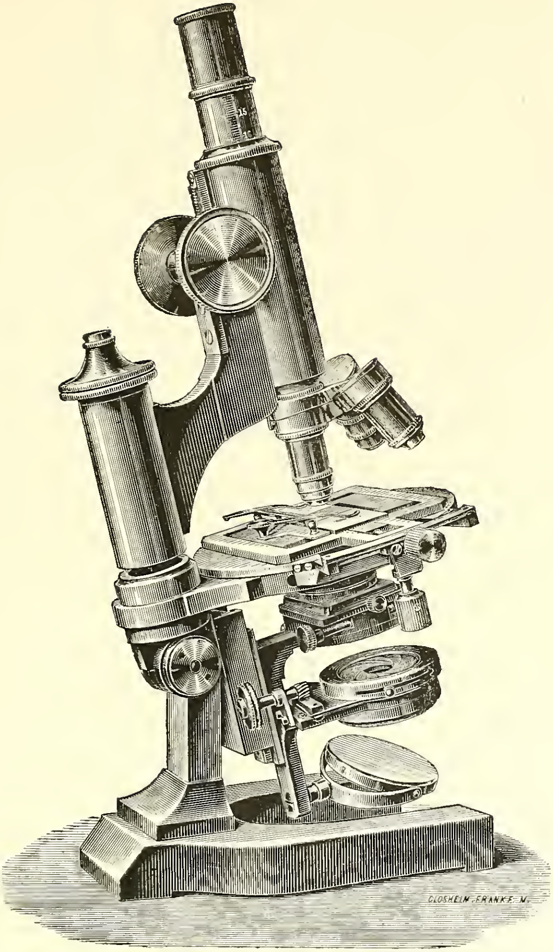


Fig. 131.

up and down. The foot of the instrument is heavy and of horse-shoe form ; the draw tube is graduated, and is provided with the English screw thread. The micrometer screw for slow movement is very precise, and the rapid movement is effected by rack and pinion. The price of this stand without accessories is £18. The complete microscope—that is to say, furnished with a nose-piece for three objectives, Abbe's camera, lucida polarising apparatus, stage micrometer, eye-piece micrometer, nine ordinary objectives, two homogeneous immersion objectives, 1-12th and 1-16th, and four oculars, giving a magnification of 27 to 1,690 diameters—costs £50.

The slow movement of this microscope, as well as Leitz's other large instruments, depends on a principle called "à pointe renversée," which is that at present used by first-class Continental makers. We have already illustrated at page 77 the principle adopted by the firm of Zeiss. We give here that employed by Leitz (fig. 131*a*).

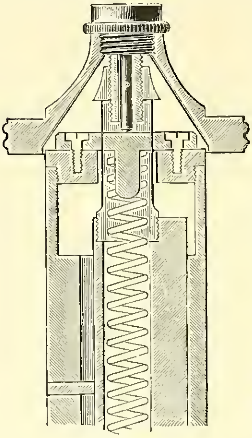


Fig. 131*a*.

As can be seen, the spiral spring presses at its lower extremity, against the end of the prism inside, and at the upper extremity against a piece of steel fixed in the outer slow adjustment tube, which also carries the body of the microscope. The screw of the slow movement is hollowed out and encloses a steel rod, which presses against the piece of steel just mentioned, and, by means of this rod, the movement is communicated to the spring. Fine adjustment, "à pointe renversée" works very easily in both directions.

Another large microscope, *Stativ 1a.* (smaller than the preceding) (fig. 132), has a rotary stage with centering arrangement.

The system of lenses composing the Abbe illuminating apparatus can be easily taken off to make way for the diaphragm tube, taking care first to remove the Iris diaphragm.

By adopting this arrangement, either the condenser or the diaphragm tube can be used, while the rack and pinion movement, in both cases, regulates the light.

The instrument, moreover, possesses a graduated draw tube and all the movements described above for Stativ 1, such as the inclining, rack and

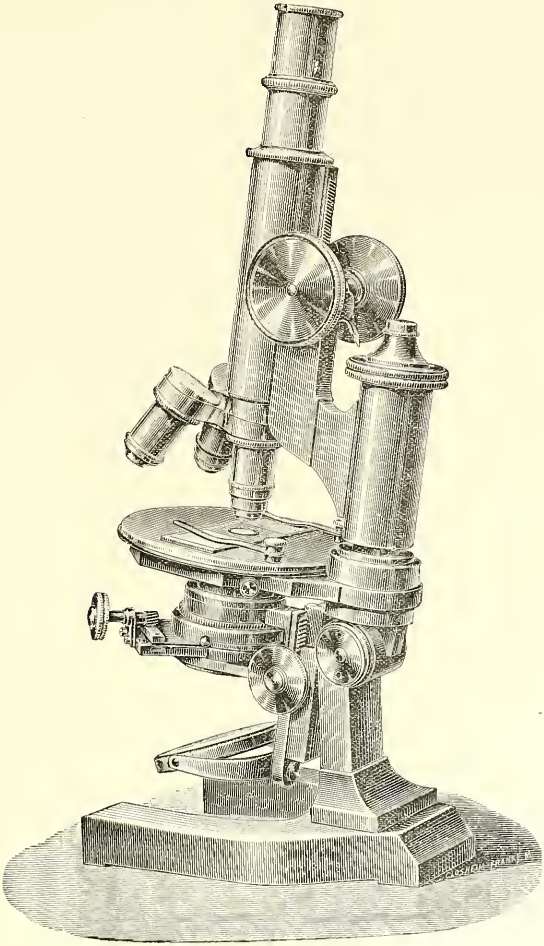


Fig. 132.

pinion rapid movement, and micrometer screw for focussing. It is accompanied by a nose-piece carrying three objectives, an eye-piece

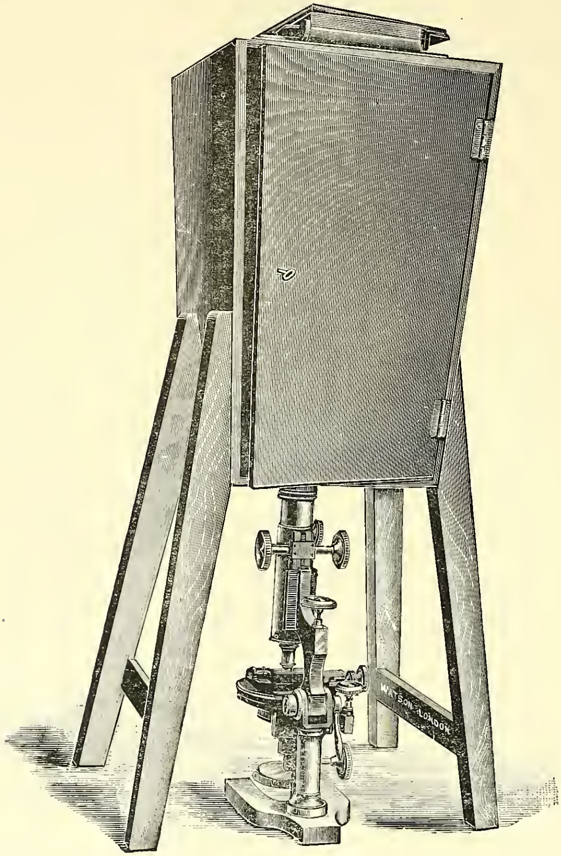


Fig. 133.

micrometer, three ordinary objectives, numbered 2, 4, and 7, a 1-12th immersion objective, and four oculars (giving a magnification of 40 to 1,310 diameters). Fitted as above this microscope costs £20.

Stativ II. (No. 9) (fig. 133), which is also called the *Medium Microscope*, is entirely of brass, with horse-shoe foot. It inclines, but

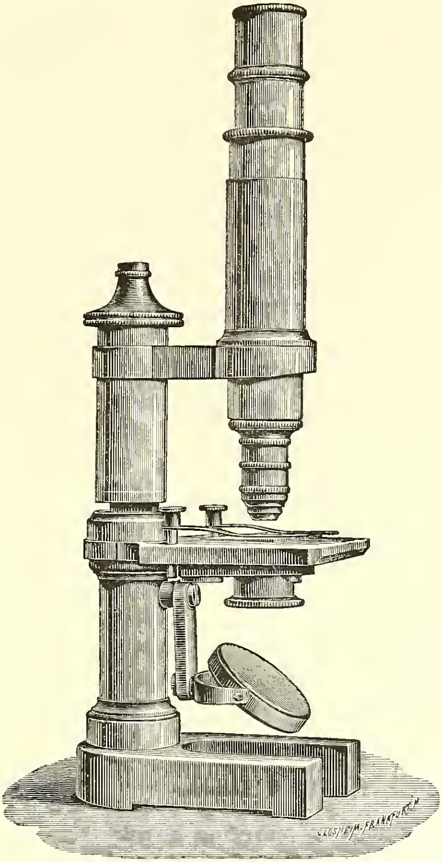


Fig. 134.

cannot move about the optical axis. The stage is covered with vulcanite, as a protection against acids. The rapid movement is effected by rack and pinion, and the slow movement by a very precise micrometer screw. The Abbe illuminating apparatus is made simply with Iris diaphragm, and can be moved up and down by means of a special screw. The tube diaphragms are adjusted on a piece of apparatus, which slides between grooves. The mirror, plane on one side and concave on the other, is jointed so as to allow of oblique illumination. This stand is sold for £15 5s., and is then accompanied by 3, 5 and 7 ordinary objectives, by a 1-12th homogeneous immersion objective and oculars i., iii., iv., which give a magnification of 70 to 1,100 diameters.

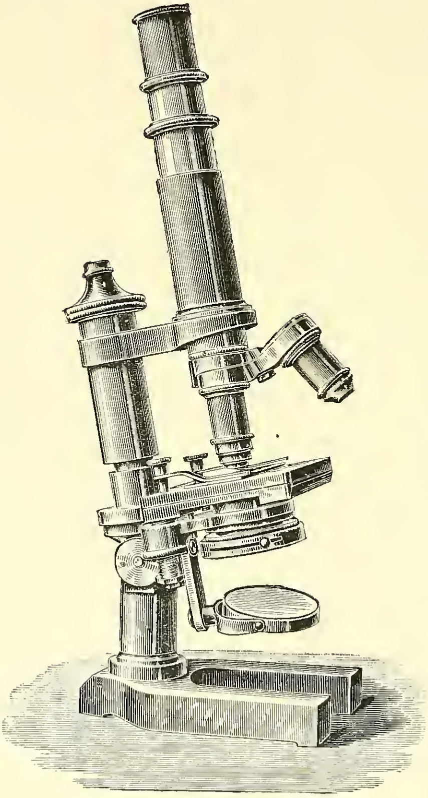


Fig. 135.

Another medium microscope (No. 14, *Stativ III.*) (fig. 135), can be inclined, and has a rotary stage having its rapid movement by sliding, and its slow movement produced by a micrometer screw.

The illumination is made (as in Stativ II.) with simple Abbe condenser and Iris diaphragm which can be moved up and down by means of a special screw. The mirror is double (plane and concave), and allows of oblique illumination. The price of this stand is only £4.

Furnished with a nose-piece for two objectives, with Nos. 3 and 7 ordinary objectives, with a homogeneous immersion objective, and oculars I. and III., the price is £13 5s.

Leitz also constructs cheaper microscopes, and amongst others a *Medium Upright Microscope* (No. 15) (fig. 134), that is to say, incapable of being inclined, and furnished with a rapid movement produced by sliding the tube, and slow movement for focussing by a micrometer screw. The illumination is effected by a mirror, and the diaphragms are placed in a tube. With Nos. 3, 5, 7 and 9 ordinary objectives, and oculars I. and III. it gives a magnification of from 84 to 880 diameters, and costs £9 15s.

The objectives of this maker are of excellent quality, and moreover are very cheap.

The following are the results which the specimens of the series in our possession give, and which date from August, 1891 :—

No. 2 (focus 30 mm. N.A. ·14) is an excellent objective for low magnifications and for photographs of entire objects. This objective is used by Möller for taking a photograph of his famous preparation of 4,000 forms as a whole.

No. 3 (2-3rd in. N.A. ·28) is a good objective for ordinary research in Vegetable Anatomy; the images are pure and clear.

No. 4 (½ in. circa. N.A. ·45) is a good objective for studies in Vegetable Histology; the *Pleurosigma balticum* is passably resolved with oblique illumination.

No. 6 (¼ in. N.A. ·82). *Pleurosigma angulatum* is clearly resolved with axial illumination and condenser open.

No. 7 (⅛ in. N.A. ·85). This object is one of the maker's best. *Bacillus tuberculosis* is shewn very clearly; the *Pleurosigma* is resolved admirably with axial illumination, which also shews Nobert's 7th group. With oblique illumination the 12th group can be resolved.

No. 8 (1-10th in. N.A. ·87). This objective differs from the preceeding only in its magnifying power; moreover, we prefer the first, the images of which appear to us to be better.

1-12th in. *homogeneous* (N.A. 1·30). The jury of the Antwerp Exhibition has spoken of this objective in very laudatory terms as one "of great clearness and of exceptional resolving power." Our own opinion entirely coincides with that of the jury. The objective shewn at the exhibition (we have since examined two other specimens, which only differ very slightly from it) is indeed extremely remarkable. The image of the *Podura* and of *Surirella gemma* are very slightly coloured and the *Bacillus tuberculosis* is seen with excessive clearness. With axial illumination Nobert's 12th group is resolved with this objective. With oblique illumination Nobert's 19th group is seen very clearly, and the *Amphipleura* is shewn distinctly beaded. The price of this remarkable objective is not at all exorbitant, costing only £5.

The objectives manufactured by M. E. Leitz are classed as follows:—

Number of Objectives.	Equivalent Focus.	Numerical Aperture.	Price.		
		Achromatic Objectives.			
			£	s.	d.
1	44· mm.	.09	0	15	3
2	30· ,,	·14	0	15	3
3	18· ,,	·28	0	15	3
4	10· ,,	·45	1	4	10
5	5·8 ,,	·77	1	4	10
6	4·4 ,,	·82	1	10	0
7	3·2 ,,	·85	1	10	0
8	2·5 ,,	·87	2	0	0
9	2·2 ,,	·87	3	0	0
10 Water immersion ..	2·1 ,,	1·10	3	5	0
11 ,, ,, ...	1·7 ,,	1·15	4	10	0
1/12 Homogeneous immersion	2·2 ,,	1·30	5	0	0
1/16 ,, ,,	1·7 ,,	1·30	7	10	4
		Apochromatic Objectives.			
	16· mm.	·30	4	0	0
	8· ,,	·65	5	0	0
	4· ,,	·95	7	10	4
Homogeneous immersion ..	2· ,,	1·35	15	0	0

NACHET (17, Rue St. Séverin, Paris). M. Nachet is, at the present time, the oldest maker in France, and, thanks to continuous progress in his factory, he maintains his position in the front rank. Indeed, with this manufacturer, it is not the maker who predominates but the microscopist, the man of research, the artiste. While holding the first place among Continental makers, he has appreciated the merit of English instruments; in addition to his simple and low-priced, but, nevertheless, good microscopes, he furnishes instruments, which for perfection, elegance and finish of the brass-work, rivals the instruments of our neighbours over the sea. Like Charles Chevalier, M. Nachet is a savant who is thoroughly conversant with all the resources of optics and mechanics. His inventions are numerous and have been much appreciated by microscopists. His microscopes are of various forms; he has unique models for special use—chemistry, petrology, college demonstrations, &c.

We will proceed to consider his principal models.

His best is what M. Nachet calls his *Large Perfected Model Microscope.*

This microscope (fig. 136) may be either monocular or binocular.

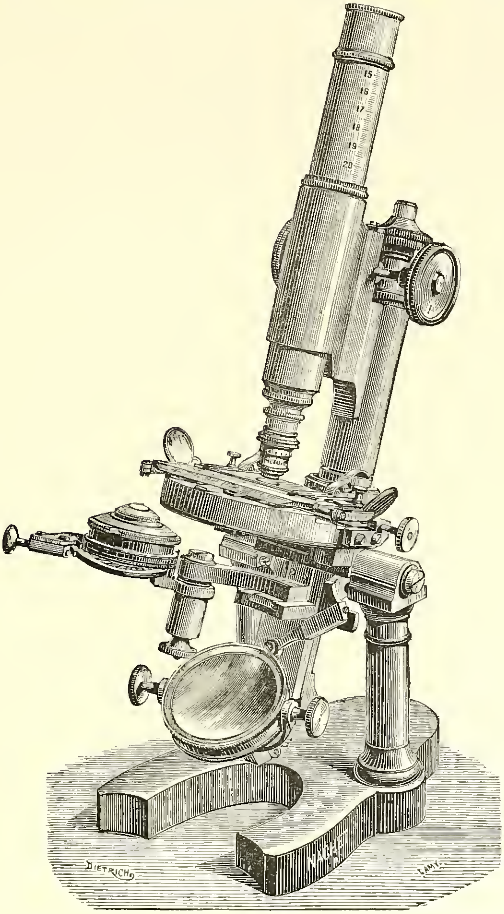


Fig. 136.

It is suspended on an axis by which means it may be inclined, and then fixed in any position between the horizontal and the vertical; it is constructed under the best conditions for solidity and precision with reference to movements and centering. The focussing adjustment is made by means of a rapid movement by a rack and pinion, and by means of a slow movement by a micrometer screw, acting on the pillar carrying the body. This micrometrical movement, in consequence of a new arrangement (the reverse of the spiral spring), is of very remarkable precision and smoothness, while at the same time entirely rigid, in consequence of the extent of the friction surface in the prismatic pillar, which has enabled him to do away with the second slow movement contained in his former large model. The milled head is graduated by divisions for measuring thicknesses, which severally correspond to 1-500th of a millimetre. The body tube can be drawn out, and is divided into millimetres.

The stage is mounted so as to rotate, and is furnished with a moveable table, with rectangular movements, produced by very delicate adjusting screws, to move the position of the object in any direction. A rectangular rule fixed in the table checks the preparation, and by means of two scales at right angles to one another, the co-ordinates can be determined; by means of their numerical values inscribed on the plate, the point which it is desired to see later on, can be found again.

When desired, a very useful arrangement can be adapted to the stage for the study of rare or valuable preparations. It is a piece of apparatus formed of two small mirrors; one concave, placed on a level with the stage on the left, and moveable in every direction, so as to send a ray of light across the other placed opposite on the right, and inclined at an angle of 45°, to reflect the luminous pencil vertically. The image of the end of the objective being brightly illuminated is projected on to the small mirror at the right, and at a single glance one may be assured whether the objective is in contact with the preparation or not. The bed of the immersion liquid allows the ray of light grazing the objective to traverse, even when the lens is all but in contact with the glass; this method which has been applied for twelve years to some of the large models, is of great service, and will become more and more general as an accessory when using very high powers.

The illumination is produced with a double mirror, plane and concave, mounted on joints, and capable of being turned in all directions, to give the effects of oblique light and variations of distance. Between the stage and the mirror is a groove system, having an easily fitting slide, which is moved by a lever and carries the sub-stage for changing the condenser and for producing different illuminating effects ; moreover, the axle, about which the sub-stage rotates with an eccentric movement, carries a small slow adjustment, by which objects can be illuminated at convenient distances from the object with the greatest nicety.

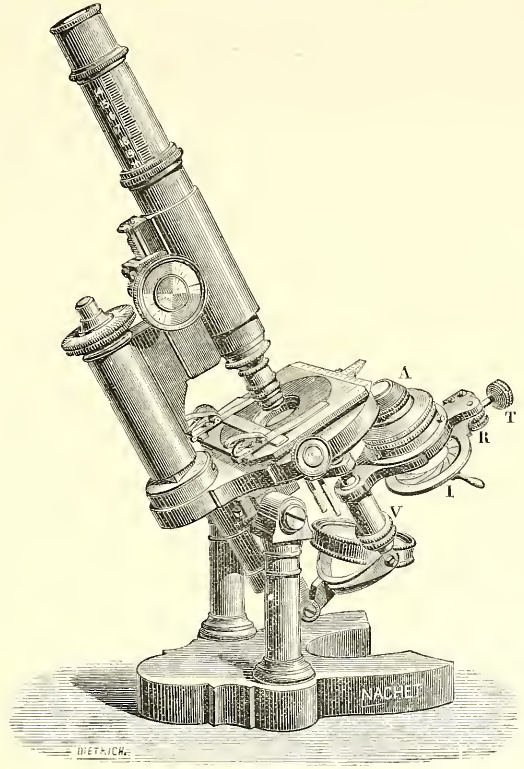


Fig. 137.

With these microscopes, M. Nachet provides a complete series of his objectives, a triple nose-piece, four oculars, a goniometer, a condenser of large angular aperture, which we have already mentioned, a complete polarising apparatus, a dark ground illuminator, a stage micrometer, an eye-piece micrometer, a condensing lens on stand, a collection of dissection instruments, &c. The whole, enclosed in a mahogany box, costs £80.

The Grand Microscope Stand, No. 2 (fig. 137), is very solidly mounted on two pillars, and suspended on an axis; the rapid adjustment is effected by a very precise rack and pinion, and the slow movement by an adjusting screw; a plane and concave mirror mounted on joints is capable of producing all the effects of oblique light. It has also a rotating stage and stage carrier, with a plate of black glass superposed and furnished with an adjusting screw for shifting the object.

The illuminating apparatus resembles the former eccentric arrangement; that is to say, the condensers, tube diaphragms, polarising apparatus, &c., can be arranged away from the stage and then brought under the object; only the movement for bringing it nearer, and the focus adjustment is made in the pillar instead of being made in the central tube. This pillar is composed of three cylindrical tubes, the external tube sustaining the arms, which carry the illuminating apparatus; this slides easily, and can be turned round the second, which terminates in a small adjusting screw, by which the condenser can be focussed, and the object withdrawn very slowly indeed. The rectilinear movement working of the microscope along the axis of the microscope is ensured by a system of springs, connecting the supporting arm with a vertical knob (not shewn in the drawing), which serves to guide it. Under the tube of the condenser is a rotating cell carrier, with an Iris diaphragm, which can be placed in all positions.

This microscope, which costs £36, includes six objectives, Nos. 2, 3, 5, 6, 7 ordinary, and No. 9 homogeneous immersion, with correction collar.

There is, in addition, a triple nose-piece, three oculars, wide-angled condenser, a stage micrometer, an eye-piece micrometer, a camera lucida, a bull's eye on stand, &c.

A much more simple microscope than the preceding, and, moreover, sufficient for every kind of research, is the *New Inclining Model Microscope* (fig. 138).

In this instrument the stage is fixed and furnished with a black glass. The quick movement is effected by rack and pinion, which is very precise, as is also the slow movement.

The condenser is of wide angle, and can be moved up and down by a fine adjustment. The instrument is accompanied by three dry objectives, Nos. 3, 5, and 7, and one homogeneous immersion, No 9. There are, in addition, three oculars and a bull's eye, mounted on a stand for illuminating opaque bodies. The price of the whole, which includes nearly every requisite for ordinary researches, is only £19 4s.

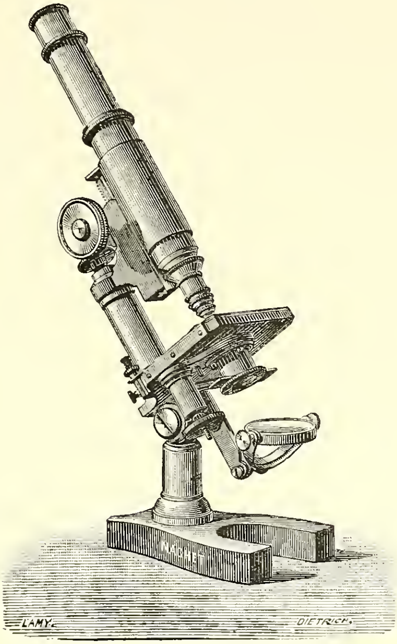


Fig. 138.

Lastly, a microscope within reach of any purse, and one which, moreover, is suitable for serious work, is the *Small Modified Erect Stand*, No. 13 (fig. 139).

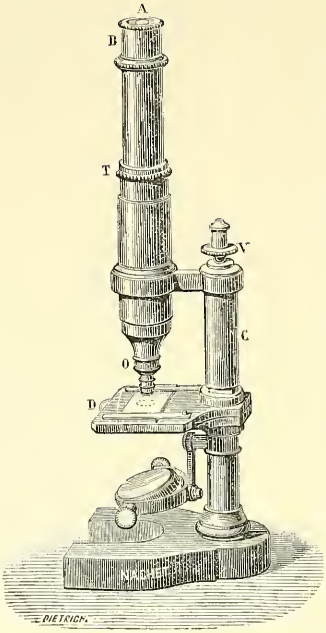


Fig. 139.

The foot is made of iron, its slow movement is very precise, and the mirror is jointed for oblique illumination. The diaphragm consists of a rotating plate.

This stand, together with an ocular and objective, No. 7, is sold for £3 12s. However, we do not advise its purchase when fitted as above. At least a No. 4 objective (½ inch), costing £1, should be added, and then it will be suitable for most of the ordinary kinds of research.

The objectives of this maker are very numerous. We shall examine the following, which are those mostly used, and of which we have examples of recent date:—

No. 2 (2 inches). Excellent objective for work with a compound microscope; suitable for dissections, sorting diatoms, &c.

No. 5 (¼ inch). The numerical aperture of this objective is only ·6, corresponding to a resolving power of 23 lines in every hundredth of a millimetre (·00394 inch). The resolution of difficult tests must not, therefore, be expected of this objective, for the formula of this combination has not been made up with this object; its limit of good resolution ceases at *Pleurosigma Balticum*, but for histological work, as well as for general examination of diatoms mounted with a cover glass, the objective is of great value. It has a very large frontal distance, as well as a considerable magnifying power, and for many years we have constantly employed it for the purposes just mentioned above.

No. 7 (1-9th inch). A good objective, with a numerical aperture of 0·87. The frontal distance is considerable, and the images given by it are clear. The limit of resolution is found with the large forms of *Vanheurckia rhomboides Breb*, which it resolves fairly well.

No. 10 water immersion (1-18th inch, N.A. 1·20). The image of the pygidium is clear and pure. The *Podura* is clear, and of a good black colour, which signifies quasi apochromatic achromatisation. The *Pleurosigma* resolved well in axial illumination, and the edges of fractures clearly shew the "stamp paper" perforations. In the same illumination Nobert's 10th group is resolved and the bacilli of tuberculosis are clearly defined. In oblique illumination Nobert's 16th group can be distinguished.

No. 10 oil immersion. This objective is in reality an apochromatic, although M. Nachet does not call it so. In axial illumination the pygidium and *Podura* are clearly defined, and the latter is of a good pure black. Nobert's group is seen very well. The *Pleurosigma* is clearly defined, as is also the bacillus of tuberculosis, which displays very clear images.

In oblique illumination the *Amphipleura* is well resolved, but the valve appears slightly deformed. By perfectly adjusting the correction collar Nobert's 19th group becomes visible in the yellow medium. The frontal distance of this objective, as well of previous one, is considerable, and work is easy.

The following table gives the details relating to M. Nachet's objectives:—

Number of Objective.	Equivalent Focus in English inches.	Angle of Aperture and Numerical Aperture.	Price.	
			Fixed Mounting.	With Correction Collar.
			£ s. d.	£ s. d.
1	—	—	1 4 0	
1*a*	—	—	0 8 0	
2	2	—	0 16 0	
2*a*	—	—	0 9 6	
3	1	20°	0 16 0	
4	1/2	40°	1 0 0	
5	1/4	80°	1 4 0	
6	1/7	120°	1 8 0	2 16 0
7	1/9	120°	1 12 0	3 4 0
8	1/11	140°	2 16 0	5 4 0
9	1/14	160°	4 0 0	6 0 0
Water Immersion.				
8	1/10	1·15	3 4 0	5 4 0
9	1/14	1·16	4 0 0	6 0 0
10	1/18	1·24	—	8 0 0
Homogeneous Immersion.				
9	1/14	1·20	6 0 0	8 0 0
10	1/20	1·25	8 0 0	10 0 0
11	1/25	1·25	—	14 0 0
12	1/40	1·30	—	20 0 0

For some months past M. Nachet has also commenced the manufacture of apochromatic objectives and compensating oculars. M. Nachet has adopted the classification at present employed by makers of these objectives. The following are those which he makes :—

		£	s.	d.
16 mm. (2-3rd inch) N.A. 0·30	Price	4	0	0
8 mm. (1-3rd inch) N.A. 0·65	,,	5	0	0
4 mm. (1-6th inch) N.A. 0·95 (with correction)	,,	7	4	0
2 mm. (1-12th inch) homogeneous N.A. 1·30	,,	16	0	0

The compensating oculars cost :—

1	4	6	8	12	18
£1	16/-	16/-	£1 4s.	£1 4s.	£1

Projection ocular costs £1 16s.

Of these objectives we have had occasion to study the 2 mm. (1-12th inch), which was submitted for examination to the Jury of the Antwerp Exhibition. The examination shewed that this objective is excellent.

The images are perfectly pure and clear, without any trace of secondary spectrum. With axial illumination the *Pleurosigma* and *Bacillus Tuberculosis* give irreproachable images; with oblique illumination the *Amphipleura* is resolved with perfect clearness.

POWELL & LEALAND (170, Euston Road, London). Messrs. Powell and Lealand occupy quite a unique position in the microscopic world. Their workshops are small, the number of instruments which they produce are few, but every piece of apparatus, marked with their name, is an artistic production, perfect in all its details. Moreover, both instruments and objectives of these makers are in the greatest request, and are used in England by all serious microscopists.

This firm only constructs three principal models. The large microscope, No. 1 (fig. 140), is an instrument supported on a tripod stand, the legs of which, being wide spread, ensures perfect steadiness in every portion of the instrument. Cork plates inserted underneath the feet add to the stability of the instrument, while at the same time they protect the table from being rubbed by the brass.

When the instrument is inclined in a horizontal position the optic axis is 25 centimetres (10 inches) from the surface of the table.

The body of the microscope is of such a length that the optical distance between the posterior principal focus of the objective and the

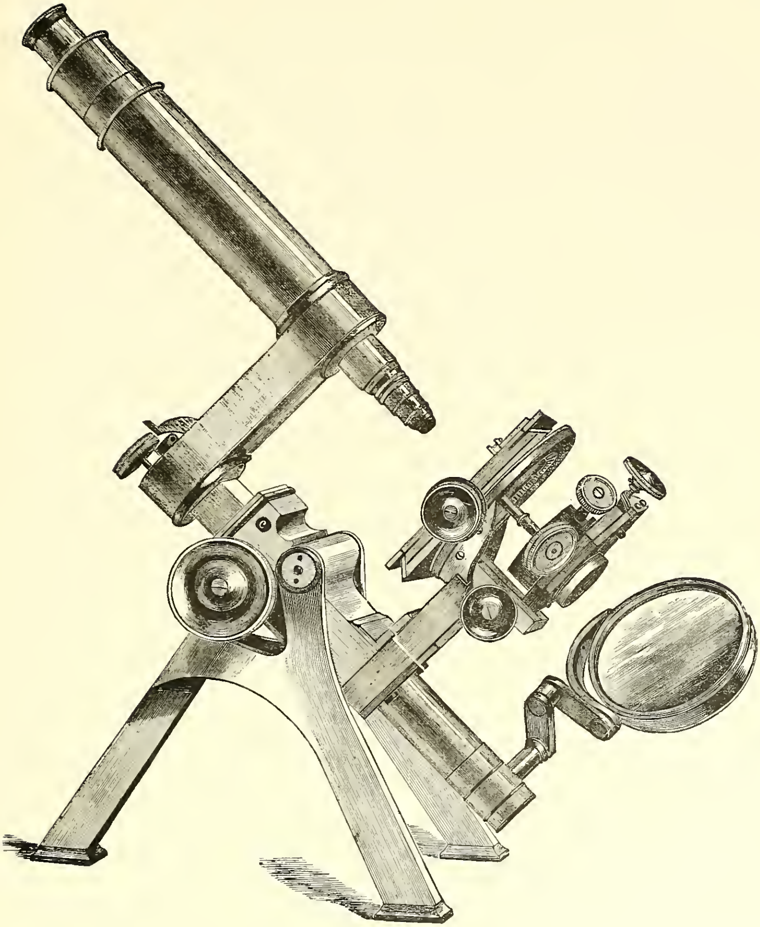


Fig. 140.

anterior focus of the ocular is about 10 inches; as we have already said, it is very important that the optical length of the tube should not vary; its variation, when the image is not altered, does not exceed $\frac{1}{4}$ inch with objectives of $\frac{1}{2}$ inch and upwards.

The 2 inch ocular has the largest field glass that can be used with a binocular, viz.: $1\frac{1}{2}$ inch.

The arm, on which the body is fixed, is $5\frac{3}{4}$ inches long, which not only gives a clearance of $3\frac{1}{2}$ inches from the optic axis, but also permits the use of a long fine adjustment lever. The moveable nosepiece is 3 inches long; it is held at both ends, so that any rocking movement is simply impossible. The fine adjustment screw is placed immediately behind the pivot which holds the bar; this prevents it from communicating vibration to the bar. The coarse movement is effected by rack and pinion.

The stage is fixed to a strong brass bracket; a carrier is fitted to it, possessing rectangular movements, made by rack and pinion, and by a screw, giving movements of 1 inch in each direction. The milled heads which produce these movements do not follow the movements of the stage, but always remain at least $\frac{1}{4}$ inch from the moveable parts when they arrive at the end of the course.

The stage can, by means of a rack and pinion, be rotated through a whole circle. The optic axis passes through the centre of rotation.

A graduated arc of silver enables angles to be measured. The moveable plates of the stage are furnished with verniers registering movements of 1-100th of an inch, and can be used as finders. The divisions correspond to the divisions of a Maltwood Finder.

The opening of the stage is very large, so that the finger may be inserted for the purpose of feeling the working distance between the objective and the preparation, with the view of preventing the breakage of the cover glass.

The sub-stage has two mechanical movements, viz., rectangular and rotary. The sub-stage is centred by milled heads.

The mirrors—plane and concave—are large, and fitted on a double-jointed arm. All the moving parts are sprung, and can be tightened up if they show the slightest play.

The instrument can be instantly changed into a binocular microscope by unscrewing the monocular tube at the arm and replacing it by the binocular tubes, and inserting the prism.

The price of this instrument as a monocular, with two oculars, is

£42. Its price is £45 when the sub-stage is furnished with fine adjustment for focussing.

The large compound microscope, stand No. 2, although smaller than No. 1, is almost similar in construction. It differs, however, in four points: 1st, the moveable plates of the stage have only a maximum motion of ¾ inch instead of 1 inch. 2nd, the stage is not rotating, but the upper part of the carrier, which keeps the preparation in position, can be turned about the optic axis. 3rd, the carrier is without verniers; and 4th, when the instrument is inclined in a horizontal position, the distance between the optic axis and the surface of the table is less than 25 centimetres (10 inches). This monocular instrument with two oculars costs £28.

Further, for the sum of £20, the compound microscope No. 3 can be obtained. It is of smaller dimensions than No. 2, and the sub-stage is without rotary and rectangular mechanical movements, which are replaced by mechanical eccentric centering movements.

The objectives of these makers, as we have previously said, are of the highest finish. We have at different times examined a certain number of them, but we give detailed notes only of the two following, which we have had in constant use.

1-8th inch new formula, which is in reality a 1-10th inch, is an objective of great beauty. It has two frontals, one to be used dry and the other as an immersion. The first has rather a short working distance, which becomes troublesome when examining many preparations, but that of the second is much longer, and allows cover glasses to be comparatively thick. The optical power of the two frontals scarcely differs; but we think we may say that we prefer the objective as an immersion.

The total angle of aperture is 140°. Measured in air by Govi's method, we find the useful angle to be 127°.

The images given by this objective are of extreme purity and clearness, leaving absolutely nothing to be desired.

With central illumination, and with a very small diaphragm, we have been able to obtain perfect resolution of the 9th group, and feebly of the 10th group of Nobert's 19 group test.

With the same illumination the *Pleurosigma* is also very clearly resolved into beads, and the objective shows the pygidium of a flea perfectly. The definition, moreover, is as good as it can be, and the depth of focus is considerable. All the requisite conditions for histological study are, therefore, perfectly fulfilled.

The objective is equally efficient with oblique illumination. All the usual tests, including the difficult *Amphipleura pellucida*, are resolved by simple lamp illumination.

The use of monochromatic sunlight, obtained by means of a bath of ammoniacal sulphate of copper, has enabled us to resolve the last number of Nobert's 19th group test.

1-8th inch aprochromatic of last year may be considered as one of the finest objectives made up to the present time. The N.A. is 1·4, the luminosity is very considerable; the images are very bright, sharp, and colourless. With axial illumination Nobert's 12th group is visible, and with oblique light the 19th group is perfectly resolved. *Amphipleura* is resolved into beads, with oblique monochromatic sunlight.

1-10th inch apochromatic, N.A. 1·50, is a very remarkable objective, and considerably superior to the previous one. The images which it gives are very beautiful. Unfortunately its price is so large as to make it inaccessible to most workers.

Of the many objectives made by Messrs. Powell and Lealand, we will mention the following:—

Nominal Focus.	Numerical Aperture.	Price.
	Dry Objectives.	
		£ s. d.
4 inches	·08	1 10 0
3 ,,	·09	2 15 0
2 ,,	·13	2 15 0
1 ,,	·26	3 3 0
2/3 ,,	·39	5 0 0
1/2 ,,	·57	5 0 0
1/4 ,,	·94	8 10 0
1/10 ,,	·94	10 0 0
	Water Immersion Objective.	
1/8 ,,	1·26	12 0 0
	Homogeneous Immersion Objectives.	
1/8 ,,	1·29	12 0 0
1/8 ,,	1·5	35 0 0
1/12 ,,	1·5	40 0 0
1/20 ,,	1·5	60 0 0
	Apochromatic Objectives.	
1/8 ,,	1·40	25 0 0
1/10 ,,	1·40	25 0 0
1/12 ,,	1·40	25 0 0
1/10 ,,	1·50	50 0 0
1/20 ,,	1·40	40 0 0

Messrs. Powell and Lealand also make a new 1-12th inch apochromatic homogeneous immersion objective with N.A. 1·40, which is sold for £15. This objective is a rapid photographer.

Messrs. Powell & Lealand's Condensers.

Achromatic Condenser of ·99 N.A.	Price	£8	8	0
Achromatic homogeneous condenser, N.A. 1·3	,,	12	0	0
Chromatic condenser	,,	2	2	0
Apochromatic homogeneous immersion condenser, N.A. 1·40	,,	15	0	0

For details of these, see the chapter on condensers, pages 84 and 85. Compensating oculars, £6 10s., for the series of oculars 10, 20 and 30, which form a very useful series.

CARL REICHERT (26, Bennogasse, Vienna).—Although only established a few years, Mr. C Reichert, who was a pupil of Dr. Hartnack, has rapidly taken a prominent position among the makers of the present time. His stands are very elegant, and manufactured with extreme care; while his objectives are certainly accounted to be amongst the best of our day.

The largest model (fig. 141) of this maker can be inclined; the rapid movement is produced by rack and pinion, and the slow movement is effected by a micrometrical screw of great precision, and very carefully manufactured, moved by a graduated milled head. The draw tube is divided into millimetres. The foot, of horse-shoe form, is very heavy, and of great stability.

The stage, which is round and rotary, is divided into 360°, and can be used with a goniometer for the measurement of angles. It is fitted with a mechanical stage (fig. 144*b*), which possesses rectangular movements, and is furnished with verniers.

The illumination apparatus comprises a plane and concave mirror, an Abbe condenser of a numerical aperture 1·20 or 1·40, an Iris diaphragm, the aperture of which can be varied from 1 to 30 millimetres (1-24th inch to 1 and 1-5th inches). The diameter of this aperture is marked on the graduated edge of the diaphragm by the small arm which is used to modify it. The diaphragm has an eccentric movement, enabling oblique illumination, in all directions, to be obtained. All the parts which compose the illuminating apparatus are fixed on one piece, to which a rack and pinion communicates a vertical movement with reference to the stage. The condenser can be removed, and replaced by a diaphragm tube. The price of the stand by itself is £18 8s. The instrument, enclosed in an elegant mahogany case, with lock and key, is sold complete for £70 8s. In this case the stand described above is provided with dry objectives, Nos. 1a, 2, 4, 6, and 8a; water immersion objective 10, and homogeneous objective 19; Huygen's oculars I., III., IV.; compensating oculars

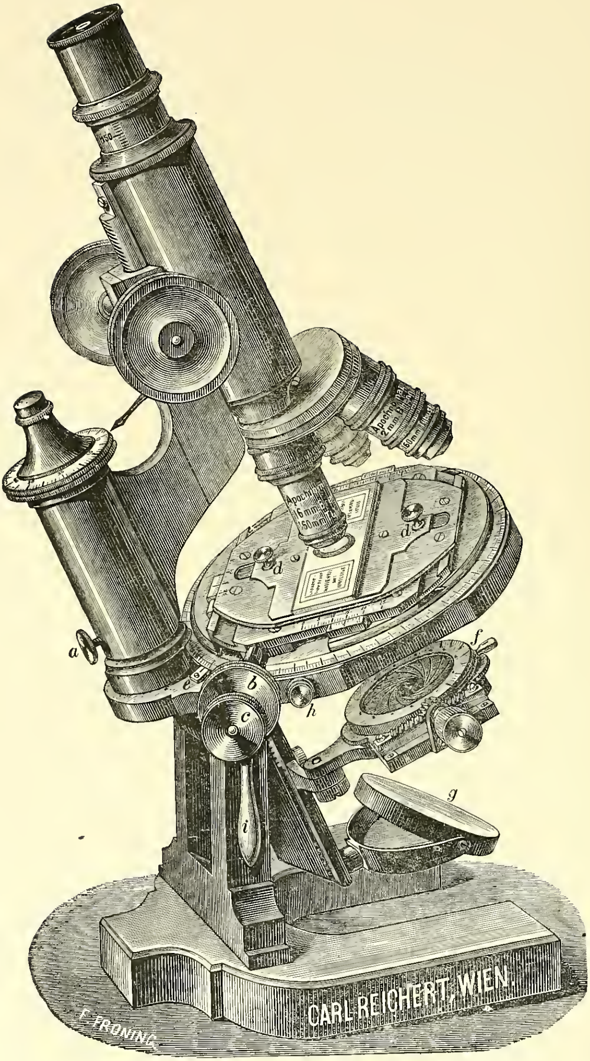


Fig. 141.

4 and 12, eye-piece micrometer II., stage micrometer, camera lucida (the Abbe model), polariscope, saccharimeter with support and reserve

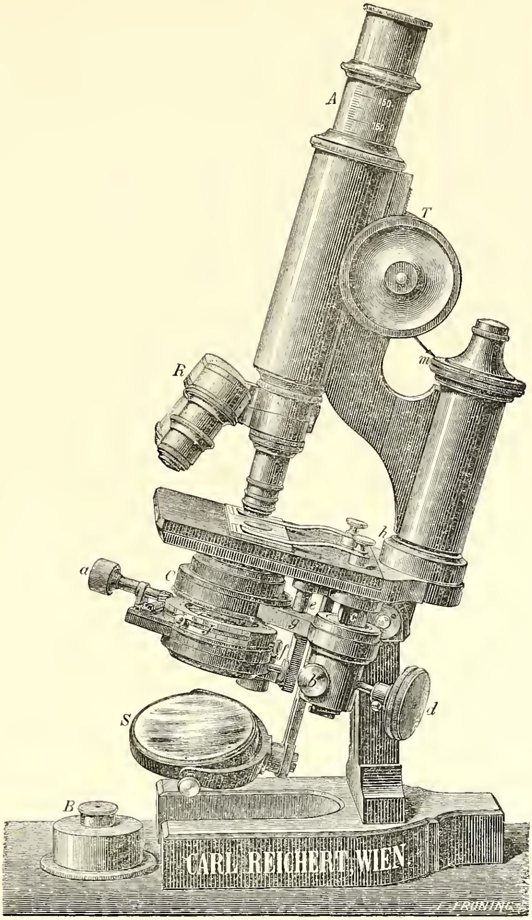


Fig. 142.

