Who was Horatio Saltonstall Greenough?
Part 2

Berndt-Joachim Lau (Germany) R. Jordan Kreindler (USA)

7. His Zoological Activities and his New and Old World's Tutors

The first European trace of HSG as an adult concerns his only one known biology-oriented education: In 1887 he worked in the histological laboratory and in 1888/89 he is mentioned as a student at the National Museum of Natural History, Paris (Muséum national d'histoire naturelle, MNHN) [Pouchet, 1888]. Founded in 1793 during the French Revolution, it became a rival to the University of Paris in scientific research during the 19th century.

Figure 14. Belmont et de Bassano Hotel in American style (postcard by Gorce et Allard, Editions d' Art, Paris)

His address, 30, Rue de Bassano, Paris, is documented by the Société Zoologique de France on the occasion of his admission in1888 [Bulletin, 1896]. He lived in the Belmont et de Bassano Hotel located not far from Champs-Élysées and the recently built American Cathedral, in between the Seine river and Arc de Triomphe. Up to now, this lovely 4.0 Star Hotel has kept the traditional American Style.

In HSG's study period, the Eiffel tower was constructed nearby as an entrance to the 1889 World's Fair. In a letter of July 30th, 1889 to his friend in Boston, A. Lawrence Lowell (1856-1943), HSG wrote "perhaps you will be coming over for the exhibition, which by the way is well worth seeing …Should you come look me up at 30 Rue de Bassano, Paris always my head quarter … We Americans have I am sorry to say made rather a poor show though we have some first rate things, several good pictures, the Edison phonograph & Tainter graphophone both much admired, the Rockwood pottery & in the Machinery gallery the Electric welding machines, amongst the most interesting of the whole exhibit in that section, & as I think of great practical utility" [Harvard 13/30].

The 43 year old HSG had to walk one hour to the Museum of Natural History. So the selection of the Bassano Hotel in its central location was more advantageous for his Mother Louisa, 76, who also lived there. HSG's Sister, Mademoiselle Charlotte-Gore showed her painting "Entrée du château de la Grand' Cour, prés Dinan" *(Castle Entrance from Main Yard, near Dinan,* the authors*)* on the 106th exposition of Societé des Artistes Francais which was held in the Palais des Champs-Élysées in 1888. She lives in Dinan on the Rance River, Côtes-du-Nord [Societé, 1888] or what is today the Côtes-d'Armor department of Brittany. Later she had her residence there as a married lady.

The French naturalist and anatomist C. H. Georges Pouchet (1833-1894) was professor of comparative anatomy at the Museum of Natural History Paris and also director of the maritime laboratory at Concarneau, Finistère department of Brittany in north-western France. This laboratory was established in 1859 and is the oldest permanently working one of its kind in Europe. The second floor of the building contained guest rooms for visiting scientists. Prof. Pouchet mentioned HSG as one of three students in his 1889 report on maritime laboratory to Monsieur Minister on Public Education [Revue, 1891]. The above quoted HSG letter of July 30th, 1889 was written in Concarneau and lets us know his intention: "In a few days I return to Paris having merely come down here for a little outing + sea air" [Harvard 13/30].

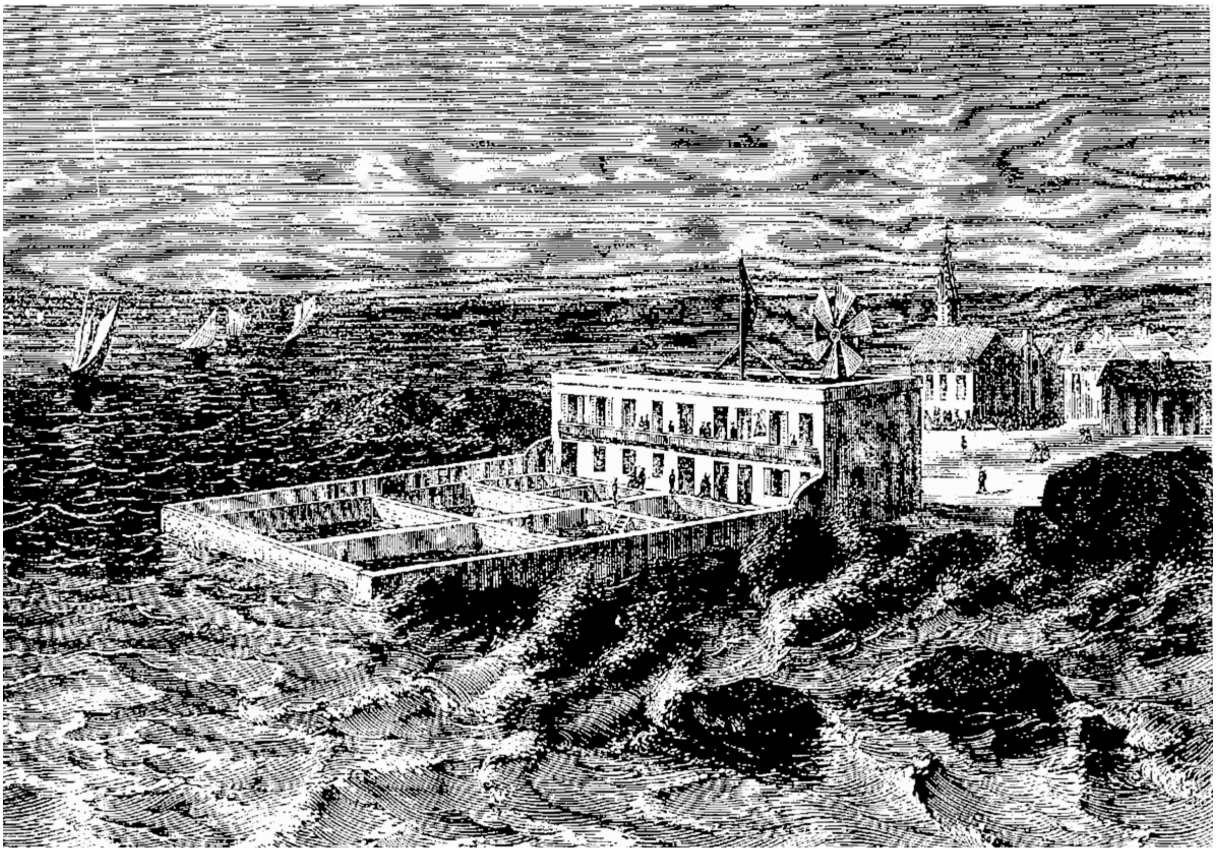


Figure 15 Concarneau maritime laboratory with its Sea Garden and De La Croix chapel in background (Le Laboratoire Vivant De Concarneau) [Figuier, 1867]

On March 11, 1890 HSG wrote from the Bassano hotel to A. Lawrence Lowell in Rome, Italy: "… I told you that since last autumn I had been going into society a little and though of the small number of drawing rooms that I usually go to the majority are either American or French-American i.e. a french husband and American wife yet there are a few purely French ones and as luck will have it of widely different "sets" which I should characterize as … Well I must close as the lunch gong has just sounded …" [Harvard 13/30].

On April 7th HSG thanks Lawrence for his reply from Naples and deals with the fundamental defect of French political life. Politics was a repeating topic in the correspondence to the author of the Essays on Government (1889).

On May 26th HSG and his mother immigrated to New York City by the Teutonic. Its passenger list was written hastily: HSG, at age 45 is listed without profession He is listed as born in the USA like all passengers and Louisa J. is his 40 years old wife. Their marriage was guessed without getting to know her due to their common no. 9 cabin of First Saloon probably [NYPL, 1890]. Mother Eliza revisited her birthplace for the last time, on December 12th, 1891 she died, age 80, in Paris.

HSG took the opportunity to visit Dr. Charles Sedgwick Minot (1852-1914) at Harvard Medical School, to see his specimens and to get his advice [Bulletin, 1892]. In 1868

Minot joined the Boston Society of Natural History and was admitted to MIT. He received the degree of Bachelor of Science in 1872. “He was always a loyal alumnus, and never approved of the Harvard A.B. in 1878 as a preparation for scientific studies ‘unless that degree represents adequate courses in chemistry, physics, biology, French and German’. In fact these courses, without the A.B. degree, seemed to him sufficient” [Lewis, 1915]. HSG had also had these courses in 1866-1868!

Minot studied biology abroad at Leipzig, Wuerzburg in Germany, and Paris. In 1883 he was appointed instructor in histology and embryology in the Harvard Medical School. By the way, this well versed microscope user and American supporter of the new rotary microtome was twice connected to the Dwight family of Bostonian academics and the fourth cousin of the anatomist Prof. Thomas Dwight [Lewis, 1915] who was the sponsor of HSG’s baptism in 1877.

In 1889 January Prof. Pouchet published two papers with Dr. Laurent Chabry (1855-1893) on the development of sea urchin (Echinocyamus pusillus) which lives as only one of the Echinidae family in European seas. On November 10, 1891 HSG spoke at the meeting of the Zoological Society about “Observations sur les Larves d’Oursin”. These observations of mesoblast cells acquired on the larvae of the sea urchin were made in Concarneau with the help of a new but not specified method by Dr. Chabry [Bulletin, 1891].

Around 1885 Dr. Chabry had created a set of micro-tools for use under the microscope and described it in his 1887 PhD thesis, which was added to his 1881 PhD of medicine. His second thesis is considered as a founding element of experimental embryology. HSG would not only use one of his micro-tools but also learn the postulate of one of Chabry’s tutors, Étienne-Jules Marey (1830-1904): “The experimenter has to be able, at each moment, to modify his instruments and frequently to construct them himself [Sander, 1997]”. Later HSG forwarded Chabry’s idea to the Zeiss Company and induced the professional construction of the capillary rotator similar to Chabry’s pipet holder. Besides the stereomicroscope, HSG invented the prism rotator which was a sophisticated addition to inspect small living specimens from any side without the need to move them.

