Who was Horatio Saltonstall Greenough?
Part 3

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11. His Adaptation of Chabry’s Pipet Holder

The years beginning in 1892 were HSG’s most creative period. He dealt with many issues at the same time and wrote on several in each letter. We will arrange these issues separately in the next paragraphs in order to present them more clearly.

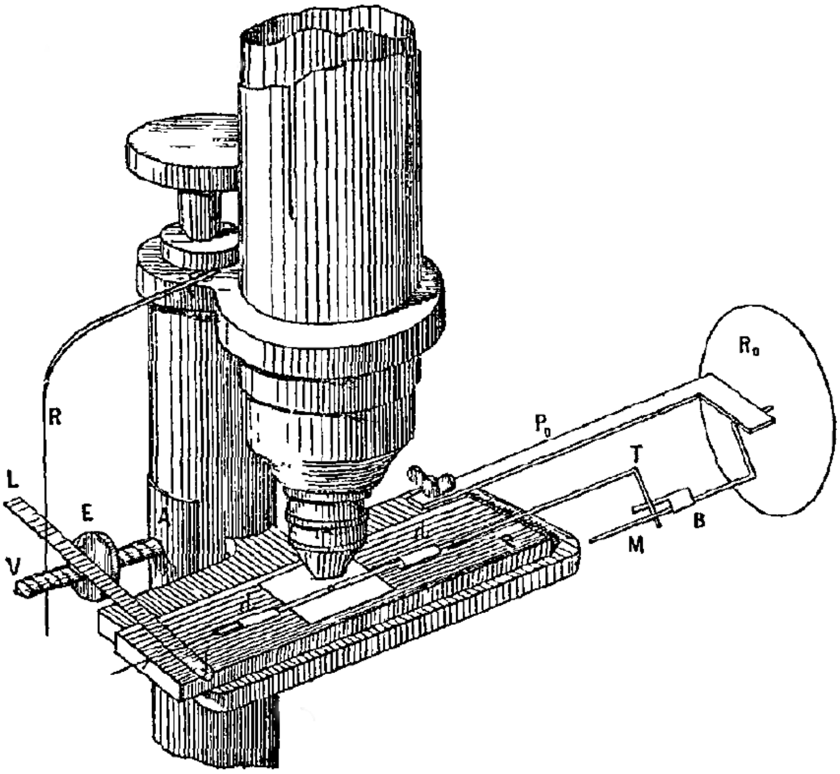
HSG directed his letters to Prof. Ernst Abbe up to November 1892. However, it was Dr. Siegfried Czapski who replied to him all the time. HSG addressed his letters to “Mess.rs Carl Zeiss Gentlemen” or “Herrn Carl Zeiss, Optische Werkstätte Jena” or “Carl Zeiss Esq.” even though the company’s founder had passed away in 1888. HSG did not know with certainty that Dr. Czapski was a member of the company’s management, along with Prof. Abbe, and his right-hand in scientific issues. HSG’s visit to Jena and a personal meeting will be needed for him to accept Dr. Czapski as addressee and qualified partner [BACZ 1578].

HSG’s request on a capillary rotator as an accessory to the compound microscope was treated faster than his request regarding his stereomicroscope. Dr. Czapski (1861-1907) knew embryologic investigation from his friend Prof. Felix Anton Dohrn (1840-1909), former student of Prof. Ernst Haeckel (1834-1919) and after that lecturer at Jena. Prof. Abbe (1840-1905) was his close friend, and he became acquainted with Dohrn by one of the discussion societies of various field scientists [Krausse, 1993] and both became collective skittle and chess players [Werner, 2005].

Dohrn founded the first zoological research station of the world in Naples (1872), and was its first director. Abbe supported his project by providing the newest Carl Zeiss apparatus. The Darwinist opened his “Stazione Zoologica” to visiting scientists and the general public. His model was copied a number of times throughout the world, e.g. at Woods Hole (1885) in Massachusetts by Prof. Charles Otis Whitman (1842–1910, see Part 2/7), Dohrn’s former American student and HSG’s example.

In HSG’s letter of September 06, 1892 [BACZ 1578, 41-42], the capillary rotator was described (See Part 2/10):

"For the study of the 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 thiness [sic] of the tube wall there is little or no perceptible distortion."



P … Massive Glass Slide (on microscope stage)

<u>For Capillary Handling</u>

d … Glued Bearing (cut from rubber tubing)

d-d Capillary and Water below Cover Slip

T … Bent Capillary End

B … Cranked Fork

R_0… Milled Knob for Capillary Rotation

<u>For Piercing a Blastomere</u>

L … Lever (joined to tiny glass lance into capillary tube)

R … Brass Spring

V … Threaded Rod

E … Adjustable Nut

Figure 31 Pipet Holder by Dr. Laurent Chabry [Sander, 1997] and Notes by the Authors.

HSG adopted his concept of capillary rotator from the pipet holder by the younger Dr. Laurent Chabry (1855-1894), Assistant Director of the Zoological Laboratory of Concarneau (See Part 2/7). After obtaining his Ph.D in medicine in 1881, he invented a sophisticated set of micro tools and described it in his thesis for the Ph.D of science (1887). This paper is considered as a founding element of experimental embryology. He also worked on the flying mechanisms of insects and birds, similar to HSG.

In October 13, 1892, HSG wrote from Concarneau, Brittany [BACZ 1578, 7-8]:

“I send you by registered parcel’s post one box containing a few preparations mounted in capillary tubes, & one smaller box containing device for holding the tubes under the microscope …

I fear the preparations are not at all good but such as they are they will suffice for a practical demonstration of this method of observation, which even in very crude way I have employed it has been useful to me & is I believe capable of being so developed as to be of considerable use to morphologists. – The tubes should be put on the glass plate with india rubber on the left side of the microscope … the rotator may then be freely turned with the left hand without taking the eye from the microscope & leaving the right hand free to work the micrometer screw ... - I must appologize [sic] for the very clumsy construction of this device which I have patched up for the most part with old laboratory truck: but it works, and the capillary tubes are too fragile to turn by hand with any convenience …

If you have time I would be obliged to you to examine the preparations sent by me at your earliest convenience as I fear they may not keep well – I have not been able to mount any in Oil of eloves [sic] nor in Balsam as our absolute alcohol has absorbed too much moisture …”

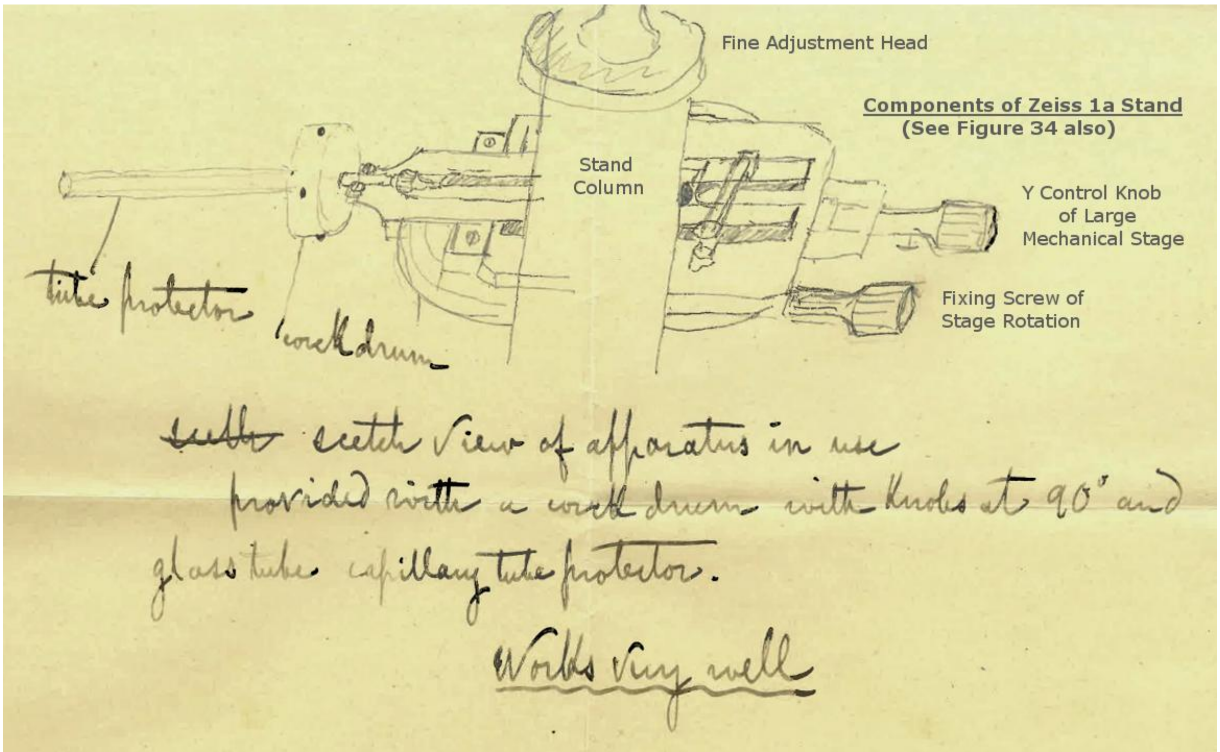


Figure 32 HSG’s Sketch of his Self-Made Capillary Rotator [BACZ 1578, 1] and Notes by the Authors.

Dr. Czapski outlined a four page draft [BACZ 1578, 33-36] in German (handwriting identifies it as him) for his reply of November 17:

"… The specimens you sent to Prof. Abbe on October 13 and the apparatus used to rotate them (together with slide with clamping device) have been thoroughly tested in our laboratory under the direction of Prof. Abbe, and the usefulness of your method for any magnifications up to homogeneous immersion has therefore been demonstrated.

First of all, we would like to thank you very much for your kind communication of this new method of preparation and for the friendly delivery of your original instruments...

With the production of a simple but still usable turning device for the capillary tubes, even at the highest magnification, we hope to achieve this in a short time. A polished groove ground into a thick microscope slide will probably give sufficient guidance with the strong adhesion of the cedar wood oil ... A rotating device would be able to be attached directly to the microscope slide. It can be attacked by means of a delicate spring, which has to press the tube against a cork abutment, so that a longitudinal displacement of the tube for searching the specimen remains possible.

We are convinced that by using such a simple rotating device, which prevent the specimen from hitting, your method will meet with general approval and can be used in various fields of microscopy ..."

HSG was awaiting the first model of capillary rotator manufactured by Carl Zeiss Company, according to his letter of February 08, 1893 [BACZ 1578, 13-14]: "When you send the rotating apparatus would you kindly furnish one slip with groove admitting a ½ millimeter tube and another of ¾ millimeter – I do not care for any larger than this."

HSG's modification requests on this first model were pointed out in his March 11 letter to Herrn Carl Zeiss Optische Werkstätte Jena, underlined by Zeiss's side [BACZ 1578, 20-21]:

"With regard to the rotating apparatus I wrote to you to charge the same to me & I shall keep it unless you are willing to make another with some modifications I will now suggest, when I would change it for the improved form.

The <u>drum to read the angles</u> of rotation would be a decided advantage, & what is even more to be wished for & was attained in a crude form in my original model is a <u>means of rotating rapidly & by touch alone</u>, without taking the eye from the microscope by an amount of 90°or 180°: 90° being the most important – this is very desirable for the study of living ciliated larva as by taking advantage of favourable positions when they are moving slowly.

Views can thus be had in all the three principle planes, viz. parallel to the plane of symetry [sic] & in the two planes normal to it & to each other. But in order to do this it is necessary to be able to effect the 90° rotation at once & by the sense of touch alone. – the finding screw of the tube holder is not convenient – I think (*sketch deleted*, the authors) a female screw-collar going over the split holder would be much better. It is very desirable to prevent all transverse movement of the tube during rotation & for this purpose I submit to you the following modification of your apparatus: use glass slip like this …

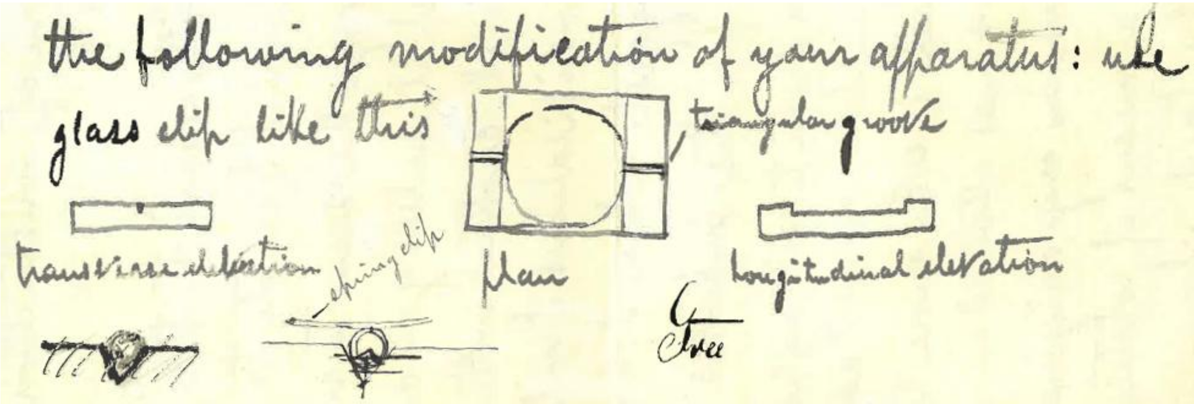


Figure 33 Sketch of Glass Slip from HSG’s Letter in 1893, March 11 [BACZ 1578, 20-21].

