Stereo Microscopy

The Stereo Microscope: Introduction and Background

2nd Edition

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Figure 1. Spider Spinneret (Silk Producing Organ) - Stereo Zoom Microscope 45X

Background

The Compound Microscope

In this paper "compound microscope" is used to stand for "non-stereoscopic microscope", although stereo microscopes are also compound microscopes,

Figure 2. Robert Hooke Microscope c. 1665 used reflected light

Most, compound microscopes, metallurgical microscopes being one notable exception, use objectives designed for specimens mounted on slides and enclosed under cover slips.

Objects are commonly flattened or cut into thin sections so they can be viewed with transmitted light, which passes through the subject before it enters the objective. Conversely, stereo microscopes view most objects using incident light that is reflected from the object before entering the lens. An exception was Hooke's microscope [i] of 1665 which used reflected light. (Fig. 2)

Compound microscopes usually have objectives designed for use with cover slips typically 0.085 to 0.640 mm thick. For high resolution imaging it's critical to correct for cover glass thickness. In the recent past, top quality, and expensive, **apo**chromatic (APO) lenses, Fig. 3, had a correction collar, to allow this adjustment, which was required on high quality high numerical aperture lenses.

Figure 3. N.A. 0.95 APO Objective with correction collar

Conversely, most stereo microscopes have dual objectives (see more detail below) designed for viewing without cover slips. They are designed to view objects at relatively low magnifications usually less than 200x, typically 10X - 40X. Although, some modern stereo microscopes can provide magnifications up to about 250x.

For most stereo compound microscopes, working distance (the distance from the bottom of an objective to the in-focus area of an object) and depth of field are relatively large. Resolution and working distance typically have an inverse relationship. Stereo microscopes provide microscopic views of the world without the need for complex object preparation. Because of their large field of view they can give us "in context" views of objects that would otherwise be impossible to obtain.

As M.C. Cooke said, and quoted in an earlier paper [ii], " ... we may be permitted to recommend the novice always commence the examination with the lowest power of his microscope ... the greatest satisfaction will always be derived from a great practical use of low powers". Although this was said for compound microscopes, it's even more relevant to stereo microscopes.

The Comparison Microscope

The comparison microscope can be considered an intermediate instrument between the compound microscope and the stereo microscope. Similar to a compound monocular microscope, it provides a single image of each object viewed, while like most stereo microscopes it has two objectives. However, unlike either microscope, it looks at two different objects at the same time. As its name implies, it is used to compare objects.

Figure 4. Bausch and Lomb
Comparison microscope. c. 1929
front View

Figure 5. Bausch and Lomb
Comparison microscope right-side view

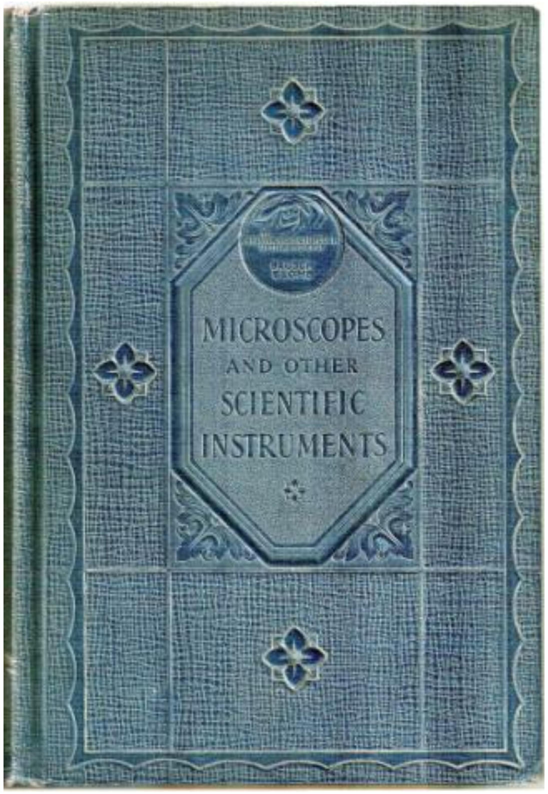


Figure 6. Bausch and Lomb's 1929 hardcover catalog

Perhaps this extract from Bausch and Lomb's (B&L's) 1929 *Microscopes and Other Scientific Instruments* book, Fig. 6, best describes this instrument.

The Comparison Microscope makes possible the comparison of any two objects that can be brought within its field, which are seen in juxtaposition through a single eyepiece. It is particularly useful to the technical expert who seeks to compare under the microscope substances, surfaces or colors. Affording, as it does, a means of accurate investigation and of ocular demonstration before courts or jury, it is of great assistance to the examiner of disputed or suspect documents.

It is especially adapted for the examination of inks, colors, erasures, changes, interlineations, and overwriting, and for the comparison of disturbed and undisturbed paper surfaces, pen, and pencil points, the tint, texture, and condition of paper surfaces, the texture and quality of typewriter ribbons, written and printed characters, and type faces. [iii]

In 1929 the comparison microscope shown in Figs. 4 and 5, with 2x objectives and 10x Ramsden eyepieces sold for USD $80.00. Other paired objectives were available for $11 and $17 respectively[iv] .

Many modern examples of comparison microscopes are often purpose-built for specific functions. One modern example, currently in use, is shown, in Fig. 7.

The Yuken Hydraulics "Microscopic Inspection Device" [v] is a comparison microscope used to measure "pollution" of hydraulic fluids. Hydraulic fluid samples are soaked up and dispersed by a membrane filter, under one of the lenses. The contamination of the dispersed fluid is compared to a standard contamination disc placed under the other objective. To provide portability, this device has built in illumination useable with either an AC or DC power sources.

