

The Stereo Microscope

Part 1: Introduction and Background
3rd Edition

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Figure 1. Spider spinneret, stereo zoom microscope 45x

Introduction

Although not as widely recognized as standard biological compound microscopes, stereo microscopes are widely used. In addition to their real world uses, some discussed in this paper, they are often seen in television shows and movies, particularly those containing elements of forensic science.

For example, the American Optical (AO) Cycloptic® microscope with its unique appearance (discussed in more detail in Part 3), and distinctive Galilean drum markings has been used in various US TV shows. This includes, possibly the most popular TV drama series of its time, *CSI* (Crime Scene Investigation) where it was used by Supervisor Dr. Gil Grissom, Ph.D. Olympus SZ series stereo microscopes are seen on *CSI:NY* (Crime Scene Investigation: New York). On *Bones*, an Olympus SZX7 is used by one of the show's continuing characters, entomologist Dr. Jack Hodgins, Ph.D. On *Body of Proof* the American TV series starring Dana Delaney as Dr. Megan Hunt, MD, Dr. Hunt is often seen using a stereo microscope.

A Leica MZ series stereo microscope appears on the BBC's *Sherlock* (c. 2010). *Sherlock* is a modern dramatization of Sir Arthur Conan Doyle's famous detective, and a Leica stereo microscope is often used by the title character, Sherlock Holmes. In this series the images, which appear to be seen through the MZ microscope, are often created using 'artistic license' and can be computer simulations or scanning electron microscope (SEM) photographs.

It's likely camera distributors pay for product placement and display on these shows, as camera names are often prominently visible. However, although they are relatively ubiquitous in forensic dramas, these shows rarely display the names of the stereo microscopes used, and if present the names and logos are often blurred or otherwise obscured.

Background: The Compound Microscope

In this paper the term "compound microscope" is restricted to mean a standard "non-stereoscopic" monocular or binocular microscope, although stereo microscopes are also compound microscopes.

