

Recording the image — past and present

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THE START of one of the most famous passages in the Scriptures reads 'In the beginning was the Word'. Words are, however, often very inadequate to communicate what are essentially visual experiences and although the verbal approach must, surely, have been tried in the seventeenth century by the first practitioners of the embryonic science of microscopy they must very soon have realised the shortcomings of verbal descriptions. These must have been rapidly followed by the words 'Look at this!' Looking down a microscope at a new and strange image is exciting but, because of the very nature of the instrument, it is essentially a new very private and personal experience. Effective attempts to describe the new structures revealed by their instruments required not only verbal skills to put into words what the observer saw but also the ability to communicate the images themselves. This was appreciated by the early microscopists and they soon used the techniques at their disposal to illustrate their published descriptions.

Among the best known of the early microscopical illustrations are those of bees, published in 1630 by Stelluti (originally drawn by him in 1625 for Federico Cesi; see Bardell, 1988), and pictures of a razor's edge, a flea, the louse and the under surface of nettle leaves by Robert Hooke. These latter appeared in 1665 in his famous *Micrographia* (reprinted in facsimile by Gunther, 1938) and must surely stand out as among the most accomplished and artistically pleasing of the earlier microscopical illustrations. Other early microscopists also attempted to illustrate their observations but in many cases their attempts were crude by comparison with those in the *Micrographia*. The illustrations of developing chick embryos in Malpighi's writings and the diagrams in the letters of Antoni van Leeuwenhoek are examples which immediately come to mind. Other slightly later illustrations were of much higher quality and the pictures of sections of various types of wood which were used to illustrate John Hill's book on timber (Hill, 1770) are obvious examples. It should be remembered that many of the

illustrations of microscopes in early works were executed by engravers who often had not seen the instruments themselves and possibly may have been unable to read the text they were illustrating. The classic examples of this are the illustrations of 'giant' microscopes which were published in Schott's *Magia Universalis* of 1658 (Fig. 1). Here one instrument appears to consist of a large tube held at arms length by a man whilst another has the observer kneeling whilst observing through what appears to be a huge bi-convex lens. Since one tends to estimate the size of an object by reference to what is drawn with it, the impression given is one of large size. In both illustrations, however, the source of light is apparently a candle in a candle stick. As Mayall pointed out (in his Cantor Lectures of 1886 and 1888), Frank Crisp suggested that these engravings were, in fact re-drawings of instruments described and illustrated in an earlier work by Kircher (1656). One represents what would now be known as a 'pulcarium' or 'flea glass' and Schott himself states that the tube

"scarcely exceeds the length and thickness of a finger joint."

Reference to Kircher, the original source of the illustrations in Schott, shows (Fig. 2) that the artist has substituted the drawing of an entire man for what was originally an eye and what he has shown as a candle flame was meant to be an insect impaled upon the point of a pin! From this we must conclude that the lens was only an inch or so in diameter.

Great care is needed to produce an accurate representation of an object seen through a microscope and such a representation often requires the observer to understand the true form of the object. Appearances vary according to changes in the method and angle of illumination and with differing preparative measures. This was clearly understood by Robert Hooke and is explained in his Preface to the *Micrographi* as follows

"I indeavored (as far as I was able) first to discover the true appearance, and next to make a plain representation of it. This I mention the rather,

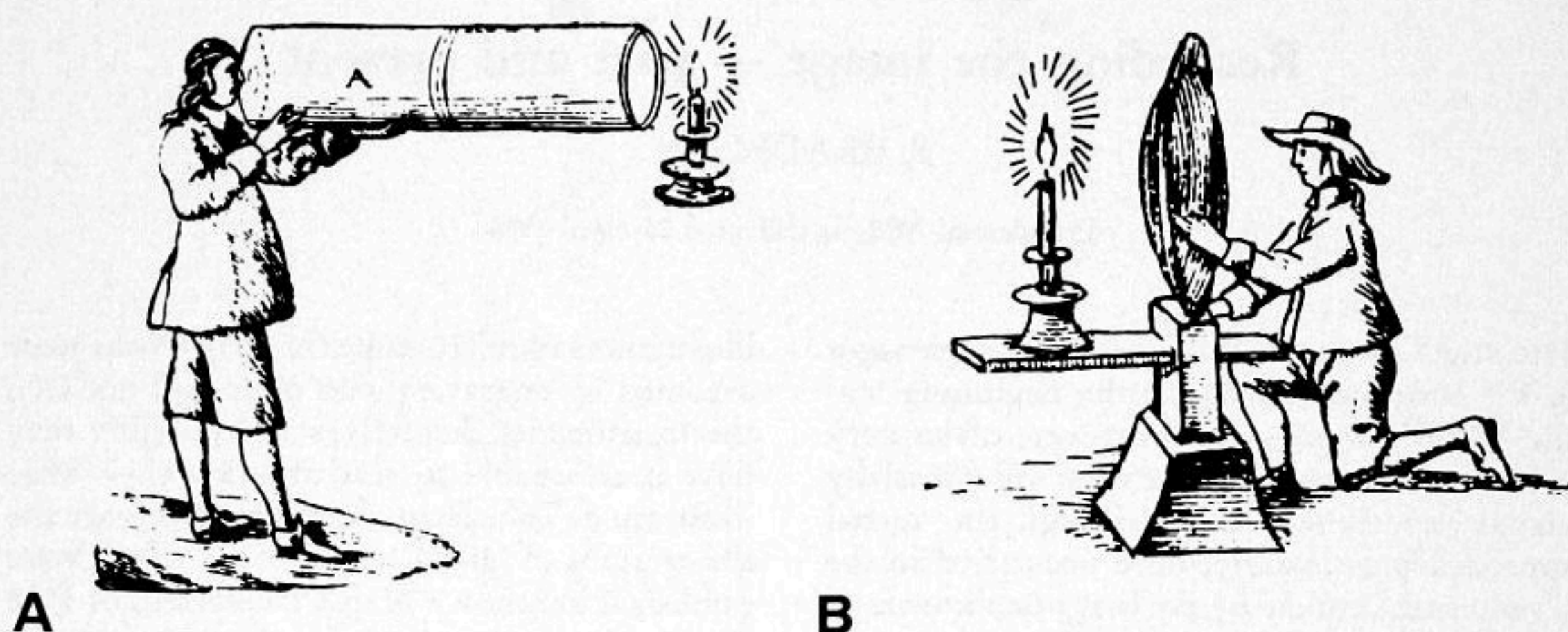


FIG. 1. Illustrations of 'giant microscopes'. These woodcuts are taken from Schott's book published in 1658.

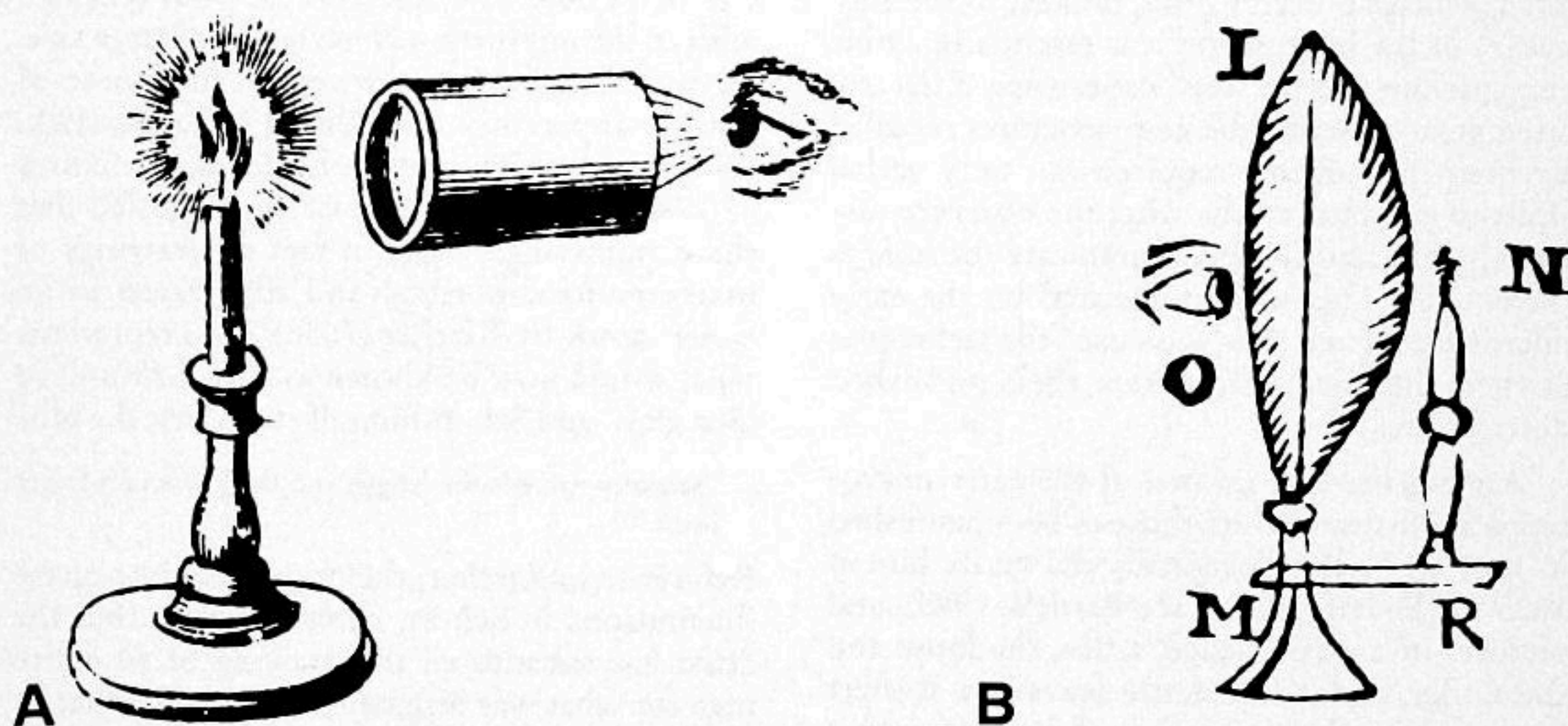


FIG. 2. The originals from which the illustrations of Fig. 1. were taken; these are to be found in the book by Kircher (1656).

because of these kind of objects there is much more difficulty to discover the true shape, than of those visible to the naked eye, the same Object seeming quite differing, in one position of the Light, from what it really is, and may be discover'd in another. And therefore I never began to make any draught before by many examinations in several lights, and in several positions to those lights, I had discover'd the true form."

With this in mind, how has the microscope image been produced over the years, firstly as a single copy and then for dissemination by printing? Turner (1974) considers that there are

six chief methods. Four of these use drawing, a method adopted since the earliest days of the microscope and still valid today; photography, however, both still and with cine film now features as the principal representative technique. In recent years new and rapidly developing techniques of video, both analogue and digital, seem likely to assume greater importance. Because of the possibilities for image storage and manipulation by computers it seems that digital video may become the norm and method of choice in years to come.