Figure 7. A Modern Comparison Microscope

The Stereo Microscope[vi]

One can be excused for believing that the first stereo microscope was designed quite recently. This is true for the first practical instrument for scientific purposes. Possibly, the first "stereo" microscope, was designed by a monk in the Orders of Capuchin Friars Minor (O.F.M. Cap) also

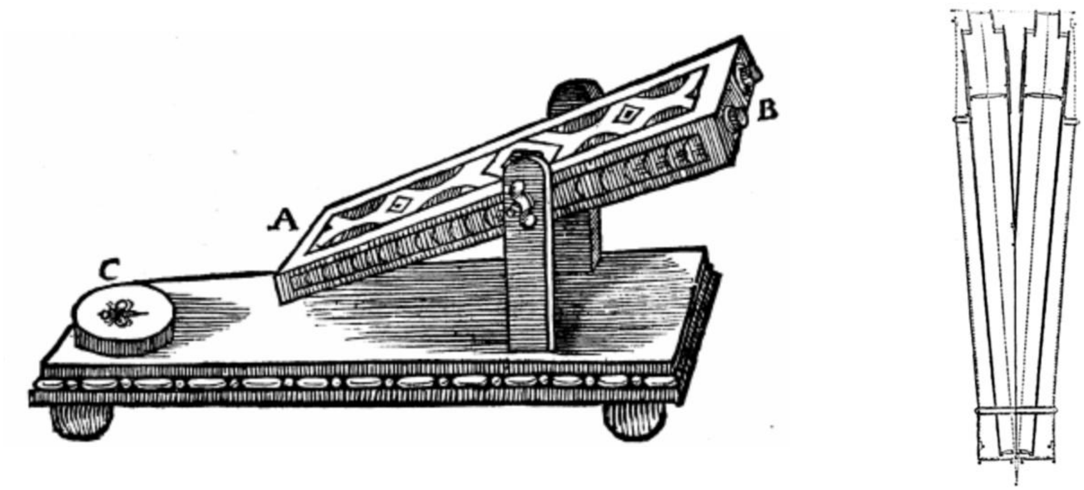


Figure 8. Père d'Orleans binocular microscope (pseudoscope)
[Ref. Journal of the Society of Arts 1886]

known as the Capuchin Franciscans; this Catholic Order derives from the Franciscans.

Father (Père) Cherubin d'Orléans (Francois Lassere) designed his binocular "stereo" microscope[vii] c. 1670s[viii] (Fig. 8). This microscope was constructed not only with dual eyepieces, but also with dual objectives, with the images to each eye reversed.

Stereo above is in quotes as this is a pseudoscopic rather than a true stereoscopic microscope [ix] [x]. In a pseudoscope images appear inverted in the vertical direction, that is high points appear low and low points high. So that object points closest to the objective appear farther away and points farthest from the objective appear closer. Thus, a toothpick viewed through Père d'Orleans microscope would appear as a mold to make copies of the toothpick.

Normally right images go to the right eye and left images to the left eye to provide stereoscopic images. However, if the images sent to each eye are reversed this is no longer true. As Dr. Kurt Schwidefsky, former head of the Photogrammetry Department of Carl Zeiss Oberkochen, notes in his book [xi], " ... if left and right images are exchanged the orthoscopic *[author: stereoscopic]* effect changes into a pseudoscopic one.

The same effect occurs if the images which are observed are rotated by 180 degrees." This 180^0 image rotation is the typical case for both compound monocular and binocular microscopes. This can be easily seen by writing "abc" in very small letters, and looking at these letters under a compound microscope using the lowest magnification available. The original and its view through a compound microscope are shown below.

abc	Original text
ɔqɐ	As seen through a compound microscope

This reversal is commonly seen using a compound microscope. It is the reason that when we move a slide right the image through the microscope moves left, and when we move a slide downward the image seen through the microscope moves upward. Compound microscope images are not seen in three dimensions, and spatial orientation is usually unimportant, so this effect is not normally detrimental to subject investigations.

The instrument shown in Fig. 8 was not the only binocular microscope designed by Père d'Orléans. He also designed a binocular microscope made of two monocular-style microscopes and held in a housing similar to a cylindrical Withering microscope c. 1678. As Wise, Ockenden, and Sartory[xii] note, although the

> *... principles of stereoscopic vision were not fully understood at the time. Nevertheless, the remarkable fact remains that the author [Père d'Orleans], in his books, had expressly recommended systems giving erect images for the monocular compound microscope. Had he used [author: any of these] his ... instrument would have rendered [author: stereoscopic images].*

D'Orleans' microscope was developed before the invention of achromatic microscope lenses, and at a time when simple microscopes provided better images than their compound relatives. Perhaps, because of the negative implications of this for serious scientific uses, there was only minimal development of the stereo microscope for the next 150 years, until the work of Prof. Ridell in the U.S., c. 1850s, who first used mirrors, and later prisms above the objective to divide the circle of rays coming from an objective into two eyepieces. The first successful binocular microscope was made in the USA by J. & W. Grunow (the Grunow brothers) according to Prof. Ridell's design. This was followed shortly by a stereo microscope from the French firm Nachet.[xiii].

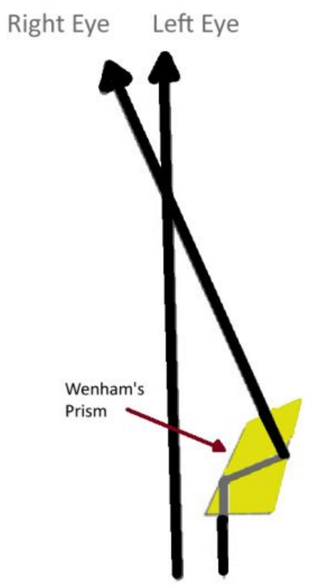


Figure 9. Wenham binocular light path

However, it was the development of the Wenham binocular, Figs. 9 and 10, that led to the rapid distribution of stereo microscopes.

The use of Wenham binoculars for stereoscopic examination has a number of difficulties. In addition to the reduced image illumination obtained with a single small aperture objective, relief is limited due to a number of factors, including (1) most objects are cut into thin sections, so relief is naturally reduced, (2) the short working distances mean that many objects cannot be placed whole under the objective, (3) cover slips may, in some circumstances, further depress potential relief, (4) the spatial separation of images is relatively small and effects relief, and (5) depth of field is quite shallow with higher magnification.