… – moreover the spring clips should move in a vertical plane by a spring with two positions of equilibrium one horizontal to press the clips down the other vertical, with the present arrangement it takes a long time to adjust the tube & rapid manipulation is very much to be desired ...”

On April 14 HSG wrote full of hope for the second model [BACZ 1578, 29]. However, before departing the below quoted Czapski letter, he said the following:

“I shall be pleased to try the new rotating apparatus whenever it may be ready – but would point out to you the desirability of searching the tubes lengthwise – with my own crude device this is easily done with some of the tubes without even unclamping the rubber slips.“

The Czapski letter of April 13 [BACZ 1578, 24-26] comes down as the earliest available copy***** of a page written in permanent ink, but, unfortunately, it is not done perfectly - the vast majority is, sadly, not legible. Fortunately we get the German manuscript [BACZ 1578, 27-28] which gives his detailed concept for capillary rotator in answering HSG's letter:

"In redesigning the rotation apparatus, which we have now tackled with the utmost consideration of your esteemed wishes expressed on the 11th of March, we have been led to make some changes, which we must also see as improvements to your proposals. However, we do not want to re-run the apparatus without first consulting you about these items..."

Czapski proposes a three jaw chuck mounted on a steel base. It carries the immersed glass plate and a brass frame with the 60° guiding groove and spring levers for clamping the capillary tube. This frame is adjustable in height to match the chuck axis by different capillary diameters. But he is still not happy:

"In conclusion, we do not want to conceal from you that it seems very questionable to us whether all these complications for the exact centering of the axes against each other really result in a more precise running of the tubes, or if rather the secure storage of the tubes in the grooves a greater depth of the latter and impacting springs, as described above, alone is authoritative. A deviation in the axes of rotation of 1.0 mm to a length of 80 mm seems to us to be irrelevant in the flexibility of the capillaries, especially since the latter are seldom completely straight, and consequently a one-sided pressure is exerted in the grooves even at the most accurate centering, Therefore, we expect you to make a further return, whether you wish to carry out the apparatus with the described complications. For the experimental determination of the influence of this deflection, the execution of the apparatus in the complex construction would be required anyway."

HSG's disapproving reply to the Czapski proposal followed on two oversized pages on April 17 [BACZ 1578, 30]:

"Your favour of the 13th inst. came to hand on Saturday last: I am unable to give you any positive reply as I do not feel at all sure that the plan you propose would work well; but should you care to try it I will purchase the apparatus of you if it is successful;

***** This procedure used a sandwich of ink written page, very thin copy sheet and damp piece of cloth which were pressed together for an appropriate period. The ink shall be solved partly and transferred on the copy sheet. The resulting mirror writing was read from rear side, seen true sided through the translucent copy sheet.

one objection that occurs to me immediately is the probability of frequent breakage of the fine tubes owing to the shearing stress which your plan seems to me to involve – Should you care to try any experiments in this direction I shall be pleased to send you several of my tubes of preparations. – Again any device to replace both my rubber-garnished glass slip & rotating stand by one apparatus should admit of searching of the tubes lengthwise, and to do this without more inconvenience that with my original device would involve a mechanical arrangement for sliding the tubes lengthwise, - six to eight centimeters is enough – and then one end of the tube must be held fast and this can I think only be done safely by rather tight pinching between rubber cushions – in this manner it can be done safely … I would suggest therefore that you first make for me two slight modifications in the device you first sent me so that I can use it on the mechanical substage which I have found most convenient used with my own device – … as my own rotating stand already works well I should like to give your first sent device a good trial and in all probability keep it in any case provide you are willing to make the suggested modifications – …

With my own apparatus and your mechanical substage I already get a good result but I should be much pleased to have this improved upon because I think if something thoroughly practical & not total expensive could be put upon the market that this method of observation would be considerably used & I am quite sure that it is really of some value – In fact I will take this occasion to say that so far as I can judge from such published accounts and drawing as I have seen the real shape of sea-urchin larvae in the stage following the gastrula is only known to myself & to the few friends who have seen my drawings – Agassiz's drawings (*See Part 1/3*, the authors) are quite correct as regards outline but the orientations assigned are twenty or thirty degrees out of the way & when the assigned orientations are really had the outlines are entirely different; so much so that the two sets appear quite independent, when considered seperately [sic] …

I hope you will find it practicable to make the suggested modifications in the tube carrier you sent me, because I think this will already be a considerable progress – on receipt of a favourable reply I will send you the apparatus by registered mail together with some tubes should you wish for them ..."

"[Y]our mechanical substage" term will be explained better by HSG on December 16 [BACZ 1578, 44]: "I send by registered parcel post the steel attachment to mechanical substage of my large stand no 1.a ..." This high-end Zeiss stand includes a large mechanical stage which consists of lower and upper part. The lower rotatable one can be centered and shifted along 35 mm by the Y control knob (W of Fig. 34). HSG designated the screwed-on (by L screw) upper part as substage which offers the clamp for slide and 50 mm X shift by control knob (K). HSG's substage term gets no relation to Abbe's ex-centering substage displacing condenser out of optical axis.

Figure 34 Zeiss 1ª Stand with Large Mechanical Stage [Zeiss, 1898].

HSG repeated the modification request of capillary rotator similarly his self-made one (See Fig. 32) on August 21 and September 3 [BACZ 1578, 37] from Concarneau:

“If you can construct me a rotating apparatus to clamp on the mechanical substage so that the tube may be searched lengthwise by the motion of the substage I shall be much obliged to you: it is necessary that the tubes should be perfectly centered, though this would be neater, but only that any traverse movement of the object in field due to rotation should be slight. For the rotating tube clamp I venture to suggest the following device as per sketch herewith: (*sketch deleted*, the authors) clamping female screw collar; one of four jaws to open by elasticity & shut by clamping screw collar; indian rubber tubing to pinch tube in centre [sic] by clamping of jams.”

The following reminder came from Paris on September 25 [BACZ 1578, 39]:

“I have been hoping to hear from you for some time & trust you will not think me too importunate if I now ask you whether you see any prospect of being able to make me a rotating apparatus for my capillary tubes?”

As mentioned already, HSG sent his steel base of rotator for modification to the Zeiss factory in December. In January 18, 1894, HSG confirmed the delivery of the next model of capillary rotating apparatus [BACZ 1578, 46]. HSG will propose further sophisticated improvements on March 13 [BACZ 1578, 63].

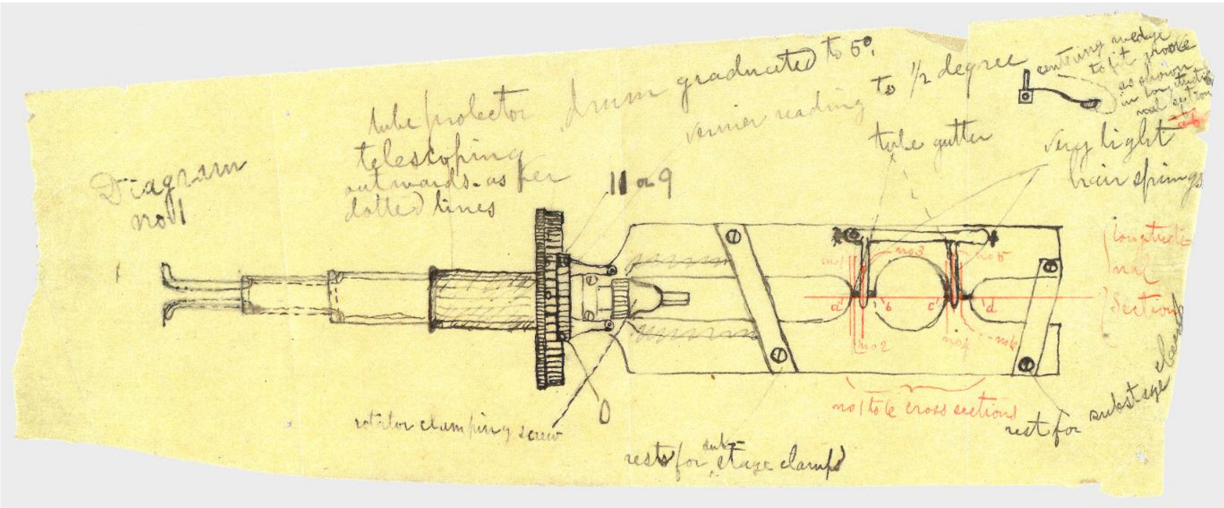


Figure 35 Sketch of Capillary Rotator on Tracing Paper with HSG’s Notes [BACZ 1578, 1].

12. His Search for Best Objective and Immersion Liquid

On October 13, 1892 HSG wrote [BACZ 1578, 7-8] regarding the registered parcel post including his self-made capillary rotator:

"The tubes contain segmented eggs of the sea urchin, embryonic sea urchins in two different stages of growth, all mounted in glycerine & young gasteropods (*gastropods = snails and slugs*, the authors) mounted in carbolic acid (*phenol, former antiseptic liquid*, the authors) …

P.S. It is needless to add that the preparations in capillary tubes may be examined with a dry object glass by putting a cover glass supported on slips of paper or card board over the immersing liquid."

Even though the specimen and the capillary tubes were immersed, the imaging was done by a dry objective. Dr. Czapski proposed the optical improvement to use oil embedding and appropriate immersion objectives for the best resolution [BACZ 1578, 33-36]. His text of the November 17 letter says:

"As already indicated, even with the homogeneous immersion with the 3 mm / 1.40 as well as the 2 mm / 1.40, one obtains a fair number of pictures of the preparations, which in any case would be completely satisfactory if cedar wood oil instead of glycerin were used as the inclusion agent in the tubes ...

With regard to homogeneous apochromats specially constructed for this method, we would like to ask you for more detailed information on the requirements to be met by this lens: Focal length, Num. Apert., free object distance. At first we can only assume that you desire a large object distance and therefore a reduced Num. Apert. to use capillary tubes of larger diameter of larger objects accordingly. We would like to try to produce such a lens according to your wishes, if the conditions are in the range of possibility. With a N.A. of 1.0 and a focal length of 4 mm, a free object distance of 1.0 mm could possibly be achieved ..."

On November 21 from Paris, HSG replied to Carl Zeiss Esq. and emphasized his preparation demands leading to water immersion. Most underlining was done by Zeiss's side [BACZ 1578, 10-11]:

"Your favour of the 17^{th} inst. reached me yesterday and I am pleased to find that you think well of my rotating device.

As the tubes sent can be examined with the $3^{\underline{mm}}$ homogenous immersion, I do not think it worth while, at least for the present to construct a longer focus apocr. homogenous immersion – I had only thought of this in case the tubes should prove too think [sic] – thick – (*added by addressee*, the authors) for study with your present $3^{\underline{mm}}$ object glass.

– moreover the use of the hom. 3^{mm} apocromatic, which would be very advantageous for the study of cytological detail, i.e. karokinetic [sic] (*karyokinetic = the dividing of the cell nucleus*, the authors) figures, protoplasmic meshwork etc. is not suitable for the study of topography of embryos because the dehydratation [sic] causes very great shrinkage & considerable distortion – for this purpose living embryos & freshly stained aqueous or partially aqueous preparations are the best – for this purpose I think a water immersion apocromatic objective would be very good – the focal distance could be 4^{mm} & the frontal distance & num aperture as great as could be used without sacrificing the lateral portions of the field as regards definition of images – say ½ or ¾ ^{mm} frontal distance - or perhaps you might think that 5^{mm} focal length would be better? …

With regard to the Homogenous imm. apocromatic, I hope you will soon decide to make the 4^{mm} 1 apert. with working distance of 1^{mm}. We should I am confident find it most useful & I should I think prefer in that case to buy your 2^{mm} 1.40 apert for the 2^{d} imm. rather than the 3^{mm}. But if you do not make the 4^{mm} I shall content myself with the 3^{mm} only in that case many objects can only be studied with the D*****.

What is the price of the 2 ^{mm} apocromatic homogenous imm of 1.40 apert

Catalog (*added by addressee,* Marks 400*,* the authors)”

HSG’s desires on objectives exceeded the state of the art at the time and stayed only a thought.

A 63:1 (f=4 mm) or 50:1 (f=5 mm) water immersion apochromat with high aperture would not give the wanted image quality due to the convex glass wall of the capillary and the missed homogenous immersion, i.e. the refracting indices of glass and water differ. Both are approximately equal in oil immersion only, which therefore allows a user to replace oil by glass. Today a sufficient working distance would be available by a very specific apochromat.

A one millimeter working distance for an oil immersion 63:1 apochromat 1.0 NA cannot be realized unfortunately. The too optimistic assumption of Dr. Czapski was incorrect. Today these specs can be fulfilled at the half of magnification requested by HSG.

HSG repeated the query on prices in his letter of January 3, 1893 and added a further idea [BACZ 1578, 12]: “Would it be possible by means of a correcting ring to use one object glass both for water and glycerine immersion?”

In those days a correction collar was known to adjust the objective to account for the thickness of the cover glass. Objectives with correction collars for immersion media will be developed for the first time in the Plan-Neofluar range by the Carl Zeiss Oberkochen Company in 1975 [Trapp, 1977].