Drawing from the Microscope

As McLaughlin (1975) remarked "Microscopic illustration is not art". In the hands of a skilled practitioner the end result may often be so good as to pass for art, but for the principal purpose of microscope illustration, which is to communicate information accurately and clearly, the message is keep the drawing as simple as is consistent with the subject matter and the information to be conveyed. All drawings necessarily involve the **interpretation** of what is seen through the microscope; it was not until the application of photographic techniques for the recording of the microscope image in the mid-nineteenth century that there was an unbiased or neutral method of communicating images between workers.

Drawing has several major advantages but set against these are equally telling disadvantages. As advantages may be cited the fact that drawing an image ensures clear and careful observation and a close attention to the detail contained in that image. At the same time, the making of a drawing allows the microscopist to select relevant features (which may be taken from several different focal planes in one specimen) or even combine detail from several different specimens into a single illustration. In making the drawing the observer may also eliminate unnecessary and confusing detail, a feature which may be of great value if the illustration is intended for, say, taxonomic purposes. Drawings made in black drawing ink on white card are very suitable for reproduction at relatively little cost in print. The major disadvantages of drawing are that the process needs a modicum of skill and practice to produce acceptable results and is inevitably time consuming. Any colour required must be added later by hand and as mentioned above, drawing is inevitably susceptible to the inclusion in the end result of observer errors and misconceptions.

Drawing Techniques

For those microscopists who are skilled with a pencil or drawing pen, the obvious technique is to observe the image down the microscope and then turn the head away and draw freehand what one remembers of the image (or what one **fancies** one remembers!). The observation and drawing is repeated over and over again until the observer is satisfied with the representation.

A variant (which requires considerable practice) of this method is for the observer to look down the microscope with one eye and, at the same time, observe with the other eye a sheet of paper for the drawing placed beside the instrument. By an effort a conjunction of the two images may be made and the drawing carried out at the same time as the observation. This technique was known and used by Hooke, especially for measurements:

"Having rectifi'd the Microscope, to see the desir'd Object through it very distinctly, at the same time that I look upon the Object through the Glass with one eye, I look upon other Objects at the same distance with my other bare eye; by which means I am able, by the help of a Ruler divided into inches and small parts, and laid on the Pedestal of the Microscope, to cast, as it were, the magnifi'd appearance of the Object upon the Ruler, . . ."

It is also clear from his voluminous correspondence that Leeuwenhoek was very poor at drawing. In a letter to Oldenburg, the Secretary of the Royal Society, dated March 1675 he writes

"Yet I am to blame, because I can't draw . . . and so I make only rough and simple sketches with lines, mostly in order to assist my memory, so that when I see them I get a general idea of the shapes."

Leeuwenhoek seemed to limit himself to a few rough sketches in the margins of his letters and habitually used draughtsmen to illustrate his observations. Dobell (1932) makes a good case for the supposition that the earlier letters were illustrated by Thomas van der Wilt, of Delft and at least some of the later ones by his son, Willem van der Wilt. From these drawings the engraver produced the plates to illustrate the published work.

One of the principal difficulties in free drawing from the microscope is that of obtaining proportions. The detail of the object is often surprisingly easy to add once the outline is set down. The use of a 'net' or squared graticule placed in the focal plane of the eyepiece allows the image to be seen with a pattern of regular squares superimposed upon it. If squared paper is then used for the drawing, it is quite easy to obtain an outline with correct proportions. This technique is described in detail in McLaughlin (1975) and in Wallis (1955). For microscopists who are totally unskilled in drawing, it is possible to arrange for a real image of the specimen to be projected so

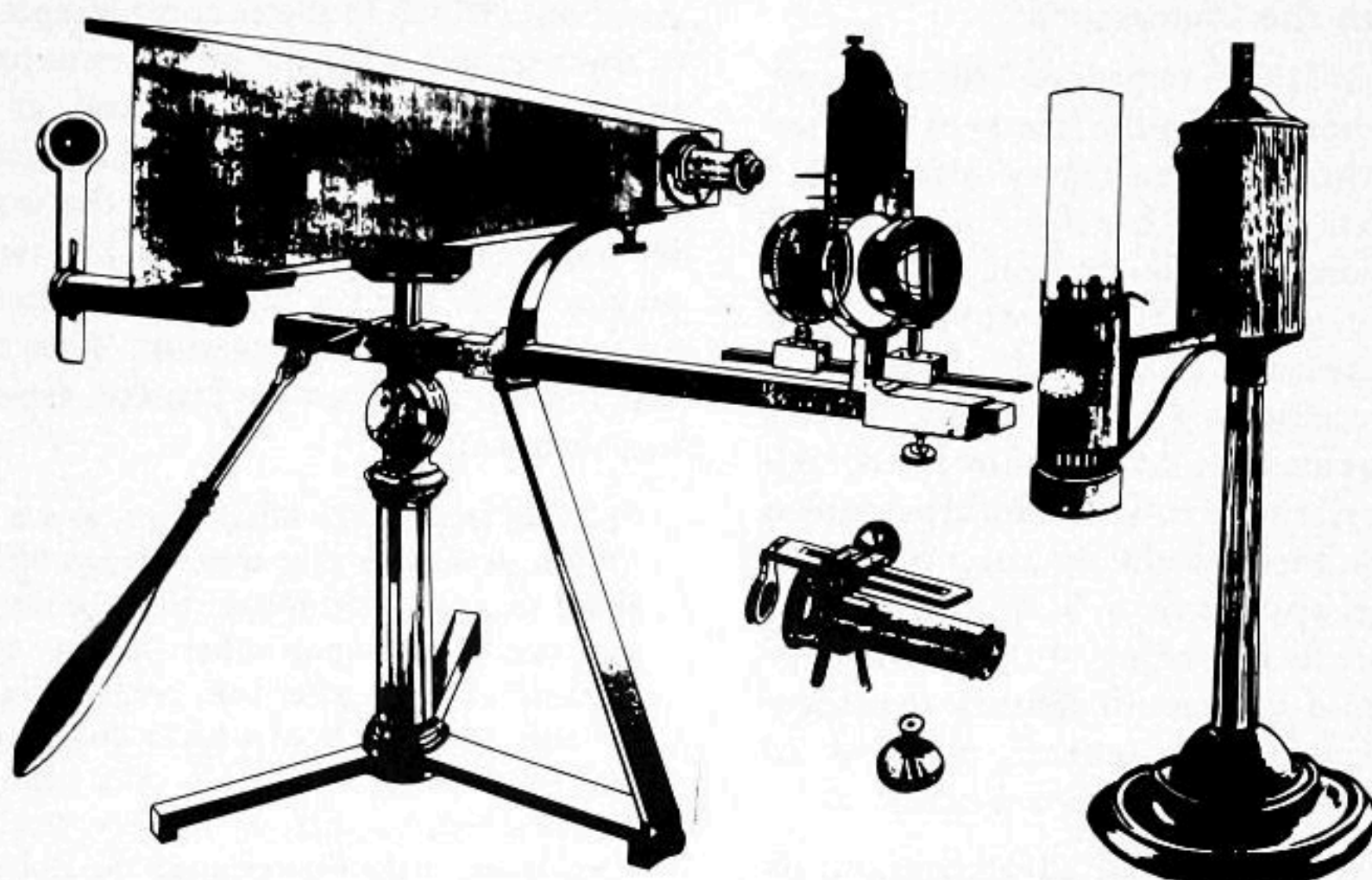


FIG. 3. A lucernal microscope of the 18th century. This used an Argand paraffin lamp, seen here on the right, as the light source. The image was observed on a ground glass placed at the left-hand end of the mahogany part of the microscope.

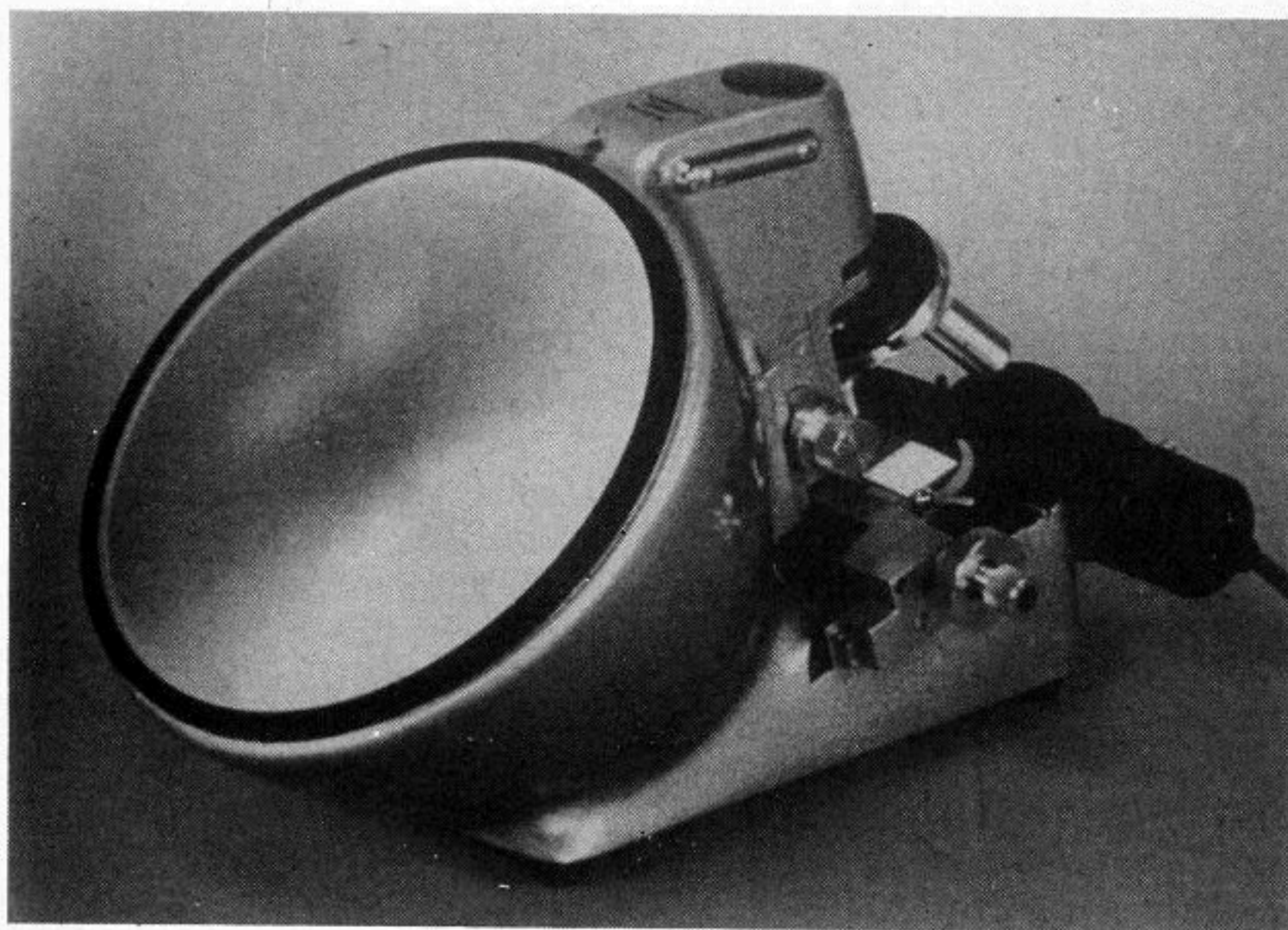


FIG. 4. The Reichert 'Visopan' projection microscope of the 1950's.

that it may be traced directly. This approach has been adopted from the eighteenth century onwards, with the use of the solar microscope and of the lucernal type with its ground glass screen (Fig. 3). In the collection of the Royal Microscopical Society there is a splendid lithograph of a drawing of the head of a flea made by J. B. Reade about 1836 which was executed with the aid of a solar microscope. Today projection is much easier with the introduction of much more powerful light sources, and prisms or mirrors which mount

above the eyepiece of the microscope. Indeed, in the recent years there have been several instruments such as the Reichert 'Visopan' (Fig. 4) which were designed specifically for projection of the image onto an integral ground glass viewing screen. A sheet of tracing paper is easily mounted temporarily onto the screen of such an instrument in order to trace an accurate outline. The whole technique of drawing from the microscope was made much easier following the invention of the camera lucida.

