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With the Respects of
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A New Form of Binocular for use with High Powers of the Microscope.* — Of the several forms of binocular arrangement for the microscope which have hitherto been constructed, only such as are adapted for use with low powers exclusively, have as yet come into general use. Of these, the Wenham prism is the popular favorite, and hardly any other form is employed at all by British or American constructors. Mr. Wenham's binocular, when employed with powers below about one-half inch, leaves nothing to be desired; but with higher powers than this, the field is so imperfectly and so unequally illuminated that it ceases to be available.

The Wenham binocular, like the original binocular of Dr. Riddell, and like the different forms constructed by Mr. Nachet, divides the light, after it has passed the objective, by a vertical section passing through the middle of the entire bundle of pencils, into two equal portions, one of which is directed to each eye. But although the entire body of the light is thus equally divided, the same is not true of the several pencils which make it up. Only those pencils in fact can undergo equal division whose radiant points in the object lie exactly in the plane of the section. All others will be divided unequally, and the inequality will be greater in proportion as the radiants are more distant from that plane. If the division could be effected at the centre of the front lens of the objective, the inequality just spoken of would disappear; but such a division is of course impracticable. With objectives of low power, the base of each conical pencil of rays (which is the area of the front lens of the system) is so large, that the inequality of illumination consequent upon the unequal division of the pencils themselves is not sufficiently great to be objectionable; but with high power objectives, the pencils are very slender; and at the distance behind the combination at which it is necessary to place the binocular construction, many are very disproportionately divided, and many escape division altogether.

By the introduction of an erector into the body of the microscope, the pencils, which cross each other once in entering the front lens of the combination, may be made to cross a second time; and it is obvious that if the dividing apparatus of the binocular be introduced at the point of this second crossing, all the pencils will be divided with the same equality as they would be if the division could be effected at the centre of the front lens itself. Availing himself of this principle, Mr. Tolles, some years since, constructed a binocular eye-piece which solves completely the optical problem under consideration for all powers; but this instru-

* Read by F. A. P. Barnard LL. D., President of Columbia College, N. Y., before the Microscopical Section of the American Association for the Advancement of Science, Troy meeting.

ment is costly, and apart from this objection, it has for some reason or other failed to become a favorite with those who have used it.

It is now two or three years since Mr. Wenham suggested the practicability of constructing a binocular for high powers, by means of a contrivance which should reflect one-half the light of each pencil and transmit the other half. This plan was to take a glass prism with parallel surfaces, and to cut this by an oblique section at an angle suitable to reflect one-half the light which should be incident upon it after entering the prism perpendicularly to one of the original faces. The two portions of the divided prism being replaced in position to reconstruct the original prism, the surfaces of section being very nearly but not quite in contact, the whole is placed behind the objective, when the transmitted portion of the light will give one image, while the reflected portion, after a second reflection within the prism, will furnish the other. In this arrangement there is a possibility of some confusion in the image seen by reflection, in consequence of the duplication of the reflecting surface. On this account, or for some other reason not stated, Mr. Wenham did not follow up his invention.

In the January number of "Silliman's Journal" for 1868, Professor Hamilton L. Smith, now of Hobart College, described a binocular arrangement invented by himself, in which it was proposed to effect the division of the light by means of a long thin glass reflector placed very obliquely in the body of the microscope. As both surfaces of such a mirror will reflect light with intensity, it is necessary that these surfaces should not be parallel. It was Professor Smith's first idea to make the reflecting plate sufficiently wedge-shaped to throw the second image out of the field; but experiment showed him that, by making the inclination of the surfaces very slight, the images might be made perfectly to coalesce. This construction involved the disadvantage that the length of the body of the microscope could not be varied, but it was attended with an important saving of light. Hitherto Professor Smith's binocular has not been constructed by regular opticians, and its merits are not fully known. The constructions by Professor Smith himself perform very well, but have a rather limited field.

Messrs. Powell and Lealand, of London, have patented a binocular which resembles Professor Smith's in that it divides the light by reflection at the first surface of a glass mirror; but the surfaces of this mirror are parallel, and the image from the second surface is got rid of by giving to the glass considerable thickness. The reflected rays are reflected a second time by means of a right angled prism. As this arrangement is actually constructed, the image seen by reflection is greatly inferior in brilliancy to that formed by the transmitted rays. In fact, when very high powers are employed, the image by reflection is practically unavailable for any useful purpose. This evil might be remedied by increasing the angle of incidence at which the rays from the objective fall upon the first reflecting surface; but this expedient would be attended by a large increase in the amount of light lost at the second reflecting surface, and by a corresponding diminution of the brightness of the image seen by transmission.