A letter of January 7th, 1892 provides some of the intentions of HSG after his mother’s death:

“My dear Lawrence

Thank you very much for your kind letter … I shall probably come to Boston in the Spring, in May most likely … I shall remain in America until October… I should very much prefer returning home + taking up my abode at Harvard as a permanent Special Student – the advantages there being in my opinion far ahead of those here available, though I suppose Germany would be better still, but I do not speak German, + then though Germany is ahead now yet I suspect that the rate of progress is greater with ourselfes, + more than all I should wish to be amongst my old friends and associates. My sister however intends to remain here indefinitely + my duty towards her may require me to stay on this side – "Time brings counsel" + we shall see by + by…" [Harvard 13/30].

A longer HSG lecture [Bulletin, 1892] follows on March 8th, 1892: "Sur les Homologies (1) des Premiers Stades suivant la Segmentation chez les Batraciens" *(On Homology (1) of the First Stages following the Segmentation in Amphibians,* the authors*)*. The (1) hint means "I use the word 'homologue' in its primitive sense, as a term of pure morphology, and not as implying a genetic relationship". HSG compares his embryo drawings of Common Midwife Toad (Alytes obstetricans) and Axolotl (Ambystoma mexicanum) with such ones of the Peripatus velvet worm (Peripatus capensis) in some strange papers and postulates the homology of nerve cord in vertebrates and articulates. This idea was born during his investigation of Common Midwife Toad in 1891 June when he did not know about the 1890 paper of Dr. Frédéric Houssay (1860-1920) with École normale supérieure [Charle, 1989] at Paris. HSG contacted this Catholic lecturer of zoology later. HSG emphasizes relating to his drawings: "I have tried, as much as possible, to make them for each embryo at least three planes perpendicular to each other". The effort and the difficulties to do this could cause his thinking about stereomicroscope and the rotator accessories.

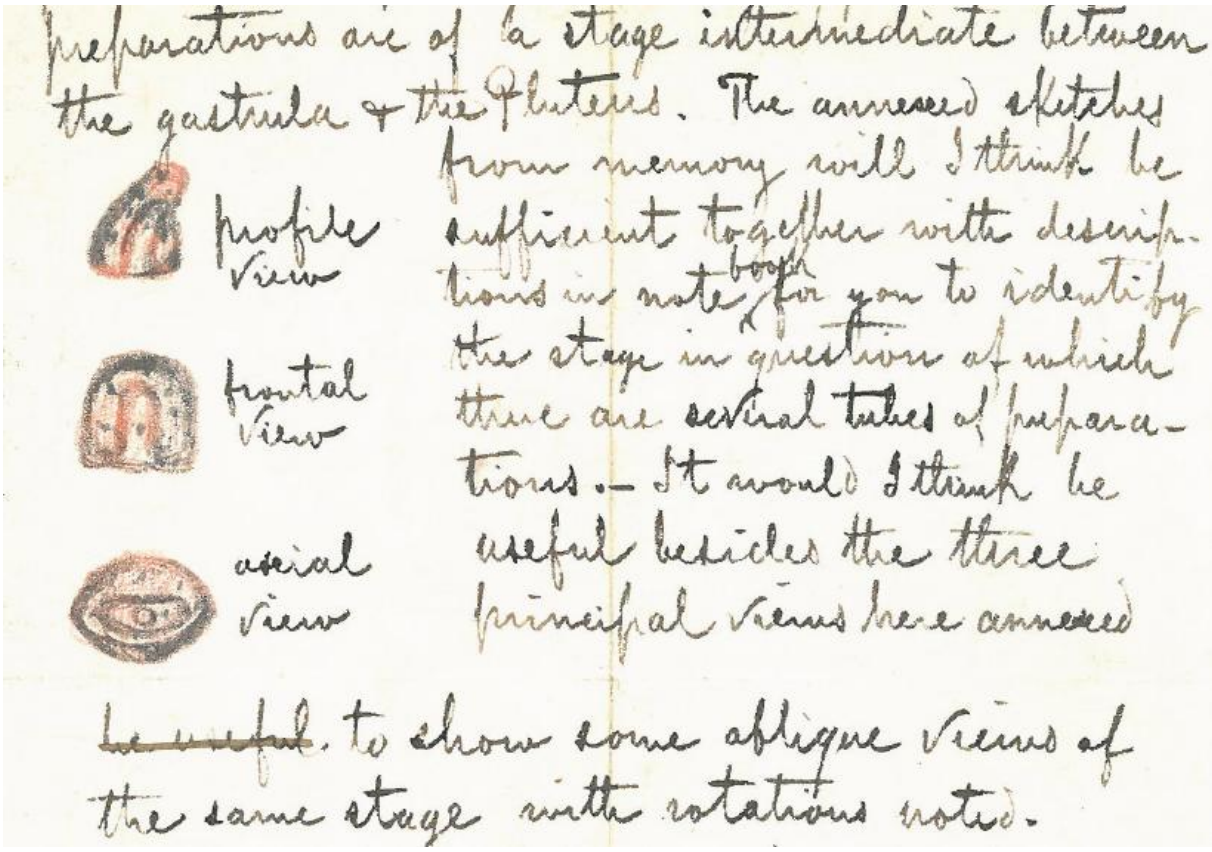

preparations are of a stage intermediate between
the gastrula & the Pluteus. The annexed sketches
from memory will I think be
sufficient together with descrip-
tions in note book for you to identify
the stage in question of which
there are several tubes of prepara-
tions. – It would I think be
useful besides the three
principal views here annexed
~~be useful~~. to show some oblique views of
the same stage with rotations noted.

Figure 16 Three principal views of an early growing phase of sea urchin, HSG's 1893 preparation and sketches from memory in his letter of February 17th, 1896 [BACZ 1578, 95]

Sometime around May 12, 1892 his mother's death is mentioned and, unfortunately, it is written incorrectly on the memorial of her and her sculptor husband Horatio (1805-1852) in Mt. Auburn Cemetery in Cambridge, Massachusetts. The date shown is likely the funeral date following her transportation to U.S. by HSG.

Figure 17 Grave linscription of HSG's parents at Mt. Auburn Cemetery in Cambridge (Courtesy Rob Velella)

In May 1892 HSG visited Prof. Charles Otis Whitman (1842-1910) in Chicago and talked with him about embryology and dissecting microscopy [BACZ 1578]. The non-Darwinian evolutionist introduced systematic methods of biological research, including the use of the microscope. The idea of the stereomicroscope could have been born during this conversation. Whitman was influenced by his training in Germany and would ask HSG to write to Prof. Abbe of the Zeiss Company some weeks later.

D. Brian Schuermann writes in his biography of Whitman [Schuermann, 2009]:

"… He then *(1872,* the authors*)* moved to Boston to accept a position as instructor in natural science at the English High School. This move was one of great importance, as it was in Boston that he became aware of Harvard University's Professor of Zoology Louis Agassiz and enrolled to become one of fifty participants in the first session of the summer marine biology program at the Anderson School of Natural History on Penikese Island in 1873. This experience had a profound impact on Whitman as well as on other Agassiz's students. In 1874 Whitman joined the Boston

Society of Natural History and, after a second summer at Penikese, he decided to dedicate himself to the full-time study of zoology.

In 1875 Whitman went to study in Europe under Anton Dohrn *(1840-1909, former lecturer at the Jena University and friend of the below mentioned Dr. Czapski with Zeiss*, the authors*)* at the Stazione Zoologica in Naples. After working with Dohrn in Naples, Whitman and his fellow Penikese Island student Charles Sedgwick Minot moved to Leipzig, Germany. There, under the direction of parasitologist Rudolf Leuckart, he learned the modern methods of embryology and microscopy. Whitman received his PhD from the University of Leipzig in 1878 …

From 1882 through 1886 Whitman worked as an assistant to Alexander Agassiz *(son of Louis Agassiz and his successor,* the authors*)* at the Museum of Comparative Zoology at Harvard University. During this time Whitman also served as the editor for the Department of Microscopy at the American Naturalist Magazine.

During the summer of 1888 Whitman was invited to direct the newly established Marine Biological Laboratory in Woods Hole, a position he held until 1908 ... In 1892 Whitman moved again to become the head of the biology department at the newly founded University of Chicago … Whitman remained at the University of Chicago until his death on 6 December 1910 … “*(end of citation)*.

Whitman came to zoology and marine biology because of the influence of Prof. Louis Agassiz. Can it be a pure chance that HSG knew him also and worked in the same fields?

On May 31st HSG personally appeared at the Justice of the Peace for the registration of his and his sister’s inheritance by the Deeds Register in Cambridge [Deeds, 1892]. He met his friend A. Lawrence Lowell and wrote to him on the following day [Harvard 13/30]:

“Totas errare Vias
My dear Lawrence
the above quotation applies perhaps to my theory of soaring flight – I believe however that it applies to your objection of yesterday as I will now endeavor to show – Your contention tacitly assumes. I think, that energy unlike velocity is not relative, & the converse is true …”

On June 16th the 47 year old HSG made a Passport Application in Boston where he states his occupation as a scientist [USPA, 1892]. A photo was not yet common, unfortunately, and so we know the “Description of Applicant” but not his picture. His description does not sound much different from HSG st 14: stature 5 feet, 2 inches,*157.5 cm,* forehead medium, eyes blue, nose regular, mouth medium, chin round, hair brown, complexion light, face oval“.

8. His Partners at the Zeiss Company

HSG returned to Europe earlier than October, as he had planned in January. It is unknown whether his first letter of July 4, 1892 on the stereomicroscope was mailed from the US or France. The sender's address was given as 30, rue de Bassano, Paris which was his permanent residence.

The authors don't know why HSG wrote to Prof. Dr. Ernst Abbe (1840-1905), head of Carl Zeiss Company in Jena, Germany but there are some indications.

At first we remember the sentence in the January 7th letter "then though Germany is ahead now yet I suspect that the rate of progress is greater with ourselfes".

Two of HSG's American tutors, Dr. Minot and Prof. Whitman studied in Germany and were experts in microscopy – they had to know the high reputation of Prof. Abbe and of Zeiss microscopes and could have recommend both.