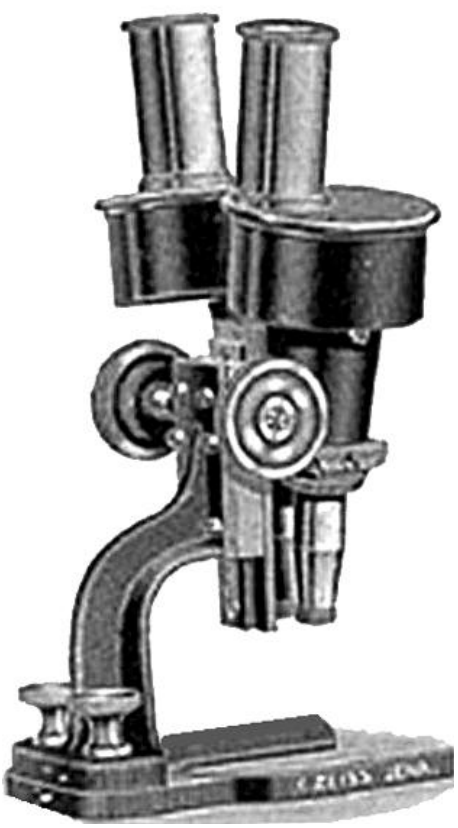
Due to the small diameter of the back lens of high power objectives, compared to the size of the Wenham prism, images are somewhat distorted by the edge of the prism at high powers, and the relief seen at low powers is significantly diminished, if present at all, when high powers are used.

Wenham binocular microscopes have prisms that can be slid outside the optical path, to allow more light to the eye when high magnification objectives are used. However, when this is done the binocular microscope becomes a monocular microscope with an unobstructed straight image path, with all the light from the objective going into the single un-tilted body tube. That is, the image is 'flat'. At low powers, Wenham binocular microscopes show relief, but not as significantly as modern stereo microscopes, and their working distances are insufficient to accommodate larger whole specimens.

Figure 10. English Crouch Wenham Binocular

These limitations were, in part, the motivation for the development of the modern low power stereo microscope, where whole objects can easily be seen in outstanding (some would say spectacular) three-dimensional relief. Most objects can be quickly (i.e., without thin section preparation or staining) placed under a stereo microscope for examination. Objects under a stereo microscope are not reversed, that is moving an object to the left moves its image to the left, and moving an object downward moves its image downward. Thus "abc" seen under a stereo microscope appears as "abc".

The modern stereo microscope, of Greenough-design, uses Porro prisms to provide erect images. This style stereo microscope was invented by American Horatio S(altstall) Greenough in the 1880s. (As an aside, Mr. Greenough was the son of, the same named, Horatio Greenough, one of the first American sculptors to gain international recognition.) Today, Porro prisms are commonly used not only in microscopes but in binoculars, where they are easy to spot owing to the tell-tale right angle turn in the viewing path. The Greenough stereo microscope design is still in wide use today. It provides images of objects that are not reversed as is typical in compound high power microscopes[xiv]. Its design is derived from the monocular compound microscope, but here with paired microscopes working in unison.



Mr. Greenough was living in Europe at the time he designed his stereo microscope. He met Ernst Abbe of the Carl Zeiss company at a hotel in Jena in 1886. Greenough drew a, now famous, diagram of his idea for a stereo microscope. Zeiss was perhaps, at that time, Europe's leading microscope maker. The timing and the meeting were fortuitous. Ernst Abbe was the world's leading expert on optics. Additionally, Abbe had become Zeiss' partner in 1875, and owned about 45% of the company. Thus, he had both the technical abilities to understand and improve Greenough's concepts, and was in a position to insure its development.

After some minor engineering modifications, Zeiss produced the first commercial stereo microscope about 1897, Fig. 11. This was known as the "Greenough double microscope of Zeiss design". Today some Zeiss catalogs for its Stemi (**Ste**reo **mi**croscopes) series use the tag line, "***Conceived by Greenough, Realized by Zeiss***".

Figure 11. First Modern Stereo Microscope by Zeiss - Greenough Design

Figure 12. B&L Stereo Greenough Microscope C. 1929

Many modern 20th and 21st century stereo microscopes use two side-by-side tubes, following the Greenough design. For example, the Bausch and Lomb (B&L) Greenough microscope in Fig. 12, shown with two detachable pair of objectives. (Here the design is quite similar to the first Zeiss Greenough, Fig. 11). Greenough microscopes are usually designed for long working distances, with a convergence angle of 10-20°. They are typically provided with the capability to adjust the separation of both binocular tubes to accommodate the interpupillary distance appropriate for any individual user.

As Marvin Reimer notes, stereo microscopes are low magnification instruments of necessity. Two objects cannot occupy the same space simultaneously. So, there is a physical limitation on how close the objectives can come to each other. That is, at some point they can be brought no closer, and that point provides the limit of magnification. [xv]

This low magnification is accompanied by relatively low resolution, compared to higher power compound microscopes. However, this resolution loss is not an issue, as more of an object is seen so that resolution reduction is balanced by the increased size of the field of view.

Early 20th century Bausch and Lomb stereo microscopes followed the Zeiss Greenoughs design and were fairly popular, as can be confirmed by the extensiveness of contemporaneous advertisements, and the number of these instruments still available today on the used market.

To provide a sense of the size and weight of these earlier Greenough designs: the Bausch and Lomb Stereo Greenough Microscope shown in Fig. 12, is approximately 13" tall in use, and is relatively heavy at almost 9 pounds. It comes with a substage mirror for transmitted light. However, a separate light source, such as the contemporary Nicholas Illuminator, was required for incident lighting. Instruments such as these usually came with detachable "arm rests", often metal or wood and metal, so they could easily be used as dissecting microscopes.

This microscope, Fig. 12, provides for slide in/out objectives. Shown beside the microscope is an optional slide-in set of 24mm objectives. In 1929 the microscope's price with one pair of 40mm objectives and 10x eyepieces was USD $126, with a second pair of objectives $149.50, and with three paired objectives $177.50.

Figure 13. Photograph through B&L Greenough Microscope

Shown in Fig. 13 is a photograph through this microscope with the 55mm objectives in place. This is a portion of a U.S. Treasury seal on a one dollar bill. It represents one of the applications, i.e., checking for counterfeit currency, for which these microscopes have been used.

As can be seen from the picture, images through this over 80 year old microscope still come into sharp focus, with good contrast, and are reasonably flat across the full field of view.

