MONOGRAPHS
OF THE
QUEKETT MICROSCOPICAL CLUB
No. 5

THE BINOCULAR MICROSCOPE ITS DEVELOPMENT, ILLUMINATION AND MANIPULATION

by

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AND
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The Quekett Microscopical Club

ROOMS OF THE ROYAL SOCIETY
BURLINGTON HOUSE, PICCADILLY, LONDON

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This Club was founded in 1865 for the purpose of affording to experienced microscopists, as well as to students, regular and frequent opportunities for an exchange of views on special subjects in which they are mutually interested, and also for promoting Field Excursions to the well-known collecting districts around the metropolis. From the commencement in 1865 until the present time members living in home counties have enjoyed these advantages of membership.

In other parts of the country it was soon found that the advantages of discussing problems with other members by letter, the posting of the *Journal* of the Club regularly, and the knowledge that a warm welcome awaited one at headquarters when visiting London, made membership desirable.

Further, the authoritative nature of Quekett publications, especially the regular publication of the *Journal of the Quekett Microscopical Club*, has gained for the Club an important membership in many parts of the world.

A fraternity of members, willing to exchange experiences in all branches of microscopical interest, is the most valuable asset of the Club, but the lending library of several thousand books on all subjects related to the microscope, and the many thousands of unique microscopical preparations available on loan are also to be noted.

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JULY 1950

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The Development of the Binocular Microscope

By F. C. WISE, F.R.M.S.

Little has been written regarding the Binocular Microscope since the year 1914, when the high-power models of both Beck and Leitz appeared on the English market. Several interesting papers appeared about that time, including one by E. M. Nelson in our *Journal*, where he describes his experience with one of the new instruments. In the year 1918, after extended use, a further paper was published in which he describes and compares the new instrument with the Greenough and the Wenham models. Since that date many new systems have been invented, and it was thought that a review of some of the more important systems employed from the earliest times to the present day would be of interest to members.

Many microscopists, even at the present day, appear to think that the sole object of binocular vision with the microscope is to obtain stereoscopic relief, and that any system not fulfilling that condition is an unnecessary expense. Stereoscopic relief is of much value in low-power work where the object is of appreciable thickness, as, for instance, in dissecting and in the study of pond-life with low and medium powers, and although it is possible to view bacteria in tissue stereoscopically it should be borne in mind that stereoscopic vision with the microscope is only obtainable at the expense of aperture as will be explained later.

The outstanding advantage of the binocular is the increased comfort it affords, coupled with the ability to work for long periods without discomfort or fatigue. Furthermore, many workers experience an increased perception of detail and of colour values. With all forms of binoculars some convergence of the eyes is necessary to combine the two images, and this may give a subconscious impression of solidity even when no actual stereoscopic relief is present.

The earliest binocular microscope of which we have any record dates from 1671 when Chérubin d'Orléans, in his book *La Dioptrique oculaire*, described his instrument, which had an adjustment for the interpupillary distance of the observer. It is figured in his later work, *La Vision Parfaite*, dated 1677.

This instrument had paired objectives of 1 in. focus, 16 in. tubes, and Campani eyepieces, thus giving an inverted pseudo-stereoscopic image. The principles of stereoscopic vision were not fully understood at that time. Nevertheless, the remarkable fact remains that the author, in his books, had expressly recommended systems giving erect images for the monocular compound microscope. Had he used for his binocular either his favourite erecting system, or substituted his compound eyepieces by the simple concave lenses in common use at that time, the instrument would have rendered an ortho-stereoscopic image. Under these conditions he could not have failed to observe the superior spatial effect, even if he were unable to account for it. No additional information regarding this binocular can be found, except that the instrument was figured later by Zahn with Campani eyepieces, and also that a microscope of this type was in the Nachet collection. However, since in those days no legal protection was afforded to inventors, optical designers were more secretive at that time than at the present day, and it is conceivable that d'Orléans actually made a binocular with his favoured erecting system, but preferred to keep it secret rather than allow it to be copied by all and sundry. If so he has robbed himself of the credit for the design of the first erecting ortho-stereoscopic binocular. Pointed remarks regarding one's rivals were a feature of the literature of the time and d'Orléans found occasion to criticize certain drawings which had appeared in a recently published book by Robert Hooke, remarking that such mistakes as appeared there would not have occurred had the observer used a binocular such as his own. Hooke, in his reply, admits errors in certain of his illustrations, which, he says, were occasioned by his graver, but retorts by asking what discoveries had been made by d'Orléans with his binocular, more than had been made before with the monocular, a subtle question, and one which, as Mr Nelson remarked, is asked about binoculars at the present day. Fig. 1 shows the optical system of the Chérubin d'Orléans binocular.

We pass on for 170 years before any developments of note take place. In the year 1838 Charles Wheatstone, Professor of Experimental Philosophy at King's College, read his paper on binocular vision before the Royal Society. From that date the stereoscope leapt into favour, and provided an incentive to all microscope manufacturers to produce a stereoscopic microscope. A few of those manufactured were successful, but some gave a pseudo-stereoscopic image.

Before proceeding to describe these systems, it may be well to make a few remarks on stereoscopic relief. Stereoscopic vision is only possible because each eye sees a slightly different representation of a near or comparatively near object. When using a microscope with a single objective the right-hand side of the objective sees a slightly different picture of the object from that which the left-hand side of the objective sees.

Binocular microscopes may be divided into four main categories;

(1) Those in which the pencil of light emerging from a single objective is divided geometrically, and which produce an inverted and reversed image. Example: the Wenham.

(2) Those in which the pencil of light emerging from a single objective is divided geometrically, and which by a series of prisms produce an erect image. Example: the Stephenson.

(3) Those in which the pencil of light emerging from a single objective is divided physically. Example: any modern high-power binocular.

(4) Those employing twin objectives and which produce an erect image.

Of these four categories it is only the first which requires a crossing over of the two tubes, if one disregards certain binocular eyepiece attachments. If the tubes were not crossed over the image produced would be a pseudo-stereoscopic one, in which raised parts of the object would appear as hollows and hollows as raised parts. The essential is that the left and right Ramsden disks shall appear as in Fig. 2, and not in the reverse order.

According to the late Mr E. M. Nelson, from whose scattered papers I am indebted for much that follows regarding early instruments, the first successful binocular was that devised by Prof. J. A. Riddell of New Orleans in 1851, a description of which was published in the *Quarterly Journal of Microscopical Science* for 1854.

Fig. 2 shows the optical system. The two upper prisms were situated above the eyepieces, the inclination of the two lower prisms could be varied, and the tubes adjusted to correspond to the interpupillary distance of the observer. The aperture of the objective was halved, the pencil of light emerging being divided geometrically. It had convergent tubes and could only be used upright. The image was ortho-stereoscopic and erect. No crossing over of the

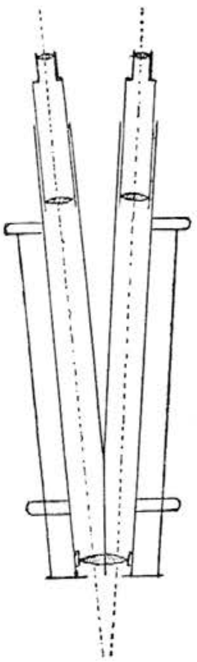

Fig. 1.

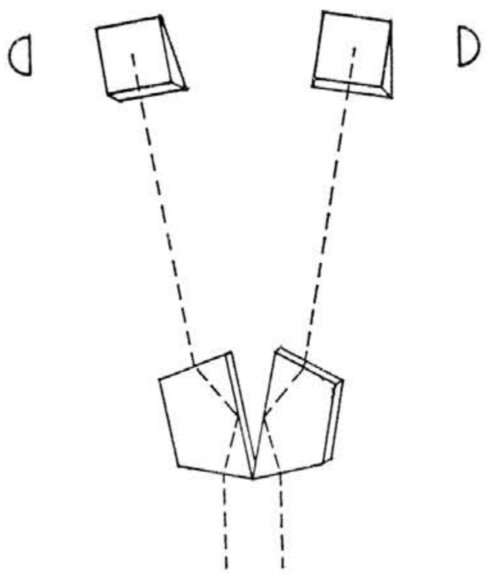

Fig. 2.

tubes was required. The shape of the Ramsden disks is shown in the figure. The Ramsden disk is the image of the aperture of the objective in use, and it will be noticed that the aperture vertically is twice as great as that horizontally, in consequence of which, structure such as striation just visible in a horizontal plane will be invisible in a vertical plane. This peculiarity is common to all binoculars in which the pencil of light emerging from the objective is divided geometrically.

Fig. 3 shows a form introduced by Nachet in 1853. It employed parallel tubes and separation was effected by movement of the tubes together with the two large prisms, the aperture was halved. Used with low powers it was said to give a highly satisfactory image, but the mechanical arrangement for the separation was not sufficiently precise to enable it to be used with high powers. The image was inverted and reversed and the necessary cross-over was effected by reflexions.

Fig. 4 shows Wenham's first binocular of 1860. It employed an achromatic prism and cross-over was effected by refraction from the upper surfaces of the prism. It had convergent tubes and separation was effected by alteration of tube length. The image was inverted and reversed, and the aperture was halved.