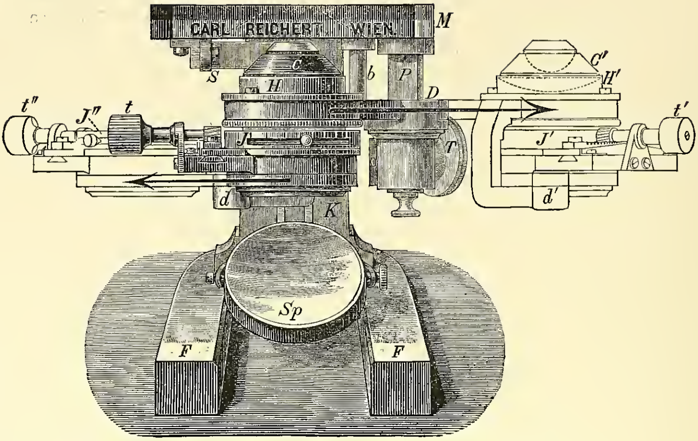


Fig. 142*a*.

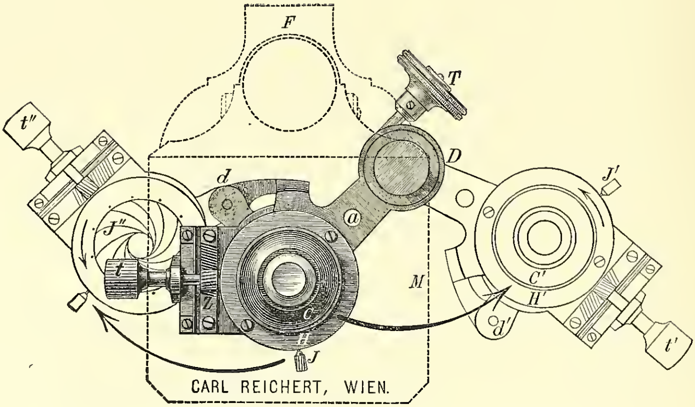


Fig. 142*b*.

tube, spectroscopic eye-piece, bull's eye on stand for the illumination of opaque bodies, dissection microscope magnifying 10, 20, and 30 diameters, hand magnifier after Steinheil, triple nose-piece, microtome, 100 glass slips, 100 cover-glasses, 12 glass slips with pillar, collection of dissecting instruments, including 2 scalpers, 1 bistoury, 1 lancet, 2 preparing needles, 1 pair of straight and 1 pair of curved scissors, 2 pairs of pincettes, and 1 section knife. The instrument, with these accessories, magnifies from 16 to 3,000 diameters.

Another large stand (fig. 142), somewhat smaller than the last, has a fixed square stage, fitted with a mechanical stage, which can be removed at will. This stage is not thick; two guides hold the preparation at the sides, and maintain it in position firmly. These guides are moved by means of milled heads, which act on a rack and pinion for longitudinal, and on a screw for transverse motion. Abbe's illuminating apparatus, furnished with an Iris diaphragm, is adapted to it which can be lifted and lowered by means of a rack and pinion. The mirror is plane and concave. This instrument, which can be inclined, has a graduated draw tube: its rapid movement is effected by rack and pinion, and its slow movement by a very carefully constructed micrometer screw. The foot is of horse-shoe pattern. Without accessories this microscope is sold for £9 5s.

It is usually fitted with Nos. 2, 4, 6 and 8a ordinary objectives, a homogeneous objective 18, oculars IV. and V., a nose-piece for three objectives, eye-piece micrometer II., and costs then £25 5s.

The arrangement of the Abbe condenser in this microscope is quite special. Although Mr. Reichert has for many years carried this arrangement out it has never yet been described. Figures 142*a* and 142*b* illustrate its details.

It will be seen that the condenser H C can be raised or lowered the length of the side bar P by means of the milled head T.

A steel bar *b*, working in the aperture *a*, maintains the centering of the condenser during its movement. This bar is shorter than the hole or recess, so that when the condenser goes beyond the bar it can be turned aside as is shewn in fig. 142*b*.

The other movements are similar to those previously described, with the exception that in Mr. Reichert's either the entire apparatus (condenser and diaphragm carrier) can be turned aside, or only the diaphragm carrier.

Stand No. III. (fig. 143) is an elegant and very well-constructed instrument. Although the price is only the moderate sum of £5 16s., it is furnished with a rapid movement by rack and pinion, slow adjustment by micrometrical screw, and is jointed, so that it can be

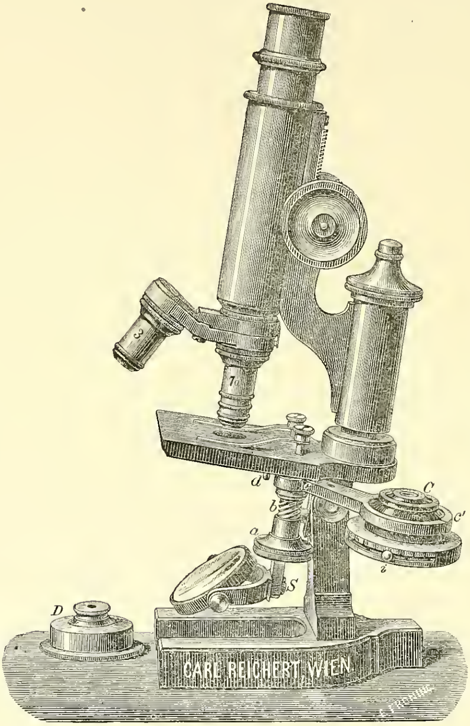


Fig. 143.

placed in an inclined position. There is a draw tube. The diaphragm tube is adapted so that it can be raised or lowered, by means of a rack and pinion, for the regulation of the light. This diaphragm can be easily removed and replaced by a simplified Abbe condenser, furnished with an Iris diaphragm. This instrument is generally sold with a triple nose-piece, two oculars Nos. II. and IV., and three objectives Nos. 3, 7a, and 18b, giving magnifications varying from 50 to 1,500 diameters. The price is then £15 6s.

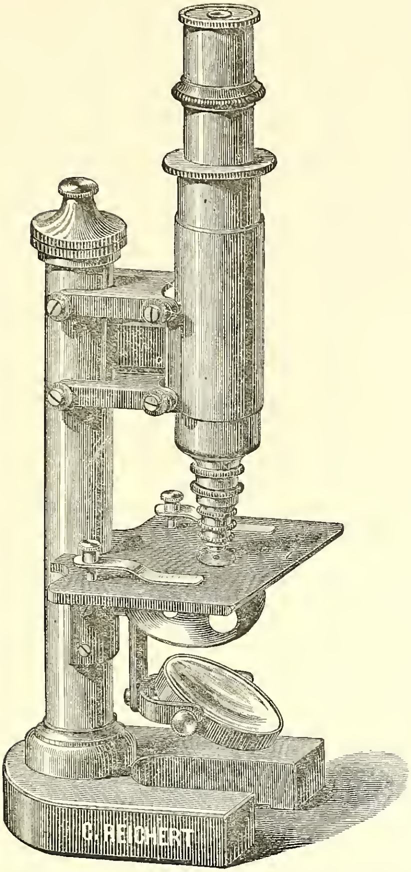


Fig. 144.

Among small stands we will mention No. IV. (fig. 144, 144*a*), which is an erect microscope, furnished with a coarse adjustment made by sliding the body tube, and a fine adjustment made with a micrometer screw acting on a lever. The diaphragm is formed of a rotating disc, which is slightly convex, and has circular openings of different diameters. The plano-concave mirror is jointed, and allows the light to be used obliquely. The price of this instrument, furnished with objectives 3, 6 and 8, oculars II. and IV., magnifying 50 to 880 times, is £6 5s.

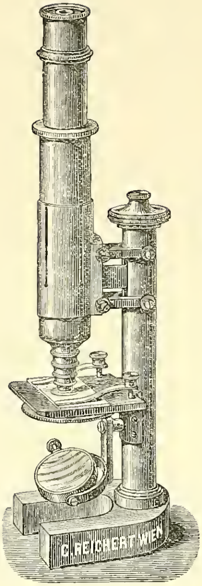


Fig. 144*a*.

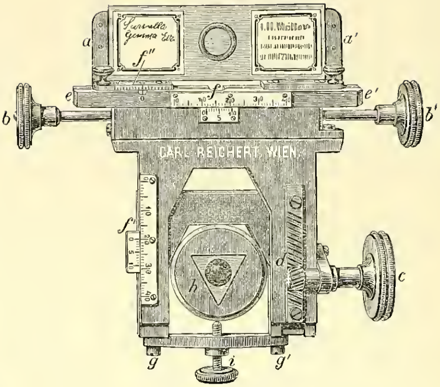


Fig. 144*b*.

We will now examine the objectives of this Viennese manufacturer. The following are the results obtained:—

I.—Achromatic Objectives.

No. 5 ($\frac{1}{4}$ inch) N.A. 0·73.—A very good objective, giving very clear and pure images. It resolves the *Pleurosigma Angulatum* dry, and in Möller's new test it shews *Vanheurckia Lewisiana* and *Vanheurckia Rhomboides* fairly well. The resolving power is also great, and the frontal distance moreover is very great, enabling the superficial examination of objects with cover-glass. With electric light Nobert's 6th group can be resolved in axial and his 10th group in oblique light.

No. 6 (1-5th inch) N.A. ·83.—With central light Nobert's 7th group is resolved; with oblique light the 10th group is; its frontal distance is large.

No. 7a (1-6th inch) N.A. ·83.—Does not differ from the last, except that the magnifying power is rather larger.

No. 8a (1-9th inch) N.A. ·83.—Central light, Nobert's 7th group; oblique illumination, the 11th group, very well.

No. 9 (1-12th inch).—We have examined two objectives of this number, one with an aperture of ·86 and the other of ·98. The first, with the exception of the magnifying power, has the same qualities as the previous one; the second resolves in oblique light Nobert's 12th group. The images are very sharp, and the frontal distance sufficiently large to admit of the use of thick cover-glasses.

Nos. X. and XI. water immersion.—These two objectives are mounted with correction collars. The numerical aperture of the first is 1·22, and that of the second is 1·18. The two objectives are very good, the images pure, clear and strong. One of our Nobert's tests, mounted in the yellow medium, shewed the 18th group very clearly, with No. X. objective. The *Amphipleura pellucida* in Möller's new test plate is shewn fairly well. In the yellow medium it is shewn perfectly; however, in both cases, when its maximum aperture is used, the frustule is slightly deformed.

Homogeneous.—We have examined two numbers: the 1-15th and the 1-20th inch. Both are without correction collars, but, if required, they are made with them. The first (1-15th) has a numerical aperture of 1·26, the second of 1·29.

These two objectives are of great excellence, and are in no way inferior to the best that we have hitherto examined. The images are excessively pure. The 1-20th shows Nobert's 19th group (yellow medium) so well resolved that there is no difficulty in counting the lines. The length of the frontal distance is sufficient to admit of the use of thick cover-glasses, which is seldom the case with other objectives of the same focus in our possession.

The *Amphipleura* is perfectly resolved throughout its length. The aperture of this objective therefore is quite perfect. We can say that few objectives give so flat an image.

II.—Apochromatic Objectives.

Mr. Carl Reichert was the first maker to follow the firm of Zeiss in the manufacture of apochromatic objectives. We gave a description of his apochromatic objectives in the Bulletin de la Societé Belge de Microscopie, dated 30th June, 1888.

His apochromatic objectives are six in number at the present time, as follows:—

An objective of 2-3rd inch.
" 1-3rd "
" 1-6th "
" 1-12th " N.A. 1·25.
" " " N.A. 1·30.
" " " N.A. 1·40.

We have had occasion to make an exhaustive examination of the 1-6th, and of two of the 1-12ths.

The 1-6th, a dry objective, which Mr. Reichert calls a "4 millimetre focus," has undoubtedly the greatest resolving power of any that we have hitherto examined.

It has a correction collar, and is made for the Continental tube of 16 centimetres (6⅓ inches); the correction is so extensive that a longer tube can be used without the image materially loosing brightness.

The numerical aperture is given by Mr. Reichert as ·95. We however find that that figure is surpassed.

The images are very bright and pure. With axial illumination the *Pleurosigma angulatum* mounted dry, as well as in styrax, is completely resolved; the marks of exclamation in the *Podura* (the only real test of apochromatic perfection) are clearly defined, are of a good black colour, and possess long light strokes, which are perfectly colourless.

With oblique illumination, the *Vanheurckia rhomboides* of Möller's test is resolved. With monochromatic sunlight the striæ of the *Amphipleura* can be seen, but its definition leaves much to be desired.

In the yellow medium and with electric light, the 10th group of Nobert's test can be seen with axial illumination, and the 15th group can be perfectly resolved with oblique illumination.

Although this resolving power is excessively large for a dry objective, nevertheless, the frontal distance, though naturally very small, is still quite sufficient for all ordinary observations. One of the 1-12th inch objectives which we have examined is made for the Continental, and the other for the English tube.

The first has an aperture of 1·3, the second of 1·4.

The 1-12th (2 mill.), made for the Continental tube, leaves nothing to be desired. With axial illumination the marks of exclamation on the *Podura* are clear, and of a good black colour, also the light stroke is very long.

All the tests, including Nobert's 19th group, are resolved by this objective with the greatest clearness.

We have not succeeded in resolving the *Amphipleura* with perfect clearness into beads by transmitted light. We think that the aperture of 1·3 is not sufficient for that purpose.

The second objective intended for use with the English tube is quite similar to the previous one, but the image surpasses in purity that given by the preceding.

III.—New Semi-Apochromatic Objectives.

Mr. Carl Reichert calls by this name objectives which only differ from apochromatics in the absence of fluorite in their composition.

We have in our possession one of these objectives, a 1-15th of N.A. 1·4.

The price of this objective is only £10. The images of the *Podura*, &c., have a little red colouring, as well as a slight secondary spectrum. But with the exception of this trifling defect, which can only be appreciated in photo-micrography, the objective is quite irreproachable, and the most difficult tests, such as Nobert's 19th group, are resolved with the greatest clearness and without much difficulty.

We cannot too strongly recommend this objective to every conscientious worker who does not wish to make photo-micrography his favourite study, since the objective is quite suitable for the most difficult researches, which an extensive use of this objective has sufficiently demonstrated.

In conclusion, we will give a summary of the different objectives made by Reichert :—

Number of Objective.	Focus.		Numerical Aperture.	Price.		
	Mill.	Inches.		£	s.	d.
Dry Objectives.						
0	60·5	2 1/2	—	0	11	0
1	40·0	1 1/3	—	0	11	0
1*a*	40·0	1 1/3	—	0	17	0
2	30·0	1	·17	0	17	0
3	15·5	1/2	·34	0	17	0
4	9·2	1/3	·50	1	4	0
4*b*	12·1	2/5	·35	1	4	0
5	5·4	1/4	·65	1	8	0
6	4·3	1/5	·77	1	10	0
7	2·8	1/8	·82	1	10	0
7*a*	3·6	1/6	·82	1	16	0
8	2·2	1/10	·87	1	15	0
8*a*	2·8	1/9	·87	2	0	0
9	2·0	1/12	·95	2	12	0
*9	2.0	1/12	·95	3	10	0

Water Immersion Objectives.

10	1·8	1/12	From 1·10 to 1·20	3 10 0
*10	1·8	1/12	,, ,,	4 10 0
*11	1·3	1/18	,, ,,	5 10 0

New Semi-Apochromatic Objectives.

12	3·6	1/6	From 1·30	8 0 0
18	1·8	1/12	,, 1·30 to 1·35	8 0 0
19	1·3	1/18	,, 1·30 to 1·35	12 0 0
18*a*	1·8	1/12	,, 1·40 to 1·43	10 0 0
18*b*	1·8	1/12	,, 1·20 to 1·25	5 0 0
19*b*	1·3	1/18	,, 1·20 to 1·25	8 10 0

Apochromatic Objectives.

Dry	16	2/3	·30	4 0 0
,,	8	1/3	·50	1 12 0
,,	4	1/6	·95	8 0 0
Homogeneous	2	1/12	1·25	12 0 0
,,	2	1/12	1·30	16 0 0
,,	2	1/12	1·40	20 0 0

* These objectives have correction collars.

Mr. Ferdinand Van Heurck, Rue du Moulin, Antwerp, is the authorized agent for Belgium and Holland for Mons. Carl. Reichert.

ROSS & CO. (112, New Bond Street, W., London). The firm founded by the celebrated Andrew Ross still enjoys a well-merited reputation. They make a large number of stands, of which we will describe two which are of exceptional merit.

The Microscope called *Wenham's Radial* (fig. 145), was made with the special object of obtaining the largest amount of light in every direction with oblique illumination, and in all its inclining and rotating movements the centre of the object is taken as the common centre of rotation.

To attain this object Mr. Wenham, the originator of this type, has furnished it with the following contrivances:—

1. A sector sliding in two grooves allows it to assume every position between the vertical and horizontal.

2. The entire optical apparatus can be inclined either to the right or to the left without moving the foot.

3. The entire optical apparatus can be rotated about the illuminating apparatus.

4. The mirror and sub-stage can be used in any oblique position that may be desired; the stage of the microscope contains the centre of these movements.

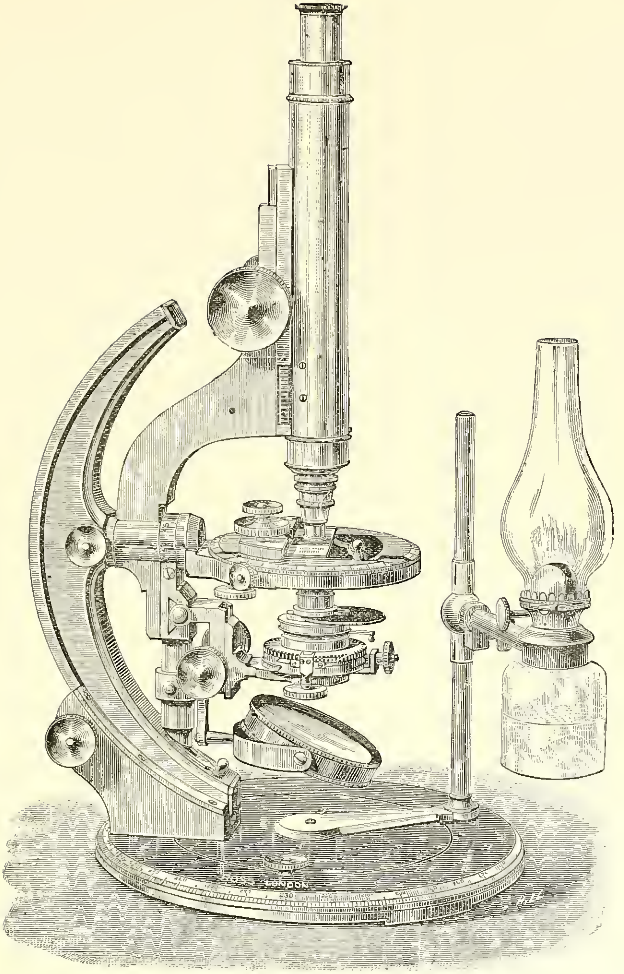


Fig. 145.

5. The stage can make a complete revolution about the optic axis, and can be centred for different objectives.

6. The illuminating apparatus can be used in all positions that may be desired, and can, while the microscope remains fixed, describe nearly a complete circle about the latter.

7. The slow movement consists of a new system, and is the first of its kind made. It works easily and with the greatest sensibility, and when once an object is focussed it remains in exactly the same focus so long as the milled head of the adjustment screw is not touched.

In this slow movement the inner tube, which is guided for some considerable distance, travels when pushed by an excessively fine graduated screw. At the same time, a spring placed in a barrel outside the tube presses a brass cylinder, which fits exactly into the barrel and constantly tends to draw it back into the tube of the microscope.

The milled head of the fine adjustment placed at the end of a long steel bar is close to the ocular. At first sight this position appears inconvenient, but one soon gets used to it, and ultimately it proves to be an excellent arrangement.

The form of this microscope differs from all that we have seen, and is likely to surprise, if not to displease, at first.

These fears are without foundation; many years' use of the instrument has proved it to be one of the best pieces of apparatus in our collection, very convenient for actual work, and, moreover, indisputably stable.

Figures 146, 147, 148, and 149 show the different positions which

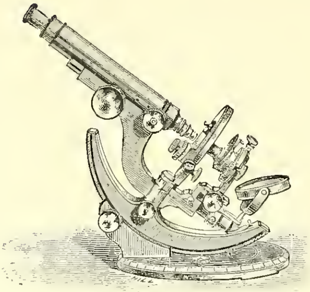


Fig. 146.

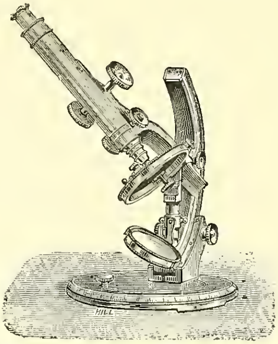


Fig. 147.

the instrument can assume without a moment's preparation, which thus proves its utility.

The price of this stand varies from £42 with the monocular, to £50 with the binocular tube.

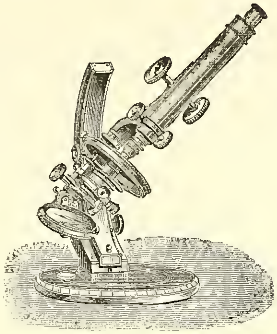


Fig. 148.

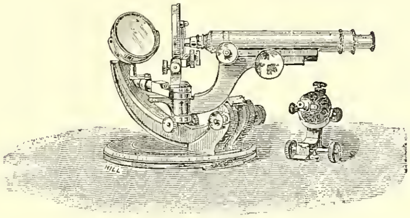


Fig. 149.

The second large model is the *Ross-Zentmayer No. 1 Microscope* (fig. 150). The stage of this instrument is thin, and the sub-stage, can be made to assume every possible inclination round the object which is the centre of all the movements of the instrument. As in the Radial, the mirror can, if desired, illuminate the object from above, and all the angles of inclination can be read off the graduated scale, which is engraved on the upper part of the pillar which carries the sub-stage and mirror.

There is a mechanical stage; its coarse adjustment is made by rack and pinion, and the fine adjustment by lever.

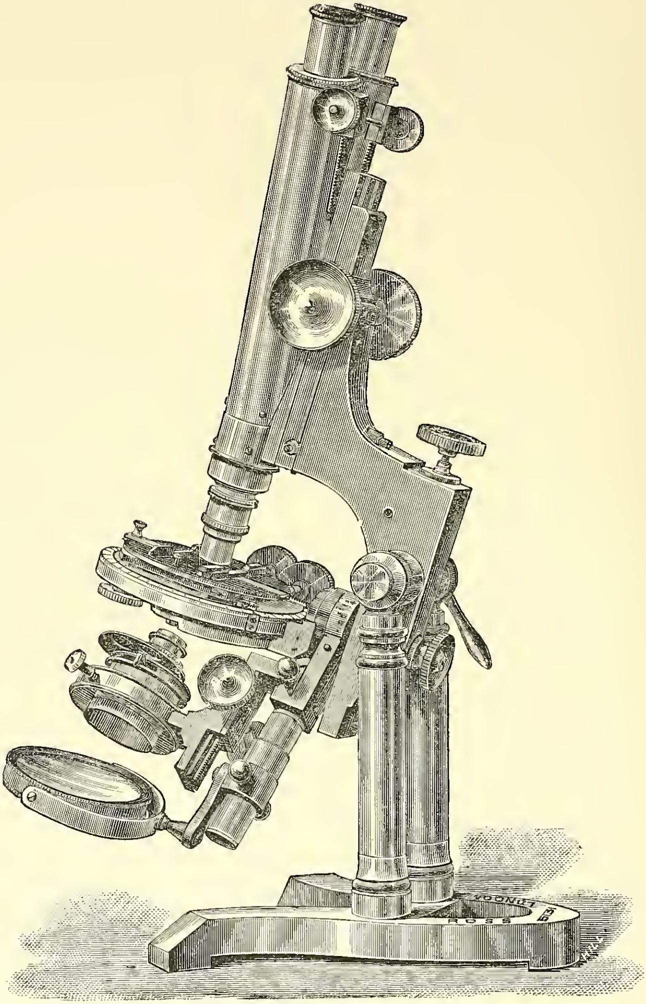


Fig. 150.

This instrument is hung between two pillars, and can be fixed at any inclination.

The price of this stand is £29 4s. with the monocular tube, and £31 with binocular.

Messrs. Ross & Co.'s objectives are constructed by a special method, invented by Mr. Wenham. They are reduced to three simple lenses, one of which is of dense flint, and the other two of crown.

The following is the result of an examination of these objectives:—

½ *inch.*—Images excessively clear. With central light, definition is perfect, and the pygidium of a flea is seen in a very remarkable manner for so low a power.

With oblique light the *Pleurosigma angulatum* can be resolved, but the colouring is, however, too strong.

1-7*th inch.*—This objective is excellent; as well as Messrs. Ross and Co.'s 1-5th, 1-10th, 1-15th, and 1-25th; they can be used as dry or immersion objectives as desired, by simply altering the correction. The extreme angle of aperture of this objective is 130°. It shows the 8th group of Nobert's test very well with central light. Its frontal distance, which is very large, makes it a very valuable objective for ordinary use. The purity of the images leaves nothing to be desired.

1-15*th inch.*—The angle of aperture of this objective is 150°. It shows the 9th group of Nobert's test fairly well in central light.

The images are very pure, and its frontal distance is pretty considerable.

The pygidium of a flea is admirably defined with central light, and with monochromatic oblique light all known tests can be resolved.

The following is the series of objectives manufactured by Messrs. Ross & Co.:—

Series of low powers.

Objective.	Aperture.	Magnification.				Price.		
		A	B	C	D	£	s.	d.
*4 inch	9°	12	18	25	40	1	11	6
*3 „	10°	15	20	35	50	2	2	0
3 „	12°	15	20	35	50	3	3	0
*2 „	12°	25	40	60	100	2	2	0
2 „	15°	25	40	60	100	3	3	0
*1½ „	15°	35	60	95	150	2	2	0
1½ „	20°	35	60	95	150	3	3	0
*1 „	15°	50	80	125	200	2	2	0
1 „	25°	50	80	125	200	3	10	0
2/3 „	35°	80	130	200	300	3	10	0

Series of Ordinary Objectives.

Objectives.	Aperture.	Magnifications.						Price.		
		A	B	C	D	E	F	£	s.	d
1/2 inch	45°	100	160	250	400	500	800	4	4	0
1/2 ,,	80°	100	160	250	400	500	800	5	5	0
3/10 ,,	60°	165	265	410	660	820	1300	4	10	0
3/10 ,,	90°	165	265	410	660	820	1300	5	10	0
1/5 ,,	85°	250	400	620	1000	1250	2000	5	5	0
1/5 ,,	120°	250	400	620	1000	1250	2000	6	6	0
1/7 ,,	130°	340	540	850	1300	1700	2700	7	7	0
1/10 ,,	140°	500	800	1200	2000	2500	4000	9	9	0
1/15 ,,	150°	750	1200	1800	3000	3700	6000	12	12	0
1/25 ,,	160°	1200	2000	3100	5000	6200	10000	21	0	0

W. & H. SEIBERT (formerly Seibert and Kraft), of Wetzlar, Prussia.—This firm manufactures excellent microscopes; the mechanical part, being as carefully constructed as the optical, leaves nothing whatever to be desired. Their large stand (fig. 151) has a very heavy brass foot, from which rises an arm which bears the entire mechanism in such a manner that the microscope can be inclined at all angles. The instrument is rotary. The double stereoscopic tube can be replaced by a monocular tube.

The instrument has three movements: a rapid movement by rack and pinion, and two slow movements—one for medium magnification and the other for very high powers. These two movements are said to be *frictionless*, like the one we shall describe later on, and that all shaking is quite prevented. The milled head of the adjustment screw for high powers is graduated.

The Abbe illuminating apparatus is moveable, and can be centred by means of springs, and is furnished with an Iris diaphragm.

The entire illuminating system can be easily removed and replaced by the usual sub-stage apparatus, such as the diaphragm tube, polariser, &c.

The stage, made after English models, is moveable in two directions and furnished with verniers. This stage can be removed at will, and can be replaced by a smooth round stage, graduated and furnished with a centering screw, allowing the glass slip to be moved within narrow limits.

Enclosed in a box the stand just described costs £19; without the mechanical stage it costs only £15.

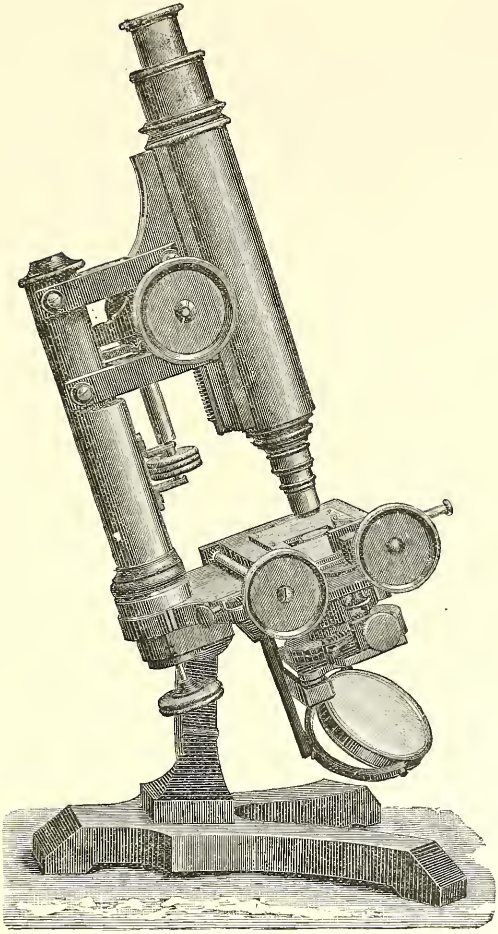


Fig. 151.

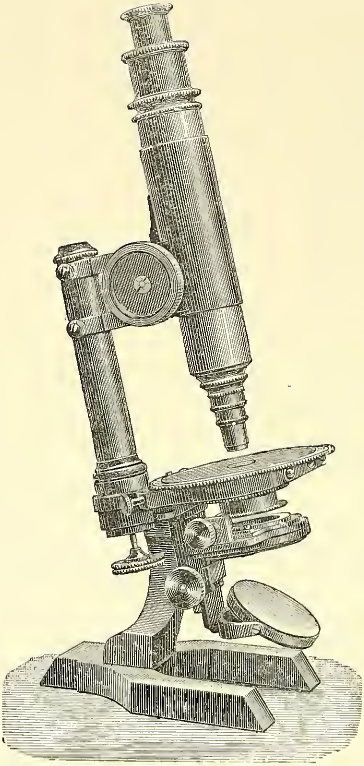


Fig. 152.

The complete apparatus is accompanied by a nosepiece for five objectives, eyepiece micrometer with optional ruling, polarising apparatus with graduated circle, Abbe's camera lucida system, bulls-eye on stand for the illumination of opaque objects, compresser and stage micrometer. Moreover, the instrument has four oculars and all the ordinary objectives from No. O O to No. VII. *b*; apochromatic objectives of 16 mm. (2-3rd in.), 8 mm. (1-3rd in.), and 4 mm. (1-6th in.), homogeneous immersion objectives of 2 mm. (1-12th in.) and 1·5 mm. (1-18th in.) with N.A. 1·30, as well as compensating oculars 2, 4, 6, 8, 12, and 18.

Test objects, slips with hollows, glass slips, and cover-glasses, usually accompany the microscope, which is enclosed in a strong polished mahogany, box with brass fittings, costing £95 10s.

Stand No. 2 (fig. 152), though of smaller proportions, is in construction almost identical with the last. It has only two movements for focussing: the rapid movement by rack and pinion, and the slow movement by micrometrical screw, the head of which is graduated. There is a draw tube, divided by a scale. The stage is rotary, and the illuminating apparatus consists of an Abbe condenser, furnished with an Iris diaphragm. The different pieces of apparatus which accompany it consist of a nose-piece for four objectives, a moveable eye-piece micrometer, polarising apparatus with graduated circle, camera lucida, bulls-eye on stand, ordinary objectives Nos. O to VII. *b*, an homogeneous immersion objective 1-12 inch with 1·3 numerical aperture, and simple oculars Nos. O and I., and periscopic oculars Nos. II. and III. giving magnifications from 18 to 1,500 diameters. The instrument, enclosed in a strong box, with test objects and other accessories, such as glass slips and cover-glasses, is sold for £46 10s.

Microscope No. 4 (fig. 153), with an ordinary stage, can be inclined, and is furnished with rapid and slow movements. Illumination is effected by a plano-concave mirror. Under the stage a system of tube diaphragms is fixed, sliding into grooves.

An Abbe condenser, a triple nose-piece, ordinary objectives I., III., V., and 1-12th homogeneous immersion of N.A. 1·3, oculars I. and III., the latter with micrometer test objects, glass slips, &c., are the accessories which usually accompany this instrument. Thus equipped, stand No. 4 gives a magnification of from 30 to 1,500 diameters, and costs £24 3s.

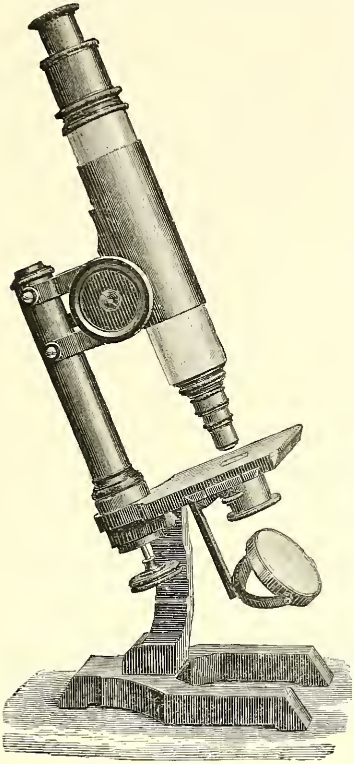


Fig. 153.

The same firm have a considerable number of other models. One of them, No. 5 (fig. 154), which we have examined at leisure, deserves all praise, and is remarkable for its cheapness. Furnished with objectives, Nos. I., III., V., and VII. *b.*, oculars O, I., and III., with micrometer (affording magnifications from 30 to 1,500), and furnished with the usual small objectives, costs £12 12s.

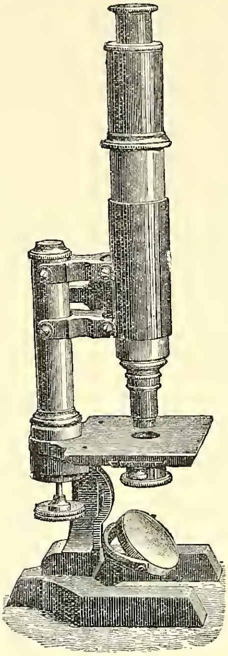


Fig. 154.

The stand has a horse-shoe foot. The stage is very low. The body tube is without a draw tube; it is moved by sliding it in a thick cylinder, a portion of the inside of which is covered with cloth. The screw of the slow movement is under the stage, and the movement differs completely from those we have usually seen.

Lastly, the outside tube of the rapid movement terminates at the side with a square piece of apparatus, some centimetres in length, the end of which is fixed in the cylinder. This piece of apparatus is pressed from above downwards by a spring, and is held at the side by four solid arms, which move diagonally. By screwing or unscrewing the milled head of the fine adjustment at the bottom of the cylinder the microscope tube is raised or lowered. This system is perfectly rigid; the objects remain immoveable during the focussing, and the makers warrant that it will never shake.

The following are the principal objectives manufactured by Messrs. W. and H. Seibert:—

1.—Ordinary Objectives.

					£	s.	d.
No. OO.	of 2½ inches,	numerical	aperture	·09	1	4	0
I.	,, 1½ ,,	,,	,,	·22	0	18	0
II.	,, ½ inch	,,	,,	·22	0	18	0
IV.	,, ¼ ,,	,,	,,	·60	1	7	0
V.	,, 1-7th inch	,,	,,	·90	1	16	0
VI*b*.	,, 1-12th ,,	,,	,,	·90 (with correction)	3	15	0
IX.	,, 1-8th ,,	,,	,,	1·30 (homogeneous immersion)	6	0	0
X.	,, 1-12th ,,	,,	,,	1·30 ,, ,, ..	10	0	0

2.—Apochromatic Objectives.

					£	s.	d.
Focus of	16mm.	(2-3rd inch)	N.A.	·30	3	0	0
	8 ,,	(1-3rd ,,)	,,	·60	4	0	0
	4 ,,	(1-6th ,,)	,,	·95 (correction)	6	0	0
	3 ,,	(1-8th ,,)	,,	1.30 (homogeneous immersion)	16	0	0
	3 ,,	(1-8th ,,)	,,	1.40	21	0	0
	2 ,,	(1-12th ,,)	,,	1·30	13	15	0
	2 ,,	(1-12th ,,)	,,	1·40	14	15	0
	1.5 ,,	(1-16th ,,)	,,	1·30	16	0	0
	1.5 ,,	(1-16th ,,)	,,	1·40	21	0	0

Messrs. W. and H. Seibert's objectives are of excellent quality. We know their apochromatics of recent date, but we have not seen examples of their present ordinary objectives. We will, therefore, examine the two kinds separately.

1.—Achromatic Objectives.

Nos. O. and 1.—Lower power very good; they have a focus of 1¾th and 1 inch respectively.

No. 2.—Excellent objective of ½ inch; it shews the pygidium of a flea fairly well. The details of a transverse section of *Pinus* are seen with great clearness, but there are some slight traces of iridescence.

No. 3 (1-3rd inch).—This objective, which has 38° of useful aperture, gives in the same manner a very slight red border to the section of *Pinus*. It shows the pygidium of a flea very well.

No. 4 (1-4th inch) has a useful aperture of 80°, shows the pygidium well, and resolves in central light *Hipparchia Janira*, as well as the 14th group of Nobert's test.

No. 5 (1-8th inch) has a useful angle of 110°; resolves clearly Nobert's 16th group with central light. With oblique light it resolves No. 15 of Möller's tests.

No. 6 (1-12th inch, with correction). Good objective, having an angle of 124°. It shows the *Pleurosigma* with central light, and resolves Nobert's 7th group very well with the same light. With oblique illumination Möller's 15th number is perfectly, and his 16th is feebly seen.

No. 7 immersion and correction (1-16th inch). This objective resolves Nobert's 8th group very clearly with central light and the *Amphipleura* with monochromatic light.

2.—Apochromatic Objectives.

8 mill. (1-3rd inch). We had occasion a year ago to examine one of these objectives belonging to a friend. We have mislaid the notes which we took at that time, but we recollect that the images were very pure, that the *Pleurosigma* was seen with oblique illumination, and that the photographs of textile fibre, for which we used it, left nothing to be desired.

1·5 mill. (1-16th inch) homogeneous immersion, dating from 25th May, 1891. Excellent objective, having a very considerable frontal distance for its focal length.

The *Pleurosigma angulatum* is resolved clearly into hexagons with axial illumination, the pygidium giving very clear and pure images.

The *Podura* gives very pure and colourless images. Lastly in the Nobert test the 12th group is clearly resolved with axial illumination, and the 19th very well with oblique illumination.

The Antwerp Exhibition afforded us an opportunity of examining the other apochromatic objectives of these makers. All of them gave perfect images and left nothing to be desired.

H. R. SPENCER, (515, Rhode Island Street, Buffalo N.Y.).—The firm of Spencer has been renowned for some time; the first information which we have about this house dates from 1848; at that time this optician's objectives were noted as surpassing those made in Europe. Shortly after, in 1852, Spencer manufactured a 1-12th inch objective having 174½°, the first having so large an angle of aperture.

The firm of Spencer has always maintained its old reputation. We are not acquainted with their stands, but their objectives deserve all praise. At different times we have used excellent ones of their make, and we have in our possession one of their latest, made about a year ago.

This objective, which enjoys an immense reputation in the United States, is a 1-12th inch, N.A. 1·37.

The objective has a correction collar; it can be used as a water immersion for axial, and with an homogeneous mixture for oblique, illumination.

This liquid need not be the oil of cedar, and indeed the maker advocates a special liquid, consisting of a solution of chloride of tin in glycerine.

The construction of this object is quite special, and differs slightly from the general type now adopted. The optical system consists of a double frontal, surmounted by a single moveable and very thick lens.

The images given by the objectives are coloured red slightly, depending probably on its construction; but with the exception of this slight defect we consider the objective to be one of the best of the present date, and we have obtained some of our best photographs with it.

With axial illumination the pygidium and the *Podura* give very clear images, and Nobert's 12th group is well resolved. With oblique light Nobert's 19th group shows up well, and with both electric and sunlight the resolution of the *Amphipleura* into beads is easily obtained.

JAMES SWIFT & SON (81, Tottenham Court Road, London) are well-known manufacturers of microscopes and photographic lenses.

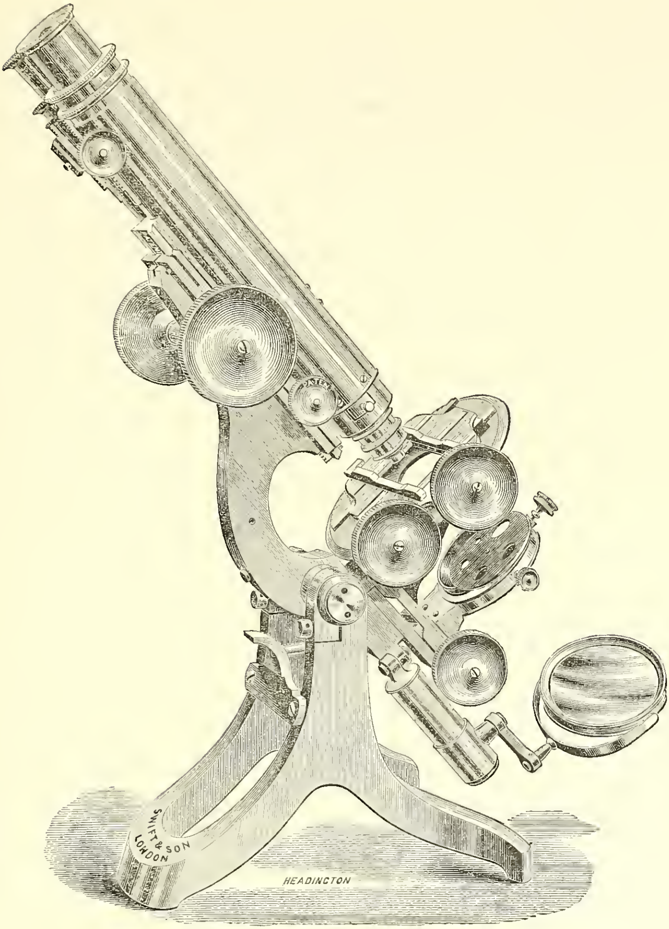


Fig. 155.

Messrs. Swift's stands are numerous, the most interesting being the following :—

The *Challenge Microscope*, very similar to Messrs. Watson's Scientist (described later); this instrument, which was made in the first place by Messrs. Swift, differs from that of Messrs. Watson principally in the fine adjustment, which is of a special form, and in the stage. The price of this instrument with 1 inch and $\frac{1}{4}$ inch objectives, bull's-eye condenser on stand, in cabinet, is £20.

The *Challenge* A (fig. 155) is a simpler form, and only costs £15 8s.; but the illuminating system is too elementary for serious work. To this the sub-stage must be added, entailing an additional charge of £2 6s.

The *Seaside Microscope* has still to be noticed.

This microscope, as its name suggests, is made with the object of occupying the smallest possible space. It is furnished with a folding stage, rapid movement by sliding the tube, slow movement enclosed in the leg of the tripod, upon which the instrument stands, an ocular, and an inch objective (figs. 156 and 157). It can be packed in a box 15 centimetres (6 in.) long, 7 centimetres ($3\frac{3}{4}$ in.) wide, and 5 centimetres ($1\frac{3}{4}$ in.) deep. The price of this microscope is £3 10s.

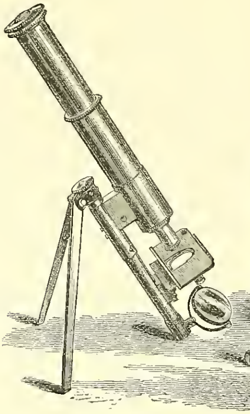


Fig. 156.