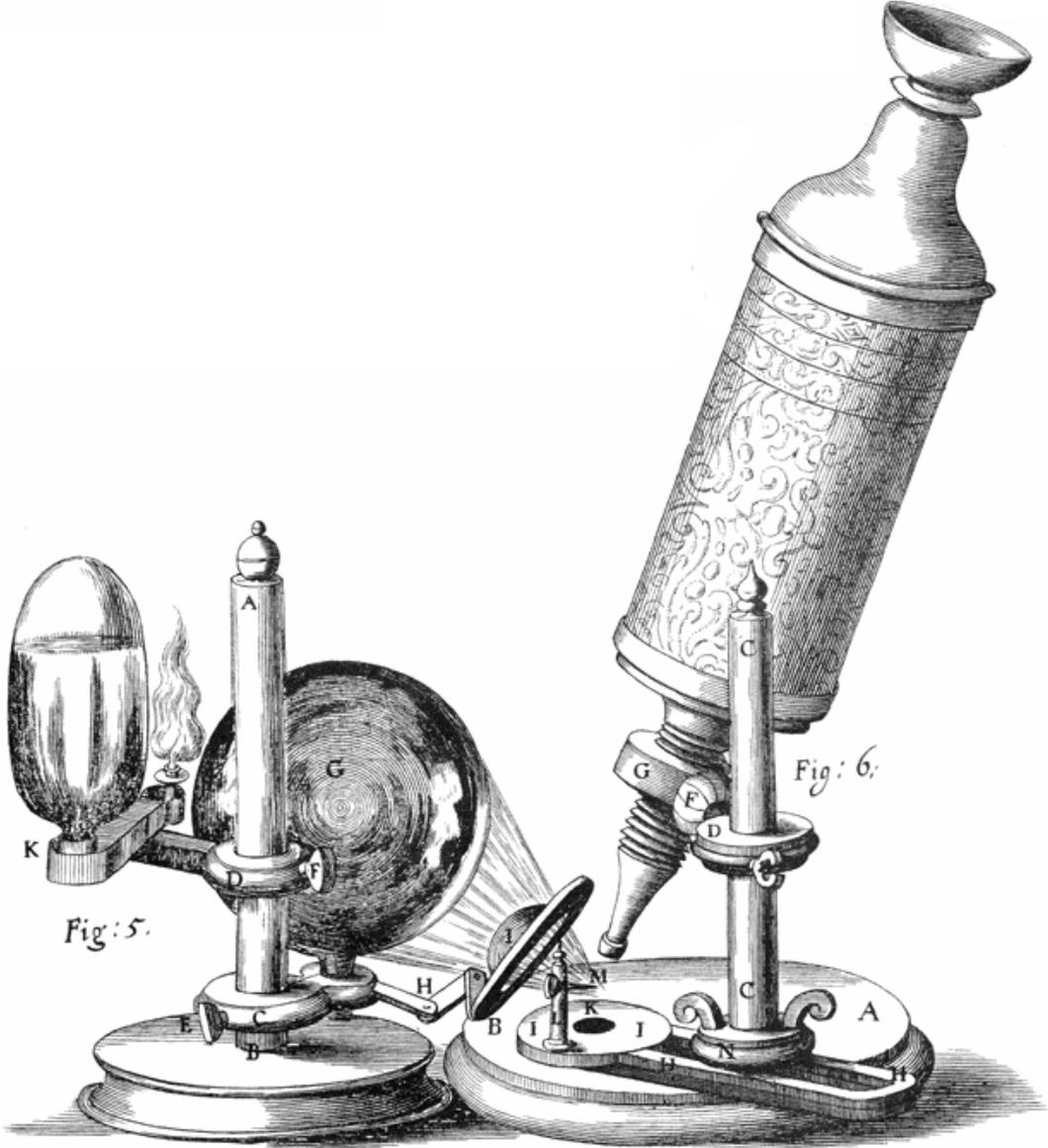


Figure 2. Robert Hooke Microscope c. 1665 used reflected rather than transmitted light

Most compound microscopes, metallurgical microscopes being an 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, light is reflected from the object before entering the lens. Early compound microscope were an exception. For example, Hooke's microscope of 1665 used reflected light, Fig. 2.



Figure 3. AO high N.A. 0.95 APO Objective

Later compound microscopes usually used transmitted light. For high resolution imaging it's critical to correct for coverslip thickness. In the recent past, top quality, and expensive, apochromatic (APO) lenses, e.g., Fig. 3, had correction collars. This allowed for the optical adjustments required on high quality, high numerical aperture lenses to account for variations in coverslip thickness. The Royal Microscopical Society (RMS) standardized coverslip thickness at 0.17mm (the current standard for No. 1.5 coverslips). This standardization significantly diminished the need for correction collars on objectives to be used in examining modern slides. However, owing to coverslip manufacturing

variations, high magnification, high N.A. objectives can still benefit from the presence of correction collars which may be needed to adjust for potential optical aberrations.

Most stereo microscopes, and comparison microscopes (described in the section to follow), have dual objectives designed for viewing without cover slips. They're designed to view objects at relatively low magnifications, typically 10x - 40x.

For most stereo 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 Kreindler (Kreindler, May 2011), " ... 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 clearly applicable to stereo microscopes.

Background: The Comparison Microscope

In 1911 W. & H. Seibert marketed the first comparison microscope, designed by chemist W. Thörner for food quality control. It was followed shortly by comparison microscope models from other German makers, such as Leitz, and U.S. manufacturers (Mappes, 2005). Pictures of a Seibert comparison microscope can be seen on-line at the *Museum optischer Instrumente* (Mappes, 2005-2006).

Seibert's comparison microscope used two substage mirrors. Similar dual mirrors had already been used by Riddell (Fig. 12) in his stereo microscope c. 1853.

Although neither a stereo or standard compound microscope, the comparison microscope can be considered an intermediate instrument between the typical biological compound microscope and Greenough stereo microscopes (Greenough's design is discussed in Part 2).

Similar to a compound monocular microscope, a comparison microscope provides a single image of each object viewed, while like a Greenough stereo microscope 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

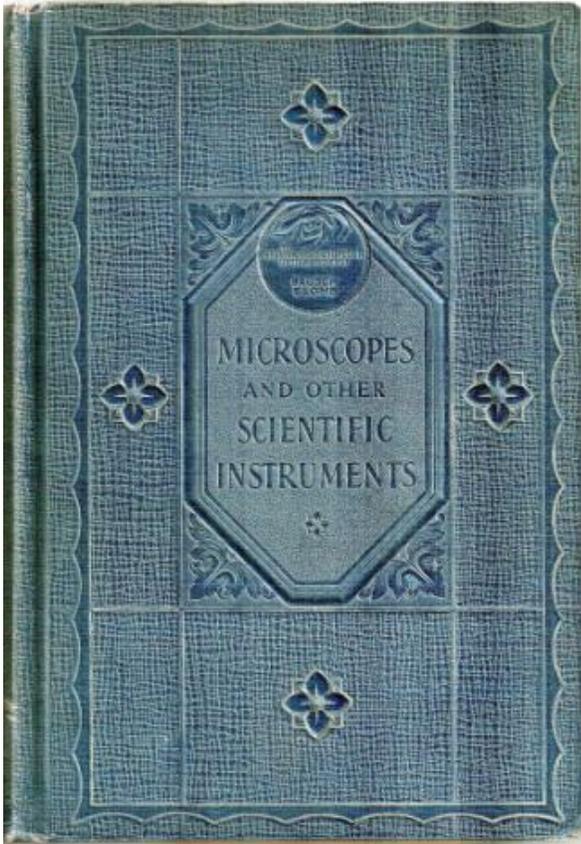


Figure 6. Bausch and Lomb's 1929 hardcover catalog

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.