The Camera Lucida

In the latter years of the eighteenth century it was the fashion for gentlemen of quality to take the Continental grand tour during which they would visit many of the sites of classical antiquity. Naturally they wished to record their experiences and the sights and appearance of the places which they visited. Unlike today, when anyone can obtain excellent colour photographs on holiday, there was no method of recording other than freehand drawing. Many travellers tried this and they often complained that they were unable to do justice to the scenes before them. This was true of William Hyde Wollaston and his friend Henry Halsted. The story, (told by Halsted and related in Hammond & Austin, 1987), and dating probably from 1800 or 1801 was of their disappointment with their attempted sketches of the scenery when they were on a walking tour of the English Lakes. Halsted subsequently called on Wollaston and was shown a rough prototype of the instrument later to be known as the 'camera lucida'. Wollaston received a patent in 1806 for "An Instrument whereby any Person may draw in Perspective, or may Copy or Reduce any Print or Drawing". In the following year Wollaston published several articles with a description of his device and for the first time described it as a 'camera lucida'. In these articles he introduced the principles and showed how a simple instrument could be made from a single sheet of glass held at 45 degrees to the paper (Fig. 5A). The artist looks through this at the paper and the pencil but will also see a superimposed image of the scene if the balance of illumination between the scene and the paper is correct. Since the image of the paper is seen through the reflection of the scene, this type of camera lucida may (to use Austin & Hammond's term) be called 'see-through'. Such a simple type of camera lucida was not much used in practice. As Wollaston pointed out, with any type of instrument in which there is a single reflection there will be a lateral reversal of the image which is often undesirable. To correct this lateral reversal a second reflector is required. This may be done with a small extra mirror but the instrument as patented by Wollaston, however, used a four-sided prism to produce the double reflection. The artist did not 'see-through' the prism, but observed the original scene with half the pupil of the eye whilst a direct image of the paper and pencil was viewed

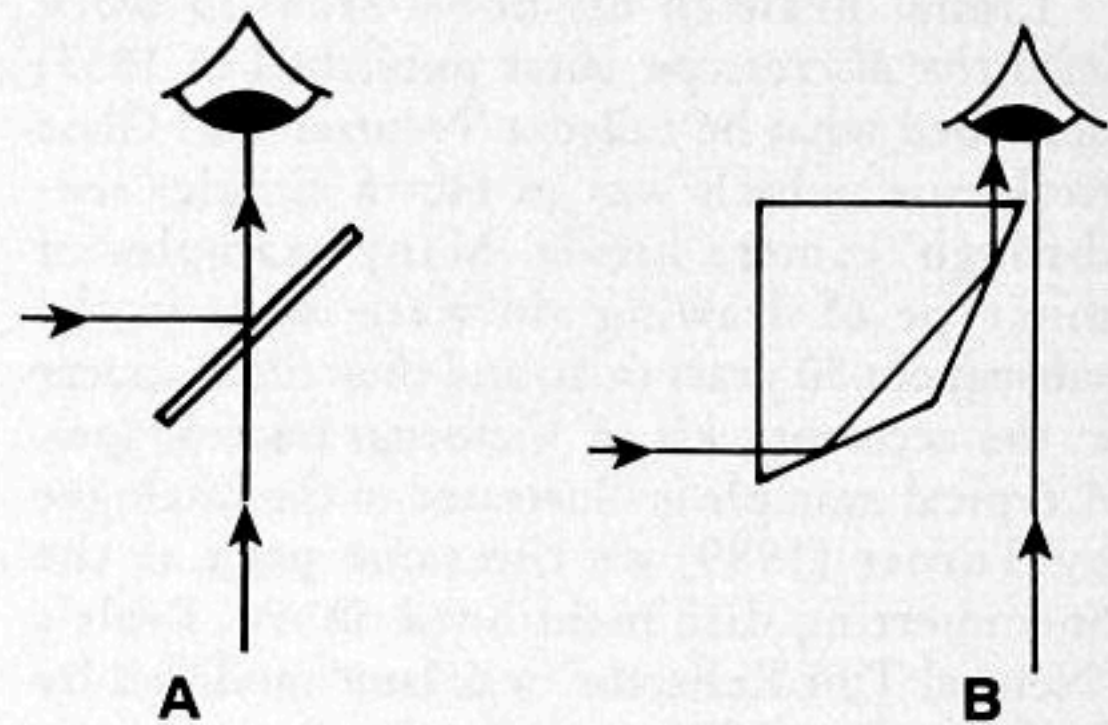


FIG. 5. (A) The principle of a simple 'see-through' camera lucida, using a thin sheet of plain glass orientated at 45° to the optical axis of the microscope which was placed horizontally.

(B) Wollaston's prism used as a 'split-pupil' camera lucida. Again the microscope optical axis is placed horizontally.

with the other half of the pupil. This type of instrument may, therefore, be called a 'split-pupil' camera lucida. In a typical Wollaston camera lucida the prism is about 15mm in depth and the obtuse angle is of the order of 131-135° (Fig. 5B). Small screens of tinted glass which could be swung into the optical path were often provided to control the intensity of the illumination reaching the eye and so allowing the two images to be 'balanced' and making it easier to use the instrument. Apparently Wollaston intended his camera lucida for artists and never specifically mentioned its use as an accessory for drawing from the microscope. The advantages of such a device for microscopical illustration were very soon realised, however, and from 1810 onwards a very large number of 'see-through' and 'split-pupil' variants on the camera lucida theme were introduced.

One of the earliest split-pupil drawing devices was that devised by the German anatomist Samuel Thomas Soemmerring who invented a stainless steel mirror between 3-5mm in diameter, held at an angle of 45° above the eyepiece of a microscope by means of an arm fixed to a brass collar which slips around the upper part of the eyepiece. This device, (illustrated in Turner, 1989, p.321), reflected the microscope image into the observer's eye through the centre of the pupil whilst allowing the drawing paper to be seen by the peripheral area of the pupil.

Lionel Beale in his book *How to work with the Microscope* (first published in 1857) described what he called a 'Neutral Tint Glass Reflector' which was in fact a simple 'see-through' camera lucida. Many examples of this type of drawing aid were made in the subsequent 50 years or so and they often appear in the accessory kit of Victorian microscopes. A typical example is illustrated in the catalogue by Turner (1989) on the same page as the Soemmerring disc mentioned above. Beale's 'Neutral Tint Reflector' was later modified by Suffolk who added a small prism between the eyepiece and the tinted glass in order to correct the orientation of the image as drawn. It was essential when using the Soemmerring, Beale and Suffolk types of camera lucida that the microscope was arranged with its tube horizontal to the desk on which the drawing paper was placed. To many workers this was a great disadvantage and in 1889 Ashe devised a variant in which a small hinged mirror was used to reflect the microscope image onto a similarly hinged tinted glass. This allowed the microscope to have its tube inclined at an angle with respect to the plane of the drawing paper. There were many other types of split-pupil camera lucida and the nineteenth century literature on microscopy contains many designs differing only in minor details. Indeed, such devices featured in the catalogues of several major manufacturers right through until the late 1930's.

The see-through versions of the camera lucida were, in general more popular since they were much easier to use than split-pupil types. Many different versions were developed independently, for each of which their originators claimed special advantages. Most of them used some form of semi-reflecting cubes. One of the earliest was that developed by Nacet in 1882. In its earliest form (Fig. 6A) this consisted of an elongated rhomboidal prism fixed over the eyepiece of the microscope. On the inclined face of the prism next to the eyepiece a small glass cylinder was cemented in order to allow the imaging rays from the microscope to pass to the eye without refraction, whilst the rays from the paper were reflected into the eye by the two sloping prism surfaces. As with many split-pupil types of camera lucida, this arrangement required the observer's eye to be held very steadily in the optical axis. Nacet soon altered his design and, adopting a suggestion of Govi, replaced the