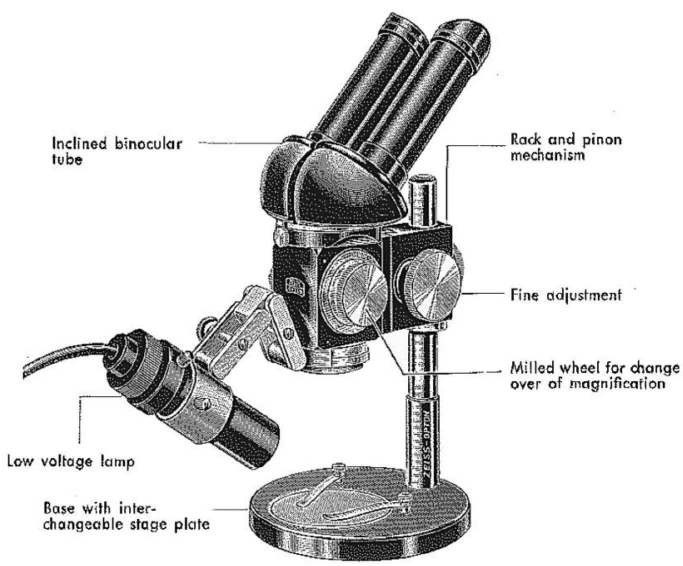
Bausch and Lomb also marketed a range of stereo microscopes, Fig. 14, that used a drum-like turret rather than the replacement option of Fig. 12 in their 'K' style stereo instruments which were available with tilted or un-tilted body tube, and were sold for, perhaps, three decades, with only modest changes over time.

Figure 14. - B&L Model BKT-5, Greenough design with rotating turret, c. 1950

Greenough-style stereo microscopes use paired objectives. So, a standard-style relatively-flat nosepiece as used on a traditional compound microscope when used on a stereo microscope needs to be fairly large, to hold the dual objectives needed for each magnification change. In spite of these size considerations, a number of companies tried this style. The Zeiss Stand XV, c. 1930s, used a standard-style, and quite large, quadruple turret with four pairs of objectives. As expected this made the microscope's width significant, and gave the microscope a unique appearance; over 700 were made. Perhaps because of its possibly impractical size, Zeiss discontinued production of the Stand XV after the war.

A less ambitious more traditional standard-style triple-turret was also used on Greenough microscopes by the AO Spencer company, e.g., in their Series 25. These had three magnifications: 1X, 2X, and 3X, but it was also dropped in favor of a drum style turret, discussed below, which allowed for a smaller and, arguably, more attractive microscope.

However, stereo microscopes with dual magnification choices and using standard-style turrets are still manufactured today. Dual objective magnifications on a stereo microscope, allow for a nosepiece similar in size to a quadruple nosepiece on a compound microscope.



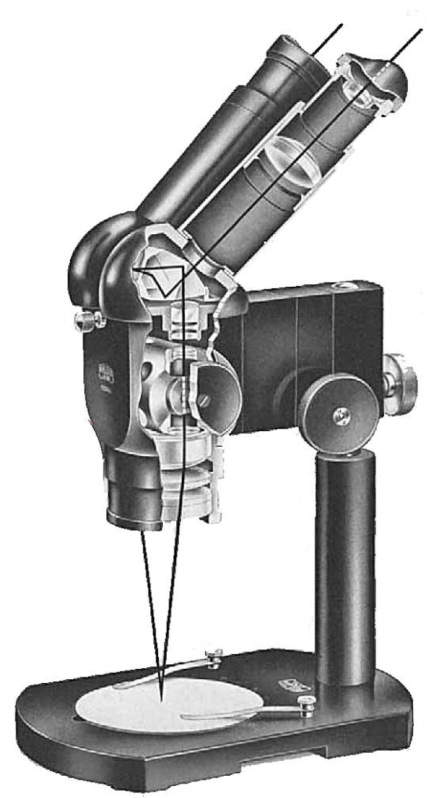


Figure 15 . From Zeiss brochures [xvi]: dates unknown. Picture at left above from West German Opton brochure (translated to English). Picture at right from Citoplast, East German, brochure

Figure 16. Zeiss Opton-branded CMO Microscope

The Zeiss Opton-branded CMO, Fig. 16, is over an inch taller and considerably wider than the Bausch and Lomb Greenough, Fig. 12, and weighs almost 50% more at slightly over 12 pounds.

To allow for a more compact design, some later stereo microscopes use paired objectives on a rotating drum-like turret, a more practical design than the standard turret style of the Zeiss Stand XV, or even the triple paired-objectives turret from AO Spencer, e.g., Series 23, 25, 26) and considerably more convenient than the removable and exchangeable objectives of earlier instruments, e.g., Fig. 12. Drum-like turrets often appear on microscopes with inclined eyepiece bodies.

The common main objective concept (although, this designation appeared later) appears to have been first developed by Carl Zeiss, Jena before 1946, and possibly as early as the mid-1930s, Figs. 15 and 16. This was perhaps two decades, before AO introduced their Cycloptic®. The first Zeiss CMO microscopes appeared commercially in East Germany as the Zeiss "Citoplast", and in West Germany under the Opton label.

The Opton version was manufactured by the Opton-Optische Werstatte Oberkochen GmbH Zeiss factory at Oberkochen, West Germany. For a period, versions of this microscope were made by both the East and West German Zeiss companies.

Production of the West German "OPTON" version, ceased in 1954, when the name of the West German Zeiss company was changed to Carl Zeiss, about three years before the introduction of AO's Cycloptic® (see below). [xvii, xviii, xix] An Opton-style CMO microscope continued in production by the West German Zeiss company until 1959, under the CARL ZEISS label. [xx] At least until the 1980s Zeiss, appears to have used CMO designs in all their stereo microscopes, except for models 01, 02, I, Ib, III, and D-series.

American Optical (AO), hoped to dominate stereo microscope sales in the late 1950s. AO achieved a major landmark in "American" stereo microscope development when they brought out the Cycloptic® microscopes [xxi, xxii]. The first American CMOs. They were designed on the Zeiss model. As with the Zeiss Citoplast, the microscope received images for both eyepieces through a bottom main objectives, large enough to support two light paths, Fig. 17 (from AO model 59F-T1).

