Stereoscopic Microscopy with the High Power Binocular

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Summary
Good stereoscopic images may be obtained from a high power binocular microscope by the use of simple accessories. Experiments are detailed showing how the stereoscopic effects occur and descriptions are given of the systems thus indicated. Drawings and notes on the construction of apparatus are given, including shaded eyepoint caps believed to be novel.

IT DOES not seem to be generally known among users of the modern high power binocular microscopes that by the use of very simple accessories their instruments may be made to yield excellent stereoscopic images with little of that loss of resolution and restriction of field which are noticeable features of the Wenham and other older type monobjective binoculars when they are used with the higher powers of objective. This article will describe some experiments to show how stereoscopic effects occur and what attachments are needed to obtain those effects.

1. Parallax

Parallax may be demonstrated by holding up a hand flat in line with the nose and some eighteen inches in front of the eyes. If first one eye then the other is shut the hand appears to move in relation to objects in the background. Note also how the hand itself appears to swing first one way then the other, the right eye seeing more of the right side of the hand and the left eye more of the left.

Parallax is the condition whereby the angular distance between objects in different planes varies according to the direction from which they are viewed. Stereoscopic vision is the natural use by the two eyes of parallax to perceive the absolute and relative distance of objects from the observer and (what is really the same thing) the relative position of parts and therefore the shape of a particular object. Various other factors assist the observer to achieve this, such as perspective, the focussing of the eyes and the obscuring of parts of distant objects by ones which are nearer.

Through a pinhole in a card observe a pin at about twelve inches distance and move the pinhole slightly up and down close to the eye. Objects in the background will be seen to move up and down relative to the pin, showing that parallactic effects may be obtained by observation through different parts of the same lens, in this case that of the eye. The apparent movement of objects due to parallax will frequently be referred to in this article as 'shift'.

2. Preparation of a test slide
A test slide for parallax may be prepared by smoking a piece of sheet metal in the flame of a candle and scraping a sparse layer of the soot on to the centre of an ordinary glass slip. Fix a thin coverglass over the soot using

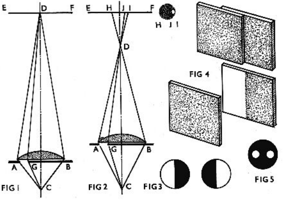


FIG I FIG 2 FIG 3 FIG 4 FIG 5

a few spots of cement round the edges. A further layer of soot is scraped on to the coverglass and similarly covered. There are now two layers of soot on the slide, separated from each other by a coverglass.

3. Microscopical observations of parallax
Set up a microscope with a ×10 objective and a ×5 or ×6 eyepiece. Bring the top layer of soot on the test slide into focus, the particles in the layer below being visible but not sharply defined. Pass the edge of a piece of card from left to right immediately below the objective and note how the out-of-focus particles appear to move to the left in relation to those in focus. The shift is in the contrary direction, of course when the card is moved from right to left. The effect is more clearly shown when a pinhole rather than the edge of a card is passed under the objective. The same movements occur if the card is passed just behind the objective, though this is not so easily arranged.

This shift is analagous to that shown in (1) by holding a hand in front of the eyes and presents to the eyes the appearances shown by viewing through the pinhole, hence if the rays emanating from one side of the objective could be observed through one eyepiece of a binocular microscope and the rays from the other side of the objective through the other eyepiece, a stereoscopic image of the object examined would be obtained. This was, in fact, the principle on which most of the early binocular microscopes were designed.

4. Cause of parallactic displacement

The reasons for the shift may be understood from Figs. 1 and 2. In Fig. 1, *AB* represents an objective receiving a cone of rays *ACB* from a point *C* and transmitting them as cone *ADB* to a focus at *D*. *D* lies in the focal plane *EF* of an eyepiece and is thus seen by the eye as a sharp point, the image of *C*. In some forms of eyepiece, notably the Huygenian, rays pass through a field lens before reaching *EF* but this is not significant in the present discussion.

A diaphragm *AGB* having a small circular aperture *AG* is now introduced at or near to a principal plane of *AB*, *AG* being the equivalent of the pinhole in (3) above. Rays from *C* to *D* can now be transmitted only by the smaller cones *ACG* and *ADG*, but they still come to a sharp focus at *D* and the eye still sees *D* as a sharp point and in the same position as before the diaphragm was inserted. The general illumination is reduced because *AG* has a much smaller area than the whole objective aperture *AB*.