-- (Bausch and Lomb, 1929).

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.

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

The Yuken Hydraulics "Microscopic Inspection Device" (Hagan, 2011) 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 source. This is a relatively heavy instrument weighing about 10 pounds.

Figure 7. A Modern Comparison Microscope



Background: The Stereo Microscope

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. However, over three hundred years ago, the first "stereo" microscope, was designed by a monk in the Orders of Capuchin Friars Minor (O.F.M. Cap), also known as the Capuchin Franciscans, a Catholic Order deriving from the Franciscans.

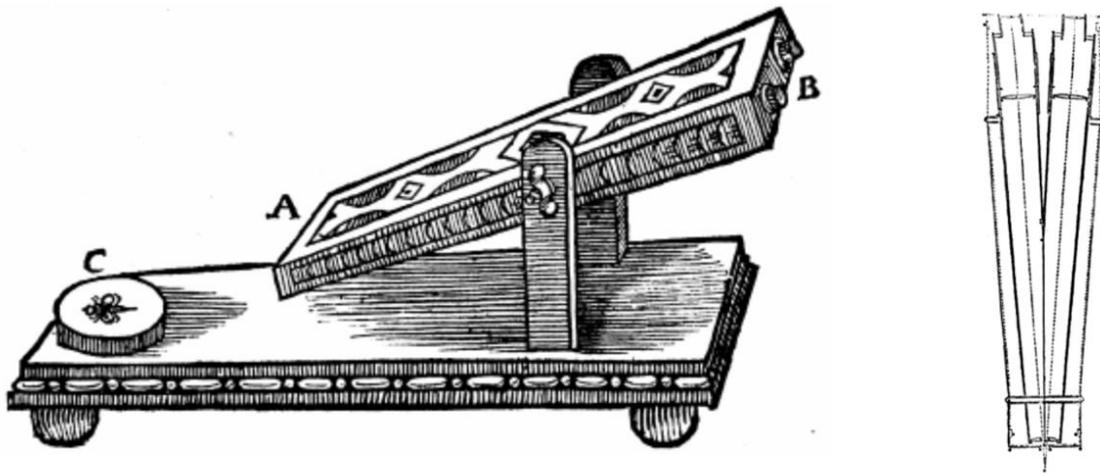


Figure 8. Père d'Orleans binocular microscope (pseudoscope) [Ref. Journal of the Society of Arts 1886]

Father (Père) Cherubin d'Orléans (Francois Lassere) designed his binocular "stereo" microscope, Fig. 8, c. 1670s, (Journal, Nov. 1886), (Cherbun, 1677). 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 (Wade, 1998), (Encyclopaedia Britannica, 1910). 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 Dement of Carl Zeiss Oberkochen, notes in his book (Schwidefksy, 1950), " ... 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 degree image rotation is the typical case for both standard 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
ꞨꞨꞨ As seen through a compound microscope

This reversal is always seen using a standard compound microscope. It's the reason when we move a slide right the image moves left, and when we move a slide downward the image 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 (Wise, 1950) 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 use, only modest development of the stereo microscope took place over the next 150 years. The next major advance was achieved by Prof. Riddell in the U.S., c. 1850s, see below, who used prisms above the objective to divide the circle of rays coming from an objective into binocular eyepieces. (Ferraglio, 2008).

However, that development would first require a greater understanding of 3D vision.

Understanding Stereoscopic Vision

As mentioned earlier, the first "stereo" microscopes were pseudoscopes, e.g., the microscope built by Cherubin d'Orleans, rather than true stereoscopic instruments. An understanding of optical principles gradually evolved, due initially to the work of English scientist Sir Charles Wheatstone c. 1833, and was documented in his *Contributions to the Physiology of Vision*, (Wheatstone, 1838). Wheatstone is perhaps best known to electrical engineers for the Wheatstone bridge (which was not his invention), to communications engineers for his work on the telegraph, and to cryptographers for his Playfair cipher. He was, in the best Victorian tradition, a "man for all seasons". However, he's rarely identified for his invention of the stereoscope.

Wheatstone's initial work on the stereoscope was later improved by Sir David Brewster c. 1849. Wheatstone's and Brewster's stereoscopes were devices for viewing two not quite identical images to produce a 3D view. Fig. 9 shows an example of a Brewster style stereo viewer.