Figure 17. AO Cycloptic "Common Main Objective" with 2/3X No. 267 achromatic aux. lens-attachment

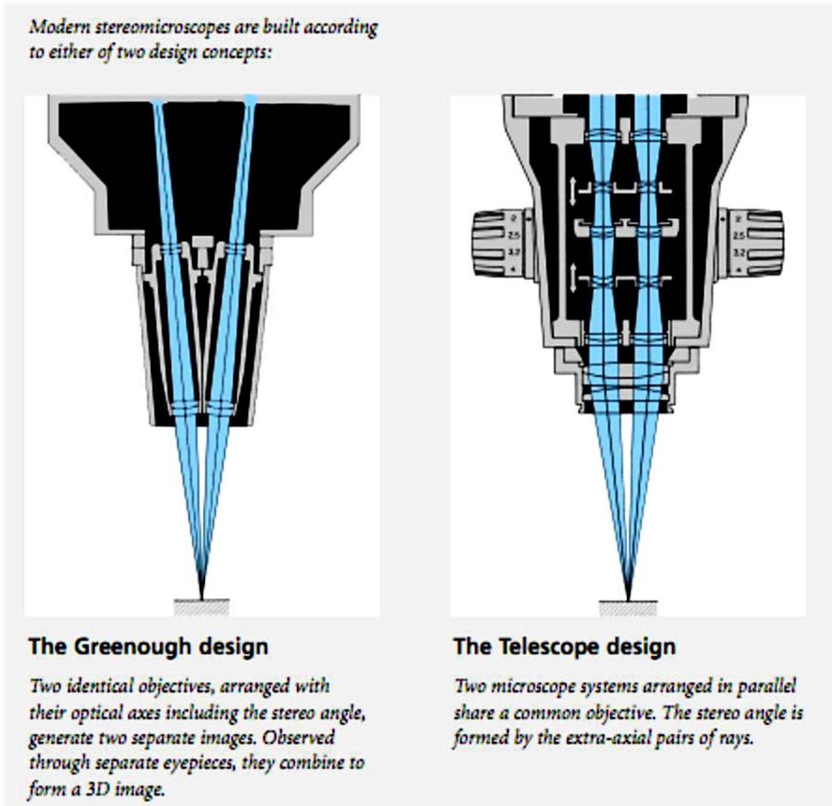


Figure 18. From the Zeiss brochure: ***Microscopy from Carl Zeiss. Stemi DR, Stemi DV4, Stemi 2000 Stereomicroscopes***

In CMO microscopes there are distinct light paths through both halves of the common lens, Fig. 18. It has the benefit of longer working distances.

Early model Zeiss CMO microscopes continued to be manufactured for some years. The Citoplast morphed, sometime in the 1950/60s, to the Zeiss SM(Stereo microscope)-20 / SM-XX, apparently, with only minor outward changes from the earlier design. The Citoplast and its derivative microscopes were popular in Eastern Bloc countries and China.

Two separate Zeiss companies had developed in the aftermath of the Second World War. Shortly after the fall of the Berlin wall in November 1989, the two separate Zeiss companies began talks and reunited in the early 1990s after East Germany's first free elections. After the reunification of the East and West German Zeiss companies, the unified company introduced the first of the Stemi Greenough models.

After the two Zeiss companies reunited they designed a new logo combining at the top a portion of the square used by the West German company, in its last logo before the two companies reunited, and at the bottom the curve from the lens logo used by the East German company.

Fig. 18 provides a comparison of Greenough and CMO designs, and Fig. 19 show microscopes using each design. Both designs have their strengths and weaknesses

The Greenough design suffers, slightly, from "keystoning" distortion due to the separation and angle of the body tubes to achieve 3D imaging. CMO stereomicroscopes have parallel paths, i.e., for practical purposes the two eyes view images at right angles to the object plane, and thus do not suffer from keystoning. Viewing objects with the eyes focused at infinity can, perhaps, be less stressful with continuous use. However, quality CMOs are expensive to make, are usually heavier, and have some optical problems of their own, see below.

The differences, although slight, can be noticed if the view through the microscope is carefully analyzed.

For non-photographic use the CMO has two minor problems: (1) due to the unusual nature to the human mind of the parallel paths for left and right images of nearby objects (parallel images only occurs naturally for items viewed at infinity), and (2) the inherent degradation of images that pass through the edges of a lens. The first issue is not a problem in photography through the microscope where images are two dimensional, and the second problem can be minimized for trinocular photomicrography by using the objective lens so its optical center coincides with the, usually, single light path used for photography.

We are used to seeing nearby objects with both eyes, at an angle, and not images in parallel. If we interpret the parallel images as coming into the eyes at an angle, this results in "perspective distortion", as the central portion of the object appears thicker than it actually is.

Zeiss helped minimized these problems, inherent in the CMO's design, with the development of their multi-element, non-APO, PLS objectives.

Leitz Greenough design

Zeiss CMO design

Figure 19. Greenough and CMO design stereo microscope

In spite of the relatively minor optical flaws inherent in CMO instruments, AO's Cycloptic® microscopes, although expensive, "led the pack", and were for a time the royalty of stereo microscopes. From the number of Cycloptic® microscopes still widely available on the used market today, the sales of these instruments, at least in Western countries, were much larger than those of the Zeiss Citoplast. Sander in his interesting and informative *Centennial Essay* [xxiii] mentions that "many [Citoplast stereo microscopes] must still be in service", and examples of the early Zeiss East and West German CMO microscopes are commonly seen on eBay.

CMO microscopes are unique, not only for their main objectives but for their use of rotating cylindrical drum assemblies (see Galilean discussion below), located above the CMO to speed magnification changes. In their CMO microscopes both Zeiss and AO used multiple pairs of lenses in a single housing to speed magnification changes, as opposed to the alternate approach in some Greenough-style microscopes, Fig. 12, of exchanging objective.

AO used single housing magnification changers of their own design in their Greenough microscopes, before the Cycloptic® was introduced. Their Greenough microscope designs were derived from the original Zeiss designs, and so, apparently, was their Cycloptic®. Thus, primacy in the two major areas of stereo microscope development belongs to Zeiss, although these developments were often capitalized on by other companies as well. Freely copying the microscope design of others was, for a considerable time, common and thus expected practice, see Kreindler and Goren, *Baker's Traveller's Microscope* (Ref.ii).