Binoculars constructed on the principles of those last described may be called *cata-dioptric*, in contradistinction from those which split the body of the light geometrically, and which are properly denominated *stereotomic*. They have not the advantage which belongs to stereotomic binoculars, of presenting the object viewed in all its three dimensions. But they permit what most observers regard as very desirable, or find at least very comfortable, the use of both eyes at the same time. It is true that there are many whom practice has so accustomed to the use of a single eye, that they profess to suffer no inconvenience from this mode of observation, and regard binoculars with indifference except so far as they are recommended by their stereoscopic effect. But however slight may be the momentary inconvenience attendant on observation with a single eye, it is believed that no microscopist can continue to observe in this manner for a series of years, without finding that his eyes have lost the equal power which they once possessed of accommodating themselves to distances. It seems impossible to prevent this result from supervening sooner or later, unless by maintaining a strict impartiality in the employment of the eyes alternately at the microscope; and this is what few remember, or if they remember, are disposed to do. If by the use of a binocular this evil can be prevented, this fact alone is sufficient to make a good form of this instrument adapted to the higher powers desirable. Such a form is believed to have been found in the construction now to be described.

If a rectangular prism of calc spar be cut with four of its faces parallel and the other two perpendicular to the direction of the optic axis, a ray of light incident perpendicularly upon any one of the lateral faces will be divided by double refraction into two rays, but both of these two rays will pursue the common direction of the incident ray continued. There is a large difference between the two indexes of refraction. The index of the ordinary ray is 1.6543, and that of the extraordinary, 1.4833. If now the prism be divided by a plane section oblique to the axis, the two rays co-incident in direction, as above supposed, will be unequally reflected by this plane. And the ordinary ray will suffer total reflection at an angle at which the extraordinary ray is almost totally transmitted. The angle of total reflection for this ordinary ray is 37° 11′, while that at which total transmission occurs for the extraordinary ray is 34° 2′. From 34° to 37°, the amount of light reflected from the extraordinary ray is inconsiderable; amounting at the latter angle not quite to eight one-thousandths of the entire ray, and to four one-thousandths of the total intensity of the ray originally incident upon the prism. If, therefore, the supposed calc spar prism were cut by a plane, making an angle of 37° 11′ with one of its lateral faces, a ray incident perpendicularly upon this lateral face and meeting the plane of section, would be half reflected and half transmitted, or so nearly so that the inequality would be imperceptible. Moreover, the very minute portion of the extraordinary ray which would undergo reflection, would deviate more than two degrees from the direction of the reflected ordinary ray; and so, supposing this prism to form part of a binocular arrangement for the microscope, would be thrown out of the field.

But the pencils of rays which go to form the image in the body of the microscope have a certain angular spread. If, therefore, the axis of the central pencil be perpendicular to a given plane, those of the lateral pencils will be inclined to the same plane. Accordingly if this central axis were to be incident on the supposed plane of section at 37°, the incidences of the lateral pencils would vary between 34° and 40°, or possibly between limits somewhat larger. Also as the lateral rays of each pencil are inclined more or less to the axes of the same pencils, the limits of maximum and minimum incidence would be more largely extended by this circumstance. For low powers we should have to allow for a range of incidences embracing perhaps eight or nine degrees of difference. For very high powers this range would hardly exceed six.

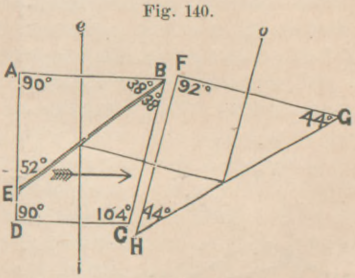
If the incidence of the central axis is fixed at 37° 11′, the angle of total reflection for the ordinary ray, then the lateral pencils of this ray, whose incidences are less than 37° 11′, will be to a certain, but not very considerable, degree, transmitted. This does not affect the definition of the image seen by transmission, but it gives it a slight superiority to the other in respect to brightness. If, however, the incidence of the central axis is made as great as 39°, the two images become sensibly equal in brightness. In this case some of the lateral pencils of the extraordinary ray will attain an incidence of 42°, at which point the amount of reflection is quite sensible, but this does not materially affect the middle of the field, nor is it sufficient to impair, perceptibly, the brilliancy of the image seen by transmitted light.