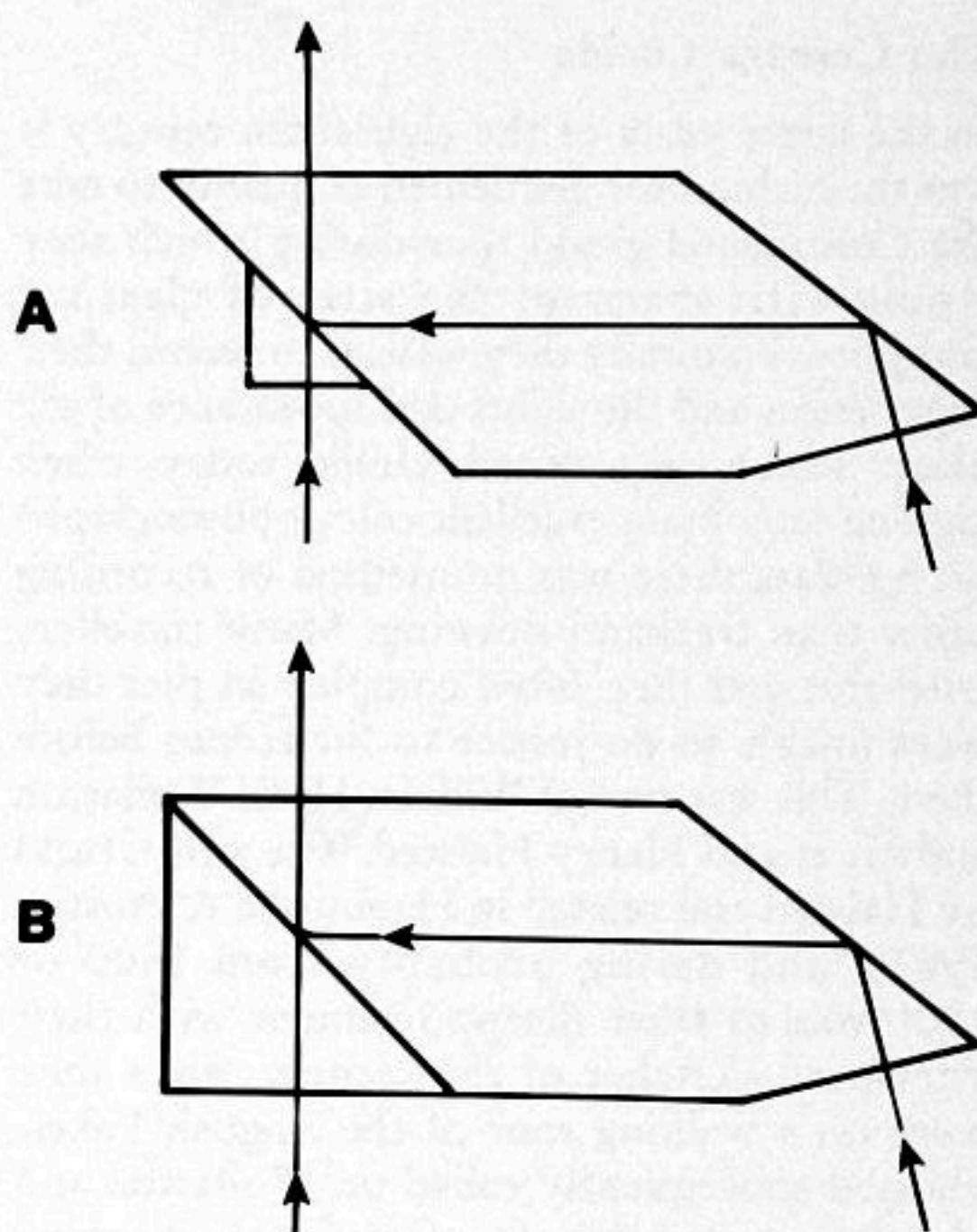


FIG. 6. (A) The early form of Nacet's camera lucida with the auxiliary prism.

(B) The later form in which Nacet used Govi's addition of a larger prism cemented to the main prism but with a thin layer of semi-transparent gold film added between the two. This made the device much easier to use.

extra glass cylinder by a thin layer of gold and an extra prism (Fig. 6B). This arrangement allowed much easier use but the image was tinted by the presence of the gold. Later this was avoided by substituting a thin layer of silver for that of gold.

Perhaps the best known of the camera lucida is that designed by Abbe and introduced at about the same time as that of Nacet. In the Abbe camera (Fig. 7A) two right angled prisms are cemented together with a heavy layer of silver between the cemented surfaces. This layer has a small clear circular area, about 2.8mm in diameter in its centre through which the image forming rays from the microscope may pass. The silvered layer together with an accessory mirror serves to reflect the image of the paper and the pencil into the ray path so that the pencil appears superimposed onto the microscope image. Later this camera was improved by the addition of neutral density filters which could be placed in either of the ray paths so as to balance the relative levels of illumination (Fig. 8). This version of the camera lucida was very successful and many are still in use today.

One variant of Abbe's design known as the Swift-Abbe camera lucida (Fig. 7B) used the heavy silvering and small central hole of Abbe's cube, but replaced the accessory mirror on its arm with an inclined prism.

In 1898, at a meeting of the Royal Microscopical Society, yet another variant form of camera lucida was described by Swift and Ives. This differed from the Abbe-Swift camera in that the cemented prisms making up the beam-splitting cube did not have a fully silvered layer with small central hole but, as in the Nachet/Govi camera, a thin semi-reflecting layer of silver. The image from the paper was reflected into the optical path by a second inclined prism (Fig. 7C). Any arrangement using an accessory inclined prism to reflect the paper image would result in distortion of the image if the paper were to be placed flat upon the table. In order to avoid this problem (which was common to many types of camera lucida then in use) it was necessary to incline the drawing board at an angle. Many elaborate drawing stands were thus designed (Fig. 9) to hold the paper at an angle and so correct such distortions. As it is difficult enough to use a typical Abbe camera lucida when the paper is flat upon the table, one shudders to think how difficult it must have been to make satisfactory drawings using such apparatus when the paper is set at some odd angle!

The Abbe camera lucida as described continued in manufacture until at least until the 1930's and possibly until the second world war. After the war, however, drawing began to be used less and less and when it was practised the instrument of choice was the drawing tube fixed as an intermediate tube into the body of a binocular microscope. The basic principle of the drawing tube (Fig. 10) is exactly the same as that of the camera lucida in that an image of the paper and the pencil is projected into the image ray path by a beam-splitting prism. The tube itself usually contains auxiliary lenses which serve (a) to alter the magnification of the image of the paper and (b) to allow the paper and pencil to be brought into sharp focus at the same time as the image is in focus. This apparatus is much simpler and less tiring to use than the traditional camera lucida since the binocular head remains in place on the microscope (Fig. 11). As with any other camera lucida, success depends upon the correct balancing of the relative intensities of illumination on the paper and through the microscope.

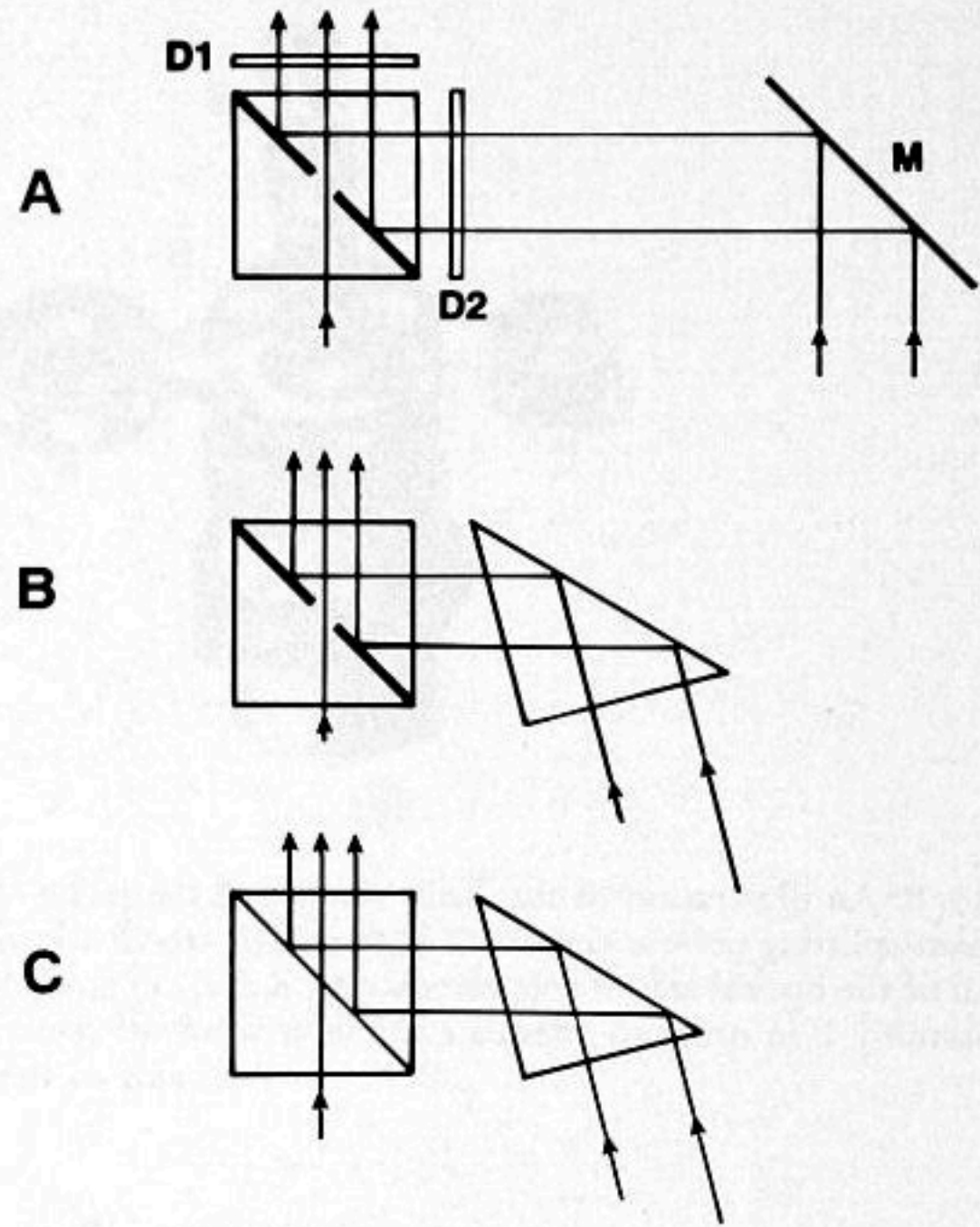


FIG. 7. (A) The optical path in Abbe's camera lucida. Light from the microscope passes through the small hole in the centre of the silvering between the two halves of the cube, whilst that from the paper is reflected by the mirror (M) into the eye by the complete layer of silvering between the two halves of the cube. D1 and D2 are density filters to modulate the intensity of the light from the microscope and paper respectively.

(B) Diagram of the ray path through the Swift-Abbe camera lucida. The complete silvering with the central clear area has been retained but the mirror has been replaced by a prism.

(C) A diagram of the Swift-Ives camera lucida in which the central clear hole in the silvering between the halves of the cube has been replaced by an overall, very thin translucent layer of silver.

As with all apparatus for drawing through the microscope drawing tubes are best used for the delineation of the outlines and the proportions of the object. Final detail in the drawing is best added free hand afterwards together with a scale bar to indicate the magnification.