In Fig. 2 the point *C* has been placed further from *AB* and its image is accordingly nearer to *AB* thus *D* now lies a little way below *EF*. The cone of rays *ADB* having crossed at *D* now reaches *EF* not as a point but as a dispersed circle of rays *HI* which the eye, looking through the eyepiece, sees as a blur or out-of-focus image of *C*. The dispersion circle will become larger, and therefore less defined and more nebulous, as *C* is taken further out of focus.

The diaphragm *AGB* is again introduced, but when the rays of cone *ADG* diverge above *D* they meet the plane *EF* as the dispersion circle *JI* which is smaller than *HI*. Moreover *JI* is not concentric with *HI* but lies towards the edge of *HI* as shown in plan. The eye now sees the image of *C* as smaller and sharper though still not as sharp as under conditions of Fig. 1. The important point is, of course, that the image of *C* appears to have been displaced as compared with its position when the diaphragm *AGB* was not present. The out-of-focus image of *C* will tend to assume the shape of the diaphragm aperture *AG* whether that is a circle or any other shape.

No doubt, under microscopic conditions, diffraction, lens aberrations and other factors have some slight influence on parallactic shift, but the above may be taken as the general explanation of it. This shows also why in ordinary microscopy images being focussed by transmitted illumination appear to move from side to side if the light is not properly centred.

5. Loss of resolution

Replace the test slide by one containing diatoms that are just within the resolving power of a ×40 objective, say a fairly coarse specimen of *Pleurosigma angulatum*. Repeat (3) using the ×40 objective and mark how the resolution deteriorates as the card covers more of the objective; this is brought out more strongly by the use of a higher power of eyepiece.

The deterioration is mainly due to a reduction of aperture in a horizontal direction. This loss of resolution is the principal objection to the use of the Wenham and other binoculars that halve the aperture; it is not unduly harmful when specimens do not present fine detail or when total magnification does not exceed, say, 300 times the numerical aperture of the objective, but some loss of crispness is always noticeable in the image.

6. Stopping-off the Ramsden disc

Some means must now be devised for moving a card across the Ramsden disc at eyepoint level. There is no difficulty about this if one of the old capped eyepieces is used, for the cap may be moved upwards until the Ramsden disc can be sharply focussed on a piece of ground glass resting ground side downwards on the cap. With an ordinary eyepiece a slice of cork with a hole through its centre may be fixed temporarily to the top, the hole being sufficiently large not to obstruct rays from the eyelens. The slice must be of the right thickness to allow the Ramsden disc to be focussed as above. Given the same eyepiece, eyepoint level will vary slightly from one objective to another but for the purpose now intended focussing should be correct for the ×40 objective, conditions being more critical for that than for the ×10 objective.

Observe the upper layer of soot as in (3) and pass the card across the Ramsden disc, holding it against the cap or cork to maintain it at eyepoint level. Note that the shift occurs as before, only in the opposite direction relative to the movement of the card. As previously, the effect is clearer with a pinhole. Figs. 1 and 2 provide the explanation, *AB* being taken as the lens of the eye and *EF* as the retina.

It follows that if rays emanating from the right hand side of the Ramsden disc can be observed with the right eye and conversely, a stereoscopic image will be seen. This principle is especially applicable to modern high power binoculars which present an identical picture to each eye. If the right hand half of the left eyepiece Ramsden disc is stopped off and vice versa, a good stereoscopic image will result, the two discs then appearing as in Fig. 3. Abbe introduced caps for this purpose to fit over the eyepieces of his binocular attachment and similar accessories were supplied with later Zeiss binoculars. These caps, which cut off half the Ramsden disc on either side, give a fine stereoscopic effect but with a similar loss of resolution as in the Wenham instrument, see (5) above. It is possible to reduce the loss of resolution, or obviate it altogether, if the cut-off is half on one side but less, or even none at all, on the other; this is really exchanging a degree of stereoscopic effect for a degree of improved resolution.