It is now about three years since the plan of a binocular founded on the principles above explained, was devised by the writer of this paper; but this plan was not immediately realized in consequence of a difficulty encountered in obtaining calcite prisms suitably prepared. Opticians were applied to in London, and in this country, but no one was found willing to attempt the preparation. In the spring of 1869, Professor Rood, of Columbia College, kindly lent his aid to the accomplishment of this undertaking, so far as to verify experimentally the anticipations of theory; but time would not permit him to give to the prisms the finish required for a perfect instrument. The work was finally done during the following summer by Hoffman of Paris, with results entirely satisfactory.

In the original construction the calcite prism was made rectangular. The ordinary ray, after reflection from the surface of section, emerged from the terminal plane at an incidence of twelve degrees. It was reflected a second time by means of a triangular prism of flint glass having nearly the same index of refraction, of which the first surface was placed parallel to the terminal plane of the calcite. It was thought that the very nearly equal and opposite refractions thus suffered by the ray would suffice to prevent sensible aberration; and this is nearly true. But the unequal dispersive power of the two substances makes itself slightly manifest when the objectives used are low; though this defect disappears in the case for which the instrument is intended — that is with high powers. Nevertheless, it has been thought best in new constructions now preparing, to give such an obliquity to the terminal plane of the calcite that the reflected ray may be incident upon it perpendicularly, and to modify correspondingly the flint glass prism. On the whole it appears to be best also to give the plane of section an inclination of about 38° instead of 39°. Indeed it would appear that, for low powers, the lower angle is preferable, and for high powers the higher; doubtless because, on account of the larger range of differences of incidence in the former case, there is a larger reflection of the extraordinary ray, which is greatly reduced by a very small change in the angle of incidence. For this reason it is convenient to have the system of prisms so mounted that it can receive a slight rotation about an axis perpendicular to the plane of reflection, and to adjust it to the position most satisfactory with the power employed.

The annexed figure (140) will serve to give an idea of the form of construction now employed. ABCD is a section, parallel to one of the lateral faces, of a calcite prism, originally rectangular, of which the optic axis is parallel to the section, and to the sides AB and DC. This prism is divided by a plane perpendicular to ABCD, making an angle of 38° with AB and 52° with AD. Also, the face, BC, inclined 14° to the original face of the rectangular prism, is made to replace that face. The prism, when completed, should have its lower face square, and the side of the square which is equal to DC, should be six-tenths of an inch. The remaining dimensions will be determined by this, and by ED, which should be three-twentieths of an inch. The surfaces of section, BE, may be brought very near to each other. In the construction actually employed they have been separated only by a single thickness of tinfoil, introduced at each of the angles.

Fig. 140.

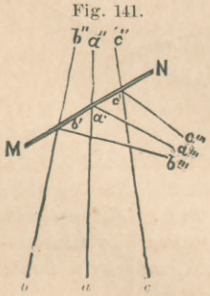


The prism, FGH, is of flint glass with a refracting index as high as 1.56 or higher. It is isosceles, having an obtuse angle of 92° at F, the acute angles being equal and each 44°. The side, FH, being parallel to BC, a ray incident perpendicularly upon DC, and doubly refracted by the prism, is resolved into the two rays, *e* and *o*, of which the first is transmitted, and the second, reflected by BE, passes perpendicularly through the two surfaces, BC and FH, is a second time reflected by GH, and finally emerges at right angles from the face FG. The inclination of *o* to *e* is twelve degrees. It would be preferable to make it somewhat less, as this inclination allows only a length of body to the microscope of about seven inches.

By employing in the prism, FGH, glass of higher refracting power, it may be made less, and by using calcite for this prism, or in other words, by making BCDE and FGH all of a single piece, the same object may be attained to any desired degree. The objections to this latter plan are two-fold. The first relates to the difficulty of construction. It is said that the Wenham trapezoidal prism of glass is troublesome to make. The difficulty would be much increased in the use of such a material as calcite, especially when it is necessary to preserve an exactly prescribed relation between the faces of the prism and the optic axis. The second objection is found in the consideration that, in order to adapt the tubes of the binocular to the eyes of different observers, it is necessary to give to one of the tubes an angular movement, moving the prism, FGH, at the same time, by half the same angular amount, as is done by Mr. Nachet in one of his forms of binocular; or to move this tube and prism laterally, as Mr. Nachet has also done in another of his forms. This necessity arises from the fact that, if the tubes are sufficiently inclined to each other to permit an accommodation to different eyes by running them in and out, as is done by Mr. Wenham, they must be made shorter than is desirable. The reflected pencils might be made to cross the transmitted before reaching the eye, as is done both in Wenham's and in Powell and Lealand's contrivances; and this would remedy the inconvenience last mentioned; but it would necessitate the use of a prism, in place of FGH, of difficult construction, and of greater size than is desirable.