The AO drum pictured, Fig 20, contains four clear openings, in two opposite pairs, and two telescopes. The clear openings allow for "straight through" images. The dual paired telescopes have four lens groups each. The telescopes can be rotated into the optical path in opposite orientations. This allows, as with stand-alone telescopes, for the magnification or diminution of images. The drum provides five magnification options. One for the "see-thru" openings, the same in either forward or backward orientations. Four additional magnifications are available using the two telescopes on the drum, in either front or back orientations.

Figure 20. AO Cycloptic® stereo microscope drum, offering five magnifications with two telescopes and "see-thru" openings

This type of magnification changer, where the same components are used but reversed to obtain different magnifications, is often referred to as a "Galilean drum", as the drum contains small Galilean telescopes. These telescopes are frequently composed of plano-convex and bi-concave lenses. Galilean telescopes provide erect images.

The Cycloptic®, with its telescope-type drum and external markings to show magnification choices, Fig. 20, has a distinctive appearance (e.g., on its Series 59J, K, and M), and has been, and is being, used in various US TV shows including, possibly the most popular TV drama series of its time, CSI where it's used by Supervisor Dr. Gil Grissom, one of the show's lead characters.

Apparently, most of AO Cycloptic's® screw-in objectives were apochromatic, although with such low magnifications this was probably not as difficult to design as it would have been for a small high magnification compound microscope objective.

As often happens when one company's technology introduction negatively impacts sales of another, the impacted company develops its own improvements. To counter AO's Cycloptic®

microscopes, in c. 1959, Bausch and Lomb (B&L) came out with their series of StereoZoom® microscopes. Instead of providing a single or various fixed focus magnifications, B&L zoom microscopes provided continuous zooming. They used mirrors instead of Porro prisms, thus reducing both weight and cost. It was not until 1961, and the Olympus SZ microscope, that zoom stereo microscopes were introduced by Japanese companies.

Before the 1970s about 3/4 of the stereomicroscope applications were in the life sciences. The 1970s saw the rapid growth of the semiconductor industry and the use of zoom stereo microscopes for the examination of thin sheets of semiconductor material, called wafers, and integrated circuits, Fig. 21. The most common zoom microscopes used by the semiconductor industry used the Greenough design. StereoZooms, in particular, became popular with the growing technology companies in Silicon Valley[xxiv], and were sold in significant numbers. They are still widely available, e.g., almost any week on eBay, although their production stopped at the beginning of this century.

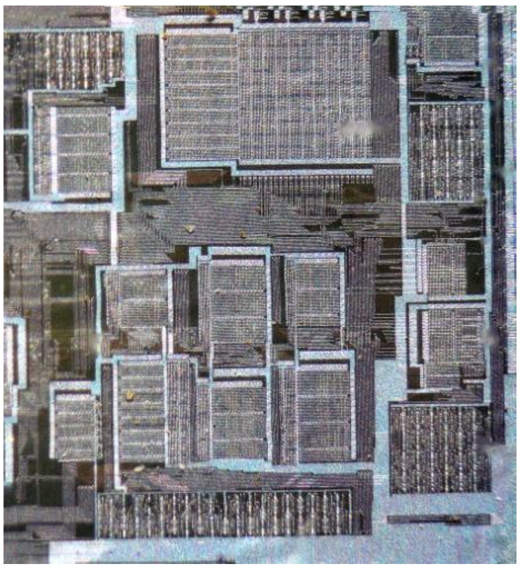


Figure 21. Portion of a damaged integrated circuit (IC) as seen through a Greenough-style stereo microscope

Many, if not most, of the StereoZoom instruments were industrial purchases. They were often used extensively, and tend to be well worn both visually and mechanically. Potential buyers need to carefully examine any possible purchase of a relatively late model stereo zoom, particularly if it's purchased for use rather than display. If an instrument's stage shows extensive wear, this is almost always an immediate indication of heavy prior use, and these instruments should usually be avoided. StereoZooms are sometimes sold as "pods" only, which can mask heavy use as it's not possible to determine stage or frame wear.

It's probably best to avoid the purchase of removed used StereoZoom pods, particularly if they shows signs of wear and rough handling.

One type of stereo microscope used daily in clinical practice is found in slit lamp instruments, Fig. 22, seen in most ophthalmologists' and optometrists' offices. Common examples of slit-lamps include models from makers already well-known to microscope users and collectors, e.g., Zeiss and, perhaps, less well known manufacturers such as Haag Streit. These instruments contain stereo microscopes, Greenough (Haag Streit), and CMOs (Zeiss), adjustable slit lamp illumination, usually a tonometer, a device for measuring intraocular pressure (IOP) in mm of mercury to test for glaucoma, a chin brace, and forehead rest on a single adjustable stand. [xxv]

Figure 22. Topcon SL-2E Slit Lamp

Slit lamps are used to examine the eye's interior, the iris, cornea, vitreous humor, and retina to allow for anatomical diagnosis. As they are built using high quality optical and mechanical components and designed for continuous medical use, they are quite expensive, but appear virtually indestructible and long functioning. Used models stay on the market only a short time as they're quickly purchased by eye care specialist. Models from the major slit lamp manufacturers such as Zeiss, the original manufacturer of the modern stereo microscope, and Haag Streit, generally retain high values in the used equipment market.

In addition to the Greenough and CMO classifications, stereo microscopes can be also be classified as zoom or fixed magnification instruments. There is an advantage in convenience in using a zoom microscope, but this should be balanced against the fixed and easily determined magnifications available when, e.g., a Galilean drum is used with its lower risk of problems.

Most professionals tend towards zoom stereo instruments, and many modern zooms offer large zoom ratios. For example, the Nikon SMZ1500 is marketed as an "optical powerhouse, with a 15:1 zoom ratio". This is an area where competitive marketing often dictates greater ratios. However, users can decide if the tradeoffs in flatness of field, color accuracy, and optical distortion of various sorts may make some larger zoom ratios counterproductive, particularly in less expensive stereo microscopes, even with the advances in computer lens design. This is similar to the problems found with large ratio SLR zoom lenses.