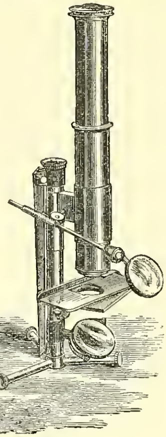


Fig. 157.

The small pocket microscope, represented in figures 158 and 159, should also be mentioned. It can be conveniently carried in

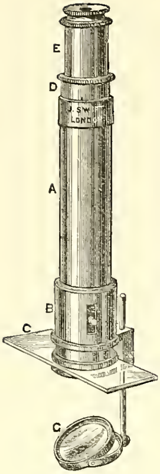


Fig. 158.

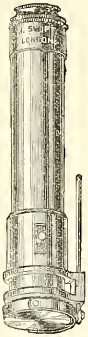


Fig. 159.

the breast pocket, for when the apparatus is closed it is only 7 centimetres (3 inch) in length and 2 centimetres ($\frac{3}{4}$ inch) in diameter. One of these figures represents the microscope closed, and the other the instrument ready for use. The preparation C is held firm by a small tube B, containing a spiral spring. The rapid movement is made with the tube D, and the slow movement by the tube E, which contains the ocular. The microscope furnished with an ocular and objectives of 1 inch and 1-5th inch, costs £5.

Not having seen any recent objectives of this maker, we cannot give an estimate of their value. Those which we examined in 1878 were good (see Third Edition, p. 172).

WATSON & SONS, (313, High Holborn, London). — This firm only commenced to construct microscopes seriously a few years ago, but the progress which it has made in this branch has been so rapid and pronounced that upwards of 3,000 have already been produced.

The stands made by this firm are numerous, but we will only describe the most important :—

The *Swinging Sub-stage Microscope* is of the Zentmayer model. The instrument is mounted on double pillars, fixed to a rotating graduated base plate, which rests on a tripod foot.

The stage is excessively thin, consisting of a base plate, having a rotary motion, on which rests a second very thin plate, to which vertical and horizontal motions can be given by means of two milled heads, placed one above the other and acting upon one axis.

The rapid movement is given with a rack and pinion having oblique teeth, and the slow movement is produced by a lever, which communicates to the tube a very even and precise movement. The tube is binocular, and carries a Wenham prism, which can be removed when desired, so as to render it monocular.

The sub-stage can describe almost a complete circle about the stage, which forms the centre of all the movements of the microscope. A graduated scale enables the angle of inclination used to be registered.

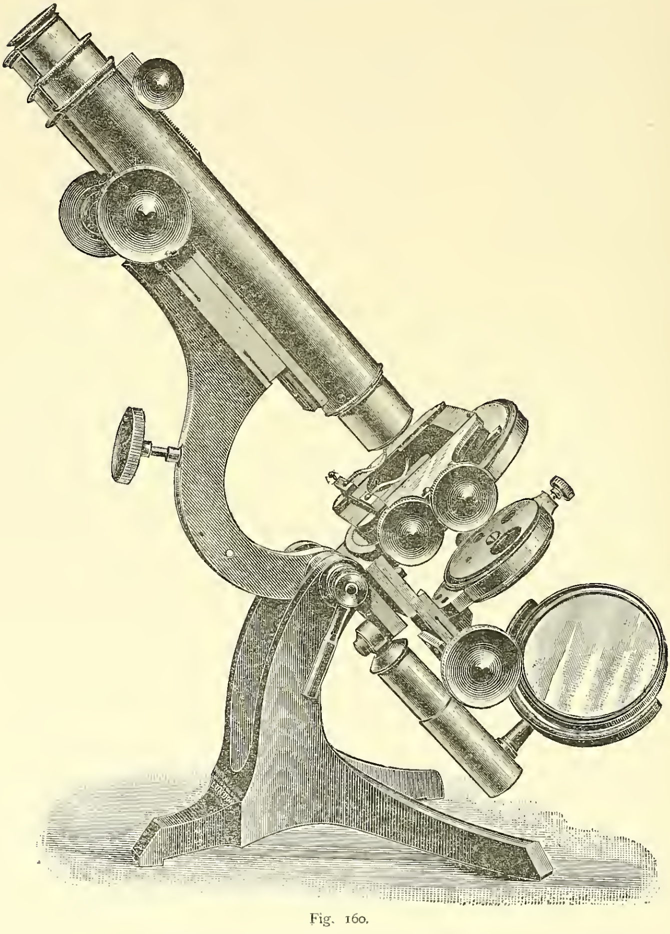


Fig. 160.

The price of this instrument, furnished with a binocular tube, is only £25.

The *Scientist's Microscope* (fig. 160) is an instrument supported on a massive foot, with two upright sides, between which it is mounted.

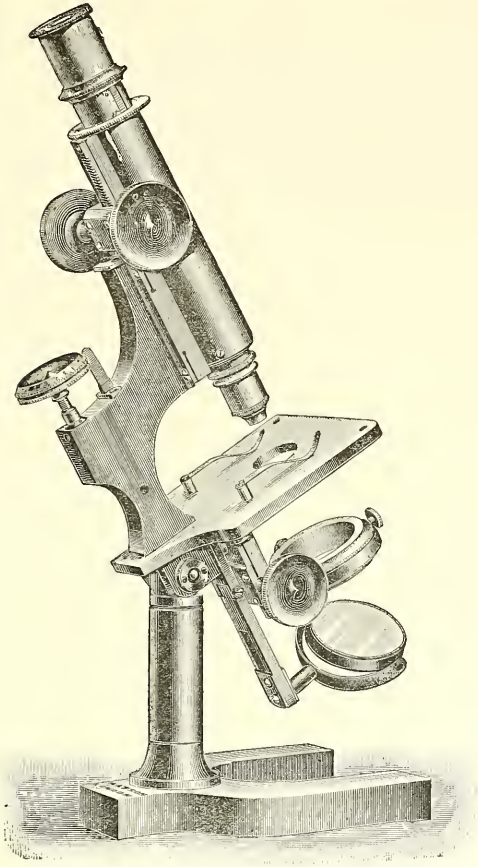


Fig. 161.

The mirror can be inclined at any angle, and the sub-stage, which can be centred, can be withdrawn from the axis of the instrument.

The mechanical stage consists of superposed plates.

The rapid movement is obtained by a rack and pinion having diagonal teeth, the slow movement by a very sensitive lever.

The tube is binocular.

The apparatus costs from £17 to £20, according to its finish.

The *Edinburgh Microscope* (fig. 161) is an instrument which Messrs. Watson have already supplied in large numbers, and of which they make several kinds, of different degrees of completeness.

One of these, which may be considered as the medium model, is called stand C.

The foot is of a horse-shoe pattern; the microscope is mounted on a single pillar, and can be inclined.

The mirror can be adjusted obliquely, sideways, and forwards.

The sub-stage can be raised and lowered by rack work, and adjustment screws allow the condenser to be centred.

The body tube is moved with a rack and pinion, and the fine adjustment, which is effected with a lever, is of great precision.

The price of this stand is only £6 6s.

But the most perfect instrument of these makers, one we may add, of the most precise and most convenient which at present exists, is that which the makers call **Dr. Henri Van Heurck's Microscope for the study and photography of Diatoms and all delicate researches.**

In this microscope (fig. 162), which Messrs. Watson and Son have been good enough to make according to our specification, we have endeavoured to combine convenience for ordinary work, with the utmost possible precision, at a comparatively low price.

Messrs. Watson have admirably carried out all the plans which we have submitted to them, and the instrument they have produced may be justly considered, as we shall see later on, to be a perfect instrument, and one which has realised in various respects a degree of perfection which has not hitherto been attained.

The base of the instrument is of the horse-shoe form, and is bronzed; at the three points on which it stands are three holes, in which slightly projecting pieces of cork are inserted. This cork reduces any vibration which may be communicated to the instrument by the table on which it rests, and also prevents the instrument from

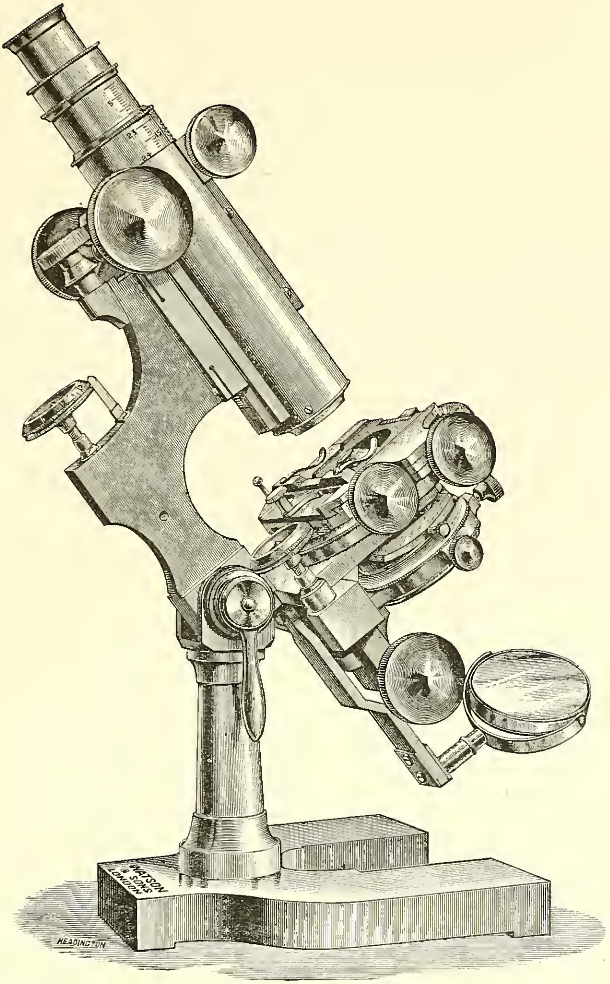


Fig. 162.

slipping and avoids the scratches which the sharp angles of the base would otherwise make on a polished table.

A substantial brass pillar, jointed in its upper part to allow the instrument to be inclined, supports the whole microscope. The microscope is also made with a brass tripod, to meet the requirements of certain purchasers (fig. 162*a*). When the instrument is inclined, this tripod gives a little more stability than the pillar; on the other hand, the pillar allows the various pieces of apparatus placed in the sub-stage to be managed with greater ease when the instrument is used in a vertical position for photo-micrography. The microscope can be fixed at any angle by means of a clamping screw, although the instrument is so well balanced as to render this almost unnecessary.

To reduce vibration to a minimum, all the parts of the instrument are made as if cast in one piece. The stage support is in one piece, and is prolonged into the articulation at the top of the pillar; in the same way the limb fits into the stage support and is fixed by six screws, so that the whole has the same rigidity as if it formed a single piece. Finally, the two pieces fitted together are traversed by a bolt on which is the clamping screw for the inclination.

The stage turns on its own axis; and instead of small gliding plates to keep the rotating circle to its bearings, there are three plates with double springs. The result is that a very soft rotation is obtained, and at the same time a perfect rigidity in any position, and this also without using a cog-wheel, which generally gives little jerks after it has been used some time.

The mechanical movements (horizontal and vertical) are effected by two superposed plates, as in the old Ross stands, actuated by lateral screws. The object rests upon a sliding bar, provided with a stop pin and clamping screw.

For ordinary work, the sliding bar can be replaced by a fixed plate, provided with two clips.

The horizontal and vertical movements have a range of 25 mm. (1 inch): the divided scales (finders) allow a reading of the movements to 1-10mm. by means of verniers. At the request of the purchaser, the stage can be made with centering movements; such is the case in the instrument in our possession.

The limb incloses the fine adjustment, and carries the tube in front; both the coarse and fine adjustments move in bearings which can be loosened or tightened as required. A screw attachment at the upper part of the limb fixes the instrument firmly in the horizontal position

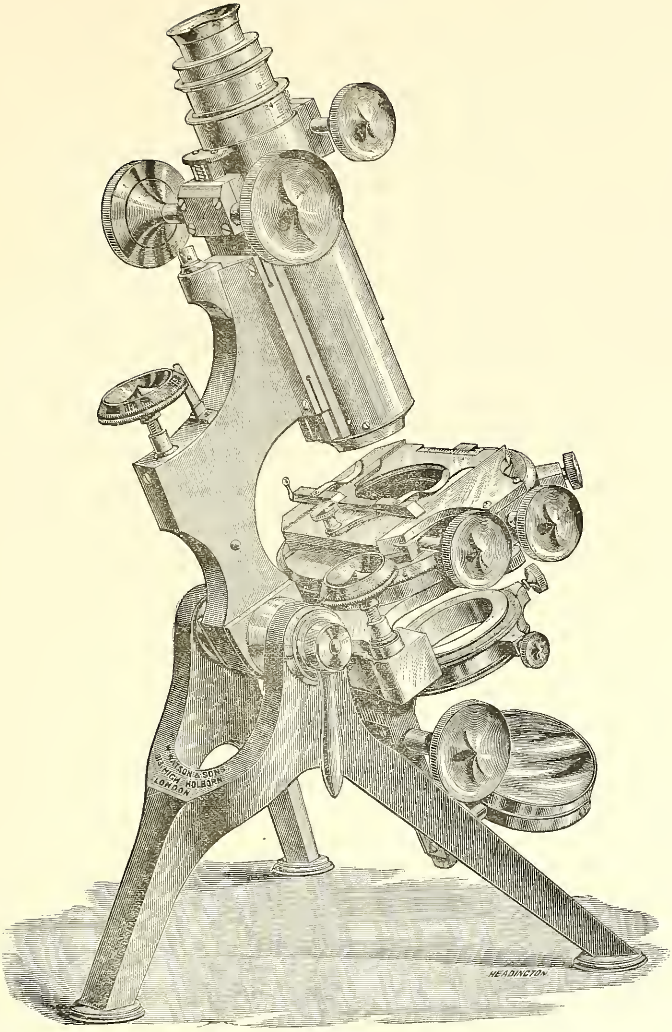


Fig. 162*a*.

when it is required to photograph in that position. We, however, seldom use it, infinitely preferring photographing with this microscope in the vertical position, as we have described in the chapter of this work on "Photo-micrography."

The fine adjustment is of exquisite delicacy, and of precision surpassing that of all other microscopes in our collection. Each turn of the milled head of the fine adjustment corresponds to 1-13th of a millimetre; so perfect is the adjustment that it is possible in certain cases to estimate to a hundredth of a turn, *i.e.*, to 1-1300th of a millimetre. As the mechanism of the fine adjustment acts in an opposite direction to that of Continental microscopes, we have marked on the milled head the letters M (*monter*) and D (*descendre*) to indicate the direction in which it is necessary to turn to make the body tube move up and down.

The mechanism of the fine adjustment is represented by figure 162*b*. As will be seen, the milled head acts on the end of a lever with a fulcrum at C.

A spiral spring coiled round a steel bar presses at its upper end on a plate attached to the dovetail bar which carries the microscope tube, and counter-balances so well the weight of the tube that the back thrust on the lever becomes very slight, this being in proportion to the tension that the maker gives to the spring.

This lever system very materially diminishes the resistance at the actuating milled head, and saves wear and tear. Also, a much finer movement is obtained by this means, the rate of movement being reduced by the long arm of the lever on one side of the fulcrum, and the short arm of the other, in the same ratio as the weight.

The limb is placed between the two guides seen in figure 162*c*. One of these guides can be tightened by the two screws AA, so as to hold the tube perfectly steady with an entire absence of shake. The pieces are so well fitted that the makers guarantee that the apparatus is absolutely free from any lateral movement.

The tube is very large, being 42 mm. (1·656 inches) in diameter, so as to be able to be used in all photo-micrographic researches. It has also both a draw tube and an optional extension by rack work. With the draw tube closed it is 142 millimetres (5½ inches) long, less than is required for use with Continental objectives. With the draw tube entirely drawn out, it is 24 centimetres (9½ inches) long. To make it larger still a milled head is turned, which acts on a rack and pinion, carrying a third tube, in reality a second draw tube. This tube enables the length to be increased to 32 centimetres (12½ inches). There is, therefore, every possible length that can be desired for the correction of apochromatic objectives, made either for the Continental or English length of tube. The innermost tube is the narrowest in the upper part, so that it can be blackened internally over half the space covered by the eye-piece; thus, all internal reflection, which is the cause of so much trouble in photo-micrography, is absolutely prevented.

It might be preferable to line this tube with black velvet.

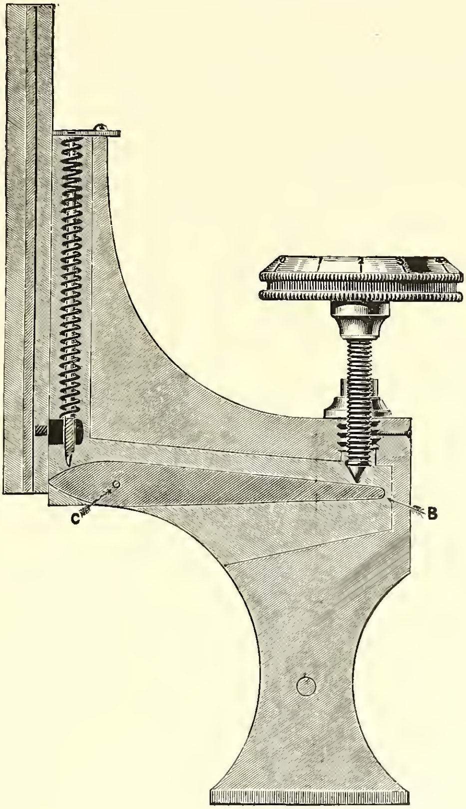


Fig. 162*b*.

The lower end of the draw tube is provided with the Society screw for use with the Abbe apertometer, &c.

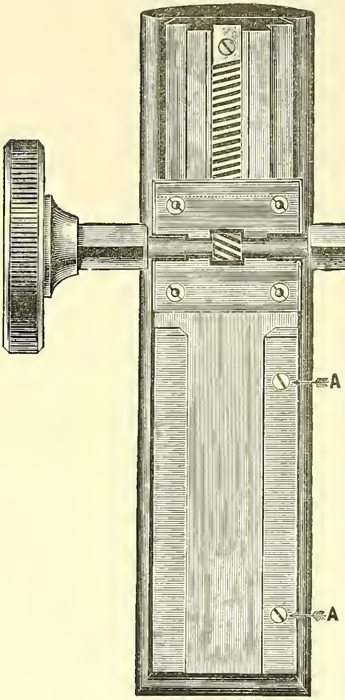


Fig. 162*c*.

The mirror is carried by a rod, having lateral movements; it can also be slid up and down within a moderate range. With regard to the substage, which we have purposely reserved to the last, we have here to call attention to improvements which are not found in any other microscope.

The condenser can of course be centred, and it can be raised or lowered by means of a rack and pinion, but, in addition, a fine adjustment of great delicacy is applied. Up to the present time, in the few microscopes to which a fine adjustment of the condenser has been applied (an adjustment so necessary in certain cases, and not yet sufficiently appreciated), the focussing has been simply effected by a screw, which does not produce a very slow movement, and there has always been loss of time (back lash) in the changes of direction.

Here the fine adjustment is produced by a lever, as in the slow movement of the body tube, and the milled head of this adjustment is placed above the stage and quite close to the fine adjustment screw of the body tube. By this means therefore it is possible to obtain a very great precision and to adjust the two slow movements simultaneously with one hand.

The arrangement of the condenser, as planned by us (and employed for several months with all our microscopes) affords, we believe, important advantages. This adjustment consists of an Iris diaphragm, surmounted by the lens holder. Between these two pieces slides a plate, removeable at will, provided with a central rotating ring, which serves for the reception of the diaphragms which, by means of the plate, is capable of being placed at any eccentricity that the numerical aperture of the objective used will allow.

The lens holder is adapted to receive the different Abbe condensers, the Zeiss achromatic condenser and also adapter plates allowing the use of all the excellent condensers of Powell and Lealand. It is thus seen that the mechanical part, allowing every central and oblique illumination desired, remains invariable, but is capable of receiving all possible optical combinations.

In fact, we have combined in this instrument all the conditions of perfection which long experience in microscopical work has taught us, and Messrs. Watson and Sons have realized all our desiderata with a precision and care which was quite beyond our expectations. If we add that this apparatus, so perfect, only costs £16, and consequently less than the large Continental models, it will readily be admitted, we believe, that the makers have rendered a real service to serious workers by the construction of this stand.

Our opinion on this point has been confirmed by the jury of Micrographic Exhibition at Antwerp, who have expressed their views on Messrs. Watson's stands as follows :—

"The perfection of these stands is extraordinary, and the fine adjustment of the body tube, which is effected by means of a lever, acted on by micrometer screw, is of incomparable smoothness and precision.

"Among the instruments exhibited, the stand called 'Dr. Van Heurck's microscope,' because it was made according to the specifications of this microscopist, has appeared the most remarkable to the jury.

The elegance of the microscope, the extreme precision of all its movements, the ease with which it can be used for all photo-micrographic and micrographic work, and lastly its comparatively moderate price, have largely influenced the jury to attribute to Messrs. Watson the high recompense which has been awarded to them."

We cannot at present say much about the objectives of these makers, Messrs. Watson having entirely abandoned their original formula of construction, and their new series, with the exception of the 1 inch and 1-6th inch, not being yet ready.

The 1 inch is excellent. The images of histological objects are excessively pure and well defined, and the objective bears very strong oculars, without deforming the images.

The 1-6th inch is a very good objective for ordinary work. It properly resolves the *Pleurosigma* with oblique illumination, has a considerable frontal distance, and the images which this objective give are excessively brilliant and well defined. For histological work the objectives leave nothing to be desired.

CARL ZEISS (Carl Zeiss Strasse, Jena).—The firm established by the late Dr. Carl Zeiss is at the present day the most important in the world.

Dr. Abbe, professor at the University, and a partner in the firm, is at present the managing director, and this scientist, who is also the highest contemporaneous authority in scientific optics, has under his skilful management made such improvements in the construction of objectives that one may infer that the progress which has already been realised in connection with the ordinary use of the miscroscope, is only the least that will be accomplished.

The models made by the firm of Zeiss are nine in number. We shall describe the principal ones.

Stand 1*a* (fig. 163) is the most perfect of these models.

The object is roughly focussed by a precise rack and pinion. The fine adjustment has been described on a previous page.

The draw tube is divided into millimetres. The stage is furnished with a rotating ebonite disc, which can be centred to the optic axis by means of two lateral screws, which compress a counter spring, inclosed within the stage. This stage can be removed in an instant, and a mechanical stage substituted for it.

The illuminating apparatus consists of an Abbe condenser of 1·40

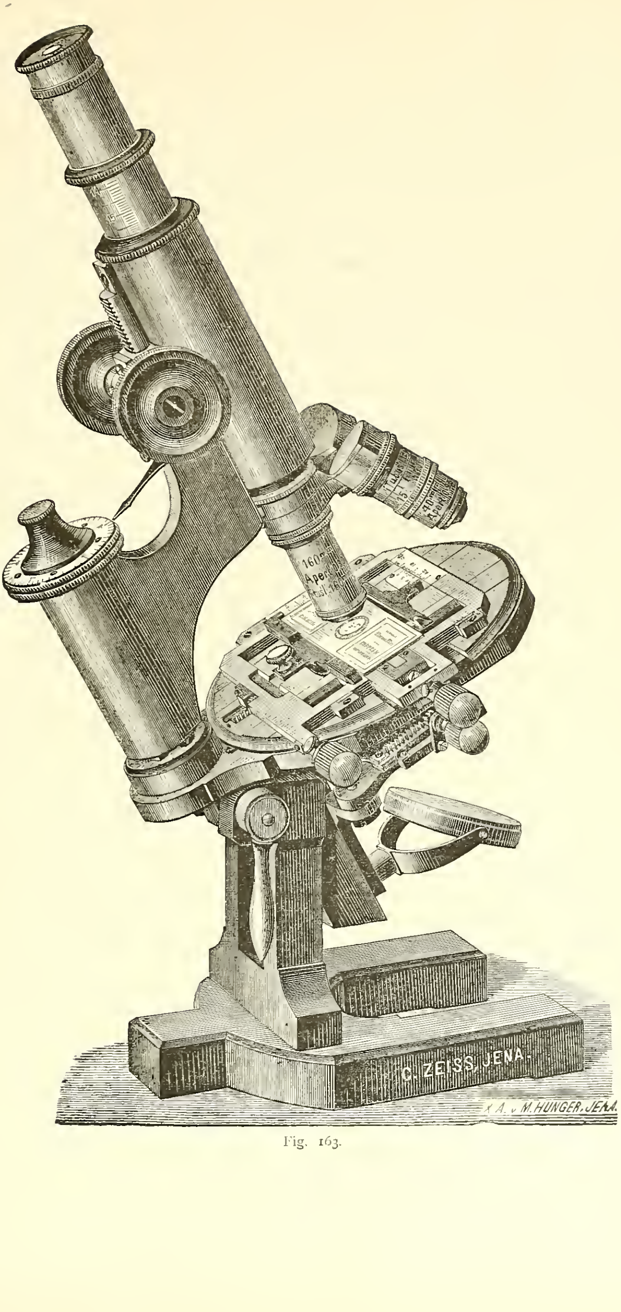


Fig. 163.

N.A., with an Iris diaphragm, furnished with an eccentric movement.

The instrument is inclinable, and can be fixed in any position by means of a clamping lever.

The price of this stand with the mechanical stage is £20, and £15 without it.

The stand for photo-micrography is very similar to the last (fig. 164).

It differs, however, in the tube, which is shorter, and in the stage, which is a mechanical stage, with excessively slow movements. The upper table of the stage rotates.

As in the previous instrument, the movements of the mechanical stage are recorded by verniers, reading to 1-10th of a millimetre.

This microscope, furnished with a special achromatic condenser, which is indispensable for photography (that of diatoms only excepted, as they can be photographed with Abbe's chromatic condenser), costs £21 5s.

In addition to these large special models, the firm of Carl Zeiss manufactures others which are more suitable for the less ambitious worker.

Thus stands II.*a* and IV.*a* are still perfect instruments, and sufficient for all ordinary work.

Stand II.*a* (fig. 165) has its coarse and fine adjustments like those of the preceding models.

The stage is furnished with a revolving vulcanite disc, which can be centred as in stand I.*a*.

The illuminating apparatus is as perfect as that of the preceding stands.

Its price is £14 10s.

Stand IV.*a* (fig. 166) only differs from the preceding in the stage, being fixed and without the revolving disc. The illuminating apparatus can be raised and lowered, but the Abbe condenser is only 1·20 N.A. The price of this stand, together with an Iris diaphragm, is £10 15s.

Stand VI. (fig. 167), which costs £3 5s., is however sufficient for such ordinary observations as do not require the extreme precision which is at the present day so sought after. The stand is a good type of the ordinary microscope used twenty years ago by most microscopists on the Continent.

The body has a draw tube; rapid focussing is effected by sliding, and its fine adjustment is precise.

The stage is fixed, having a tube or diaphragm carrier, which is

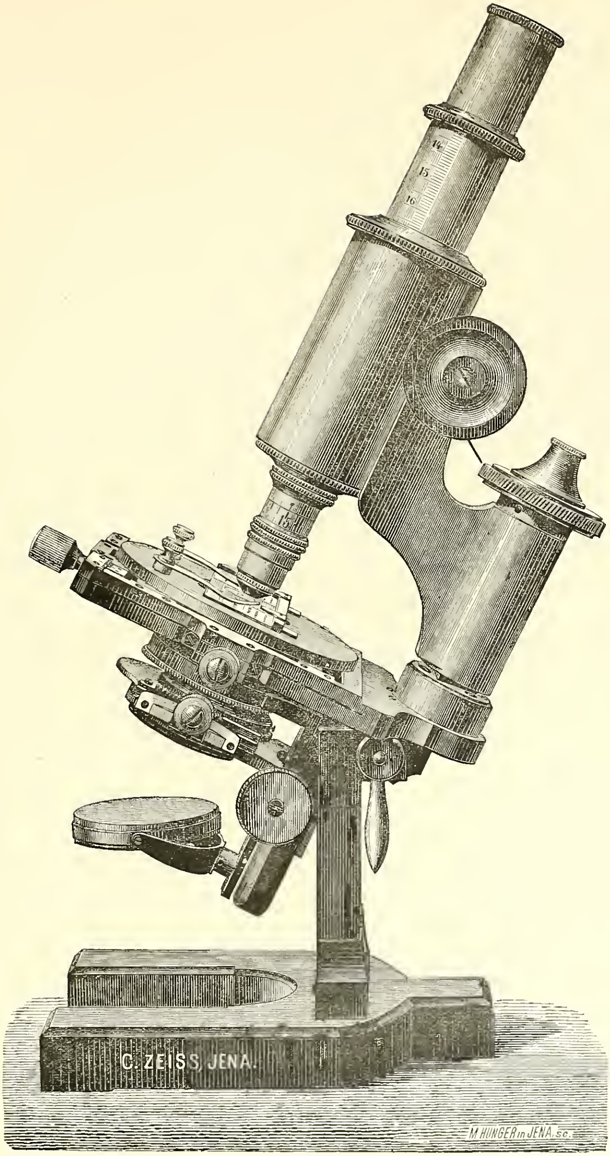


Fig. 164.

fitted to the under surface by a bayonet point; the whole of this can be removed when oblique light is required.

The mirror, plane on one side and concave on the other, is fitted to a jointed bar giving oblique illumination in all positions.

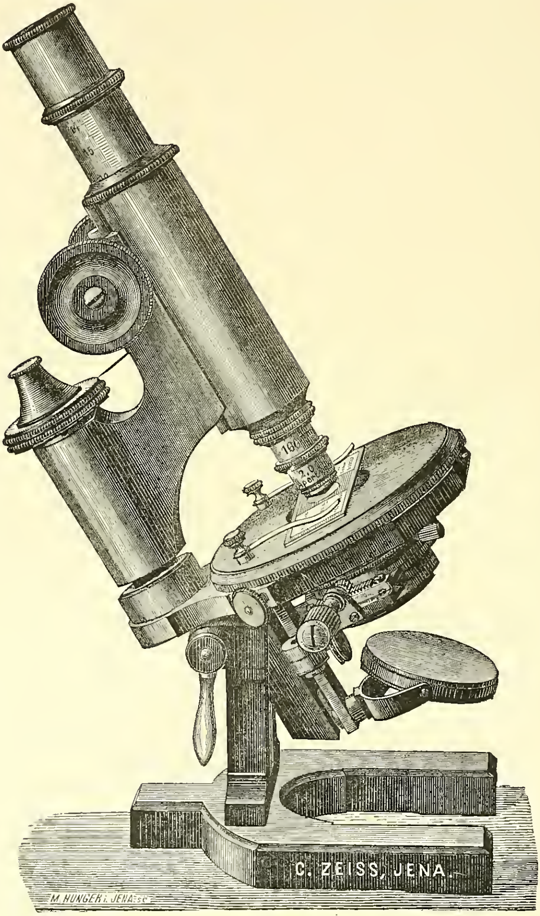


Fig. 165.

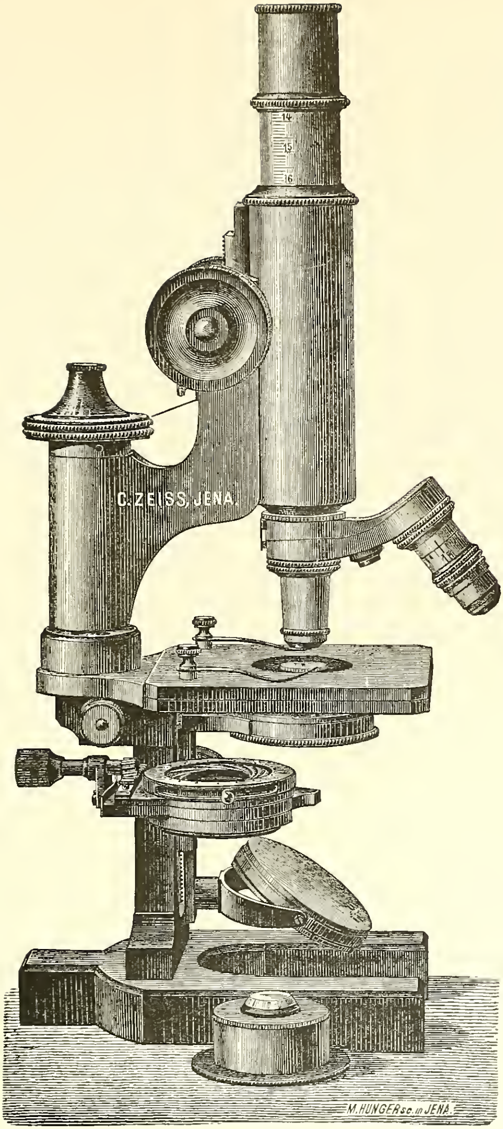


Fig. 166.

The instrument can be inclined at any angle as far as the horizontal position.

We will now examine the principal objectives of the firm. As we have already stated, their ordinary objectives are excellent, and the apochromatic

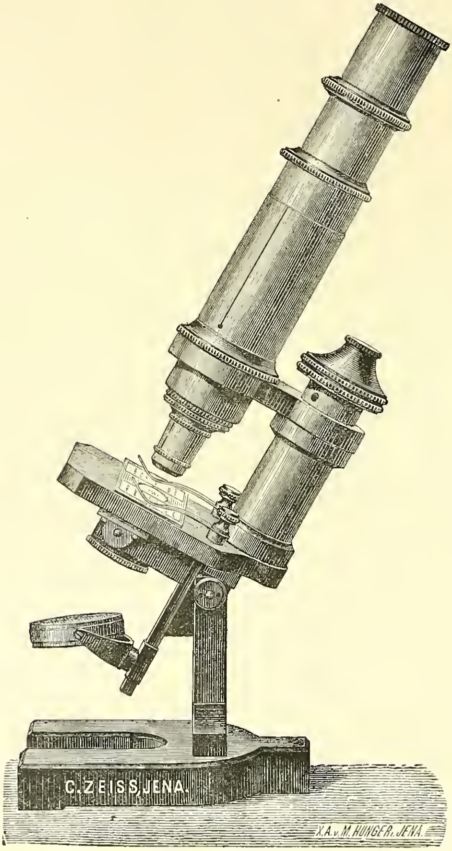


Fig. 167.

ones include specimens whose perfection has not been equalled by any other maker.

We will first take the ordinary series and examine the objectives called CC, D, DD, and F, with which we are well acquainted from a prolonged usage.

All of these give perfectly clear images, and define the pygidium of a flea and a section of *Pinus:* all have equally a comparatively large working distance, which is very convenient. The following are the results obtained with reference to the resolving power of those we have examined; such examination has been made by means of a lamp and a microscope furnished with an Abbe condenser.

CC. (objective of $\frac{1}{4}$ inch, N.A. ·71). With perfectly central light Nobert's 16th group and Möller's No. 8 are feebly resolved. With oblique light Möller's No. 11 is seen perfectly.

D. (1-6th inch, N.A. ·65). We cannot praise this objective so highly, but as long as we have had it in our possession we have used it daily, and prefer it to all our objectives of the same amplification for ordinary observations. The clearness of the images is very marked, and the working distance is so great that we can dispense with the use of a cover-glass when making hasty observations. With central light the objective resolves Nobert's 15th group and Möller's No. 8 very well. With oblique light No. 11 of the same test (*Pleurosigma Angulatum* in balsam) is seen very well.

F. (1-14th inch, N.A. ·90). This objective is an excellent one, and justly deserves the great reputation it enjoys among microscopists. It resolves Nobert's 17th group and Möller's No. 10 passably well with central light. With oblique light it resolves the first 17 specimens in Möller's test plate, *i.e.*, all the specimens which are resolvable with light which is not monochromatic.

Apochromatic Series.—We have made considerable mention of apochromatic objectives on page 47, to the manufacture of which we owe our introduction to Professor Abbe. We have, therefore, only to add a few words on the principal types of this series.

Objective of 24*mm.* (1 inch) N.A. ·30. This objective is intended for the English tube. It is an excellent objective, especially for photographic work with low powers. The images given by it are excessively pure, clear, and bright. It is very convenient for vegetable and histological work, but for diatoms its N.A. is too small.

Objective of 8*mm.* (1-3rd inch) N.A. ·60. This objective is only for use with the Continental tube. It is a very good objective, enabling the *Pleurosigma* to be resolved, and has a very large working distance.

Objectives of 6mm. (1-4th inch) *and of 4mm.* (1-6th inch), both having N.A. ·95; the first is made exclusively for the English and the second for either the English or the Continental tube as the purchaser may desire. These two objectives represent the apochromatic specimens for ordinary work. The image of the pygidium of a flea is admirably clear and pure. The *Pleurosigma* is resolved with great ease. These are the two objectives which we use daily for the ordinary study of diatoms and for determining their species. With the appropriate oculars, 12 and 8 respectively, a magnification of 500 diameters is obtained, which is amply sufficient for everything but the examination of the valve structure. For ordinary histological work these objectives are quite sufficient.

Objective of 2·5mm. (1-10th inch) water immersion N.A. 1·25. The pygidium and the *Podura* give very good images, and the *Bacillus tuberculosis* is clearly defined. With axial illumination Nobert's 12th group is seen pretty well, and the *Pleurosigma* shews clear and very black beads. With oblique illumination the *Amphipleura* prepared in the medium 2·4 is resolved very clearly, and the same test mounted dry is fairly well resolved.

Objective of 3mm. (1-8th inch) N.A. 1·4, homogeneous immersion. According to our observations, extending over six years, this objective is the best which exists at present; we know no other which is its complete equal.

The images of the pygidium and the *Podura* are of perfect purity; the bacilli shew excessively clear outlines; the *Amphipleura* is clearly resolved into beads, and the image of a diatom resolved into striæ is perfectly pure, and equally so throughout the extent of the valve. Even with great obliquity the image remains flat, and the valve is not deformed in the slightest.

With axial illumination Nobert's 12th group is seen perfectly, and with oblique illumination the 19th is resolved without difficulty. The frontal distance of this objective, notwithstanding its great N.A., is considerable.

Objective of 2·5mm. and Numerical Aperture 1·6.—This objective is the first of a new series commenced by Zeiss. It will probably be followed by one or two other numbers.

This objective has the largest resolving power hitherto attained. Unfortunately it is difficult to use, and excessively costly, consequently its practical use for ordinary work is not great. Its real use is for the elucidation of details, which it has been impossible to ascertain by objectives of the most perfect construction up to the present time.

We will examine this admirable piece of apparatus in greater detail.

The objective is 1-10th inch, and of course apochromatic.

Its numerical aperture is 1·63, and its construction is such that the whole of this enormous aperture can be utilised.

However, for this purpose, it requires special conditions, viz.:—

1. A cover-glass of high refractive index, which must be at least 1·6.

2. The object must be embedded in a medium, which has equally an index of 1·6 *at least.*

3. Lastly, if it is desired to utilise the whole aperture *with oblique light* (that is to say, if the maximum resolving power is required of this objective with the above illumination), the slips must also be of flint, with an index of refraction of at least 1·6.

All these conditions have been realized by Messrs. Zeiss, who have also made a special ocular, which suppresses the slightest trace of colour, and a condenser whose front lens is made of flint, and allowing the most oblique illumination.

The objective is formed of five lenses, superposed in the following order:—

1. A simple frontal lens, greater than a hemisphere which is made of flint, and has an index of refraction of 1·72.
2. An achromatic lens formed of two simple lenses.
3. A simple lens of crown glass.
4. An achromatic lens consisting of three simple lenses.
5. A correcting achromatic lens formed of three glasses.

In three of these lenses crown glass is replaced by fluorite.

The liquid used for immersion is monobromide of naphthaline, the refractive index of which is 1·65.

To resolve tests with greater ease the slip and cover-glass are made of a medium having the same index as the frontal lens, *i.e.,* 1·72.

According to Professor Abbe's formulæ an objective of 1·63 can resolve—

1. With axial daylight illumination ... 3,000 lines per millimetre.
2. With oblique illumination ... 6,000 „ „ „

By using the objective for photography from 5,000 to 10,000 lines can be resolved; the resolution in this case naturally depends upon which part of the spectrum the plates used are most sensitive, and for which part the spherical correction is the most perfect.

Let us now notice the advantages of the optical combination described above.

With oblique illumination the *Amphipleura* shows the entire valve resolved in beads, as clearly as we can see the *Pleurosigma* with the best objectives in our possession, although we find that these beads are closer together than our previous incomplete resolutions had led us to believe; measurements made from several of our photographs show that our *Amphipleura* has from 3,600 to 3,700 tranverse striæ, and 5,000 longitudinal striæ per millimetre. It is not therefore surprising that previously we had so much difficulty in seeing all those beads.

But it is only for resolving these beads that oblique illumination has to be used. All the other difficult tests, *Van Heurckia crassinervis* Breb (*Frustulia Saxonica*), *Surirella Gemma*, and even the transverse striæ of the *Amphipleura* are resolved with axial illumination with a large diaphragm.

Let us add that, latterly, by employing oxy-hydrogen light and focussing the objective in the image of the flame we have succeeded in resolving the *Amphipleura* into beads with axial illumination, but with a larger diaphragm which gives a mixture of axial and oblique rays.

We have in our possession a negative made under these conditions.

The time of exposure adopted was, unluckily, much too short. The beads, though quite visible, are much too faint to be printed on paper.

Pleurosigma angulatum gives an image differing from those which we have been accustomed to see of late. The objective allows the grating to be perfectly focussed, and the beads no longer appear round, but hexagonal.

Van Heurckia, *Surirella*, *Amphipleura*, &c., show square beads, with a slight tendency here and there towards the hexagonal form.

The luminosity of the objective is very great. We have obtained vigorous negatives of the beads of the *Amphipleura* (with a magnification of 2,000 and monochromatic solar light) in six minutes, while with the previous apochromatics at least ten minutes are required for a magnification of 1,000 diameters with the most oblique light.

It was with this objective that the photographs of the tests, which appear in this volume, were made.

This objective is, as we have said, expensive. Its price is £40.

In conclusion, we give here the price and magnifying power of objectives made by the firm of Zeiss :—

1. Achromatic Objectives.

Objectives.	Numerical Aperture.	Equivalent focal length.		Magnifying Power.					Price.		
				Ocular 1.	Ocular 2.	Ocular 3.	Ocular 4.	Ocular 5.			
		mm.	inches.						£	s.	d.
*a*1		40	1 9/16	7	10	15	20		0	12	0
*a*2		35	1 3/8	11	16	23	30		0	12	0
*a*3		30	1 1/4	20	30	40	50		0	12	0
*a**		38-26	1½/1	4-8	7-14	10-20	15-30		2	0	0
aa	·17	26	1	25	35	47	60	77	1	7	0
A	·20	18	3/4	37	50	70	90	115	1	4	0
B	·35	12	1/2	60	85	115	145	185	1	10	0
C	·40	7	1/4	105	145	200	265	325	1	16	0
D	·65	4·3	1/6	175	240	325	420	540	2	2	0
E	·85	2·7	1/9	280	390	535	680	865	3	6	0
F	·90	1·85	1/15	415	585	790	1000	1275	4	4	0
H water immersion	1·20	2·4	1/10	320	440	610	770	985	5	10	0
J water immersion	1·20	1·8	1/14	430	585	810	1030	1315	7	4	0
1/12 homogeneous immersion	1·20	2·0	1/12	385	530	730	925	1180	8	0	0
1/12 homogeneous immersion	1·35	2·0	1/12	385	530	730	925	1180	15	0	0

E, *F*, *H* and *J* with correction are £1 extra. Each of the oculars costs 7s.