In the letter of February 8, 1893 [BACZ 1578, 13-14], HSG changes his demand of the development of an unrealistic water immersion apochromat to the purchase of a water immersion achromat from Carl Zeiss catalogue:

"Your esteemed favours of the 1st & 3d insts. are duly received & also the D***** water immersion objective (*See A note*, the authors) in payment for which I yesterday sent you postal order for Marks 76.10 as per invoice. – In view of the statement contained in your last letter I deem it best to use the D***** objective for the study of living eggs & embryos in connection with the capillary tubes & to give up all idea of an apocromatic immersion objective for this purpose: - In view of the favourable opinion of my device expressed in your's of the 17 Nov. ult. I venture to offer a few suggestions for your consideration …

– Now I have hitherto found it entirely impossible to dehydrate with alcohol the very delicate eggs & embryos I wish to study without causing an <u>enormous</u> shrinkage – on the other hand I have been able by means of certain precautions in manipulation to obtain preparations mounted in pure glycerine & presenting little shrinkage & I am quite confident that the shrinkage can be still further reduced by improved manipulation – I think it therefore very desirable to examine glycerine preparations under the most favourable conditions that can be obtained. For this purpose two methods are available –

1ly to use glycerine immersion objectives either acromatic or apocromatic as may be deemed best; I presume however that this would present, for use with capillary tubes, the same disadvantages though in a less degree, as would obtain with water as set fourth in your letter of Febr. 3d (*See B Note*, the authors) –

the 2d and better method is to use, if practicable, <u>extra refracting glycerine</u>; I have read in Bolles Lee & Henneguy's treatise on microscopic technique that by the dissolution of suitable metallic salts, the index of refraction of glycerine can be raised sufficiently to utilize the full power of homogeneous immersion objectives, the salt producing the least increase of refractive index gives that of 1.4 … that producing the greatest gives1.6 … I have not been able to obtain any of this Glycerine in Paris, it is not to be had; and am entirely unable to prepare it myself by making the indicated solutions in Price's Glycerine, for the proportions are not given & on the other hand we have no instruments permitting us to measure the index of refraction ...

It is of course possible there may be embedding liquids unknown to me that would admit of the preparations being made without material shrinkage & at the same time having a sufficiently high refractive index to give completely satisfactory images with the homogeneous immersion, should you know of any such prey advice me (*See C Note*, the authors) …

P.S. I earnestly request that you will do your best to push forward the new stereoscopic microscope as I am very desireous [sic] of trying it on the eggs & embryos of Bufo Calamita (*Natterjack toad*, the authors) & cannot do so here except rather early in the season."

A Note:

HSG accepts the available D***** water immersion achromat (40:1; 0.75 NA; 1.5 mm WD) which is less optically sensitive on HSG's application. This objective was calculated with the demand for a long working distance and launched by the 1891 Carl Zeiss catalogue. It is from the common achromat structure but the flint glass of second lens component stands on the image side unusually [Boegehold, 1955].

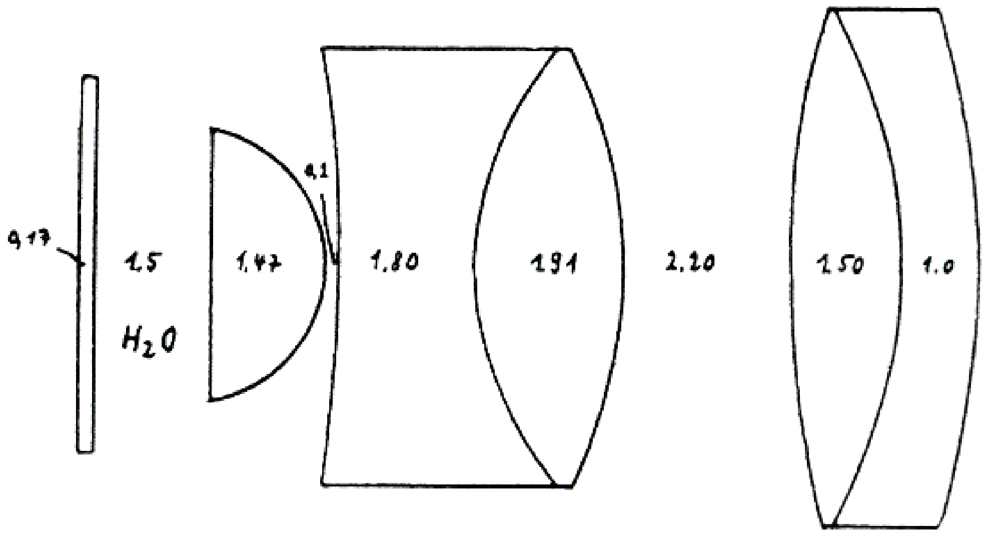


Figure 36 Carl Zeiss D* Water Immersion Objective from 1891 Design [Boegehold, 1955].

B Note:

Czapski proposed, apparently, some objective variants in his letters of February 1 and 3 which are not handed down. As a first option, HSG requested a glycerin immersion objective, considering the demands of preparation.

In 1867 the first glycerin immersion objectives were presented by Ernst Gundlach (1834-1908) from Berlin, Germany at the Exposition Universelle, Paris and by the American Robert B. Tolles (1820-1883). The first claimed "the first instance of the intentional construction of objectives for use with an immersion fluid of higher refractive index than water". The second one reached 1.27 NA by an advanced 1/5 inch glycerin objective in 1873 and introduced also the Cedar wood oil as common homogenous immersion which matched the refractive index of front lens [Solliday, 2007].

In the 20th century, glycerin immersion became important in UV microscopy due to its refractive index, near quartz and fused silica, e.g. the Ultrafluar objectives were created by Carl Zeiss Oberkochen in 1959.

C Note:

As a second option, HSG discusses how to increase the refractive index of glycerin embedding to fit the requirement of oil immersion objectives. Czapski assists this idea and writes on April 13 [BACZ 1578, 24-26]: “The glycerin solutions have been delayed due to difficulties in obtaining the material in the required purity. In about a week you will receive them ...”

The embedding of biological specimens in glycerin was well known. So the German botanist G. H. Leopold Dippel (1827-1914) wrote in his book “The microscope and its application” [Dippel, 1867]:

“Some objects, which would be observed under water or under one of the above-mentioned aqueous liquids have a transparency which is too low to be able to recognize their structural conditions with sufficient clarity, are surrounded by media which refract the light more strongly than that. Depending on the degree of whitening required by a preparation, either different additives are used or, where appropriate, different degrees of concentration of one and the same additive.

For objects that appear more or less permeated by water, the glycerol, which has a refractive index of 1.475, while that of water is equal to 1.336, is particularly suitable as an additive liquid. Glycerin can be diluted with water as required, reducing the refractive exponent in proportion to the mixing ratio. For example, the ratio of a mixture of equal parts of glycerol and distilled water is 1.40 ...”

The living specimen were guided from water to glycerin by HSG’s ten step preparation method and softly killed in this procedure. The residual gap to the immersion oil index (1.518) would be only ¼ of the already mastered span but glycerin and oil cannot be mixed. HSG hopes on glycerin of higher refractive index, as reported by Arthur Bolles Lee (1849-1927) and Louis Félix Henneguy (1850-1928) thus did not prove to work. His French colleagues wrote [Lee, 1887]: “Glycerin jellies have a higher refractive index than pure glycerin. We believe that these media are of very real importance, and that the histologist must always have a good glycerin gel. These ready-made jellies are available from opticians, at least in London; also from microscopy suppliers in Germany, as we see from Dr. Grübler’s Current Price (Leipzig, Dufour-Strasse, 17).”

A German chemist from Jena had given details for higher refractive glycerin [Burgemeister, 1871]: “Glycerin is almost as good a solvent as water for the alkalis and some runny metal salts, it also dissolves not insignificant amounts of lead oxide and copper oxide.”

Today e.g. the OHZB aqueous liquids are available with each n_D refractive index (at 589 nm and 25°C) between 1.465 and 1.556 [Cargille, 2019].

HSG wrote a letter [Harvard 13/30] also to his American friend on the Panama Canal Scandal in France, the largest monetary corruption scandal of the 19th century. The envelope is addressed to A. Lawrence Lowell Esq. Counsellor at Law, 7 Exchange Bdg., Boston, Mass., USA – nearby HSG worked as a young clerk (See Part1/5). The date stamp says “London Fe 20 93” and proves that HSG spent a few days in London but it does not show us why he went to England. Did HSG try to buy high-refractive glycerin due to the hint by Lee & Henneguy that it should be available from opticians, at least in London? Or did he go in search of his ancestors in England?

We know that his ancestors came from Lancashire County and a few Greenough’s lived in London in those days. The geologist George Bellas Greenough (1778-1855) was the most famous of the English Greenough’s.

Laura Wagnière-Huntington wrote about the pedigree of American Greenough’s [Wagnière, 1930]:

“The origin of my mother’s family of Greenoughs was supposed by some to have been Norman. The name was written in various ways as is so often the case in old times of many other families. Greenough as it is written now, Greenhow, Greenhough, and Greenhalge the oldest ways of writing it and I am happy to say I am not obliged to add ‘Greenhorn’ to the list! In the Visitation book of the county of Lancaster in England under the name of Greenhalge the coat of arms is like ours, a ground of argent with three hunting horns in black surmounted by a giddy bow knot with a larger horn below it.

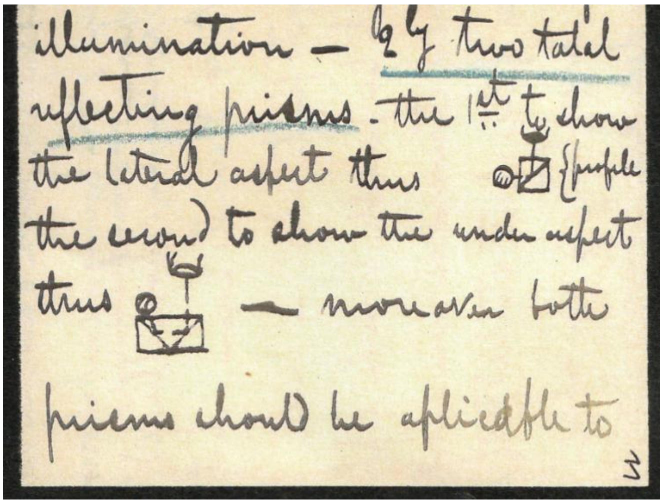
My Uncle Horatio (*HSG’s Father*, the authors), in a letter which I own and that he wrote to his mother when he was a young man travelling in England, says:

‘My fathers in England were by fortune and by lot of those who used the sword and not of those who felt it. They were driven out in the wars of the White and Red Roses *(1455-1487 Wars of the Roses*, the authors). They fought for Lancaster and now Greenough Castle is only one solitary fragment of a Tower forming a pretty Vignette for many a sketch book and little do they think, who sketched it, that blood is stronger than stone and that the race who lived there once, now lives in a distant land and thinks more of the next month than all the past. This ruin and an old Bridge, a few years ago passable, are all that now bear the name of Greenough in England.’

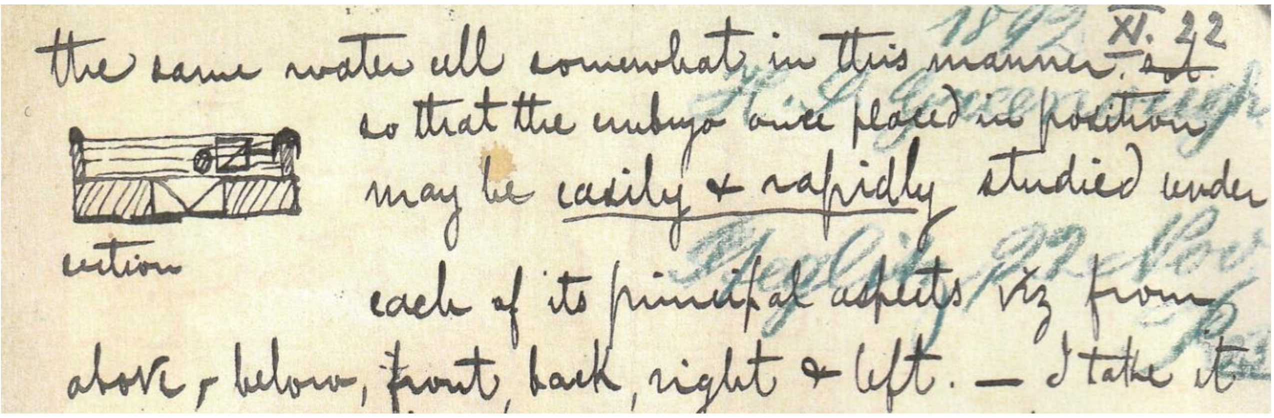
The first Greenough whom we have record was born in England in 1617 and came to the United States ... His will is recorded in the New England History. This Captain Greenough had a cousin William who was the second Greenough that came to Boston in 1641. He was born in England but died in Boston, Mass. U. S. A. He had several sons one of whom was certain Thomas from whom we are descended …”

13. His Prism Rotator as Accessory for the Stereomicroscope

Now we go back to November 21, 1892 [BACZ 1578, 10-11] to follow on the unique HSH idea suggested to Carl Zeiss Esq., most underlining was done on Zeiss's side: "… if you could construct for me the necessary accessories viz 1^{ly} <u>two long focus condensors to fit onto platinum gause incandecant gass lamps</u> [sic] (*platinum gauze incandescent gas lamps*, the authors) …



illumination – <u>2^{ly} two total reflecting prisms.</u> The 1^{st} to show the lateral aspect thus {profile} the second to show the under aspect thus – moreover both prisms should be aplicable to …