Conclusion

Currently microscopes can be thought of as belonging to one of four general application areas: (1) biological (including medicine), (2) geological (including mineralogy and gemology), (3) industrial, and (4) other specialized applications (including archaeology, numismatics, philately, and forensics, etc.). Although the first is probably the largest, it's in the last three areas, augmented with some notable additions from the first, where the stereo microscope finds its greatest applications.

In a compound microscope most objects to be viewed are first "sliced" into thin sections, often 1 to 100 micrometers thick. Section thicknesses toward the lower end of this range are more common. This allows transmitted light to pass through a specimen. In these microscopes working distance and depth of field are shallow, and resolution is relatively high. Most compound microscopes are built to view objects under "coverslips". However, stereo microscopes are designed to view specimens directly, without "coverslips". So they can be used to see microscopic subjects without the need for complex preparation for viewing.

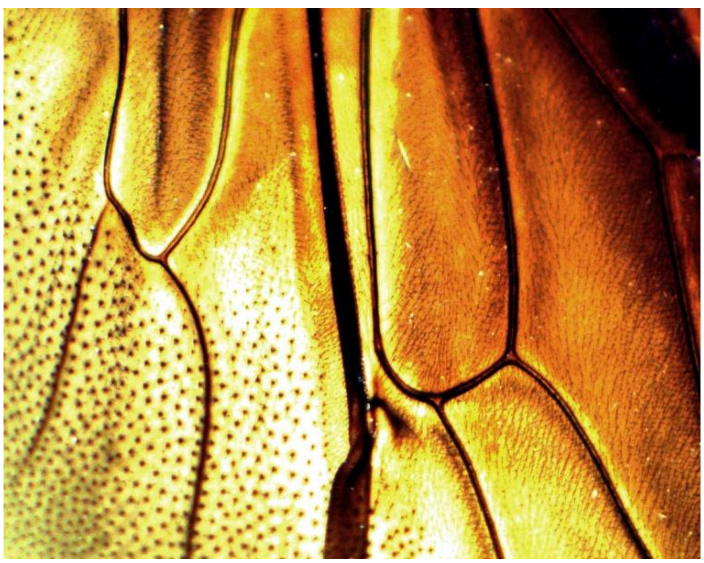


Figure 23. Distal region of wasp wing

Stereo microscopes yield quite spectacular views of larger subjects "in context", and with their larger field of view and greater depth of focus, they can provide insights that are simply impossible to get with a higher power instrument. Compound microscopes are usually used at 100x and above, while stereomicroscopes are frequently used at 40x and below. It's often best for many microscopic examinations to start with lower magnifications, the domain of stereo microscopes. Stereo microscopes show the true colors of the objects studied, Figs. 1, 23-25, as opposed to the false colors of stained specimens often used with higher magnification instruments [xxvi].

Older stereo microscopes can be attractive and were often solidly constructed and are now available at relatively low prices. However many modern stereo microscopes are available new at attractive prices. With their computer-designed lenses, built-in high-longevity cool LED illumination, and strong chemically resistant finishes, modern stereo microscopes are quite appropriate for serious use.

Figure 24. Hand dug, small crystals, Mt. Ida, Arkansas USA

Figure 25. Microfossil, MO USA

As regards illumination, LEDs generate almost no heat and last, perhaps, 50,000 to 100,000 hours, compared to the usually less than 500 hours for traditional tungsten or halogen bulbs. LEDs also use less power. Thus, it may seem that some of the more compact models with LED illumination would be appropriate as field stereo microscopes, as those with batteries can continue to provide functional illumination through many field trips. Typical modern stereo microscopes with battery powered LED illumination will last for over a week of field trips (i.e., over 48 hours of continuous use). Because of their ability to work with battery power, microscopes with built-in LEDs need not be near power outlets to use.

However, many compact and battery powered LED stereo microscopes have diminished optical quality compared to their benchtop cohorts. On some compact models built-in LED illumination can be insufficient to provide the intensity of light needed for photography. Thus, a higher quality stereo microscope without built-in lighting, can be a viable and possibly more appropriate option for field use than a compact low-cost LED instrument. If LED illumination is needed, it can be provided by external LED lamps with or without intensity controls, such as those shown in Fig. 26.

Figure 26. LED lamps. Left: Diffuse lighting with 12 LEDs, on/off only. Right: Single bulb, spot with on/off and intensity control

Although they can function satisfactorily, in general older models should be considered primarily as collectibles, in view of the quality, relatively low cost, and features of more current models. Although as noted above, this is not necessarily true for older compact stereo microscopes without built-in illumination that may be used for field work.

Many recent discontinued models by American Optical, Bausch and Lomb, Haag Streit, Leitz, Olympus starting with the SZH CMO model, Reichart, and Zeiss are generally of higher quality than most of their competition, albeit at a higher cost. However, some of these companies no longer make stereo microscopes or are no longer in the microscope business, and replacement parts are harder to obtain for discontinued instruments. Today Leica, Nikon, Olympus, and Zeiss make some exceptional top end stereo microscopes.

Stereo Microscopy

With the evolution of computer-designed lenses, many relatively inexpensive stereo microscopes sold by AmScope, Barska, Carolina Biological Supply Company (Wolfe), Swift and other modern Chinese-made stereo microscopes are of good optical quality, and available at relatively low cost. Although, with inexpensive instruments care must be taken, as some models from less well-known vendors, and low end models from known vendors can be of diminished quality.

Some factors to consider when selecting a modern stereo microscope, in addition to image resolution, contrast, and flatness of field are:

(1) an illumination intensity adjustment rather than just a simple on/off switch,
(2) the presence of top and bottom illumination that can be used simultaneously if desired,
(3) "cold light" as provided by fluorescent or LED illuminators (although this can be added as ring lighting later, it's better if also available built-in),
(4) the magnification range, a single fixed magnification is generally not as desirable
(5) the presence of zoom capability, or the number of changeable fixed magnification choices,
(6) the presence of diopter adjustments on the eyepieces, better if you wear glasses,
(7) the presence of a column height adjustment in addition to rack and pinion focusing, this can allow for a greater vertical range and the examination of taller objects,
(8) eyepoint, or eye relief, the distance above the eyepiece at which you can still see the entire field of view (FOV), high eyepoint eyepieces allow you to hold your eyes further away, (High eye relief eyepieces are particularly important for eyeglass users.)
(9) the field of view,
(10) height of the focus knob, a lower knob is usually easier to use.

