The Magazine from Carl Zeiss

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Innovation

15

In Memory of Ernst Abbe

ZEISS

Contents

Formulas for Success...

Formulas describe the functions and processes of what happens in the world and our lives. It is often the small, insignificant formulas in particular that play a decisive role in what we know and in the functionality of modern instruments and examination methods.

for the large...

The fiftieth anniversary of the death of *Albert Einstein* (1879-1955) also marks the centennial of his theory of relativity; a theory that revolutionized perceptions, made the processes of life more understandable and began to explain the dimensions of time and space. The short formula, $E = m \cdot c^2$, expresses the infinite complexity of our world. *Einstein* had contact with *Zeiss* throughout the course of his scientific activities. In 1925 he wrote to the company Anschütz in Kiel about producing a gyrocompass: "The difficulties of manufacturing are so great – accuracies of 10^{-4} have to be achieved – that Zeiss is currently the only company capable of meeting the requirements."

...and small things in life.

2005 also marks the 100th anniversary of the death of *Ernst Abbes* (1840-1905). Numerous events throughout 2005 honor his many great achievements. His extensive examinations within the scope of his activities at Carl Zeiss' optical workshop also resulted in the formula for the resolution of a microscope:

$$d = \frac{\lambda}{2n \sin \alpha}$$

It clearly and concisely describes the resolution of optical instruments using the visible spectrum of light and contributed to the improvement of optical devices.

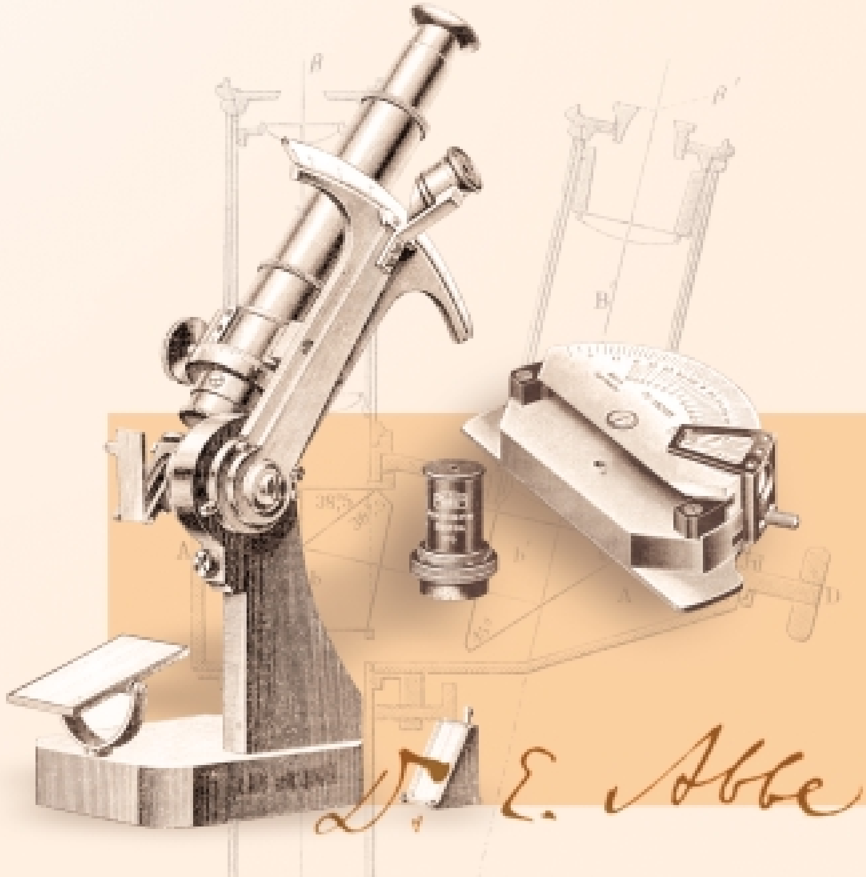
The same year also saw the passing of another German microscope manufacturer with connections to *Abbe* and *Zeiss*: *Rudolf Winkel* (1827-1905). During *Abbe*'s times, good microscopes were also built at *Winkel*'s workshop which was founded in Göttingen in 1857. *Abbe* visited *Winkel*'s workshop while he was a student in Göttingen. His visit in 1894 led to closer cooperation. In 1911, *Zeiss* became *Winkel*'s chief partner. In October 1957, the firm R. Winkel GmbH became part of the Carl Zeiss Foundation.