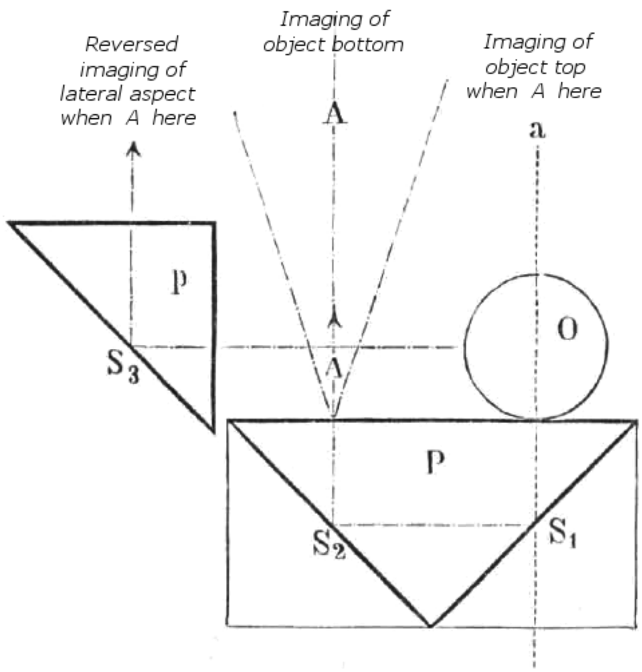
… the same water all somewhat in this manner. --- so that the embryo once placed in position may be <u>easily & rapidly</u> studied under each of its principal aspects viz from above, below, front, back, right & left. – I take it …

Figure 37 Sketches of Prism Rotator from HSG's Letter of November 21, 1892 [BACZ 1578, 10-11].

for granted that the working distance of the new for the microscope will be sufficient to admit of the use of total reflecting prisms as in above diagram. Could you give me an estimate of the probable cost of the condensors & prisms? –

I hope as I have already said to give you an order for the new microscope, but these accessories are very necessary for the work I have in view, also I hope to purchase one of your 3m/m homogenous apocromatic immersion together with the apocro [sic]. water im. above alluded to also rotating apparatus etc. but all this will be expensive I must know what the total cost will be and get first what is most immediately wanted - Would it be possible to make a photographic attachment for the new stereoscopic microscope so as to take stereoscopic pictures of the objects studied if so what would be the cost? …"

The idea of a prism rotator seems to have originated from HSG, and is sketched below. A first model is delivered together with the stereomicroscope prototype as planned by HSG. A stereoscopic camera will be launched by the Carl Zeiss Company soon after the stereomicroscope using its objective pairs and stand. We see HSG's interest in optics both in these ideas and the lens discussion.



A … **Symmetry Axis of Optics**
a … **Axis of Prisms Rotation**
O … **Object**
P … **Large Reflector Prism**
$S_{1,2}$… Silver-plated Short Faces
p … **Small Reflector Prism**
S_3 … Silver-plated Prism Basis

Figure 38 Section of Prism Rotator after Dr. Walter Gebhardt [Czapski, 1897] and Notes by the Authors.

Prof. Abbe employed the anatomist Dr. Walter Gebhardt (1870-1918) and he was with Zeiss Company during 1897-1899. Later he became a respected Professor at Halle, Germany [Eulner, 1964]. Gebhardt will introduce an improvement with two reflections instead of the small prism to avoid the reversed lateral image.

We learn also that HSG had more desires than was conducive to his financial resources. No source of income is known during his second life period in Paris. So he wrote on March 7, 1893 [BACZ 1578, 15]: “P.S. I should perhaps have rather said collaborator of M. Houssay than collegue [sic] as I have no official connection with the Ecole Normale Superieure.”

We, the authors, thus assume that HSG lived off his Father’s and Mother’s inheritance.

On the following day, HSG wrote an extensive letter [BACZ 1578, 16-18] on all of his projects, please see the pages in this paper on the prism rotator. Here HSG requested an illuminator on prism rotator “… and it is quite essential that it should easy two small voltaic arc electric lights in opposition relatively to the object; they should be movable & might be separate & adjustable with clamps.”

Another illuminator will be proposed by HSG on December 26 [BACZ 1578, 45]: “With regard to illumination, Professors Brillois & Viol both suggested to me the same device, namely an annular electric-glow lamp, but I have not yet found any constructor who is willing to make me a few for trial, perhaps you might have better luck in Germany …”

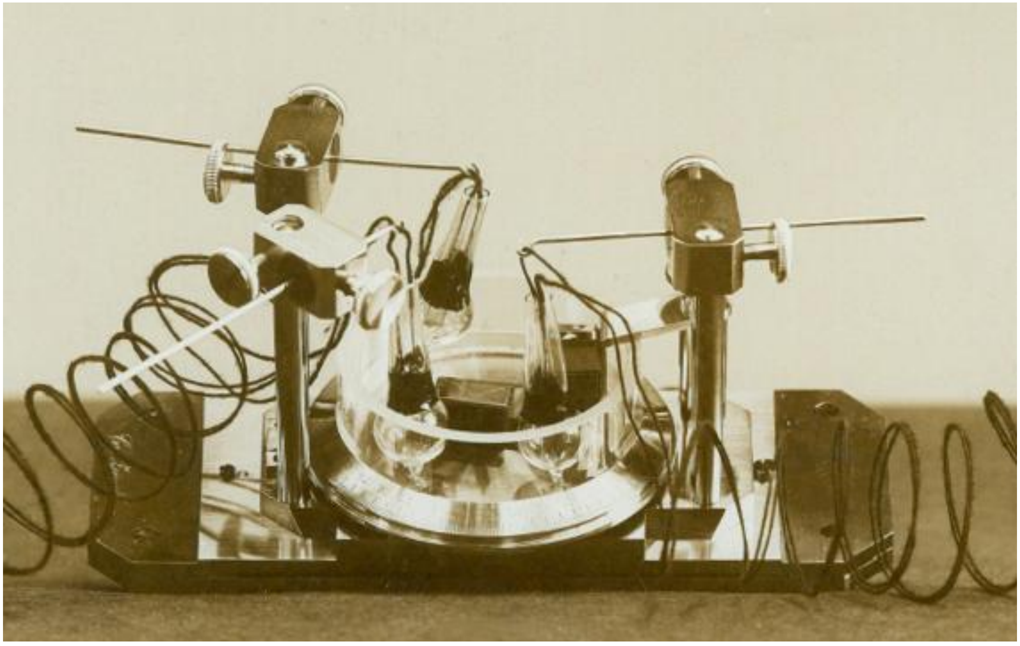
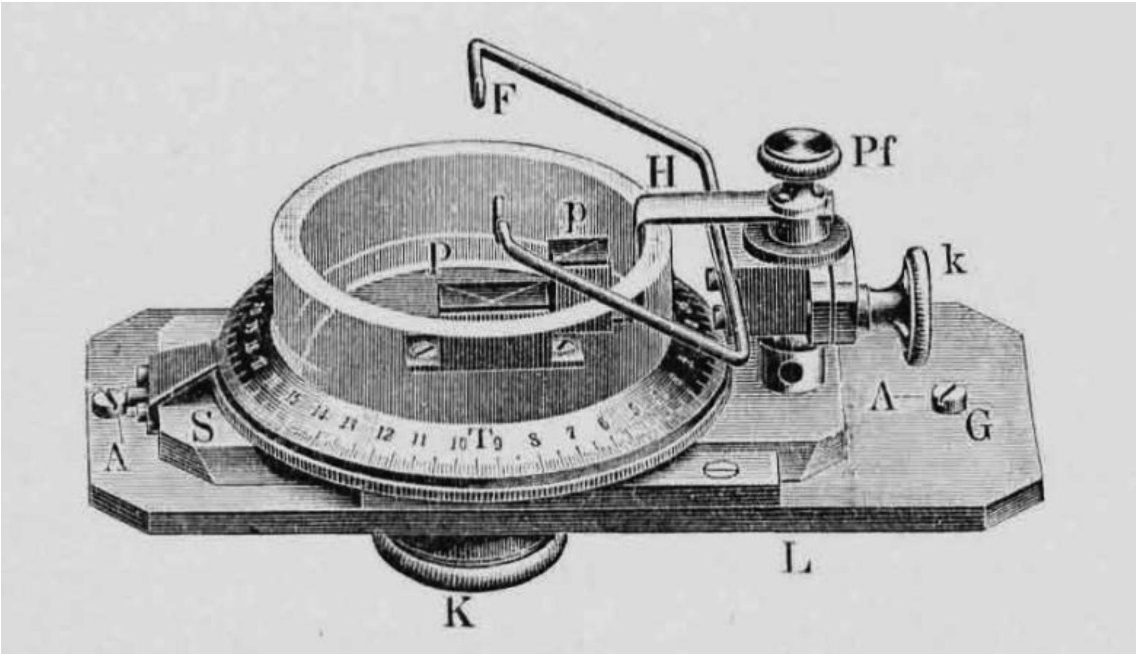


Figure 39 Model of Prism Rotator Equipped by Three Incandescent Lamps [BACZ 1578].

HSG’s letter of April 17, 1893 says that he had experimented with prisms in the object space and requests the prism rotator as important accessory to the stereomicroscope [BACZ 1578, 30]:

“The total reflecting prisms referred to in a former letter of me have given very satisfactory results in prelimenary [sic] trials on amphibian ova & embryos – … it was necessary to use sunlight slightly condensed; … – it will however be necessary to have the prisms well & properly mounted for the work to be done by them, my present mounting in work being unsuitable & insufficient not anything more than a prelimenary [sic] trial ... I will not hide from you that I think these accessories likely to give some little trouble – I say this because I find it entirely impossible to get any competant [sic] person here to take the matter in hand, and because considering them essential to a good performance of the proposed new microscope. I think it would be well to take them in hand as soon as may be should you care to do so I will write you in detail concerning my experiments with the total reflecting prism-mirrors & the results arrived at, which we think already of some value.”



G … Metal Base Plate 90x40x3 mm
L … Sliding Way with Slide (S) and Mechanical Limit Stops (A)
T … Circular Scale around the Glass Ring for Holding the Water Immersion
P … Large Reflector Prism, its Short Face is Intersected by Rotation Axis
H … Holder of Small Reflector Prism (p), Clamped by Screw (Pf)
F … Forked Wire Clamped by Screw (k), Intended for Carrying Lamps
K … Knurled Knob for Prisms Sliding and Rotating

Figure 40 Prism Rotator after Dr. Walter Gebhardt [Czapski, 1897] and Notes by the Authors.

The first model of prism rotator will be delivered together with prototype of stereomicroscope to HSG in March 1894. The improved version of prism rotator was offered up to the 1939 Zeiss catalogue.

14. His Comparison of Abbe’s and Nachet’s Binocular

HSG’s first letter written on the notepaper with the imprint of Laboratoire de Zoologie, Ecole Normale Supérieure shows a date of March 25, 1893 [BACZ 1578, 22] and deals with Abbe’s Stereoscopic Eyepiece (See Part 2/8 also): “I would ask if you are willing to make me one of your stereoscopic eyepieces no. 55 but with compensating “oculars” so that it may be used with the apochromatic objectives 16 mm & 8 mm & also of coarse with the D* object glass …

P.S. I judge from a careful study of Professor Abbe’s paper on your no 55 stereoscopic eyepiece that the effect must be much better than with Nachet’s (*Binocular,* see details below, the authors) at least for medium & higher powers & since finding that the stereoscopic effect is essential to the best working of my rotating device I am the more desireous [sic] of having one of your eyepieces – I had not thought of it before as it was only on trial of your microscope with my tubes and in studying an object of complicated shape that I became aware of & how important the stereoscopic effect is for this purpose – with it; it would be easy to make an accurate 3 dimensional model of the objects studied – without it would be acceedingly [sic] difficult if possible at all!”

HSG recognized Abbe’s essential moving of the ray division from the nearness of the back focal plane on Nachet’s Binocular to the neighborhood of a firm image plane. Therefore, all objectives deliver a regular field of view - not only the weak ones with their back focal plane located optimally behind the objective barrel. So, HSG hoped to get stereoscopic view on specimens inside the capillary clamped by his rotator. In this application, he didn’t see Abbe’s inverted image as a drawback - in contrast to manipulating embryos under low magnification, and the known comfort of Nachet’s Binocular.

On the next day, HSG replied [BACZ 1578, 23] to Czapski’s letter of March 24:

“… it is with deep regret that I learn of the indisposition of your Professor Abbe, and I hope a few months’ vacation may restore him to perfect health. I wrote to you yesterday, but in view of the news contained in your above mentioned letter I take it for granted that my request for making of one of your stereoscopic eyepieces with compensating “oculars” can not [sic] be at present compiled with; …

I would ask you therefore to send me for trial one of your no 55 stereoscopic eyepieces together with 4 acromatic object glasses, of focal lengths as follows or as near as may be – I have not your catalogue at hand – 40$^{\underline{mm}}$ ***a***; 20 or 25$^{\underline{mm}}$ ***aa*** 16$^{\underline{mm}}$ ***A*** & 8$^{\underline{mm}}$ ***C*** … If the no 55 stereoscopic eyepiece used with your acromatic object glasses a better effect than the Nachet Binocular, as I believe it will, I shall keep it & the object glasses and send you draft as soon as I shall have had time to test the matter to my satisfaction ***it is not so urgent with it***. The magnifications wanted are from <u>20 or 30 up to 250 or 300</u>. - & I suppose my own D* would give somewhere about the larger limit when used with your no 55 stereoscopic eyepiece ***Yes***.”

The German notes by addressee are translated and typed in bold Italian by the authors. The abbreviations mean the Carl Zeiss designations of achromatic objectives:

List of Achromatic Objectives.