Photomicrography

The full history of photomicrography, defined by Spitta (1899) as 'the art of photographing a magnified image' has yet to be written and will form a complete subject in itself. To us, with modern cameras, film, and processing, photomicrography now seems the natural

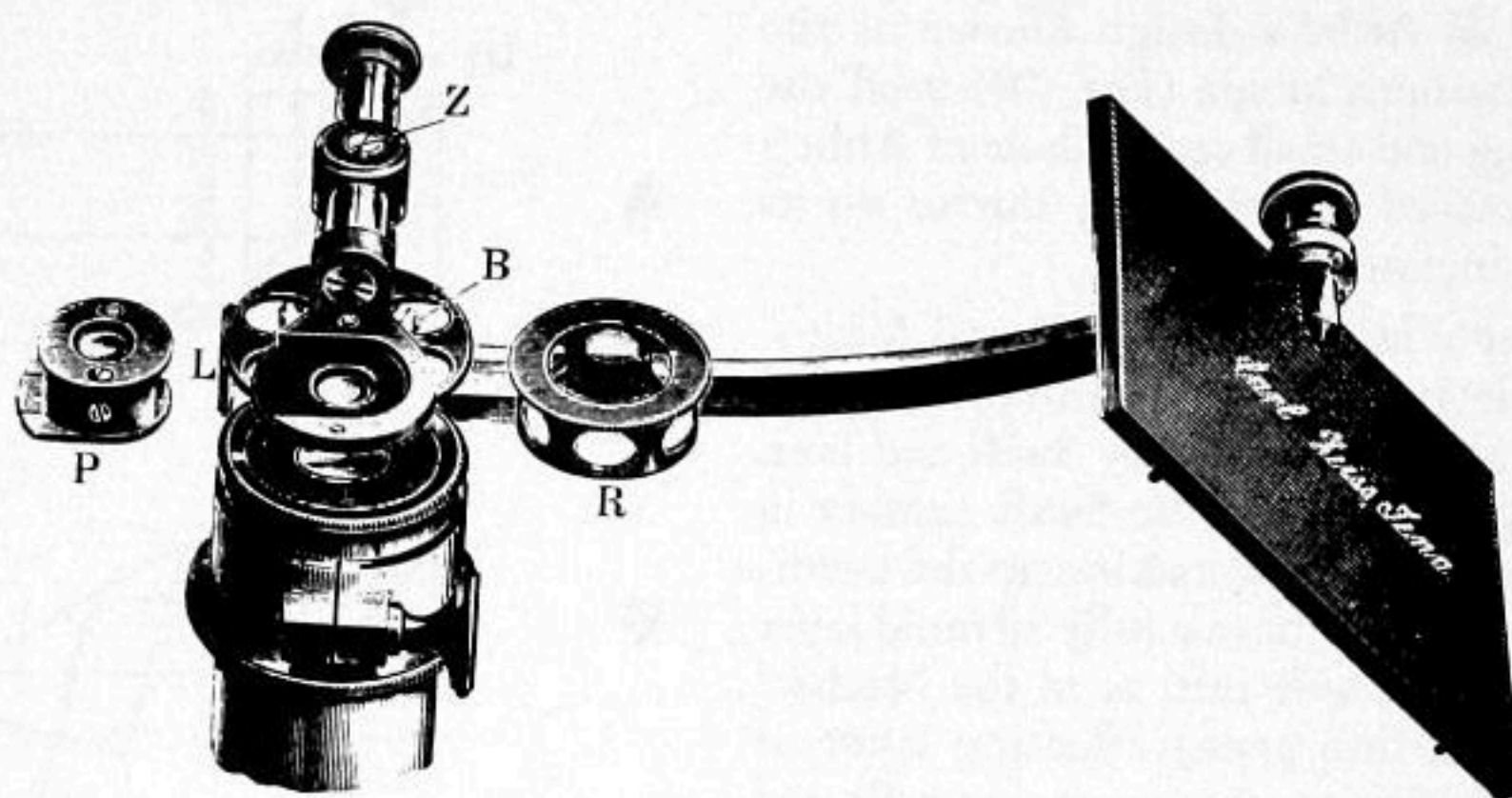


FIG. 8. An illustration of the Zeiss version of the Abbe camera lucida taken from a catalogue published in 1931. The beam-splitting cube is contained in the slider labelled P; Z is the pivot to allow the whole cube assembly to be swung out of the optical axis of the microscope; R is a cap containing a graded series of density filters which fits over the cube assembly P in order to attenuate the light from the paper and B is a disc with similar filters to insert into the optical axis of the microscope.

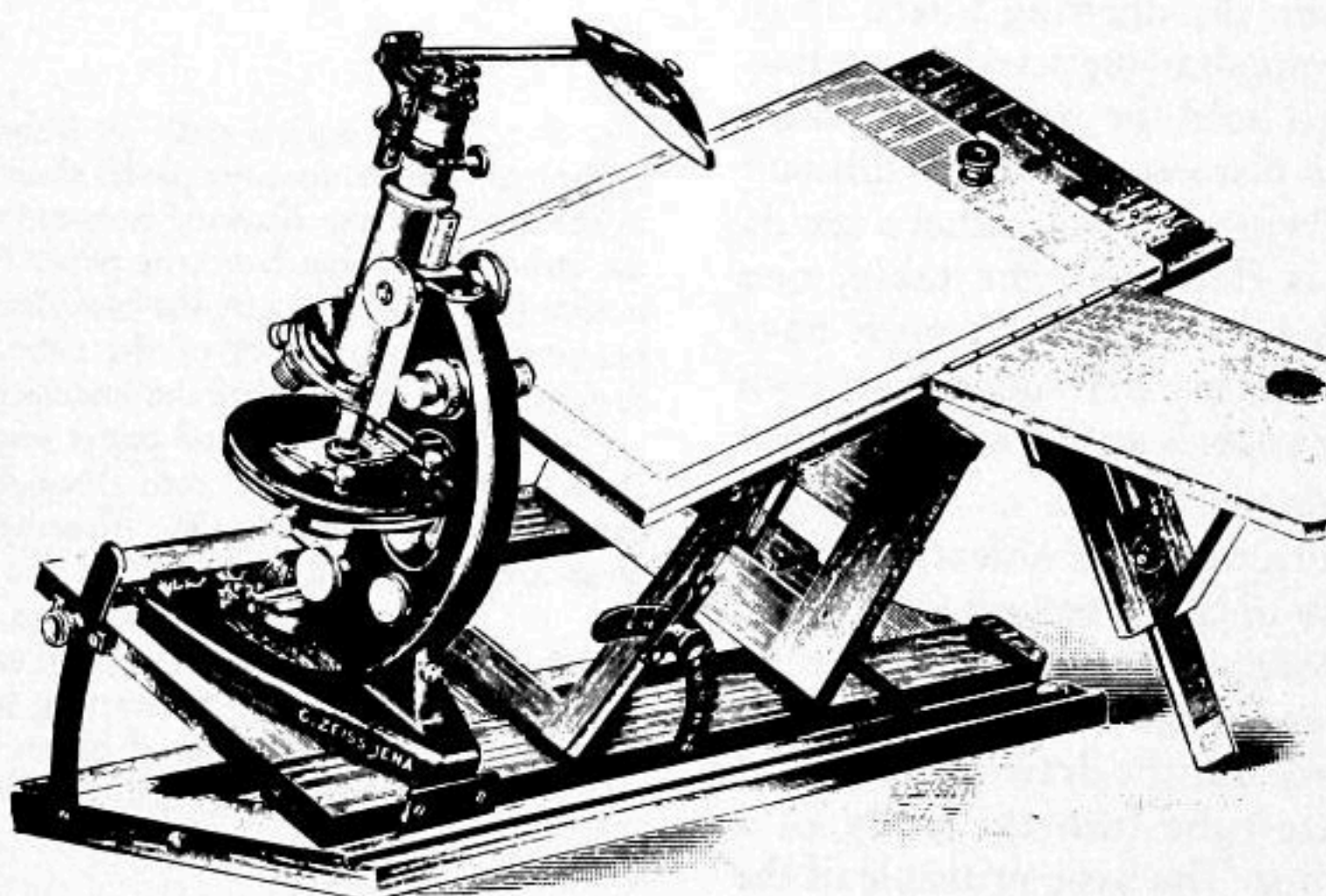


FIG. 9. An engraving (also from the Zeiss 1931 catalogue) of the compound drawing board designed by Bernhard to allow compensation for distortions of the drawing introduced by the camera lucida. Note the several axes of movement of the board holding the paper.

method of recording the microscope image but this has only come about during the last fifty years or so. Before this time the production of a satisfactory micrograph was not the simple thing it is today! The first attempts were made about 1802 by Thos. Wedgwood, the son of the famous potter Josiah Wedgwood. He used a solar microscope and projected the image onto paper or white leather which had been soaked with a silver nitrate solution. His work was repeated by Humphrey Davy and reported to

the Royal Institution. Their results were not permanent since the images slowly darkened on exposure to light. At that time the action of sodium thiosulphate (hypo) in dissolving unchanged silver salts was not known; it was not until 1819 that Sir John Herschel described this phenomenon.

The early work of Wedgwood and Davy was repeated in the 1830's by Fox Talbot working at Laycock Abbey. Because of the

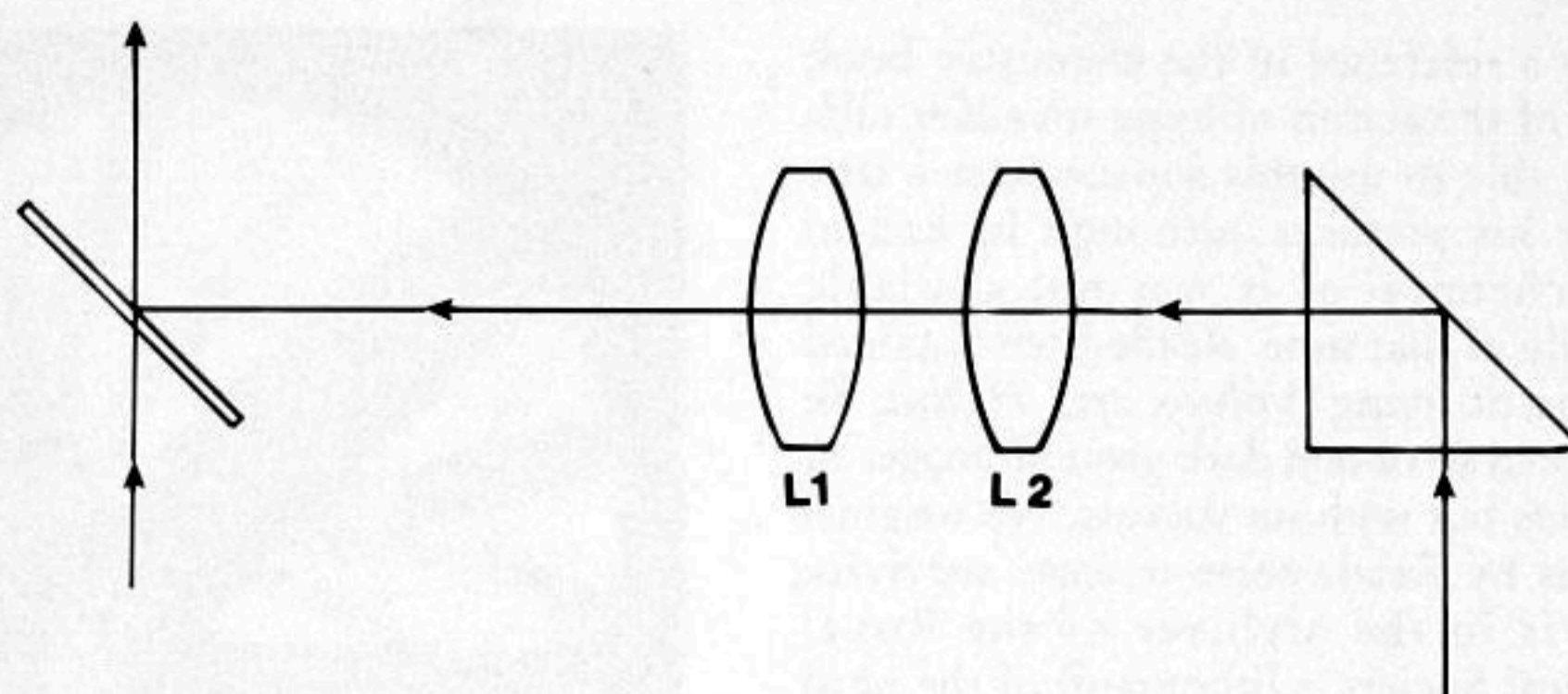


FIG. 10. A simplified diagram of the ray path in a drawing tube intended to fit into the body of a binocular microscope. The lenses L1 and L2 allow changing the magnification of the image of the paper and its focusing.

relative insensitivity of his sensitised materials to light he also used the solar microscope. In about 1835 Fox Talbot succeeded in producing 'photogenic drawings' of sections of plant stems at a magnification of $\times 17$ using an exposure of about 15 minutes. These micrographs were what we would now call negatives. Talbot soon realised that these original photogenic drawings could be recopied; he wrote

"by means of this second process the lights and shadows are brought back to their original disposition."

ie a positive resulted. His early images were stabilized by treatment with a strong salt solution or with a solution of potassium iodide. Later, using his Calotype process, Fox Talbot produced a micrograph of a crystal with polarized light showing the typical cross of polarization. A good account of Fox Talbot's work is to be found in the book by Arnold (1977).