Wheatstone's original interest in stereoscopic vision related to the development of the stereoscope, but his optical investigations were important for their understanding and explanation of 3D. Wheatstone's stereoscope was developed before the widespread use of chemical photography. Thus, it was necessary for him to commission artists to draw pictures he felt would be viewed as three dimensional. His papers were key to the later development of the modern stereo microscope.

It was Queen Victoria's interest in the Brewster stereoscope, seen at the London Exhibition of 1851, that generated widespread public awareness and interest.

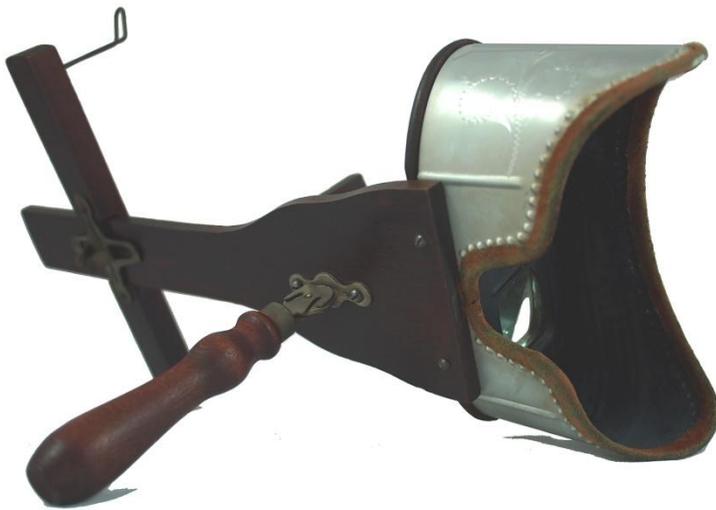
Later in the United States, Oliver Wendell Holmes (the son of the Associate Justice of the Supreme Court of the United States, whose life is documented in the 1950 movie *The Magnificent Yankee*, and grandson of the medical doctor and writer of the same name) developed an American stereoscopic viewer.



Figure 9. Brewster-style stereoscope. Courtesy, and with permission of Rainer Maertin, www.photoarsenal.com

This development combined with the growth of photography led to growing popularity and sales of stereo viewers. The Holmes Stereo Viewer was popular for almost 60 years, starting in the latter 19th century.

Brewster-style stereo viewers, primarily made of wood, are today relatively expensive antiques, but are still often found for sale. After changes and simplification the Brewster stereoscope evolved to become the parlor stereo viewer popular in the early 20th century, Fig. 10. These modern viewers are unmistakably similar to the Brewster stereo viewer. As a major contributor to the Encyclopaedia Britannica editions of 1842 and 1860, Brewster was able to document his work for a larger audience.



Inexpensive stereoscopes made of wood and metal were common sights in many middle and upper class households in the 20th century, and remained popular for about 60 years, diminishing gradually with the rise of radio and movies.

Figure 10. 20th century (Holmes-Bates) stereoscope. The Monarch. Keystone View Company.

The ubiquitous stereoscopes, also known as stereo viewers or stereopticons, were open viewers of Holmes' design, improved by Joseph L. Bates, and often referred to as Holmes-Bates stereo viewers.

The most widespread viewers and views, at the start of the 20th century, were those made by the USA's Keystone View Company, although other companies, e.g., Underwood and Underwood, H.C. White, and Sears also produced these instruments. Stereo viewers were, in their time, often the primary device that brought the distant world to local living rooms.

Waldsmith (Waldsmith, 1991) provides a more detailed discussion on the history of stereo viewers and views.

Stereo Microscopy

The popularity of stereo viewers led in the 1930s to the development of the *Tru-View* stereo viewer which used 35mm film strips with over a dozen stereo images per strip.

Tru-View was eventually acquired by View-Master, the makers of the *Sawyer View-Master*, designed by William Gruber. Many readers of this paper may have used a *Sawyer View-Master* as children. View-Masters are still sold today by Fisher-Price, usually for about USD \$9.00, and are marketed primarily to pre-teens.

Stereo camera and viewers are still available. Fig. 11. shows an inexpensive digital 3D camera currently available, c. 2012. Other stereo digital camera and accessory manufacturers include SVP, Fujifilm, Loreo, etc. Many TVs are now 3D capable.



Figure 11. Digital 3D camera and viewer, c. 2012

It was the evolution of understanding of 3D vision, following on the work of Sir Charles Wheatstone in the 1830s and his intellectual descendants, that led to the development of modern stereo devices and the stereo microscope (see below).