2. Apochromatic Objectives.

Objectives.	Numerical Aperture.	Magnifying Power.							Price.		
		Oculars.									
		1.	2.	4.	8.	12.	18.	27.			
*24mm. (1 inch)	·30		21	42	83	125	187	281	7	0	0
16mm. (2/3 ,,)	·30	15·5	31	62	125	187	281		5	0	0
*12mm. (1/2 ,,)	·60		42	83	167	250	375	562	8	10	0
8mm. (1/3 ,,)	·60	31	62	125	250	375	562		6	10	0
*6mm. (1/4 ,,)	·95		83	167	333	500	750	1125	11	0	0
4mm. (1/6 ,,)	·95	62	125	250	500	750	1125		9	0	0
3mm. (1/8 ,,)	1·30	83	167	330	667	1000	1500		20	0	0
3mm. (1/8 ,,)	1·40	83	167	333	667	1000	1500		25	0	0
2·5mm. (1/10 ,,)	1·25	100	200	400	800	1200	1800		15	0	0
2mm. (1/12 ,,)	1·30	125	250	500	1000	1500	2250		20	0	0
2mm. (1/12 ,,)	1·40	125	250	500	1000	1500	2250		25	0	0

3. New Apochromatic Objectives.

3mm. dry	·95	83	167	333	498	667	1000	1500	10	0	0
2·5 monobromide	1·60	100	200	400	600	800	1200	1800	40	0	0
1·5 homogeneous	1·30	167	333	667	1000	1334	2000	3000	22	0	0

The Objectives marked with an asterisk (*) are made for the English tube only, the others, except the 8mm., can be obtained for the English tube.

The price of compensating oculars is as follows:—

1. For the Continental tube—

1	2	4	8	12	18
£1	£1	£1	£1 10s.	£1 10s.	£1 5s.

2. *For the English tube*—

2	4	8	12	18	27
£1 5s.	£1 5s.	£1 15s.	£1 10s.	£1 10s.	£1 5s.

The price of projective oculars is as follows:—

1. For the Continental tube, 2 and 4 } £2 each.
2. For the English tube, 3 and 6 }

In the above series of oculars each number denotes the magnifying power.

CHAPTER II.

MEASUREMENT AND REPRODUCTION OF MICROSCOPICAL OBJECTS.

PHOTO-MICROGRAPHY.

1.—Measurement of Microscopical Objects.

Several means are employed for measuring the size of objects seen through the microscope. We shall only mention here the easiest and most general method, *viz.:* that in which the eye-piece micrometer previously described is used.

With an eye-piece micrometer the maker usually includes a table, giving the relation that exists between the ocular and the different systems of lenses employed. If necessary, such a table can easily be calculated by the student himself. To do this, he has only to place on the stage a millimetre, divided into one hundred parts, and observe how many divisions of the eye-piece micrometer (one-tenth of a millimetre in value) go to a division of the stage micrometer.

If, for example, two divisions of the stage micrometer (one-hundredth of a millimetre in value) corresponds to 12·5 divisions of the eye-piece micrometer, we obtain as the value of a division of the eye-piece micrometer $\frac{\cdot 02}{12\cdot 5} = \cdot 0016$ of a millimetre.

Having determined this relation, in order to calculate the actual size of an object, we have only to ascertain the number of divisions of the eye-piece micrometer which it occupies, and to multiply this number by the figure expressing the relation between the eye-piece and the objective used. Thus, suppose an object occupies six divisions and the relation is represented by ·002, we have ·002 × 6 = ·012, *i.e.*, the size of the object examined is twelve thousandths of a millimetre.

However simple and easy this calculation may be, it, nevertheless, is tedious, when a large number of measurements have to be made, as is, for example, the case when diatoms are being studied; consequently we have, for some time past, substituted for it a more convenient method.

The ocular, which we have constructed for the purpose, carries a side piece, in which is fitted a small brass frame, larger than the diaphragm, sliding in two grooves, which can be withdrawn by means of a screw. In this frame is placed a thin glass plate, on which is marked decimal divisions, and graduated so that with a 1-10th inch objective, each small division corresponds to a thousandth of a millimetre. The large divisions of the micrometer are therefore equivalent to a hundredth of a millimetre. By making the divisions in this way, all other objectives give whole number measurements, any small differences being removed by properly adjusting the tube of the microscope.

Lately, this kind of ocular has been also adopted by the firm of Zeiss, who now make their No. 6 compensating ocular give, with their apochromatic objectives, an exact value for each division. However, we find the base adopted by Messrs. Zeiss for the value of the divisions to be much less convenient than our own.

With our own ocular we can make in a few minutes, without any chance of error, a series of measurements, which by the ordinary method would take ten times as long.

The size of microscopical objects can be expressed in several ways. M. Harting has with good reason suggested that the millimetre be discarded as the base of measurement, and that the unit be the thousandth of a millimetre (·001 mm.), which he proposed to call a mikron, and represent by μ. An object measuring 15μ would therefore be 15-1,000ths of a millimetre, which might also be written ·015mm.

This mode of expression is far more rational than having to quote, for example $\frac{3}{293}$ of a millimetre, &c., since fractions convey but an inadequate idea to the mind, because it is necessary, in order to appreciate their value, to reduce the unit of measurement to decimal fractions.

Experience has shown us that a thousandth of a millimetre is much too small a unit for measuring diatoms. We are nearly always obliged to use a large number, without any adequate reason, since their size varies so much that their maximum may be double their minimum size. In this case then the hundredth of a millimetre should be used, and we are thus in the same position as when both the metre and centimetre are used in expressing macroscopic measurements.

2.—Measurement of Magnifying Power.

It is a very easy matter to measure the magnifying power of a microscope. Two methods are open to us.

In the first place, a micrometer (or a millimetre divided into a hundred parts) having been placed on the stage, its image can, by means of a camera lucida, be projected on to a sheet of paper, placed at a distance of 250 millimetres (10 inches)—the conventional distance of distinct vision—from the ocular. A certain number of lines, ten for example, projected on the paper are then traced with a pencil. Upon the scale thus drawn on the paper is placed a two-decimetre rule divided into millimetres, and the number of centimetres which a division of the drawn scale occupies is ascertained. If a division of the drawn scale is equal to a centimetre, the micrometer, divided into hundredths of a millimetre, the magnification will be 1,000. By drawing ten divisions, and taking the mean, a more exact measurement will be obtained. It is evident that in the case supposed (the magnification being 1,000) ten divisions will be equal to a decimetre. By drawing several divisions we render the fractions of a centimetre more noticeable. It can thus be easily ascertained that ten divisions, occupying ten centimetres together with two millimetres, the magnification will be 1,020, while if only a single division had been taken the small fraction would not have been observed.

The second method, called double vision, is more difficult and requires some practice. As before, the paper is placed at a distance of 25 centimetres, and the left eye is directed down the microscope whilst the right eye looks at the paper. The two images then coincide, so that the projected lines of the micrometer can be drawn on the paper; from this point we proceed as before.

This method requires a great deal of practice, but it has great advantages with high powers, because the field of the microscope is already dark enough, and by using the camera lucida, which further diminishes the light, serious difficulties arise.

3.—Drawing Microscopic Objects.

Microscopic objects can be drawn either by double vision or with the camera lucida. The paper having been placed on the table, preferably at a distance of 250 millimetres from the ocular, provided that it does not make drawing too inconvenient or fatiguing, the image of the object, projected on the paper, is drawn in with a pencil.

It is very necessary in this case that a suitable illumination be found by experiment, shewing distinctly at the same time the object, and the tip of the pencil. To ensure success, the paper and object should be illuminated as nearly as possible the same. This is done by either suitably fixing the mirror or shading the paper with a screen. Experience and practice will assist us most here.

It is most important to always signify on each drawing what magnification has been used. This is easily done, because we have only to measure once for all what the magnifying power of the objective used is, at the distance at which one draws. This magnification is expressed by a fraction, whose numerator is the amplication, and whose denominator is unity, thus $\frac{500}{1}$ indicates a magnification of 500 diameters or 500 times the unit which represents the real size of the object.

As we have said before, it is not essential that there should be a distance of 250 millimetres between the camera lucida and the paper.

Preference is given to this distance, because the magnification is then immediately known, and, moreover, it is the distance of normal vision with most observers. There is nothing to prevent us from drawing directly on to the table, if that distance is more convenient, as is often the case. The only essential point is to note the exact magnification used, and also it is advisable to state what objective has been employed. It can be easily understood that any given magnification for the drawing of a delicate object will be much more valuable if made with an apochromatic objective of 1·4 N.A., than if it were obtained with a powerful ocular and a low power which had an N.A. of only ·4.

PHOTO-MICROGRAPHY.

All that the eye can see through the microscope can be reproduced by the sensitized plate. Sometimes indeed this discloses details which the observer cannot see, for a large number of rays, *e.g.*, the ultra-violet, which do not affect our eyes, act nevertheless on the sensitized photographic plate.

From the time when photography was first discovered, the idea of employing this new art for fixing microscopic images was constantly entertained. As early as 1844 Donné and Léon Foucault published their "*Atlas d'anatomie microscopique*," which was designed from daguerreotypes.

We believe that Bertsch, about 1857, produced the first paper proofs. Among the very first workers Belgium can claim M. A. Neyt, of Ghent, who worked with Bertsch at photo-micrography, and who at the present day still occupies one of the first positions among photographic enthusiasts. The work, published in 1887, by Messrs. E. Van Beneden and A. Neyt, on *Ascaris megalocephalus*, included some particularly successful photographs, although the thick ink, used in printing, gives a very poor rendering of the remarkable clearness of the negative, as is invariably the case. M. A. Neyt devoted himself to astronomical photography at a time when it had scarcely been thought of, and he has published a very remarkable photograph of the moon.

At the International Exhibition at Antwerp we exhibited some photographs taken by us in 1862.

Among micrographers who have devoted themselves successfully to photo-micrography, the late Dr. Woodward and Dr. Maddox, of whom, fortunately, the science has not yet been deprived, must be mentioned first.

Nachet, De Brébisson, Castracane, Hon. J. D. Cox, C. Houghton Gill, Pringle, Dr. Neuhauss, Dr. Moitessier, R. Koch, Th. Comber, Dr. R. Zeiss, and our excellent pupil, M. Gife, of Antwerp, have done credit to photo-micrography, and produced remarkable photographs.

When, in 1865, in the first edition of our work on the microscope, we set forth the processes then in use, photo-micrography could only boast of a few adepts. At that time, indeed, it was neither convenient nor agreeable to micro-photograph.

Besides being troubled with photographing with collodion, the staining of the hands, the very long exposures during which the coating dried unevenly, the frequent spoiling of the negatives from being unable to always anticipate the correct time of exposure, &c., shewed that an altogether special contrivance was required, and that only an intense source of light could be used; sunlight nearly always had to be resorted to, and the cuproammoniacal bath, together with the heliostat, were indispensable to anyone who wished to do serious work.

A great change has taken place since then. Photo-micrography, thanks to gelatinobromide, is at everyone's disposal; indeed, it is a process that should be used by every serious microscopist, for it is by no means difficult, and can render most valuable assistance. It can quickly and conclusively test the truth of any statement made by the observer, and it can also be made to keep an exact record of all his researches. Moreover, it can often accomplish more than direct observation can, for, as we have already stated, certain rays, *e.g.*, the ultra-violet rays, still affect the sensitized plate when the eye is no longer able to perceive them.

We shall describe in succession:—

1. The installations.
2. The apparatus used.
3. The illuminant.
4. The photographic processes.

§ 1. The Installations.

Three typical installations can be mentioned:—

1. *Woodward's Installation.*—The microscope is placed in a horizontal position, on a firm support, *e.g.*, some masonry.

In front of the instrument is placed the source of light; behind the microscope slides, on rails, a carrier, to which is attached the frame containing the sensitized plate. Of course, the whole room is kept as dark as possible, and no other light is admitted but that which passes through the lenses of the microscope.

This is an excellent method, and our late friend, Dr. Woodward, of Washington, produced negatives which have never yet been surpassed, but this is only suitable to one who is willing to make a speciality of photo-micrography.

2. *The ordinary method.*—The microscope is placed in a horizontal position, the ocular is either removed or left in, and the end of the tube of the microscope is connected with an ordinary photographic

camera. The image is focussed on the ground glass, which is then raised and replaced by the slide containing the sensitized plate, proceeding in just the same way as in ordinary photography.

As a source of light, daylight, electric light, or even a petroleum lamp, can be used.

This is the arrangement usually adopted by micro-photographers.

3. *The Author's Installation.*—After having employed the two preceding methods for a long time, we definititely abandoned them, for reasons given by us, in March, 1885, in the "American Monthly Microscopical Journal," which we will summarize here. In our opinion photography ought not to be an end, but a means, in the hands of the micrographer, *i.e.*, photography should be employed not for the pleasure of producing photographs, however beautiful or interesting they may be, but as a substitute for the camera lucida, when we desire to represent complicated and extremely delicate details, or still more when an irrefutable proof is necessary in support of some new and contested fact.

Now for such a purpose the preceding methods are not very convenient; it is by no means a matter of certainty, when we are dealing with an object having very delicate details, that the same conditions of illumination can be again obtained when the microscope has been deranged: in any case one would only succeed after great loss of time; we have therefore thought of a really practical method, which we have carried out in two different ways.

First, by a method giving, without trouble, small photographs. For this, we have constructed a small camera, which is very light, and capable of holding a sensitized gelatine-bromide plate $5\frac{1}{2}$ c. × $4\frac{1}{2}$ c. (2·2in. × 1·8in.). The front of the camera terminates in a copper tube, carrying an achromatic concave lens or *amplifier.* The tube of the camera fits nicely into the tube of the microscope, and the *amplifier* is placed at such a distance from the sensitized plate, that when the image is sharply in focus with Powell and Lealand's No. 1 ocular, it is also in focus on the sensitized plate. This effect, thus produced automatically, gives with Zeiss's 1-12th homogeneous objective a magnification of 300 times. If a larger magnification is required, the photograph must be enlarged.

A ground glass can be substituted for the frame when we wish to use a different objective to that for which the apparatus is constructed.

It is evident how very convenient this arrangement is. The apparatus is always at hand and in working order. If an interesting object is seen, in a moment, without deranging the microscope, the photograph desired can be taken by simply changing the ocular.

This arrangement has been very useful and of great service to us, but we have modified it for some time since, so as to obtain, without enlargement, photographs of every size up to 5 × 7. This is our second method, which we find is preferable whenever details or work requiring great precision have to be photographed. The apparatus, which is extremely simple, will be described in the following section.

§ 2. Apparatus.

The apparatus, which appear in manufacturers' catalogues, are very numerous. We shall review those which to us appear to be the most ingenious.

A. NACHET (17, Rue St. Séverin, Paris). M. Nachet, who is himself a distinguished photo-micrographer, sells several very ingenious pieces of apparatus.

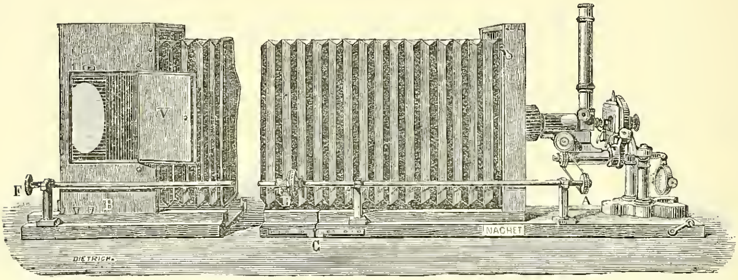


Fig. 168.

The *large Micro-photographic Apparatus* (fig. 168) is a fine instrument, consisting of a solid base with grooves made very exactly, so as to allow the part of the camera marked B, which carries the bellows, to slide for a distance of two metres (6½ft.) It is also provided with a rod at the side in two parts, terminating near the microscope in a pulley A, to which is attached either a small piece of string or an india-rubber band, communicating with the fine adjustment milled head. If we wish to work with short extension, the base board is folded by means of the hinge G; the apparatus is most frequently used in this manner. If, on the other hand, we wish to work with long extension, the base board is replaced and the end of the moveable rod F is united again to the button D, on which is bored a tapering groove, so as to make the two rods rigid, the hinder part of the rod resting on a guiding post, which can be taken off at will in order to allow the table to be folded. One can focus on to the ground glass or inside on a Bristol board by opening the lower side door V. This camera can hold plates of all sizes up to the full French plate (18 × 24 c. = 7 × $9\frac{1}{2}$ inch).

The microscope is connected with the camera by means of a system of tubes, which excludes all light from without.

Nachet has adapted to his photographic microscope a very useful modification (fig. 169). It is a rectangular box, containing a total reflexion prism, which can, when desired, by means of a rack and pinion, be introduced across the path of the rays coming from the objective. Every facility is thus obtained for putting the object in the position required, for arranging the illumination in the best manner, &c.; and when all is found to be satisfactory the prism is withdrawn, and nothing further has to be done beyond sharply focussing on the ground glass.

Nachet also manufactures an apparatus for instantaneous proofs, which works perfectly.

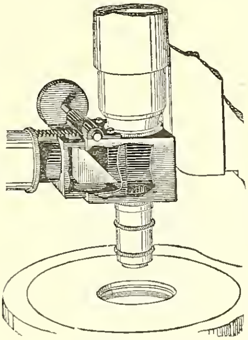


Fig. 169.

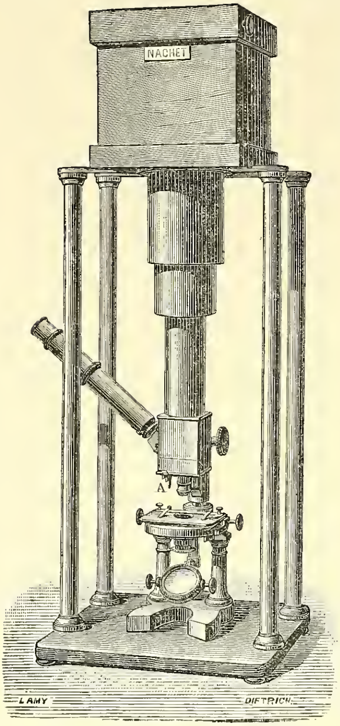


Fig. 170.

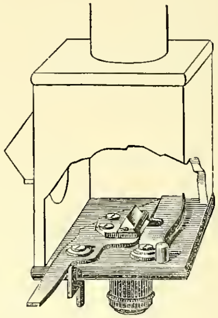


Fig. 171.

This instrument (fig. 170) is based on the principle of a microscope, with two body tubes. Above the objective (fig. 171) a prism reflects the image into the body tube at the side containing the ocular. Observation is thus carried on as with an ordinary inclined microscope. The camera, solidly mounted on pillars, contains the sensitive plate, from which all light is shut off, the reflecting prism itself serving as a shutter to the objective.

While the observer is examining the object his finger is placed on the catch A, but when he is satisfied with the image, a slight pressure on the catch withdraws the prism and allows the image to pass for a very short time. With a vivid light, such as the sun, electric light, or oxy-hydrogen light, the negatives are produced perfectly.

Focussing on the glass screen is produced by a special arrangement of lenses, contained in the ocular tube, by means of which each observer must regulate his focus once for all in such a way that when the image is quite clear in the ocular it is equally in focus on the photographic plate.

A small camera (figs. 172 and 173), which can be sufficiently understood by the illustrations, appears to be a very good apparatus for elementary photography. The apparatus is neither cumbersome nor expensive, and by it photographs can be taken with the microscope in any position.

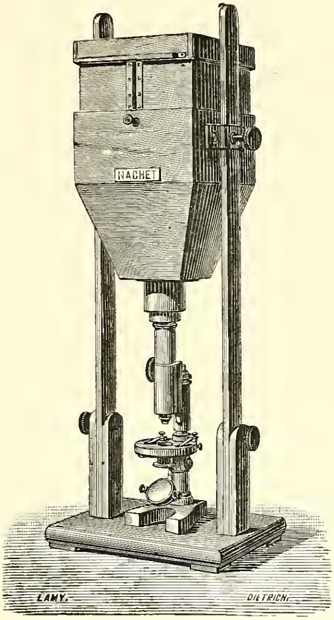


Fig. 172.

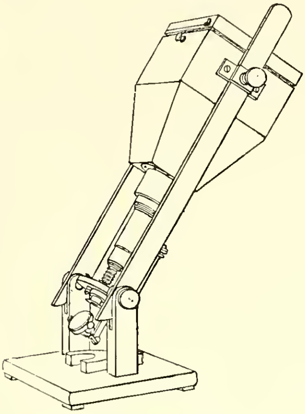


Fig. 173.

Lastly, Nachet's large inverted microscope (fig. 174) is also an excellent apparatus for photography. With this it is only necessary to replace the ocular by a camera.

Thus arranged, it is an instrument of extreme stability, and probably superior to any other combination. It is not affected by tremors, either from passing vehicles or from any other cause. We have had the curiosity to experiment with it by the side of our gas engine, and have obtained in that position perfectly clear images. Our friend, M. Neyt, writes us: "I have employed it while a hole was being pierced in the kitchen wall."

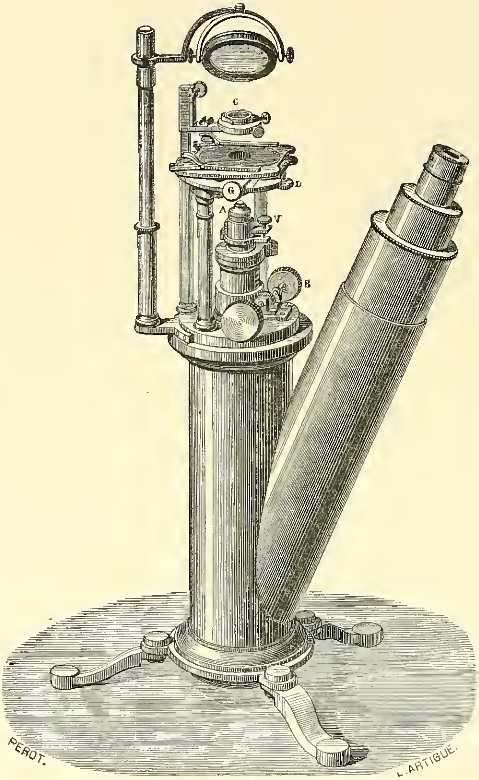


Fig. 174.

The only inconvenience is that projection oculars cannot be used with it. When this apparatus is used with apochromatic objectives, a concave achromatic lens, which will make the focus of the objective coincide with the surface of the sensitive plate must be placed immediately above the objective.

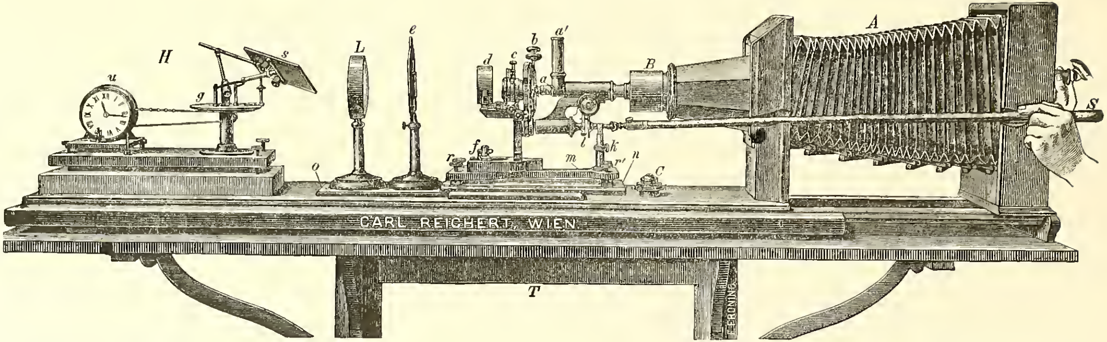


Fig. 175.

CARL REICHERT'S LARGE PHOTO-MICROGRAPHIC APPARATUS.

With this arrangement the instrument gives perfect results, which are obtained with extreme ease. We have obtained excellent negatives of the *Amphipleura* with it.

CARL REICHERT (viii., 26, Bennogasse, Vienna). M. Carl Reichert makes two kinds of photographic apparatus.

The large apparatus (fig. 175) is mounted on a table of polished wood, which has at one end a camera, moved by a rack and pinion, and at the other end the illuminating apparatus, which consists principally of a large mirror moved by clockwork, a condensing lens L, and a bath with parallel sides *d*, in which is placed either a solution of alum or a coloured solution. The microscope is placed in the centre. The illustration sufficiently explains the details of construction.

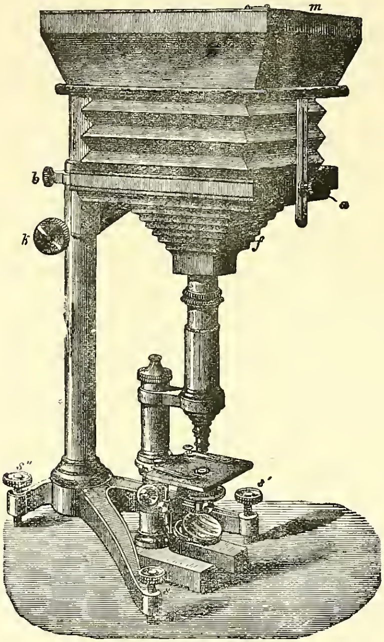


Fig. 176.

The other apparatus (fig. 176) is intended to be placed above the microscope ocular. This apparatus is very convenient in all cases where only a small microscope is used, and where only preparations which do not require extreme precision have to be photographed.

DR. CARL ZEISS (Carl Zeissstrasse, Iena). The firm of Zeiss have made a special study of photography, and one of the heads of the firm, Dr. R. Zeiss, has acquired a great reputation for his photo-micrographical work. A large number of the illustrations which appear in their Photo-micrographical catalogue are really very beautiful specimens, and show that he has known how to avail himself fully of the exceptional resources at his command. The catalogue of this firm present various models for workers.

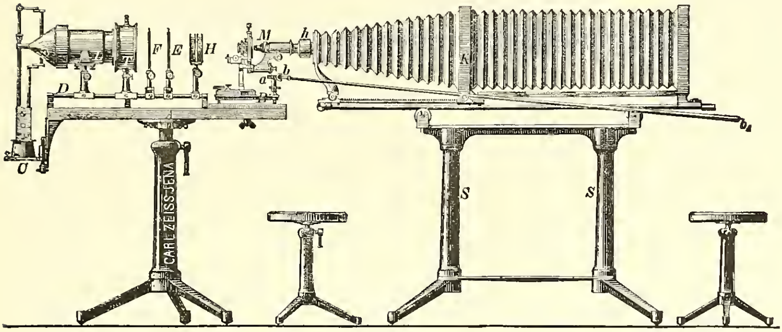


Fig. 177.

The *Large Apparatus* (fig. 177) is an excellent instrument, very complete and perfect, but it is too complicated for ordinary work. Its costliness, moreover, puts it out of the reach of all but the more wealthy photographers.

Its principal parts consist of a special microscope M, which is placed with the illuminating apparatus on a table made of cast-iron. A second table of the same material, which can be withdrawn from the first, carries the camera K and a jointed hand lever, by which the fine adjustment of the microscope can be regulated. The front part of the camera can be swung back and be used as a vertical apparatus.

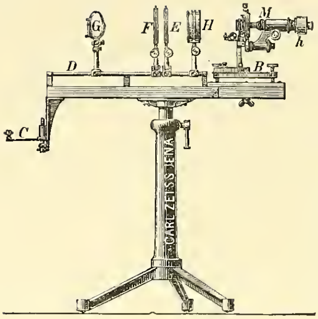


Fig. 178.

The optical parts (fig. 178) on the smaller tube consist of a plane mirror G, two screens F and E, and of a support for the baths H.

An electric arc lamp and its accessories can also be adapted to it.

This arrangement, as may be seen, fulfils all the worker's requirements, but we repeat that the apparatus is too complicated and too expensive. The truth of this has, we know, been felt by Messrs. Zeiss, who have for some time past produced a simpler but sufficiently complete apparatus.

Lately Messrs. Zeiss have constructed a vertical apparatus (fig. 179), composed of a solid camera of ample length, sliding up and down a rigid bar, divided and carried on a large cast-iron tripod.

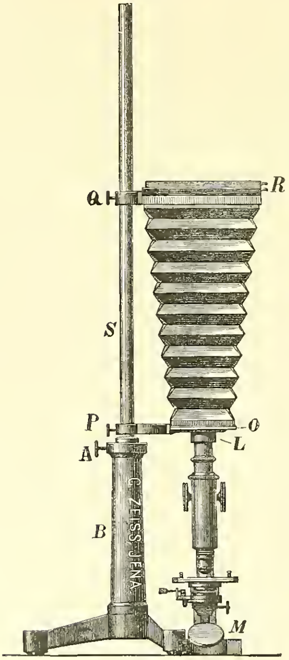


Fig. 179.

The support bar S can be turned round on its axis in the iron socket B, which rises from the centre of the tripod. A clamping screw A enables the bar to be fixed in every position of its rotary movement.

These arrangements are very happily conceived. They render the apparatus really useful, and enable it to be used in researches requiring the greatest precision.

Various useful accessories can be obtained, when desired, from the makers separately. Amongst others are :—

A diaphragm apparatus, mounted on a stand, with a complete series of diaphragms and ground glass focussing plates.

A bath carrier with two baths.

A bi-convex lens mounted on a stand with tripod, &c.

M. E. LEITZ, of Wetzlar, also makes a small photographic apparatus, which differs from the preceding ones by being adaptable to the microscope when in an inclined position.

The apparatus consists of a camera suspended between two pillars which, by means of a clamping screw, can be fixed at any inclination. The inner tubes of the pillars can be drawn out by

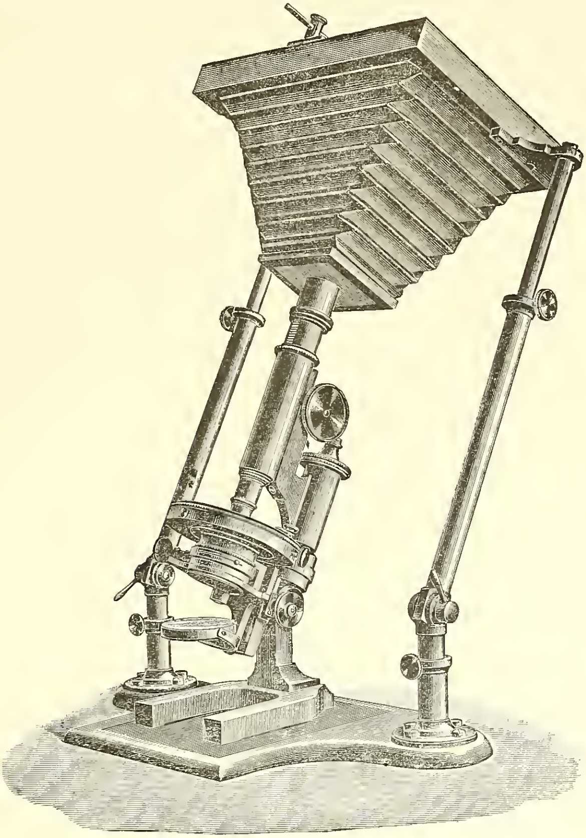


Fig. 180.

means of rack and pinion adjustments (fig. 180), and so the length of the pillars can be increased. Thus photographs can be made at different magnifications. They must, however, be kept within sufficiently restricted limits, because the camera cannot be lengthened to any great extent, especially when the apparatus is in an inclined position.

DR. HENRI VAN HEURCK'S *Photo-Micrographic Apparatus.* The apparatus, which we have used for the last three years, and which is the result of every kind of experiment, has the advantage of being perfectly stable, as cheap as possible, and extremely simple. Any intelligent carpenter can make it.

Several workers have come and asked us to photograph various objects for them: one some starch or fibre; another, histological tissue; and another, diatoms, &c. We have never had occasion to make a second experiment.

Our apparatus (fig. 181) consists of an oblong wooden box mounted solidly on four legs, (¹) carrying at the top the frame for the ground glass screen, &c., and it can be placed on the work table on which the microscope stands. In the bottom of the box is an aperture, which can be closed at will by a small funnel of black cloth attached to it. The height of the legs is sufficient to allow the tube of the microscope to pass through the aperture into the box, so as to be from five to ten centimetres (two to four inches) above the bottom.

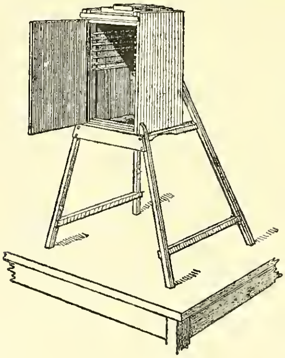


Fig. 181.

The apparatus is always used in a vertical position. For thus alone can work be done conveniently, and in this position only can such fluid liquids, as the essence of cedar, monobromide of napthaline, iodine of methyleine, &c., which are now used as immersion liquids, be kept in place on the condenser and preparation.

(¹) It would be more convenient to have only three feet, but then we should constantly be interfering with the movements and illumination.

The great essential difference between our apparatus and every one similar to it is, that the whole front of the box opens.

Owing to the breadth of the box, which is 25 centimetres ($9\frac{3}{4}$ inches), one's head can be very conveniently placed inside the camera, where the eye of the observer is screened from all light but that coming from the tube of the microscope. The image can thus be focussed

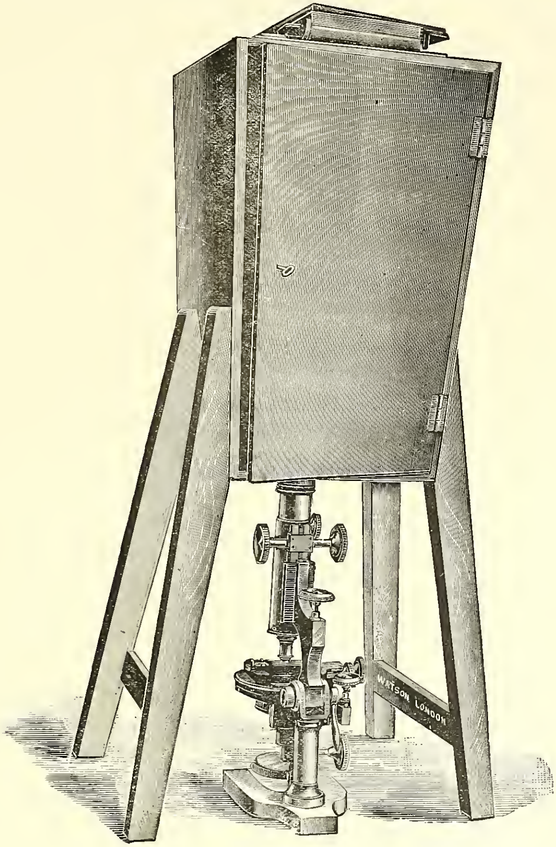


Fig. 181*a*.

under the most favourable conditions. When this is finished, the ordinary ocular is replaced by a projection ocular (*if that is necessary*) and the camera door is closed.

By standing on a chair or stool, the focus is tested for the last time on plate-glass (ground-glass being unable to give sufficient precision) by means of a focussing lens, and the plate is then exposed.

The outside dimensions of the box are fixed and invariable, but a system of racks in the inside allows the distance between the sensitive plate and the microscope to be modified. However, experience has shewn us that this is needless, for by combining apochromatic objectives with various compensating oculars, any series of magnifications may be obtained.

It is the invariable length of the arrangement which gives such rigidity to the apparatus, and enables the most delicate objects and their minutest details to be photographed. Our camera is 50 centimetres (19¾ inch) in length. If this dimension be increased, it is impossible to manage the fine adjustment conveniently while looking at the image on the plate-glass.

This length is really more than sufficient. With an objective of 1-10th inch, magnifications of 500 and 1,000 diameters, with projection oculars 3 and 6, are obtained, and of 2,000 and 3,000 diameters, with compensating oculars 12 and 18.

It was in this way, with an objective of N.A. 1·6, that we produced the negatives of the "Tests" which appear in this Work.

Messrs. Watson and Son make our photographic apparatus, and supply it for £4 15s. (fig. 181*a*).

§ The Illuminant.

To obtain good negatives an illuminant, which is both convenient and powerful, must be employed to produce what in photography is called contrast, *i.e.*, that which sets off the object against the background. If the light is too feeble the image will always be flat, and the details will only be slightly visible or not at all.

The luminants in photo-micrography may be classed according to their intensity, as follows:—

Sunlight.
Electric arc light.
Electric incandescent light.
Oxy-hydrogen light.
Light from a mineral oil lamp.
Light reflected from white clouds.

Sunlight.—In order to use sunlight suitably, a heliostat must be employed. The simplest, most practical, and, at the same time, least expensive heliostat that we know of is that of Prazmowski, which is supplied in Paris by Messrs. Bézu, Hauser and Co., and in Potsdam by Hartnack. We have used one for several years, and think it deserving of all praise.

The instrument (fig. 182) consists of a solid piece of clockwork which, once in 48 hours, turns an axis on which can be adjusted a square mirror, which is thus set in rotation. On the circumference of the drum, containing the clockwork, is placed a clock dial, on which the hours are divided into intervals of ten minutes. The drum itself is held by a support which is fixed to a horizontal surface, and allows it to be inclined so that the axis of the clockwork coincides with the direction of the earth's axis (in the place where the instrument is being used).

This direction, which is given by the latitude of the place, need not be known by the operator, the instrument setting itself automatically, so to speak, both with regard to latitude and the declination of the sun corresponding to the day of the year, at the same time.

Moreover, when it is set, the instrument will be fixed in the position demanded by the latitude, by means of a clamping screw acting on a limb which carries latitudes marked from 0° to 70°.

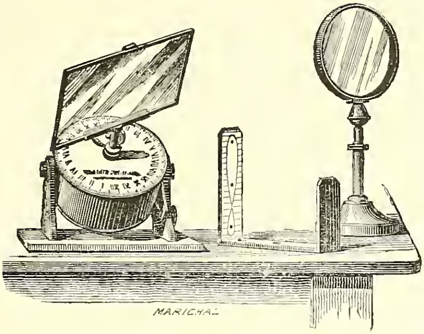


Fig. 182.

To set the instrument, after the clockwork has been wound up, it is placed on a perfectly horizontal surface, and having removed the mirror, a metal rule, diametrically placed with regard to the dial, is fitted into the axis of the clockwork, which passes through it like a spindle. The two extremities of this rule end in perpendicular arms: the shorter one is pierced with a small hole (a pinnule in fact), the longer one is marked with divisions corresponding to the equation of time and the declinations of the sun for every ten successive days. At the end of the shorter arm the rule is pierced with a slit, through which the numbers of the hours engraved on the dial can be seen. To set the apparatus at any hour of the day, the rule is turned round the axis, like the hand of a watch, until the figure representing the hour and fraction of the hour at which operations are made (the time must be taken from a well-regulated watch), appears in the slit, and the division representing it on the dial coincides with an index placed on the edge of the slit.

To set the instrument definitely it has only to be turned horizontally on the table, and inclined more or less on its support, until a ray from the sun passing through the hole of the pinnule is depicted on the line of declinations, upon the branch opposite the rule, while, at the same time, a small image of the sun falls exactly on the point corresponding to the day of the year.

This operation takes but a few moments, and, as can be seen, is very easy.

This done, the instrument is set; the screw regulating the inclination on the circle of latitudes is screwed up, the rule is removed, and the shank of the mirror, which can be turned without acting on the clockwork, is pushed into the axis of the clockwork. A steady horizontal ray is thus obtained, which can be reflected on to another plane mirror, placed at a short distance, and fitted with ball and socket adjustment so that the ray can be turned in any desired direction.

We may add that if the hour is not exactly known, the instrument can be regulated with sufficient accuracy by setting it at *about* mid-day. One can, however, operate by first setting it at nine o'clock in the morning, and then again at three in the afternoon. In each of these operations a line is traced on the table with a pencil, the foot of the instrument being used as a ruler. These two lines form an angle, which is divided into two equal parts by a bisector, along which the foot of the heliostat is placed. In this way the instrument is set for mid-day.

The clockwork specially constructed for this heliostat is very exact and solid; it has an anchor escapement, and can move a mirror a great deal larger than the one adapted to it. By means of a small dial placed on the drum, and divided into sixty minutes, on which a minute hand moves, the regularity of its movement can be verified. The hour dial, and the division into days on the square, are enamelled, and consequently prevent accidents and mishaps. The instrument can be used in all places situated between the equator and a latitude of 70°.

The heliostat is accompanied by a second mirror, mounted on a heavy foot, with ball and socket motion, and the whole is enclosed in a box, which is of small dimensions and very portable. To use the heliostat, it is first arranged in position, and then fixed according to the instructions which have just been given. Then the large mirror is placed so that the solar rays strike the second mirror, which is mounted on a foot and placed near the instrument.

The larger mirror as it turns sends the solar rays on to the mirror of the microscope, which is placed in the most convenient position for illuminating the object. Notwithstanding these successive reflections, which might be expected to absorb a great deal of the light, sufficient, however, remains for obtaining a good negative in an exceedingly short time.

It is superfluous to say that in the path of the rays should be placed a vessel having parallel sides, containing a coloured liquid, giving a monochromatic light, and, at the same time, serving to protect the eye-sight while focussing, &c. If apochromatic objectives be used, this vessel can, if required, be dispensed with during exposure, although it is much better to leave it; but if simple achromatic objectives are used it is indispensable to leave it in position. The cuproammoniacal solution, giving blue monochromatic light, is to be preferred.

This solution is obtained by dissolving one part of powdered sulphate of copper in four parts of liquid ammonia.

A certain amount of distilled water is then added, so as to give a moderately dark solution, depending on the intensity of the sunlight, and also on the distance between the two sides of the vessel, *i.e.*, upon the width of the coloured liquid.

Electric Light.—The voltaic arc light has little to recommend it because it is so unsteady and difficult to produce. Incandescent light is, on the other hand, very advantageous, and we invariably use it when we cannot employ sunlight, which very rarely happens in our climate. We have already shewn in the first part of this work how the electric light is produced and used. We will only here add that when using the incandescent light we prefer the photophore, and we generally arrange it so that the light of the luminous source reaches the condenser directly without the intervention of the mirror.

By using electric incandescent light and Zeiss's achromatic condenser, which gives a wide image of the luminous source, photographs can be taken in the image of the flame without difficulty with 3mm. (1-8th inch) and 2mm. (1-12th inch) apochromatic objectives. The whole secret lies in using suitable lamps, having a sufficiently large and straight filament. Mons. Trouvé, of Paris, supplies such lamps, which leave nothing to be desired.

Oxy-hydrogen Light.—Oxy-hydrogen light, which is produced by a jet of oxygen and hydrogen, and makes a cylinder of lime incandescent, is admirably adapted to photo-micrography, and English amateurs use it very largely. It is, however, in every respect inferior to electric light.

A burner with separate jets is generally used. Ordinary house gas is used instead of hydrogen, and the oxygen is bought ready made, compressed in steel cylinders. These cylinders, which are proved to a pressure of 250 atmospheres, contain the oxygen compressed to 125 atmospheres. The pressure naturally diminishes as the gas is used; it is therefore necessary, in order to have constant pressure, to make use of a "*pressure regulator*," which is provided, if desired, with the cylinders. When a cylinder is empty it is returned to the maker, who supplies another in its place. The cylinders can, therefore, be bought or hired.

There is a manufactory, where oxygen is compressed, in the Rue Gavarni in Paris.

We have already stated that ordinary gas can be taken from the mains, but this can only be done where separate jets are used, for when the "*mixed jet*" is used, in which case the two gases are mixed before being lighted, it is absolutely necessary to employ two india-rubber bags, and to submit each to an equal pressure, otherwise an explosion may occur.

When ordinary gas is not at hand, a special apparatus can be used, in which ether vapour can take the place of gas. Although inferior to the light produced by ordinary gas (which again is not equal to that given by pure hydrogen), the light obtained in this way is very serviceable. The apparatus can be bought at Antwerp, from Messrs. Van Neck and G. Brand, and in London, from Messrs. Watson and Son, and others.

We give here an illustration of the photographic apparatus, made as specified by our friend Mr. A. Pringle, the skilful English photo-micrographer. This apparatus (fig. 183) is specially intended for use with the oxy-hydrogen light.

Lamp Light.—By means of an oil lamp very good negatives may be obtained, especially if the magnification adopted is only moderate.