Fig. 5 shows the second binocular of Wenham that appeared the same year, and was described in the *Transactions of the Microscopical Society*. This instrument has enjoyed enormous popularity amongst amateurs from the time of its introduction. Wenham was optical adviser to the firm of Ross, and in addition to supplying new instruments embodying the prism the firm undertook the conversion of existing monoculars of their own make. Vast numbers

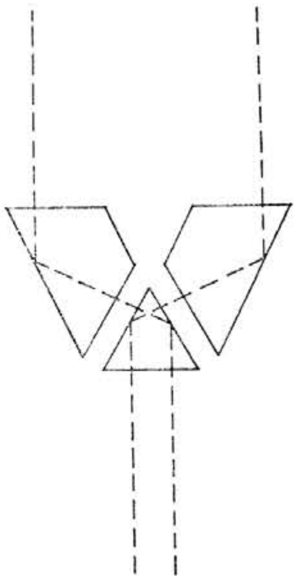

Fig. 3.

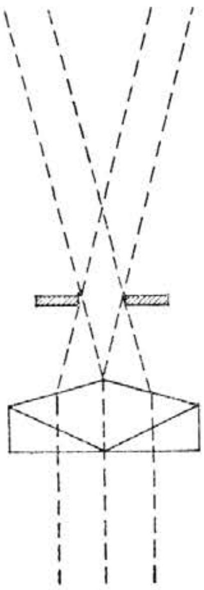

Fig. 4

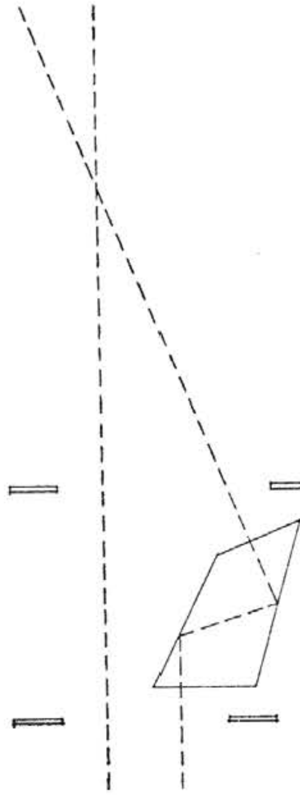

Fig. 5.

of these were converted. Wenham is said to have refused to take out patent rights, and the instrument was soon being manufactured by all the British makers, large and small, a few being sadly inefficient.

This binocular gives an inverted and reversed ortho-stereoscopic image. The aperture is halved, the pencil of light emerging from the objective being divided geometrically. It may here be remarked that it is sometimes of advantage not to push the prism right home, so that rather more than half the aperture is employed in one tube and rather less than half in the other, the mirror being adjusted to give equality of illumination. The tubes converge and the interocular distance is variable by alteration of tube length.

It can be used stereoscopically with a limited range of objectives, say from a 2 in. up to a $\frac{1}{6}$ in., or apertures of N.A. 0·15 to N.A. 0·90. Mr Nelson remarked that it was at its best with a $\frac{2}{3}$ in. or low-angled $\frac{1}{2}$ in. He put the upper limit of aperture at about N.A. 0·50, being dissatisfied with anything short of a strictly critical image, but deplored the fact that a larger prism could not be fitted to enable him to use the 12 mm. apochromat, a lens with an exceptionally large back component. Little if any stereoscopic effect is present with objectives over 2 in. focus as the angle is too small. High-power objectives are said to be best mounted in short mounts, so that the back lens is as close as possible to the prism. With apertures such as N.A. 0·90 there is of course some degradation of the image, and unless eyepieces magnifying at least ten diameters are employed part of the field is obscured. Wenham recognized this, and attempted to overcome it by actually mounting the prism inside the mount of a high-power objective. Dr N. E. Brown made use of the Wenham with a $\frac{1}{12}$ in. oil immersion objective when studying diatoms, but admitted that little more than half the field was illuminated under each eyepiece. Few would consider such an image a satisfactory one. Subject to these limitations the Wenham is a highly satisfactory instrument which has held its place for nearly ninety years. The reason for its popularity is not far to

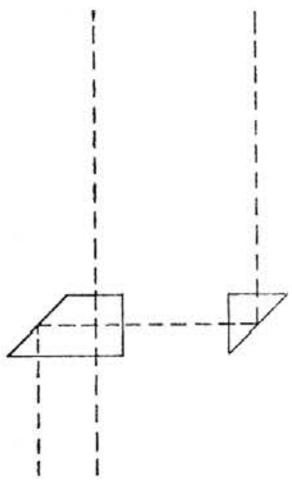

Fig. 6.

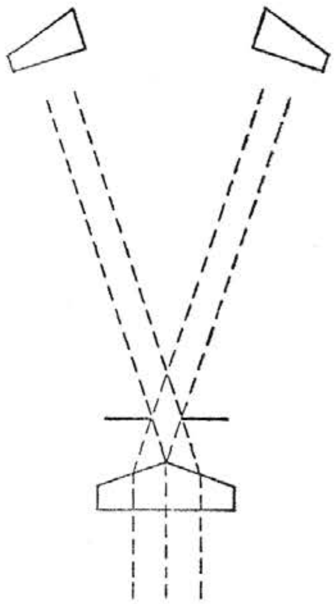

Fig. 7.

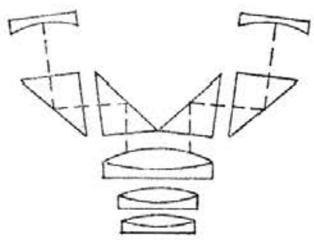

Fig. 8.

seek, the image in one tube is unimpaired, and slight imperfections in the other due to the prism do not materially affect the resultant combined images. By a touch the prism can be displaced and the instrument used monocularly with the full aperture of the objective. In the bar models a short monocular tube can be substituted for use with short tube objectives.

The next two systems are due to Nachet.

Fig. 6 shows a very simple design, but the difference in the length of the two optical paths is too great for it to be of practical value.

Fig. 7 is from a set of prisms lent me by Mr P. K. Sartory. Here the central prism resembles that of the Wenham no. 1, but is not achromatized. The cross-over being effected by refraction, colour is introduced due to dispersion, this however is compensated by a pair of prisms of similar dispersion placed above the eyepieces.

The system of prisms in Fig. 8 is due in the first instance to Prof. J. A. Riddell of New Orleans, who described his instrument in the *Quarterly Journal of Microscopical Science* for 1854. He recommended the use of this system for low-power work without any eyepieces, under which condition the image would be erect and ortho-stereoscopic. The system came under notice again in about 1874 as Nachet's binocular erecting dissecting microscope as used by Dr Carpenter, who thought highly of it and appreciated the long working distance. Concave lens eyepieces were used and it thus gave an erect ortho-stereoscopic image. It was fitted with a 1 in. objective of $\frac{3}{4}$ in. clear aperture. Interocular adjustment was effected by a movement of the outer pair of prisms and the tubes. The time was now ripe for the introduction of an attachable eyepiece to convert the monocular into a binocular at will.

Fig. 9 shows Tolles system introduced in the U.S.A. in 1864 or 1865. It was made in this country by Ladd. The prism arrangement is essentially the

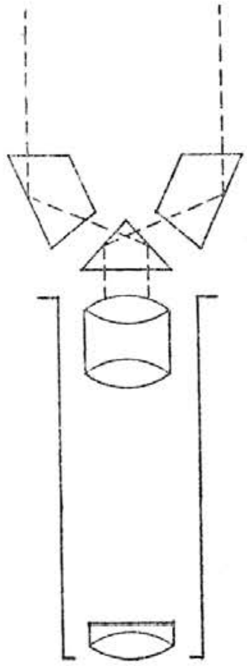

Fig. 9.

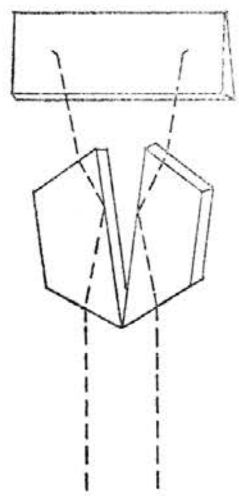

Fig. 10.

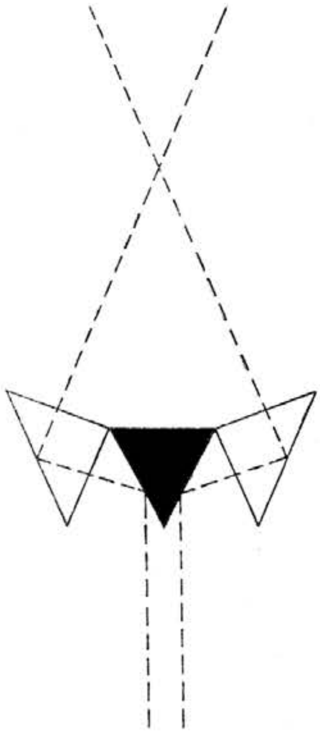

Fig. 11.

same as that of Nachet in Fig. 3. It differs, however, from all the preceding systems in that whereas with those the pencil of light is divided immediately above the objective, in this attachment it is divided at a point nearer the primary image formed by the objective in conjunction with a series of lenses.

Fig. 10 shows the system devised by J. W. Stephenson, a gifted amateur optician, and by profession an actuary. It is to Stephenson with his exceptional mathematical ability that we owe the invention of the homogeneous immersion system which he communicated to Prof. Abbe. This binocular is described in the monthly *Microscopical Journal* for 1870. Although invented independently the system is essentially the same as that of Riddell, whose priority Stephenson acknowledged. The instrument is of more convenient form than that of Riddell, the prisms are fixed and separation is effected by alteration of tube length. It has an upright stage, inclined converging tubes, and gives an erect ortho-stereoscopic image. For high powers the lower pair of prisms made to smaller dimensions were mounted inside the objective mount. This instrument has

Horizontal

deservedly enjoyed great popularity for dissecting and for the mounting of foraminifera and diatoms.