In the Concarneau maritime laboratory, the US American marine biologist Prof. Charles A. Kofoid (1865-1947) found a high-grade apochromatic, Zeiss and two Zeiss-Greenough microscopes, on his Europe travel in 1908/09 [Kofoid, 1910] – the first mentioned could be used by HSG who wrote in 1892 Sep. 06th "…I am delighted with the 16 mm & 8 mm apochromatic obj. glasses and compensating eyepieces furnished me by your Mr. Zeiss" [BACZ 1578, 41-42]. The apochromatic objectives were created in 1886 for the first time according to Abbe's calculations.

Ernst Carl Abbe was born in Eisenach, Thuringia below the Wartburg castle where in 1521 Martin Luther (1483-1546) had translated the New Testament into German and the freedom celebrations of progressive students had started in 1817. His father was foreman in the local worsted spinning mill and supported the education of his talented son in spite of his low income. Abbe studied in Jena, was graduated in Goettingen and in 1863 lived in Jena. After publishing many scientific papers he became a professor at the Jena University in 1870. Carl Friedrich Zeiss (1816-1888), the Mechanic of University, had won Abbe over as his scientific assistant in 1866 [Gerth, 2005].

Prof. Abbe had realized the increasing requests for binocular and stereoscopic observation a dozen years before HSG's idea. Therefore he invented the "Stereoscopic Eyepiece" [Abbe, 1880] as an accessory to the monocular microscopes of the small continental shape (ca. 16 cm tube length). Its use in binocular (2D) and stereoscopic (3D) mode provides the same capability as the below mentioned Anglo-American binocular microscopes of large shape (about 25 cm tube length) and also offers an economic retrofitting of an existing monocular microscope. The addition of half-aperture diaphragms (β' on figure 18) onto the eyepieces and a twin-hole diaphragm into the condenser provides stereoscopic viewing in transmitted light.

Prof. Abbe investigated to this end the conditions of stereoscopic and pseudoscopic viewing on the microscope. 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.

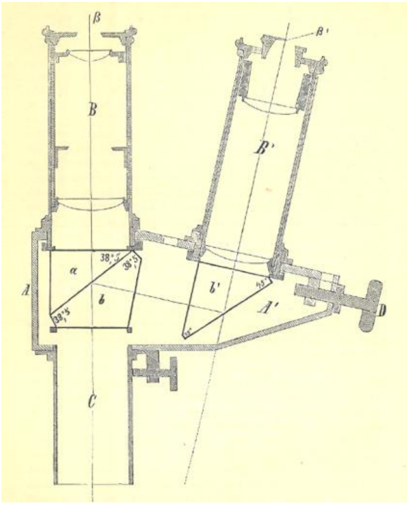


Figure 18 Left is the Zeiss II stand (1887) equipped with Abbe's Stereoscopic Eyepiece (Courtesy Dr. Timo Mappes, http://www.musoptin.com) and above right is the cross section of the Stereoscopic Eyepiece [Abbe, 1880]. Above rght is the Abbe bronze sculpture by Klaus-Dieter Locke (2014) placed in front of Zeiss Planetarium Jena, Germany.

Prof. Abbe spent holidays in Switzerland, but this did not become a disadvantage for HSG. His personal assistant, Dr. Siegfried Czapski (1861-1907), replied and held the correspondence and additionally personal contact with HSG for several years. Both became friends in spite of some conflicts in technical issues.

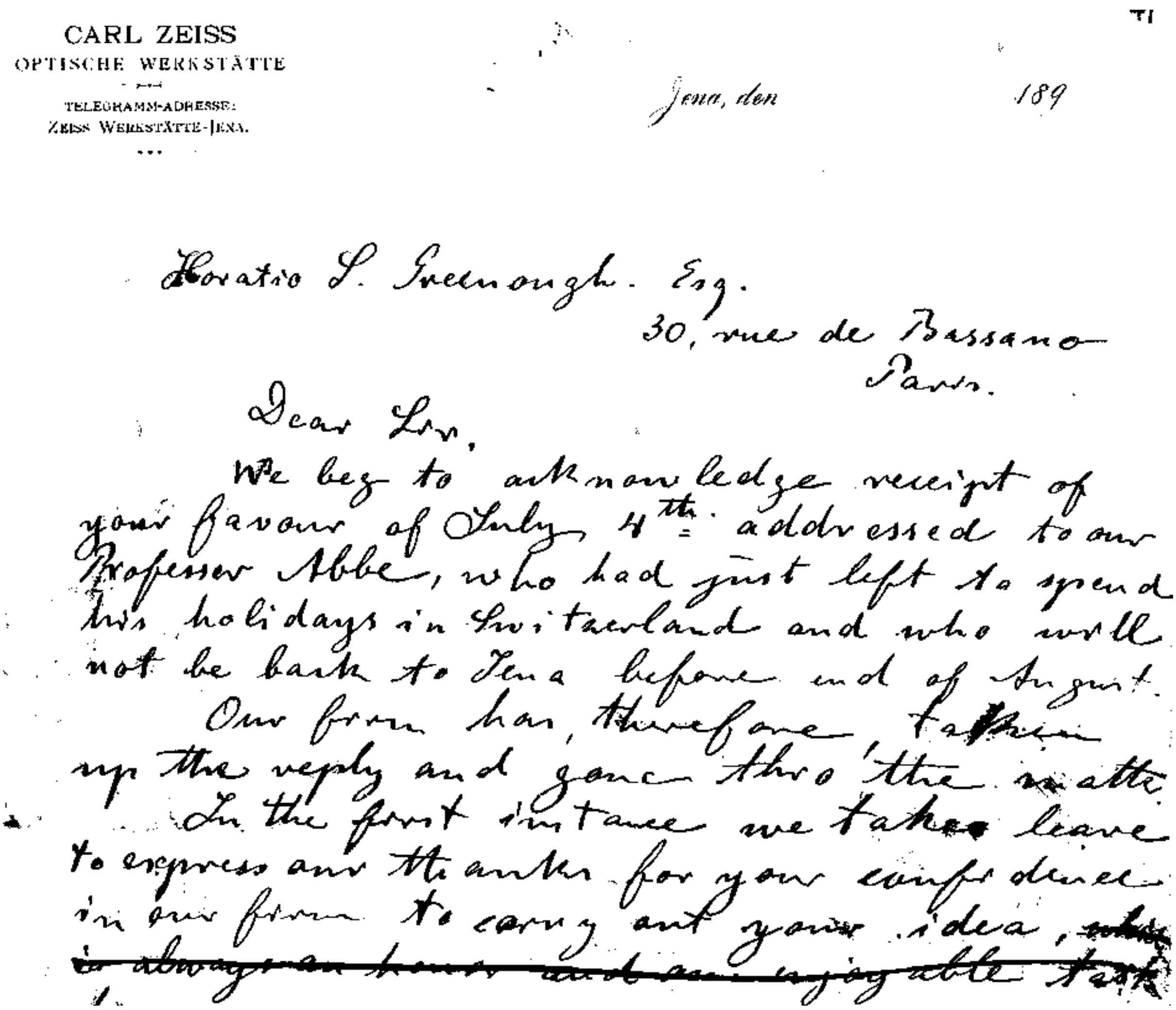
Abbe established the Carl Zeiss Foundation after the death of company founder in 1888. He was also the leader of the Zeiss Company, with its approximately 550 employees and approximately1,800 microscopes sold every year [Auerbach, 1904]. In July 1891 Dr. Czapski and Dr. Otto Schott (1851-1935) became members of the company's management along with Prof. Abbe.

Figure 19 Dr. Siegfried Czapski, ca. 1890 (Courtesy Carl Zeiss Archive)

Siegfried Czapski was the son of a Jewish landowner and attended the secondary school in Breslau, a former German city in Silesia Lowlands, and today Wroclaw in Poland. Beginning in 1879 he studied physics, mathematics and chemistry at the German universities of Goettingen, Breslau and Berlin. In 1884 he graduated and his

Jewish countryman and physicist Leopold Loewenherz (1847-1892) brought him in contact with Prof. Abbe.

For practical training in technical optics, he began with time, in the Berlin work shop of Carl Bamberg (1847-1892), a former trainee of Carl Zeiss and correspondent of Prof. Abbe [Rohr, 1932]. Prof. Abbe employed Dr. Czapski to edit his scientific publications and to continue his research tasks. In 1891 the first part of “Theory of Optical Instruments after Abbe” came out by Winkelmann’s Handbook of Physics, but Dr. Czapski could finish the complex edition until 1893.



CARL ZEISS
OPTISCHE WERKSTÄTTE
TELEGRAMM-ADRESSE:
ZEISS WERKSTÄTTE-JENA.

Jena, den 189

Horatio S. Greenough. Esq.
30, rue de Bassano
Paris.

Dear Sir,

We beg to acknowledge receipt of your favour of July 4th addressed to our Professor Abbe, who had just left to spend his holidays in Switzerland and who will not be back to Jena before end of August.

Our firm has, therefore, taken up the reply and gone thro' the matter.

In the first instance we take leave to express our thanks for your confidence in our firm to carry out your idea, ~~which is always an honour and an enjoyable task~~

Figure 20 The beginning of Dr. Czapski’s concept for his reply of Aug. 27th [BACZ 1578, 41-42].

Dr. Czapski’s concept is written in German with the exception of an English start (Fig. 20). He promised the supply of a stereoscopic microscope according to five paragraphs which include his expert analysis of HSG’s wishes:

1. It seems expedient to make the angle which the axes of the objectives form with one another equal to the angle which the eye axes enclose in fixing a point which is within the conventional image distance of 250 mm, i.e., in the case of the *(62 mm distant; the authors)* eyes approximately 14 °, since it is expedient for the achievement of the strongest possible stereoscopic effect and the highest possible aperture to take this angle as large as possible, but on the other hand a permanent fixation of a point nearer than 250 mm, both the convergence of the eye axes would be inconvenient also for the accommodation.