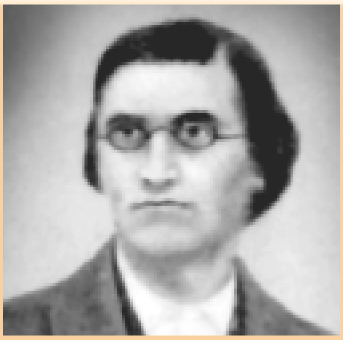
The same year that *Abbe* died, *Robert Koch* (1843-1919) received the Nobel Prize for Medicine for his examinations and discoveries while researching tuberculosis. In 1878, *Robert Koch* used the *Abbe* oil immersion system for the first time and was impressed by the "quantum leap" made by the "*Carl Zeiss* Optical Workshop using Professor *Abbe*'s ingenious advice." In 1904, Carl Zeiss management presented *Robert Koch* with the 1000th 1/12 objective lens for homogenous oil immersion.

Many articles in this issue are dedicated to *Ernst Abbe* and his times. We reflect on what *Ernst Abbe* meant to *Carl Zeiss* and what he did for optics, and we take a special look at developments that were and continue to be significantly influenced by *Ernst Abbe* and his scientific results. This is emphasized by the image on the cover pages: an historical tribute to the more than 150 years of optical development with a focus on microscopy.

July 2005

Dr. Dieter Brocksch





1857

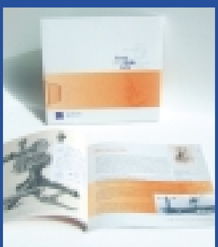
Education and early years

Ernst Abbe was born in Eisenach on January 23, 1840, as the son of master spinner and subsequent factory attendant *Georg Adam Abbe* and his wife *Christina*. He attended elementary school from 1846 to 1850, after which he was a student at the local high school in Eisenach. He finished his school education in 1857 and graduated with above-average grades. In the period to 1861 he studied mathematics and physics at the Universities of Jena (1857-1859) and Göttingen (1859-1861). *Abbe* completed his studies by obtaining his doctorate in Göttingen on the subject "Experiential substantiation of the theorem of equivalence between heat and mechanical energy". He subsequently worked for two years as a teacher at the Physics Association in Frankfurt/Main.

Family and science

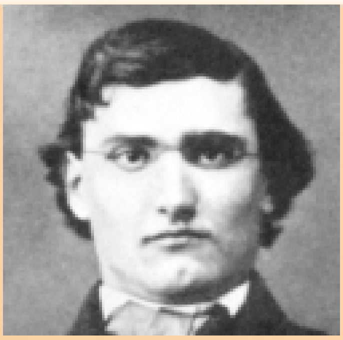
Abbe's mother died early in his life: July 14, 1857. During his studies, his father married for the second time, to the widow *Eva Margarethe Liebetrau* on November 11, 1859. After his time in Frankfurt, *Abbe* joined the Mathematical Association in Jena in 1863. In the same year, he obtained his post-doctoral qualification as a lecturer with his paper on "the laws in the distribution of errors in observation series". He taught as a private mathematics and physics lecturer at the University of Jena.

In 1863 *Abbe* also became a member of the Jena Association of Medicine and Science, in which he gave a total of 45 lectures in the period to 1895. From 1866, he was a freelance scientist with the court and university mechanic *Carl Zeiss* in Jena. In 1870 *Abbe* formulated the famous sine condition subsequently named after him, a condition that must be met by any spherically corrected lens if it is also to be free from coma in the neighborhood of the lens axis in microscope image formation. In the same year he became an extraordinary professor at the University of Jena. On September 24, 1871, he married *Elise Snell*, the daughter of lecturer *Prof. Snell*, a mathematics and physics lecturer at the University of Jena. Three years later, the first child, his daughter *Paula*, was born. His father died on August 18, 1874. *Abbe* was director of Jena Observatory from 1877 to 1900. On May 1, 1878, he was appointed as an honorary member of the London Royal Microscopical Society. In June of the same year, he became an ordinary honorary professor at the University of Jena. He was awarded the title of Dr.