Fig. 11 may interest the petrologist. For various reasons existing binoculars were not entirely satisfactory with Nicol prism analysers, and an alternative was suggested by Ahrens. A prism of black glass is placed immediately above the objective with its hypotenuse upwards. The sides of the prism are ground to an angle of 57° to the axis of the objective, which is approximately the angle of polarization. Light passing through a suitable rotating polarizer under the object is analysed by reflexion from the sides of the black glass

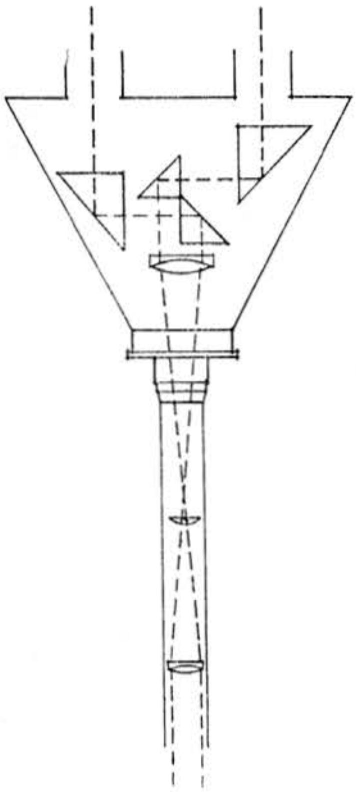

Fig. 12.

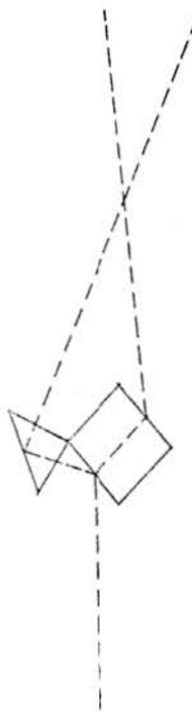

Fig. 13.

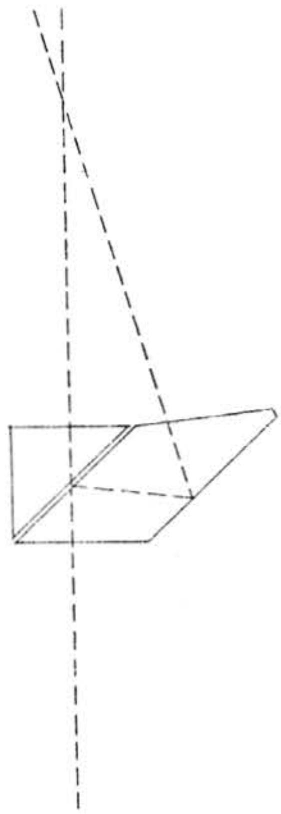

Fig. 14.

prism above the objective. Cross-over is effected by a pair of right-angle prisms. The system is described in the *Journal of the Royal Microscopical Society* for 1889.

Fig. 12 shows a stereo-attachment invented by Oscar Heimstadt and made by Reichert in 1921. In this attachment, owing to a series of lenses, the primary image is formed by the objective at a much less distance than usual. This primary image is then observed by a stereo-microscope consisting of another objective, the two eyepieces and the prisms effecting the division of light.

That completes the review of those binoculars in which the pencil of light emerging from a single objective is divided geometrically and we pass on to those in which it is divided physically.

Soon after the introduction of the Wenham prism in 1860 the firms of both Powell and Lealand and Ross constructed prisms suitable for use with the highest powers and utilizing the full aperture of the objective made to be interchangeable with the ordinary Wenham prism, having in mind to retain the advantages of binocular vision without any stereoscopic relief.

Fig. 13 shows the high-power non-stereoscopic prism of Powell and Lealand introduced in 1865. It will be seen that part of the light passes by refraction through the right-hand prism to the left-hand tube, and the rest passes by reflexion from the first surface of the same prism to a second, whence it is reflected to the right-hand tube. The weak point in this system is the very unequal illumination in the two tubes, approximately six to one.

Fig. 14 shows the Wenham high-power prism introduced by Ross in 1866. This consists of two prisms separated by a substratum of air, part of the light passes through without deviation to the right-hand tube, while the remainder is reflected from the two surfaces nearly in contact to the left-hand tube. The makers claimed that there was equal illumination in both tubes, but Mr Conrad Beck states that the difference was three to one. Very careful adjustment of the two prisms was necessary and Dr Carpenter states that his prism was personally adjusted by Wenham.

The cross-over in the last two systems was not an essential, the prisms were constructed thus to make them interchangeable with the Wenham stereoscopic prism, and by modification they would have been equally effective with parallel tubes. While the designers of the last two systems made no such claim numerous observers expressed their conviction that these instruments rendered at times stereoscopic relief. The explanation was not provided for some years when it was pointed out by Prof. Abbe in connexion with the next system.

Fig. 15 shows Prof. Abbe's stereoscopic eyepiece introduced by the firm of Carl Zeiss in 1880. Prisms *A* and *B* are separated by a substratum of air which in the earlier models gave rise to a double image. This film was said to have been reduced eventually to a thickness of 1 μ. Owing to the difference in the length of the two optical paths dissimilar eyepieces were provided. Separation was effected by a lateral movement of the right-hand prism and eyepiece, the tubes were convergent and there was two and half times as much light in one tube as in the other. Half-moon caps were provided for the eyepieces, by the use of which, Prof. Abbe pointed out, the Ramsden disks were bisected, and by assisting the eyes to look through the outer edges of the eyepieces stereoscopic relief was obtained. He also pointed out that with strictly central vision there was no stereoscopic relief, while if one separated the eyepieces and looked through their inner edges a pseudo-stereoscopic effect was obtained. In practice it will be found that with this and other systems using convergent tubes the use of half-moon caps is not a necessity as the same effect is readily obtained by a slight movement of the head towards the microscope. It should be emphasized here that bisection of the Ramsden disks whether by half-moon caps or otherwise also halves the aperture of the objective.

Fig. 16 shows a system embodying a new feature which forms the basis of all modern high-power binoculars, namely the Swan cube. This binocular was the invention of Mr F. E. Ives and was described by him in a paper read before the Franklin Institute of Philadelphia in 1902. The Swan cube consists of a pair of right-angle prisms cemented by their bases, one of which before cementing has been given a coating of silver of such a thickness that it transmits half, and reflects half the light. This was the first single objective binocular to utilize the full aperture of the objective with equal illumination in both tubes. Ives also appears to have been the first to make use of the extended glass prism to equalize the optical paths in a binocular microscope. In this instrument the right-hand prism can be tilted and the eyepiece independently adjusted to vary the interocular distance, the eyepieces converge and by a slight movement of the head one can obtain ortho-stereoscopic, non-stereoscopic or pseudo-stereoscopic images.

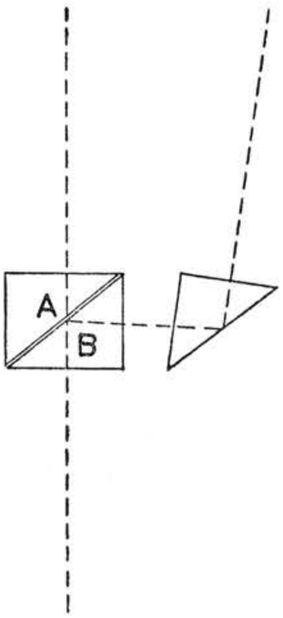

Fig. 15.

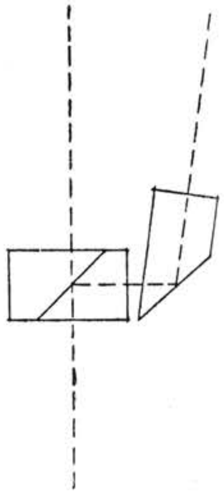

Fig. 16.

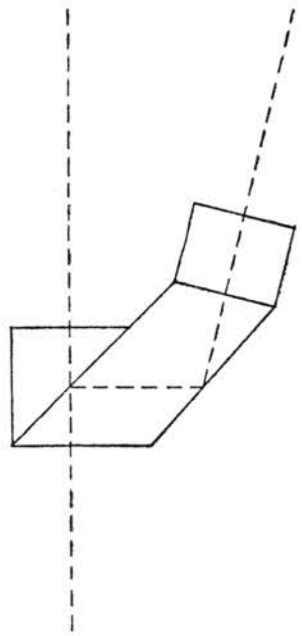

Fig. 17.

Fig. 17 shows the form introduced by our late Honorary Member, Mr Conrad Beck, in 1913. This was another case of an independent invention of a previously published system. It will be seen that this design differs in no material form from that of Ives, and on it being pointed out, Mr Beck acknowledged Ives priority. The tubes converge and the interocular distance is controlled by alteration of tube length. Although a binocular employing parallel tubes introduced about the same time proved to be popular, Mr Beck stoutly defended the converging tubes, contending that the eyes naturally converge for near objects. Those who favour parallel tubes contend that the eyes should be relaxed when using the microscope, under which condition the image is situated more or less at infinity, and that therefore the axes of the eyes should be parallel.

Fig. 18 shows the system invented by Dr Jentzsch in 1913 and manufactured by Leitz. This and the previous system were described in the *Journal of the Royal Microscopical Society* for 1914. Platinum was used as the reflecting surface in the Swan cube instead of silver resulting in a complete absence of colour in the transmitted beam. The interocular distance is altered by separation of the two outer prisms together with the eyepiece tubes which are parallel. This design is the basis of the majority of binoculars manufactured at present. Note the elongation of the right-hand prism to equalize the optical paths, and the fact that there are but two reflexions on each side.