2. In order to produce the correct perspective for each eye and in each case of magnification, it is only necessary that the entrance pupils of the two objectives satisfy in their position the equation A/a=D *(Distance of Eyes / Distance of Objectives = Magnification; the authors)* given in your letter, and that the tangent ratio of the angles enclosed by the main rays with the microscope axes in the whole subsequent magnification remains constant.

3. A second pair of objectives behind the first pair is, as noted above, a deleterious complication *(The rejection of a second objective pair raises the undecided question how to erect both images to get regular stereoscopic viewing, the authors)*. The correct magnification can be achieved by a suitable choice of the eyepiece. To obtain different magnifications, it is most convenient to change the objectives.

4. Since the opening angle for the objectives must in any case be smaller than the angle which the two axes form with each other – i.e. less than 14 °, i.e. the objectives can receive at most a numerical aperture of 0.12, then the outermost permissible magnification is given by a hundredfold be.

5. In relation to the sharpness of the sketch of depth, the conditions can not at all be equated with those of unarmed eye seeing, since the diffraction phenomena of light, for every magnification, it should be usable, it cannot go below a certain opening *(This formulation is not explicit in quantity and may to misunderstand by an amateur in optics like HSG. Czapski meant that the depth of field will be much smaller than such of naked eye and the diameter of microscopic field also because each useful magnification requires a numerical aperture larger than this of eye, the authors)*.

9. His Predecessors in Trying Dual-Tube Microscopes

Dr. Czapski's historic investigations for optical monography led him to reply that HSG's idea had a first predecessor more than 200 years ago.

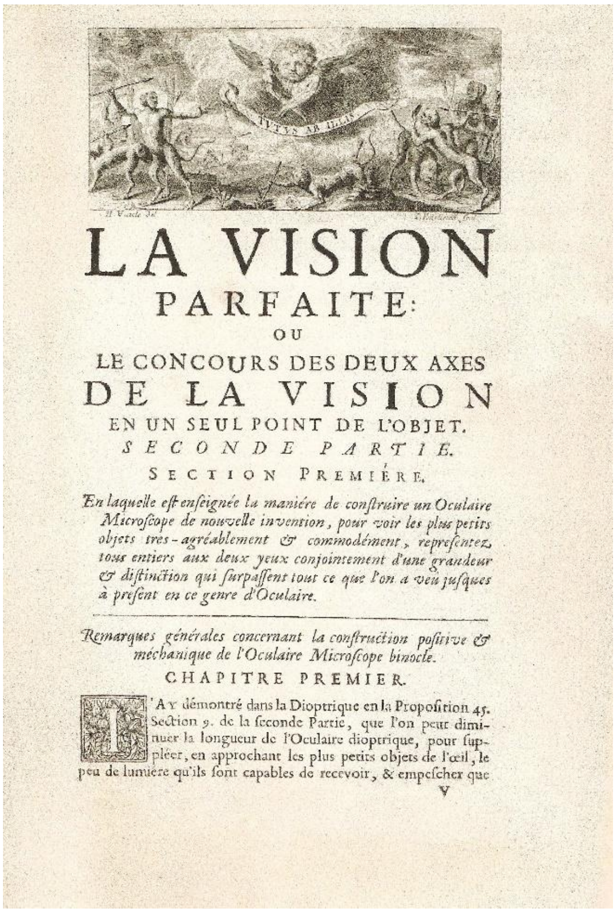
The detailed design of a dual-tube microscope apparently was first published by a French monk Chérubin d'Orléans (1613 -1697, Michel or François Lasseré). He was in the Order of Capuchin Friars Minor (O.F.M. Cap), also known as the Capuchin Franciscans, a Catholic Order deriving from the Franciscans. His second French book of two volumes came out in 1677 and later in Latin also:

"La Vision Parfaite: ou le concours des deux axes de la vision en une seul point de l'objet" [Chérubin, 1677] (*The Perfect Viewing: or the coincidence of two viewing axes at one object point;* the authors*)*.

Father Chérubin d'Orléans designed his dual-tube microscope recognizing the work of Anton Maria Schyrleus of Rheita (1597 or 1604 -1659 or 1660, from Reutte in Tirol). As a Capuchin monk he also gave a description of the binocular telescope in his Latin book published at Antwerpen, Netherlands in1645. He defined the fundamental optical terms "Objective" and "Eyepiece".

Chérubin's microscope was constructed not only with dual eyepieces, but also with dual objectives (Fig. 21), with the images to each eye reversed. His goal was not a three-dimensional image, the image realization could be improved, by creating a microscope for both the eyes, which were given to us by God. He felt that visualization would be improved by viewing objects with both eyes simultaneously - in contrast to the majority of scientists at that time. The title engraving is an allegory about o*pponents and shows the words "TUTUS AB ILLIS" (Protected from them;* the authors*)*. But his work on binocular telescopes were sponsored by Louis XIV (1638-1715). "Le Roi Soleil" of France, who valued the military advantage of binocular telescopes.

The theory of stereoscopy was developed by Sir Charles Wheatstone (1802-1875) 160 years later. So Chérubin's dual-tube microscope was pseudoscopic rather than a stereoscopic microscope [Wade, 1998]. D'Orleans' microscope was developed before the invention of achromatic microscope lenses, and at a time when simple single lens microscopes provided better images at lower costs than their compound relatives.



LA VISION
PARFAITE:
OU
LE CONCOURS DES DEUX AXES
DE LA VISION
EN UN SEUL POINT DE L'OBJET.
SECONDE PARTIE.
SECTION PREMIÉRE.

En laquelle est enseignée la maniére de construire un Oculaire Microscope de nouvelle invention, pour voir les plus petits objets tres-agréablement & commodément, representez tous entiers aux deux yeux conjointement d'une grandeur & distinction qui surpassent tout ce que l'on a veu jusques à present en ce genre d'Oculaire.

Remarques générales concernant la construction positive & méchanique de l'Oculaire Microscope binocle.

CHAPITRE PREMIER.

J'AY démontré dans la Dioptrique en la Proposition 45. Section 9. de la seconde Partie, que l'on peut diminuer la longueur de l'Oculaire dioptrique, pour suppléer, en approchant les plus petits objets de l'œil, le peu de lumiere qu'ils sont capables de recevoir, & empescher que

V

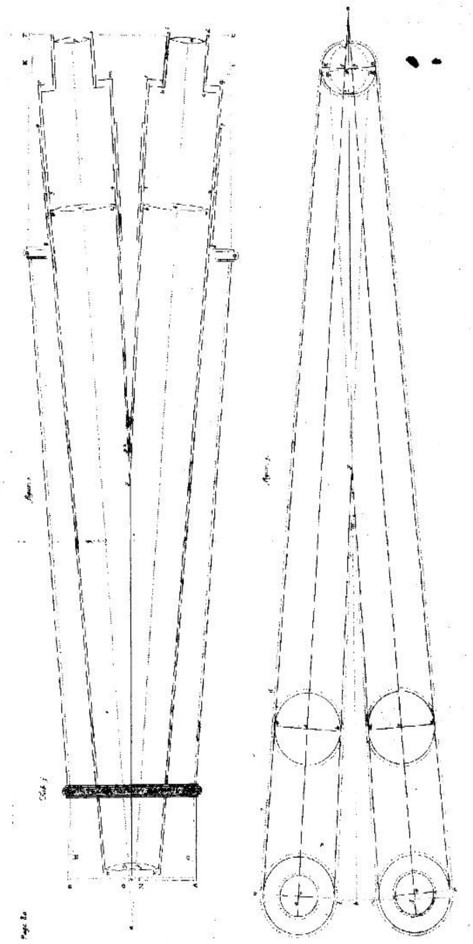


Figure 21 Left is the title from the microscope chapter of La Vision Parfaite, right is the cross section of the dual-tube microscope from same chapter [Chérubin, 1677].

The engraving in Fig. 22 has been widely disseminated [Britannica, 1910]. However, it is difficult to tell its size from this engraving. Fortunately, a third Capuchin built a dual-tube microscope using the design of Chérubin d'Orléan. The microscope of Pére Anian de Paris is on exhibit in Jena, Germany (Deutsches Optisches Museum).

The photographs of that Anian microscope show its real shape, see Fig. 23. The lenses and base plate were replaced in first half of 19th century and its technical data were determined today as followed [Blanchard, 2013]:

Dimension: 370-380 mm length including eyepieces; 330x170x95 mm body without eyepieces in difference to Chérubin's 381 mm length.

Objectives: ca. 25 mm focal length and ca. 5 mm free diameter.

Eyepieces: replaced by aluminimum supported lenses; 60-75 mm adjustable distance.

Power: ca. 50x magnification; ca. 2.5 mm object field diameter.