In 2005, the book titled "*Ernst Abbe* – Scientist, Entrepreneur and Social Reformer" was published by Bussert & Stadeler, Jena Quedlinburg to mark the 100th anniversary of *Ernst Abbe*'s death.

[ISBN 3-932906-57-8]


1863


1870


1875


1880

med. h. c. by the University of Halle in 1883 and the title Dr. jur. h. c. by the University of Jena in 1886. In 1900 *Abbe* became a corresponding member of the Imperial Austrian Academy of Science in Vienna. In 1901 he was appointed as an honorary member of the Saxon Academy of Science and of the Academy of Science in Göttingen.

Abbe as an entrepreneur

The process of integrating science into industry already started in the 1860s. In addition to Carl Zeiss, Siemens and Bayer were also pioneers of this development. By hiring scientific staff, *Ernst Abbe* was a decisive driving force behind this process at Zeiss: the integration of R&D into the company was an important step toward technology leadership. The training of capable employees and successors also played a significant role in the entrepreneurial and commercial areas. Competent staff and constant quality control allowed the implementation of high quality standards. The corporate organization was successfully focused on growth by the clear allocation of responsibilities for scientific, technical and commercial staff.

From 1872, all ZEISS microscopes were built in line with *Abbe*'s calculations. Three years later, in 1875, *Abbe* became a dormant partner in the Optical Workshop of *Carl Zeiss*. *Abbe* pledged not to increase his academic activity beyond the current measure and not to accept a professorship in Jena or elsewhere. One year later, he traveled to London to attend the international exposition of scientific instruments on behalf of the Prussian Department of Education. In 1878, due to his obligations at Zeiss, he turned down the offer of a post as professor in Berlin instigated by *Hermann von Helmholtz*. He also declined the offer of an ordinary professorship in Jena.

He initially came into contact with *Dr. Otto Schott* in 1879. Their collaboration began one year later. In 1882 a private glass laboratory was set up for *Otto Schott* in Jena. The following year saw the signing of the new partnership agreement in which *Abbe* became an active partner together with *Carl* and *Roderich Zeiss*.

In 1884 the Glastechnische Laboratorium Schott & Gen. (later to become Jenaer Glaswerk Schott & Gen.) was founded by *Otto Schott*, *Ernst Abbe*, *Carl Zeiss* and *Roderich Zeiss*.

In search of calcium fluoride for optical applications, *Abbe* traveled to Oltscherenalp in Switzerland for the first time in 1886. After the death of *Carl Zeiss* on December 3, 1888, *Abbe* became the sole owner of the Zeiss works in 1889. At the same time, he discontinued his teaching activities at the University of Jena. From 1890 onwards, *Abbe* expanded the product spectrum on an ongoing basis: measuring instruments (1890), camera lenses (1890), binoculars (1894), astronomical instruments (1897) and photogrammetric instruments (1901). As a result, the number of employees rose to over 2000 by 1905.

special

Global Player

As many as 100 years ago, Carl Zeiss was already what would now be called a global player: the first sales branches were founded in London (1894), Vienna (1902) and St. Petersburg (1903). Today, the company has 15 production facilities in Germany, USA, Hungary, Switzerland, Mexico, Belarus and China as well as 35 sales organizations and 100 agencies across the globe.

1888

1901

Abbe's persistence in his endeavors to also provide other manufacturers with new types of optical glass was of great help to the German optical industry. He was skeptical about the patenting of products, which he saw as an obstruction to scientific progress in general. Not until competitive pressure made it unavoidable did the patenting of camera lenses and binoculars begin. However, his early pioneering work remained accessible for general use. With the aid of *Abbe*'s comparator principle, instruments for the highly accurate measurement of workpieces were produced. These were important aids for instrument construction in Germany.

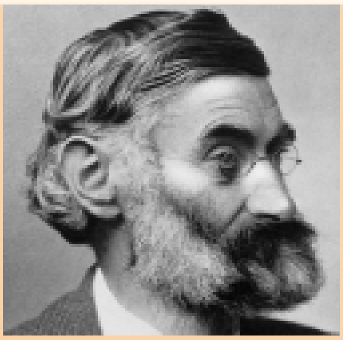
Abbe retired in 1903. To mark this occasion, a torchlight procession took place with 1500 employees of the Foundation companies. Two years later, *Ernst Abbe* died on January 14, 1905, after a long, serious illness.