Fig. 19 shows the system invented by Siedentopf about 1924, and made by Zeiss as the Bitumi attachment. Adjustment for interocular distance was made by rotation of the left-hand prism. This method has the advantage of involving

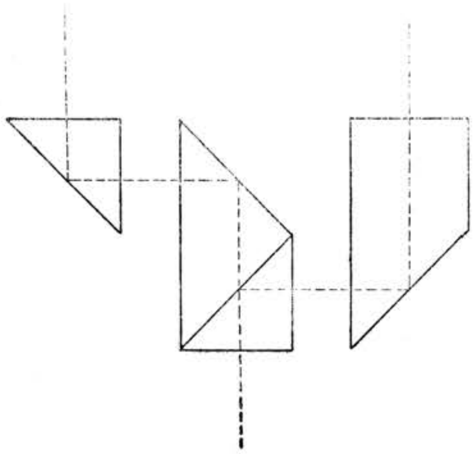

Fig. 18.

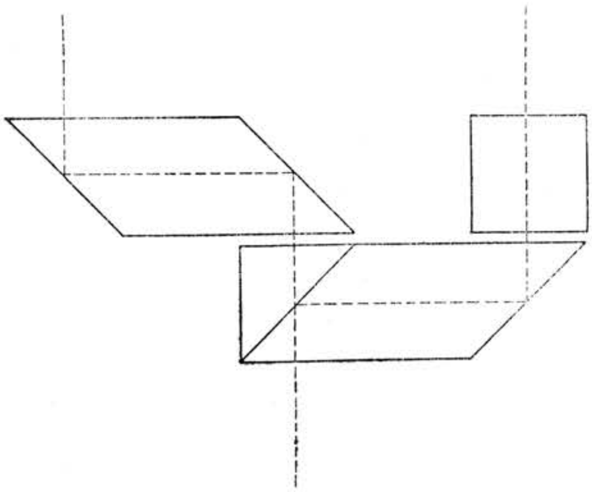

Fig. 19.

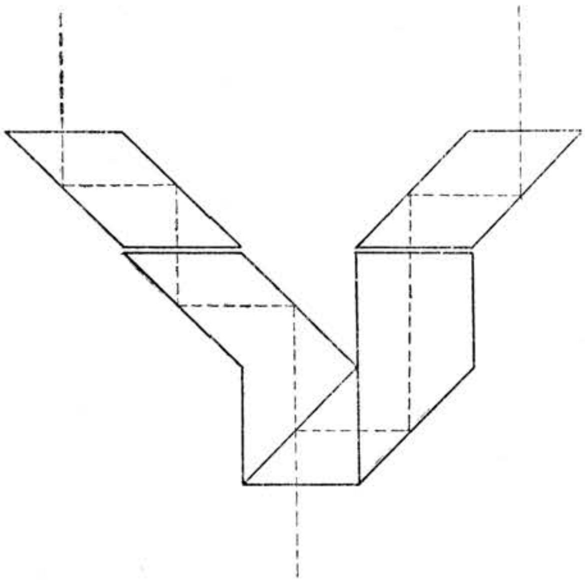

Fig. 20.

no alteration in tube length. Parallel tubes are used. When used as an attachment to the monocular an achromatic concave lens is provided in the mounting below the prisms to compensate for the increased tube length. The extra magnification thus afforded may or may not be of advantage, but the preferable form for the binocular is that in which it is interchangeable with the monocular body and gives the same magnification.

Fig. 20 shows another system introduced by Zeiss about 1926. Here again interocular adjustment is made by rotation of the uppermost pair of prisms involving no alteration in tube length. In spite of the fact that there are four reflexions on each side no deterioration of the image can be detected when compared with the image in the interchangeable monocular body. In common with all Continental models parallel tubes are used.

Fig. 21 shows a system due to Oscar Heimstadt and made by the firm of Reichert in 1923 embodying a device to emphasize stereoscopic relief. It follows the Jentzsch form of 1913, but the reflecting film in the Swan cube is in the form of an optical wedge, the left half reflecting less and transmitting more light, while the right half reflects more and transmits less. In the figure the more intense rays are represented by broken lines, and the weaker rays by dotted lines. It will be seen that neither ocular used alone would render

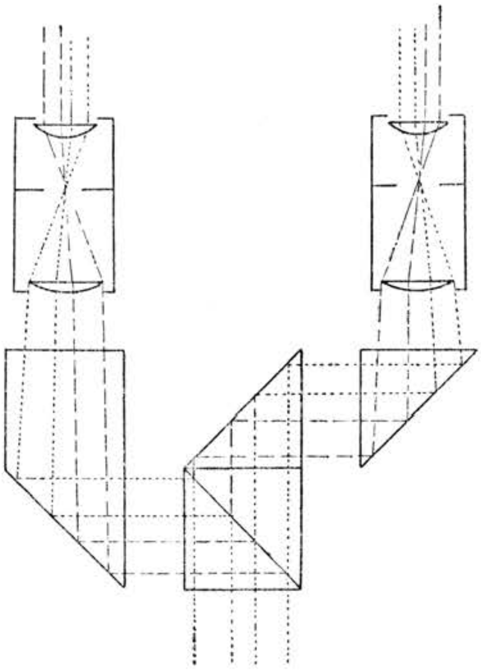

Fig. 21.

a satisfactory image, but each of the two images possess parallactic differences, and these blend producing a stereoscopic image when the interocular distance is equal to the interpupillary distance.

Other methods of enhancing stereoscopic relief with the high-power binocular have been shown at our Club meetings. Mr F. E. J. Ockenden exhibited one in which adjacent half-moon red and green disks were placed in the substage stop ring, and green and red disks over the respective oculars. Mr J. J. Jackson (1948) exhibited a somewhat similar method using disks of Polaroid film with opposite orientation. Either of these two systems reduces the aperture.

In his book, *The Use of the Microscope*, Belling has suggested that a low-power dissecting binocular giving an erect image and utilizing the full aperture of the objective but without any stereoscopic relief might be of value, but gave no design. Fig. 22 shows a possible design for the purpose indicated. A simpler design by Mr B. Taplin is shown in Fig. 23. Fig. 24 shows a design by Mr A. E. McClure for a high-power binocular, in which a device is embodied to give enhanced stereoscopic relief at will. It follows the Jentzsch design except that the path equalizer has been added to the Swan cube instead of to the right-hand prism. A shutter is provided in the mounting, which can be operated at will, to bisect each of the two pencils emerging from the Swan cube. Theoretically, this device would appear to be only wholly effective with

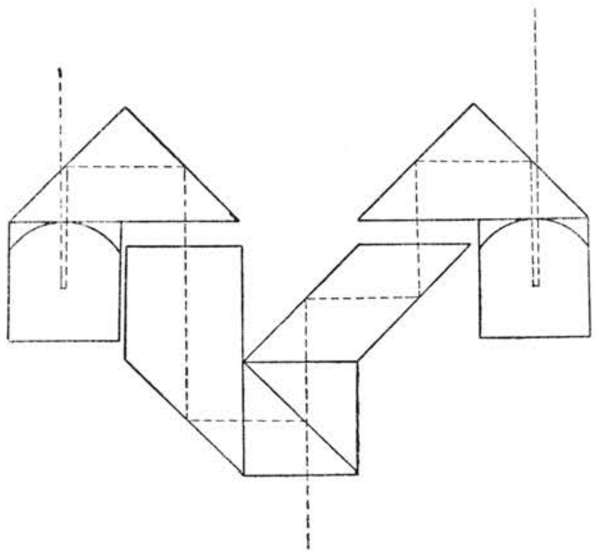

Fig. 22.

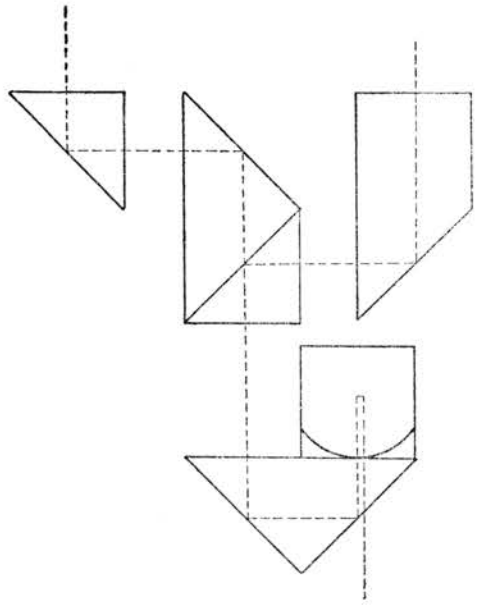

Fig. 23.

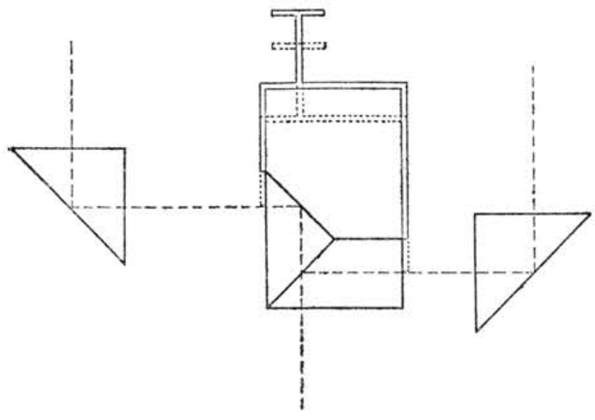

Fig. 24.

low-power objectives as with high powers the rays will have partly intermingled before reaching the point of bisection, the objective, however, screws into a mount almost in contact with the Swan cube partially offsetting the above objection.