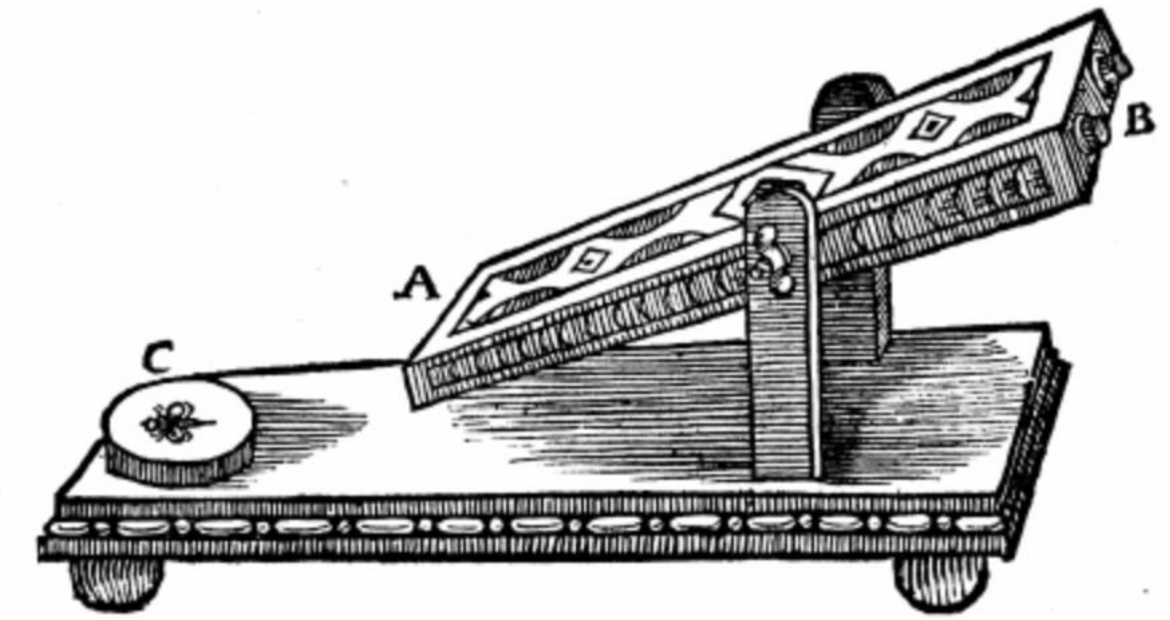


Figure 22 Chérubin's dual tube microscope (Journal of the Society of Arts 1886)

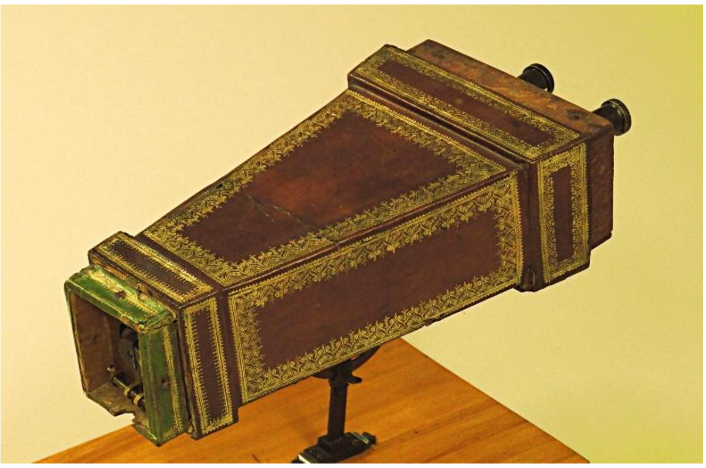


Figure 23 Left is the Anian microscope built before 1712 on Chérubin's design, right is its lower end with both objectives and its drive specified by Anian (Courtesy Deutsches Optisches Museum in Jena, Germany)

Czapski mentioned also the idea of a dual-tube microscope by Prof. Pieter Harting (1812-1885). The Dutch biologist and naturalist is remembered for his work in the fields of microscopy. Throughout his career he maintained an avid interest in the historical development of the microscope and in the manufacture of lenses. He is credited with making design improvements to the microscope, and was the author of a landmark book on microscopy in 1859. In §187 he discusses a design of a first objective pair followed by two compound microscopes (Fig. 24) exactly as wished for by HSG. But Harting felt that his optical attempt was not practicable:

“Even if you use lens systems that produce a fairly long focal length of 1 to 2 centimeters to create the images, the difference between the images and the object is too large as a result of some of the experiments I specifically made about it. Therefore, this means cannot be successfully used to represent binocular microscopes. This is all the more regrettable because such a device, better than any other, seems to have to meet the requirements of truly stereoscopic viewing of microscopic objects. Perhaps, however, later improvements in the manufacture of lenses can lead to this.” [Harting, 1859]

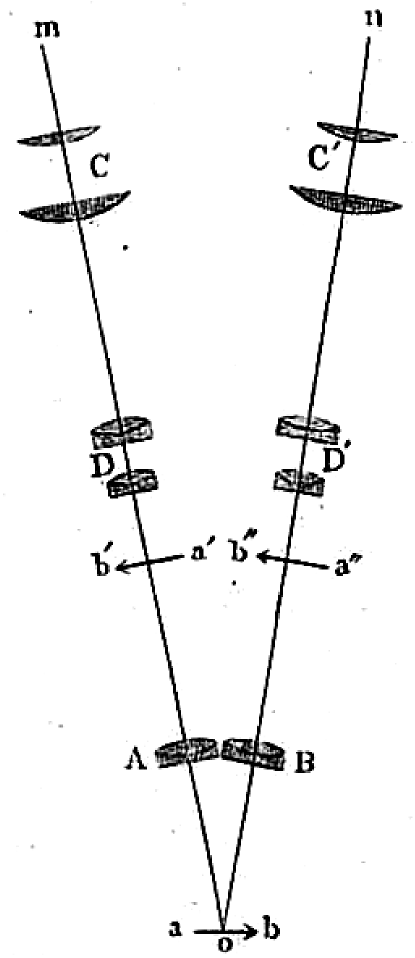


Figure 24 Dual Tube Microscope by Prof. Harting including two objective pairs (A+B and D+D’) [Harting, 1859]

Dr. Czapski also knew of the single-objective (CMO) stereomicroscopes used commonly in the Anglo-American region but he did not point out this rival design principle.

He wrote: “However, we believe that such an *(double objective,* the authors*)* instrument, while rationally designed, is closer to the conditions of natural vision than the newer *(CMO, the authors)* stereoscopic microscopes, and so we are prepared to make you an instrument with the following geometrical considerations … "*(which were quoted above already, the authors)* [BACZ 1578, 41-42].

The term "Stereoscopic Microscope" was given in 1861 by the British marine engineer and aeronaut, Francis H. Wenham (1824-1908):

"I have been frequently asked why I have not termed my binocular the 'Stereoscopic Microscope?' … What I should term a 'Stereoscopic Microscope' would be literally two microscopes, with their object-glasses, placed side by side, like an opera glass, with similar adjustments for the distance between the eyes. If such an instrument were furnished with erecting-glasses and draw-tubes, for varying the magnifying power, only one power of object-glass would be requisite …" [Wenham, 1861]

As can be seen in Fig. 25, Wenham used a single objective (CMO) and a single prism 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. Both Chérubin and Wenham microscopes show reversed images but the light paths cross each other in the newer one and therefore a regular stereoscopic viewing was achieved.
The wide acceptance of the Wenham's binocular design was likely not due to its stereoscopic capabilities, but to it being a binocular, rather than a monocular, microscope. This allows viewers to use both eyes, as occurs in a binocular microscope, which is usually more comfortable.

Nonetheless, the Wenham binocular microscope, in various versions, dominated the production of British, and American, binocular microscopes in the 19th century. Fig. 25 shows a relatively large Crouch Wenham binocular microscope. This microscope was expensive, and available with many accessories. Thus, it was only practical for wealthier hobbyists or scientists.

But Wenham gave the stereoscopic microscope into others hands - to these of HSG and Czapski as we know today:

"I have abandoned all attempts at making a binocular microscope with two objectives, as I found that I could not get even a pair of 1½ s *(3.8 mm, the authors)* to bear upon the object together. Having now stated distinctly that the binocular microscope is at present far from being a perfect thing, and in what direction greater perfection is to be sought for, I trust that others will tax their ingenuity in effecting improvements; for even as it now is, all must agree, on seeing the magnificent perspective of some objects (particularly living and infusorial) that is obtained through its means, that no efforts should be spared in attempting to improve it." [Wenham, 1854]

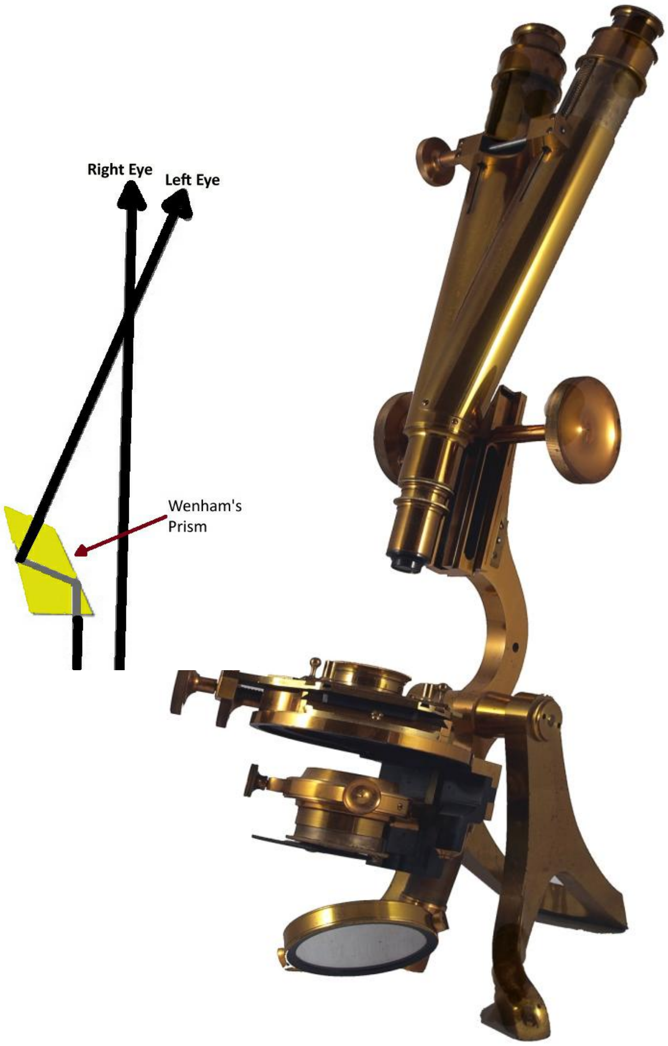


Figure 25 Crouch Wenham Binocular, complete view and light path with Wenham prism

10. His Wishful Thinking

The first maintained HSG letter [BACZ 1578, 41-42] (Figure 26) to Prof. Abbe was written on Sep. 06 in Concarneau and replies to the Czapski letter. The 8 page letter describes his wishes and suggestions; some should repeat thoughts of the lost first HSG letter of July 4:

"Professor Dr. Abbe
Dear Sir

Your esteemed favour of Aug.27th is at hand.