Designs of Prof. John Leonard Riddell of New Orleans, USA

Wheatsone's publication (Wheatsone, 1838) and his subsequent work influenced researchers in England and the US to explore further development of stereoscopic devices. The first functional stereo microscope was made in the U.S. by J(ulius) & W(illiam) Grunow according to Prof. J. L. Riddell's design, c. 1853. Riddell had likely been influenced, directly or indirectly, by Wheatsone's work.

The two Grunows were brothers, and were joined briefly by a third brother Charles. The formal designation "Grunow Bros." was used only briefly as the company name. (Over time, the brothers went their separate ways.) The Grunows were known for the quality of their instruments, which compared favorably to those of British manufacture. The Riddell microscope, and the design of its prisms, is shown in Figs. 12 and 13. An example of Riddell's microscope can be found in the Billings collection, Fig. 257 (Purtle, 1987).

The description in Billings states that the Riddell microscope in their collection is 16 inches tall, and it includes the inscription "*Invented by Prof. J. L. Riddell, University of Louisiana, Made by the Grunow Broths. New Haven, Conn*"

One of the seminal features of the original Riddell microscope is the use of two substage mirrors, i.e., two light sources to independently illuminate each of the microscopes. This dual illumination feature would continue to be used in more recent times. For example, it is used in conjunction with the Bausch & Lomb Stereo 240 microscope designed for photo interpretation, and discussed later in Part 2 of this paper.

Note the prisms atop each eyepiece in Fig. 12. These not only negate the need to look directly down into the eyepiece tubes but, perhaps more importantly, they're also used to produce a normal orientation of the image, i.e., erecting vertically the images which were corrected horizontally by the lower set of prisms. The final result, for the user, are images where movements at the stage are shown correctly, not inverted, i.e., movement to the right is shown as movement to the right, and movement upward is shown as movement upward. (*Ferraglio, 2008*).

The Riddell microscope in Fig 12 uses two independent light paths through a common relatively small objective with prisms above the objective to divide the circle of rays coming through the objective into two eyepieces.