Abbe caps suffer two disadvantages as compared with the Wenham type of arrangement. First, the eyes have to be placed close to the caps which some find uncomfortable and which precludes the use of spectacles. This difficulty may be alleviated to some extent by withdrawing the eyes a little way and accepting the reduced field that results. Narrow field eyepieces help here as the eyes can be held quite a way above eyepoint level with the eyepiece diaphragms still defining the field; alternatively the lamp iris may be used to limit the field. Secondly, a given pair of caps will normally suit only one pair of eyepieces, as eyepoint height varies according to the design and power of eyepiece.

Nevertheless, Abbe caps work well, are simple and can readily be applied to and removed from the microscope. A very suitable combination for use with these caps is a ×20 objective of N.A. 0·40 to 0·50 with ×6 eyepieces.

It is not necessary to use caps at all to obtain some stereoscopic effect with modern binoculars, as the setting of the eyepieces a little closer than the interpupilliary distance of the observer will result in the iris of each eye cutting off the inner part of its respective Ramsden disc. When the discs are large, as when low power eyepieces are used with a low power objective, the results are fairly good though the head needs to be kept very still otherwise objects in different planes appear to move about in relation to each other. When high powers of eyepiece or objective are in question the method is unsatisfactory.

7. Stereoscopic effects and resolution

It has been commonly held that a good stereoscopic image with the mon-objective binocular can only be obtained at the expense of halving objective aperture, entailing an unacceptable loss of resolution with high powers. The experiments so far seem to support this idea. Stereoscopic effects, however, depend on the apparent position of out-of-focus images whereas resolution has to do with the separation of closely adjacent points which are in focus, so there appears to be no fundamental reason why the two things, satisfactory stereoscopic effect and good resolution should not be present at the same time. If in securing the necessary shift the aperture of the objective is reduced, as in systems which cut off part of the aperture of the optical system somewhere between specimen and eye, then resolution will certainly suffer. However, it can be shown that the shift may be obtained without interfering with objective aperture at all, or by shading and not entirely obscuring part of that aperture. Even so, there is some incursion into the path of rays between illuminant and retina and therefore resolution cannot be as perfect as if there were no impediment at all, nevertheless the objective is free to pick up and pass to the eyepiece all rays diffracted by the specimen, even if they are then attenuated by shading.

The foregoing experiments with test- and diatom-slides are repeated but the card is passed immediately below the condenser mount. A shift is again seen though the resolution appears, if anything, to be enhanced by the oblique lighting. This shows that stereoscopic images may be secured by manipulation of illumination, and though the dioptric aperture of the whole optical train is reduced, there is no diminution of aperture above the stage. If the field seen through the left hand eyepiece is illuminated only by rays from the left side of the condenser and conversely, a stereoscopic image is obtained.

A system such as is now indicated, and using Polaroids, was introduced by Jackson (1948), though it would appear from the records that neither he nor anyone else at the time realised that here was a system quite different from its predecessors and which provided greatly improved resolution. In the condenser tray Jackson placed a polariser comprising two semi-circles of Polaroid, their polarising axes being at right angles to each other and their junction running vertically. Each eyepiece had a Polaroid cap, their axes also being at right angles and so orientated that rays proceeding from the right hand half of the condenser were extinguished by the left eyepiece cap, the opposite taking place on the other side.

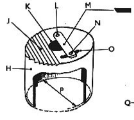
This system gives good resolution with strong (sometimes over-strong) stereoscopic effects, and suffers none of the difficulties of Abbe caps. It can, however, give rather a harsh or confusing image with many objects due to the illumination being from the left for one eyepiece and from the right for the other. It fails when the field contains much material that is not very transparent and is not applicable with illumination by reflected light under which stereoscopic effects are at their best. Results with darkground illumination have not proved very satisfactory.

8. Shaded eyepoint system

The experiment in (6) may be repeated using a filter instead of a card. To prepare the filter take a large square coverglass and place another on it so that the two overlap by half as in Fig. 4. Hold them in this position by means of forceps and smoke them on one side in a candle flame until they appear brown by transmitted light. The tint should be just light enough to allow the darkest object in a normally lighted room to be seen clearly. Allow the fully smoked glass to fall away, leaving the other one half covered by a film of soot having a straight sharp edge. Fix a clean coverglass over the latter one as a protection, tacking it down with a little cement at the edges.