Mr. J. D. Cox, one of the most skilful American diatomists, has thus obtained an entire series of photographs, which he has used to illustrate his beautiful work on the structure of the valves of diatoms. However, long exposures are necessary when an oil lamp is used, and

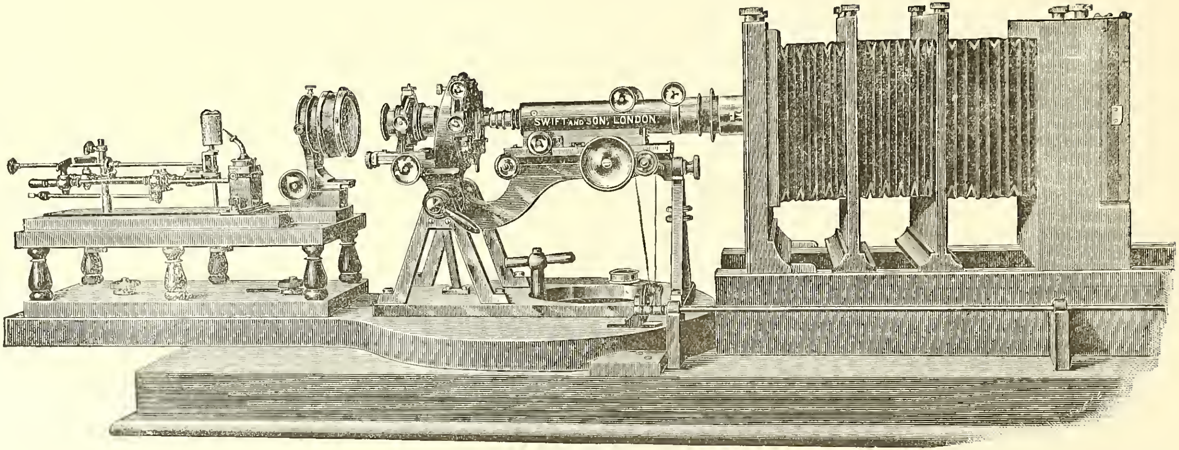


Fig. 183.

Mr. A. PRINGLE'S PHOTO-MICROGRAPHIC APPARATUS.

thus the focussing is liable to vary, and, moreover, there is very little contrast between the object and the background.

White Cloud Light.—What we have just stated about lamp light applies also to light reflected from white clouds. It can only be used for very low powers, and always with the risk of an alteration in the focussing.

4.—The Photographic Processes.

It still remains for us to describe how to take a photograph. We shall do so very briefly, especially as the subject is very simple, and, thanks to the wonderful invention of "gelatino-bromide," by our friend the skilful English microscopist, Dr. Maddox, photographic processes are so well known that at the present day almost every one has some knowledge of photography.

The production of a photograph involves, as is very well known, two operations, the production of the negative and the paper print.

1. *The Production of a Negative.*—A negative is produced with our apparatus in the following way:—After having placed in the field of the microscope the object to be photographed, the camera is arranged above the instrument, so that the end of the tube is 5 or 6 centimetres (2 or 2¼ inches) above the bottom of the interior. All light outside of the tube is carefully stopped, first by fastening round the tube the small bag made of black material, and then by sliding over the tube of the microscope a small disc of black cardboard. The hole in this disc is such that it just rests on the projecting rim of the tube.

The object is then carefully focussed and suitably illuminated in accordance with the instructions which will be given further on.

When the image appears to be satisfactory, a projection ocular is substituted for the ordinary ocular, and the camera is then closed.

It must then be ascertained whether the image falls well in the centre of the ground glass screen; if so, a plane glass is substituted for the ground glass screen. With the assistance of a lens correctly focussed for the under surface of this glass, one can see whether the details of the image are as clear as possible; if not they can be corrected by means of the fine adjustment.

A card screen is now placed in front of the microscope to prevent any light reaching the instrument. The dark slide containing the sensitive plate is now substituted for the glass screen, and then the plate is exposed by removing the card screen for whatever length of time is thought to be right. This length of time having elapsed, the card screen is returned to its place to cut off the light, the dark slide is closed, and taken into the dark room. The dark room should be quite light-tight; all light, whether natural or artificial, used during the development of the plate, should be filtered through orange or ruby-red glass. It is even advisable to cover up the developing dish with a card until the image has made its appearance.

Development is either effected by placing the plate in the developer, which is previously poured into a developing dish, or by pouring the developing mixture over the plate, in a developing dish, film upwards.

The developer is kept constantly moving over the surface of the exposed film. When the image does appear with every detail, and has acquired sufficient density, which can be tested by looking through the plate held up to the light, it is then carefully washed under a jet of water, and afterwards placed in the fixing bath.

The plate is *fixed* when no white part is seen on its under-surface. It is then washed afresh, and placed for some minutes in a saturated solution of alum, which has the advantage of preserving the gelatine film, at the same time rendering it more transparent, and making it adhere firmly to the glass carriage.

The plate, having been taken out of the alum bath, is placed upright against the sides in a large tank containing soft water. It is left there for 11 or 12 hours, but the water of the tank is changed two or three times, so that the last traces of the fixing solution may be dissolved and removed by the running water. The plate, when taken from the water, is allowed to dry of its own accord (without the intervention of heat, which dissolves the gelatine), and then printing can be commenced.

Developer.—There are a large number of substances which can be used for developing the photographic image. Iron, pyrogallic acid, hydroquinone, eikonogen are used most frequently, and can be made up according to the formulæ, which are found printed on every box of plates.

All these developers, in the hands of a skilful manipulator, give good results, provided the plate has been given the correct exposure. The whole secret lies in correctly estimating the exposure and in managing the developer skilfully.

After having tried a great many formulæ, we invariably use either "P. Mercier's Perfect Hydroquinone and Eosine developer" (1) or a formula which we give below.

---

(1) Faubourg, St. Martin, 158, Paris.

Mercier's developer, which keeps well for a long time, provided it is preserved in stoppered bottles and kept in the dark, has the advantage of allowing a certain amount of latitude in the time of exposure, while at the same time a correctly-exposed negative can be given any required density.

We shall now give some supplementary instructions as to development.

If the exposure has been good, the image begins to show itself in *three minutes;* makes its appearance gradually, first the sky and the high lights, then the half-tones with all their details. These are allowed to develop and the image to lose itself in the shadows until the plate is clouded, and begins to assume a nearly uniform tint over its entire surface, except round the edges, which, *remaining a pure white*, shows that there has been no fog.

The operation should take at least ten minutes or a quarter of an hour, according to the sensitiveness of the plates. When the image takes longer to appear, whether from under exposure or from want of sensitiveness in the plate, or because a bath which has become too weak is employed, the only thing is to await it cautiously; it always appears as vigorous and detailed as possible, and unless the plate has been exposed to a light it is *never fogged* (1).

As many as ten or twelve plates can be developed in the same bath without its getting dark, *i.e.*, without its losing much of its strength, especially if it is revived from time to time with a little fresh solution—100 to 150 grammes ($^{1}/_{6}$ to $\frac{1}{4}$ pint) of liquid being enough for a dozen plates 9 × 12 ($3\frac{1}{2}$ × $4\frac{3}{4}$ in.).

Care should be taken not to throw away old baths (having been used several times); they develop slower, but they are excellent for ordinary work.

Normal Negatives and over-exposed Negatives.—It is well-known that the *great difficulty* in photography is to calculate the exact time of exposure depending on the illumination of the subject to be taken, the quality of the plates, and that of the objective, &c.

With the developers that we used before the above, Ferrous oxalate, pyrogallic acid, and often even with the ordinary hydroquinone baths,

---

(1) It is precisely the slow development peculiar to this developer, which gives the beauty and energy to negatives thus obtained, even with half the ordinary length of exposure; the liquid has time to re-act on the entire thickness of the exposed film, and the high lights stand out in relief from the darker parts, while objects not so light and details come out equally well.

Further, owing to the slowness of development, this developer can be manipulated as desired, either by forcing or retarding it, according to the requirements, so that the negative can be withdrawn at exactly the right moment, which therefore always ensures satisfactory results.

an over-exposed plate fogs, assumes a uniform grey tint, and is sometimes irremediably lost.

The Perfect Developer allows a considerable error in the time of exposure to be allowed for, and disappointing miscalculations to be avoided.

It is sufficient to recollect that when the time of exposure has been almost correct, *about three minutes are required with a fresh bath, four minutes with an old bath, for the image to commence to show itself* in the high lights. If it appears before this, it is caused by great over-exposure; in this case the plate must be taken out and placed in an older bath, or the bath used must be simply weakened with distilled water. When it is known beforehand that the plate is much over-exposed, a commencement can be made by putting it in an old bath and leaving it there to develop slowly, to try it; it can be brought on to the desired end by adding, if required, a few drops of new developer from time to time. By following these simple instructions, whenever it is unknown if the exposure has been correct, everything is reduced to a matter of care and attention, and there ought *never to be a failure.*

With correct exposure the silver is reduced to a beautiful black tint; over-exposure produces a sepia equally good for printing.

It is evident that an over-exposed negative must not be kept too long in a fresh bath without watching.

When suitably developed, a plate, although much over-exposed, can be brought out with a light tint as if it had been under-exposed, and it only requires intensifying with bi-chloride of mercury and with ammonia to change the colour and make it capable of producing excellent prints.

Instantaneous and under-exposed Negatives.—The Perfect Developer, by reason of its extreme energy, is admirably adapted for development of these kinds of images. It is sufficient to use a new bath, and to leave the exposed plate in it for a quarter of an hour, and more if necessary, until, by examining it with transmitted light, it is seen to require no further density. Several successive new baths can be used with advantage, but in these cases it is very necessary to cover the dish with a screen, to avoid even the direct light of the ruby lamp.

In this way excellent instantaneous negatives are obtained as good and sharp as can be desired, and more vigorous than with any other negative.

Intensification of the Negative.—A negative which is too thin can be intensified by known methods. One of the simplest and most effective is mercury intensification. The plate, already fixed and well washed, is placed in a five per cent. solution of bi-chloride of mercury, containing five per cent. of common salt, where it is left *to be bleached until it attains the degree of intensification desired.* It is then washed in plenty of water, and then sprinkled with a mixture of two or three parts of ammonia to six or eight parts of ordinary water. It darkens while it is acquiring density.

The ammonia can be replaced by the hydroquinone developer diluted with water, but this method, which is very effective, demands that the preliminary washings be a great deal more thorough.

One can often obtain good prints with a thin negative by printing *in the shade*, or in the sunlight with several thicknesses of paper interposed.

The formula we use instead of the perfect developer is as follows :—

Hydroquinone	8 gr.
Sulphite of soda (chemically pure) ...	50 gr.
Carbonate of soda	50 gr.
Bromide of potassium	1 gr.
Eosine	1 centi.-gr.
Distilled water	1 litre.

We invariably use a fresh bath, which serves us for several plates; if the image comes out too quickly we add some water, if it comes out too slowly we strengthen it on the other hand by adding several small quantities of the fresh bath.

Hydroquinone is inconvenient, in consequence of the rather large graining which it shews on the sensitive film; therefore, when we require very delicate detail, and especially when the negatives are intended for enlargement, we now prefer Eikonogen, which gives a very delicate and transparent image. The following is the formula we use:

Eikonogen	3·5 gr.
Pure carbonate of soda	2·5 ,,
Pure sulphate of soda	3·5 ,,
Water	100·0 ,,

We proceed as with the hydroquinone bath, and when necessary we add a few drops of a concentrated solution of bromide of potassium.

A bath previously used, to which a certain quantity of fresh bath is added, gives very harmonious negatives.

By operating with care, negatives can be produced as fine as with collodion.

Fixing Solution.—To fix gelatino-bromide plates we use a solution of 200 grammes (7 ounces) of hyposulphite of soda, dissolved in one litre (1¾ pints) of water. The required quantity of this bath is poured into a dish which holds enough to allow the plate to be well covered. This should always be used fresh. As soon as it gets brown it ought to be thrown away, otherwise it has a prejudicial effect on the plate, by interfering with its perfect transparency.

Before closing the chapter we ought to say a word on the sensitive plates used.

All plates are not equally adapted for photo-micrography. It is necessary that the film should be sufficiently sensitive, the grain as fine as possible, and the image capable of penetrating evenly through it.

It is a rare thing to find all these conditions fulfilled. It is now eight years since we pointed out, in our work on electric illumination, the Ilford plates, which at that time were sold under the name of *Marion plates*, from the name of the dealer who had for the moment got the monopoly of their sale.

Since then we have made numerous experiments, and tried very different kinds. Each time that we tested a new sort of plate we always imagined that we had discovered a marvellous plate, and that we were bound to obtain quite phenomenal results.

Unfortunately, this is never the case, and one only finds that new difficulties have been created. Each time we have to begin quite afresh, and again experiment on exposure, developers, &c., &c. After endless disappoinments we come back to the Ilford plates, and we strongly recommend this brand, which is universally sold throughout London.

Negatives intended for reproduction by phototype must not be made on glass, since the image being thus reversed often causes inconvenience. We have not up to the present been able to remedy this defect. But now for some months past some very fine and rapid films have been produced, which are stretched on a metallic frame, which can be managed as easily as glass plates. From the experiments we have lately made with them, we are enabled to recommend them. They are made by Messrs. Victor Planchon & Co., of Boulogne-sur-mer (France), and sold under the name of *Pellicules auto-tendues*. Their price only slightly exceeds that of extra rapid glass plates.

For *Bacteria* the ordinary Ilford plates are not suitable. In this case special plates, called Isochromatic plates, are necessary. Those which have given the best results are Carbutt's *Orthochromatic plates*, and Vogel-Obernetter's *Eosine plates*, by Otto Perutz, of Munich.

Ilford plates can also be used if they are previously placed for two minutes in the following bath:—

Aqueous solution of erythrosin (to 1-1,000th) ...	25 cent. cubes.
Alcoholic solution (to 1-500th) of cyanine ...	1 cent. cube.
Liquid ammonia	4 cent. cubes.
Water	175 cent. cubes.

When the plates are taken out of the bath they are placed on blotting paper and rapidly dried while sheltered from the dust. The plates, prepared in this way, can only be preserved for a few days.

2. *Printing on paper.*—When photographing the details of a very delicate structure, the author of the negative alone is able to make a suitable print on paper. But in the case of ordinary negatives we advise microscopists to have the printing done by an experienced professional photographer, after having given him the necessary instructions. The net cost under such circumstances will often be less than if the printing were done by oneself, for if one cannot have an eye constantly on the printing, there is a risk of spoiling a good deal of paper.

Printing on paper is easy in any case, and it is simply a matter of time and patience. We will describe the operation:—

In the first place we will give the formulæ:—

1.—Silver Bath.

Silver nitrate	15
Water	70
Alcohol	30

2.—Toning Solution.

Water	4 litres.
Auric chloride	1 gramme.
Calcium hypochlorite	1½ grammes.

Chalk, a small quantity so as to make the bath alkaline.

3.—Fixing.

Water	100
Soda hyposulphite	15 to 20

The albumenized paper, which can be bought ready prepared, and should be of the first quality, is stretched over the surface of the silver bath, which has been previously poured into a glass or porcelain dish. After contact for three or four minutes, the paper is taken out by holding one of its corners and fixed, by means of a wooden clip, to a cord stretched across the dark room, and there left to dry.

The sensitized paper is then placed behind and in contact with the surface of the negative on which the image is, then both are enclosed in the printing frame and exposed to the light.

When the image appears to be sufficiently printed, the paper is immersed in the toning solution and there left until it has acquired a pleasing tint.

The print is then immersed in the hypo bath, from which it is removed, when, on examining it by transmitted light, the unaffected parts appear quite white.

It is, finally, left for twenty-four hours in a tank of pure water, which should be renewed two or three times during that period.

The print is then dried and mounted.

M. Mercier some time ago introduced a new paper, called *Paper isotoned with uranium nitrate*, which gives very beautiful images, and only requires, after printing, to be fixed with hypo. This paper is very convenient, and can be obtained from all good vendors of photographic materials; and we advise all photo-microscopists to give it a trial, because we feel sure that they will be as satisfied with it as we have been.

3. *Production of Lantern Slides.*—Lantern slides can be obtained by means of special silver chloride plates. These plates are printed with artificial light—just like printing on paper—with an exposure of from two to three minutes. When the plates have been exposed, they are developed like silver bromide plates, or if special ones are used, the instructions printed on the box must be followed.

The Ilford positive plates (called special transparency plates) have a great and deserved reputation.

At the Antwerp Microscopical Exhibition, Messrs. Auguste et Louis Lumière, of Lyons, shewed some new plates which they had invented, on which objects shewed the colours which were seen on them when observed in the microscope.

These positives were used in the conferences held at the exhibition, and were held to be a great success. We have to thank Messrs. Lumière for the following note, in which the mode of obtaining these results is explained.

Process for obtaining micrographs intended for projection.—The positive photographic images hitherto used for projection have generally the following inconveniences :—

1. They are deficient in transparency.

2. They are monochromatic, either black or bistre, except when they are hand-painted, in which case they partly lose their authentic

character, which constitutes the principal advantage of photographic prints.

In the case of positives representing microscopical preparations this is most inconvenient.

Photographs in black, indeed, give only a very imperfect idea of such preparations, which are generally of very bright tints.

It is a matter of some interest to search for a process by which they can be produced mechanically and more faithfully.

We have been able to attain this end, and we have obtained double colourings by combining photographic processes with the methods of colouring microscopical preparations.

The best images have been obtained by proceeding in the following manner :—

We first chose a paper, called *carbon paper*, the film of which is poor in colouring matter. It is indispensable that the positive be very clear if it is desired that its tint should not sensibly act on the colouring, which should be definitely given to them. This paper is rendered sensitive by a solution containing :

Water	650	parts.
Bichromate of potassium	25	,,
Alcohol	350	,,

In summer the solution should be cooled ; its temperature ought not to be more than 15°C (= 59F).

After the paper has been immersed for five minutes, it is suspended to dry in a position screened from light and dust.

The paper is then exposed under the negative in the Chassis-press and the carbon process is carried out according to directions.

In a word the sensitizing and the printing are both carried out with the precaution which that process demands, but which we will not here dwell upon.

The hardness of the impression is determined by means of a photometer.

When the register of the photometer shews that the exposure is sufficient, the image is developed according to the known methods, on a thin polished glass, the surface of which has been previously rubbed perfectly clean, the print being applied to the polished side.

Care should be taken that the print is completely developed. As soon as this is the case, the positive is washed in cold water, immersed in alcohol for ten minutes, and then left to dry.

If the work has been properly done, the print is feeble, and sometimes scarcely even visible.

To colour it, the requisite solutions are prepared, the colours employed in microscopy, or those which are nearest them, such as violet, methylene blue, gentian, violet coton, blue, magenta, macarat, demethylated safranine, malachite green, &c.

The concentration which appears most suitable varies from 1-100 to 1-500, according to the solubility and strength of the substance.

If any colour is insoluble, or only slightly soluble in water, it is dissolved in alcohol, as dilute as possible, and the solution mixed with water.

A large number of other substances could, of course, be added to the list of colouring agents mentioned above, but the fact must not be lost sight of that certain aniline colours are rapidly altered by light. Those having this property must be rejected.

The solution chosen to colour the positive is poured over the image. In a few seconds the liquid will penetrate the gelatine, which will retain the colour, and take a bright tint identical with that of the microscopical preparation, if the right colour has been chosen.

When the colouring is too intense it should be copiously washed with water. Generally the colour will be slowly and uniformly diminished.

The effect of washing can be easily watched, and must be stopped at the right moment.

The decolourizing action of water is generally sufficient when malachite, macarat, or methylene blue are used.

When the washing is insufficient, alcohol should be used instead of water, but the decolourization is effected much more rapidly than in the previous case, and consequently the operation must be conducted with greater care.

Treatment with alcohol must always be followed by subsequent washing in common water.

The effect of alcohol is rapid with methylene violet and magenta. Decolourization is much more difficult with coton blue and safranine.

For this reason the last-mentioned colours should be used in a more diluted state, in order that their action can be followed more closely, and to prevent the necessity of having recourse to decolourants.

With these brief instructions it is easy to obtain double stains like those seen in certain microscopical preparations ; when preparing microbes for instance, the microbe is frequently coloured red, and the ground substance blue.

To produce the same effect on the photographic positive, it is first treated with an intense red tint, but such that it is not opposed to ultimate partial decolourization of the print. A one per cent. solution of magenta will be found best in this case.

After this treatment, the print is found to be coloured throughout. To fix our ideas let us pursue this case ; the microbe is seen to be a deep red colour, and the ground substance a clear red.

We then proceed to partially decolourize it, first with water, then, if necessary, with alcohol. When the ground begins to lose its colour it should be treated afresh with that colour.

A weak solution must be used, such as diluted solution of coton blue of 1-500.

The grain of the ground glass, which acts as a support to the negative proof, is detrimental to the transparence of the positive.

For projection, it is important to varnish, in order to destroy the grained appearance of the surface. The projected images are then much more brilliant.

The varnish below seems to us to be suitable for this purpose :—

Benzine	300 parts.
Gum Dammar	5 „

It is applied cold like collodion.

The varnishing can be avoided by replacing the ground glass by transparent glass, but then the gelatine is often liable to become unfixed during development.

Positives produced by this method, when projected on a screen, show very superior effects to those in black obtained by ordinary methods.

4. *General Instructions.*—We still wish to give some general information which we have purposely reserved till now, so as not to interfere with the general course of our remarks.

1. In order to reproduce the image on the sensitive plate with the greatest amount of clearness and detail, the image of the luminous source must coincide as far as possible with the image of the object. This is absolutely necessary whenever any high power is used, and the object is photographed in axial illumination.

If the magnification is small, on the other hand a convergent beam of light must be used, so that the image of the luminous source falls above the lenses of the objective.

2. It naturally follows from what has just been said that a microscope intended to be used for photography must be furnished with a condenser.

The excellent Abbe condenser is not always quite sufficient here, except for oblique illumination. A condenser required for the photographic microscope should be achromatic, and should give as broad an image off the luminous source as possible, so that the whole field is uniformly illuminated.

The achromatic condenser of Zeiss, which has been specially constructed for the requirements of photography, perfectly fulfils the end for which it has been designed.

In certain cases, however, we prefer Messrs. Powell and Lealand's apochromatic condenser, of N.A. 1·4. In other cases again, as mentioned elsewhere by Dr. R. Zeiss, it is found very useful to employ weak objectives, achromatic or apochromatic, such as the 16 mm. (2-3rd inch) Zeiss' A., AA., &c. For low magnifications an achromatic bi-convex lens is used as a condenser. What condenser one uses must depend a little on circumstances. The essential is to illuminate the image suitably, proportionately to the numerical aperture of the objective, without destroying detail or occasioning a curved and, consequently, deformed image, by using a cone disproportionately illuminated.

Dr. R. Zeiss in his treatise on photo-micrography lays down the general rule that both for direct observation and for photographing coloured objects (except bacteria), the cone of illumination ought to be of sufficient size to cover a third of the free aperture of the objective. This can be ascertained by removing the ocular, and looking down the tube of the microscope, after having previously placed in front of the eye a piece of smoked glass, to protect the retina from the too brilliant effect of the light. The smoked glass is absolutely necessary when sunlight is used as the illuminant.

3. In the two preceding paragraphs we have had histological objects specially in view. On the other hand, when it is desired to photograph the delicate striæ of diatoms with oblique light, nothing is better than the Abbe condenser, N.A. 1·40. Even with axial illumination we frequently use this condenser to great advantage.

Ordinary gelatino-bromide plates, although excellent for the reproduction of colourless objects, are not so suitable when certain objects are to be photographed (*e.g.*, bacteria artificially stained), which require long exposure, and are, moreover, very difficult to reproduce.

If the bacteria were always coloured with Bismarck brown, the photography of their micro-organisms would not present such difficulties, for this colour being only slightly active enables very good negatives to be secured by ordinary processes. Unfortunately, many of the bacteriological preparations are coloured with red aniline dyes, the chemical nature of which makes it impossible to obtain negatives with sufficient contrast. It is, therefore, necessary to find a medium to diminish the actinic power of the rays of red light which pass through the bacteria, so as to retard the impression of them on the sensitive plate. This problem, which was once thought insoluble, has been solved by M. Henri Schleusner, of Antwerp, by a process as simple as it is ingenious, simply by colour compensation, *i.e.*, by placing between the objective and the photographic plate a green glass of such a tint that it most completely neutralises the red light. An image is thus obtained, composed of black bacteria on a green ground, two colours, the contrast of which, relatively to their actinic power, is much more considerable than that which exists between yellowish white and the red of the uncompensated image.

By this process the time of exposure becomes necessarily very long, but the negatives thus obtained leave nothing to be desired, and they have secured for M. Schleusner Dr. Koch's warm congratulations.

Since then equally satisfactory results have been produced in photographing preparations of this kind, by using plates called "isochromatic," which are treated with eosine, a substance which has the same effects as M. Schleusner's compensating glass, by retarding the appearance of certain colours.

Isochromatic plates were first used in photo-micrography by M. Schleusner and ourselves in researches made together in 1884. Since then they have been used by all bacteriologists. We have already, at page 275, described the best makers.

Such are the principal rules which should be observed by any beginner in photo-micrography. In this, as in so many other subjects, it is only possible to give general instructions which the worker himself must modify a little, according to his personal tastes and inclination. In order, however, to present instructions of greater extent and diversity, we have asked three of our friends to favour us with a note of the way in which they carry out their work.

These are the most skilful English photo-micrographers, and may justly be considered as masters of the art; their observations will be all the more valuable to our readers, as the branches of study in which these skilled workers are engaged are dissimilar. Dr. Maddox, the celebrated inventor of gelatino-bromide, which has so fortunately altered the whole aspect of photography, is occupied with histology and diatoms; Mr. Comber devotes himself exclusively to diatoms, and his prints are regarded as unequalled; Mr. Andrew Pringle, the author of an excellent treatise on photo-micrography, gives special attention to bacteria.

We strongly advise beginners to study carefully the remarks, with which this chapter closes.

Remarks by Dr. R. L. Maddox.—"As you have expressed a desire that I should tell you how I worked in photo-micrography, I must go back to the days of Collodion. I do not exactly recollect the date of my first efforts, but I believe it was in 1863-64.

"As soon as possible I arranged a small room, with a window facing the south, furnished with shutters, having two small panes of deep orange glass. The lower shutter had an opening in the middle to admit the rays of the sun projected from the outside by means of a Dubosq solar camera, or a heliostat with two mirrors. All the operations, collodionizing, sensitizing, exposing, and developing were carried out in the room with the greatest ease. The base or table which supported the solar camera when the microscope was used, with the plate holder and its shutters, was made of strong board, blackened, bound with iron, and resting on four triangular feet, arranged so as to give great stability against any vibration.

"This board was 5 feet in length and 12 inches in width.

"The heliostat was placed outside the open window; it was furnished with two mirrors and arranged so as to project the reflected rays along the axis of the microscope, which was placed in a horizontal position. Although with the solar camera it was easy to use convergent solar rays or a parallel beam, the latter was preferred; oblique light was rarely used. Outside the underneath shutter, and exactly in the path of the reflected light, was often placed a vertical bath with parallel surfaces, containing a solution of sulphate of copper-ammoniac. The light, furnished either by the solar camera or the heliostat, was projected directly on to the condenser of the microscope. The microscope, which was one of Ross' large models, had wider and shorter tubes than usual, and was fixed on a well-finished mahogany stand. The whole was carefully adjusted so that all the axes corresponded and the pieces of apparatus arranged to slide between the guides on the blackened board, while the frame for the sensitive plates was made so as to be inclined in different directions, in order that the surface of the sensitive film could be placed correspondingly parallel in case of any deviation in the mounting of the object. The image was projected on Bristol cardboard and examined with a lens.

"In front of the cardboard was placed a screen with an aperture in the middle, depending on the size of the field desired, and a second screen with a smaller opening was placed nearer the microscope tube. Exact focussing was made by means of an adjusting rod tipped with a small grooved wheel suspended under the blackened base board; a loop of waxed silk cord passed through a slot in the base board, connecting the pulley of the rod with the divided head of the fine focussing screw.

"To increase the magnification, as the room did not admit of the use of a longer board, an achromatic concave lens was used, placed, according to the necessities of the case, from two to three inches behind the objective, in preference to any eye-piece.

"When using polarizing apparatus I employed light direct from the heliostat. Sometimes a large achromatic prism was used in place of the condenser of the microscope. For stereoscopic negatives, a half diaphragm, which could be rotated round the objective, was placed before the front lens for low powers; for those of short focus an arrangement was made to project the rays of the condenser at a small angle (9° to 13°) on to the opposite sides for the two images, but it was very difficult to illuminate a second time the same part exactly and to the same extent as on the first occasion.

"Some of the objectives were corrected for photography, but others had the ordinary visual focus. From time to time different changes in detail were made as occasion required. Such was briefly the modus operandi at this period.

"Since the year 1871, when I announced the substitution of gelatino-bromide for collodion, which two years later began to be a commercial article, and which now has extended in an extraordinary manner through all countries, my method of work may be described as follows:—

"Having changed my residence, and seeing that the sensitive plates of gelatino-bromide required precautions which would have been useless with collodion, I chose for my illuminant the flame of a good paraffin lamp with a large wick. The blackened board with its four feet was preserved, but I added another above it. On this upper base board rested the camera with bellows at such a height that its centre corresponded with the centre of the tube of the microscope when placed horizontally. To assist the explanation, a diagram is given (fig. 184). The front of the camera is fixed, and is pierced in the centre for two brass tubes, of which the inner one can be moved by sliding it sufficiently to enter the shortened draw tube, thus forming a closed connection between the microscope and the camera. The sliding tube and the draw tube are lined with black velvet.

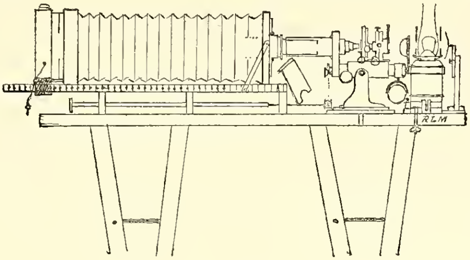


Fig. 184.

"The back part of the camera can be slid between guides on the upper base board and fixed at any distance. The edge of this base board has a scale of half inches and is pierced with holes for fixing the camera; in the space between the two base boards is a rod passing through holes made in the vertical supports carrying the upper base board. This adjusting rod ends in front in a bit of stout brass wire or fine rod, which enables the tip, furnished with a small pulley with a very narrow groove to be slightly displaced. This pulley, by means of a loop of waxed silk braid, works the milled head of the fine focussing screw. At the other end the rod is furnished with a wooden knob. The rod slides easily, but without too free a movement, in the holes of the supports, and can be manipulated in any part of its length to fix the final focus. The space between the two base boards is very useful for putting down any small objects for a moment on the lower board. In front of the camera is placed a thin board, furnished with a central pinion, which fits into a hole in the stout black base board; this allows the small board to be turned on its axis while resting on the base board, and is provided with guides to receive and retain exactly in its place the mahogany stand fixed to the foot of the microscope.

Further, in front is the lamp mounted on a support, so as to be able to be raised or lowered, or moved to either side. These movements are made by means of screws, so that the axis of the flame can be accurately regulated with the axis of the objective. The base of the lamp stand is furnished with a small flap to support a reflector or metal mirror. The glass of the lamp is surrounded with a large blackened tube, pierced both in front and back with a hole facing the axis of the flame. The edges of the aperture in front are furnished with grooves for retaining in place a coloured glass slide.. The lamp stand can be fixed at different distances from the microscope, and in the intervening space a condensing lens can be placed, in order to render the diverging rays from the lamp parallel.

"By rotating the board which supports the microscope, and lamp, and turning up the mirror, the microscope can be used in the ordinary way, but an adapter is required for the eye-piece.

"Before making a photo-micrograph precaution is taken to correctly centre the object on the stage, and to make the axis of the sub-stage condenser correspond with the axis of the objective. The lamp having been lighted and centred beforehand, the small board support is turned back, the ocular removed, and the microscope lowered to a horizontal position between the guides on the small board, then the connection is made by the sliding tube and the silk cord is carefully passed round the head of the fine focussing screw and the pulley on the rod. The camera is then closed up, and the image examined on the ground glass screen. If the object is of a delicate nature, the ground glass is replaced by a piece of plain glass of the same thickness, having on its front surface some fine lines drawn upon it with a writing diamond. The image is again examined to ascertain if the image and the fine lines exactly coincide. The plain glass can be replaced by a wooden block or screen, having one or several holes in it, in which an ordinary ocular can be fixed, its exact position having been determined beforehand, so that the image corresponding with the ruled lines on the plain glass shall be in correct focus. In the body proper of the camera is placed a blackened diaphragm, pierced to limit the field and prevent the action of reflected light. After the focussing, some minutes are allowed to pass, to see if the heat from the lamp may not have disturbed the focus. Then after having stopped the transmission of the light, by placing a card between it and the sub-stage condenser, the plate-holder, with the sensitive plate, is inserted in its place and its slide withdrawn, the card removed after a few moments, and the exposure made; the length of time required depending on many factors, as the distance of the image, the power of the objective, the rapidity of the plate, the nature and colour of the object, &c. After the exposure, I have always the habit to replace the plain or ground-glass screen and to again examine the image, in case that the negative obtained should not correspond with the image seen, or that the focus has been deranged by vibration. Often the lighting is effected direct, that is, without any lens between the light and the sub-stage condenser.

"When a projection eye-piece is used, I prefer to finish the adjustment, as far as possible, before placing the microscope in position. If preferred, by turning the small board round with the microscope in place upon it, the object can be examined and arranged whilst sitting down; but generally the examination is made whilst in a standing posture. Every precaution is taken to avoid all reflected light not in the axis of the microscope, by hanging a black curtain upon the wall nearest the instrument, and by excluding the light from the window by curtains. The camera and microscope are also covered by a black velvet cloth. As photo-micrography is accompanied by many details, the explanations needed are somewhat long. Lately, I have experimented with another method of lighting the object, which differs from that generally employed, and which has some promise of utility. Upon the surface of the ordinary plain mirror of the microscope is fixed a tablet in fine porcelain, and of perfect whiteness. The focussing of the object being made by daylight reflected from the surface of the tablet, sunlight is then thrown upon the surface of the porcelain by a large condensing lens, in such a manner that the solar rays illuminate a sufficiently large surface, so that the reflected light does not show in the resulting negative the apparent motion of the sun. The final focussing is easily made during this soft, yet strong, illumination. This method has given me some results that I scarcely expected. The plan requires a different position of the apparatus, unless a heliostat be used. The development of the image and other operations are conducted in the dark room in the ordinary manner."

Note by Mr. Andrew Pringle.—"For my special work I use an apparatus constructed on the same principles as those of the apparatus manufactured by Messrs. Swift (fig. 183). That is to say, the end of the tube carrying the ocular is supported by a firm and rigid stand. The part of the apparatus which bears the tube is long and strong. The manner of focussing is different, and the fine adjustment is obtained by Campbell's differential screw. But the general conditions always remain the same; the greatest possible rigidity of all the parts, with the most delicate working.

"I almost always use oxy-hydrogen light. The point of incandescence should be very small and as brilliant as possible; for this purpose I use the mixed jet and as hard a lime as possible. I also almost always use a doublet quasi-achromatic lens, for rendering the rays thrown on to the condenser parallel.

"Sometimes I use Zeiss' achromatic condenser N.A. 1·0; and sometimes Powell & Lealand's oil immersion achromatic condenser N.A. 1·4.

"According to the colour of my objects, I use ordinary plates, with a very thick film of gelatino-bromide emulsion, or orthochromatic plates. As a rule, Edwards' isochromatic plates give me the best results, but for very deeply-coloured red objects I require plates treated with an ammoniacal solution of cyanin of a strength of 1 to 10,000. I prefer apochromatic objectives to all others for every kind of photo-micrography.

"I generally use as developer, hydroquinone, alkalized with a caustic alkali, such as potassic hydrate.

"But for certain objects and for special results, I use other developers, such as pyrogallol or Eikonogen.

"For diatoms, of which my experience is limited, and for bacteria, of which I have a large experience, I generally use caustic hydroquinone, Thomas' formula, diluted with 50 to 70 per cent. of water, according to circumstances.

"To screen the light in treating coloured objects, I use a great number of colours, *e.g.*, yellow, blue, rose glasses, Zettnow's liquid, having always a regard to the colours of the object. To succeed completely I believe it is necessary to use the best apparatus, with the greatest skill, in both microscopy and photography.

Note by Mr. Comber.—"The heliostat, with which I work, consists of an ordinary brass time-piece, provided with an extra motion, so that its spindle turns round once, instead of twice, in the twenty-four hours. It is set at an angle corresponding to the latitude of the station in which it is to be used, so that when its highest point is turned due south, the clock is in the plane of the equator, and its spindle parallel to the axis of the earth.

"Its motion then exactly compensates for the rotation of the earth. Fitting on the spindle is a small plane reflector, of speculum metal, with universal motion; and when this is set to reflect the sun's rays in the direction to which the spindle points, that is towards the north pole of the heavens, the beam remains without any apparent motion.

"When the sunbeam crosses the optical axis of the microscope is placed a fixed mirror (plane), inclined to such an angle (half the latitude of the station), as will reflect the beam horizontally along the axis of the microscope.

"In the practical use of the apparatus, the points respecting which I am accustomed to use great care, beyond, of course, the cover-correction of the objective, and the adjustment of the projection eye-piece to the distance of the sensitive plate, are the following:—

"1. That the optical axis of the whole apparatus is directed due north and south. This is requisite to ensure a motionless illuminating beam.

"2. That the achromatic condenser is exactly centred and the cone of illumination absolutely axial. Even a very slight degree of obliquity is apt to produce 'diffraction fringes,' and give rise to images more or less false.

"3. That no lens, insufficiently achromatised, forms any part of the system. The use of a common 'bull's eye,' which some have recommended, I find to introduce aberration, and to yield an image more or less confused.

"4. The width of the illuminating cone should vary I believe according to the objective used and the nature of the object.

"Using my own 2mm. Zeiss' apochromatic objective N.A. 1·43, my experience is that the best delineation of these objects, such as 'test' diatoms, is given when the illuminating cone is such as will fill about two-thirds of the back lens of the objective; but for objects of considerable thickness, a somewhat narrower cone. As a general rule, a very narrow illuminating cone produces 'diffraction' effects, a very wide one 'haze,' arising, I think, from certain imperfections in the corrections of the objective. I should be only too glad to possess an objective which would stand an illuminating cone of as large an N.A. as itself."

CHAPTER III.

CAUSE OF ERRORS IN MICROSCOPICAL OBSERVATIONS.

§ 1.—Iridescence and Diffraction.

Iridescence, which not very long ago rendered the use of the compound microscope impossible for serious observations, may now be said to exist no longer. In the objectives made by our best opticians it is practically eliminated, even if there does remain some colour produced by the secondary spectrum, but this is no consequence, except in photography. It is for this reason that in the latter work nothing can equal apochromatic objectives.

Iridescence cannot therefore any longer occasion inconvenience, except in the case when too strong a light is used, and then it can be made to disappear by suitably arranging the light.

We cannot, however, say this of the effects produced by diffraction, namely, the illusory existence of double outlines of objects, which is all the greater as the magnification used is increased. Sometimes in the place of a double outline, a triple or even a quadruple one is seen. An experienced observer will never be deceived by diffraction phenomena. There is, moreover, an easy means of ascertaining if apparent lines have a real existence: by successively illuminating the object when possible, first by transmitted light and then as if the object were opaque. It can easily be understood that in the latter case, in consequence of the very nature of the diffraction lines, not the slightest trace of them will remain.

It can also be ascertained whether the existence of a line is real or not by changing the direction of the illumination. Thus, by illuminating obliquely first from the left side and then from the right, the line, if it is real, will not change; on the other hand, it will disappear or will come from one side to the other if it is illusory.

Finally, the effects of diffraction are in a great measure avoided by not using too strong a light, and especially by rejecting sunlight altogether.

§ 2.—Flying flies *(Muscæ volitantes)*; Dust on the glasses.

Observers frequently see, especially when a brilliant artificial light is used, lines of dark points, often like rows of threaded beads (fig. 185), which obstinately fix themselves on the object which is being examined. They are called "flying flies" *(Muscæ volitantes)*, and these images are produced by filaments or corpuscles in the vitreous humour of the eye. The existence of these bodies in the eye has been demonstrated by researches made in common by Messrs. Harting and Schroeder Van der Kolk. Probably no one is exempt from flying flies, but there is no cause for anxiety about them.

Experience has proved that the use of the microscope does not increase them, for the flies which sometimes annoy us at the present time are exactly the same as those we noticed fifteen or twenty years ago. They have not increased in any way, and the drawing which we made of them at the time is almost the counterpart of what we see now.

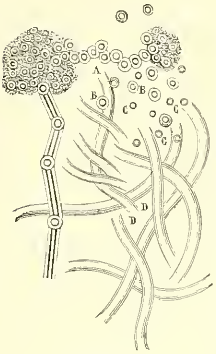


Fig. 185.

Flying flies are more visible and tenacious one day than another; a brilliant light or physical fatigue renders them more apparent. We sometimes perceive these flies with ordinary light when looking up at the sky or at a strongly illuminated surface, such as the ground covered with snow. At other times, notwithstanding the most fatiguing examination of diatoms, we have remained for entire weeks without being aware of their existence.

About twenty years ago, after prolonged observations of the sun's disc, the retina of our eyes became congested, and flying flies became so abundant that for a long time we were unable to devote ourselves to any serious observation. Professor Harting advised us to adapt an elbow ocular to our microscope, so that the corpuscles might be withdrawn from the axis of the eye, and not inconvenience the sight.

This means succeeded perfectly, and we recommend it to anyone who may find himself in the same trouble.

When much annoyed with flying flies the best course is to suspend observations. A few minutes' rest is sometimes sufficient to restore the eyes to order.

We therefore repeat that there is no reason to feel anxious about flying flies; they are not produced by the use of the microscope, and they do not, as is often supposed, indicate any disease of the eye.

Minute particles of dust often adhere to the surface of the glass slips, and to objectives and oculars. With care these cannot cause mistake. The spot where they may be found can easily be recognised by turning the ocular on its axis, and by moving the glass slip. Particles of dust on the lenses of objectives destroy the clearness of the image.

When a liquid containing very attenuated corpuscles is examined under the microscope, they appear to change their place as if they were animal objects.

By observing the movement with much attention it is soon noticed that it resolves itself into a species of oscillation of the corpuscles. These displacements, which are a phenomena of molecular attraction, have been called the molecular movement or *Brownian movement.*

§ 3.—Defects of the Eye.

Astigmatism.—The human eye is rarely perfect; perhaps it is never so. The principal defect and the one, with which it is always more or less tainted, is called *Astigmatism*, and is in most cases caused by the unequal curvature of different meridians of the cornea.

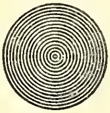


Fig. 186.

If the figure at the side (fig. 186) be looked at with one eye (while the hand is held before the other) and held at the distance of normal sight, the black lines will then appear to be neither equally black nor equally clear throughout; a certain part will appear grey and more or less extended, and this extended part will probably not be the same for each of the eyes.

It is well to examine the eye made use of in observations, and to place in the direction in which the lines appear the clearest the fine details (*e.g.*, the striæ of diatoms) which may have to be studied.

We had occasion, some years ago, to observe the enormous influence that astigmatism can exercise on the appearance of fine details.

We have on several occasions tried to point out the transverse striæ of the *Amphipleura* to a very competent and skilful diatomist, who always refused to acknowledge the existence of striæ that we could see distinctly.

It then occurred to us that astigmatism might be the cause of this, and an examination of his eyes confirmed this view; the eye of our friend was found to be greatly deformed in the direction in which the diatom valve was placed. It was only necessary to turn the diatom round a quarter of a circle for him to see the lines with the greatest clearness.

CHAPTER IV.

PRESERVATION OF THE MICROSCOPE.

The microscope is a delicate instrument, and great care must be taken of it if we want it to retain its original value. We, therefore, think that a few words on this subject may be useful.

The instrument should be preserved under a bell-glass. In this way it will be screened from the dust which penetrates even into the best made boxes, and it will always be close at hand and ready for making observations. It is, moreover, impossible to take out and put back the instrument into a box many times without either receiving a few little blows or being placed in a slightly strained position, which after a time inevitably interferes with the centering.

The lenses being the most important part of the microscope must be taken the greatest care of. If they are covered with dust it should be carefully wiped off with a very clean brush, from which all grease has been previously removed by washing it in ether.

It is an excellent rule to dust each lens after use before putting it away.