One of the primary weaknesses of lower cost instruments is their often limited field of view (see below) usually measured in millimeters for the diameter of an object seen through the eyepieces. You can determine the field of view for any combination of optical components in a stereo microscope by simply placing a millimeter ruler under the microscope and counting the millimeters across the diameter of the circle seen.

Field Numbers (FNs in mm) are often placed on eyepiece housings by stereo microscope makers. Here, the larger the better. That is, if a larger field of view (FOV) is desired select eyepieces with a larger field number. To mathematically determine field of view in millimeters, when a FN is available, just take:

[Field Number of the eyepiece] / [(objectives magnification) x (auxiliary lens magnification, if any)],

assuming no other magnification changes.

Thus, if your eyepieces have a Field Number of 25, and are used with 5x magnification without auxiliary lenses, the field of view is 25/5 = 5mm. That is, about 5mm of an object diameter can be seen without moving the object. (Recall there are 25.4mm/inch.) This calculation can be worked in reverse using a millimeter ruler to determine the FN if not available for any eyepieces (see below). If an eyepiece FN is available, the magnification of the eyepiece is not needed to determine the FOV in the formula above. So, a 12.5X/23 and a 10X/23 would have the same field of view.
Today, common wide field stereo eyepiece field numbers are plus or minus:

26 for 5x eyepieces,
23 for 10x eyepieces,
20 for 12.5,
15 for 15x, and
7 for 30x.

The field number is always slightly less than the diameter of the eyepiece tube. Some stereo binocular heads may prevent the full realization of an eyepiece's field number. This is not the case for stereo microscope and their companion eyepieces made by the major manufacturers.

One way to conceal poor optics is to reduce the eyepiece field of view, so FOV should always be considered before a purchase. Fortunately, most low-cost stereo microscopes are fully satisfactory, except for more demanding research applications. Even inexpensive Chinese microscope can have reasonable FOVs. I recently measured the FOV for an inexpensive Chinese trinocular with WF10X eyepieces using an objective magnification of 1. It yielded an object diameter of 20mm. So, it had a FN of 20 (20/1 = 20mm).

Stereo microscopes make great gifts for beginners, as an object can be placed under the microscope, without preparation, and the viewer is usually amazed with the magnified 3D view they find. Also, the long working distance and relatively large distance between the stage and the objectives allow for larger objects to be examined, if desired. Stereo microscopes are also excellent tools to have for some household activities from the repair of small objects, to examining contamination in plumbing, checking knife edges for damage, looking more closely at coins, stamps, or jewelry, etc.

Modern stereo microscopes range in cost from relatively low prices, less than $50 USD to quite expensive instruments, above $6,000. More expensive models often come with higher quality objectives, high build quality, multiple pairs of objectives on a rotating turret or large zoom ratios, trinocular arrangements, longer working distances, and built-in and adjustable LED illumination for transmitted and reflected light.

With the introduction of modern relatively inexpensive Chinese stereo microscopes, there is now a "stereo microscope for every budget".

The author welcomes suggestions for corrections or improvement.

He is compiling a matrix of Leitz and Zeiss stereo microscopes, and would appreciate any information on model introduction and discontinuation dates.

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End Notes

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[ii] Kreindler, R.J. and Yuval Goren. *Baker's Traveller's Microscope*, Micscape, May 2011

[iii] Bausch & Lomb Optical Co. *Microscopes & Accessories: Photomicrographic and Micro- Projection Apparatus Microtomes . Colorimeters Optical Measuring Instruments and Refractometers. Bausch & Lomb"* New York: 1929 p 81.

[iv] Ibid

[v] The author would like to thank Kevin Hagen, of ALA industries Limited, Valparaiso, Indiana for his kindness in providing a Contamikit brochure and PDF of the "Instruction Manual".

[vi] For a no frills overview to stereo microscopes, see David Walker's short introduction. http://www.microscopy-uk.org.uk/dww/novice/choice3.htm

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[xvi] The author would like to thank Zeiss Microscopy, LLC for providing pictures and information which are included in this article. For specific individual recognition see reference directly below.

[xvii] The author's thanks to both Kristen Orlowski, Product Marketing Manager, Light Microscopes, Carl Zeiss Microscopy, LLC and Dr. Michael Zölffel, Carl Zeiss MicroImaging Gmb, Jena, Germany for the information and materials they were kind enough to provide regarding the Zeiss Citoplast steromicroscope and Zeiss history.

[xviii] Carl Zeiss, Jena. *Citoplast.* brochure. Jena: Carl Zeiss, date unknown.

[xix] Thanks to Micscape editor David Walker for providing additional references to material on the Zeiss Citoplast, and the paper by Klaus Sander.

[xx] Thanks to Fritz Schulze for his kindness in providing information on the date the change from the OPTON to CARK ZEISS logo occurred.

[xxi] Jay Phillips kindly provided a copy of Zeiss' catalog "*Mikroskope für Wissenschaft und Technologie" (1951)*. This confirms Zeiss as an earlier developer of the CMO stereo microscope.

[xxii] Nikon Microscopy U in their "*Introduction to Stereomicroscopy"* states, "The first modern stereomicroscope was introduced in the `United States by the American Optical Company in 1957. Named the **Cycloptic**®, this breakthrough design...". Although this introduction was a landmark in American stereomicroscopes development, as this paper notes, the common objective concept was developed by Zeiss at least a decade earlier.

[xxiii] Sander, Klaus. *An American in Paris and the origins of the stereomicroscope*. Institut für Biologie I (Zoologie). Freiburg, Germany: Springer-Verlag, 1994

[xxiv] Having worked in silicon valley for a number of years, the author saw the extended use, and occasionally abuse, of stereo microscopes in the semiconductor industry.

[xxv] Thanks to Dr. Mark L. Bryant and his staff for permission to photograph their Topcon slit lamp.

[xxvi] Kreindler, R.J. and Yuval Goren. *Comparison of the Swift FM-31 Portable Field Microscope and an FM-31 Clone,* Micscape, March 2011, Figs. 11, 12, and 13.

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