In recent designs inclined eyepieces are very much in evidence, but except to those whose work is with wet preparations, their value is open to question. An instrument without an inclination joint and with the eyepieces set at an immovable angle has certain disadvantages, one being that it is not possible to use such an instrument for photo-micrography on a horizontal optical bench, except with a vertical camera.

Fig. 25 shows two designs for the extra prism necessary for the use of inclined eyepieces, the first that of Zeiss and the second that of Cooke, Troughton and Simms.

Fig. 26 shows a design by Mr A. E. McClure for a binocular with inclined eyepieces, giving an erect image, and with a means of giving enhanced stereoscopic relief at will. The main dividing prisms and the shutter are the same as in his previous design, but under each eyepiece, which in this instance is inclined, is a somewhat complex roof prism, which by means of four more reflexions erects the image.

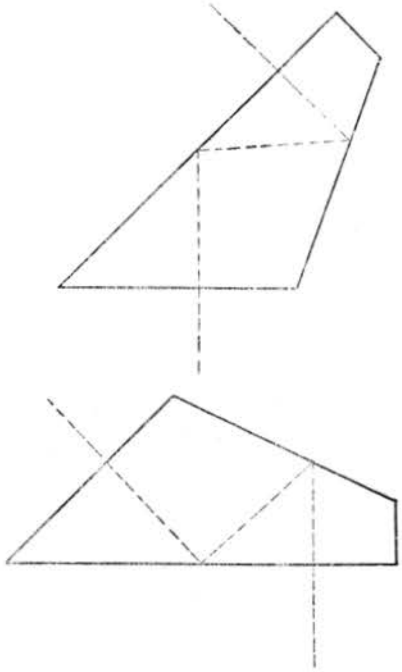

Fig. 25.

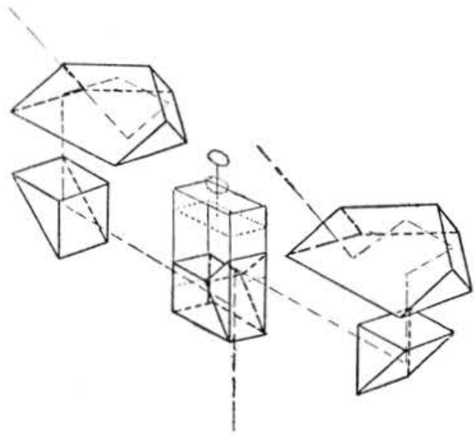

Fig. 26.

The Lihotzky image erecting binocular stereo attachment was introduced by Leitz about 1925. Below the prisms, which are the same as those shown in Fig. 18, is a tube containing two spaced achromatic lenses. These, in combination with the Swan cube, produce within the system two images of the posterior focal plane of the objective, one of which, by means of a shutter, may be bisected at will. Thus the emergent rays from the objective proceeding to one eyepiece may be halved, while the other eyepiece makes use of the full aperture of the objective. The two lenses mentioned also serve to erect the image. It was claimed to give a stereoscopic effect under the highest magnifications without prejudice to the resolving power of the objective, provided that the object was one presenting perceptible differences in depth.

Finally we come to those binoculars employing twin objectives. These are necessarily only suitable for comparatively low-power work, but they render a truer stereoscopic image than any other form of binocular.

Although perhaps not microscopes in the strictest sense, the next two systems are too valuable to omit.

Fig. 27 shows the simple head band type of magnifier, giving a magnification of about three diameters, which will be found extremely efficient and comfortable in use.

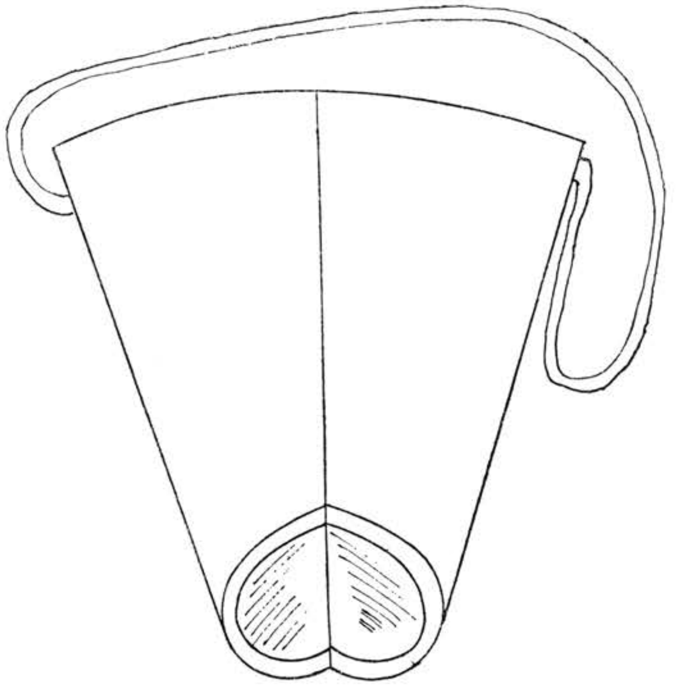

Fig. 27.

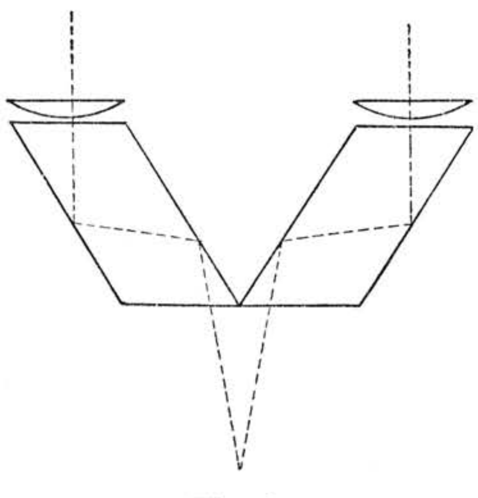

Fig. 28.

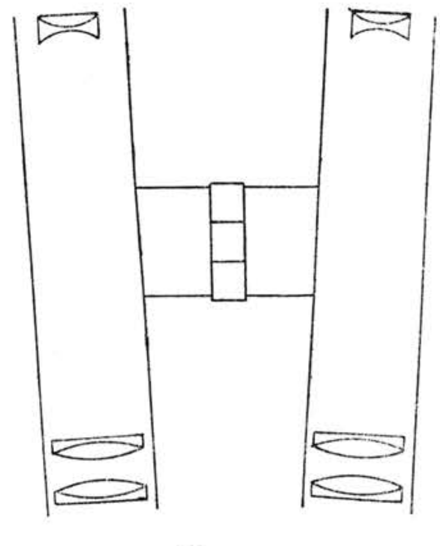

Fig. 29.

Fig. 28 shows the prismatic magnifier as made by many opticians with interchangeable lenses of different magnifications.

Fig. 29 shows a form of binocular magnifier from the Leitz catalogue of 1907. It consists of a pair of Brücke lenses connected by a hinged joint. It gives an erect stereoscopic image and is quite efficient, although the field is small. It can be used either in the hand or supported on a stand and has a long working distance. Magnification is about four diameters.

Fig. 30 shows the form of Porro prism used in Dr Greenough's binocular dissecting microscope introduced by Zeiss in 1897. Fig. 31 shows a later design with more compact prisms. Dr H. S. Greenough was an American zoologist, who, soon after the introduction of the prismatic field glass, suggested to the firm of Zeiss that they should construct for him a binocular microscope on the same principles, using paired objectives and giving an erect stereoscopic image. Dr Czapski co-operated and the resulting instrument was a great success in spite of the fact that it has only been possible to employ objectives of low aperture and that the focusing of a plane object is only correct along the median line from back to front.

This instrument is at its best with magnifications of from 8 to 80 diameters. The most modern form with wide field eyepieces and inclined tubes is a highly efficient instrument both for dissecting and for the study of pond life. It should

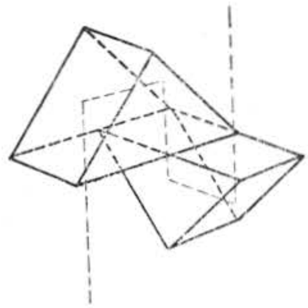

Fig. 30.

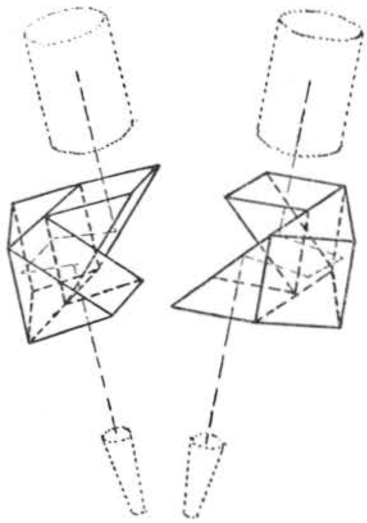

Fig. 31.