The Rev. J. B. Reade was also experimenting with the production of what he called 'solar mezzotints'. It is often stated that his work preceded that of Fox Talbot, but Wood (1971) has produced clear evidence that Read's involvement in photomicrography immediately followed Fox Talbot's announcement of his process. Reade increased the sensitivity of the sensitive material (he used paper coated with silver nitrate and dried in the dark) by soaking it just before use in an infusion of galls and exposing whilst still damp. At first he was unsuccessful, as a result of using too strong a solution of the gallic acid, but eventually he obtained images which were displayed at the Royal Society in April of 1839 and at a Soirée



FIG. 11. A photograph of the drawing tube in use. It is fitted to a Wild M20 microscope. The reading lamp is used to provide extra illumination on the paper.

given by the Marquis of Northampton (the then President of the Royal Society) a few days later. Using magnifications between $\times 50$ and $\times 150$ and an achromatic cemented lens in his solar microscope, Reade obtained images of subjects such as the spiral vessels in the stalk of rhubarb, and various insects with exposures of between 5-10 minutes (Wood, 1971a and b). Reade had

learnt from a reference in the chemistry book of Brandes of the action of hypo on silver salts and he was able to use this substance as a true fixative for his pictures, although he had to make the chemical as it was not available commercially at that time. Reade later obtained micrographs of living *Volvox* and *Hydra*; he even attempted to obtain dark ground images of these subjects but without success. No original micrographs by Reade seem to have survived, but there is in the archives of the Royal Microscopical Society a lithograph of the head of a flea which was drawn from one of his illustrations by Lens Aldous. From the large depth of field shown in this lithograph, it could well be that the original was not a 'solar mezzotint' but a projection drawing. Reade was known to have produced several of these some years before he attempted recording the image on sensitised paper. For many years the redrawing by an artist of a micrograph or an original drawing onto a lithographic stone was the only easy way in which multiple copies of micrographs could be produced.

In France, the recording of an image on a highly-polished copper plate had been described by Dageurre in 1839. The copper plate was treated with silver which was then subjected to the vapour of iodine, so forming a layer of photo-sensitive silver iodide. After exposure, the image was revealed by treatment with the vapour of heated mercury which formed a whitish amalgam where the iodide had been exposed to light. The unused silver iodide was then removed to stabilize the image. Daguerrotypes were of high quality but each consisted of an individual image and copies were not possible; some Daguerrotypes were used to illustrate micrographic subjects although the images had to be redrawn onto lithographic stones for reproduction. They were used by A. Donné for his micrographs of bone and teeth, by J. B. Dancer who made a Dageurrotype of a flea's head in 1840 and by Foucault who produced an image of fish red blood cells in 1844.

Photomicrography was changed dramatically by the invention of the wet collodion process by F. Scott Archer in 1851. With the greatly increased sensitivity of this emulsion much shorter exposures were possible. The new technique was soon used by Shadbolt, Highley and J. Delves who published what is believed to be the first photomicrograph (of insect trachea

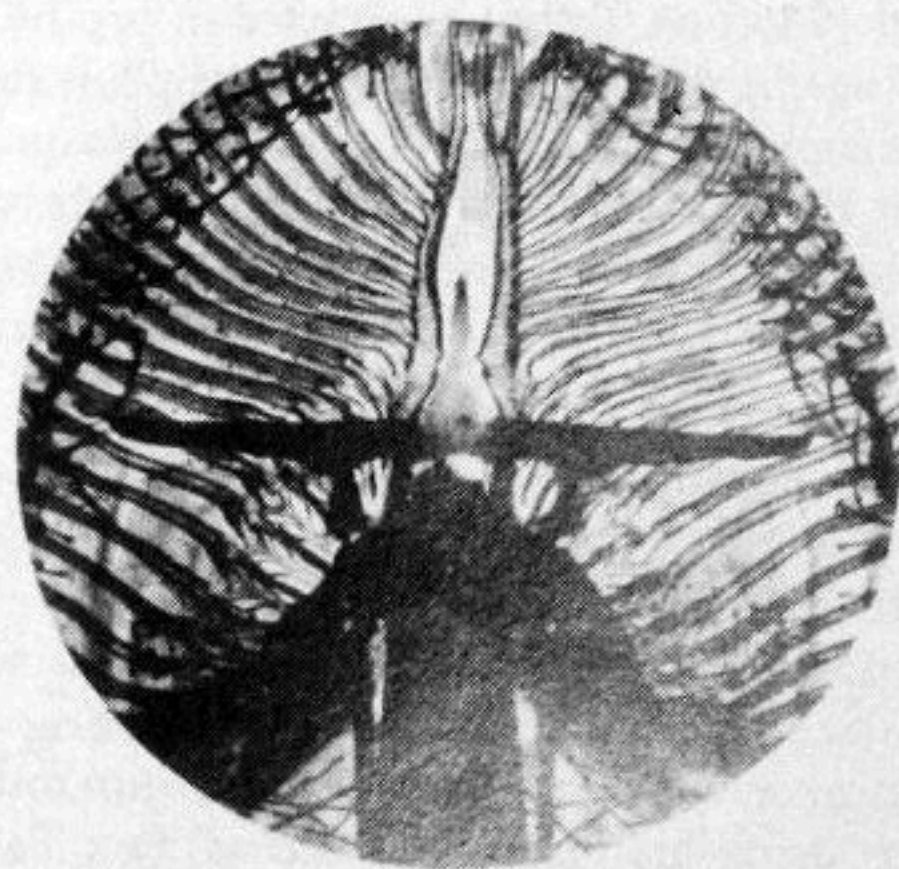
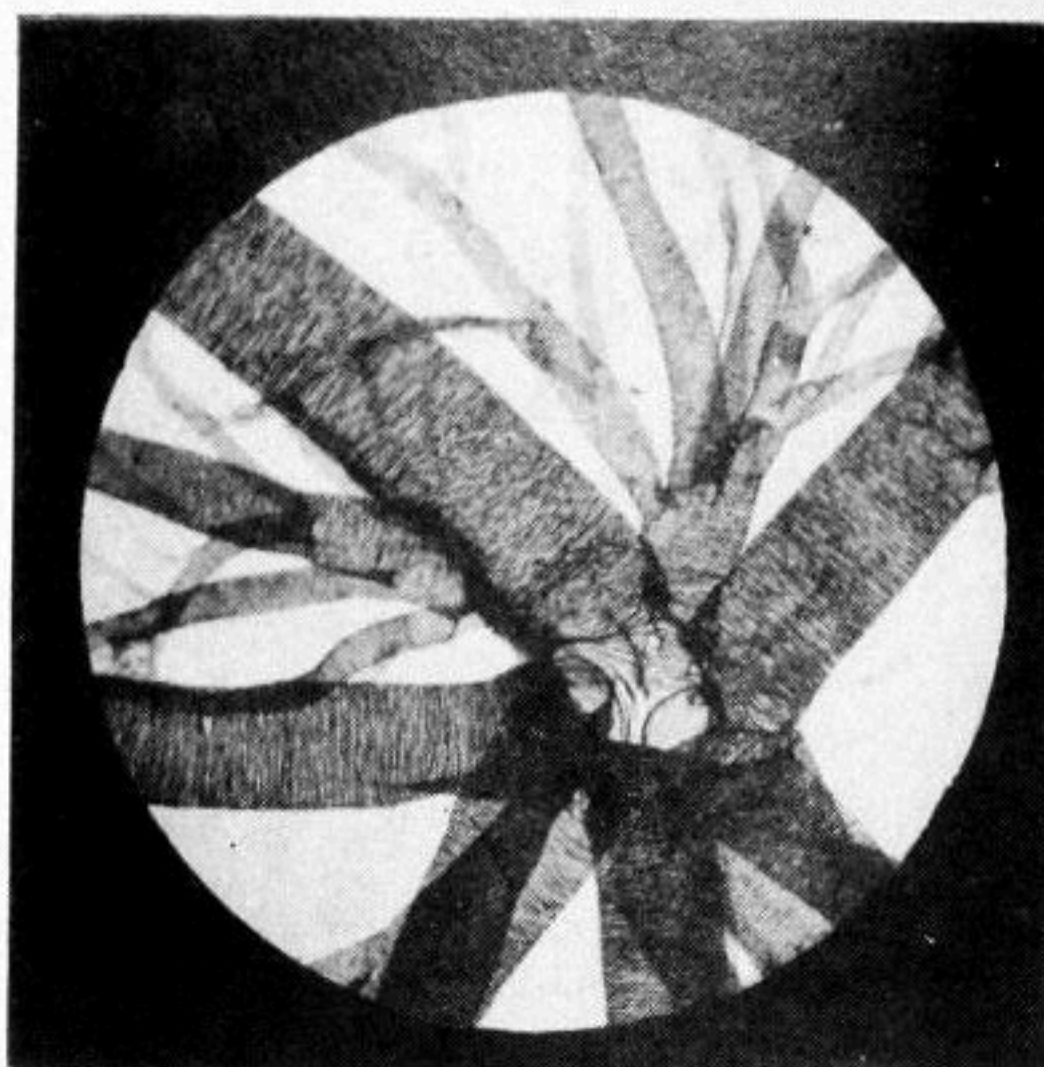
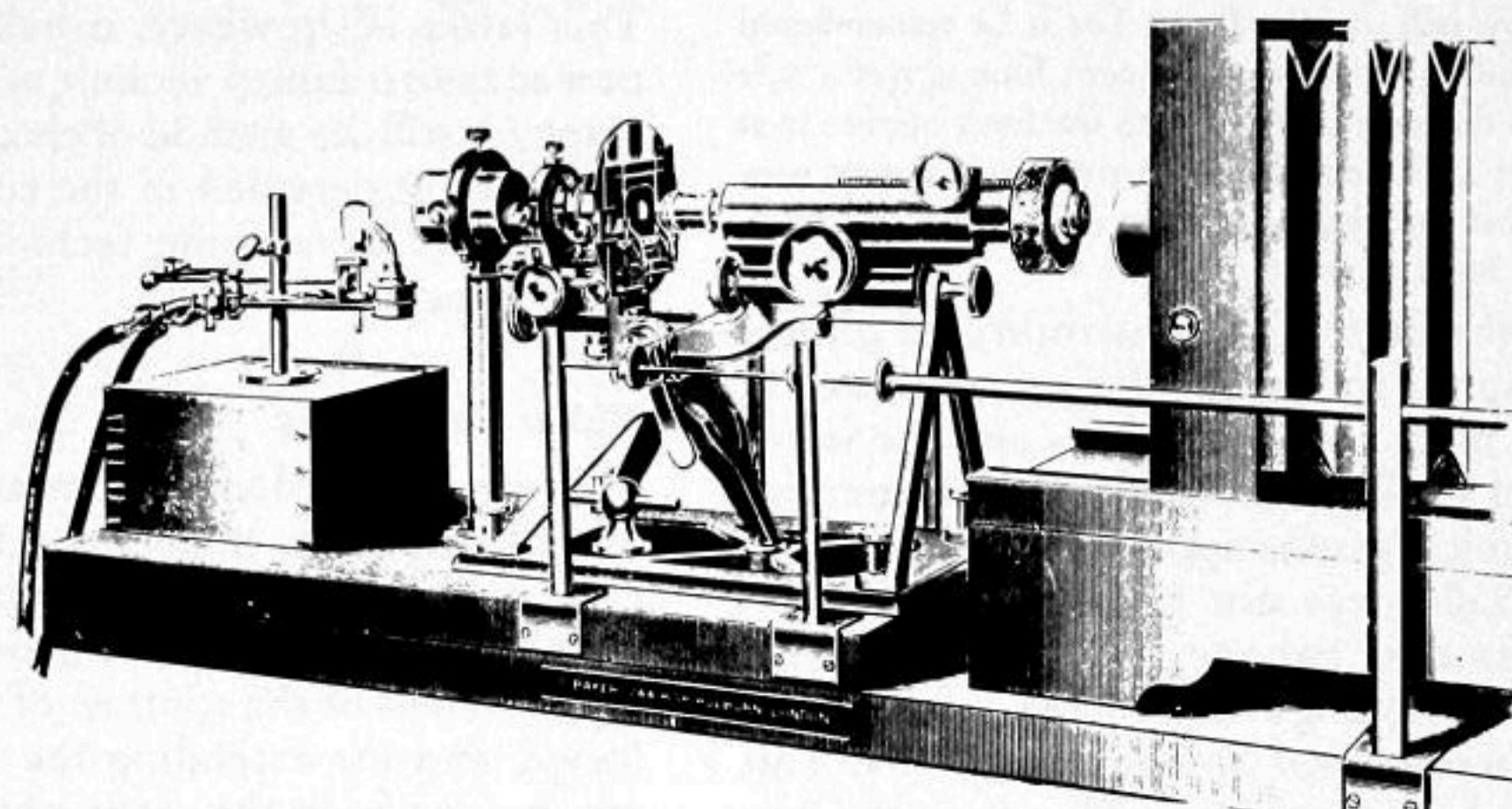