In reply I have first to present you my best thanks for your liberal offer to have a working model of my plan for a stereoscopic Microscope constructed at the expense of your firm. – When the Model is made please forward it to me …

I note with satisfaction what you say concerning objects whose depth is not much less than the diameter of the field: for it was for the very purpose of seeing such objects that I made the plan in question. Or rather to be more exact in order to get a correct solid view with a depth if possible even greater than the diameter of the field *(See A remark, the authors)* - If you can produce a good working result up to 20X & if possible 30X the instrument will be well worth making. - Indeed in this connection Professor Dr. Whitman told me last May, when I had the pleasure of visiting his Laboratory in America, that for purposes of embryological study he found powers up to 20 the most useful & that he very much desired improvements in such powers *(See B remark,* the authors*)*:

It is needless to say that I did not expect to obtain a practical result for outline more than medium powers at the outside & it was for the purpose of obtaining increased depth even more than to get an erect image that I proposed using a second pair of object glasses combined with an intense illumination as I will now endeavor to explain, premising at the outset that what is wished for is to get a flat image of a solid object - I enclose a diagram based on Professor Hasting's formula $L=M^2/S_o$ when L is the depth magnification, M the breadth or field magnification & S_o the index of refraction. In my diagram I have assumed M=3. & S_o =2 which gives L=4½ … *(See C remark, the authors).*

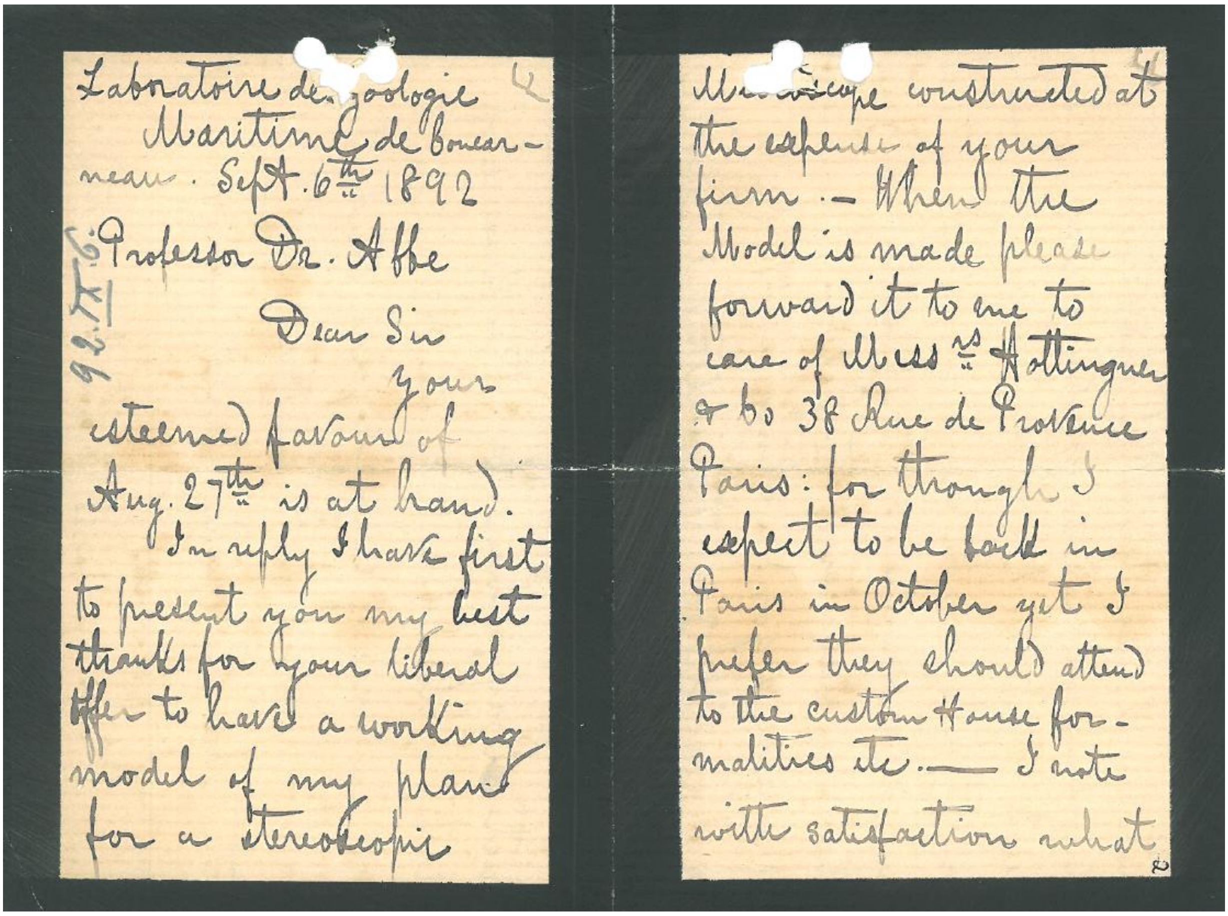
For the study of the ~~form~~ shape of isolated objects requiring medium & rather high powers I employ a radically different plan that I have used with practical advantage

for some time. It is a modification to meet my own wants of a device of Dr. Chabry's. – I use a capillary tube into which the object is introduced, the tube is then immersed in the same liquid that it contains & held in place & rotated by a suitable device. &because the index of refraction of the glass tube wall is not very different from that of the liquid & because of the thin*(n)*ess of the tube wall there is little or no perceptible distortion *(See D remark, the authors)*.

I hope presently to send you some of these tubes containing prepared objects with a view to your making for me for use with the same one or two apochromatic immersion lenses specially constructed for this purpose. – I say no more at present but will only add that for section work I am delighted with the 16 mm & 8 mm apochromatic obj. glasses and compensating eyepieces furnished me by your Mr. Zeiss *(See E remark,* the authors*)*.

With many thanks and apologizing for the present long-winded letter I remain dear Sir

yours faithfully
H. S. Greenough"



Laboratoire de Zoologie
Maritime de Concarneau. Sept. 6th 1892
Professor Dr. Abbe
Dear Sir
Your esteemed favour of Aug. 27th is at hand.
In reply I have first to present you my best thanks for your liberal offer to have a working model of my plan for a stereoscopic

Microscope constructed at the expense of your firm. – When the Model is made please forward it to me to care of Messrs Hottinguer & Co 38 Rue de Provence Paris: for though I expect to be back in Paris in October yet I prefer they should attend to the custom House formalities etc. — I note with satisfaction what

Figure 26 First page of the 1892 Sept 6 HSG letter

A remark:

Czapski's formulation to depth of field in his fifth paragraph is not explicit in quantity and there is no other sentence known in available concept pages where this contradiction to HSG's request is clearly stated. We do not know whether HSG's phrase "I note with satisfaction …" was a misunderstanding of the fifth paragraph or a conciliatory phrased opposition.

B remark:

Prof. Whitman published his book "Methods of Research in Microscopical Anatomy and Embryology" seven years before. In its embryological methods' chapter he wrote about his drawing apparatus: "As every working naturalist knows, an apparatus that admits the use of the camera Lucida with a low magnifying power, varying from five to to forty diameters, offers many advantages that are not to be obtained from any system of microscopical objectives" [Whitman, 1885].

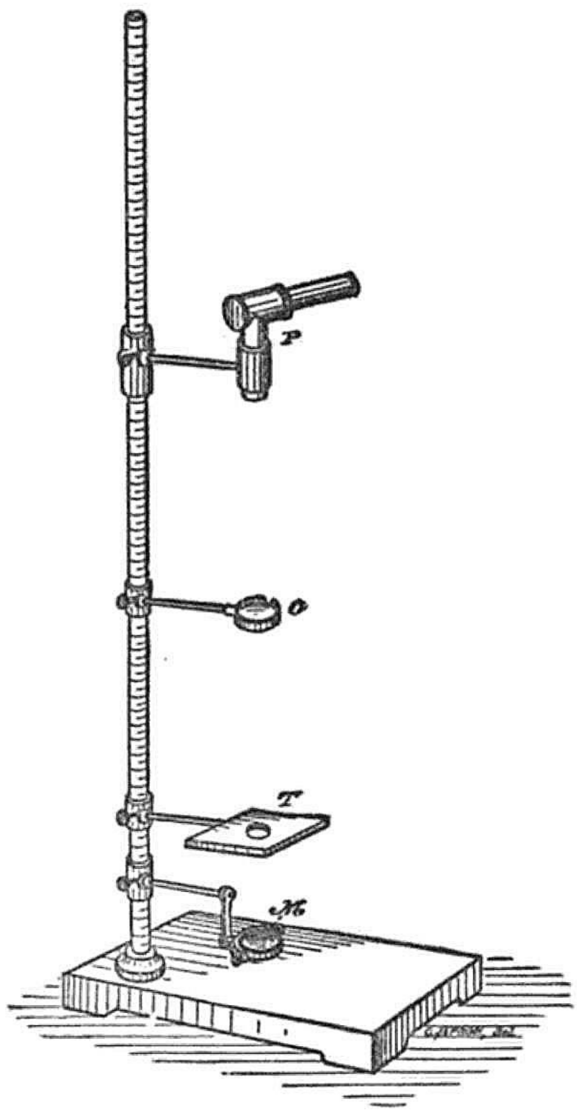


Figure 27 Drawing apparatus of Prof. Whitman [Whitman, 1885]. The items are illumination mirror (M), object table (T), objective (O) and camera lucida (P), all supported by horizontal bars on sliding ferrules that move along a graduated brass rod.