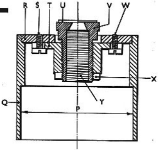
As the edge of the film passes over the Ramsden disc the shift will be seen to occur, but little or no deterioration will be apparent in resolution. Sufficient rays are getting through the film to allow of good resolution. Degradation of the image will be shown up by a really high eyepiece such as ×30, and consideration of Figs. 1 and 2 will indicate that though the shift is as extensive as when a card is used there is less contrast in the shifted image.

This result points the way to an improvement in the Abbe caps which the writer believes to be novel. If the Ramsden discs are half covered by tinted glass rather than by anything opaque a stereoscopic image will result without significant loss of resolution, nor is the image noticeably tinted. Some care is needed to get just the right depth of tint otherwise either the resolution or the stereoscopic effect suffers unduly. Caps made on this system have proved highly satisfactory, allowing of good resolution but having the disadvantage of the Abbe caps in that one pair of them will suit only one pair of eyepieces. There are similar difficulties regarding the placing of the eyes, with the added drawback that the close proximity of



ABBE CAP

FIG 6



SHADED EYE-POINT CAP

FIG 7

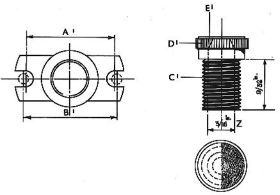
FIG. 6. *H* Cap bored out to fit eyepiece flange or eye-tube of microscope.
J Anti-reflection grooves.
K Central hole bored in cap.
L Cut-off bar fixing screw inserted from underside.
M Cut-off bar with knife edge. *See cross section.*
N as *L* above.
O Radial slot for adjustment of extent of cut-off.
P Bored diameter to provide ledge. Rests on eyepiece flange so that knife edge of cut-off bar is at eyepoint level.
Tops of caps and all internal surfaces to be blackened.

FIG. 7. *P* Bored diameter to fit eyepiece flange or eye-tube of microscope, whichever is the wider.
Q Body for shaded eye-point-cap.
R Top plate with concentric anti-reflection grooves to be turned in top of cap.
S, *W* Fixing screws.
T Half-shaded screw carrier tapped internally ¼ in. × 40 t.p.i.
U Half-shade glass cemented to top of half-shade screw.
V Half-shade screw.
X Lock nut ¼ in. × 40 t.p.i.
Y Inside surface of half-shade screw given very fine internal thread to prevent reflection.

the eyelids and lashes tends to make the glass greasy. However it will be found that the tinted glass, which may be referred to as the half-shade(s), can be placed a little below eyepoint level without ill effect, and if the field of the eyepieces is reduced by smaller limiting diaphragms or by simply closing the lamp iris a perfectly comfortable working distance for the eyes may be secured.

Substage diaphragms

Diaphragms shaped as in Fig. 5 and inserted below the condenser have long been advocated for stereoscopic binoculars. They enhance the stereoscopic effect quite considerably with the Abbe and shaded eyepoint caps



HALF SHADE SCREW

FIG. 7 (continued) *Detail of half-shade screw carrier.*
A' Centres for drilled holes in carrier. Slots to be wider than diameter of screw in order to provide adjustment of cut-off.
B' Centres for fixing screws.
Detail of half-shade screw.
C' ¼ in × 40 t.p.i. thread.
D' knurled rim.
E' Half-shade glass cemented to top of half-shade screw.
Z Internal surface of 3/16 in. dia. bore to be fine threaded to prevent reflection.

when aquatic organisms are being observed by transmitted light, or in other cases when the specimen and its surrounding medium have much the same refractive index. Resolution is liable to suffer, however, just as it may be when the condenser is much stopped down.

Different objectives require diaphragms with different sized holes, the best diameter being rather under half that of the substage iris opening when the edges of the iris leaves just show in the back lens of the relevant objective, both objective and condenser being focussed on the same object.

Notes on the construction of accessories

ABBE CAPS

Almost any design is suitable provided it fulfils the following conditions:

a. The edges cutting the Ramsden discs are at eyepoint level and bevelled away underneath to form knife edges.

b. Provision is made for adjusting the extent of cut-off when the caps are actually in position.

c. Caps fit sufficiently closely for the knife edges consistently to take up the right position, but also allowing them to be applied and removed easily.

d. Caps have flat non-reflecting top surfaces without any projections exceeding $\frac{1}{8}$ inch or so.