If any dampness or dirt has attached itself to the lenses they should be delicately wiped with a piece of well used fine linen. Chamois leather, which is also sometimes used for the purpose, is also very good, provided it has been well washed and is very soft.

Re-agents must never be used without the intervention of a cover-glass, and care must always be taken that the liquid does not wet the objective, which might otherwise become tarnished and corroded. Should such a thing happen, the lens should be immediately washed in distilled water and carefully dried. Similarly the lower lens of an immersion objective is liable to be injured if it is not wiped before being put away.

Homogeneous objectives should be cleaned with a piece of linen or chamois leather, moistened with benzine.

The microscope must also be preserved from every kind of vapour. If the body of the microscope slides with difficulty, it should be moistened either by breathing on it or with a little saliva and then immediately wiped with a piece of linen and briskly rubbed. The same should be done for the tube in which the body of the instrument slides.

An important point to observe is never to lay aside the instrument with an objective left in, without at the same time leaving an ocular in; without this precaution small particles of dust penetrate into the tube, whatever may be done, and fall onto the upper lens, which then has to be cleaned; the more often the lens is cleaned the greater chance there is of it deteriorating.

And now a last recommendation. Keep the temperature of the room neither too high nor too low; if possible, it should not exceed 70° to 80° Fahrenheit, nor be below 2° or 3° of freezing point, in order that the variations of temperature may not affect the Canada Balsam with which the lenses of the objectives are cemented. In any case the instrument must be preserved from rapid changes of temperature, which are much more injurious than slow variations.

Apochromatic objectives require special care. Many of the glasses of which they are composed are very tender, and liable to attack. Messrs. Zeiss condemn their use in tropical regions; they should be preserved from every kind of vapour, however slightly caustic or acid it may be. It is also necessary, especially with the 1·6, to avoid all rubbing, because the flint glass is very easily scratched.

When cleaning a lens it should always be rubbed in a circle, as a scratch concentric with its circumference is less serious than one across the lens.

In an excellent little book (1) Mr. E. Bausch gives some very good hints for preserving the microscope. We reproduce it here, although some of it repeats the recommendations we have just made.

To take care of a Stand.—One of the first rules should be to keep the instrument free from dust. This may be done in the manner above described. If dust settles on any part of the instrument, remove it first with a camel's hair brush, and then wipe carefully with a chamois skin, with the grain of the finish and not across it, as in the latter case it is likely to cause scratches. Keep the working and sliding parts absolutely free from dust, as this will make the parts to grind together, and will soon cause play.

Use no alcohol on any part of the instrument, as it will remove

---

(1) "Manipulation of the Microscope," by Edward Bausch.

the lacquer. As the latter is for the purpose of preventing oxidisation of the metals, it is important to observe this rule. In using the draw tube, impart a spiral motion. In instruments which have no cloth lining a straight up and down movement should be employed, as the tube will otherwise become scratched.

If it becomes necessary to lubricate any of the parts, use a slight quantity of soft tallow, or good clock oil.

In an instrument which is in constant use it sometimes happens that the pinion works loose, and occasionally to such an extent that the body drops of its own weight. Tightening screws are provided to take up the play: in the Professional, American, Concentric, Universal, Physician, Biological, and Library microscopes, these are situated in the back of the pinion. In the Investigator Model and Family microscopes they are seen in the slide by removing the body. In using a screw-driver, grind its too large surfaces so that they are parallel, and not wedge-shape, and so it will exactly fit in the slot of the screw head.

In inclining the stand, always grasp it at the arm, and never at the tube, as in the latter case it may loosen the slide, or tear off some of the parts.

Where repairs or alterations are necessary, always have these made by the manufacturers; they can, from the system of duplicate parts, not only do it cheapest, but best.

To take care of Objectives and Eye-pieces.—It is necessary to keep these as free from dust as the stand, indeed even greater cleanliness should be observed.

When indistinct dark specks are seen in the field lens, and sometimes in the eye lens also, the dust may be removed with a camel's hair brush, but when this is not sufficient, use a well-washed piece of linen, such as an old handkerchief. On account of its fine texture chamois skin is desirable, but as it is fatty at first it should never be used until after it has been well washed. The same method applies to cleaning objectives. Clean an immersion objective immediately after it has been used, first by removing the fluid with a moist linen and then by using a dry piece.

Be particular to keep the objectives in a place where they are not subject to extreme and sudden changes of temperature, as the unequal expansion and contraction of the glass and metal may cause the cement between the lenses to crack. Also keep them from direct sunlight.

Screw them into the nose-piece, and unscrew by grasping the milled edge.

Avoid any violent contact of the front lens with the cover-glass. Usually the latter suffers, but it is also liable to damage the former.

Above all, no one but the owner should handle the microscope and its accessories. One person may be expert in manipulating one kind of instrument but find it difficult to work with another. The fine adjustment always causes the greatest difficulty, as in some instruments its movement is the same as that of the micrometer screw, while in others it is quite different, and thus the objective, as well as the object, are endangered.

BOOK IV.

CHAPTER I.

GENERAL RULES FOR PREPARING MICROSCOPICAL OBJECTS.

§ 1.—Medium used for Observation; Preparation and Preservation of Microscopical Objects.

Objects which are to be examined under the microscope are placed on a glass slip, which is called a *slip* or *slide* (French *lame*), and are covered over with a second and smaller slip of very thin glass, called the *cover* or *cover-glass* (French *lamelle*).

It would be well, as has been proposed by Professor Leo Errera, to call these only by the two words, "lame" and "lamelle."

Two principal sizes are adopted for object glass: the size called Giessen's (48 × 28mm.), which is only used in Germany, and the "English size," where the slips are 25 millimetres (1 inch) in breadth by 76mm. (3 inches) in length. These slips are sold all ready made and rounded at their edges; the bevelling of the edges prevents any injury to the hands, and at the same time preserves the stage from scratches.

The cover-glasses are of various sizes; for ordinary work square cover-glasses are used, 21 or 18mm. ($\frac{7}{8}$ or $\frac{3}{4}$ inches) square. In the case of valuable preparations, or those mounted in resinous media, &c., round cover-glasses are employed, 15 or 12½mm. (3-5ths or ½ inch) in diameter.

The thickness of cover-glasses for ordinary work is about 1½ tenths of a millimetre (3-500ths of inch).

The slides usually sold vary very much in thickness, but for very delicate work the maximum thickness should not exceed 1 millimetre (1-25th inch), otherwise condensers of large aperture cannot be conveniently used.

The object ought never to be examined dry, but it should be immersed in an appropriate liquid, *i.e.*, one which does not affect it; for instance, if the object is an organic substance the liquid should be one which does not inflate it by absorption, or which does not deprive it of its water, or further, which does not dissolve it.

For ordinary examinations of vegetable organisms, water is a very convenient liquid, and is that used in a large number of cases. But generally water is not sufficient for certain tissues which require to be brightened up, *i.e.*, rendered more transparent, also water is not sufficient for permanently preserving tissues. It is, therefore, necessary to have recourse to preservative media, which differ greatly according to circumstances. We will consider those which we most frequently use.

1.—Aqueous and Oily Media.

1. *Chloride of Calcium.*—This is used as a saturated solution. The proportions are one part of chloride to three parts of distilled water. The solution is filtered, and well preserved from dust. It is used for transparent objects. Chloride of calcium, which was very largely used twenty years ago, is now rarely employed.

2. *Glycerine.*—Glycerine is used pure, and must on no account be contaminated. It is used for objects which are slightly transparent, such as sections of wood, &c., and also for preparations of starch, which would undergo alteration in the chloride of calcium.

3. *Glycerine Jelly.*—Glycerine jelly is an excellent medium for all vegetable tissues which do not require to be strongly illumimated. The English have used it for a long time. In Germany it is called "Kaiser's Gelatine." Its preparation is very simple. One part of the best gelatine is allowed to soak and swell up in six parts of water. After being left for twenty-four hours, the whole is heated with a Marie-bath, until completely dissolved; to this is then added seven parts of distilled glycerine, and a 100th part of carbolic acid. It is then stirred until completely mixed, and filtered through fine flannel. The jelly is preserved in bottles with wide necks, and well stoppered to prevent the access of any dust.

4. *Camphorated Water.*—This is the only liquid which we have found to be suitable for preserving the delicate spiral bands of chlorophyl in some algæ, such as the *Spirogyra.* These spirals are destroyed by every other solution. To prepare camphorated water, take a flask half filled with water, add to it three or four drops of spirits of camphor and

shake it well. More spirits of camphor is then added, and the whole well shaken again. This process is repeated until a considerable bed of powdered camphor floats on the surface. The liquid is then filtered and preserved in a well-stoppered bottle.

5. *Saccharinated Water.*—Unless camphorated water is hermetically sealed the camphor which it contains after a while escapes, and then the liquid is no longer capable of preserving objects.

The experiments which we have made during the last three years have proved to us that it may be advantageously replaced by a solution of a gramme (15½ grains) of Fahlberg's saccharine in a litre (1¾ pints) of water. This solution may be made with boiling water, and preserves for any length of time.

6. *Fine Oil.*—We use the fine oil employed by watchmakers instead of the essential oils recommended by most authors. The advantages which we find are that ordinary black varnish can then be used as a cement and preparations be easily made. Oil is used for pollens, aleuron, and some other objects.

7. *Liquid No. 28.*—We invented this liquid twenty years ago for animal histological preparations, but afterwards we found that it was useful for a large number of vegetable substances; for drug preparations intended for microscopical research in materia medica we find that nothing is better. When it is used pure, without the addition of water, it possesses the important property of not evaporating; we have preserved for many years a series of preparations of different objects placed in a drop of this liquid between a slip and cover-glass without any cement, and we have found no alteration whatever has taken place. This liquid is used as follows:—To a part of the liquid an equal quantity of distilled water is added, and this second liquid is placed in a bottle and put on one side. When used, the object is placed in a watch glass and covered over with a small quantity of the liquid. It is then left for some minutes or for some hours (according to the more or less transparency of the object) to evaporate spontaneously. When the object has become sufficiently transparent, the preparation is made according to the usual method in the same liquid in which it has been cleared, or if it is not too transparent, it can be prepared in a drop of liquid No. 28.

For vegetable substances we prepare it thus:—

Uncristallisable honey sugar, thickened by boiling until it registers 33 degrees of the acidimeter	300 grammes
Cristallisable acetic acid	25 ,,
Alcohol at 90 degrees	50 ,,

Add distilled water until the liquid marks 28 degrees by the acidimeter.

In order that the honey sugar may be good, it is necessary that it should be old. The liquid which floats on the honey is what we mean by honey sugar, and should be obtained from the druggist. This liquid is left in a bottle to itself for some months, and afterwards the upper part, which is the part used, is separated from the rest.

2.—Resinous Media.

1. *Canada Balsam.*—This is rarely used except for diatoms and very opaque objects. Canada balsam is advantageously preserved in a bottle of the special form represented in figure 187.

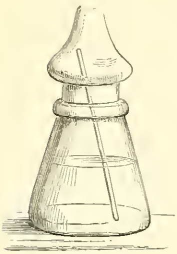


Fig. 187.

2. *Styrax and Liquidambar.*—We introduced these two substances into microscopical technique in 1883 (¹) to replace Canada balsam. They were promptly adopted by diatomists who now no longer use Canada balsam, which after a time becomes brown and resinous, while the new products keep without alteration, and become by age absolutely colourless.

Styrax is the balsam given out by *Liquidambar Orientalis Mill,* from Asia Minor and liquidambar is furnished by the *Liquidambar Styraciflua L.,* from North America.

The following is the descriptive note which we published on these media, in July, 1884:—

"Since the publication of the note, which we had the honour of presenting to the Society in last year's issue, the new products which we then made known have been most favourably received by microscopists. The most competent diatomphiles at the present time use styrax exclusively, and numerous papers have been published in Germany, America, England, and France, recommending its use."

"Many media," writes the celebrated preparer, A. C. Cole (²) "such as phosphorus, monobromide of naphthaline and others, have been tried, but it is unnecessary to enter into details concerning them, since the desired effects have been recently obtained by Dr. Van Heurck, who has succeeded in providing an admirable substitute for balsam in gum styrax, which yields the best possible results. It will probably be found that diatoms mounted in gum styrax are less liable to accidents than

---

(¹) "Billetin de la Soc. Belge de Microscopie," 30th June, 1883.

(²) A. C. Cole, *The Methods of Microscopical Research,* London, 1884.

Balsam 'mounts,' as the latter becomes resinous in time, and the covers are liable to 'spring,' the result of which is the appearance of prismatic colours in the Balsam, which are not only a great eye-sore, but also sadly deteriorate the slide. Gum Styrax may be considered absolutely permanent and unalterable. Purified Styrax contains a granular substance, which must be removed by dissolving it in chloroform and filtering the solution. The solution thus obtained is used in the same manner as Canada balsam. Styrax solution is even easier to work with than Balsam, and air bubbles are not produced in it by the application of heat, &c."

Mons. Dippel (1) has equally recommended styrax and Grunow (2) insists that difficult forms prepared with styrax show details almost as well as dry preparations, which are now generally condemned on account of the alterations which they inevitably undergo after a short time.

M. Kitton (3) has demonstrated that styrax shows clearly in certain diatoms (for example in *Polymyxus Coronalis*, *Bail.*), details of structure which are visible neither in dry preparations, nor those made with Canada balsam. The same diatomist recommends styrax for the preparation of sections of wood, insects, &c., and Professor Strasburger (4) recommends the same product for diatoms, and for rendering visible the nucleus of vegetable cells previously coloured with hœmatoxylin. "A solution of styrax in chloroform," writes this professor of botany, "possesses the high index of 1·63; the colour of this hœmatoxylin is well preserved by it, the cystoplasm becomes invisible, while the details of the nucleus appear with the greatest clearness (5)."

Styrax is, therefore, destined to play an important part in the laboratory of the microscopist, and we are now pleased to be able to announce a new property of this substance; instead of becoming further coloured by time and light, as in the case of Canada balsam, preparations in styrax become absolutely colourless. For the publication of our "Types of Diatoms" (which now includes 275 slides), our preparers have already completed several thousand examples, and we can testify that at the present time those of the first series are quite colourless. This confirms our advice to expose the raw styrax to the light and air for some time.

---

(1) DIPPEL, *Botanishe Centralblatt*, 1883.

(2) GRUNOW, *Botanische Centralblatt*, 1883.

(3) KITTON, *Science Gossip*, 1883.

(4) E. STRASBURGER, *Das Botanische Practicum*, Jéna, 1884.

(5) E. STRASBURGER, *Das Botanische Practicum*, Jéna, 1885.

"In our previous note we expressed regret that the liquidambar, which surpassed styrax in its beauty, in the ease with which it could be managed and the magnitude of its refractive index, could not be obtained in Europe. Since then, thanks to one of our best friends, Dr. José Clairac, who is head of the histological laboratory of the Military Hospital, of Havana, we have been able to obtain the raw liquidambar in quantity.

"In this state, the liquidambar is found in the form of a sticky, grayish mass, containing various fragments of wood and bark; it is very similar to the appearance of raw styrax.

"The raw liquidambar should be warmed with a Marie-bath, in a mixture of equal parts of genuine coal benzole and absolute alcohol (1). The solution is then filtered and evaporated at such a temperature that the mass becomes slightly brittle at about 10° C. (2). The mass is then again placed in the same solvent as above. The solution should be quite liquid.

"The following is the way in which we now use the solutions of styrax and liquidambar:—

"We begin by placing the cover-glasses on a large glass slip, and on each of them, by means of a pipette, we place a large drop of distilled water, on which we allow a drop of liquid, containing diatoms, to fall (3). These diatoms disperse throughout the drop of distilled water, which consequently is slightly disturbed.

"The cover-glasses thus charged with diatoms are covered over with a hand-glass, and left to dry naturally.

"When this is completed, the cover-glasses, taken one by one, are heated to red heat on a plate of platinum, and then put back on the large glass slip; a drop of very liquid solution of styrax or liquidambar is then placed upon them, and they are again left to dry under the hand-glass.

"After a few seconds the layer whitens; but this circumstance need cause no apprehension (which does not happen when the solution is with chloroform), and at the end of twenty-four hours the benzole has completely evaporated. The cover-glass is then placed on the glass slip and slightly warmed, preferably with a Marie-bath. A slight pressure

---

(1) Recent research has shown us that this mixture is the best solvent of styrax. Benzole or alcohol alone are not sufficient.

(2) Without this preliminary operation, the preparations would not harden.

(3) We preserve our diatoms in alcohol, which we decant before use, and substitute distilled water.

with forceps, drives away all air bubbles, if there are any, as well as any superfluous medium, which can be taken off when it is cold."

3.—Chemical Media.

1. *Monobromide of Naphthalin.* — Monobromide of naphthalin was introduced into microscopical technique, in 1880, by Professor Abbe.

This substance, which is a colourless, oleaginous liquid, has somewhat the disagreeable odour of naphthalin, but to this one soon gets accustomed. It has a refractive index of 1·658. It is used for preparing diatoms, and as an immersion liquid for the objective of N.A. 1·60.

Monobromide of naphthalin is not volatile, but it is very irritating to the eyes; the greatest care, therefore, should be taken not to touch them with the fingers when using the liquid.

Monobromide of naphthalin dissolves most resinous bodies. The preparations must, therefore, be enclosed by several coats of very liquid glue, and when these are thoroughly dry, by placing over them a thick solution of gumlac.

Monobromide of naphthalin, as well as the other chemical media which we shall afterwards mention, is used specially for diatoms.

Any object inserted in a liquid is visible according to the amount of difference between the refractive indices of the medium and the object.

The silica of diatoms has a refractive index of 1·43, the index of water is 1·33; the difference between these two indices, viz., 10, expresses the visibility of diatoms in water.

Canada balsam has an index of 1·54, the corresponding visibility is, therefore, 11.

Pure styrax has an index of 1·6, consequently the visibility is 17.

The monobromide having an index of 1·66, the visibility is 22.

2. *Iodide of Methyl.*—Iodide of methyl is a colourless liquid, very dense (2·27 at 22°), slightly volatile, with an odour somewhat like chloroform, smelling slightly of iodine.

Its index of refraction 1·743, and consequently its visibility is 31.

By saturating the iodide of methyl with sulphur, the index is increased to 1·787, and the solution has then not less than 36 as its visibility.

Iodide of methyl is destined to fill an important place in miscroscopy. It will serve as the immersion liquid for the next objective, with a higher index, which the firm of Zeiss may make, unless indeed a liquid with a still higher index shall be found, but this is not very probable.

3. *Medium having the high refractive index of* 2·4 *or arsenical medium.*—In 1884 our friend, Professor H. L. Smith, made the important discovery of his highly refractive yellow medium. We have good reason for calling this discovery "important;" however, to fully appreciate the service rendered to diatomists by the American savant, one must be making a study of diatoms and have realized how difficult, I should say almost impossible, it was to examine the striation of the most minute forms.

The yellow medium of Professor Smith consists of realgar dissolved in bromide of arsenic. It is not quite the same as the article known as realgar in commerce, which is a substance as brittle as glass, brownish yellow in colour and quite opaque, but rather the realgar known to mineralogists, which is of a beautiful ruddy yellow colour and is perfectly transparent. When Professor H. L. Smith acquainted us with the formula of his medium, he produced this realgar by melting two parts of sulphur with one part of metallic arsenic, and fusing the mass at a red heat for several hours.

When we had made the realgar in this manner, we found out after a few trials that the product could be obtained more easily, and at the same time in a purer state, by fusing together in a retort one part of sulphur and 1·7 parts of arsenious acid, and by raising the temperature to the point at which the product distills. Realgar thus obtained by distillation has quite the appearance of the natural realgar of mineralogists.

The realgar is then dissolved by heat in a test tube in some tri-bromide of arsenic, also obtained by distillation, and a syrupy liquid is thus produced of a yellowish green colour, almost black when seen in bulk.

The diatoms having been fixed on the cover-glass by dessication are covered with a drop of the liquid medium, and the cover-glass is then turned over on to the slip, and the latter is raised to a high temperature by a spirit lamp. Large air bubbles are thus produced, and the medium assumes a dark red colour, while at the same time the bromide of arsenic evaporates.

When the air bubbles cease to form and the bromide of arsenic has completely evaporated, the heating is stopped, the cover-glass gently pressed, and the whole left to cool slowly.

In cooling, the medium loses its red colour, and finally assumes a pale yellow tint.

Such is the *modus operandi;* it presents no difficulties, but the dangerous vapours which are thrown off during the operation, should be carefully avoided.

The medium, prepared in the manner indicated above, presents two great inconveniences; in the first place, the liquid deteriorates very quickly and can only be preserved in hermetically sealed tubes; secondly, two-thirds of the preparation gets spoiled often very rapidly without any apparent cause for the alteration.

We have made numerous experiments with a view to remedy these defects, and have at last discovered a process giving a solid product, which can be preserved without deterioration in a bottle with a ground-glass stopper; preparations which we have made with it have so far kept excellently and in perfect condition.

We prepare our medium as follows:—

In a glass flask or retort 30 parts by weight of flowers of sulphur are dissolved in 10 parts of bromine, and thus is obtained a solution of sulphur in bromide of sulphur ($S_2 Br_2$).

After perfect combination, 13 parts of finely pulverized metallic arsenic are added, and the whole is heated until the arsenic is completely dissolved.

It is then turned into a porcelain evaporating basin and heated in the direct flame, being stirred all the while with a glass rod until a drop of it, when cooled, becomes very brittle.

The medium is then turned out upon a cold plate; after cooling, the whole is broken up into pieces, which can be preserved in a bottle fitted with a ground-glass stopper.

The product, which forms a beautiful vitreous mass, of a greenish yellow colour, may be termed the first step.

Its index of refraction is $N_D = 2{\cdot}1203$, say $2{\cdot}12$, according to the calculation for which we are indebted to Messrs. Zeiss.

By heating it for a longer time, until the mass becomes very thick, the index of refraction is raised to

$$N_D = 2{\cdot}2534, \text{ say } 2{\cdot}25.$$

During its preparation some of the sulphur evaporates, and by suitably raising the temperature the index can be increased to 2·4.

These two products can be used indifferently; but they are both—and especially the second—rather difficult to melt. They can, if desired, be dissolved just before use in a little bromide of arsenic, but then the inconveniences of Professor H. L. Smith's above-mentioned medium may again be met with.

We find that preparations in the arsenical medium are very liable to undergo alteration. To preserve them intact the following precautions must be observed:—

1. The preparations should be made in very dry weather, in the open air and in the sun.

2. The arsenical medium should be heated until it cracks more or less, when cooling.

3. The preparations should be made very quickly; the covers and slides should be warm just when the medium is applied.

4. As soon as the preparation is completed, and while it is still lukewarm, a thick layer of gum lac should be applied round the edge of the cover-glass.

5. The preparations should be kept in a dry place.

Varnishes for Cells.—Varnishes are used for the purpose of making cells, in which microscopic objects are preserved in appropriate media, as will be described in the following paragraphs:—

The simplest of these gums consists of a thick solution of gum lac in alcohol, its gummy part being got rid of, either by allowing it to settle, by filtration, or by decanting. However, we cannot guarantee that this gum will keep well, because it is very liable to get detached from the glass.

For this reason we use with advantage *Schwarzer Maskenlack No.* 3, sold by Besseler (Schützenstrasse, No. 66, Berlin), which is probably an alcoholic solution of gum lac, mixed with some resin and lamp black. But as it is difficult to obtain, a thick solution of black bituminous varnish, to which a small quantity of wax dissolved in turpentine has been added to avoid cracking, will do as well.

All the compounds which we have considered in this chapter, and those to be noticed hereafter, can be obtained at the "*Laboratory of Technical Chemistry*" of Mr. Ferdinand Van Heurck, Rue de Moulin, Antwerp. Test preparations, and especially those of *Amphipleura* mounted in the arsenical medium, can also be obtained there.

2.—Chemical and Staining Reagents.

The following chemical reagents are those most frequently used for research in vegetable anatomy:—

Iodized chloride of zinc.
Solution of Iodine.
Mercury Nitrate.
Ether.
Ammoniacal cupric oxide.

Nitric acid.
Sulphuric acid.
Potassium Chlorate.
Caustic potash.

Iodized Chloride of Zinc.—Its action is the same as a compound of sulphuric acid and iodine, but the blue colour which it imparts to cellulose varies according to the degree of concentration. Its blue colour changes to violet or red at the expiration of twenty-four hours.

According to Schultz the iodized chloride of zinc should be prepared as follows:—

A solution of zinc in hydrochloric acid is evaporated to the consistency of syrup: it must be kept stirred with a strip of zinc. Iodide of potassium must then be added until it is saturated. The operation is completed by adding iodine and water in sufficient quantity.

Solution of Iodine.—Is used to colour the membrane of the cell as brilliantly as its contents.

It is prepared by adding 5 centigrammes of iodine and 15 centigrammes of iodide of potassium to 30 grammes of water.

Mercury Nitrate.—This is employed in solution. It imparts an intense red colour to all substances containing nitrogen; it takes at least a quarter-of-an-hour to act, but a better and more rapid effect is obtained by slowly heating the preparation.

Ether.—For the purpose of dissolving fixed and essential oils, as well as resins.

Alcohol.—Used for the same purpose as ether, but above all it is useful for removing air from vegetable sections. Before preparing the latter they are immersed for some minutes in a watch-glass containing alcohol.

Ammoniacal Cupric Oxide.—This is prepared by dissolving in liquid ammonia, cupric oxide, which has been recently precipated and is still moist. Ammoniacal cupric oxide dissolves cellulose.

Nitric Acid.—This turns intercellular membrane, and matter containing nitrogen yellow. After the nitric acid has been made to react upon them, they should be floated in liquid ammonia. It is also used in Schultz's macerating process, hereafter described in the article on potassium chlorate.

Sulphuric Acid.—When concentrated it is used in researches on pollens and spores; in a diluted state (three parts of sulphuric acid to one of water) it is used to colour cellulose blue. To produce this effect the preparation is first soaked in solution of iodine, and then having removed the superabundant solution of iodine, by using some blotting paper, a drop of sulphuric acid is added, and the preparation is covered with a thin lamina of glass. The blue colour changes in twenty-four hours to a violet or red colour.

Potassium Chlorate.—Used in the macerating process discovered by Schultz. The object is taken and cut into thin slices, which are placed on a glass slip; they are then covered with a quantity of powdered potassium chlorate equal to them in volume, and a few drops of nitric acid are added. The glass slip is then heated for from one to three minutes with a spirit lamp.

After the reaction, they are washed by painting them over with water several times with a brush. In this way the cells are isolated.

Caustic Potash.—This is used in solution, and as a rule with the assistance of heat. It is employed to dissolve fat, and intercellular matter, as well as lignin and suberin. Schacht advises that it be preserved in the powdered state because, as he says, the solution attacks cork stoppers, and in bottles fitted with glass stoppers, it forms between the neck and the stopper a silicate which prevents the bottle from being opened.

Staining Reagents.—The staining reagents frequently used at the present time for throwing into relief certain tissues and details are innumerable, but the botanist may be quite satisfied with those which we are about to mention. As our friend, Mr. Arthur C. Cole, (1) well says in his little work, *Methods of Microscopical Research*, which we cannot too strongly recommend:—

"We advise the histologist, on the point of commencing work, to ask himself the following preliminary question: What am I about to do? Do I desire to make instructive preparations capable of elucidating details of structure, or only a spread of tint and colour?"

The solution should not be uncertain. We recommend the following list of dyes:—

Logwood or Hœmatoxylin.
Carmine.
Ammonium Picrocarminate.
Sodium Sulphindigotate.
Nigrosine.

---

(1) Mr. Arthur C. Cole (29, Thurleigh Road, Streatham Common, London, S.W.), is probably the most skilful and best informed preparer of the present day. Some years ago he published, under the name of *Studies in Microscopical Science*, an admirable series of preparations of animal and vegetable histology, and also of pathological tissues. These preparations were accompanied with photographs and coloured plates, together with descriptive text for each series of preparations, written by the best English specialists.

Fuchsine.
Iodine green.
Methyl green.
Double staining.

These are prepared as follows:—

Logwood.—Take 60 gr. of dried extract of logwood, and 180 gr. of powdered alum. Mix them thoroughly together for some time in a mortar, adding by degrees 300 gr. of distilled water. When the solution is thoroughly mixed, filter. To the filtrate add 20 c.c. of absolute alcohol and preserve the dye thus made in a well-stoppered bottle. In order to act well, the dye should have been made for some days before being used; the older it is the more excellent it becomes. The solution we now use will soon be twelve years old, and acts wonderfully.

Carmine.—Take 4 gr. of the best carmine, rub it thoroughly in a mortar with 8 gr. of concentrated liquid ammonia. Leave the mixture for 24 hours, then add 120 gr. of distilled water saturated with borax, and pound the whole again in the mortar. Then filter and preserve in a flask fitted with a ground-glass stopper. Carmine gives a stain very similar to that of logwood, but many observers prefer logwood as being less fatiguing to the eyes. On the other hand, for photographic reproductions carmine is preferable.

Ammonium Picrocarminate or *Ranvier's double stain.*—The following formula, due to Weigert, gives the best results:—

Mix in a mortar 2 gr. of carmine and 4 gr. of ammonia; at the end of twenty-four hours add to this mixture 200 gr. of saturated solution of picric acid and a little acetic acid until a precipitate is formed by shaking; leave for twenty-four hours, filter, and add liquid ammonia until the liquid becomes clear. Then dilute to a one per cent. solution, *i.e.*, to 1 gr. of the solution made as above, add 99 gr. of water. This liquid colours protoplasm a yellowish red and the nucleus a bright red. Its action should be somewhat prolonged.

Sodium Sulphindigotate.—This stain is obtained by making a saturated solution of sulphindigotate of soda with distilled water.

Nigrosine.—This product has been introduced into the laboratory by the skilful Belgian botanist, M. Leo Errera, professor of the University of Brussels.

It colours the nuclei of cells a very deep blue, while all the rest of the cellular tissue remains practically colourless. After remaining but a short time in an aqueous solution of nigrosine, the microscopical section is washed with distilled water. It can then be mounted in glycerine jelly if we wish to study the photoplasm and the part of the nucleus formed by the *Achromatine* of Flemming. If, on the other hand, we wish to study the *chromatine* (= nuclein), then it should be washed in alcohol cleared, with essence of cloves, and mounted in Canada Balsam or styrax.

Some technical study on anilines which we pursued some years ago enable us to point out that if all aniline colours are rapidly destroyed by the light this does not apply to nigrosine which remains unaffected even when indefinitely exposed to the sun.

Iodine Green.—This is obtained by making a saturated solution of this product in distilled water. It is then made up to a 1 per cent. solution with distilled water.

Iodine green is a multiple stain which, when applied to tissues, colours them in different tones of the same colour.

Fuchsine.—1 gr. of fuchsine is dissolved in 30 gr. of alcohol, which is then diluted with water. Fuchsine is very far from being a stable colour, as it is soon destroyed by light. The same remarks apply to the following:—

Methyl Violet, which is prepared in the same way.

Double staining with Anilines is effected by first staining with an alcoholic solution of Fuchsine, and then with one of methyl violet.

Methyl Green, which is prepared in a concentrated aqueous solution and afterwards diluted with water.

This stain renders grains of chlorophyl very conspicuous, and Professor Strasburger, after having diluted it with a 1 per cent. solution of acetic acid, uses it for *nuclei*. Nuclei, which are not in the act of division, are coloured a very light green, while *Nuclear plates* in every phase of division assume a very intensely green colour.

This stain has always given us excellent results, but we cannot guarantee its preservation.

§ 3.—Instruments used in preparing Objects.

Use of Microtomes.

The instruments and accessory apparatus which we use are razors, scalpels, forceps, a hand-vice, evaporating basins, a spirit lamp, some glass rods and pipettes, and some watch-glasses.

When we want to make some good preparations of wood or botanical drugs, a good microtome should be added.

Razors.—The razors should be of the finest quality. We prefer those which have been made by the English firm of John Barber. Some should be hollow and some not. The first are used for delicate substances and the latter for hard objects, such as wood, &c.

Razors are never supplied by the grinders with a sufficiently sharp edge; moreover, they should be sharpened afresh after making a few sections. One should therefore be able to sharpen the razors oneself. For this purpose we use an excellent, but unfortunately rather expensive, composition (10s. to £1, according to the size of the tablet), called *The Celebrated Magnetic Tablet* (Rigge, Brockbank & Rigge, 35, New Bond Street, London, and 5, East Street, Brighton). After passing the razor several times over this composition, taking care to hold the razor very flat, the operation is completed by passing it five or six times over the strop on the other side, on which is spread with the finger some of *Rimmel's genuine diamond dust*, which can be purchased at any of Rimmel's perfumery shops. We have razors which have been treated in this way, possessing an extraordinarily sharp edge, and although we have used them daily for several years, we have never found it necessary to have them ground.

For some years razor strops have been sold in Paris which, for microscopical purposes, surpass all others. These strops, or so-called strops, are known as *cuirs donateurs.* The substance of which they are made is none other than the tissue of the stem of the *American aloe*, on which is rubbed some grease and fine emery powder. We highly recommend these strops, which were brought to our notice by the late Mr. Bourgogne, Sen. They have proved quite marvellous.

To make sure that the razor is sharp enough, a hair is placed between the thumb and first finger in a convenient position, and then it should be possible to cut the hair right down by pressing gently with the razor at a distance of four or five millimetres above the thumb.

Needles.—The needles, mounted in handles, which are generally sold with microscopes, are of little use. It is necessary to have a needle-holder, in which needles can be inserted. Such needle-holders can be obtained in Germany, at a small cost. They consist of a pointed rod of wood, ending at the top in a brass shank. This is split into four parts, in the middle of which the needle is inserted, and held there by means of a screw, the outside of the brass shank having a thread (fig. 188).

The needles used should be as fine as possible. Generally Nos. 11 and 12 are employed.

Needles are used for microscopical dissections; but when light objects have to be transported, they are taken up with hair pencils, slightly moistened, as needles often damage microscopical objects.

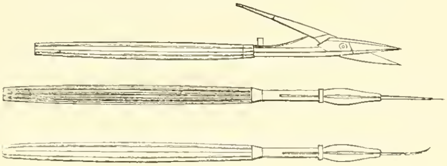


Fig. 188.

Scalpels (fig. 189) are needles, the ends of which terminate in an edged blade in the form of an iron lance. They are used for dissections.

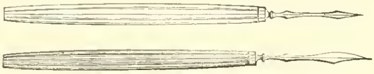


Fig. 189.

Forceps (fig. 190) are used to take hold of small objects. It is necessary to have some with a smooth inside surface and others grooved.

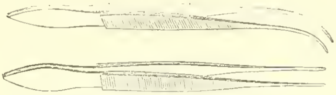


Fig. 190.

The Hand-vice (fig. 191) is used to press objects, such as leaves between elder pitch, in order to make transverse sections.

Fig. 191.

Glass rods and pipettes are used to take up drops of reagents, and *evaporating dishes* and *watch-glasses* to insert objects in appropriate liquids, such as alcohol and ether, so as to get rid of the air which is found in sections.

Hand sections and Microtome sections.—All sections which are required in the study of vegetable anatomy can be made with the hand; but when we wish to make sections of a definite size, to show the whole of the tissues of some organ, or when very fine and large sections of hard and ligneous bodies are required, recourse must be had to microtomes.

Hand sections are made in a simple manner. The object to be cut is held tight between the thumb and first finger of the left hand so as to project as little as possible, and the forearm is pressed against the chest in order to render the hand steady. Then with the right hand holding the razor firmly at the base of the blade, a superficial cut is made rapidly to make the surface on the object even. The subsequent cuts are made slowly by pressing the blade forward, and at the same time moving it from base to tip.

Before and after each cut the razor and body to be cut is moistened with a mixture of equal parts of water and alcohol.

The sections adhere to the razor. They are taken off with a fine hair pencil, and placed immediately in a watch-glass containing a mixture of water and alcohol. After remaining a short time in this first medium they are removed either to distilled water or to pure alcohol, according to the nature of the medium to be used in the ultimate mounting.

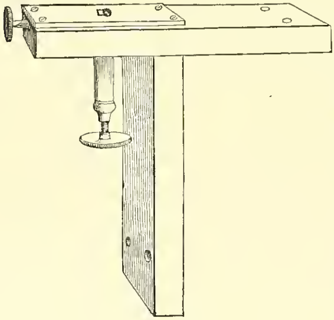


Fig. 192.

Bodies too thin or too small to be held between the fingers are placed in a cylinder of elder pith or of carrot cut lengthways for the insertion of the object, and then pressed in the hand-vice represented above in figure 191.

Pulverulent bodies, such as pollen, &c., are inserted in a drop of a solution of gum arabic and sugar, placed on the surface of a transverse section of a rod of elder pith. When it is all dry the surface of the gum is moistened by means of the breath, and sections are made with the razor in the same way as any tissue.

We will now proceed to the consideration of microtomes.

The simplest of these instruments which suffice in most cases is Topping's Microtome made by the firm of Chevalier (fig. 192).

Its price is £1. The object to be cut is enclosed in the tube, and by means of an inner knob a small part is made to project, and this is cut off with a very sharp razor. After each section is made a drop of water and alcohol must be placed on the object.

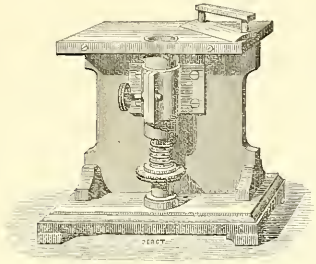


Fig. 193.

A more complicated model is sold by Nachet for £2 (fig. 193). Differing more particularly from the previous one from the micrometric screw having an index by which the thickness of the object can be ascertained.

Microtomes still more perfect are made. In the one we generally use, which was made in our amateur workshop, the section cutter is managed by means of a wheel, and fixed on a thick piece of brass which slides in a bronze groove. This addition enables the cutting to be done with greater regularity, especially with large and hard objects. No object if properly prepared can effectively resist such an instrument.

There has been a very remarkable progress of late years in the manufacture of microtomes. The microtomes of the present day are instruments of extraordinary precision, in which all the resources of the mechanic have been utilized, and which could not have been produced, except by makers having a special experience in the matter.

Among these makers we may mention as of the highest excellence Messrs. Carl Reichert and Chr. Erbe.

Carl Reichert's large microtome (fig. 194), is, as we have already said, an instrument of great precision, and it is made after the design of Rivet.

The stage carrying the object is moved forward on an inclined plane, the length of the slide bar being 30 c.m. (one foot). The carriage, with the object clamp, is moved upwards on the inclined plane by means of a micrometric screw, which enables sections to be cut to a thickness of ·001 mm. This micrometric screw possesses a piece of mechanism, by which each completed section is told by the catch of a wheel. The microtome has also an object clamp, as recommended at the Zoological Station at Naples, and an arrangement for fixing

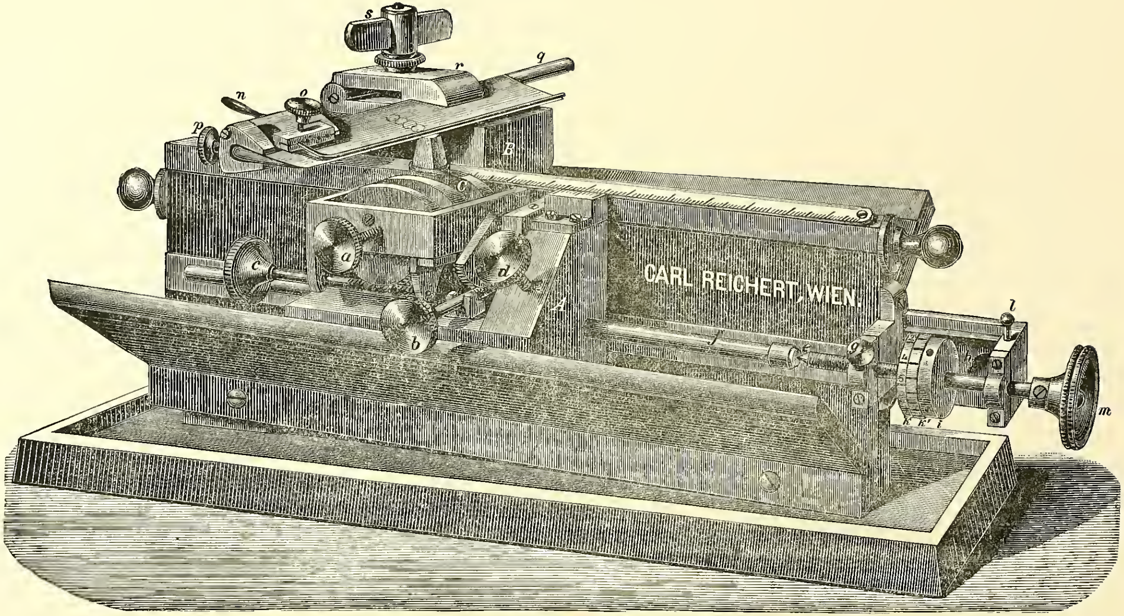


Fig. 194.

CARL REICHERT'S LARGE MICROTOME.

crosswise two knives, which are 13 and 16 c.m. (5 and 6¼ inch) respectively in length.

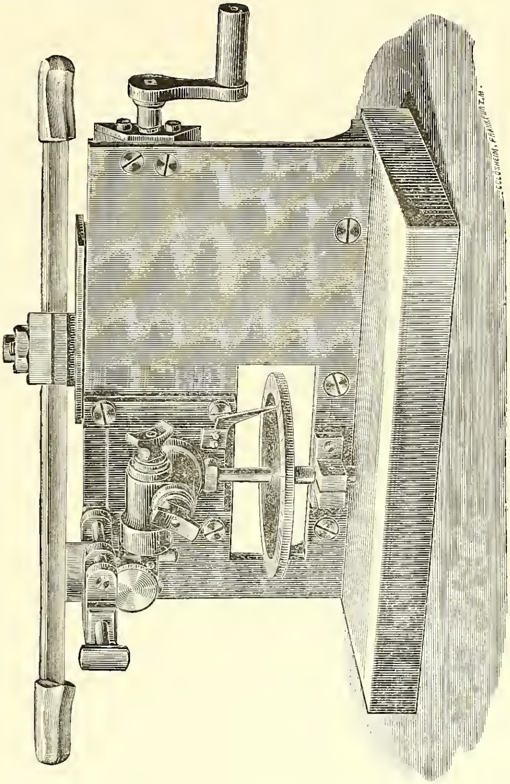


Fig. 195.

A similar, but simpler, microtome is that sold by Leitz (fig. 195) for £6. In this apparatus the knife is moved by a crank piece of mechanism fixed on the support. Consequently, a section can be made with greater precision, more evenness, and less exertion.

Messrs. Watson & Sons make an excellent little microtome, called in England the Cathcart Microtome, after the name of its inventor. This microtome, which figure 196 sufficiently explains, is specially intended for making sections of frozen tissue, but an accessory tube enables it to be used for ordinary unfrozen tissues. We have used it for several years, and can recommend it with confidence. The smallness of its cost (£1 1s.) places it within reach of all.

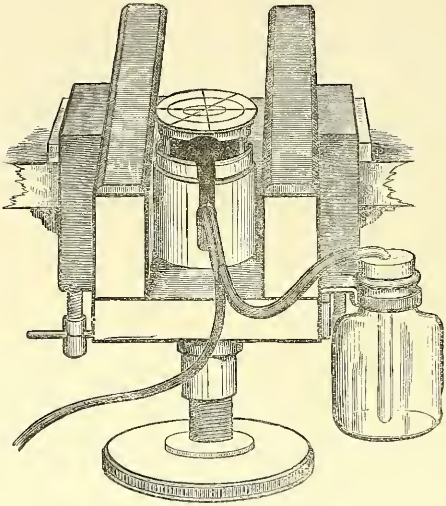


Fig. 196.

Erbe's Microtomes.—The Antwerp Microscopical Exhibition made known to us the excellent apparatus manufactured by a skilful specialist, Mr. Chr. Erbe, of Tubingen.

His apparatus, which are all most carefully made, are also comparatively cheap and very remarkable. Moreover, the Jury of the Exhibition gave him their highest award—the *diplome d'honneur*—and testified to the praiseworthy character of his productions.