Designation	Numerical aperture	Equivalent focal length
a_1	—	40mm ($1\frac{9}{16}''$)
a_2	—	35mm ($1\frac{3}{8}''$)
a_3	—	30mm ($1\frac{1}{4}''$)
a*	—	38—26mm ($1\frac{1}{2}''$—
aa	0.17	26mm ($1''$)
A	0.20	18mm ($\frac{3}{4}''$)
AA	0.30	18mm ($\frac{3}{4}''$)
B	0.35	12mm ($\frac{1}{2}''$)
C	0.40	7mm ($\frac{9}{32}''$)

Table of Magnification
of the Achromatic Objectives with the Huyghenian Eye-pieces
calculated for a tube-length of 160 mm and an image distance of 250 mm

Eye-piece:	1	2	3	4	5	
a_1	7	10	15	20		a_1
a_2	11	16	23	30		a_2
a_3	20	30	40	50		a_3
a*	4—8	7—14	10—20	15—30		a*
aa	25	35	47	60	77	aa
A, AA	37	50	70	90	115	A, AA
B	60	85	115	145	185	B
C	105	145	200	265	325	C

Figure 41 Low Magnifying Achromatic Objectives [Zeiss, 1891].

In following we give some details of the Common Main Objective (CMO) stereomicroscope used by HSG and probably owned by Ecole Normale Superieure.

After 1850 the Parisian optician Camille (Sébastien) Nachet (1799-1881) designed his first binocular microscope which was a true stereoscopic one and provided erected images. His 1863 catalogue shows the version of following Figure 42 [Nachet, 1863]. The English engineer Francis H. Wenham (1824-1908, see Part 2/9) praised Nachet's prism solution [Wenham, 1854]:

"Where two prisms are employed for dividing the pencil behind the object-glass, some of the most valuable portion of the surface of the latter, straight across the diameter, is lost at the junction of the prisms. M. Nachet has most ingeniously remedied this defect, by using only one isosceles prism for splitting the pencil in both his binocular and duplex microscope."

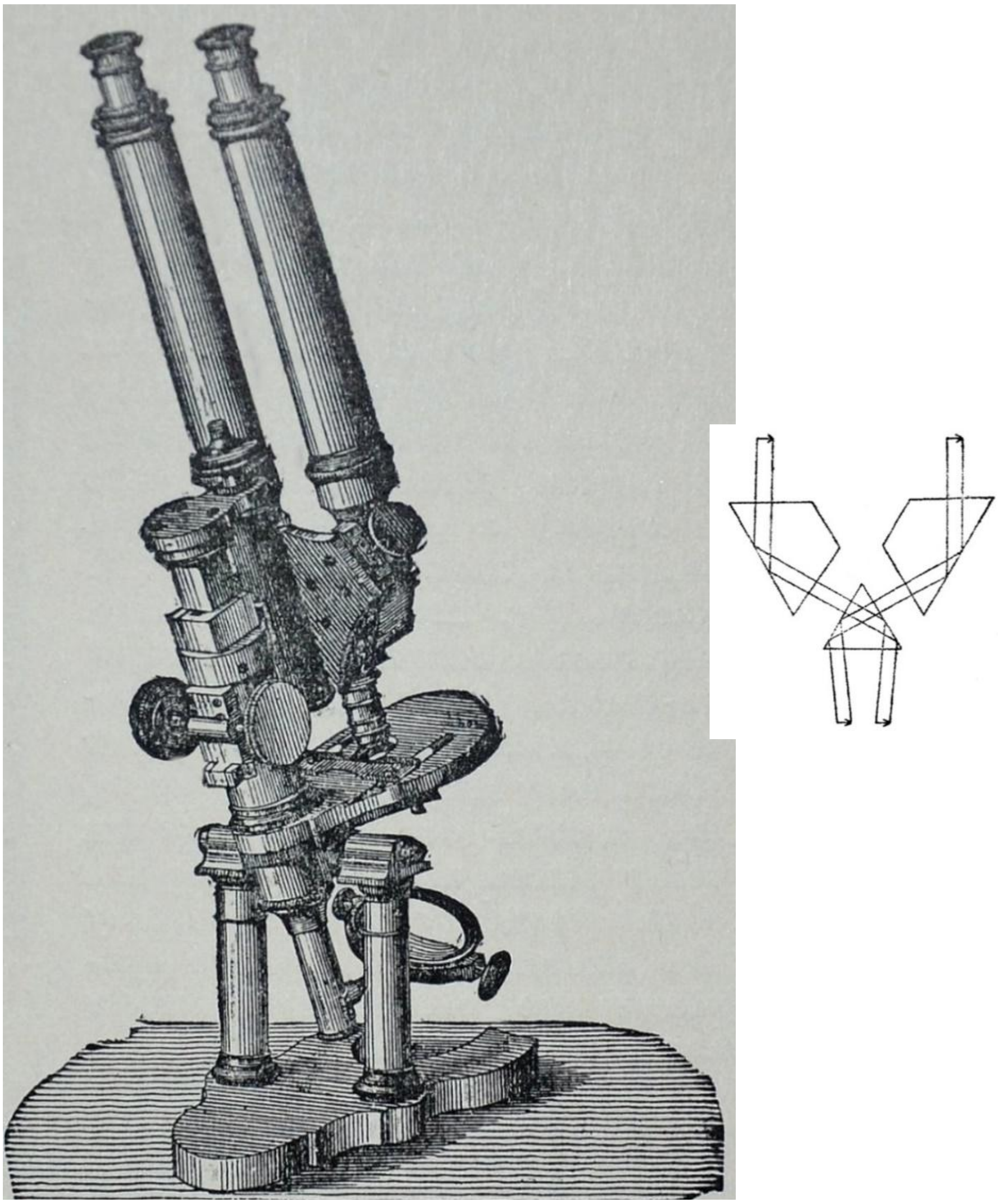


Figure 42 Nachet’s Binocular Microscope [Black, 1878] and its Orthoscopic Prisms Set [Rohr, 1920].

Nevertheless HSG had to struggle against the low light capability of Nachet’s Binocular using the slim objectives of compound microscope. The availability of half back focal plane for each channel is the typical disadvantage of a CMO and the four glass-air interfaces of prisms cause ca. 60% light loss. Therefore HSG wrote about the need for strong illumination on April 17 [BACZ 1578, 30]:

"… Nachet has modified one of them so as to give a focus of size to 7 centimeters with a Zircon gas lamp & if he can & will similarly modify the other & mount two Zircon gas lamps in a suitable manner this should be sufficient for use with any ordinary low power microscope … I found by trial this spring that sunlight could be sufficient condensed to render eggs of the common toad well visable [sic] with nachet's binocular & no. 2 object glass & this without any precautions whatever beyond avoiding anything more than a slight condensation. - Now these eggs are much more heavily pigmented than those of the frog, and are probably nearly if not quite as dark as anything it may be desirable to observe."

The "no. 2 object glass" (2 inch focal length) provided 30x…60x magnification depending on eyepiece [Nachet, 1886]. This magnification and the light loss by design reduce the brightness of intermediate image to less than 1% compared to object plane and so HSG's request for strong illumination may be understand.

The April 14 HSG's letter replies to Carl Zeiss invoice on the stereoscopic eyepiece (Marks 150 Price) and requested objectives [BACZ 1578, 29]: "Endorsed herewith I hand you draft for £ 12-10-8 in payment of your invoice of April 8th 1893 amounting to Marks 250.70. – Also I return to you by registered parcels post objective a_1 as I find I can not [sic] use it with the nosepiece – will you kindly send me a_2 of $35^{\underline{mm}}$ instead. I have carefully tested the no 55 stereoscopic eyepiece & am much pleased with it finding that a very perceptible stereoscopic effect is had even with the D* water immersion ..."

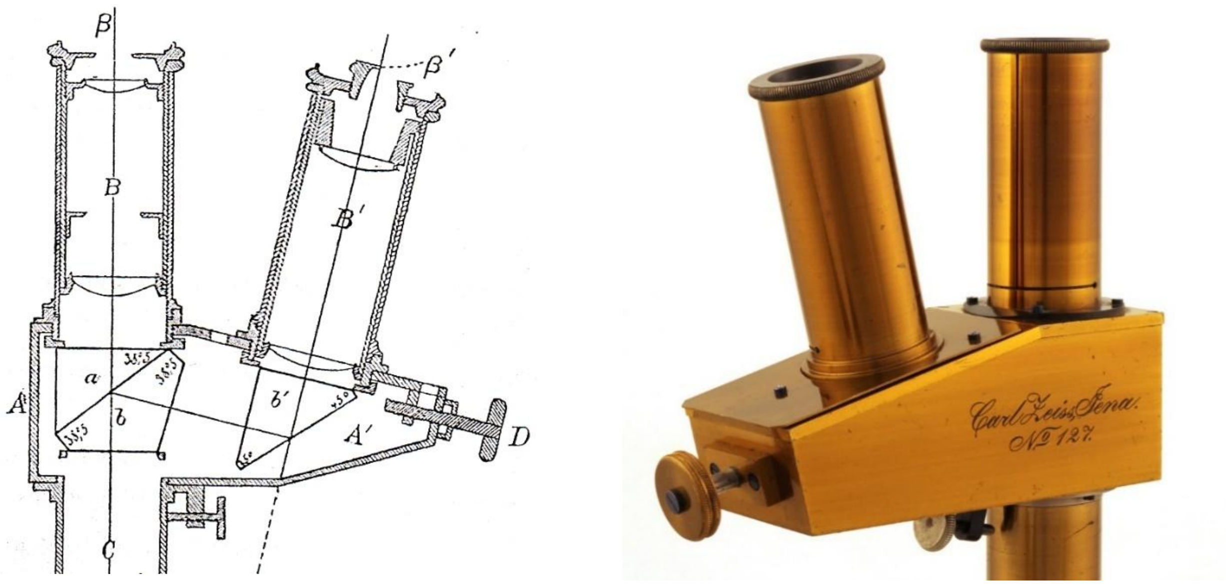


Figure 43 Abbe's Stereoscopic Eyepiece, Section [Abbe, 1880] and Photo (Courtesy Prof. Timo Mappes, http://www.musoptin.com).

This kind judgment didn’t mention the low light capability of Abbe’s double eyepiece which was similar to such of Nachet’s Binocular. Prof. Abbe had replaced Nachet’s geometrical division of back focal plane by physical splitting provided “by an exceedingly thin stratum of air - less than 0.01 mm” [Journal, 1894]. His splitter led more than 2/3 of light to the axial Huyghenian eyepiece (B in Fig. 45) and less than 1/3 to the 13° inclined Ramsden one (B’). Abbe considered this imbalance* as an advantage where the lower sensitive but higher resolving eye gets more light than the higher sensitive but lower resolving one.

In stereoscopic mode, the semicircular diaphragm (β’) reduces the B’ brightness by further 50% resulting in ca. 12% of the objective’s pupil plane. Abbe wrote that this single diaphragm often provides a sufficient stereoscopic effect - but this means ca. 1:5 brightness imbalance [Abbe, 1880]. On the other hand this “halving the cones of rays above the eyepiece” [Journal, 1894] by plug-connected caps provided an easy changing between binocular 2D vision and a stereoscopic or pseudoscopic 3D one.

It’s interesting that the Zeiss Company don’t offer any stereoscopic arrangement of loupes providing low magnification and bright image even though many kind of loupes were available. But the Ernst Leitz Company did so: Two Bruecke’s loupes provide 4x magnification and ca. 250 mm distance between specimen and eyes.

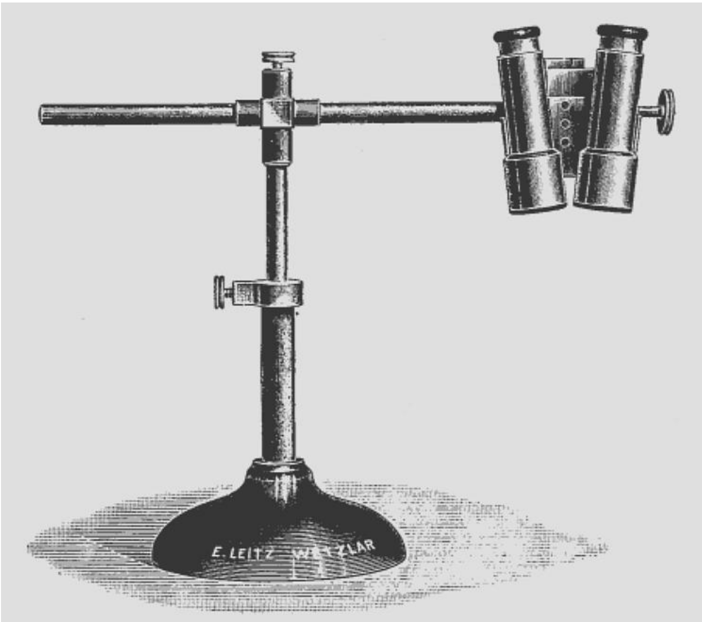


Figure 44 Westin’s Binocular Dissecting Loupe after Eilhard Schulze [Leitz, 1897].

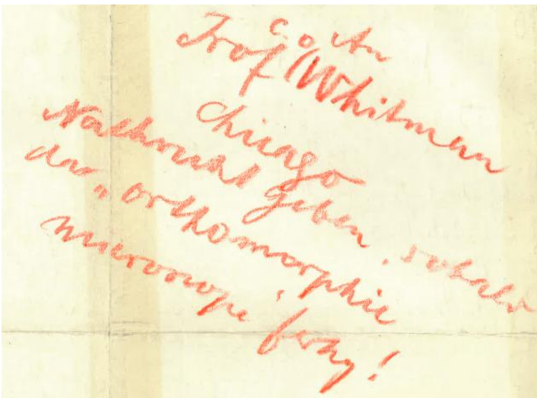
* The modern FusionOptics™ technology from Leica Microsystems is based on imbalance of resolution and depth of field in stereoscopic vision.