The following pages show and describe his drawing apparatus (Fig. 27) constructed similarly to the Embryograph of his Swiss teacher Prof. Wilhelm His (1831-1904) at Leipzig, Germany. These devices provide an erected image and were state of art in embryologic imaging before the stereomicroscope invention, and HSG likely knew of these. Thanks to some clues such as the “Steinheil Aplanat No. 1 and 2.5 cm diameter”, one of mentioned lenses was identified by the authors: The “Preis-Courant” of company C. A. Steinheil Soehne, Munich, Germany [Steinheil, 1882] states a wide-angle Aplanat lens with this diameter and 36.5 cm focal length for reproductions which distinguish flat image, maximum sharpness and remarkable viewing field. Its low 0.034 numerical aperture or slow 1:15 f-number provides a good 450 µm wave- and geometric-optical depth of field (WGD) or focus tolerance at 20x magnification.

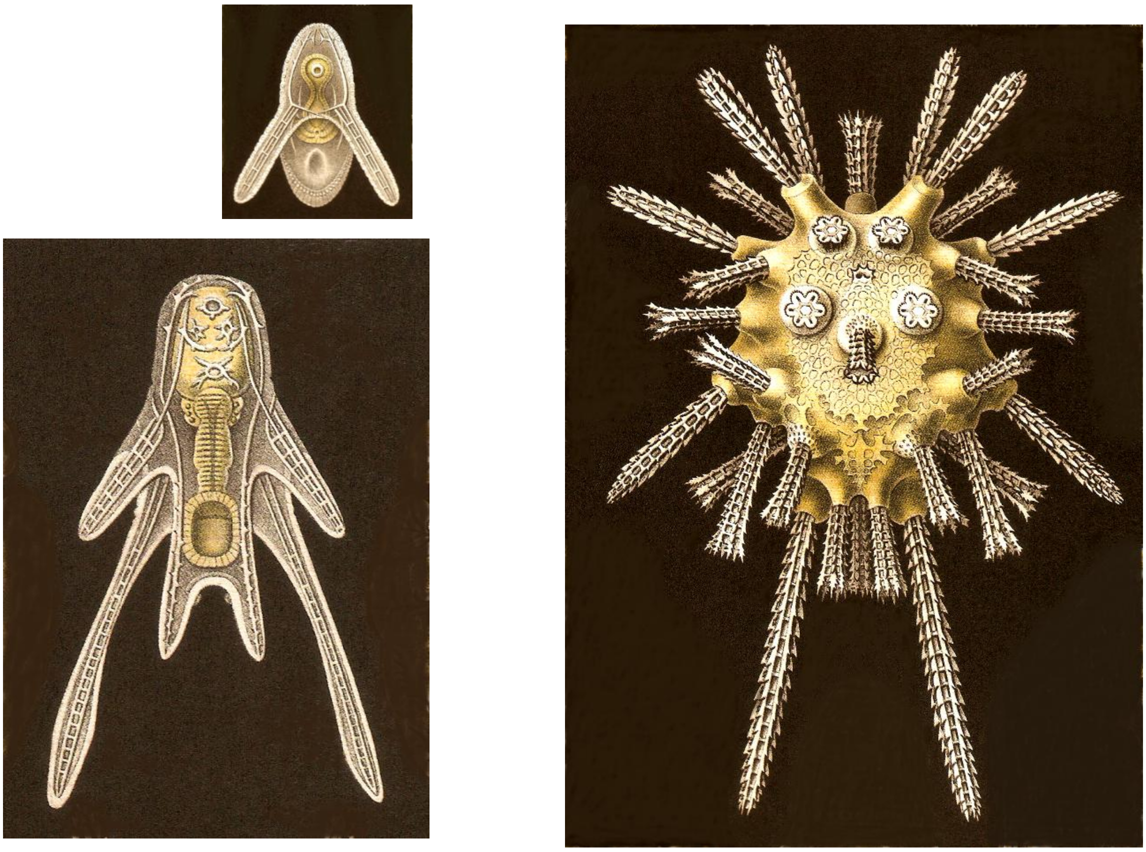


Figure 28 Metamorphosis (Astrogenesis) of European sea urchin (Echinocyamus pusillus Mueller), individuals from [Haeckel, 1904] shown in same scale

The young, 48 hours old, and 1/4 mm long larvae of sea urchin (Plutellus Echinocyami), is flat enough for easy observation. The 8 arms of a 10 days larvae reach the WGD limits. The approximately 0.8 millimeter diameter of a 60 days young sea urchin (Fig. 28) is no longer covered by WGD. At low magnifications, the focus layer can be shifted additionally by visual accommodation in a range larger the WGD. An 8 diopters accommodation would shift the WGD over one millimeter but only a relatively young person, no older than 30, would be able to reach this diopter value.

The 47 years old HSG could probably accommodate two diopters and get a 310 µm shift only, and so he needed successive mechanical focusing steps for a complete record. The many spines can cause some uncertainty in the exploring of such sea urchin by this method. Problems such as this, may have led HSG to request a WGD similarly large, like the field diameter, to see round specimen simultaneously. His optical knowledge was not yet developed sufficiently to understand that such a desire opposes the needed resolution of the stereomicroscope.

C remark:

Charles Sheldon Hastings (1848-1932) was an American physicist. He earned a PhD from Yale in 1873. In 1875 he started to study and travel in Europe for the next three years. He attended courses given in Berlin by Hermann L. F. von Helmholtz (1821-1894) and in Heidelberg by Gustav R. Kirchhoff (1824-1887). Hastings' optical designs enabled much progress in astronomy at U.S. observatories. A triplet magnifying glass design is based on his optical calculation.

The formula quoted by HSG gives the depth magnification depending on lateral magnification and is not applied especially to the microscope because Prof. Hastings dealt with such optics. HSG uses this formula to describe the relation of WGD to the depth of image. He wants a WGD amount comparable the field diameter and tries to achieve this by a second pair of objectives behind both "object glasses". These second lenses shall erect the image also.

His attached diagram sketches one ray path of stereomicroscope. It is not scaled exactly corresponding to the written data. The authors are not able to understand all his thoughts, e.g. why he assumed the $S_o = 2$ refractive index instead of $S_o = 1$ in air. HSG's diagram description seems equally confused, and the authors try to summarize his intensions by inserting his own phrases to corresponding positions (Fig. 29.).

HSG suggests to use the image of the first lens (first magnification step) as the object of a second lens with a shorter focal length (second magnification step):

- In first step, the WGD is expanded to the depth of image by the square of lateral magnification corresponding Hastings' formula of depth magnification. This is pointed out correctly by HSG, the isosceles triangle of red dots in object space is imaged to an enlarged equilateral triangle in image space.

- In second step, this expanded depth should be transmitted to eyepiece and eye. This requires longer focal length and lower magnification than in first step when the magnification of second step is larger than 1x. The eyepiece of a compound microscope does so. HSG's suggestion of shorter focal length of second lens produces the opposite effect.

- In contrast to the common point of view, HSG wants to acquire a fictitious image plane only, which includes the whole content of image depth. The short focus lens suppresses the image structures below and above his plane. Indeed its image quality would not be optimal, many details are blurred and of relatively low contrast because its sharp images are located outside of this single plane. HSG doubts in working of his fictitious image plane and discusses a translucent screen also to get a real object for the second magnification step – with the disadvantages of much loss of light and the need of high intensive illumination.

The transmission of only one image plane would also prevent the helpful visual shifting of focus by accommodation.

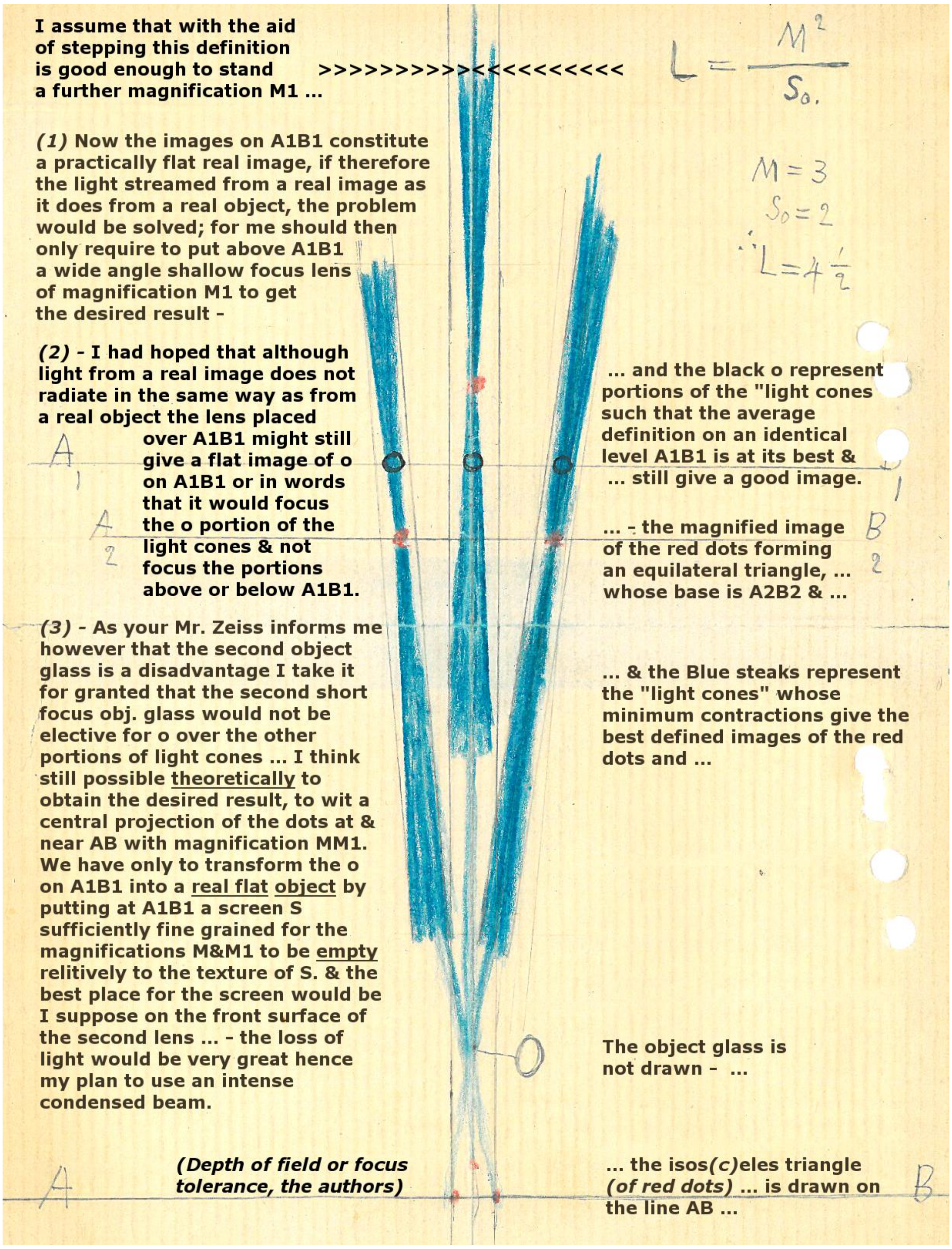


Figure 29 Diagram from HSG’s letter of 1892 Sep. 06 commented by his phrases. Please read upwards on right side following the light path and downwards on the left.