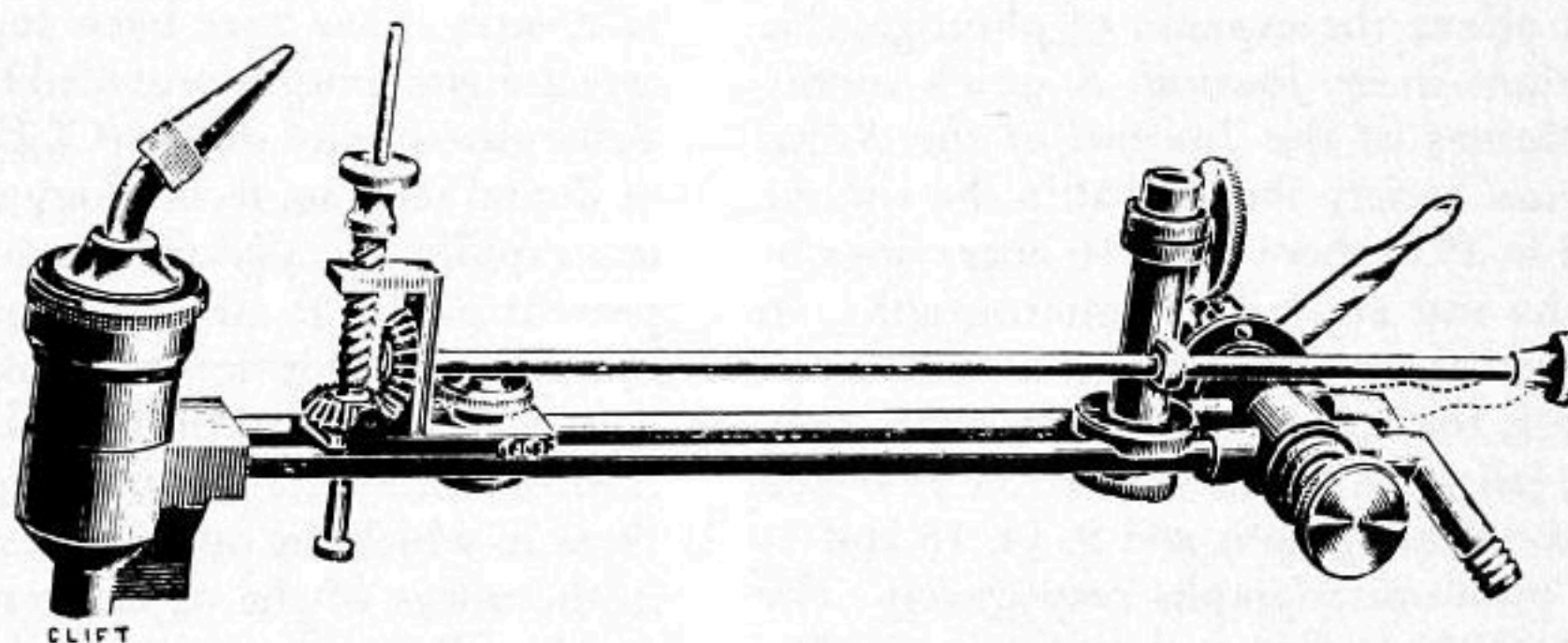
FIG. 12. The first photomicrograph used in the *Transactions of the Microscopical Society of London* (1853, 1, 57-58) to illustrate an article by Delves. The micrograph was taken on a wet collodion plate and printed on a sheet of albumenised paper which was then pasted into each copy of the journal. The upper picture is of the trachea and spiracles of the silkworm, the lower shows the proboscis of a fly.

and spiracles, reproduced here as Fig. 12) to appear in a scientific periodical (Delves, 1853). The positive prints were made on albumenised paper and each print was individually stuck in its correct place in the relevant issue of the periodical.

Later J. J. Woodward in America became well known for his high quality micrographs of diatoms, pathological tissues and Nobert test rulings. He was using the newly introduced dry plates and these, together with the later introduction of panchromatic emulsions,



A



B

FIG. 13. (A) An early horizontal photomicrographic camera by C. Baker. Note the oxy/gas burner for the lime light at the left, the separate, horizontal microscope with the extension rod to operate the fine focus and part of the horizontal bellows of the camera on the right.

(B) an enlarged view of the oxy/gas burner, showing the jet, the spike on which the cylinder of lime was held and the bevel gears to alter its position with respect to the flame. Illustrations taken from Spitta (1899).

ensured that the use of photography to illustrate microscopical observations became available to most workers. In 1864 the Woodburytype process was introduced which allowed for the first time the production of photographic prints in reasonable quantity. In this process the negative was printed onto carbon tissue to give a gelatin relief. This in turn was pressed into a lead sheet with a hydraulic press to form a 'printing plate'. A warm solution of pigmented gelatine was poured into the lead mould, allowed to set and then pressed into a sheet of paper placed in contact with it. The resulting positives still, however, had to be individually stuck onto a printed page. Woodburytypes were used to illustrate Sorby's work on the structure of metals published in 1887.

Books soon began to appear on the techniques of photomicrography (eg Spitta, 1899). Photomicrography at the turn of the century was carried out with cumbersome but very rigid horizontal cameras mounted in alignment with a horizontal microscope (Fig. 13A); because of the often high magnifications employed and the still relatively insensitive plates the light source had to be very bright. Many serious photomicrographers preferred to use limelight which required the use of an oxy-hydrogen or oxy-coal gas blowpipe (Fig. 13B) to heat the lime to incandescence. This was not without hazard for as Spitta remarks:

"Sand or water must be kept within easy reach in an open bucket, to pour over any piece of incandescent lime which may perhaps fall on the table, or more

unluckily still, on the floor. Let it be remembered that treading on an incandescent lime is not a safe thing to do, save perhaps with the heel; neither is at all times sufficient to put it out, and it may very easily cost the photographer a new sole to his boot, if not a burn on his foot."

Despite the increasing availability of photomicrography, following the introduction of faster (*ie* more sensitive) plates and the introduction of smaller, vertical cameras, the number of photomicrographs appearing in journals up to the 1950's was not large. Turner (1974) comments that lithographs were the usual means of illustrating articles in the *Journal of the Royal Microscopical Society* until 1904. This may have been a reluctance to accept the new technique of using a screen for printing a half-tone photomicrograph or it may, as Turner suggests, have been because the Society could not afford the expense of photographic reproductions in its *Journal*. A quick survey of the volumes of the *Journal of the Royal Microscopical Society* shows that in the volume published in 1930 there were 16 engravings or lithographs and eight photomicrographs. In 1940 because of wartime restrictions a count is meaningless; the volumes for 1945, 1946, 1947 and 1948, (all small and published in 1947 and 1948), had no lithographs and 5, 14, 16 and 11 half-tone photomicrographs respectively. The volume for 1950 had two engravings or lithographs but, because it was a special volume devoted to the new technique of electron microscopy, had 76 half-tone micrographs. At the present time photomicrographs, often in colour, appear to be used almost exclusively to illustrate scientific publications.

It is clear that photomicrography has several advantages when compared to drawing from the microscope. These are that the illustrations are objective, are easy to produce both in black and white and colour and show great detail of the object structure. In addition photomicrographs are regarded as a neutral and unbiased means of communicating images between microscopists. The principal disadvantages of photographs as compared to drawings are that the photomicrographs often contain out-of-focus detail which may be very confusing, and there may be problems with the shallow depth of field. This latter is especially true for high power objectives. Objections may also be raised to photomicrography on the grounds of cost of the raw materials and, if in colour, on the faithfulness of the colour reproductions.