15. His First Mention of the "Orthomorphic Microscope" Term

We find the "stereoscopic microscope" term in many HSG's letters before, e.g. on January 3, 1893 [BACZ 1578, 12]:

"As there are now only about two months remaining before I shall need to take up my study of amphibian ova & embryos, I write to ask concerning progress on the new stereoscopic microscope?"

This HSG letter shows an interesting note handwritten by Czapski: Firstly the "orthomorphic microscope" term is stated which will be the subject of long winded discussions and controversy between both partners.



To
Prof. C. O. Whitman
Chicago
message to send as soon as the "orthomorphic microscope" will be ready!

Figure 45 Czapski's Note on HSG's Letter of January 3, 1893 [BACZ 1578, 12].

At the time "orthomorphic" was not a common optical term, the quotation marks in the note indicate this fact. Prof. Abbe spoke on orthoscopic (stereoscopic is used today) and pseudoscopic images in his paper on microscopic stereoscopy [Abbe, 1880]. Much later a monograph by Zeiss scientists mentions "orthomorphic" and the register explains the "orthoscopy" term as "uninverted spatial image, better orthomorphy" [Czapski, 1904]. By the way the "conoscopy" term did not yet exist, which is now known in contrast to orthoscopy in polarized-light microscopy.

A German dictionary of foreign words explain the orthomorphy as "Greek, the true formation or shape, art to heal the curvature of spinal column" [Samostz, 1902]. We find orthopaedic in the book title (1828) by the French surgeon Jacques Mathieu Delpech (1777-1832): "De l'orthomorphie, par rapport à l'espèce humaine; ou recherches anatomico – pathologiques sur les causes …" (*Orthomorphy, relative to the human species; or anatomic-pathological research on the causes …,* the authors).

We guess someone on the Carl Zeiss staff adapted the “orthomorphy” term (from the Greek orthos = straight, and morphe = shape) to optics, similarly in cartography: Carl Friedrich Gauss (1777-1855) had devised the conformal map projection which was renamed orthomorphic at the time [Hinks, 1912] but is referred to as conformal today. Such a map renders a small geographical area in its true shape.

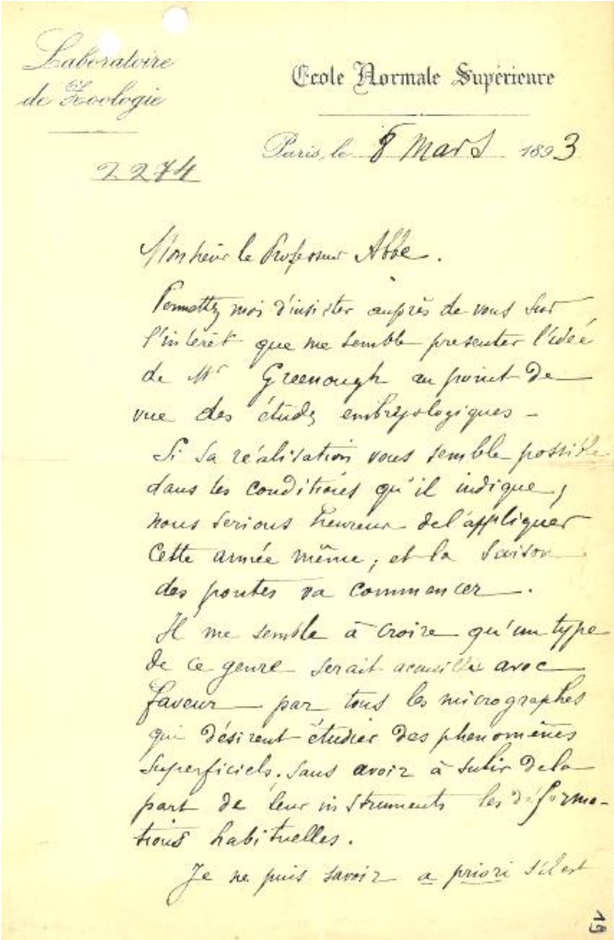
The optical definition was given by Czapski based on HSG’s formula from his first letter in July 1892 [Czapski, 1897]: “A more detailed discussion of this condition implies that, for this purpose that is orthomorphic vision, the linear (lateral) magnification V of the individual microscopes must be made equal to the ratio of the pupil distance of the observer D to the distance d in which the openings for the light entry of the two microscopes ... stand V = D / d or that these openings must be placed at the pupil distance in the ratio indicated by the magnification number. Another equivalent formulation of the condition for orthomorphy arising from the first as well as an independent consideration is shorter: The image must appear at the same angle in all its parts in each microscope tube from the eye point as the object from the point of intersection of the principal rays, or even easier: Entrance pupil and exit pupil of the microscope must be nodal points of the same.”

By definition in Gaussian optics, an input ray directed at a nodal point leads to an output ray which has the same direction, only possibly with a parallel offset. For that, an incoming beam from the input side must be directed to the front nodal point, and the corresponding output ray then appears to come from the back nodal point [Photonics, 2019].

On March 7, 1893 HSG announced an important letter [BACZ 1578, 15]: “My Collegue M. Frédéric Houssay Director of the Laboratoire de Zoologie at the Ecole Normale Superiéure and myself intend writing your firm a joint letter in the course of a few days, more especially concerning the new stereoscopic microscope; and I defer answering your present letter in some detail until then …”

The Catholic Frédéric (Adolphe, Célestin, Arsène) Houssay (1860-1920) studied mathematics, physics and natural sciences at Parisian Ecole Normale Supérieure (ENS). After his doctorate in 1884 he became a lecturer of zoology with ENS in 1892 [Charle, 1989]. HSG had not known about Dr. Houssay’s paper of 1890 when he prepared his second lecture with the Museum of Natural History (See Part 2/7).

Two letters were written on next day. The first one was by Frédéric Houssay [BACZ 1578, 19]:



Laboratoire de Zoologie

Ecole Normale Supérieure

2274

Paris, le 8 Mars 1893

Monsieur le Professeur Abbe.

Permettez moi d'insister auprès de vous sur l'intérêt que me semble présenter l'idée de Mr Greenough au point de vue des études embryologiques -

Si sa réalisation vous semble possible dans les conditions qu'il indique, nous serions heureux de l'appliquer cette année même, et la saison des pontes va commencer.

Il me semble à croire qu'un type de ce genre serait accueilli avec faveur par tous les micrographes qui désirent étudier des phénomènes superficiels, sans avoir à subir de la part de leur instruments les déformations habituelles.

Je ne puis savoir a priori s'il est

19

Laboratory of Zoology **Ecole Normale Supérieure**

Paris, March 8, 1893

2274

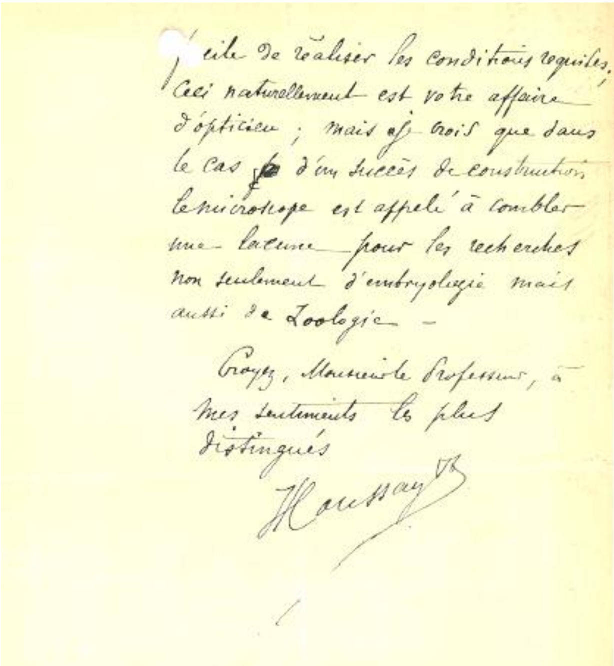
Monsieur Professor Abbe.

Allow me to insist to you on the interest that the idea of Mr. Greenough seems to me to offer in embryological research -

If the realization seems to be possible for you under the conditions specified by him, we would be happy to apply it in the same year, and the season of oviposition can begin.

It seems plausible to me that a type of this kind would be appreciated by all micrographers who would like to study surface phenomena without having suffered the usual deformations through their instruments.

I cannot know a priori whether



facile de réaliser les conditions requises, ceci naturellement est votre affaire d'opticien; mais je crois que dans le cas d'un succès de construction le microscope est appelé à combler une lacune pour les recherches non seulement d'embryologie mais aussi de Zoologie -

Croyez, Monsieur le Professeur, à mes sentiments les plus distingués

Houssay

the necessary conditions are feasible;
Of course that is your business, that of the optician; but I believe that in the case of success of construction the microscopy is called upon to close a gap in research not only in embryology but also in Zoology -

Be assured, Monsieur Professor, of my most distinguished sentiments

Houssay

Figure 46 Letter of Prof. Frédéric Houssay in March 8, 1893 [BACZ 1578, 19].

The second letter, 6 pages long, was written free flowing and often without punctuation by HSG and signed by Houssay [BACZ 1578, 16-18]:

"M^{ess} Professor Dr. Abbe and Carl Zeiss Gentleman

In regard to the new stereoscopic microscope devised by one of us & for which the name "Orthomorphic" was suggested as describing its essential character viz. the furnishing to the observer a solid image similar or rather identical to that which naked eye vision would give of a similar object greater than that under the microscope in the ratio of magnification and under an angle of the optic axes such as will well show the real shape of the object in question, we would point out to you that we wish it as a working instrument for several purposes none of which interfere with each other but which necessitate the use of certain accessories & because of the considerable time ahead lost owing to unavoidable delays we venture to suggest that you will take into serious consideration a plan for a finished microscope to be executed as soon as your working model shall have met with our approval, of which we are quite confident. – In the first plan though we should certainly defer to your judgement in the last instance, yet it seems to us that the use of a "main magnifier" in either of the microscope tubes & back of the first objective would absorb less light than would the prisms which are otherwise needed to effect the crossing of the objective's images: moreover the 2nd objectives giving an erect image will make dissections very much easier (*See A Note*, the authors) & we hope with this instrument together with special dissecting tools to be constructed hereafter to be able to perform dissections that we have not yet been able to accomplish.

For the study of Living embryos & more especially of Vertebrate embryos certain accessories are needed & have, in part, been already used with good effect by one of us, under the Nachet Binocular (See *Fig. 42,* the authors) – these consist in a pair of total reflecting prisms as above in sketch herewith – the sketch shows the prisms in profile & also the views given by one of them under the microscope (See *Fig. 47,* the authors) … it should be possible to clamp these dishes onto the substage & this should be furnished with rack & pinion movements at right angles & also rotating device – the substage should be <u>large & strong</u>, …

We wish for the following magnifications 5, 10, 20, 30, and if possible 60 the latter we should only expect to use for the study of mesoblastic blastodermes (*Cells at yolk sac in blastula stage of embryo*, the authors) when the depth is small in proportion to the field - If sufficient light can be had, we would point out to you that the following method would perhaps give sharper deep images than any other – Use for the 1st object glasses diamond index of refraction = 3 … and a magnification of 1 that is to say no magnification. Then by the formula $L=M^2/S_0$ we have L=1/3 and by stopping a good sharp & deep image should be had, this might be received on a screen of unpolished glass made of the thinnest cover slip material, and could then be thrown up by a wide angle objective to the required amount of magnification.