Mr. Chr. Erbe makes a whole series of microtomes, but we will specially notice Thomas' Microtome, Erbe's Universal Microtome, the large Freezing Microtome, Hughes and Lewis', Cathcart's, and Cathcart and Erbe's.

Thomas' Microtome.—This instrument (fig. 196*a*) is well known in laboratories. It is palpably only Rivet's microtome, with the woodwork which that skilful microscopist used, replaced by cast iron—a substitution which enables the instrument to be constructed with greater precision.

In the Rivet-Thomas' microtome the knife is fixed on a block of iron, which is moved forwards and backwards with the hand, to make the sections. The iron block is guided in a groove, and is only borne on three ivory points, which slide on a well-polished plane, well oiled before being used.

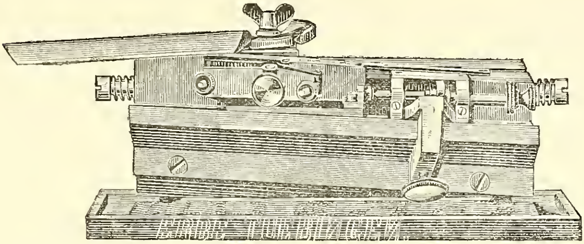


Fig. 196*a*.

The object can be held in forceps of different forms, which can be placed in any desired position. The forceps are fixed to an iron block, which slides on an inclined plane. A micrometric screw presses the block forward as far as may be desired; this space, which may be adjusted to a mikron, determines the thickness of the section.

Erbe's Universal Microtome (fig. 196*b*) differs from the previous one in that the object does not slide on an inclined plane, but is pressed from below, upwards, by a very precise micrometric screw. The object is held in a similar manner in forceps, which can be placed in any desired position.

The knife is held on an iron block, and only rests on three ivory points; but in place of a cast-iron plane, these points slide on glass slips, which diminish the friction.

This microtome has very exact movements, and as the object is held more firmly than before, it can never be displaced, which may however happen in the previous instrument, in which the block carrying the object is only held by its weight.

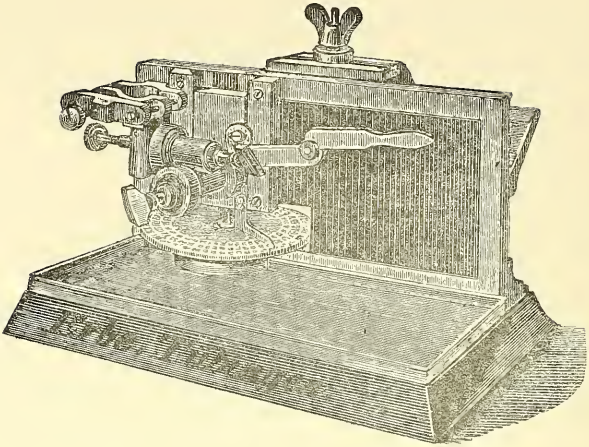


Fig. 196*b*.

The *Large Freezing Microtome* (fig. 196*c*) is only a modification of the last; the apparatus, which the illustration sufficiently explains, is specially intended for sections of frozen tissue.

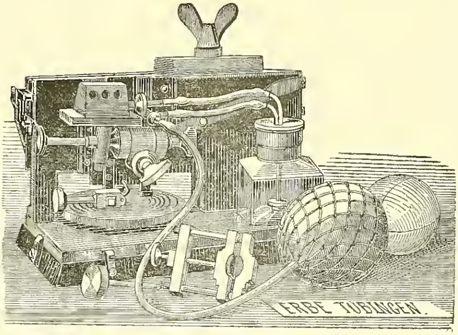


Fig. 196*c*.

Erbe's *Cathcart Microtome* in no way differs from that of Messrs. Watson's, which is represented in fig. 196.

The *Cathcart-Erbe Microtome* (fig. 196*d*) differs from the previous one in the form of the knife, which is supported on a cast-iron block, sliding in a groove, and also in the micrometric screw, which is more precise.

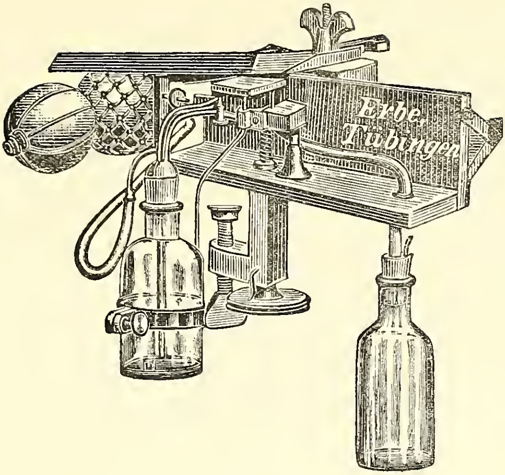


Fig. 196*d*.

Lastly, *Hughes and Lewis's Microtome* (fig. 196*e*) is an apparatus intermediate between the last two, both in its price, which is only £1 19s., and in workmanship.

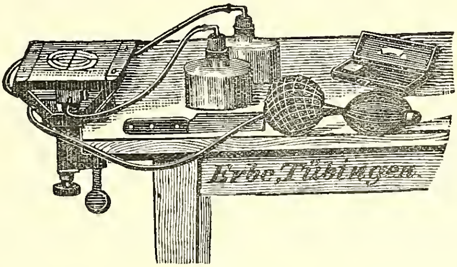


Fig. 196*e*.

But whatever microtome be used, the objects which are cut with these instruments have to undergo a previous preparation, more or less complicated.

The objects must be softened (wood, shell, &c.) or hardened (soft tissues) which, in the case of fresh vegetable substances, is best accomplished by freezing; and lastly, they must, as a rule, be embedded in some other substance.

In animal histology, the embedding medium used is paraffin, which is poured round the object, when placed in a suitable mould. Vegetable tissues are conveniently enclosed, either in elder pith or pieces of carrot, which can be obtained fresh nearly all the year round.

Preliminary softening may be effected by placing woody substances either in pure water or in water to which a small quantity of soda has been added. The time during which these substances should remain in the medium will vary from a few hours to several days, according to the hardness of the object.

Tissues and objects to be frozen must be previously treated in a solution of gum and sugar until they are well soaked.

This solution is obtained by dissolving on the one hand four parts of Senegal gum in six parts of distilled water, and by preparing on the other hand syrup of sugar, similar to that used by chemists, and which is made by dissolving nine parts of refined sugar in six parts of boiling water and boiling it again for a moment before taking it off the fire.

These two solutions when made are mixed in the proportion of five parts of the gum solution to three parts of the syrup. To this mixture one per cent. of carbolic acid should be added to prevent fermentation.

Tissues deposited in this mixture can remain there as long as may be desired. They will be preserved there unaltered.

These preliminaries being disposed of we may pass on to the mode of operation.

Sections by Freezing.—From the tissue to be cut, a small piece not more than three millimetres thick is taken, the gum in it is squeezed out with a fine cloth. Then in a little gum previously placed on the stage of the micrometer, the piece to be cut is inserted, and covered over with gum on all sides by means of a brush.

The jet of pulverized ether which is then directed on the piece of the object by means of the special pulverizer, furnished by the makers with the microtome, immediately freezes the mass, and enables sections to be cut. It should be observed that the freezing must be carried only to a convenient degree, and no further. The freezing is correct when the sections can be easily made, as for example when cutting cheese. When the freezing is carried too far the mass is too brittle, and the tissues are torn.

By embedding large diatoms in this way — Pinnulariæ, Triceratia, Coscinodisci, &c.—in a drop of frozen gum, suitable sections can be made of them. However, in this case, much necessarily depends on chance, as there is no means of placing the diatoms in a satisfactory position to obtain the sections in the desired direction in the gum solution.

Sections by Embedding.—While delicate tissues are advantagously cut by congelation, those of greater consistency, such as stems, stalks, &c., as well as animal tissues which have been hardened by being placed for some time in alcohol, can be easily cut after having been previously embedded in a suitable substance.

Paraffin is generally used for this purpose, but this substance, in most cases, is not as suitable as a small piece of fresh carrot, because the natural moisture which the latter contains favours the sliding motion of the knife. Then again, when the section has been made, the remains of the carrot are easily removed, while on the other hand, the paraffin crumbles, and moreover, the use of carrot does not necessitate the employment of heat as is the case with paraffin, which must be previously melted and afterwards allowed to cool round the object.

First, by means of a knife, a cylindrical piece of the carrot is cut lengthways, so as just to fit in the cylinder or the forceps of the microtome. This cylinder should be from 3 to 5 centimetres (one to two inches) in length.

Having made the cylinder, it is divided lengthways into two parts, and hollowed out so that the objects to be cut, having been placed in the hollow thus formed, the two parts can be fitted back again to one another, and maintained in position by a thread, so as to press the inclined object very slightly.

The cylinder is now pressed into the pincers of the microtome, and sections are then cut in the usual manner.

After each section has been cut a few drops of alcohol, mixed with water, are placed on the surface, and the knife is also dipped in a dish containing the same mixture. By this means the section is detached from the knife and floats off in the liquid. These are afterwards withdrawn, by decanting the greater part of the liquid, and then lifting each section with a fine brush.

§ 4.—Staining Tissues.

It would be difficult to determine at what period the staining of tissues was first thought of, but it is certain that for a very long time only carmine was used for this purpose. It was only about fifteen years ago that different colours were attempted, and aniline dyes in the first place became the fashion, and were used for all kinds of things.

If the reader will trust us, he will avoid all colours of this kind; the effect produced is very pretty and the result interesting, *for the moment*, but there is no certainty that the results will be durable; and from what is known of aniline dyes he may be assured that these colours will last but for a short time.

We have in our possession several preparations of bacteria made by skilful mounters, which were very pretty to look at when we first received them, but now no bacteria are visible.

If therefore it is desired to make preparations of coloured tissue, only colours whose lasting qualities are known, should be used. Their number is unfortunately very limited, and only logwood, carmine, picro-carminate of ammonia, and probably also nigrosine can be recommended with certainty. Methyl green appears also to be sufficiently stable.

If a person confines himself to these colours, writes Mr. A. C. Cole, he will be certain to find his preparations intact after any lapse of time; especially if he mounts his preparations strained with logwood in Canada Balsam, and his preparations strained with picro-carminate in glycerine jelly of good quality.

Our own experience corroborates the statements of our esteemed correspondent. Preparations, which we made in this way three years ago and which since then have been constantly exposed to the light, are as bright now as they were on the day they were made.

These preliminaries being disposed of, we will now mention how preparations are to be made with the colours alluded to. The tissues must undergo a series of operations, viz.: decolourisation, staining, washing, dehydration, clearing, and finally, mounting.

Mounting Vegetable Tissues with a single colour.—As soon as the sections (which have first been immersed as they were obtained in the mixture of water and alcohol), are ready, they are lifted and transferred to a second mixture of equal parts of water, alcohol, and glycerine. This is what Bourgogne, Senr., called his preservative mixture. The entire pieces or the sections can be left there for any length of time without altering, if the bottle is well closed.

But we will continue our operations by passing our sections through a preliminary decolourisation.

If the tissue is very delicate, immersion in strong alcohol for some time is sufficient to decolourize; but hard and highly-coloured tissues, such as that of a woody stem, requires the action of *Eau de Javelle*.

This liquid can be made by taking, first, half a litre (7-8ths of a pint) of water, and adding to it about 60 gr. of calcium hypochlorite, leaving it to dissolve for twenty-four hours, but shaking it from time to time.

Next make a saturated solution of sodium carbonate (common washing soda), in water, and after decanting the solution of calcium hypochlorite to it is added by degrees the solution of soda, until it no longer forms a precipitate.

The *Eau de Javelle* thus obtained, is then filtered, and kept well stoppered in a dark place.

The sections to be bleached are then immersed in a small quantity of this fluid, and are left there until the bleaching is complete, and then washed several times. Lastly, they are again left for twenty-four hours in distilled water, to which has been added 8 to 10 drops of nitric acid to the half litre.

At the end of this period the sections are inserted in alcohol for an hour or less, and then we proceed to stain, choosing preferably logwood, which admirably sets in relief all structural details and the cell walls. The staining will be systematically carried out by following carefully the following steps.

1. Raise the sections from the alcohol and immerse them in water for a few minutes.
2. Place the sections for ten minutes in 3 per cent. solution of alum.
3. Stain the section with logwood by immersing it in a small quantity of the normal solution, then wash it in water until it is judged that the colour is sufficiently intense.
4. Place it again in the solution of alum, so as to remove the stains from the surfaces.
5. Wash thoroughly in water.
6. Place it in alcohol for at least two hours.
7. Deposit the section on the surface of some essence of cloves, poured into a watch-glass. When the section sinks to the bottom it is quite prepared, and can then be mounted in Canada Balsam.

Double Staining Vegetable Tissues.—These can be stained either iodine green and carmine or ammonium picro-carminate.

I. *With Iodine Green.*—1. Place the section in an alcoholic solution of iodine green for one or two hours. This solution should be in the proportion of 15 centigr. of green to 30 gr. of alcohol.

2. Immerse the section in alcohol for six minutes.

3. Place it in water for a minute.

4. Immerse the section in the carminated solution for two hours.

This solution is made by dissolving in a gentle heat; 1 gr. of carmine, previously pulverized, in a gramme of liquid ammonia, and then adding 75 gr. of water, and filtering the whole.

5. Carefully wash with water.

6. Insert it for ten minutes in alcohol.

7. Float it on the essence of cloves, and finish as in the previous case of single staining.

II. *With Picro-carminate.*—This process gives results which cannot be surpassed.

1. Place the section in alcohol for an hour.

2. Stain in the picro-carminate for a period, varying from half-an-hour to three hours.

This solution can be made according to the instructions previously given for picro-carminate. It can be bought ready-made, but it is much better when made by oneself as follows:—

Dissolve a decigr. of carmine in 2 gr. of distilled water in a gentle heat, then add to it 30 gr. of distilled water.

Next dissolve 4 decigr. of nitric acid in 30 gr. of alcohol, which has been slightly heated.

Mix the two solutions. The resulting solution obtained should be filtered every time it is used.

3. Wash in alcohol.

4. Immerse again in picro-carminate.

5. Wash again in alcohol.

6. Float on the essence of cloves, and mount in Canada Balsam (according to A. C. Cole).

§ 5.—Mounting Preparations.

Many preparations are made in liquids, and so one should first make the cell which is to contain the liquid.

For this purpose one should take the glass slip intended to carry the object, and paint on it with a brush, two streaks of black varnish as seen in figure 197.

The varnish should be left to dry, and when it is thoroughly so, one, two, or three fresh coats of varnish are added, and are again left to dry. Of course, the number of coats of varnish applied to the glass must vary according to the thickness of the object intended to be enclosed in the cell.

When the varnish is again thoroughly dry, a drop of the liquid to be used is deposited in the middle of the glass. This liquid naturally varies according to the nature of the object. The latter is then placed in the liquid, and covered over with a cover-glass. During this operation, if any air bubbles form in the cell, the cover-glass is half raised gently, and the bubbles are got rid of by pricking them with the point of a needle and inclining the slide. The cell having been deprived of all air, any liquid that has overrun the side is dabbed up with a piece of blotting-paper, and a coat of black varnish is given to the upper surface of the cover-glass in the same direction in which the first coats were placed, so as to moisten the latter. The preparation is then laid aside for twenty or thirty minutes. At the end of this time, the varnish being somewhat dry, and the cover-glass adhering more or less firmly because the upper coat has softened the lower ones, two coatings are added to the sides of the cover-glass, so that the brush touches the cover-glass and the slip at the same time. When these coats are dry, two or three others are successively added, at some days' interval, so that the cell shall be perfectly closed. There is then nothing more to do besides labelling the preparation. In Germany two strips of glass are often stuck to the two ends of the cover-glass with potassium silicate, so that the preparations may be superposed without fear of damaging the cover-glass. This process is a bad one, as there is no guarantee that the silicate will last.

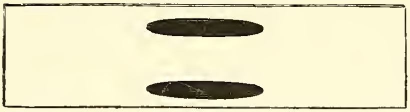


Fig. 197.

Round Cells.—Most mounters instead of making square cells, such as we have just described, prefer to use round cells, which are more elegant, but not so firm. These cells are generally used in mounting diatoms dry.

To make round cells a small apparatus, called a *turn table* (fig. 198), is used.

The slips having been fixed by means of two clips on the turn table, a brush is steeped in black mastic, which should be somewhat fluid; and having set the rotating table in motion, the brush is lightly applied so as to form a circle of the desired size. When the cell is somewhat tightly stuck, the object is placed within it, together with a drop of appropriate liquid. The cover-glass is then put in its place and held there for a time, pressing on the cell, either by

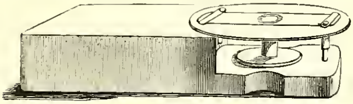


Fig. 198.

means of small weights or of a spring. When it has stuck sufficiently fast it is wiped, and the sides of the cover-glass washed, and a fresh coat of mastic applied, so that the sides of the thin glass are thoroughly united to the slip.

With preparations in Canada Balsam, a drop of the balsam is placed on the slip, which is gently warmed.

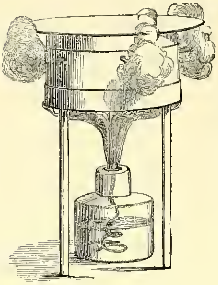
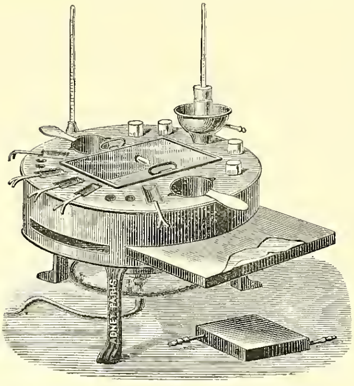


Fig. 199.

When the balsam is liquified the object is deposited in it, avoiding the formation of air bubbles; but should they occur, they should be got rid of by pricking with a needle. Then a cover-glass, having previously been slightly warmed, is placed over it and gently pressed. Nothing then remains but to remove the excess of balsam which has run out from the sides of the cover-glass. This can be effected by gently rubbing it with a piece of linen, moistened with alcohol.

The small *Marie-bath* (fig. 199), manufactured by the firm of Chevalier, is very useful for liquifying the Canada Balsam on the slip.

The *Naples Marie-bath*, by M. Adnet (26, Rue Vanquelin, Paris), which was figured for the first time at the Antwerp Microscopical Exhibition, answers the same purpose and is in other ways an apparatus capable of rendering great service in the laboratory of every microscopist. This instrument, which is made of copper, consists of a small copper boiler, bearing at its side a heating plate, on which preparations can be placed. In the centre of the boiler is a small portable glass chamber, on which cultures of bacteria can be made, &c.; the latter can also be made in tubes, which can be placed as desired in the round openings, which may be seen in the illustration. In the



Fig, 199*a*.

small pots figured, paraffin or glycerine jelly can be liquified. A series of paraffin moulds may also be seen in the figure.

A regulator, with a metallic membrane situated underneath the boiler, enables the temperature to be regulated with the greatest accuracy. The heat is produced by a small Bunsen burner, fixed to the regulator. By means of a bent thermometer, the mercury reservoir of which is inserted in the stove, the temperature of the whole apparatus can be told. This very complete little apparatus costs £4.

Liquidambar and Media of high Indices.—We have previously described how preparations are made in these media, and there is therefore no necessity to revert to the subject.

§ 6.—Preservation of Preparations.

We have still a few words to say upon the preservation of microscopical preparations.

Above all, damp is what has most to be guarded against; it easily filters through the best cements, destroys their adherence with glass, and consequently renders the preparation useless after some time. Cold is also capable of exercising a most vexatious influence. Preparations therefore should be kept in a convenient apartment, where there are no injurious influences to be feared, and should be examined from time to time, in order to repair, where necessary, the cements which have become detached or cracked.

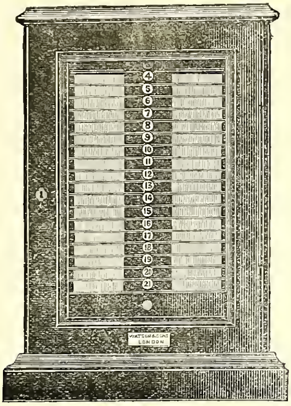


Fig. 200.

Preparations should be arranged so as to lie flat. This system is almost exclusively adopted in England, and enables any preparation to be found directly; it has only the inconveniences of being rather costly and cumbersome.

Grooved boxes are more economical and more manageable. Preparations can then be placed on the shelves of a library; but care should then be taken in this case not to put the boxes flat, but upright—like books—so that the sections immersed in liquids cannot become deranged, for this inevitably occurs in the other position.

It never does to trust to the memory and to put on one side a preparation which has not been suitably labelled. The label ought to have written on it all the details which it is convenient to know, the nature of the object, colouring, if any be used, the nature of the medium used, &c., &c. Any of these details may have importance at any moment.

CHAPTER II.

THE MICROSCOPIST'S LIBRARY.

Under this title we have collected together a number of books which the microscopist, and especially the botanical microscopist, may with advantage consult.

1.—Periodicals.

London (J.R.M.S.)—"Journal of the Royal Microscopical Society." (London: Williams & Norgate). A part appears once every two months.

Since Mr. Crisp gave it its present form, in 1878, this journal has been the most important in the world, and is absolutely indispensable to the microscopist who wishes to keep himself in touch with the science. The J.R.M.S. publishes the transactions of the R.M.S. and the original papers presented to the society.

It publishes, in addition, an analysis of all articles interesting to microscopists, as well as descriptions of all old instruments whenever they are discovered, and also of all newly-invented apparatus.

Pelletan.—"Journal de Micrographie," by Dr. Pelletan, Rue de Berne, Paris. It has been published since 1877, and is always in touch with all novelties, and equally indispensable to French readers.

W. H. Berens.—"Zeitschrift fûr Wissenchaftige Mikroskopie und für Mikroskopische Technik,' von Dr. Wilh. Jul. Behrens. Braunschweig, 1884-1892.

New York.—"Journal of the New York Microscopical Society." New York, 1885-1892. Its articles are often very important.

Brussels.—"Bulletin de la Société belge de Microscopie." Brussels, 1876-1892. It publishes the transactions of the meetings and original articles by members of the society.

Antwerp.—"Annales de la Socie'té Phytologique et Micrographique de Belgique." Antwerp, 1864, and following years. This publication is temporarily interrupted. Original articles by its members.

2.—History of the Microscope.

Deby (Julien.)—"Bibliotheca Debyana" London, August, 1889. Not publicly sold. A catalogue of a valuable library of microscopical works.

Harting.—"Das Mikroskop," second edition. Braunschweig, 1865.

Mayall.—"Cantor Lectures on the Microscope," by John Mayall, Jun. London, 1886.

Peragallo (H.)—"Histoire sommaire du microscope composé et de ses recents perfectionnements." Toulouse, 1883.

3.—General Works.

Adan (H. P.)—"Le Microscope, coup-d'œil discret sur le monde invisible." Brussels, 1873.

This is the first edition of the following work:—

Adan (H. P.)—"Le monde invisible dévoilé. Révélations du Microscope." Brussels, 1879, with 24 plates.

This work, intended for the microscopical beginner, as well as those whose interest is merely one of curiosity, is the best written of all popular works. Written in that clear and elegant style which characterises M. Adan, it is able to sustain the attention of the reader without flagging, notwithstanding the dryness of the subject.

Beale (Lionel S.)—"How to work with the Microscope." Fifth edition. London, 1880 (excellent).

Behrens.—"Leitfaden der Botanischen mikroskopie." Braunschweig, 1890. We have borrowed from this work figures 52, 53, 55, 56 and 59, which the editor has been good enough to lend us.

Carnoy.—"La Biologie cullulaire." Lierre. (Only the first part hitherto published).

Carpenter.—"The Microscope and its Revelations." 1891. New edition, edited by Dr. Dallinger, who has entirely re-modelled and considerably improved and increased this work.

Chevalier (Arthur.)—"L'Etudiant micrographe." Paris, 1882.

Cole (Arthur C.)—"The Methods of Microscopical Research." London, 1884.

Dippel (Leopold.)—"Das Mikroskop und seine Anwendung." Second edition. Braunschweig, 1882.

Francotte (P.)—"Manuel de Technique microscopique." Brussels, 1887. (The application of the microscope to animal histology, comparative anatomy, &c.)

Giltay (E.)—"Inleiding tot het gebruik van den Microscoop." Leiden, 1885.

Giltay (E.)—"Seven objects observed by the Microscope." Leiden, 1890.

An excellent small work for beginners.

Griffith & Henfrey.—"The Micrographic Dictionary," 4th edition. London, 1883. In 8vo, of 829 pp., with 812 figures, and 53 plates partly coloured.

Harting (P.)—"Het Mikroskoop, deszelfs gebruik, geschredenis en tegenwoordige torstand," 4 vols. Utrecht, 1848-54.

The German edition which follows is much more complete and important.

Harting (P.)—"Theorie und Algemeine Beschrebung des Mikroskopes." Second edition, 3 vols. in 8vo. Braunschweig, 1866.

Latteux (Dr. P.)—"Manuel de Technique Mikroscopique." 3 vols. Paris, 1887. Excellent, especially in connection with human histology.

Naegeli und Schwendener.—"Das Mikroskop: Theorie und anwendung desselben." Leipzig, 1867. (An English translation of Parts I. to VII. was published in 1887).

Pelletan (J.)—"Le Microscope, son emploi et ses applications." In 8vo, with 278 figures and 4 plates. Paris, 1866.

Robin (Ch.)—"Traité du Microscope." In 8vo, with 317 figures and 3 plates. Paris, 1871.

Schacht (H.)—"Le Microscope et son application speciale à l'étude de l'anatomie végétale." Paris, 1865. Rather out of date, but a book which can still be very advantageously studied.

Trutat (E.)—"Traité elementaire du Microscope." Paris, 1883.

Van Heurck (Dr. Henri).—"Synopsis des Diatomeés de Belgique." In Imperial 8vo, 2 vols., text and tables, and an atlas of 139 plates, containing 3,100 figures, drawn from nature. Antwerp, 1880-85.

4.—Photo-micrography.

Marktanner-Turneretscher.—"Die Mikrophotographie. Hilfsmittel natur wissenschaftlicher Forschung." Halle, 1890.

Moitessier (A.) — "La Photographie appliquée aux recherches Micrographiques." Paris, 1866.

Neuhauss (Dr. R.)—"Lehrbuch der Mikro-photographie." Braunschweig, 1890.

Pringle (Andrew). — "Practical Photo-micrography." New York, 1890.

Zeiss (Dr. R.) — "Special-Catalog über apparate für mikrophotographie." Iena.

BOOK V.

THE MICROSCOPE IN THE PAST AND IN THE FUTURE.

1.—The Microscope in the Past.

Notes on the History of the Microscope.

It follows, from a passage in Seneca, that the ancients knew that when writing was observed through a glass globe filled with water, the characters appeared considerably enlarged. But they attributed the magnifying power to the water, and every fact shows that glass lenses remained unknown to them. All assertions to the contrary made on this subject rest on error.

In 1285 Salvino d'Armato degli Armati, of Florence, discovered the art of working glass and manufacturing glass spectacles.

It is known how this occurred. The glass taken from the crucible, after being slowly cooled, is divided into thin plates by means of a saw. In Zeiss' workshops this division is effected by means of a circular steel saw, the periphery of which is spread with diamond dust.

When plates or discs have thus been obtained of the desired thickness, they are carefully examined with a lens, and all parts rejected mercilessly which shew either globules (fig. 201) or veins (striæ) (fig. 202) which are occasioned by the matter when in a state of fusion not having been stirred with the requisite care, or not having been fused long enough, or again, not having been cooled with the necessary precautions.

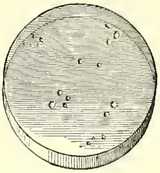


Fig. 201.

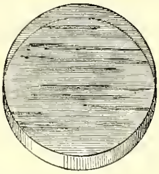


Fig. 202.

This cooling is, in fact, a matter of great importance. It should be carried out very slowly, otherwise the glass cracks; and in some cases it should be prolonged for weeks and even months.

Glass which has on its surface globules or striæ—and especially the latter—will give more or less cloudy images, in consequence of the unequal refractions which occur in the different parts of the lens.

After the glass has been slit into plates, it is cut up into pieces of approximately equal in size to that required, by grinding them with sifted and moistened sand in moulds of a suitable shape, placed on a lathe or special apparatus, generally turned in large workshops (such as those of Zeiss) by steam.

When the glass is roughly shaped, and the desired curvature nearly obtained, the serious and final operation is commenced. This work is carried out by means of a special horizontal lathe, called an "optician's lathe."

This lathe (fig. 203) consists of a solid table, usually of walnut wood. On the left is a vertical shaft, fixed in collars, and terminating in a point, which pivots in a metal centre placed on a horizontal support underneath.

Fig. 203.

To this shaft is fixed a fly-wheel, and at its upper extremity a piece of iron placed horizontally receives a wooden handle.

On the right of the lathe there is a shaft similar to the preceding and furnished with a pulley. The pulley and the fly-wheel are connected by a leather band. By means of a screw thread, the tool is fixed at the upper end of the right-hand spindle. This tool, which is of brass, is concave for convex lenses, and is then called a *basin* (fig. 204); it is convex for concave lenses, and is then called a *ball* (fig. 205).

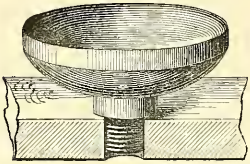


Fig. 204.

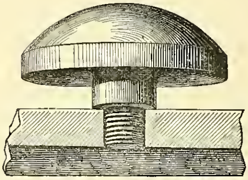


Fig. 205.

To make these tools it is first necessary to have what is termed a gauge. This is made by cutting out of a plate of brass or steel a curve, depending on radius required. The tool is then shaped by turning it on an ordinary lathe until its surface accurately coincides with the curve of the gauge.

The small piece of glass, one of the surfaces of which ought first to be made more or less plane by sawing, after being roughly shaped, is then roughly ground, which is done by working it in the iron moulds (ball or basin) by means first of emery Nos. 1 and 2, and then finer with Nos. 3 and 4.

Finally it is finished in a very accurate basin by means of emery No. 5.

When the glass has been made smooth, softened, refined, and polished, which is accomplished by successively using putty powder, of different degrees of fineness, moistened with water, it is worked to the correct curve.

During all these operations the glass is attached to a small cork handle, called a *holder*. The lens is fixed with a mixture of pitch and wood ash, which is softened by heat for attaching, and cools quite hard.

The finished lens is set into its mounting on the lathe, if it is intended to be left in the state of a simple lens; or if it is to be achromatized, it is first fixed to its complimentary lens with Canada Balsam.

The finished lenses are then matched to one another: formerly, and this is still the case in some workshops, the mounting is done empirically, *i.e.*, the lenses are fixed one above another and experiments are made until the required quality of image is obtained.

By this means excellent combinations can be obtained, but the majority of such objectives are more or less defective, and many lenses have to be rejected.

In Zeiss' workshops these combinations are regulated by very precise and ingenious apparatus, and the objectives are only tested in the microscope when they are entirely completed.

Such are briefly the processes used at the present time in the manufacture of lenses. Formerly lenses were made having a slight curvature, intended only to be used as spectacle glasses; by successive steps they were improved, their curvatures were made greater and greater, and the lenses becoming smaller; it was thus that they were brought by gradual stages to be employed as magnifying glasses and simple microscopes.

An engraving is in existence, copied from a picture by Raphaël, dating from about 1513—1520, in the Palais Pitti, at Florence, where Pope Léon X. is represented looking at some minatures with the assistance of a magnifying glass.

It was while arranging some glasses for spectacles, that Zaccharias Janssen is said to have discovered the compound microscope.

However, it will be convenient to treat the history of the simple and that of the compound microscope separately.

Simple Microscope.—We have seen above how the manufacture of spectacle glasses led to the construction of magnifying glasses, and how these, becoming more and more convex, and consequently more and more powerful, were able to justify the title of microscope.

The first microscope, though questioned by different authors, was called by the name of *vitrum pulicarium,* and consisted of a small cylindrical box (fig. 206); the magnifying lens was set in the upper cover, and the lower cover or bottom was made up of two small pieces of glass, between which was deposited the object for examination, which generally was a flea; and in this way the above name was given to the instrument.

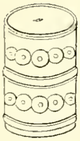


Fig. 206.

There was also in use a seed microscope, a little toy, such as may still be found in the windows of small opticians and other shops. It was composed of a small brass cylinder, the sides of which were open throughout the greater part of its length, and it was inside a glass tube to admit the light. The upper extremity was fitted with a lens, and at the bottom was placed a mixture of different seeds.

Another early form of the microscope consisted of a magnifying glass set in a mount and carried on a small foot. A needle was fixed at a short distance from the lens and the object for examination was stuck on the point of the needle.

It was this sort of microscope which gave rise to the microscope of Leeuwenhoeck, and with which this illustrious microscopist made his splendid discoveries.

Leeuwenhoeck's microscope (figs. 207 and 208) differed from the previous one in the perfection of his lenses, which magnified highly, and in the fact that the point which carried the object was capable of being raised or lowered by means of a screw stem. The stem could spring back easily, and by means of a small screw-nut the object could be brought nearer to the lens, so as to be focussed perfectly.

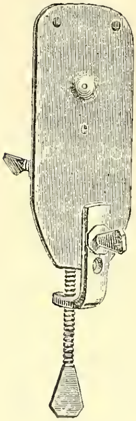


Fig. 207.

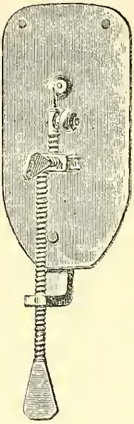


Fig. 208.

Leeuwenhoeck had microscopes of different magnifying power; one is known to have given 270 diameters. The lenses are bi-convex and very well made, and Harting was able with the last-mentioned one to observe the fourth group of Nobert's Test.

Simple microscopes, all more or less similar, were made by different microscopists, all of whom used cut lenses; but some opticians and microscopists replaced these by lenses of cast glass.

These, it appears, were first invented by Hooke, who introduced them in 1665 in his *Micrographia*.

A great number of microscopists used and described them; among these Père della Torre, of Naples (1776), appears specially to have succeeded in constructing globules of high magnifying power.

The last savant, who appears to have been successfully occupied in producing such globules, is Lebaillif. The method employed by this skilful observer has been described by Ch. Chevalier in his treatise on the microscope, as follows:—

Two conditions are necessary in order to obtain perfect globules: 1st, it is necessary that they have a perfectly spherical form given to them; 2nd, it is important that the glass employed is pure and without bubbles.

To avoid bubbles, a small piece of glaziers' glass must be taken, which can be easily melted and is fairly pure. If the flame of a candle, intensified by a blow-pipe, be directed full on the glass it will melt, and often by directing the point of the flame to the end of a crack, one can even succeed in giving to the fragment an elongated form (it is well that their breadth should not exceed from 5 to 6 millimetres). In this way the fraying is avoided, which the best diamond produces at the edges of the strips cut off by it; the bubbles almost always result from these frayings which persistently remain in spite of the fusion.

The ends of one of these fragments is cemented to two pieces of glass, or to the ends of two small tubes; then taking hold of these accessory appendices with the two hands, the central fragment is placed in the hottest part of the flame, and soon it takes almost the form of a cylinder and half a millimetre in diameter. When a sufficient length of glass has been thus made it is best to examine it with a magnifying glass to select the purest parts; then they are placed back in the fire to be lengthened into threads, the thickness of which should be proportional to that of the globules desired. If it should happen that sufficiently long fragments of glass become detached, it is useless to attempt to solder them to the appendices.

It now remains to melt the globules, and at the same time keep them spherical in form. To accomplish this, a piece of glass thread is taken and cut at one end in the flame, for breaking it would give rise to some inequalities. Then the thread is held by one of its ends with a watchmaker's pincers, and the opposite end is inserted in the flame. It contracts into a globule, which will not drop until it touches the pincers, because they keep the piece of thread, which they hold, from becoming hot enough to melt and unite with the globule. This globule remains suspended by a very delicate strand, which is placed at the side of the mount, so that the clearness of the vision may not in any way be obstructed.

The smaller these globules are the rounder they are.

To test their purity they are taken up with the pincers by their strand and held up to the light. They will appear perfectly clear if they are pure, and studded with black spots if they contain striæ or bubbles. A spirit lamp is preferable to a candle, being less liable to dim or stain the work.

We have in our possession some of the material which Lebaillif used in the manufacture of his glass globules, as well as several globules mounted by him. We can certify that the images they give are very good.

The simple microscope was considerably improved by Wilson about 1740. Wilson furnished his instrument with a mirror, and mounted it on a foot (fig. 209).

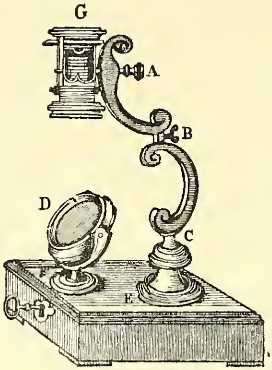


Fig. 209.

The object was placed between two glass slips, which were held tight between two small brass plates. A tube with a screw-thread enabled the object to be raised or lowered so that it could be examined in distinct vision. A spiral spring pressing from above downwards holds the plates close, and counteracts at the same time the back lash of the screw used for focussing.

Wilson's instrument was in great repute, and was imitated on all sides.

We have in our possession a very interesting specimen, bearing the inscription "Jacobus Lommers fecit Utrecht, Ao. 1758." The various lenses have a screw-thread, which enables them to be adapted to a short tube, furnished with an ocular, in order to transform the simple into a compound microscope.

Cuff improved the simple in the same way as he did the compound microscope, *i.e.*, he made the stage moveable so that work could be carried out more conveniently.

The microscope which Cuff made, about 1750, for Ellis, is still the type of those made at the present day.

The instrument (fig. 210) consists of brass pillar A, which screws on the box and bears an arm ending in a ring, in the groove of which is fitted a glass disc, which serves as the object carrier. Opaque bodies are placed on a black spot near the centre of the disc. On the right side of the ring, pincers intended to hold insects can be slipped into a hole there, which is made for this purpose. A cylindrical rod C, which turns in a hollow cylinder, soldered to the pillar A, enables the arm D, which carries the lenses, to be raised or lowered as desired. This last-mentioned arm slides backwards and forwards in the socket which is at the end of the rod C, and these different movements enable the lenses to be brought over the whole surface of the object carrier. The lenses are fixed in the ring at the end of the arm D by means of a screw-thread. They are of two kinds: one E, mounted in the centre of a concave silver mirror, is used for examining opaque objects; others, without a mirror and similar to that illustrated at F, are used for examining transparent objects. Under the object carrier is a concave glass mirror G, which can move easily in every direction, and is used to illuminate, from underneath, the object which is above it.

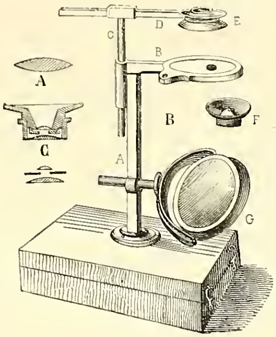


Fig. 210.

If the simple lens A in this instrument is replaced by the doublet C, which we have described at pages 18 and 19, we have an instrument which can be usefully employed at the present day.

Towards the end of the third decade of the present century Raspail found fault with Cuff's microscope, and added to it a number of useful modifications. The rod C was replaced by a rack and pinion, and the backward and forward movement of the rod D was produced by a screw. The instrument also had fitted to it diaphragms and a series of accessories, and the arm E, which carried the single lenses, was made so that an achromatic compound microscope could be substituted. Thanks to his *Traité de chimie*, in which the instrument was warmly recommended, this microscope was much used, and became known only as *Raspail's Microscope.*

But the popularity of this instrument could not long be maintained. The compound microscope was constantly being improved and soon it definitely supplanted the simple microscope, the use of which diminished to what it is at the present day, *i.e.*, it became a convenient auxiliary for microscopical dissections.

Compound Microscope. — The invention of the compound microscope is attributed, as we have already stated, to Zaccharias Janssen (fig. 211), a small optician of Middleburg, whose residence was attached to the church.

Fig. 211.

ZACCHARIAS JANSSEN,

Inventor of the Microscope,

Fac-simile

AFTER P. BORELLUS, DE VERO TELESCOPII INVENTORE.

Lately, the Italians have claimed the invention for Galileo—heaping wealth on the rich—but nothing has hitherto occurred to weaken the serious and conscientious researches of Harting, and it is proved that Galileo's instrument, formed of a convex objective and a concave ocular, is not in any way the same as Janssen's instrument.

Harting's researches, the particulars of which are given in great detail in his interesting pamphlet (¹), shows that Janssen's invention can be referred back as far as 1590. We are not acquainted with the exact arrangement of the instrument, but it is known that it was composed of one or two tubes fitting one in the other, and terminated by convex lenses.

An instrument, called "Janssen's Microscope," is still preserved at Middleburg, which, according to Harting, can be referred back as far as his period, without its being the original instrument. This instrument appeared at the Antwerp Exhibition.

This microscope, an exact fac-simile of which, made under the superintendence of Mr. Mayall, is in our possession, consists of four tubes made of iron and soldered together, coated inside with tin.

The outer tube A (fig. 212) is of the greatest diameter, and contains the tubes B and C, which slide into it.

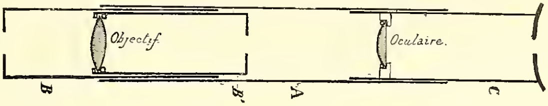


Fig. 212.

The tube B contains within itself a fourth tube B', having at its lower end a bi-convex objective lens of 3½ inches focus.

The ocular lens, of about 3 inches focus, is plano-convex, and is held by a ring made of iron wire in a wooden cell. The tube C which contains it is terminated at the upper end by a concave diaphragm.

The tube B' which contains the objective, is terminated at the upper extremity by a diaphragm, flush with the end.

The tube B is terminated at its lower extremity by a diaphragm.

In using the microscope, B' is pushed right down into B, and the tubes B and C are drawn out as far as possible from the exterior tube A. The instrument is directed towards the object.

(¹) *De twee gewichtigste nederlandsche uitvindingen op naturrkundig gebied*—without place and date; if we are not mistaken, the late Professor Harting sent us our copy about 1865.

The oldest microscope, of which we possess a figure, is that of Hooke (fig. 213), which is represented in the *Micrographia* of that author, published in 1665.

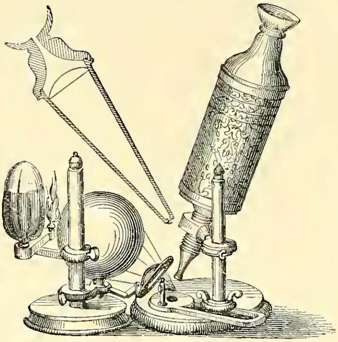


Fig. 213.

The tube was about 18 cent. (7 inches) in length, and was formed of four tubes fitting into one another, and capable of being drawn out to increase the amplifying power. Beyond the objective and ocular, there was an intermediate glass, but this Hooke withdrew in his delicate observations.

The tube could be inclined, and focussed by means of a screw-thread, in which it ended. Only objects illuminated from above could be observed by it, and for this purpose a glass globe concentrated the rays of a lamp on the object.

Campani, who lived at the same period, had on his part invented a microscope without a field-glass, but one which allowed transparent objects to be seen by directing the instrument towards the light.

It is impossible in the space at our disposal, to enumerate all the apparatus invented one after the other, and which had but a slight reputation. For this reason we shall not speak of the microscope of Perè Chérubin, of Orleans (1671), who also invented a binocular microscope, a similar and very curious microscope being in M. Nachet's collection; nor of that of Grindelins (fig. 214) (1687), very similar to the previous one in its appearance, but very singular in the arrangement of the glasses of the ocular and the objective.

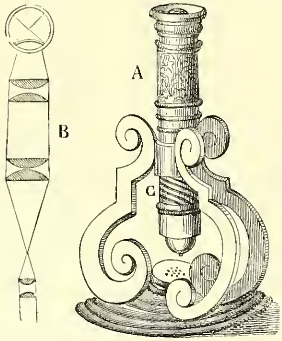


Fig. 214.