Abbe the social reformer and the Carl Zeiss Foundation

Many companies introduced their social policy in the late 19th century. As a reformer, *Abbe* was far ahead of his times with his socio-political ideas. In 1889, in order to safeguard the existence of the enterprises Carl Zeiss and SCHOTT irrespective of personal ownership interests, *Abbe* set up the Carl Zeiss Foundation which he made the sole owner of the Zeiss works and partial owner of the SCHOTT works in 1891. In the same year, *Abbe* transferred his industrial assets to the Carl Zeiss Foundation With the appropriate compensation, *Roderich Zeiss* also transferred his shares to the Foundation, making it the sole owner of the firm Carl Zeiss and partial owner (sole owner from 1919) of Jena Glaswerk Schott & Gen. Until 1903, *Abbe* was the authorized representative and one of the three directors of the Carl Zeiss Foundation. The corporate statute of the Foundation came into force in 1896. The first supplementary statute followed just four years later.

With his corporate statute of 1896, *Abbe* gave the enterprise a unique constitution. In addition to its exceptionally progressive stipulations concerning corporate management and legally anchored labor relations, the constitution also reflected *Abbe*'s social commitment. For example, a council was set up to represent the interests of employees. Although this could not be seen as codetermination in the modern sense of the term, it did entitle the representatives to voice their opinion in all matters concerning the enterprise. Paid vacation, profit sharing, a documented entitlement to pension payments, continued pay in the event of illness and, from 1900, the eight-hour working day were further social milestones. This all made the Foundation enterprises Carl Zeiss and SCHOTT forerunners of modern social legislation.

Tolerance was central to *Ernst Abbe*'s basic philosophy of life. Although he was certainly not a social democrat, it was important to him that this political party was able to evolve and develop freely. He was also vehemently against racism, a phenomenon which was already prevalent during his times. He ensured that no-one at Carl Zeiss suffered in any way due to their origin, religion or political affiliation. This attitude was reflected in the fact that two of his closest management



1905

colleagues, *Siegfried Czapski* and *Rudolf Straubel*, were Jewish citizens.

Promoter of science and research

Abbe always attached great importance to the promotion not only of science and research, but also of culture. As a private citizen, *Abbe* supported the university with anonymous donations. The university and the city of Jena were both sponsored by the Carl Zeiss Foundation after its creation. As early as 1886, the promotion of science and research began with the secret "endowment fund for scientific purposes".

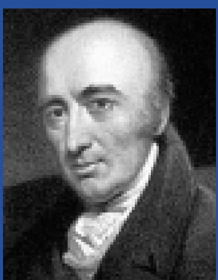
special

Products for Science

Shortly after the development of the new microscopes, decisive breakthroughs were made in the field of bacteriology. In 1904 *Robert Koch* wrote: "I owe a large proportion of the success I have achieved for science to your excellent microscopes". In the decades before the First World War medical research in Germany had a world standing that was paralleled only by the reputation enjoyed by ZEISS instruments. *Emil Behring* in the field of serology or *Paul Ehrlich* in the field of chemotherapy are only two examples of many. Needless to say, their success was not attributable to their instruments alone, but the microscopes did play an important role. The firm Carl Zeiss also created products for the field of chemistry, some of which were customized solutions: the gas interferometer for *Fritz Haber*, for example.

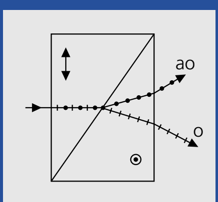
Microscope Objectives

Figs 1-3:
Early immerson objectives.



William Hyde Wollaston (1766-1828), English physicist, chemist and philospher.

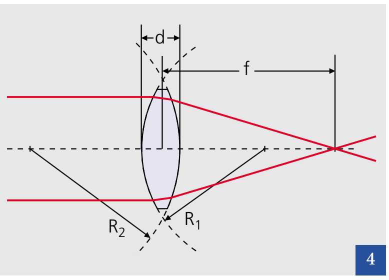
The Wollaston prism of the DIC microscopy technique is named after him. *Wollaston* discovered the elements palladium and rhodium and was the first scientist to report about the dark lines in the solar spectrum. His way of viewing the geometric arrangement of atoms led him to crystallography and to the invention of the modern goniometer for the angular measurement of crystal surfaces. In 1806 he invented the **Camera lucida**, an optical aid for perspective drawing that allows the observation of an object on a drawing surface. In its basic structure, the **Camera lucida** is a glass prism with two reflecting surfaces inclined at an agle of 135° that generates the image of a scene at right angles to the eye of the observer.