D remark:

The capillary rotator was the main issue of the following correspondence to Zeiss Company and became a prototype in March 1893 and a Zeiss product in 1898.

E remark:

HSG requests low-power lenses for water-immersion in the highest Zeiss quality, specially constructed for the investigation of specimen in capillary tubes.

Both mentioned apochromatic objectives work in air with 0.15 mm cover slip and compensating eyepiece at compound microscope and need covered preparations for thin sections. The f = 8 mm lens provides 0.65 numerical aperture, one millimeter of free working distance, and also of specimen field diameter, at 125x total magnification using 4x eyepiece. The f = 16 mm lens provides 0.3 aperture, 5 mm working distance and two millimeters field diameter at 62x magnification using the same eyepiece. It could be used also as a makeshift for dissection work offering 19 µm WGD when it was combined with the 2x overview eyepiece for 31x total magnification [Zeiss, 1891], [Zeiss, 1898]. A visual accommodation of only two diopters allows focus plane to shift approximately 130 µm – about 7 times the low WGD!

In 1893 March HSG will develop his idea of orthomorphic principle which seems to him a need in his investigation. He will replace the term stereomicroscope by orthomorphic microscope and a disagreement will be caused about the Zeiss design.

Figure 30 Relatively Modern Leica Greenough S8 APO Stereo Trinocular Microscope

References

We would like to acknowledge Dr. M. B. for his intensive literature researches.

[Abbe, 1880] Abbe, Ernst: Beschreibung eines neuen stereoskopischen Oculars nebst allgemeinen Bemerkungen über die Bedingungen mikro-stereoskopischer Beobachtung. Zeitschrift für Mikroskopie, II, pp. 207-234, 1880

[Auerbach, 1904] Auerbach, Felix: Das Zeisswerk und die Carl-Zeiss-Stiftung in Jena. Jena, 1904

[BACZ 1578, 41-42] Archive of Carl Zeiss AG, BACZ 1578, Microscope correspondence 1892-1896, No. 41-42

[BACZ 1578, 95] Archive of Carl Zeiss AG, BACZ 1578, Microscope correspondence 1892-1896, No. 95

[Blanchard, 2013] Blanchard, Guillaume: Chérubin d'Orléans and his Binocular Microscope. In: Treasury of Optics. Jena, 2013, pp. 127-144

[Britannica, 1910] Encyclopaedia Britannica, A Dictionary of Arts, Sciences, Literature and General Information, 11th Edition, Volume 3, Binocular Instrument. New York, 1910, p 950

[Bulletin, 1891] Bulletin de la Société Zoologique de France pour l'année 1891. Volume XVI. Paris, 1891. p. 239

[Bulletin, 1892] Bulletin de la Société Zoologique de France pour l'année 1892. Volume XVII. Paris, 1892. p. 57-59

[Bulletin, 1896] Bulletin de la Société Zoologique de France pour l'année 1896. Volume XXI. Paris, 1896. p. XII

[Charle, 1989] Charle, Christophe & Telkes, Eva: Les Professeurs de la Faculté des Sciences de Paris. Dictionnaire biographique (1901-1939). Paris, 1989

[Chérubin, 1677] Chérubin, d'Orleans: La vision parfaite, ou le concours des deux axes de la vision en un seul point de l'objet. Paris, 1677. Seconde Partie, pp. 77-98

[Deeds, 1892] Middlesexdeeds1892vol2129to2131images442to443

[Figuier, 1867] Figuier, Louis: Merveilles de la science (ed. Furne, Jouvet et Cie), Volume 3, 1867, p. 681, figure 547 Le laboratoire vivant de Concarneau (https://upload.wikimedia.org/wikipedia/commons/f/f2/T3-_d689_-_Fig._547._%E2%80%94_Le_laboratoire_vivant_de_Concarneau.png)

[Frey, 1868] Frey, Heinrich: Das Mikroskop und die mikroskopische Technik. 3. Auflage, Leipzig, 1868, p. 36-37

[Gerth, 2005] Gerth, Kerstin und Wimmer, Wolfgang: Ernst Abbe: Wissenschaftler, Unternehmer, Sozialreformer. Jena-Quedlinburg 2005

[Haeckel, 1904] Haeckel, Ernst: Kunstformen der Natur. Tafel 30 – Clypeaster (Echinidea). Leipzig und Wien, 1904

[Harting, 1859] Harting, Pieter, Theile, Friedrich Wilhelm: Das Mikroskop, Theorie, Gebrauch, Geschichte und gegenwärtiger Zustand desselben ... Deutsche Originalausgabe vom Verfasser ... vervollständigt. Aus dem Holländischen übertragen von F. W. Theile. 1859, pp. 180-181 (https://books.google.de/books?id=fMJbAAAAcAAJ)

[Harvard 13/30] Harvard University Archives, Cambridge/USA under UAI 15.896 Box 13 Folder 30 Greenough, Horatio S.

[Kofoid, 1910] Kofoid, Charles Atwood: The Biological Stations of Europe, Washington: US Bureau of Education, Bulletin, 1910, No. 4. pp. 89, 92, 132

[Lau, 2018] Part 1 of HSG article http://www.microscopy-uk.org.uk/mag/artfeb18/rjk-bjl-HSG-11a.pdf

[Lewis, 1915] Lewis, Frederic T.: Charles Sedgwick Minot. An address to the American Association of Anatomists, delivered at the New Haven meeting of the Association, December 28, 1915. (https://embryology.med.unsw.edu.au/embryology/index.php/Talk:Embryology_History_-_Charles_Minot)

[NYPL, 1890] “New York Passenger Lists, 1820-1891,” database with images, FamilySearch (https://familysearch.org/ark:/61903/1:1:QVSL-Y9SF : 15 April 2015), Horatio S Greenough, 1890;citing NARA microfilm publication M237 (Washington, D.C.: National Archives and Records Administration, n.d.); FHL microfilm .

[Pouchet, 1888] Pouchet, Georges: Laboratoire d'histologie zoologique au Muséum d'histoire naturelle. In: Rapport sur l'École pratique des hautes études, 1888-1889. 1888. pp. 93-94. (http://www.persee.fr/doc/ephe_0000-0002_1888_num_4_1_19273)

[Revue, 1891] Author’s team: Revue des Sciences Naturelles de l’ouest. Paris, First Volume 1891. p. 269

[Rohr, 1932] Rohr, Moritz von: Siegfried Czapski zum Gedächtnis. Zeiss-Werkzeitung. Neue Folge, Vol. 7, Issue 2, Juni 1932, p. 28 (BACZ 74593)

[Sander, 1997] Sander, Klaus and Fischer, Jean-Louis: How to dart ascidian blastomeres: The embryological micro-tools of Laurent Chabry (1855-1893). In Landmarks in Developmental Biology 1883–1924, Springer Berlin Heidelberg, 1997. pp. 191-193

[Schuermann, 2009] Schuermann, D. Brian: Charles Otis Whitman (1842-1910). Embryo Project Encyclopedia (2009-01-21). ISSN: 1940-5030. (https://embryo.asu.edu/pages/charles-otis-whitman-1842-1910)

[Societé, 1888] Société des Artistes FRANÇAIS pour l'Exposition des Beaux-Arts de 1888: Salon de 1888. p. 96

[Steinheil, 1882] C. A. Steinheil Soehne: Preis-Courant ueber Objective, Prismen und Loupen fuer Photographie … Muenchen,1882, p. 8

[USPA, 1892] "United States Passport Applications, 1795-1925," database with images, FamilySearch (https://familysearch.org/ark:/61903/1:1:Q24F-6MLP : 4 October 2016), Horatio S Greenough, 1892; citing Passport Application, Massachusetts, United States, source certificate #, Passport Applications, 1795-1905., 395, NARA microfilm publications M1490 and M1372 (Washington D.C.: National Archives and Records Administration, n.d.); FHL microfilm 1,497,917.

[Wade, 1998] Wade, Nicolas: A Natural History of Vision. Cambridge, Mass: MIT press, 1998, p 301. Bristol: Adam Hilger.

[Wenham, 1854] Wenham, Francis H.: Binocular Microscope. Quarterly Journal of Microscopical Science 1854 s1-2: 132-134 (http://jcs.biologists.org/content/joces/s1-2/6/129.full.pdf)

[Wenham, 1861] Wenham, Francis H.: Remarks on the Binocular Microscope. Quarterly Journal of Microscopical Science 1861 s2-1: 109-111 (http://jcs.biologists.org/cgi/reprint/s2-1/2/109.pdf)

[Whitman, 1885] Whitman, Charles Otis: Methods of Research in Microscopical Anatomy and Embryology. Boston, 1885, p. 131

[Zeiss, 1891] Carl Zeiss, Optische Werkstaette: Microscopes and Microscopical Accessories. No. 29. Jena, 1891, pp. 7-17 (BACZ 30533)

[Zeiss, 1898] Carl Zeiss, Optische Werkstaette: Mikroskope und Mikroskopische Hilfsapparate. No. 31. Jena, 1898, p. 19

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