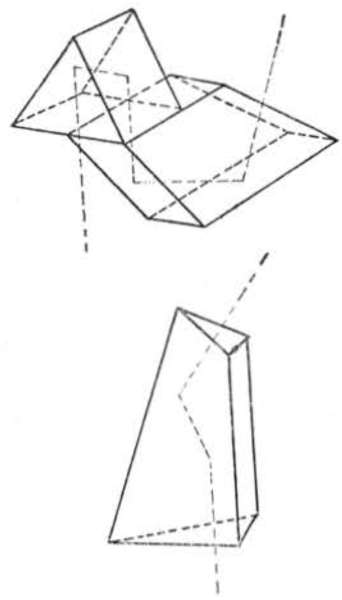

Fig. 32.

be fitted with an efficient dark ground system of illumination, and means provided for obtaining concentrated top light. For transmitted light as well as for dark ground the Akehurst (1923 and 1928) split mirror will be found of great advantage. Of recent years forms of this instrument have been introduced with parallel tubes, notably the low-power dissecting microscope of Messrs Watson.

Fig. 32 shows two forms of prisms which could be used in the construction of low-power twin-objective binoculars, each of which is calculated to give an erect image, and to be used with inclined eyepieces. The first is composed of two prisms, the upper of which is a right-angle prism reversing the image in a lateral direction, cemented to another inverting the image in a vertical direction. The second is a roof prism as used in a gun-sight telescope.

In conclusion it may be pointed out that a stereoscopic effect and a three-dimensional effect are not necessarily one and the same thing. A stereoscopic effect necessarily involves the use of two eyes, while a three-dimensional effect can be obtained with one eye accompanied by a movement of the head or a movement of the object.

It is possible to make use of this three-dimensional effect with the monocular microscope under certain well-defined conditions, involving the use of a large Ramsden disk. The Ramsden disk is the image formed by the eyepiece of the back lens of the objective or of the aperture to which it may be stopped down. Consequently objectives of low power and with large back components, when used with a low-power eyepiece, produce a large Ramsden disk. When this disk is equal to, or greater than, the diameter of the eye pupil, which may be said to average one-eighth of an inch, the eye can be moved about over the eyepiece or the object can be given some motion by means of the mechanical stage when a very striking three-dimensional effect will be observed. Of objectives the 36 mm. of Zeiss, the 12 mm. apochromat of Zeiss, and the 12 mm. Holoscopic of Watson, are each well adapted to show the effect. The matter was discussed at some length in a lecture delivered to the Photomicrographic Society by Commander M. A. Ainslie in 1916.

The author wishes to express his thanks to Messrs McClure and Hallam for kindly executing the diagrams from his rough sketches. It should be pointed out that certain of the designs figured are the subject of patents.

Summary

For low powers the Greenough, with its erect ortho-stereoscopic image, is almost indispensable if work is prolonged.

For medium powers the Wenham and Stephenson instruments are by no means obsolete, and possess the advantage of the stereoscopic rendering of objects, at the expense of some aperture, not possessed by the monocular.

For all medium and high-power work the high-power binocular will be found to possess an advantage over the monocular both in the comfort it affords the observer over long periods and in the better perception of detail. The limited amount of stereoscopic relief obtainable at the expense of aperture by approximation of the tubes is at any time available, and once seen the effect is not lost on separating the tubes and making use of the full aperture. Its one disadvantage is the absence of any means of shortening the tube length for thick covers. For thin covers a small correction can be made by partially withdrawing the eyepieces, and high-power dry objectives can be obtained with correction collars, but it is with that most valuable objective, the 8 mm. apochromat, that the absence of means of correction is most apparent. The only possible solution appears to be a Jackson tube-length corrector, and it is to be hoped that this may be eventually designed in a more compact form than at present.

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ALPHABETICAL REFERENCE LIST OF BINOCULAR SYSTEMS ILLUSTRATED BY TEXT-FIGURES

		CLASS				
Pencil of light emerging from single objective						
Divided geometrically						
Inverted and reversed image ...		1				
Erect image ...			2			
Divided physically						
Any modern high-power binocular ...				3		
Employing twin objectives (erect image) ...					4	
Date	Inventor or manufacturer	Text-fig. number				Text page
1880	Abbe, Prof. (Zeiss)			15		13
1889	Ahrens	11				10
1913	Beck, Conrad			17		13
1671	Chérubin d'Orléans (non-erecting)				1	7
1897	Greenough, Dr (Zeiss)				30, 31	19
1921	Heimstadt, Oscar (Reichert)	12				11
1923	Heimstadt, Oscar (Reichert)			21		15
1902	Ives, F. E. (Swan cube)			16		13
1913	Jentzsch, Dr (Leitz)			18		14
	McClure, A. E.			24		16
	McClure, A. E.			26		17
1853	Nachet	3				8
	Nachet	6				9
	Nachet	7				9
1874	Nachet (Prof. J. A. Riddell)		8			9
1865	Powell and Lealand			13		11
1851	Riddell, Prof. J. A.		2			7
1907	Schulze, E. (Leitz)				29	18
1924	Siedentopf (Zeiss)			19		14
1870	Stephenson, J. W.		10			10
	Taplin, B.			23		16
1864–5	Tolles	9				10
1860	Wenham	4				8
1860	Wenham (low power)	5				8
1866	Wenham (high power)			14		11
	Wise, F. C.			22		16
1926	Zeiss			20		14
	Head-band magnifier				27	18
	Prismatic magnifier				28	18

Illumination and Manipulation of Binocular Microscopes

By F. E. J. OCKENDEN, M.I.E.E., F.Inst.P.

The fundamental principles controlling the correct handling and operation of a microscope are, of course, applicable to monocular and binocular instruments alike. The use of the latter however may, sometimes, involve special problems which demand that closer attention be paid to 'setting up' than is normally necessary with an instrument of the monocular pattern.

Types of binocular systems

It will have been apparent from the foregoing pages that there are, broadly speaking, three designs requiring consideration. The first two comprise instruments which provide, inherently, stereoscopic vision, that is, those of the Greenough pattern, which consist essentially of two microscopes mounted side by side, each containing the erecting system which is essential if the formation of pseudoscopic images is to be avoided, and those in which the angular 'pick-up' of a single objective is divided into two portions by means of a prism system mounted in close proximity to the back lens, a pseudoscopic image being avoided by making the two beams cross over on their path from the objective to the eyepieces, as in the Wenham low-power instrument.

The third and most important class is that in which the whole of the objective aperture is available in each tube, the beam-splitting device consisting of a prism system such that approximately one-half of the light in the beam is transmitted to one eye by reflexion and one-half to the other by direct transmission. Examples are the Wenham high-power system and the various arrangements incorporating a 'Swan Cube' and manufactured by Watson, Beck, Zeiss and other leading makers.

This group may be yet further subdivided into two, since it includes both instruments in which the tubes carrying the eyepieces are parallel and those in which they are convergent.

So far as principle of operation is concerned the simplest of all binocular microscopes is, of course, the Greenough. The low-power low-aperture objectives to which its use is restricted precludes the necessity for any form of cover-glass correction, and the only serious problem encountered is the provision of a sufficiently high illuminating intensity when the instrument is used at the upper limits of its magnification.

Sources of illumination

Many modern instruments in this category have a small projection lamp built into them, situated either between the objectives or mounted on a projection slightly forward from them. In a recent 'Fenestration' model by Watson two sources of light are incorporated, one in each of the objectives and working on the vertical illuminator principle. By this means not only is shadowless lighting on the area being operated upon ensured, but even should one of the lamps fail sufficient light is available from the other to permit the continuation of the operation.

When no self-contained illuminator is available a lamp condenser or 'bull's eye', in combination with a low-voltage headlight-pattern lamp, will provide a beam of ample intensity. Since such a beam does not enter into the optical system of the microscope, the corrections of the condenser are of little importance, and therefore a simple plano-convex lens will give excellent results.

When used with transparent specimens illuminated from below, however, a difficulty arises, because the angle subtended by the microscope tubes calls for illumination by a double lighting system having a similar angle of convergency. This condition is often difficult, if not impossible, to obtain with the single small mirror usually fitted. The possibility of using either two lamps or a 'split' mirror has received consideration, but the simplest expedient is to construct the stage from a piece of finely ground glass.

The light source is then reflected on to the underside of the stage by means of the mirror, and the dispersion caused by the grinding spreads the light sufficiently to produce an even illumination in both tubes. An alternative arrangement is to place a piece of white card or matt opal below the object (which is then carried on a clear-glass support) and illuminate this white reflector from a powerful spot-light. An intense yet comfortable white background is readily produced in this way without that tendency to 'sparkle' which tends to be a characteristic of ground glass.

Interocular adjustment

The 'eye-pitch' or interocular adjustment is usually made by partially rotating the boxes containing the erecting (Porro) prisms, but when, as is sometimes the case, the whole of the prism system is mounted in a single box, the eyepieces only are traversed to and fro by means of a screw or pinion.

A strongly stereoscopic effect is, of course, obtained whatever the setting may be, but the actual amount is to some degree controllable in that the maximum is obtained when the eye-pitch is slightly less than that of the observer's pupils. If slightly greater then the degree of relief is somewhat reduced, but in no case can a pseudoscopic effect be obtained.

It has been pointed out by E. M. Nelson that the degree of stereoscopic relief observed with some specimens varies with their angular position in the field of view. This, of course, is true of many objects when seen with the unaided vision, but, unlike these, microscopic objects placed on the stage of the microscope may be oriented for viewing to the maximum advantage. Where a revolving stage is available, some very remarkable results can be obtained by its use.

As with all binocular microscopes, the limitations imposed on the observer by the presence of two eyepieces, which must be reasonably correctly spaced if comfortable vision is to be obtained, makes preferable the use of positive eyepieces. These may be either of the Ramsden or Kellner patterns. Not only are the relatively long eye clearances so provided of material assistance whilst the eye-pitch adjustment is being made, but they also permit full advantage to be taken of the wide field usually available in low-power microscopes, without at the same time making it necessary to place the eyes unduly close to the lens fittings.