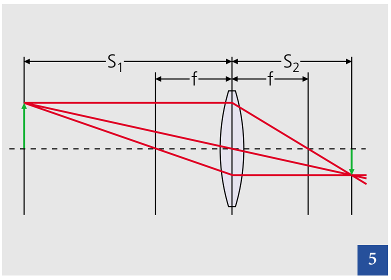


The quality displayed by early microscope objectives was usually very modest. The images were slightly blurred. Producing a microscope objective required a lot of hard, intricate work until well into the second half of the 19th century. The standard complex trial and error process needed to construct the optical systems was extremely time consuming and thus expensive.

Sometime around 1810, *Joseph Jackson Lister* (1786-1869) referred to the connection between the angular aperture of the objective and the attainable resolution for the first time. Two years later, *William Hyde Wollaston* (1766-1828) improved the optics of the simple microscope: using Wollaston doublets, he introduced a new lens combination – it consisted of two plano-convex lenses with a stop in the middle. *Sir David Brewster's* (1781-1868) idea of manufacturing objective lenses from diamonds was implemented in 1824 by *Andrew Pritchard*. *Brewster* recommended using oil immersion to secure achromatism in 1813. In 1816, *Joseph von Fraunhofer* (1770-1841) produced the first achromatic lens that could be used in microscopy. In 1823, Paris based physicist *Selligue* combined up to four achromatic cemented elements into one objective – this was the breakthrough in the manufacture of achromatic microscope objectives with high resolution.

In an age of increasing mechanization and the beginning of industrial manufacture, *Carl Zeiss* quickly recognized the link between theory and practice, between science and production required to effectively





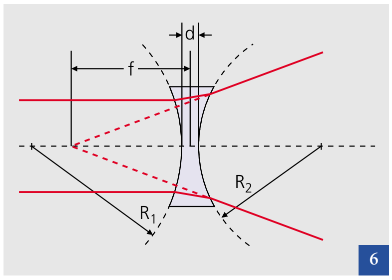


Fig. 4:
Positive lens element.

Fig.5:
Diagram showing image generation.

Fig. 6:
Negative lens element.

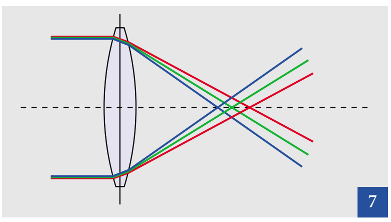
Fig. 7:
Chromatic aberration.

Fig. 8:
Spherical aberration.

manufacture powerful instruments that would be able to stand up to the pressures of competition. Zeiss looked hard for a solution. The initial attempts to compute microscope objectives between 1850 and 1854 by himself and his friend, mathematician *Friedrich Wilhelm Barfuss*, however, did not return any noteworthy results.

In 1866, *Carl Zeiss* approached a young, private tutor, *Ernst Abbe*, and requested help in developing improved microscope objectives. Over the next few years, *Abbe* developed the new theory of microscope image formation which is based on wave optics (theory of diffraction) and was published in 1873. During this time, the sine condition for imaging, which defines the resolution limits of a microscope, was also formulated. Using the new theory, *Abbe* calculated several new microscope objectives. The construction of measuring devices which are required for efficient production of objectives with consistently high quality, finally enabled *Abbe* to produce objectives on a scientific basis. He expanded the division of labor and specialization of employees that Zeiss had started in the 1850s. Measuring machines and testing instruments such as a thickness gages, refractometers, spectrometers and apertometer later entered volume production.

In his early works, *Abbe* already recognized that microscope objectives would only be able to achieve their full performance with the help of new types of glass. This led *Abbe* to bring young glass maker *Otto Schott* to Jena in 1882. Two years later, *Abbe* and *Zeiss* became partners of the newly founded Glastechnische Laboratorium Schott & Genossen. The new Schott glass materials enabled *Abbe* to construct the apochromatic objective – the most powerful microscope objectives of the late 19th century – in 1886.