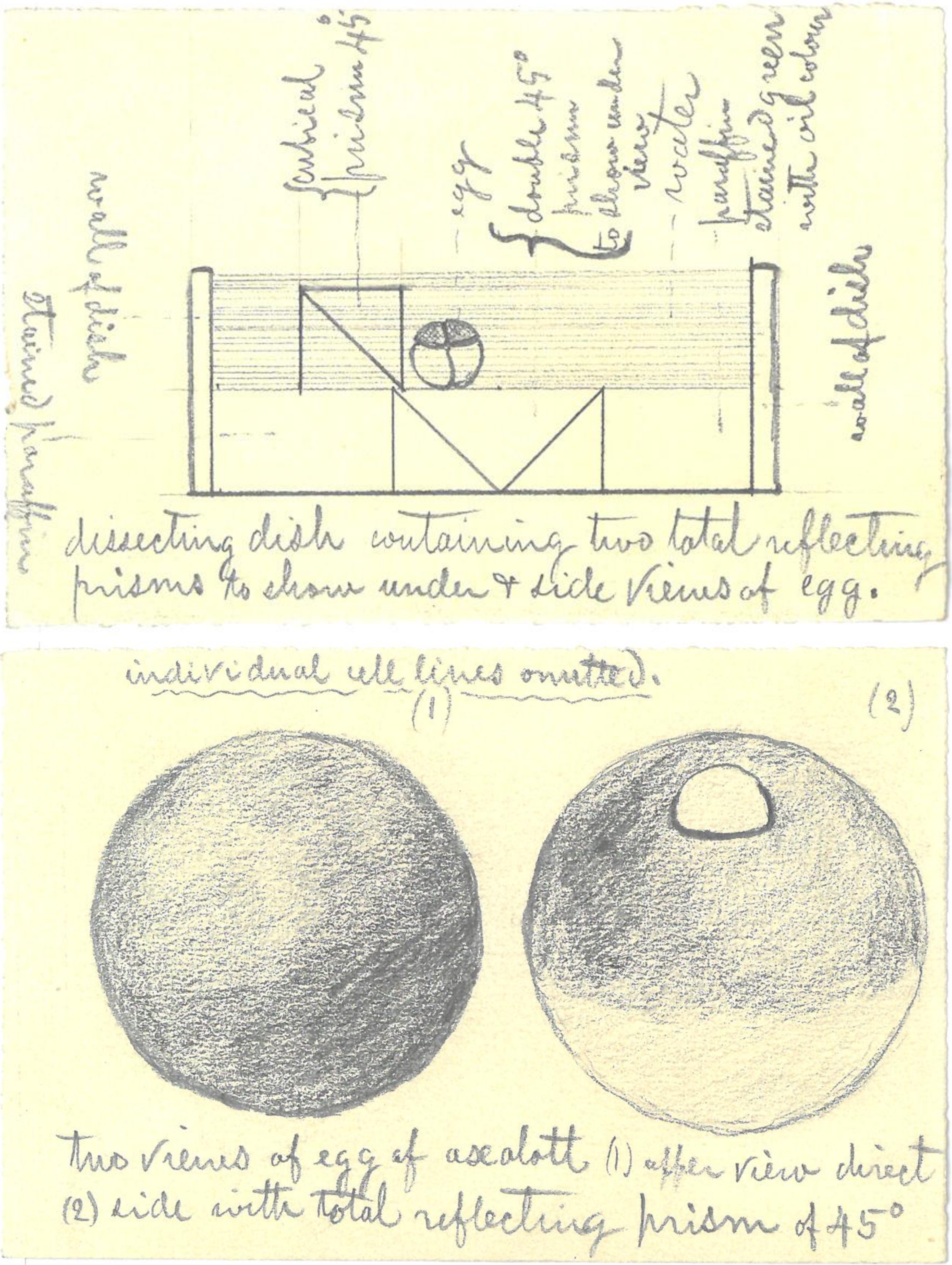


Figure 47 HSG's Diagram of Prism Rotator and Two Views of Axolotl Egg [BACZ 1578, 1].

Then by using a seeker eyepiece embracing the same angular field relatively to the magnified image that the 1st objective does relatively to the object the eye will receive an image identical with that of a similar object to that under the microscope but larger in the ratio of the magnification as required – The only doubt is whether sufficient light can be had for this device when operating with opaque objects which moreover frequently very dark - we would point out however that the principle of division of labour is in this device completely realized the 1st object glass gives a sharp deep image but no magnification. The unpolished glass screen transforms the image into a <u>flat</u> object the "main magnifier" gives the required magnification & the seeker eyepiece having the angular field relatively to magnified image identical with that of the 1st object glass relatively to the object establishes the required <u>angular invariance</u> of the dioptric system … (*See B Note,* the authors)

We have already alluded to two purposes to which we wish to put the proposed Orthomorphic microscope, viz. examination of living embryos & dissection; we wish finally to employ this instrument for the purpose of taking stereoscopic photographs and we beg you will take into consideration a suitable attachment for this purpose …

With regard to the extra refracting glycerine we shall attend to its preparation in accordance with your instructions & by means of the test bottle sent by yourselves to one of us, we shall then make some fresh preparations as soon as other work allows of and will advise you of result & send you some of the preparations if successful. We note what you say concerning the use of cedar wood oil as the outward immersion liquid & shall so use it.

We remain gentleman yours faithfully

Horatio S. Greenough   Houssay"

A Note:

HSG's phrase "a main magnifier … would absorb less light than would the prisms which are otherwise needed to effect the crossing of the objective's images" refers to Nachet's prisms and their task to achieve the erected stereoscopic image pair. The low light capability of Nachet's microscope was already described (See page 22).

The phrase, "moreover the 2nd objectives giving an erect image will make dissections very much easier" goes back to HSG's 1892 concept (See Part 2/10) of first and second objective (last one now called main magnifier) in each channel to erect the image by an additional imaging step and without using any prism.

B Note:

HSG dreams of a “method that would perhaps give sharper deep images than any other” or “a field of 5 mm diameter & 3 mm depth would under 30x be most satisfactory & I hope that Professor Abbe’s computations may show this not to be unattainable” [BACZ 1578, 30]. The wide-field microscopy was, and is not able today, to do so with the sufficient resolution – physics cannot be fooled. The electronics of today and software go another way, and stack many optical slices to obtain a highly resolved 3D animation.

But the principle of this method was known since 1887 [Strasser, 1887]. Whitman’s tutor, the Swiss Professor Wilhelm His (1831-1904) gave an example: At Leipzig, Germany, 520 microtome slices (0.01 mm thick) of a 9.6 mm long human embryo were drawn 100x enlarged on cardboard (1 mm thick). The embryo contours were cut out and one cardboard piece stuck on top of the other in right order. This model was the base of a colored and dismountable showcase manufactured by the artisan Paul Osterloh (1850-1929) in ca.1910 [Hossfeld, 2012].

The suggestions of HSG and Houssay as amateurs in optics are a mix-up of fact and fancy:

- The already mentioned formula $L=M^2/S_0$ (L= axial image scale, M= lateral image scale, S_0 = refractive index) came from Prof. Charles Hastings (See Part 2/10) but HSG understands S_0 as the lens index instead of the index in image space. He wants that “the 1st object glass gives a sharp deep image but no magnification”. The demanded M=1 and the correct S_0 =1 for air results in L=1 – this is the unique case of equality of lateral and axial scale in images. HSG likes “an image identical with that of a similar object to that under the microscope”.

- The 3.0 amount approximates the 2.4 refractive index of diamond. HSG hopes the small but incorrect L=1/3 axial magnification would result in a “deep image” containing more depth in the object. Increasing of the refractive index in a lens of given shape shortens its focal distance, enlarges the numerical aperture, and lowers the depth of focus. HSG misses that these effects are equal in object and image space when no magnification shall work. He wants on the contrary long working distances and “a good sharp & deep image”. Moreover the optical correction would not be easy to do by 1:1 scale and needs a further medium in the first objective. Who would pay for two lenses made from diamond? The heavy flint glass as an alternative reaches 2.0 refractive index at a maximum.

- HSG emphasizes that “the principle of division of labor is in this device completely realized”, meaning that his design of two microscopes provides bright images due to missing of any light division.

- HSG's idea of an unnecessary screen to compress the image depth of first objective (See Fig. 30 in Part 2/10) is specified: "a screen of unpolished glass made of the thinnest cover slip material … transforms the image into a flat object". HSG's example could be the paper plane of a drawing apparatus where the image depth is collected.

- The image of first objective "could then be thrown up by a wide angle objective to the required amount of magnification". This short focus lens also called main magnifier catches the "flat object" and creates a magnified and erected image.

- The five magnification steps are new and probably a request of Houssay. Together with the above mentioned suggestion that "the main magnifier gives the required magnification", this would result in the hard task of changing five lenses into each microscope tube simultaneously and have them precisely aligned. Moreover some magnification steps oppose the condition of orthomorphy (Please see page bottom).

Five weeks later HSG comes back to his former concept: "I hope however that when you make the model you will see your way to doing so with a magnification of 30 instead of 20. I consider the latter more generaly [sic] favourable for greater part of our work …" [BACZ 1578, 30].

- The "seeker eyepiece" works as loupe and is mentioned in sentences describing the provisional condition of orthomorphy: "Then by using a seeker eyepiece embracing the same angular field relatively to the magnified image that the 1st objective does relatively to the object / the eye will receive an image identical with that of a similar object to that under the microscope but larger in the ratio of the magnification as required" or in other words "the seeker eyepiece having the angular field relatively to magnified image identical with that of the 1st object glass relatively to the object establishes the required angular invariance of the dioptric system".

HSG wrote the "orthomorphic" microscope term first in above quoted letter of March 7, 1893. On June 22 HSG remembered from his formula describing the orthomorphy condition [BACZ 1578, 31-32]: "… I note with much satisfaction what you say concerning the stereoscopic microscope does the idea you have hit upon satisfy my equation A/a=D?"

The V=D/d equation by Dr. Czapski (Magnification = Pupil Distance of Observer / Distance of Openings for Light Entry) is the German and more precisely expressed version of HSG's A/a=D (Distance of Eyes / Distance of Objectives = Magnification).

The distance of both objective centers is given by the microscope design and should not be shorter than ca. 9 mm in interest of bright images. The individual pupil distance of observer (e.g. 54 - 72 mm) determines the demanded orthomorphic magnification and would result in as low as ca. 6:1 up to 8:1 image scale at a maximum. Therefore each observer would need an individually specified stereo-microscope to cause the orthomorphic condition exactly in the main imaging step.

Figure 48 Concarneau in ca. 1950, Laboratoire de Zoologie Maritime before Reconstruction, Seen with its "Sea Garden" at Foreground Right of Middle (No. 2846 Postcard by Greff, S.E.R.P., Editor, Paris).

HSG outlines his frame of mind to his friend in Boston, A. Lawrence Lowell, on August 13 from the Laboratoire de Zoologie Maritime de Concarneau [Harvard 13/30]: "My dear Lawrence –

I really must apologize for not answering your two letters before, the last one of July16th 93 reached me here some time ago, but I have been very busy ever since & today is the very first time I can write conveniently.

We are now in the "Période Électorale" (*legislative period*, the authors) …

You ask me about my embryological work: well I made some more observations this last spring on embryo Toads & Frogs but was unable to procure sufficient material & also my technique was not yet in full working order – now I am at work on early stages of the common sea urchin, & hope to finish what I have in hand either this season or next as the case may be...

With regard to soaring flight I do not think Prof. Agassiz's (*See Part 1/3*, the authors) explanation is adequate [sic]. – I believe the explanation is in the power of the birds soaring, to utilize wind pressure at will, either as a source of energy or as an almost purely deflecting force consuming no energy & this by a change of "Trim" if this not the essential character then I do not understand it at all except in certain special cases as the Albatrosses referred to by Lord Rayleigh in a letter to Nature in May 1888 I think...

Write when you can & tell me about fishing at Cotuit …"

16. His Supplier's Introduction of the Porro-Abbe Prism

Also from Concarneau, HSG sent preparations to Mess.[rs] Carl Zeiss Gentlemen on August 21, 1893 [BACZ 1578, 38] to try its imaging by various objectives: "segmented eggs & larvae of the common sea urchin mounted in capillary tubes & for the most part in Oil of Cedar, the others in Jodate (*iodate*, the authors) of Zing (*zinc*, the authors) Glycerine solution … & the largest containing young Pluteus (*larva*, the authors)."

HSG made significant demands on the very busy manager Dr. Czapski: "I would therefore request that you examine the preparations at your earliest convenience & advise me as to the result". No wonder that we find in this letter and the following two of September the "Brat" shortcut meaning Karl Bratuschek (1865-1913). He was Abbe's talented assistant for objective calculations in the Microscope Department, but with the company only between April 1892 April and November 1893 [Rohr, 1918]. Dr. Czapski will write on February, 7, 1894: "Due to the leaving of Mr. Bratuschek from the association of the workshop last autumn, unfortunately, the execution of many such tasks has been delayed, since now all these things fall to my other obligations … As I said, these apparatuses (*stereomicroscope, prism and capillary rotator*, the authors) are already in progress and will be ready by the end of March if nothing comes in between" [Flitner, 2000].

Dr. Czapski reported also that Bratuschek modified the Porro-Abbe prism support for adjusting the eyepiece distance on the stereomicroscope or further binocular instruments [Rohr, 1907]. HSG had not thought to serve the same purpose in his concept. His second objective or main magnifier would provide the image erection like the Porro-Abbe prism does. This pair of crossed roof mirrors will replace HSG's lens in the Carl Zeiss design.

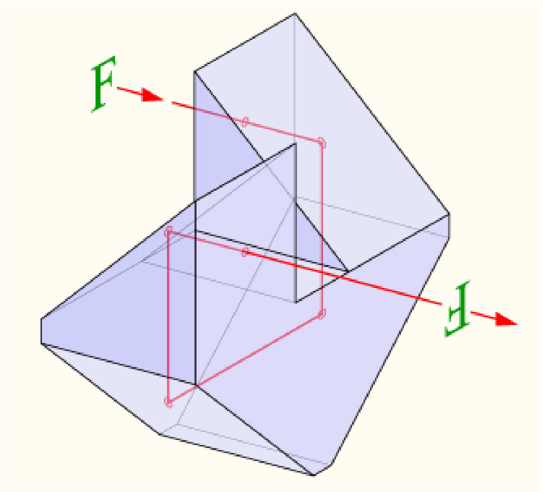


Figure 49 Image Reversion by Porro-Abbe Prism (https://en.wikipedia.org/wiki/Porro%E2%80%93Abbe_prism#/media/File:Porro-abbe-prism.png).

Dr. Czapski and Dr. Otto Schott (1851-1935) took up Abbe's ingenious idea on the manufacturing of a Keplerian hand-held telescope and using a prism for image erection. Their optimizing of design and glass led to a working prism of such kind like the Italian Ignazio Porro (1801-1875) had patented for France and England in 1854. This patent could not be used widely due to insufficient glass quality and grinding technique in Porro's time. So the patent was forgotten and also the Carl Zeiss staff, unfortunately, did not know it.