This latter is, however, usually attributable nowadays to faulty technique. Photomicrography is still the method of choice, even though it may be superseded in the coming years by the rapidly developing techniques of digital video imaging.

Video techniques

The use of a video camera attached to the microscope has been common for some years, principally for displaying the images in real time to others for teaching, for allowing electronic enhancement of the contrast of the microscope image, and for extending the imaging of the microscope from the range of the visible into the infra-red and ultraviolet regions of the electromagnetic spectrum. In recent years the analogue signals provided by conventional television tubes have been supplanted by the direct digital output provided by cameras using a charged-coupled device (CCD). This new field of digital imaging technology is developing far too rapidly for any adequate coverage in the present paper. It may be remarked, however, that such CCD devices are sensitive to very low light levels and are thus invaluable for use in fluorescence microscopy. Digital images are those in which the optical density at each point in the image of the object is represented by a number. In a common convention of digitising these range from 0 (for black) to 255 (for an area of pure white). The large matrix of resulting numbers may be stored directly in the memory of a computer and subsequently the image may be manipulated arithmetically in numerous ways by the use of suitable computer processing (Bradbury, 1988). Such alteration by computer processing is now so easy, and the resulting images may be printed out with such fidelity, that the possibility of misleading the reader (either unintentionally or for scientific misrepresentation) must be taken seriously. It would seem essential for the caption of a digitised illustration to state clearly whether or not any enhancement or manipulation has taken place before its reproduction. High quality video images, both analogue and digital and in either colour or monochrome, may now be recorded on tape or onto disc and 'hard copy' for illustrations reproduced very rapidly by special printers linked to the camera or recorder. It seems probable that in future this form of recording from the microscope may come to challenge photomicrography.

Reproducing the illustration in print

It is not enough for information to be recorded from the microscope; it must also be made available widely to other interested parties. Books with illustrations have been available now for nearly six hundred years, printed using carved wood and later cast metal type. This process with type standing up in relief and coated with a greasy ink before passing through the press has been called 'letterpress'. The illustrations were prepared in much the same manner by using woodcuts (Fig. 14A). The illustrations from Schott and Kircher reproduced as figures 1 and 2 of the present paper were woodcuts. In this process a hard wood block has the design drawn on its smooth surface and the intervening space between the lines is then cut away with sharp chisels of various shapes and sizes. When inserted into a block of text and inked the results, although crude, do convey much of the required information.

Woodcuts were superseded for producing illustrations by the use of what is often called a gravure or intaglio process. In such methods the areas which are to print are cut into the surface of a metal plate so that they lie **below** the surface (Fig. 14A). Greasy ink is spread over the surface of the plate, also filling the incised depressions (Fig. 14B); the surplus ink is then removed from the surface by scraping the plate with a 'doctor' blade leaving ink only in the incised lines (Fig. 14C). On passage through the press the ink in the grooves transfers to the paper so forming the illustration. It is obvious that with woodcuts and with gravure processes the image is either black or white, no true gray tones are possible. There are many examples of gravure illustrations in the microscopical literature, and excellent examples are to be found for example in the first seven chapters of Carpenter and Dallinger (1901).

An alternative to the gravure and letterpress techniques in use since the early nineteenth century is lithography. This originally involved an artist drawing the illustration by hand onto the surface of a smooth slab of stone using a special ink. The surface of the stone was then dampened and the greasy printers ink applied. This was absorbed only in those areas where there was image and on passing the stone through a press in contact with paper the areas

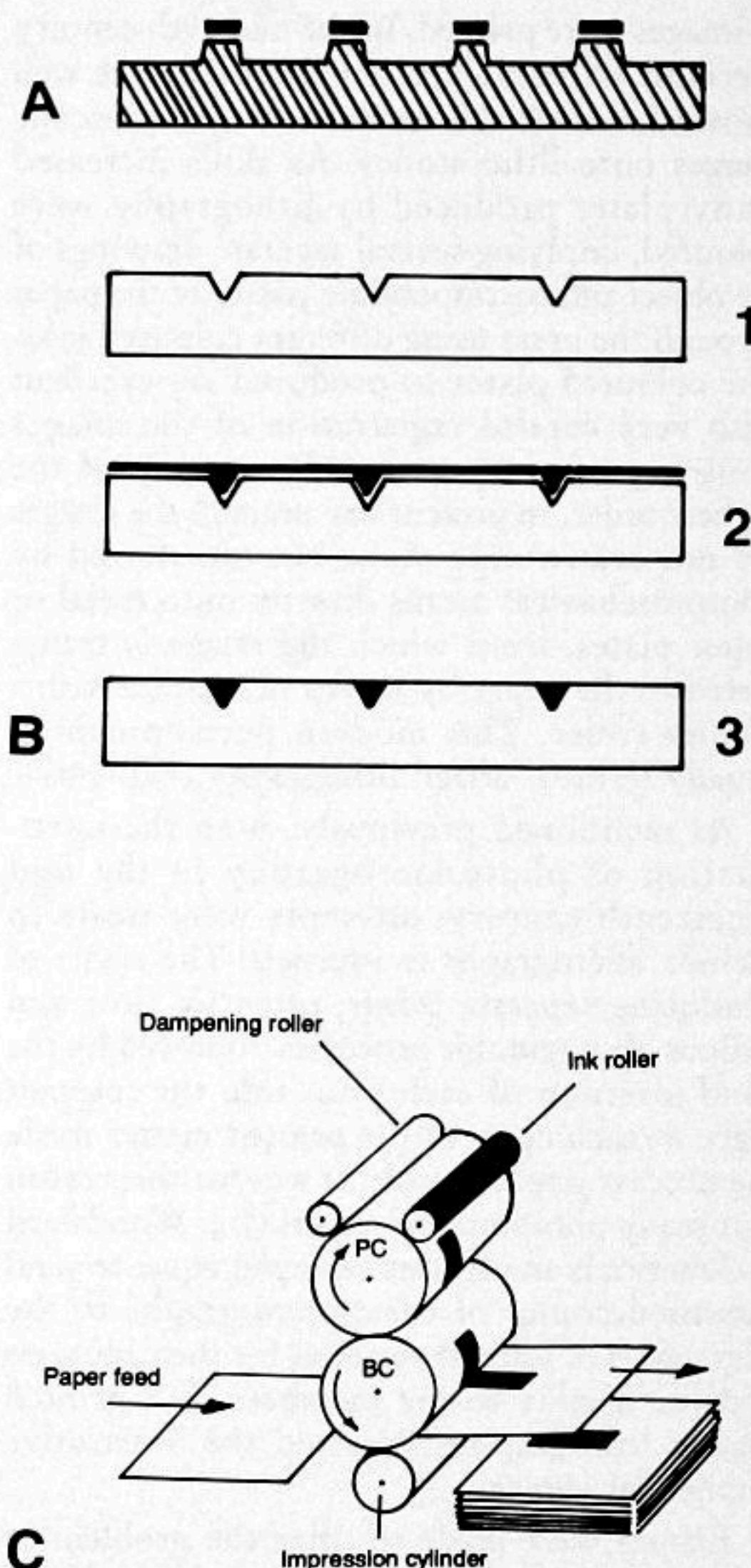


FIG. 14. (A) Wood cut or letterpress illustration. The areas to print are raised above the level of the remainder. They are shown here with the layer of ink on their surfaces which the press will transfer to the paper to form the illustration.

(B) A gravure or intaglio illustration. The image is incised or etched into the smooth metal plate (1) which is then coated with a layer of ink (2) Before printing the ink is scraped from the smooth surface of the plate with a 'doctor' blade so that only ink remaining in the incised lines (3) prints the line.

(C) The lithographic (sometimes called planographic) process. This shows the so-called 'off-set' version in which the image is reproduced photographically onto roller PC. Dampening and inking rollers run in contact with this but the ink only adheres to the area of the image. The image is transferred via the 'blanket cylinder' (BC) to the paper, the necessary pressure being applied by the impression cylinder.

of images were printed. In the mid 19th century specialist artists such as Tuffen West were well known for their skill in redrawing microscope images onto litho stones. As skills increased many plates produced by lithography were coloured, implying several separate drawings of the object and corresponding passes of the paper through the press using different coloured inks. The coloured plates so produced are excellent with very careful registration of the images implying accuracy and craftsmanship of the highest order. In present day practice the images are not drawn onto stone but transferred by photomechanical means directly onto metal or paper plates, from which the image is transferred to the paper by means of contact with a second roller. This modern development is usually termed 'offset' lithography (Fig. 14C).

As mentioned previously, with the introduction of photomicrography in the mid nineteenth century, attempts were made to include micrographs in journals. The effort of producing separate prints, often by slow and tedious photographic processes, followed by the hand insertion of each print into the relevant place in each copy of the printed matter made the process impracticable. It was for this reason that many photomicrographers (J. J. Woodward in America is an obvious example) chose to send mounted copies of their photographs to the Secretaries of learned societies for their libraries and for display to the members. For printed matter lithography remained the illustrative method of choice.

Efforts were made to solve the problem of printing photographs with all their shades of gray or 'half tones'. This was achieved with the invention in 1883 by Max and Louis Levy of the half-tone process which uses a ruled screen, a device improved by Ives two years later. This screen consists of a network of opaque lines, ruled at right angles to each other, on a glass plate which is placed just in front of the sensitive emulsion of the photographic plate onto which the image is to be copied. The grey tones in the image are broken up into a series of dots of equal optical density and equal spacing between their centres but of different sizes. The larger the dots — the darker the tone. This half tone process relies on the fact that the eye has a limited visual acuity and at the normal reading distance cannot resolve as separate two dots separated by 1/250th of an inch. Normally the dots are not seen as separate, the eye and

brain interpreting the area as one continuous shade of gray. Inspection of the illustrations in this journal with a magnifier will show the effect of the half tone screen very clearly; further details of the technique of half tone screening will be found in Langford, 1989. Although the technical methods of including half tones in journals were available for the latter twenty five years of the nineteenth century they were not often used. As already mentioned, Turner (1974) notes that half tones were not numerous in the *Journal of the Royal Microscopical Society* until about 1906 and suggests that this may possibly have been due to their expense. One is tempted to draw an analogy with the situation today concerning the reproduction of colour micrographs in journals!

Today the new techniques of electronic image scanning and digitisation, coupled with desk top publishing packages in small computers are revolutionizing the process of printing and will doubtless have their effects on the distribution of microscopical images and information. The need for good microscopy will still be present as the images, however they are processed, must originally be of the highest quality. The storage of digitised images on CD discs will become commonplace and their retrieval and documentation will become much easier. It may well be that by the end of the decade or shortly after both student and professional microscopists will call up the images from large picture libraries available 'on-line' and be able to see the best images available without even looking down a microscope! Perhaps this latter activity will become solely the province of members of microscopical clubs such as the Quekett who use the instrument for the pleasure which they gain from it!

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