A satisfactory design is given in Fig. 6, this being carried out in brass which is probably the most suitable metal. To maintain position the caps should be bored out to a close fit over their respective eyepiece flanges or microscope eye tubes, whichever are the wider. Alternatively a slightly looser fit can be allowed if a binding screw is fitted to each cap so that slack is always taken up in the same direction.

The optical and mechanical axes of either or both tubes may not coincide, so caps should be marked 'left' and 'right' and always so used. The same should be done with the relevant eyepieces.

A magnifier should be used when the cut-off is set. A knife edge is at the right height when, to quote Carpenter & Dallinger (1891), on moving the eye laterally the image (i.e. of the Ramsden disc) appears always to adhere to the edge. Cut-off should be half on one side, but on the other a quarter cut-off is recommended with the ×40 objective which should be used for all the setting, this proportion rising of itself when objectives of lower power and giving larger Ramsden discs are brought into use. Setting should be done with the condenser iris open.

If a separate pair of eyepieces can be spared for stereoscopic work construction may be simpler. A slice of cork of suitable thickness, blackened on the top and with a hole through the middle, can be cemented to the top of each eyepiece. A thin piece of blackened metal or other material can then be cemented to the top of the cork and its edge correctly positioned before the cement sets. Cork can be worked very easily with a hacksaw, sandpaper and a fairly coarse file, and holes bored in it with a piece of thin-walled metal tubing bevelled away inside to form a cutting edge.

Jackson's Apparatus

This polarising apparatus is very simple to construct, no accurate workmanship being required. The Polaroids must be carefully orientated, however, for the prisms of a high power binocular sometimes have a marked depolarising effect unless the polarising axes are in certain defined positions in relation to them. The positions should be ascertained before the semi-circular Polaroids for the substage are cut out. This power of the prisms to polarise as well as to depolarise may result in a high power binocular giving a weak stereoscopic image when only the substage polariser is used.

If the lenses of the condenser are clamped too tightly, as they sometimes are in inexpensive non-corrected types, the consequent depolarisation may render the system inoperative, when a better class condenser should be tried.

SHADED EYEPOINT CAPS

Requirements are similar to those for Abbe caps, but a height adjustment screw is desirable. A proved design is given in Fig. 7, though it has been found convenient to use a similar arrangement permanently mounted on a pair of eyepieces. Some trials may be needed to secure just the right degree of smoking, otherwise resolution or stereoscopic effect may be unsatisfactory. Cut-off should be exactly half on either side. As mentioned above, the half-shades may be set below eyepoint level to obtain additional clearance between them and the eyes, but not so far below that the stereoscopic effect is lost or the field becomes unevenly illuminated.

This system provides a particularly satisfactory stereoscopic image if the caps are used in combination with the substage polariser of Jackson's system.

ACKNOWLEDGMENT

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A Century Ago

SIR DAVID BREWSTER died in 1868 at the age of eighty-seven. This distinguished Scottish scientist was first destined for the Church, but after completing the course in divinity turned instead to science. He had entered Edinburgh university at the age of twelve and when twenty received an honorary degree. The study of light became the ruling passion of his life; and he also gave considerable time to literary work, contributing to, among others, the *Philosophical Transactions*. In 1802 he became editor of the *Edinburgh Magazine* and of the *Edinburgh Encyclopaedia* in 1808. His most famous contribution to the literature was his life of Sir Isaac Newton published in 1855. He was elected to fellowship of The Royal Society in 1815.

He was instrumental in founding the British Association for the Advancement of Science in 1831 and in the following year received his knighthood.

One of Brewster's best known inventions was the fascinating kaleidoscope (1816). In 1849 he greatly improved the stereoscope by substituting refracting elements for Wheatstone's original mirrors. He had to take this invention to Paris, however, before he could interest anyone in its commercial possibilities. His outstanding invention was the *dioptric apparatus*. This arrangement, in which the radiation from a centrally positioned source is reflected and refracted by a series of annularly disposed lens-sections which concentrate the maximum possible amount of light into the beam, in due course came to be universally adopted in light-houses. A moulded 'lens' based on the same idea is commonly employed for stage and photographic spotlights. The invention is often wrongly