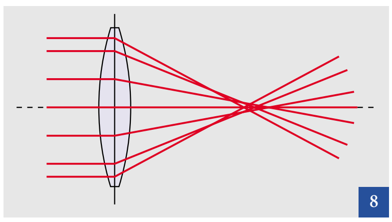
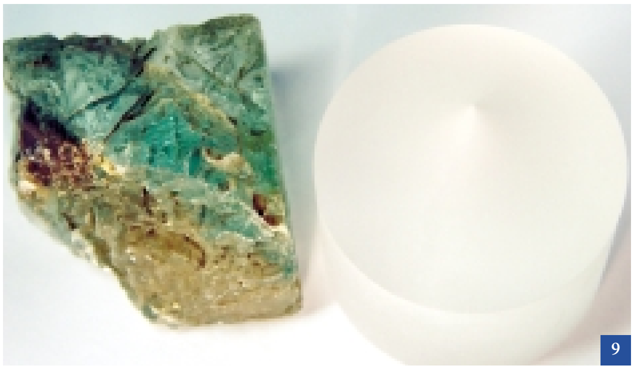


Fig. 9:
Natural (left) and artificial fluorite.



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Reason for Abbe's trip to Switzerland

16 February 1889, lecture by *Dr. Edmund von Fellenberg* during a meeting of the Natural Research Society in Bern, Switzerland: About the Fluorite of Oltschenalp and its Technical Utilization. "An historical, scientific memorandum for later times".

…In our Alps calcium fluoride or fluorite is no rarity and is quite frequently found in the area of protogine (gneiss granite), the various types of gneiss and crystalline slate and sometimes with excellent coloring and interesting crystal shapes…

In 1830, on a scree slope at the foot of the Oltschikopf (2235 m) on the Oltscheren mountain pasture, some Alpine enthusiasts discovered fragments of a shining, spathic mineral of outstanding transparency that they naturally thought to be rock crystal.…

…The mineral emerged from oblivion again in the summer of 1886. When visiting mineral inspector *B. Wappler* in Freiberg (Saxony) during his search for water-clear fluorite, *Dr. Abbe*, professor of physics at the University of Jena, had seen pieces of this material which *Wappler* had received from me in exchange for minerals from Saxony many years before.

…*Wappler* indicated that he had received the pieces from me and correctly stated that they had been found in the lower Haslithal in the canton of Bern in Switzerland. Acting upon this information, Professor *Abbe* traveled immediately to Switzerland to visit me. He showed me a piece of transparent fluorite and asked me whether I could tell him where this mineral could be found in Switzerland.

Source: Mitt. Naturf. Ges. Bern (1889) p. 202-219

Calcium fluoride or fluorite (CaF_2)

Fluorite is a mineral of the halogenides class. It is not only a popular gem, but also an important raw material for the production of hydrofluoric acid, fluorine and fluxing agents (e.g. for the manufacture of aluminum) and for the etching of glass. Clear crystals are used as lens elements for optical instruments. Nowadays, artificially produced fluorite is used in optics. The name fluorite comes from the Latin word fluere (to flow) and resulted from the use of the mineral as a fluxing agent in the extraction of metals. Fluorite displays the colors purple, blue, green, yellow, colorless, brown, pink, black and reddish orange. At the end of the 19th century *Ernst Abbe* was the first person to use natural fluorite crystals in the construction of microscope objective lenses in order to enhance chromatic correction.

Oltscheren mountain pasture (1623 m)

Hut no. 86 with the inscription “B 1873 H*: edifice on a solid foundation, with a kitchen-cum-living room since 1996; saddle roof with …, three-room living area facing NE on the first floor (two rooms in the front, behind them a now unused kitchen and behind this a store and barn. Beside these a milking installation with 5 stands. The hut belonged to the Zeiss Works in Jena during the period when the company was mining for fluorite.

Fig. 10:
The Alpine house in Bielen (Bühlen) on the Oltscheren Alps in 1889. *Ernst Abbe* can be easily recognized in the enlarged section produced by *Trinkler* in 1930 using the best Carl Zeiss copying lenses available at that time.

Numerical Aperture, Immersion and Use

Fig. 1:
Illustration of the invariance of the numerical aperture with regard to refraction at a plano-parallel glass plate (e. g. a coverslip).