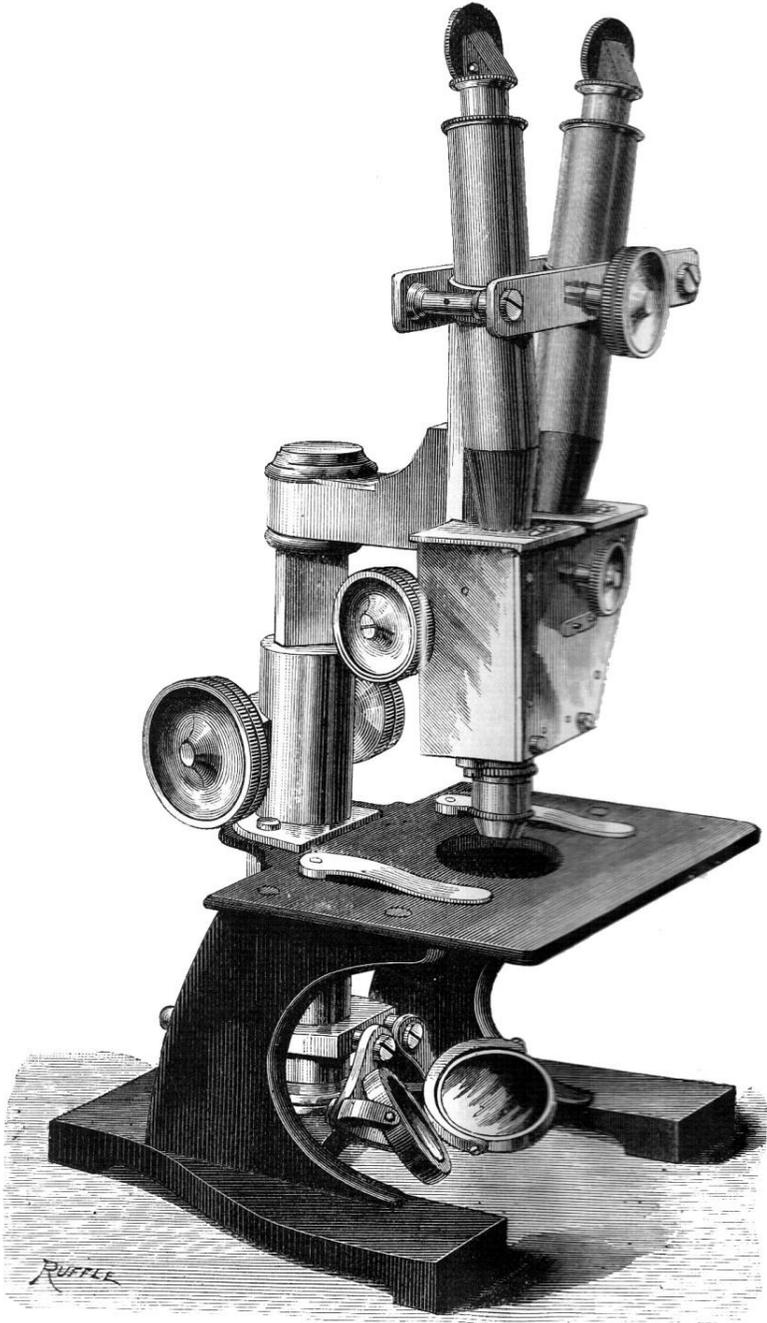


Figure 12. A representation of Riddell's original microscope, slightly software enhanced, by the author (Carpenter, 1901)

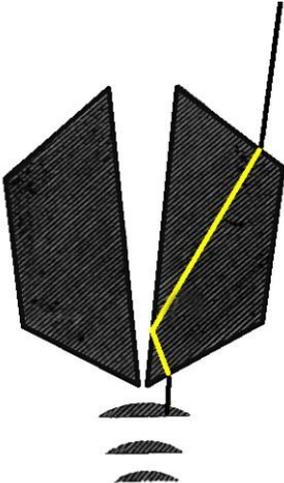


Figure 13. Riddell's Trapezoidal Prisms (Carpenter, 1901) Modified here for illustration

As can be seen in Fig. 13, both light paths go through a common objective. The use of a common objective would evolve in the 20th century into the Common Main Objective (CMO) stereo microscope discussed in more detail in Part 3 of this paper.

As Ferraglio notes,

Despite its useful features, novelty, and production by America's premier microscope maker of the time. Riddell's binocular microscope seems to have failed in the marketplace. Only one example survives: Riddell's own microscope ... It seems demand for such a microscope was very low during these early years of microscopy in America.

Stephenson Stereo Microscopes

Fortuitously, the basic design of Prof. Riddell's microscope was discovered independently, several decades later, by John Ware Stephenson, R.M.S., F.R.A.S of England. Stephenson was elected to the Council of the Royal Microscopical Society and was its Treasurer c. 1880s. He was also a contributor to the Encyclopaedia Britannica.

One of Stephenson's modifications used Riddell-style prisms (possibly made by Browning), that were much smaller, and were mounted inside a small tube that projected from the microscope and extended into the objective housing in close proximity to the back element of a lens. That is, the prism and its housing stayed with the microscope and not with the objectives. The Riddell-Stephenson design, with various modifications, was used in some 19th and early 20th century British binocular microscopes. These microscopes were produced by various British makers, including Ross (although these are rarely found), John Browning, Charles Baker of London, and James Swift & Son of London. Swift is the maker most commonly seen, (Ferraglio, 2008).

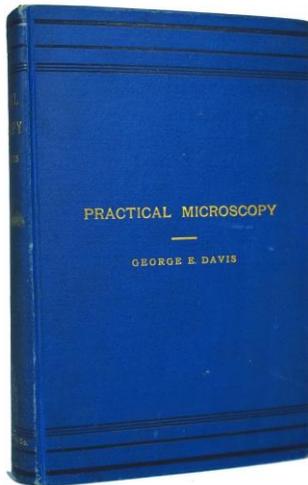


Figure 14. George E. Davis.
Practical Microscopy, 1882

See, Kreindler and Goren (Kreindler, March 2011) for the differences between the unrelated Swift companies in England and the US.

A picture of a Stevenson style binocular microscope, made by Swift, can be found in the Truman G. Blocker, Jr. History of Medicine Collections, *Fig. 1.020*, (Blocker 2012), as well as in the article, *Introduction to Stereomicroscopy (Fig. 1.)*, at NikonU (NikonU, undated)

As will be discussed in a later section, the Riddell-Stephenson design can be considered the precursor of the modern common main objective (CMO) stereo microscope.

A picture of a Riddell-Stephenson binocular made by John Browning, along with a brief discussion is given in Davis (Davis, 1882). Figures 15 and 16, taken from Davis, show this microscope and its prisms.