In May1893, Dr. Czapski expressed good prospects for the development of the future field glasses [Flitner, 2000]. Each of its Keplerian telescopes firmly contains a Porro-Abbe prism and the distance between both telescopes is changed for interpupillary adjustment. In contrast, both microscopes in Greenough's design have to stand stationary. Bratuschek proposed to rotate the Porro-Abbe prism against microscope tube and to use the parallel offset of optical axis to match the individual eyebase.

Figure 50 At Salvator Pub in 1892/93, Dr. Czapski sits left at foreground and Karl Bratuschek stands right beside barrel (Courtesy Carl Zeiss Archive).

17. His Delayed Trip to Jena

In 1893 September HSG returned from Concarneau to Paris, but to 21 Rue Beaujon - a new address nearer to the Arc de Triomphe than the Belmont et de Bassano Hotel which had been his residence since 1888 (See Part 2/7). We may guess from the letter to his Bostonian friend in September 5, 1894 that he had to move due to a change for the worse [Harvard 13/30]:

"My dear Lawrence – your kind letter of July 29th … reached me a few days ago, having been kept some time at 30 Rue de Bassano, as Mrs. Storck has retired & the new occupant Mr. Schall did not know my present address."

On September 25, 1893, HSG wrote the first letter from his new Parisian address to ask Zeiss on the progress of his devices [BACZ 1578, 39]:

"I have been hoping to hear from you for some time & trust you will not think me too importunate if I now ask you whether you see any prospect of being able to make me a rotating apparatus for my capillary tubes? Also I should be glad to know what proportion of the preparations I sent you admit of examination under the 2mm apochromatic homogenous immersion of apert. 140 & whether you see your way to making me a 4mm apochro. homogeneous [sic] immersion of apert 1. as per one of your letters of last season.

Concerning the new Stereoscopic microscope I would ask whether you think it probable that you can make it in time for use next season, i.e. not later than March. I am sorry to trouble you with these various matters, but my own plans will depend largely upon your answer. I am quite aware that the making of anything new requires a good deal of time & trouble, but inasmuch as you have expressed from first a favourable opinion of my two devices I venture to hope that you may see your way towards carring [sic] them out."

On October 18 HSG sent a reminder for a meeting with Prof. Abbe [BACZ 1578, 40]. Did he want to accelerate the manufacturing of his devices or to insist on his second lens instead of the Porro-Abbe prism? We don't know. However, on November 18 HSG wrote [BACZ 1578, 43]: "… as my trip to London has been unavoidably postponed – I hope to be able to come to Jena somewhat later on, just now I am unable to do so; & within a few days I hope to be able to advice you of the probable approximate date of my visit. With many thanks for the kind attention you have given to my matters I have submitted to you …"

Why was HSG's London trip unavoidably postponed as was as his Jena visit? On November 9 HSG had to be a witness for his Sister's wedding fixed on what was probably short notice.

The 43 years old American Charlotte Gore Greenough (1850-1919) married the 64 years old French Alphonse Marie Hervoches du Quilliou (1829-1903) at the 17th arrondissement of Paris [Paris, 1893]. Alphonse came from old Breton aristocracy and had served during his life as: Mayor of Lanhélin, General Councilor for the canton of Combourg, President of the Departmental Commission of Ille-et-Vilaine (1897/98), and Deputy of the district of Saint Malo [Frotier, 1924].

We wonder whether this unusual association relates to the contemporary report of the American Walter F. Lonergan: “A realistic ‘mot’ (*French for aphorism*, the authors) was coined by some French boulevardier … to describe the process of marrying American girls to the needy noblemen. It was ‘manurer les fraises’ - to manure the strawberry leaves of the coronets. This is one of the acute and cutting ‘mots’ of which the French are masters” [Lonergan, 1907].

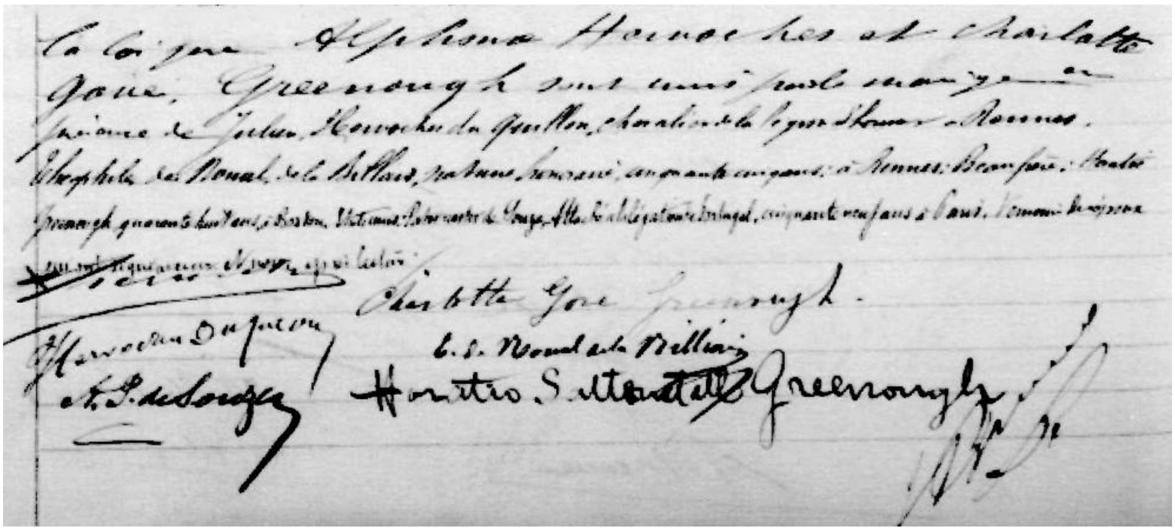
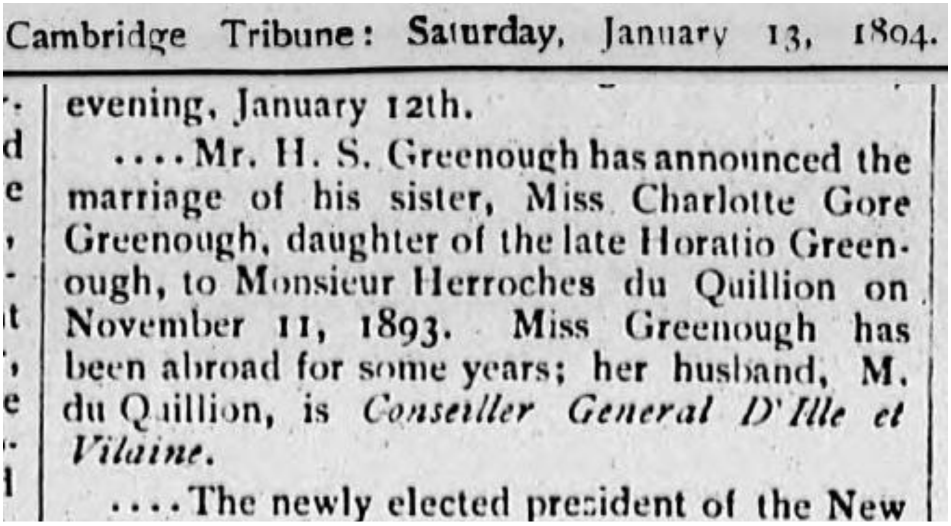


Figure 51 Signatures at Certificate of the Parisian Marriage Register [Paris, 1893].

Charlotte had visited, at least, the ancient Dinan on the Rance River before 1888, located in the Côtes-du-Nord, today Côtes-d’Armor department of Brittany, as can be seen in her her painting “Entrée du château de la Grand’Cour, prés Dinan” (*Castle Entrance from Main Yard, near Dinan*, the authors) shown at the 106th exposition of Societé des Artistes Francais which was held in Palais des Champs-Élysées, Paris [Societé, 1888]. Only one attempted sale of Charlotte’s paintings is known and was arranged at Boston after her death: “Artist’s sale of paintings by Miss C. G. Greenough. Sale on account of her departure for Europe” [Leonard, 1920].

Her move to Paris, France was later than the middle of 1885. She was accompanied by her French artistic tutor Achille Oudinot (1820-1891) and probably HSG. Her Mother Louisa (Eliza) (1812–1891) followed a year later [BD, 1885, 1886, 1887]. Charlotte inherits two oil paintings from Louisa, and a marble bust of Horatio Greenough, 1838 created by Hiram Powers (1805-1873) [Baigell, 2018]. All heirlooms will eventually be returned as Charlotte's bequest to their Massachusetts' origin, and are now displayed in Bostonian museums.

Henri Frotier de la Messeliére describes Charlotte onomatopoeticly as "Grinot, widow, residing in Dinard, Ille-et-Vilaine (*native country of her late husband*, the authors) and Lanhélin in 1914" [Frotier, 1924]. She spent her last years near Lake Geneva in the French speaking part of Switzerland and died in Vevey after HSG.


Cambridge Tribune: Saturday, January 13, 1804.

evening, January 12th.

....Mr. H. S. Greenough has announced the marriage of his sister, Miss Charlotte Gore Greenough, daughter of the late Horatio Greenough, to Monsieur Herroches du Quillion on November 11, 1893. Miss Greenough has been abroad for some years; her husband, M. du Quillion, is *Conseiller General D'Ille et Vilaine.*

....The newly elected president of the New

Figure 52 News Item by Cambridge Tribune.

HSG's first visit in Jena took place in 1893 between the end of November and the beginning of December, because he wrote on Dec. 16 [BACZ 1578, 44]: "Dear Dr. Czapski … Before closing I will say that I have very pleasant recollections of my visit to Jena & with many thanks for your kindness I remain …" Now HSG became acquainted with Dr. Czapski and started to address his letters to him.

In February 12, 1894 HSG will write [BACZ 1578, 47-50]:

"Professor Dr. Abbe

Dear Sir

I am writing to you today in view of a conversation we had when I was in Jena and also because of a portion of Dr. Czapski's letter of Jany. 30th ult. to which I will allude presently…"

The sometimes quoted creative conversation of Abbe and HSG and their collective dining at the “Weimarischer Hof” restaurant are not verified. HSG’s idea of a double microscope was sent to Abbe in July 1892, the diagram shown below will not be drawn not until 1894. In 1895 autumn, HSG will give a lecture for Zeiss technicians probably at the Weimarischer Hof restaurant. These facts are hidden behind a nice legend.

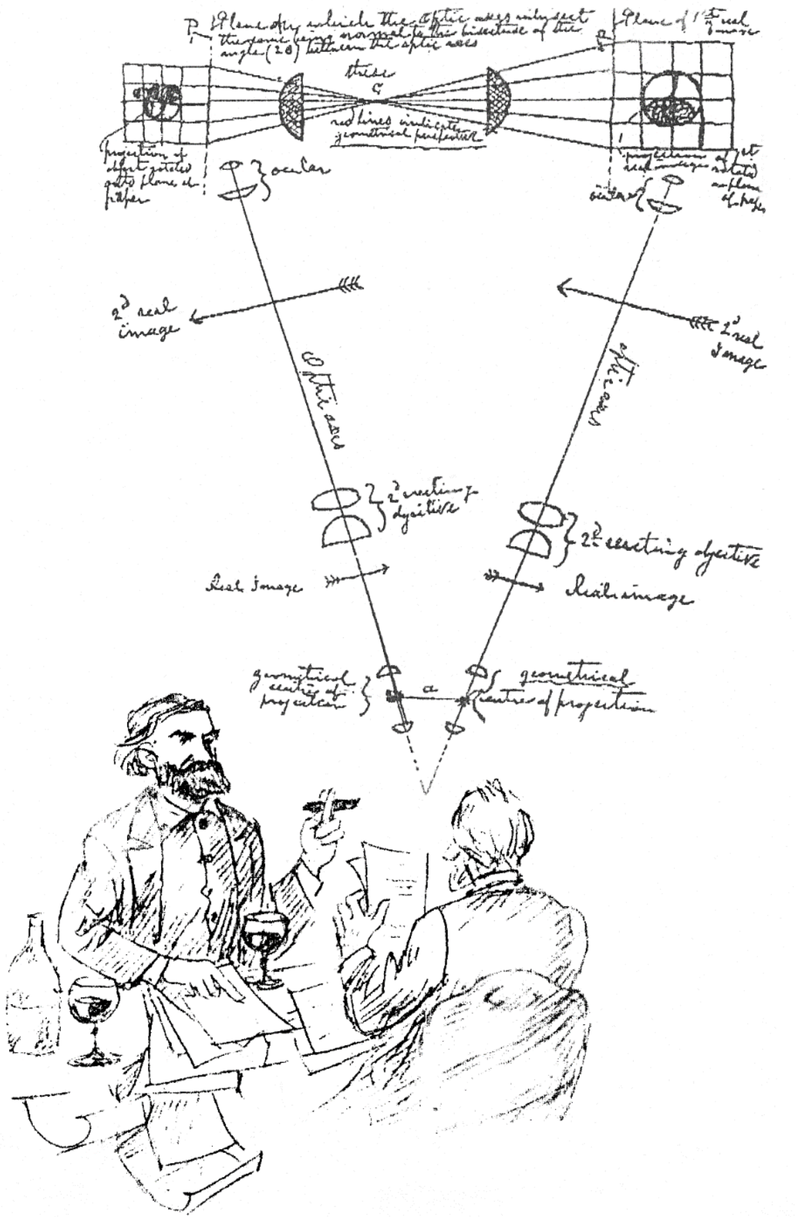


Figure 53 Legend of Abbe’s and HSG’s Collective Dining (Courtesy Thomas Serfling).

References: We acknowledge Dr. M. B. for his intensive literature researches.

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