From this we come at once to the very interesting microscope of Père Bonanni, figured in his *Micrographia*, published in 1691.

This microscope is very remarkable for its appliances.

It is horizontal (fig. 215), and possesses a rapid movement by rack and pinion, and a slow movement by screw.

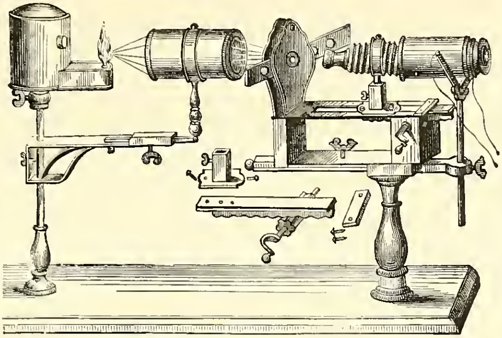


Fig. 215.

The tube contained three lenses, and Bonanni used three similar tubes, giving different magnifications.

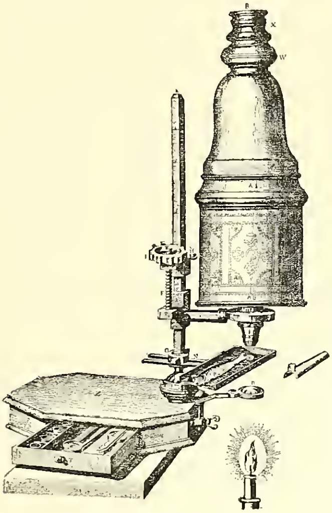


Fig. 216.

The object for examination was held tight between two springs and lighted by a lamp, whose rays were concentrated on the object by a true condenser formed of two lenses, which could be brought nearer to or withdrawn farther from the stage.

This instrument, as may be seen, is very perfect for that period, and presents the germs of all the appliances adopted at the present time.

John Marshall, a London optician, made, about 1704, a microscope which enjoyed a great reputation (fig. 216), and only differs from the last in having a series of objectives.

This microscope can be inclined by means of a ball and socket joint M ; first, it is focussed roughly by sliding the whole tube along the square pillar K. After fixing it at a convenient height, by means of the clamping screw H, the focussing is effected by the slow screw movement at F.

The object is placed on the stage C, which can be moved in any direction. The bottom of the stage is formed of a sheet of glass.

In the first instance, Marshall illuminated the object in a very inconvenient manner by means of a condensing lens R. Afterwards he replaced this by a plane mirror.

In Marshall's instrument, one of which we have in our possession, there are six objectives, each of which can be successively screwed to the tube.

They form a well-combined series; when the tube is closed, the following are the magnifications given by the objective :—

No. 1	4	diameters.
„ 2	7	„
„ 3	12	„
„ 4	25	„
„ 5	50	„
„ 6	100	„

When the tube is drawn out the magnification is increased by a quarter.

A peculiarity which we have not seen elsewhere noticed consists in the fact that the ocular lens is made of smoked glass, which has evidently been made so as to render the coloured edges of the object less evident. This end is completely attained, and with the low powers the images are remarkably clear.

It is curious that no subsequent maker of non-achromatic microscopes ever thought of imitating Marshall in this arrangement.

Marshall's microscope was superseded some years afterwards (about 1738), by that of Culpeper and Scarlet (fig. 217). In this instrument the focussing was effected by sliding the outer tube as in many modern instruments, and the stage was supported by three pillars.

The mirror could be set in all directions, and the aperture of the stage was made to receive either a diaphragm X, or a piece of apparatus with a spring N, intended to hold the preparation.

Various accessories seen in the figure accompanied the instrument.

We have in our possession a series of instruments of this form, dating from different periods, for it was manufactured for a long time; and we still remember a celebrated old Antwerp optician, named "Ongania," who died in our childhood, and who had similar instruments in his shop window.

The most perfect example of this form of instrument that we possess is of English origin, and it belongs to the middle of last century, according to the written instructions which accompany it. With it are five supplementary objectives.

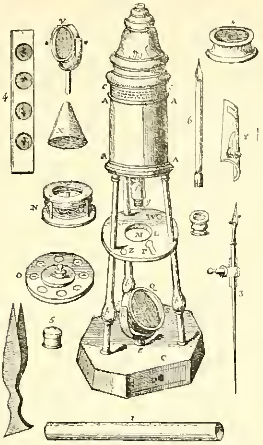


Fig. 217.

The popularity of this microscope arose from its being able to be made entirely of wood and cardboard; also the Nuremberg makers took it up and made it in large numbers. One of these microscopes, called *The Nuremberg*, was sold at *Ongania's* for twelve shillings.

However, the arrangement of the instrument was inconvenient, and above all, it was difficult to manipulate the preparation advantageously. This objection was soon recognised, and the stage in consequence was made free from any obstruction.

Thus it is that in a Nuremberg instrument in our possession, which belonged to an Antwerp physician named *Vervliet*, who died in 1764, the tube carrier has at the side two arms one above the other which can be made to slide on a solitary bar, to which also the stage is attached; to this bar the tube carrier can be fixed at any height (fig. 218).

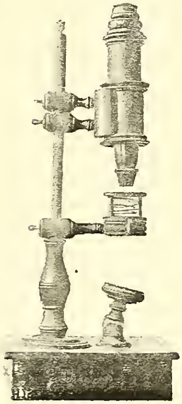


Fig. 218.

The final focus was effected by sliding the tube in its carrier.

The maker's name is not known, but the instrument bears his mark (fig. 219), burnt in with a red hot iron, which is also found on other Nuremberg microscopes in our possession.

During the second half of the last century several makers appeared who were true connoisseurs, and who produced instruments offering points of real interest and innovations that are remarkable, such as Cuff, Jones, Adams, Martins, and Dellebarre.

Fig. 219.

Cuff's instrument was patented in 1744, and displays many ingenious arrangements (fig. 220). The stage is free, and can take several pieces of apparatus above and a diaphragm underneath.

The mirror can be set in any direction. The rapid movement is produced by sliding the case C along the bar through the square plate B.

The adjustment screw *c* was used for exact focussing. Lastly, the whole microscope body could be taken off the ring *a* in order to change objectives. In the specimen in our possession there are six very well made objectives.

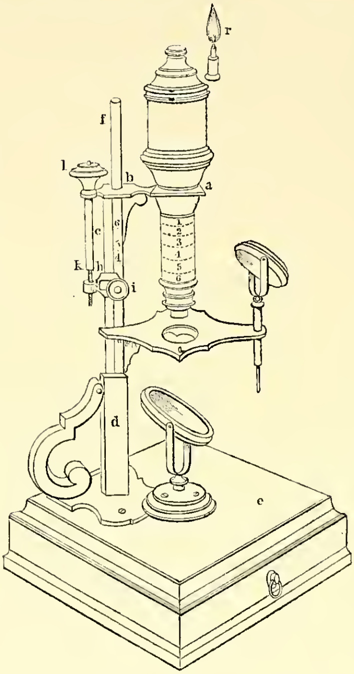


Fig. 220.

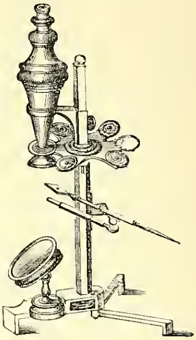


Fig. 221.

Adams made several microscope models. The first (fig. 221), dating from 1776, is without a stage; the lenses are arranged on a rotary or revolving plate; there is a fine adjustment, the milled head of which is concealed in the box above the tripod which carries the instrument.

But the microscope models made by Adams are numerous. His variable microscope (fig. 222) was mounted on a cog-wheel, which enabled it to be inclined at any angle. The rapid movement was produced by a rack, and the fine adjustment by an adjustment screw copied from Cuff.

We have in our possession a pocket microscope of this maker, which is a little gem. In its main features it approaches Cuff's microscope, but the fine adjustment is effected by a milled head above the limb, as in microscopes of the present day.

The whole microscope can be slid into a dovetail fixed on the box.

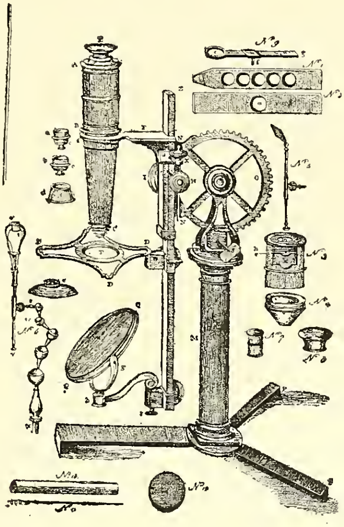


Fig. 222.

The instrument is packed away in the same box, which is covered with leather, and is only 18 cent. (7 inches) long by 10 cent. (4 inches) broad, and 4½ cent. (1¾ inches) deep; it can therefore be easily put in the pocket. Accompanying this microscope are six objectives and also the numerous accessories used at that period.

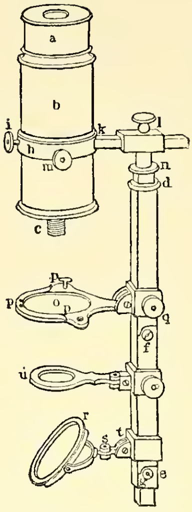


Fig. 223.

Dellebarre's microscope was described, in 1778, in a report presented to the Academy of Sciences of Paris. The whole instrument is carried on a tripod, supporting a round plate, from which springs a square pillar (fig. 223). The various pieces of apparatus slide over this pillar, and can be fixed to it with clamping screws.

These pieces of apparatus, commencing from the base, are as follows :—

1. Plano-concave mirror of large size.
2. Condensing lens.
3. Stage formed of a large ring, on which rests a glass slide *o*, at least 7 cent. ($2\frac{3}{4}$ inches) in diameter. The stage can be brought closer to the objective by means of a rack and pinion.

The body of the microscope is carried on a ring; it can be moved backwards and forwards, and also sideways, so as to sweep the entire extent of the stage.

There are three objectives.

But the special characteristic of Dellebarre's microscope is that the ocular consists of no less than six lenses, which can be combined in any way desired.

The field is excessively large, and observation is very wearisome; Dellebarre consequently abandoned it, and the instrument which we now have before us has an ocular formed of only two lenses, one of crown glass and the other of flint. The objective is of white crown.

Dellebarre claimed achromatism for his combination, and false colouration is not so perceptible in it as in other microscopes of this period.

This microscope has been much praised. The *Athenée des Arts* of Paris awarded to the maker a silver medal, the "22 Floreal an XI."

This medal was lent to us by his great grandson, who treasures it exceedingly, to exhibit at the Antwerp Exhibition.

Louis François Dellebarre was a Frenchman of noble birth; his true name was *de Streck*; he was born at Abbeville on the 16th August, 1726. In consequence of his religious opinions he was obliged to take refuge in Holland, where he assumed the name of Dellebarre. Afterwards he returned to Paris, where he died on 16th March, 1805.

But his children, who had tasted Flemish liberty, returned to Holland at the death of their father, and there established themselves permanently.

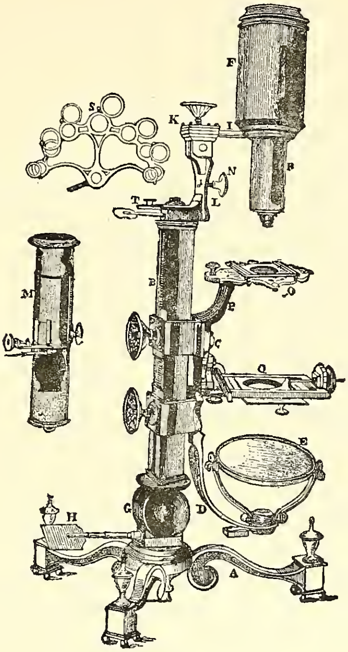


Fig. 224.

MARTIN'S MICROSCOPE.

Martin's Large Universal Microscope, which was made about 1780, and of which a fine example, formerly belonging to Queckett, is in London, is a very elegant instrument, expensively and stylishly set up (fig. 224).

The foot is a tripod, the pillar is triangular and jointed at the base so as to admit of it being inclined. This is produced by the action of an endless screw, moved by the key H, acting on a wheel.

The mirror is jointed for oblique illumination, and moveable in all directions.

Another stage, Q, furnished with micrometrical movements, can be substituted for the stage O.

Lastly, the body of the microscope FR can be taken off, and a catadioptric microscope M be substituted.

The entire instrument is made with great precision and extraordinary care for this period.

We have still to mention Jones's Microscope (A.D. 1798); that called *The Perfect Microscope* evidently served as the model of Ch. Chevalier's universal microscope, to which we shall subsequently refer.

We have now reached the present century, during which the microscope has made such enormous progress.

Towards the end of the last century, in 1791, Beeldsnyder, a Holland amateur, had made an achromatic objective, consisting of two convex exterior lenses of crown glass, together with an intermediate bi-concave lens of flint.

The lenses were made carefully, and the objective, screwed on a good Amici mount, give a very suitable image.

His countryman, Van Deyl, went much farther. After having made an achromatic lens, at a date which has not been fixed, he recommenced work in 1807, when he had already reached his 70th year.

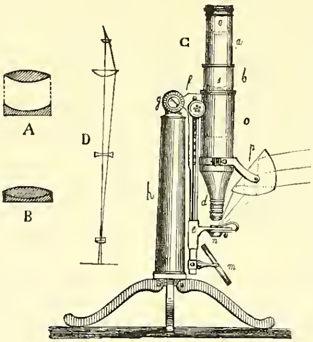


Fig. 225.

He made a microscope after Jones' model, and adapted to it two achromatic lenses, one having 18mm. focus, and the other only 13. The lenses are concavo-convex, having the *concavity*, which is very slight, *turned towards the object*.

We well remember the experiments we made with this instrument, and on one occasion with Harting, at Utrecht. The images were clear, and when the lenses were placed one above the other, the images were not inferior to those produced by objectives of equal power twenty or thirty years ago.

Unfortunately Van Deyl does not appear to have himself made the experiment which would have effected a complete revolution in the microscope.

We must now proceed as far as 1824 before meeting with another substantial improvement. At this period Selligue had a microscope constructed by Messrs. Vincent and Charles Chevalier, which was called achromatic.

In the instrument (fig. 225) which was constructed from the specifications of Selligue, a mechanician, there are three or four plano-convex achromatic lenses superposed (an idea due to Ch. Chevalier); the convex surface is turned towards the object. Between the ocular and the objective is introduced a bi-concave lens, which is intended to increase the magnification.

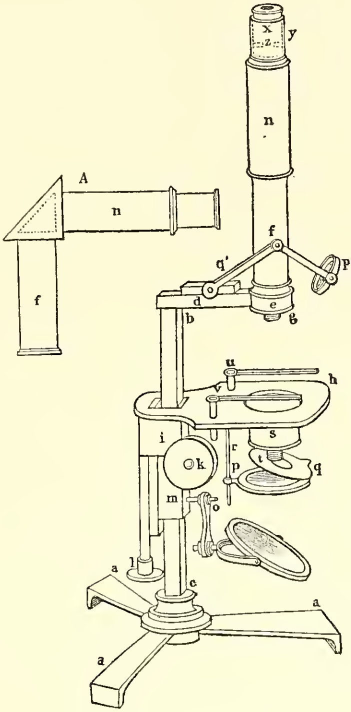


Fig. 226.

The lenses are 12½mm. (½ inch) in diameter, and of about 37mm. (1½ inches) focus.

Immediately above the upper lens there is a very small diaphragm, the aperture of which is scarcely 2½mm. (1-10th inch) in diameter.

The images do not shew much colour, but the objective is unable to resolve any delicate detail. Thus the scales of *Macroglossa Stellatarum* show no detail, while previous microscopes which were not achromatic shewed the longitudinal lines.

It appears that but few of these microscopes were made, for examples of them are very rare. We believe that at present none is known to exist but that which we have just described.

Vincent and Ch. Chevalier themselves bore the expense of all experiments and the contruction of the microscope, called "*The Selligue.*" Moreover, they were justly incensed that their name was not mentioned in the report presented to the Academy. They made their discontent known in a pamphlet, which they published in 1825, in which they at the same time described a similar microscope constructed by them, as they say erroneously, according to the specifications of Euler, published in 1774, the single lens of which had a focus of 8 mill. (⅓-inch) and a diameter of 4 mill. The crown and the flint were in this case for the first time joined together with Canada Balsam.

Two years afterwards, in 1827, Amici took his achromatic compound microscope, represented in figure 226, to Paris. The microscope which we have in our possession was made about 1835, and is just like that in the figure. The rapid movement is produced by rack and pinion *k*, and the slow by a micrometer screw *l*.

The ordinary tube could be supplemented by an elbow-piece, containing a prism A.

The stage *h* is far too small for serious work, and the instrument lacks stability.

There are four objectives; some of the lenses can be combined in different ways with one another, and also with some accessory lenses. The object of these combinations is to give a clear image, with cover-glasses of different thicknesses.

The image given by these objectives is very remarkable for this period. Thus the objective marked O •:⁝ gives a good image of the pygidium; it becomes even excellent when the lens marked 6 is mounted on it.

But the instrument of this period, which rapidly acquired a considerable reputation, was the instrument which Ch. Chevalier produced in 1834, to which he justly gave the name of *The Universal Microscope.*

In fact, this instrument could be used, with an elbow-piece, as a horizontal microscope, as well as with the vertical tube; the tube could also be reversed, the objective being turned towards the sky for observations in chemistry, and lastly, the compound tube could be taken off in an instant, and a simple microscope be substituted for it.

The coarse adjustment was by rack and pinion, and the fine by a very complicated, but very precise, micrometric screw.

The microscope had a rotary diaphragm, with a series of apertures; and these, at pleasure, could be turned aside from the axis of the microscope by inclining it.

We will mention how, according to Chevalier himself, the various transformations in the universal microscope came about.

Figure 227 represents the instrument which is screwed to a brass foot. In this microscope the tube T is moved by gently sliding it in the tube Z, the stem D turns round in the piece S. The tube carrying the objective turns also at P, so as to be able to change the latter.

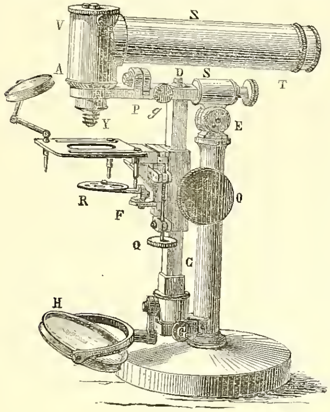


Fig. 227.

The prism carrier V slides into the tubes A and Z, to make a horizontal microscope. To make the microscope vertical the piece V, with the body of the instrument Z, is first removed, then the prism carrier V is separated from the body Z, and lastly, the latter is pressed on to the tube A, and in this manner the instrument becomes a vertical one.

The piece A P is adjusted on the stem D by means of a moveable pin, having a knob *g*. The piece V, which enters the tube A by slightly pressing it, enables the body Z and the prism carrier V to be turned round on an axis, which passes through the objective Y.

The stem C is fixed at the lower end to the piece E by means of the headed pin G.

The mirror H moves round in a circle so as to admit of oblique illumination. The stage is moved by the pinion O. The adjusting screw Q produces the slow movement. The variable diaphragm R is fixed on a piece fitted with a hinge and pivot, so that it can at any time be removed. We have already seen how the horizontal can be changed into a vertical microscope; to transform it into a simple microscope, it is only necessary to remove the body of the microscope, which is fixed to the support on the piece P A by means of the knob *g*; ring for the purpose of holding the doublets is substituted for it, and also fixed in position by the knob *g*. It is very easy to make a chemical microscope of it: the tube Z and the prism carrier, which move over the tube A, are made to describe a quarter of a circle from right to left. This done, remove the pin G, and lift the pillar C on the hinge E, then make it describe a semi-circle on the pivot S; let the whole turn on the hinge so that the apparatus becomes horizontal, and you will have an excellent arrangement for chemical experiments. It will only be nesessary to replace the stage and place it above a shelf carrying spirit lamps, if we require to use heat during the observations.

This microscope may also be used at every desirable inclination by turning it on the hinge E. If we want to use direct light, the apparatus may be set up horizontally on the hinge E, or after that it can again be easily placed in a horizontal position by turning it through a quadrant of a circle on the pivot S.

Finally, by means of the hinge E and the pivot S, it is easy to conceive that the microscope may be placed in every desired position. If this description has been read attentively, it can be seen that the universal microscope combines every desirable advantage.

The universal microscope in our possession is accompanied by two objectives.

The first is a half-inch having a N.A. of 0·2.

The second is a 1-5th inch which has a N.A. of 0·27.

The images of histological objects are very good, but with this feeble aperture one should not attempt to look for detail in diatoms.

A little later, Ch. Chevalier constructed very powerful objectives, following exactly the same methods. A half-inch in our possession is capable of resolving Nobert's 6th group. At this point we may bring to a close what may be considered as the ancient history of the microscope. The present form of microscope, *i.e.*, the true modern microscope, dates from the time when Amici introduced different kinds of glass into the construction of lenses; in particular, various kinds of flint, and from the time when each glass was no longer separately achromatized. It is this last modification in their construction which has enabled their numerical apertures to be increased, and more and more delicate details to be resolved.

The introduction of immersion by Amici, about 1855, was the second important transformation that the modern objective has undergone, and has been the means whereby the splendid results obtained by contemporary manufacturers have been realized.

2.—The Future of the Microscope.

DEAR SIR,

When, during your last visit to Iena, we discussed several questions concerning microscopical optics, we also very naturally came to speak of the future reserved for this powerful instrument of investigation, as far as scientific knowledge and the technical means at our present disposal could allow us to divine.

I observed on this occasion, that, in my opinion, the greatest progress we could still realize would have to be brought about in a direction which had not been pursued as far as it reasonably could have been. However, even in this case great advance has been made, and we are drawing near to its possible limits. I promised to commit my opinion on the matter in writing, and now I am about to fulfil it. Let us first establish the fundamental formula, giving the real magnifying power of the microscope. Let δ denote the smallest interval in a regular structure which can be resolved with an optically-perfect objective ; let λ denote the wave length, in vacuo, of the light employed, and a the aperture of the system ; then for central light we shall have the formula :

$$\delta = \frac{\lambda}{a}$$

both according to Abbe's theory and that of Helmholtz.

An increase in the power of the microscope is generally measured by the smallness of the elements of a structure that can be clearly distinguished; we can therefore denote the power by the smallness of δ. Now, as in the formula, δ is simply the quotient of two magnitudes we can diminish it in two ways, either *firstly by making* a *larger*, or *secondly by making* λ *smaller.*

In the first method, we know by the works of Abbe and Helmholtz, that increasing the magnitude of a, *i.e.*, *the aperture of the* *objective* is the method which has been adopted successfully by every optician for improving the microscope.

Let us examine to what limits this method can be carried, and how near we are to them at present.

We shall assume that $\alpha = n \sin u$, a formula in which n represents the index of refraction of the medium in front of the frontal lens of the objective, and n the angle that the extreme ray capable of penetrating it makes with the axis of the lens. This angle cannot, for purposes of ordinary geometry, exceed about 65° in any case; for there must always be a certain distance, no matter how small, between the object and the objective, both for inserting a cover-glass and for purposes of focussing. It follows then that $\sin u$ cannot exceed 0·95. There is therefore as soon as this geometric limit is reached, which usually happens with very powerful systems, no other means open to us except that of increasing the value of n, the index of refraction of the medium placed in front of the objective. It was this that led to the principle of *immersion*. It must, however, here be mentioned that it is not sufficient to interpose between the cover-glass and the frontal an immersion liquid of as high a refractive index as possible, but it is also necessary that between the object and the immersion medium there is no layer, however thin it may be, whose refractive index is lower than that of the medium, unless the aperture of the objective, however high the index n of the immersion liquid may be, is reduced to the magnitude $a' = n'$ where n' is the index of the layer of lowest index lying between the object and the immersion liquid. I have already mentioned this in my note entitled "Ueber ein system von der Aperture 1·60, &c." (On a system of an aperture of 1·60, &c., J.R.M.S., 1890).

Now the greater part of preparations require a cover-glass. The index of refraction of cover-glasses usually employed varies from 1·52 to 1·53. This kind of cover-glass is easy to manufacture, and can therefore be supplied at a reasonable cost; moreover, they are very convenient to use, but they can only be used so long as the aperture of the objective does not exceed the value 1·45.

To pass this limit, the cover-glass, as I have shewn in my previously mentioned note, must be made of highly refractive glass, which offers innumerable difficulties.

It is very true that the glass works of Jena, belonging to Messrs. Schott & Co., have turned out glass of every possible refractive index, even up to 2·00. But cover-glasses made of such glass are very expensive. They cannot be produced by blowing, but they have to be made in the same way as are the plane slips supplied by opticians. They have to be reduced by sawing to a thickness of about 0·15 to 0·2mm. (1-16th to 1-12th inches), then they have to be polished. In the first place a very large quantity of expensive glass is lost during these operations, and then the manual labour absorbs still more money. But this is not all, for, when the cover-glasses are obtained in this way, it appears that while they are being used they offer many inconveniences, which are not met with in the ordinary ones, and with which no one perhaps is better acquainted than yourself, dear Mr. Van Heurck. Then, as has been mentioned, the figure representing the index of refraction of every medium between the object and the frontal should at least be equal to that representing the aperture of the objective. Also, the object should be prepared in a medium of an index at least equal to the above. This is not impossible, for we have in our possession media whose refractive indices exceed 2·0.

But these media and the method of employing them present inconveniences. Such are the preparations of arsenic and phosphorus, which have to be heated while the object is being prepared. Now these substances, when heated, give off very poisonous fumes, and may also occasion explosions. It follows that preparations made with such substances endanger the life of the operator.

Moreover, the inconveniences arising when an objective of N.A. 1·6 is used, eclipse any others that may arise, for these substances attack the flint of which the cover-glass is made, which becomes dull, and hinders vision after a variable length of time, which is sometimes very short.

It is our intention to see whether this inconvenience can be avoided by using objectives of large aperture, whose construction will yet have to be attempted, but there is no reason for saying definitely that it will be possible. On the contrary, it can be anticipated from now, that cover-glasses of very refractive flint will always be more sensitive to re-agents than ordinary cover-glasses of crown; and, consequently, the number of useful media will be fewer in number. It may also be foreseen that preparations made with these special glasses will be, incomparably, more expensive than those made with the ordinary crown.

But, besides these objections, it should be remembered that media, like the above, would be bound to affect *the substances* in which objects are prepared; if these, as is so in most cases, are organic substances, they would, if the present methods of preparation were used, be either attacked or even destroyed, either by the medium or the increase of temperature. Such alteration would ensue, even when the naked eye could not observe it. The majority of organic substances will therefore always, as well as now, require refractive media, whose index is generally 1·35 and, at the most, 1·6. Such are the reasons which will ever prevent the optical power of the microscope from being increased by increasing the aperture beyond the limit which we have already reached, and we shall be obliged to see whether we cannot find the solution of the question in some other way.

II. Another actually does exist, and as has already been mentioned above, it consists in diminishing the value of λ which represents the wave length of the light used during observations.

By decreasing λ a diminution of n is produced in all the immersion liquids which have a normal dispersive power, which diminution corresponds to an increase acting on the magnitude of δ in the *same sense* as the diminution of λ. However, this is, comparatively speaking, too insignificant a factor for us to dwell on here.

If we make observations with ordinary sunlight (light reflected from white clouds), then a large number of different wave lengths would act simultaneously, *i.e.*, those of the visible spectrum. But the absolute energy (physical or mechanical), of the solar rays is not the same in all parts of the spectrum, no more in the same way is the eye equally sensitive—to a physically equal excitation of the retina—to all the colours, *i.e.*, the *physiological* energy of the rays of different colours is itself also different. The result of this is that the intensity of the impression which white light from the clouds produces on the normal eye, varies according to the wave length, by a law which can be represented by an undulating curve whose maximum height is given by $\lambda = 0{\cdot}55\mu$. The eye then receives the most vivid impression of rays of this wave length, and of those very near to it, and this impression is so powerful that the production of other wave lengths, which are greater or smaller, is either quite destroyed or at least rendered inactive, except in the case in which their properties are equivalent to those which produce the image $\lambda = 0{\cdot}55\mu$. If, on the other hand, one can successfully suppress these rays of a wave length of $0{\cdot}55\mu$, both those which act most energetically and those of a greater wave length—whether really or physiologically—and consequently only the shorter rays reach the eye, then in favourable cases, and noticeably when using sources of light which are too intense, then, I say, one can succeed within certain limits in making them active in their turn. Indeed, it is too well known how that the resolving power of any objective is increased when it is used in a blue light, obtained either with a complex apparatus for producing monochromatic light, or even by simply using solutions or glass absorbents (1). It can then be seen that striæ, &c., which remain invisible in white light, are with the same objective perfectly resolved, all other conditions remaining the same. Indeed, the eye is always sufficiently sensitive to rays which have a wave length of 0·44μ for obtaining on the retina a very vivid image in these rays by themselves. Now a reduction from 0·55 to 0·44 gives the same ultimate optical effect as if *the aperture* of an objective were raised from 1·40 to 1·75. As is evident, a very considerable progress is realized in this way by excessively simple means.

This is the reason, as has been established by Helmholtz and others, why photography is a means of increasing the resolving power of the microscope. However, practice has not in every case confirmed this theory, because a very important factor, which is indispensable for its realization, has been neglected. Indeed, to obtain the required result it is always necessary that the objective used in photography for rays of feeble wave length be made so as to give with such rays quite as perfect images as with the white light usually employed. Now this is not the case as a general rule. On the contrary, with achromatic objectives of the ordinary kind, *i.e.*, the only ones which have been available for some years, such images could *not* be obtained. When the objective was corrected so as to give good images with light of a wave length 0·55μ then images obtained in light of 0·44μ were so bad, *i.e.*, the chromatic and spherical corrections of the objective were so defective in this illumination that the theoretical affirmation of the increased resolving power could not be demonstrated. The difficulty was then got over, as it used to be done, and as it is still done now, with ordinary photographic objectives. The objective was corrected spherically for the most active rays in photography, and the chromatic correction of the objective was made so that the image formed by the rays of 0·55μ nearly coincided with the photographic rays. Consequently, with the naked eye, one could focus the photographic image with sufficient accuracy. However, the result thus obtained stil left much to be desired, for, *firstly*, the active *optical* image was *bad;* it was spherically under-corrected (insufficiently corrected) and chromatically over corrected (too much corrected); *secondly*, the active part of the

---

(1) See pp. 124—125 of this book.

spectrum in photography was incompletely concentrated (or re-united); the images which correspond to the different active wave lengths of the spectrum coincided neither in position nor in size in consequence of the chromatic under-correction of this part of the spectrum. These various images cannot therefore *combine with each other*, on the contrary, there is a danger of them mutually destroying each other. An attempt has also been made to remedy this in some measure by employing only a very small part of the spectrum. It is evident that the intensity of the light is much reduced in this way, which has its inconveniences. In every case the objectives specially constructed by opticians for photo-micrography can never be advantageously employed for observations and inversely.

The immense advance which has been realized in this way, by the construction of *apochromatics*, consists in the fact that in these objectives the images given by the different wave lengths of the spectrum, up to the violet inclusive, coincides for all practical purposes exactly in position and size. Also, the advance realized by these objectives is much greater in photography than in direct observation. Again, since the introduction of these objectives, photo-micrography has made enormous progress, and the cases in which structures that are invisible, or scarcely visible at all in direct observation, have been photographed and made to appear quite sharp, are numerous.

However, in my opinion, all that can be desired is not yet supplied by these objectives. We can only hope to reach the maximum resolving power, as I have already mentioned above, by employing rays of feeble wave length, *all other rays being excluded;* for when the rays of large wave lengths help to produce the photograph, then the same effects as we have already noticed when using white light, may also be produced; that is to say, the longest waves predominate and conceal the feeble image given by the shorter rays, for the sensitive plate has not really the property as is often attributed to it, owing to the imperfection of the eye. On the contrary, and this can be done and well understood from our knowledge of chemistry and the practique of photographic processes. We have therefore really nothing to wait for, neither orthochromatic plates, nor filters of green, yellow, or even brown light. Besides, it is well known that very often the natural colour of the object necessitates the application of like filters, if the detail of the object is wanted to be very pronounced. There are some photographic reasons which demand these conditions. The hope of being able to advantageously photograph this kind of object is quite excluded.

However, by that we do not mean to convey that photographs of such objects are unable to have their advantages, but that these advantages are of quite a different nature, which we have no room to mention here.

The cases in which photography with the objective can present advantages over direct vision, *i.e.*, shew further than this last and the limit to which these advantages can go, depend on the *two following circumstances* :—

I. That the objective be corrected so that the image to be obtained with the short rays $\lambda = x$ be in itself sharp, and coincide in position with the point where it is so for the eye, unless it cannot be focussed. This correction, which is obtained so far for $\lambda = 0{\cdot}44$ or for $\lambda = 0{\cdot}5$, can also be obtained for much shorter rays. One can find and determine, by photography itself, the index of refraction of glasses which would have to be used, so as to make the objective use up those rays which have no marked action on the retina of the eye; both the optician, the manufacturer, and also the mathematician, actually have at their disposal sufficient means to construct objectives which could be handed over to the microscopist, thus giving him *a priori* the assurance that they are suitably corrected for the invisible rays, without having to use the eye to control it. The same thing should be done for *every desired limit of* λ.

II. In the second place, the light coming from the short rays in question must be *photographically* active. We here encounter four considerations of a second kind: *firstly*, the rays from the luminous source should *have* in this part of the spectrum the required short wave length and be sufficiently intense; *secondly*, the rays of large wave length should be intercepted by appropriate filters, without at the same time on that account diminishing the intensity of the rays of short wave length too much; *thirdly*, the photographic *plate* should be sufficiently sensitive to the light employed, and if the plate has its *maximum* sensitiveness when light of the required wave length is used, then the same effect will be produced as by using filters; *fourthly*, all the media between the luminous source and the photographic plate should allow the short rays in question to penetrate them.

This last condition, in my opinion, marks the farthest limits we can reach. It is known that ordinary glasses only admit a very small fraction, 0·3, of the rays. The difficulties which arise, in consequence of using rays of short wave length, are enormous, and an idea of their number can be formed by reading the works of physicists who, like Cornu and

SCHUMANN have photographed the ultra-violet part of the spectrum. I conclude by saying that if luminous rays of a wave length of 0·35μ be used, the farthest limit is thus given, which will be attained in a given time unless the question becomes inconceivably complicated.

But even to reach this limit considerable work is necessary, in which opticians, physicists, photo-chemists and micrographers will have to take part. But their united efforts will produce a sufficiently substantial effect to make the subject attractive. Indeed, by employing a light of 0·35 instead of ordinary daylight, composed of rays of a mean wave length of $\lambda = 0{\cdot}55\mu$, the same advantage would be gained as if the apertures of our present objectives were increased from 1·40 to 2·20!

Accept, dear Sir, my best wishes,

DR. S. CZAPSKI.

ADDENDA.

1. Messrs. Bausch and Lomb's Fine Adjustment.—We have already described this fine adjustment briefly on page 145, but having lately been able to procure a wood-cut illustration of it, we give it here (fig. 228), and at the same time take advantage of the occasion to describe it in greater detail.

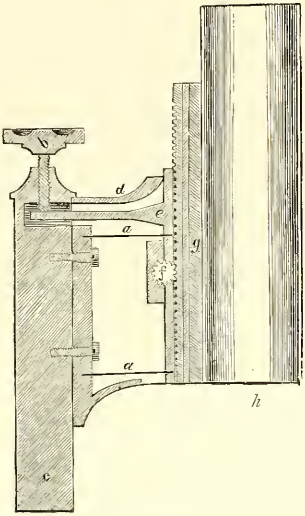


Fig. 228.

aa represent two strong blades of finely-tempered steel, set parallel to each other, and securely fastened at one end to the back of the case *d*, and at the other to the arm *e*, which carries the rack and pinion; *b* represents the micrometer screw, which is fitted to the upper part of the upright arm *c*; *f* is the pinion; *g* the rack; and *h* the tube. Two screws fasten the adjustment case *d* to the pillar *c*. An arm projects from the part *e* and passes into a recess in the pillar *c*. The springs support the entire weight of the body, and as their tension is upward, the projecting arm presses continuously against the micrometer screw *b*, and it is evident that whatever distance is traversed by the screw, the arm *e*, and consequently the whole body, must move through the same distance. The only points of contact are at the ends of the springs *aa*, where they are both fastened respectively at *d* and *e* and on the micrometer screw; and, as in the former, there is absolutely no friction, there is no wear; while any that may eventually arise in the latter, is made up for by the force of the springs.

Since page 140 and those which follow were printed, we have had occasion to examine a 1-5th inch objective of these makers, with correction collar in their Professional Series. It has an angular aperture of 130° or a N.A. of about ·91. The images are very clear, and with axial illumination the Pl. angulatum can be resolved. With oblique illumination both the striæ of the large forms of Vanheurckia rhomboides and the 12th group of Nobert's test can be seen well.

Before concluding this note we desire to modify the assertion we made at page 144, that the medium Continental microscope "is a very inferior model." It is almost unnecessary to explain that we were not denouncing the manufacturer's work in the instrument, but that we found the microscope insufficient for many serious and delicate researches, and that, consequently, we advised the purchase of a model of superior make.

2. Note on Apochromatic Combination.—No precise information has hitherto been published on the arrangement of lenses in apochromatic objectives and in compensating oculars. It is therefore believed that the following note will be read with interest, supplying as it does, the above-mentioned omission, and also giving the path of rays in these pieces of apparatus.

As will be seen in the adjoining illustration (fig. 229) the general path of the rays does not differ from that which takes place in instruments which are not apochromatic. The objective projects into the diaphragm of the ocular (the small arrow in the diagram) a real image of the object inverted and enlarged. The object, which is placed near the front focus of the objective, is not shown in the figure on account of its small size.

With compensating oculars Nos. 4 and 6 the image, formed by the objective, is diminished in size; and, moreover, the divergence of the principal rays (axis) of the pencil undergoes a change by passing through the field lens, just as happens in the Campani's (Huyghen's) oculars, usually employed in microscopes.

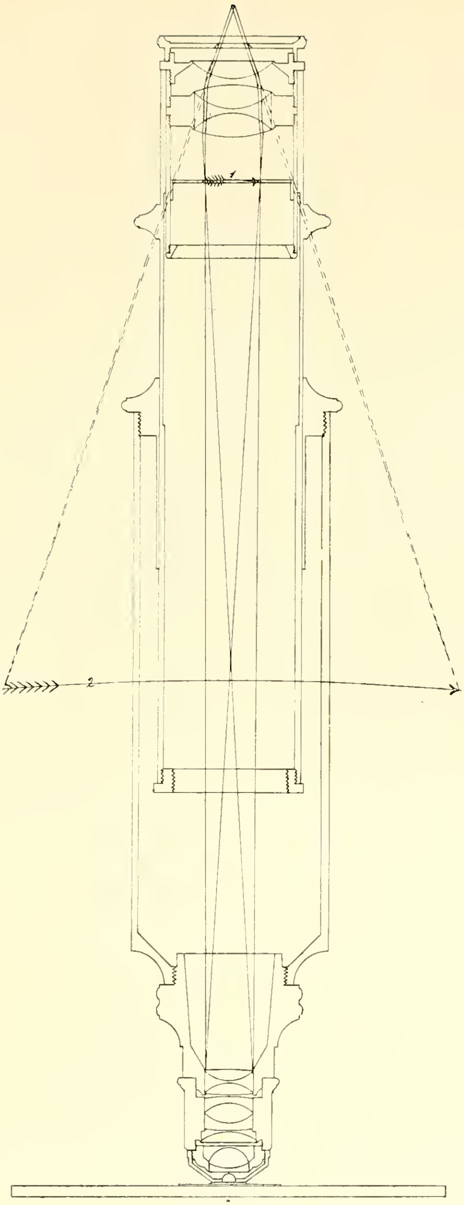


Fig. 229.

In oculars Nos. 8, 12 and 18, a type of which appears in the illustration, there is no field lens; the eye lens itself fulfills both functions: firstly, by rendering the principal rays convergent, and then by increasing, *i.e.*, by diminishing the divergence of the pencil emanating from different points of the object. The eye lens therefore (*i.e.*, the front lens of the combination in these compensating oculars), produces entirely the essential refractive effect, while the sole purpose of the triplet underneath is only to correct the image of chromatic and spherical aberration effects; its focus is very long, so that pencils leave the triplet with very nearly the same divergence that existed between the principal rays (axes) and their secondary rays when they entered the triplet.

The image produced by the oculars is drawn in the figure very near the point of vision, as actually happens with a myopic eye. With a normal eye the image will be situated at almost double the distance, say 25 centimetres (10 inches), the distance of normal vision.

The distance for short sight has been purposely adopted in the figure; if that corresponding to a normal eye had been taken, the distance would have been double, and the magnification also, so that in that case the arrow 2 would have been too large for the size of the page.

With regard to the objective its specific action may be described as follows: the simple frontal lens, which is nearly hemispherical in shape (indeed, in the case in the figure, which represents a 3mm. ($\frac{1}{8}$ inch) objective, with N.A. 1·40, it is even *more* than hemispherical) is employed, after Amici, for all high power objectives.

The object of a lens of this form is to bring about a sufficient change of divergence in the pencil emanating from the different points of the object (*i.e.*, to enlarge the object) without at the same time introducing great corresponding chromatic and spherical aberrations.

If the object were placed at the true aplanatic point of the spherical surface, and if the immersion fluid were perfectly homogeneous, *i.e.*, if the coefficient of refraction of the immersion liquid was exactly the same as that of the front lens, then the virtual image of the object, produced by this front lens alone, would be entirely free from aberration, and aplanatic for one of the colours of the spectrum.

In practice, however, this is not so, because often it is advantageous to intentionally introduce slight aberration so as to be able to destroy it more completely afterwards.

This front lens reduces the aperture of the pencil from 1·40 to 0·65.

The double lens which follows is used for the same purpose in all high-power objectives, firstly, to still further diminish the divergence of the pencil (in the system in the figure this diminution reduces the aperture from 0·65 to 0·29), and secondly, that that amount of chromatic and spherical aberration may be intentionally introduced, which can be most perfectly corrected by the succeeding lenses.

It is characteristic of apochromatic objectives that this front part of the system should consist of a simple plano-convex lens and a triplet. In many systems of objectives there is after the simple front lens an additional simple convex meniscus, which increases the effect of the front lens.

It has been found most advantageous that the front part of the system should consist of a simple lens, which produces the total dioptric effect desired, and a triple combination, which produces scarcely any convergence (magnifying effect or power), and which only so affects aberration as to eliminate the chromatic difference of the spherical aberration for all the zones simultaneously.

Lastly, the final upper lens, which is also a triplet, is used to destroy the secondary spectrum.

The simple lens in the middle (the third lens from the object under examination) makes all the rays converge sufficiently, *i.e.*, this lens alone produces the ultimate magnification which was commenced by the two lower lenses, while both the two triplets that follow have almost infinite focal distances. They therefore only act on the rays as two planes with parallel faces; they do not magnify at all, but simply correct the chromatic and spherical aberrations as already mentioned above.

INDEX.

Angle.	Sine.	Angle.	Sine.
15	·2588	65	·9063
30	·5	70	·9397
45	·7071	75	·9659
50	·7660	80	·9848
55	·8191	85	·9962
60	·8660	90	1·0000

ERRATA.

Before *luminous* insert *the* (p. 11, line 5 from bottom).—For *spectra lrays* read *spectral rays* (p. 35, line 21).—For *visability* read *visibility* (p. 36, line 15).—For *slip* read *glass* (p. 46, sec. 3).—Insert *in* before *the microscope* (p. 47, line 21).—For *give* read *gave* (p. 47, line 22).—For *adapted* read *adopted* (p. 49, line 20).—For *admissable* read *admissible* (p. 131, line 9).—For *Pleurosigna* read *Pleurosigma* (p. 190, line 18).—For *object* read *objective* (p. 218, line 12 from end).—For *megalocephalus* read *megalocephala* (p. 249, line 17).—For *Leon* read *Leo* (p. 337, line 20).—For *Grindelins* read *Grindelius* (p. 344, line 11 from end).