Stereo Microscopy

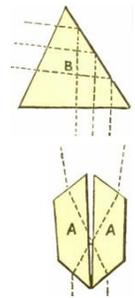
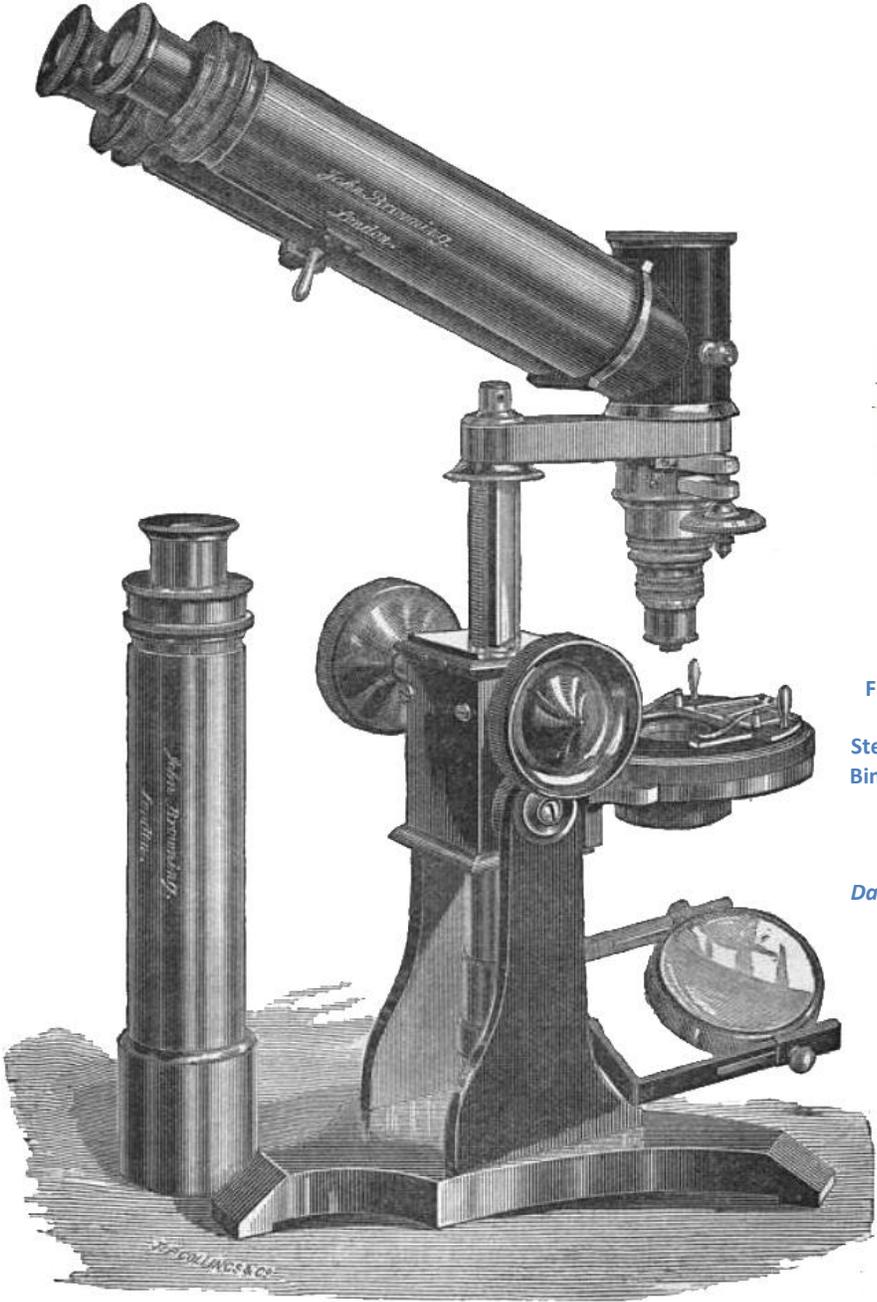


Figure 16. Prism designs for Stephenson Stereo Binocular shown at left. Modified and colored from Davis (Davis, 1882)

Figure 15. Riddell-Stephenson stereo binocular microscope made by Browning. (Davis, 1882)

Wenham Stereo Microscopes

However, it was the development of the Wenham binocular, Figs. 17 through 19, that led to the rapid distribution of stereo microscopes.

As can be seen in Fig. 17, Wenham used a single prism, different from that used in Riddell's microscope, to reflect half the semicircle of light entering the objective into an angled tube. The remaining half of the semicircle of light passed unobstructed and without reflection by Wenham's prism into the other eyepiece tube.

As the images from the objective are reversed, as in a normal microscope, to obtain a stereoscopic effect the image from the right-side of the objective must be sent to the left eye, and the image from the left-side of the objective to the right eye. If these images had not been crossed, to go to opposite eyes, the resultant image would have been pseudoscopic, as in the binocular microscope of Père d'Orleans, Fig. 8.

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, Fig. 18b, to allow more light to the eye when high magnification objectives are used. However, when this is done the binocular microscope becomes a non-stereo monocular microscope, with a prism-free image path, with all the light from the objective going into a single 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. Also, as the light paths are not similar, the illumination variations to the left and right eyepieces make these microscopes more fatiguing for some to use.