But there is another objection to the crossing of the pencils which is more serious. This binocular, as actually constructed, produces, when used with moderate powers, a sensibly stereoscopic effect. Nor is it difficult to understand why it should do so. In any stereotomic binocular, Wenham's for instance, it will be observed that the half of each pencil which falls upon the front lens of the objective, is carried to the opposite eye; and this ought to be so, because the image actually seen is reversed in position. Now, by considering the figure annexed (141), it will be seen that if $aa'a''$ be the axial ray of a converging pencil of which $bb'b''$ and $cc'c''$ are the lateral limiting rays, and if a transparent reflector, MN, be interposed obliquely in the path of this pencil, the angles of incidence of all the rays intermediate between a' and b' will be larger than those of the rays between a' and c'. Of the reflected rays, therefore, those between a''' and b''' will be more abundant than those between a''' and c'''; while of those which are transmitted the excess will lie between a'' and c'', and there will be a corresponding deficiency between a'' and b''. Now if all the light except these excesses should be extinguished, it will appear at once that the illumination still outstanding would be such as is required to produce stereoscopic vision; that is, each half of the pencil would go to the opposite eye. In our calcite prism, we have seen that in, for instance,

Fig. 141.



the central pencil, there is total reflection for the ordinary ray between a' and b', but that there is some transmission toward c'. The extraordinary ray, on the other hand, is almost totally transmitted between a' and c', and loses something by reflection toward b'. These effects are more marked in some of the oblique pencils, and the consequence is, that, with low powers, the stereoscopic appearance is very perceptible. To cross the reflected rays upon the transmitted behind the prisms would therefore be productive of a pseudoscopic effect which would be objectionable. But with high powers, on account of the small difference of incidence existing in that case between bb' and cc', the image appears plain.

As a test of the performance of this binocular, it may be mentioned that, by means of it, the most difficult natural objects have been resolved by observation with both eyes, or with either eye singly. With a Wales' objective marked one-thirtieth, but more exactly rated one-twenty-fifth, and with the B oculars, the Providence Grammatophora is thus resolved with great facility.

When the power used is below one-fourth, there is a little haziness produced in the image seen by reflection, in consequence of the mingling of the, to some extent, reflected extraordinary ray, from the clear field surrounding the object. This effect is immediately removed, by placing over the slide a card, out of which has been cut a slip having the width of the field. Such a card, or a similar thin plate of metal, may be easily secured to the stand, so that the stage and slide may move beneath it while it remains fixed. This haze is moreover suppressed still more easily by slightly tilting the system of prisms, so as to diminish by a degree or two the angle of incidence upon the reflecting plane of section. This really gives to the image seen by transmission the advantage in respect to illumination; but as, with low powers, both images are strongly illuminated, the difference is scarcely noticeable. It is well, therefore, in mounting the prisms, to provide some system of adjustment by which the position may be varied to correspond to the power employed.

Some experiments have been made with calcite prisms cut in such a manner that the extraordinary ray proceeding from common light perpendicularly incident upon the first surface, should fall at a smaller incidence than the ordinary upon the surface of the reflecting section. Thus, if, in figure 140, the optic axis has the direction BE the extraordinary ray will deviate toward the left, from the ordinary, after perpendicular incidence on DC, by nearly five degrees. This is favorable to the transmission of the extraordinary ray through BE; but as the index of extraordinary refraction is considerably greater in this direction, the amount of loss by reflection is about the same as before. The construction employed at first gives results which are very satisfactory; but it is designed to pursue experiment further, and with the able assistance of Mr. Joseph Zentmayer, whose zeal for the improvement of the microscope has induced him to undertake the rather troublesome task of preparing the prisms, it will soon be ascertained whether or not any material advantage can be gained, by adopting a different plan of cutting them.