Parallel or converging eyepieces

An interesting and debatable point applicable to all modern binocular microscopes is the relative desirability of parallel and converging eyepieces. The prism system of the Wenham instrument makes the use of convergent tubes a necessity, but all other forms, including in principle the Greenough, can be made in either way.

Much has been written on the subject, claims being made equally, either that the 'normal' reading distance of 10 in. or the 'infinite' setting of distant vision is the more usual and, therefore, the most restful to the eyes. It is the writer's experience that, for observers unaccustomed to the use of the microscope, who tend, therefore, to look down the tubes as though they are looking 'at' the object on the stage, the fusion of the fields formed by a converging system presents less of a problem than when parallel tubes are in use.

To the experienced microscopist, on the other hand, it appears to be largely a matter of habit, either arrangement being found satisfactory once it has become 'used to'. A rapid switching from one to the other, however, is not usually practicable on account of the eyestrain which sometimes follows.

An interesting feature of the use of the parallel system, and one also to which Nelson has drawn attention, though without offering any complete explanation, is the increase in apparent magnification which is so obtained. The reason would, in fact, appear to be that the image, instead of being seen on a plane which is mentally some 10 in. from the observer, is projected to infinity against the horizon. This can be clearly demonstrated by taking two similar eyepieces and, holding one to each eye, 'fusing' the fields whilst looking towards the sky or a uniformly illuminated surface, the tubes being held as nearly parallel as possible.

If the tubes, without losing the field registration, be then gradually converged to the limit which the eyes will stand, it will be found that the apparent size of the field will decrease with increasing convergence and vice versa. Although it is obvious that this can have no effect whatever on the actual resolution or definition obtainable, the effect, so far as the sense of dimensions is concerned is very real.

Brightness of visual field

It is an interesting fact that the two pencils of light which enter the right-hand and left-hand eyes respectively are not additive so far as the observer's sense of luminosity is concerned. The brightness of, as examples, the sky or a sheet of card appears the same whether viewed with either eye or with both, hence any optical system which splits the beam emergent from a micro-objective into two must necessarily reduce the apparent brightness of the visual field to at least half its original value.

When, moreover, the system employs a metallic transmission/reflexion film the actual amount of light appearing in each half of the instrument is often as low as 30%, i.e. at least one-quarter of the beam is totally lost, partly of course at the surfaces of the prisms and partly in the film itself.

It has been shown that, at high magnifications, even with a monocular, the cumulative effect of the loss of light which takes place at the multiple lens faces and the diminutive size of the Ramsden circle is such as to reduce the brightness of the field to some $\frac{1}{2}$% of that of the illuminant, a reduction of 200 times. The additional losses taking place in a high-power binocular system can cause a yet further reduction of three times a total diminution of 600.

Because of these factors, the brightness of the field obtainable with a light source of average intensity is generally quite inadequate, and illuminants of greater brightness than usual become essential. Much has been written on the danger of using too high a field brightness during prolonged microscopical research, and there is probably a good deal of justification for such warnings when the use of only one eye is envisaged.

When, however, both eyes are in use simultaneously the employment of as high an intensity as is practicable has much to recommend it. It is but rarely that the brightness of, for example, a newspaper held in full daylight (0·01 lumen per sq. mm.) is likely to be exceeded and the increase in visual acuity is considerable.

The conventional 'opal' globe is generally unsuitable and insufficient, but frosted (Pearl) lamps having ratings up to 100 W. can be used with safety, provided, that is, the lamp-house will stand up to the considerable heat dissipation. Köhler illumination where the full intensity of the actual light source is employed may, however, be dangerously brilliant unless some diffusing medium be interposed, but if the work is such that deep colour screens are required, the employment of this form of illumination becomes almost a necessity.

Independent eyepiece focusing

Two adjustments which even experienced workers sometimes find difficult to carry out with complete satisfaction are: the correct setting of the 'independent' eyepiece focus, and the inter-pupillary distance or eye-pitch.

With regard to the first of these, a primary essential is, of course, that the two eyepieces are, in fact, propeıly matched. Where Huygenian oculars are concerned it is highly desirable that they should be purchased in pairs, but for the more complex patterns, such as the Compensating, Telaugic, Holoscopic and Orthoscopic, the computations are so exact, and the accuracy of assembly so rigorous, that any two nominally similar units of the same make may safely be assumed to be identical so far as their use in a binocular is concerned.

A special difficulty does, however, arise in those instances such as the Holoscopic, where the degree of compensation is variable. A simple way of pairing the adjustments is to place the two eyepieces on the table side by side and then run the finger lightly over the point of contact. Any slight difference in level is immediately detectable and similarity of adjustment so ensured.

Where a prolonged course of work by a single observer is to be undertaken, it is frequently desirable to set the eyepiece focusing adjustment 'once for all';

this is best carried out with a low-power objective, a 1 or 2 in., and the highest powered pair of eyepieces available, for example, $\times 10$ or $\times 15$. Such a combination, whilst relatively insensitive to object-glass focus, is highly sensitive to eyepiece focus, i.e. mechanical tube length. At the same time the high power of the eye lenses ensures that the accommodation of the normal eye is comparatively ineffective, thereby ensuring that any difference in the focal settings is not taken up in a way which may ultimately result in considerable eyestrain when lower powered eyepieces are in use.

Unless it is known that the observer's eyes are a perfect match each tube must be tested with its relevant eye. The insertion of a piece of black card or a black cap over the eyepiece not in use is better than any attempt at closing each eye alternately, since the latter technique is extremely tiring and may result in small muscular changes taking place which can cause considerable confusion.

A simple way of finally checking the similarity of a pair of eyepieces is to interchange them. In the event of there being any dissimilarity they may be marked R and L respectively and always used in these positions. Inconvenience may, however, arise if similar and dissimilar pairs are to be used in quick succession, and it is usually more satisfactory to return them to the makers for adjustment.

Another important source of eyestrain can be that resulting from imperfect registration of the two fields. An accurate way of checking this is to focus a low-power objective on a small black circle, such as is often used to indicate the centre of a diatom slide. By suitably choosing the powers of the objective and eyepiece the circle can be so enlarged that it does not quite fill the field as seen in one of the tubes. Its appearance in the second should then be an exact replica of that in the first.

The most objectionable prism errors are those causing the images to appear either relatively high/low (skewed) or divergent, since either of these defects can result in serious eyestrain.

A small amount of convergency, that is, the circles appear set relatively slightly inwards, is not serious, being in fact considered by some to be desirable. It should not amount to very much, however, and if excessive, or any of the other defects are found, the microscope should be returned to the makers.

Inter-pupillary distance

The best working setting for the eye-pitch adjustment depends largely on the type of observation which is to be carried out and the magnification employed, but it is nevertheless usually desirable first to determine with some exactitude the eyepiece setting which agrees precisely with the observer's interocular distance.

This is best carried out by observing a 'thick' object with low-power objectives, so avoiding the formation of a Ramsden circle which is small compared with the diameter of the normal pupil, about 3 mm. Precise alinement between pupils and eye-points can then be checked by each or all of the three following methods:

(*a*) By increasing and decreasing the tube separation until the position is found at which the illumination of the field is a maximum. This represents the required separation, and its value in millimetres can be noted on the scale usually attached to such adjusters.

(*b*) Under the foregoing conditions the stereoscopic effect (provided that the head be held absolutely still) should be nil, i.e. neither stereoscopic nor pseudoscopic. If the former be present the tubes are too close together, if the latter, too far apart.

(*c*) (Applicable only to parallel tubes.) On gradually withdrawing the head from the microscope, without losing the 'focus' of the object, the effective field will become smaller and smaller, finally appearing as a blurred circle some few millimetres wide with a tiny fraction of the object in focus in the centre. The two fields, however, should still coalesce; if they tend to separate either the eyepiece pitch is incorrect or the prism adjustments are faulty; the latter possibility may be checked in the manner indicated earlier.

As explained in the section dealing with binocular instruments in general, closing the eyepiece separation to a distance somewhat less than the inter-pupillary distance will result in the formation of a stereoscopic image, even in microscopes which are not specifically designed with this in view. The extent of the perspective so obtained will depend both on the nature of the object and the total magnifying power employed, that is, on the diameter of the Ramsden circle. If the object is 'deep' and the Ramsden circle is, as the result of using low-powered eyepieces, large, the images formed are extremely satisfactory and an exaggerated perspective is unlikely.

When, however, the Ramsden circle is large as the result of the use of a wide-aperture lens the foregoing is not necessarily true, and any attempt to close the tubes to such an extent that 'half-circle' conditions obtained may, in the case of objects of appreciable thickness, result in a grossly distorted picture being seen. Three-quarter or even four-fifth circles (requiring only a small amount of closing of the tubes) are preferable. Not only does this setting give the observer greatly increased comfort and freedom with regard to the exact positioning of the head while making observations, but the reduction of the effective N.A. which results from the partial masking of the Ramsden circle (the eyepiece image of the back lens of the objective) also becomes of less importance.

Tube-length considerations

The optical arrangement of a high-power binocular is, of course, similar to that of a monocular so far as the lens system is concerned, but the problem of tube-length (or cover-glass) correction assumes a new degree of complexity. In most cases it is not possible to provide any means for altering the tube length mechanically, neither is it always practicable to include the whole of the prism system in the limited space of 170 mm. which is the standard distance to which most modern objectives are corrected.