Stereo Microscopy

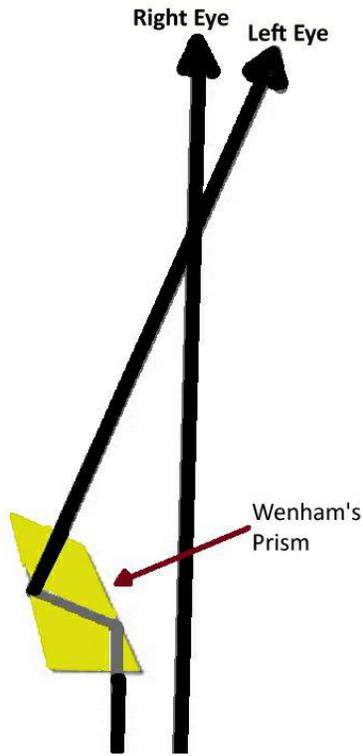


Figure 17. Wenham binocular light path

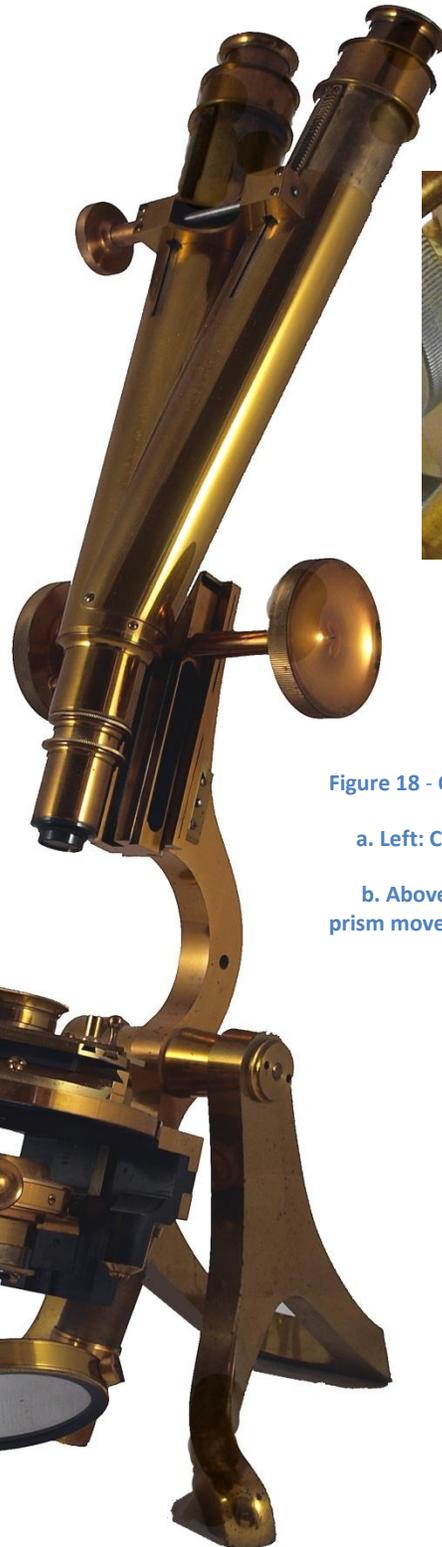


Figure 18 - Crouch Wenham Binocular

a. Left: Complete view

b. Above: Close-up with Wenham prism moved out of light path

Figure 19. Collins Ladderback
Wenham Binocular



Nonetheless, the Wenham binocular microscope, in various versions, dominated the production of British, and American, binocular microscopes in the 19th century. Wenham English binocular microscopes are easily identified by their one "straight" and one angled tube, Figs. 18 and 19. Wenham's binocular microscopes were suited to the longer English tube length of 10 inches. However, this prism design did not work well for continental microscopes with their shorter tube lengths, slightly over six inches.

The wide acceptance of the Wenham's binocular design may not have been due to its stereoscopic capabilities but its being a binocular, instead of a monocular, microscope. Using both eyes, as occurs in a binocular microscope, is usually more comfortable for users.

The stereoscopic limitations of Wenham binocular microscopes 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. An object's image is not reversed by a stereo microscope. 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 Wenham binocular presents dissimilar light paths to each eye. Light not going through the prism provides relatively greater intensity to its eyepiece than light traveling through the prism does to its eyepiece. Thus, it is the Riddell-Stephenson design, rather than the Wenham design, that should be considered the direct predecessor to the Common Main Objective (CMO). A discussion of CMOs is given in Part 3 of this paper.

As Wenham's prism design proved inappropriate for continental instruments, other style stereo microscopes were developed in Europe, initially by the French firm Nacet, (Moe, 2004).

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The author welcomes any suggestions for corrections or improvement. He can be reached at:

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Combined References and End Notes

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