It is usual to correct for any appreciable deviation from this quantity by interposing in the optical system a correcting (negative) lens. This, however, also increases the effective magnifying power of the eyepieces, the extent depending on the power of the lens and its distance from the back lens of the objective, being a minimum when the two are coincident. Zeiss at one time designed their high-power objectives for long tube lengths by reducing the curvature of the back lens instead of decreasing the separation between the components.

Whilst such devices are satisfactory as fixed adjustments they offer no provision whatever for making those small changes which are essential if dry high-power objectives are to perform at their best on objects mounted under varying thicknesses of cover-slips. For this reason the provision of a correction collar on those objectives, particularly the 4 and 8 mm. which are to be used on binocular instruments, is highly desirable.

An alternative device is the 'Tube-length Corrector' designed by Sir Herbert Jackson. This is a compound lens having a variable separation between the two components which is controlled by a milled ring. The corrector is screwed between the objective and the nosepiece of the microscope and the milled ring used in precisely the same way as in an ordinary correction collar. This unit is extremely simple in use and can be employed with objectives of all powers whether dry or homogeneous immersion.

Illumination by transmitted light

The illumination of transparent objects is subject to the same considerations and limitations whether a monocular or binocular microscope is being used, and the provision of means for critical illumination, whereby an image of the light source is so focused as to ensure that the whole of the working aperture of the objective is utilized, is equally important in either case.

A feature which is, however, peculiar to binocular instruments, especially when set to provide stereoscopic vision, is the marked difference in level which becomes painfully obvious unless the light source and the object are in fact focused in the same plane. The former tends to appear as a 'solid object' in the field, and its coincidence or otherwise with the object field becomes instantly apparent. The well-known expedient, therefore, of raising or lowering a condenser of slightly inadequate performance in order to fill the back lens of the objective with light is no longer satisfactory, and a substage condenser of adequate performance becomes a necessity. It may, in fact, safely be said that a good achromatic and aplanatic condenser of wide aperture is never so greatly appreciated as when it is used in combination with a high-power binocular microscope.

The images produced by a binocular instrument of modern design, when properly illuminated and set to give stereoscopic vision, are of unsurpassed beauty; nevertheless, the major contributions made to microscopical science by these instruments are the greatly increased comfort and freedom from eyestrain which their use, when correctly adjusted, makes available.

They are not only capable of revealing structure in a way not hitherto possible, but when used on thin non-stereoscopic material they facilitate the recognition of fine detail to a degree which becomes immediately apparent when comparison is made between the visual acuity obtainable with two eyes and that obtainable with only one.

Notes on the Older Binocular Microscopes

BY P. K. SARTORY, F.R.M.S.

Whilst the modern high-power binocular instrument is coming more to the fore in laboratories, the amateur is still the great user of the Wenham, and Powell and Lealand binocular instruments in both the high- and low-power forms; these instruments, when produced by firms of repute, gave very good results. It must be remembered, when criticizing the old instruments, that although the optical requirements were well understood at the time, the technical difficulties in producing surfaces of the required accuracy were not completely overcome. For many years it has been a relatively simple matter to work accurate spherical surfaces, but it is only in comparatively recent times that accurate flat surfaces have been obtainable. Even to-day, unless a large sale is foreseen, small accurate prisms are extremely expensive. In the large instruments of Powell and Lealand, Ross, and Crouch, the prisms were of surprising accuracy, and, when properly adjusted, gave superlative results.

In order to obtain the best results with the Wenham low-power system it is essential that the edge of the prism shall accurately bisect the rear aperture of the objective. In old instruments the prism boxes are sometimes strained and, consequently, travel beyond the centre of the optical axis. The user should always try the effect on the image by slightly withdrawing the box or by moving it a small amount from side to side. With the proper adjustment of a good prism, it is quite possible to use the Wenham system up to an N.A. of 0·9.

The high-power systems of Ross, and Powell and Lealand are frequently put out of adjustment by careless attempts at cleaning the prism surfaces. These should only be cleaned by experts who are capable of putting the system back into alinement if any of the prisms should shift during the cleaning process.

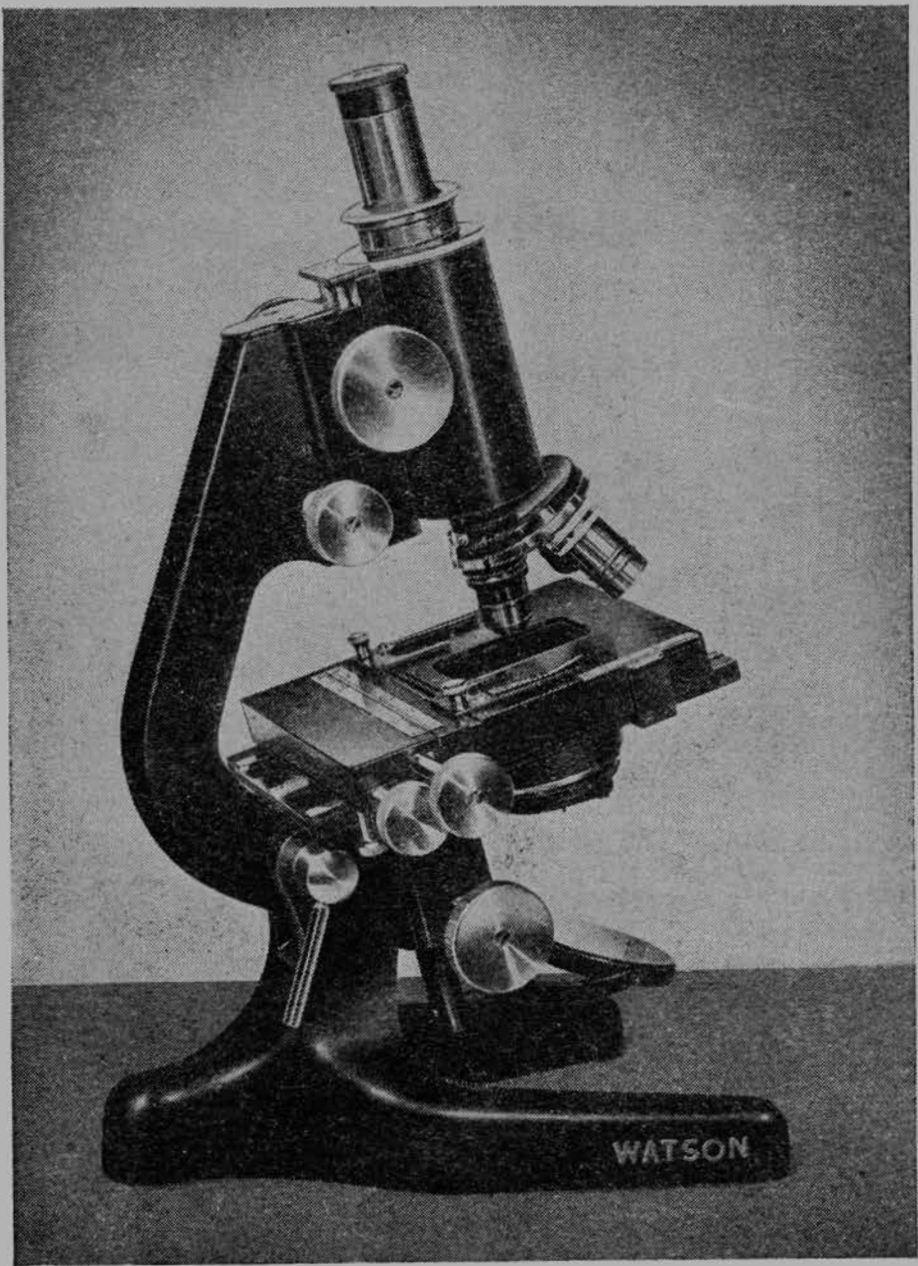
The high-power system of Wenham is capable of producing images equal, if not superior, to the modern instrument if it is modified by suitably semi-silvering the reflecting face of the small right-angle prism and balsaming it on to the larger prism. Due to the small amount of glass employed, this system has a less degrading effect upon apochromatic objectives than the modern forms. A Wenham modified in this way was recently exhibited at a meeting of the Quekett Microscopical Club, where the quality of its performance gave rise to considerable favourable comment.

Owners of the Stephenson low-power binocular should inspect the silvered reflectors from time to time. Specimens of this type have been exhibited, both at the Quekett Microscopical Club and in the shops for sale, in which the silver film has been entirely removed by injudicious cleaning, with the result that the instrument needed a powerful illuminant in order to get a bright image. If the silvered surface is tarnished or damaged it should be replaced by a first surface aluminized mirror, or the existing glass should be sent to a firm who will aluminize the surface; the process is relatively cheap and will enormously improve the light transmission of the instrument.

The performance of this instrument, and also the Greenough when used for transmitted light, is improved by placing a piece of opal glass under the object and using the concave mirror or a condenser to illuminate the opal glass. This provides a very even illumination without shadows and is simpler than the divided and inclined mirror of Akehurst.

For amateur use the Stephenson microscope, if in good working condition, will be found superior to the Greenough system, because its stereoscopic properties are more correct. This can be demonstrated if tested on truly spherical objects, when the Greenough system will be found to be hyper-stereoscopic. Further, its light transmission is better, whilst any standard objective can be used provided its back lens is not too small.

MICROSCOPES



The "SERVICE I" Microscope illustrated is a robust monocular microscope which has those features required for the research worker. The mechanical movements, in the Watson tradition, are of the highest standard of precision, designed to withstand arduous conditions of general laboratory work. It is a typical example from a complete range of microscopes designed by experts and assembled by craftsmen.

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