$n_1 = 1.518$,
$\alpha_1 = 40°$,
$n_2 = 1.0$,
$\alpha_2 = 77.4°$,

$n_1 \sin \alpha_1 = n_2 \sin \alpha_2$

Fig. 2:
Large-aperture dry objective: the sine condition has been met (explained in the text).

Fig. 3:
Same objective type: the sine condition has not been met; off-axis image points display pronounced coma (explained in the text).

(Figures 2 and 3 by courtesy of *M. Matthä*, Göttingen, Germany).

Causal connection between numerical aperture and resolution

The key parameter of a microscope is known to be its ability to resolve minute object details, and not its magnification. To define the resolving power and its reciprocal value, the limit of resolution, *Ernst Abbe* coined the term numerical aperture (apertura [lat.] = opening, numerical aperture = dimensionless aperture). The numerical aperture is the product of the refractive index$_{OR}$ and the sine of half the angular aperture in the object space, and has one decisive advantage over the sole use of the parameter "angular aperture = 2α": its behavior is not changed by refraction at plano-parallel surfaces (e. g. coverslips).

Snell's law of sines

(1)

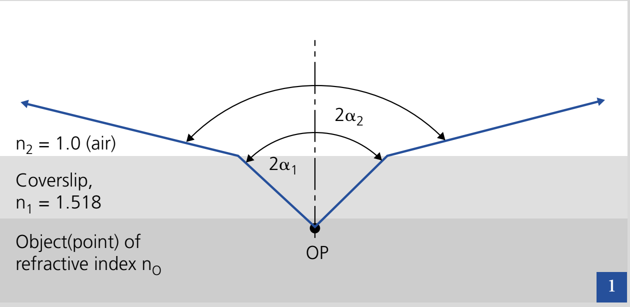
$$\frac{\sin \alpha_1}{\sin \alpha_2} = \frac{n_2}{n_1}$$

allows easy proof of this invariance (Fig. 1):

(2)

$$n_1 \cdot \sin \alpha_1 = n_2 \cdot \sin \alpha_2 = \ldots = n_i \sin \alpha_i$$

1) (R.W. Pohl aptly described spherical aberration as "…poor combination of axially symmetrical light bundles with a wide opening…")



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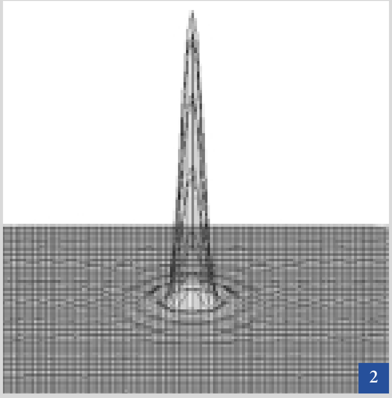
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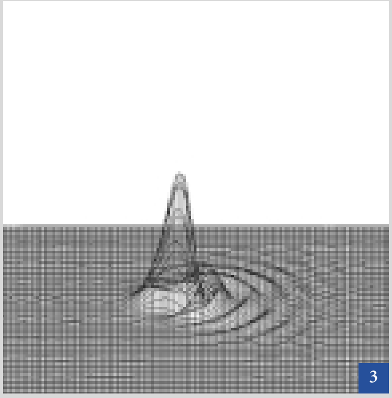
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Readers interested in mathematics might be surprised to see that *Abbe* used the sine instead of the tangent of half the angular aperture, as required by Gaussian image formation, for example. The latter, however, is only concerned with very narrow ray pencils, i. e. the sines and tangents of the angular apertures are interchangeable. After initial failures, *Abbe* quickly realized that a very specific condition must be met for microscopic imaging, namely the sine condition: if surface-elements are to be imaged without error by means of widely opened ray pencils, the ratio between the numerical apertures on the object and image sides must equal the lateral magnification, and thus must be constant. If this condition has been met and the spherical aberration[1] (aberratio [Lat.] = going astray) corrected, the image is described as "aplanatic" (α – πλανασδατ [Gr.] = not going astray); off-axis object points are imaged without coma. Fig. 2 shows the 3-dimensional, almost error-free diffraction image of an illuminated off-axis point (star test) that was captured with an objective meeting the sine condition. If the sine condition is not met, however, the image cannot be aplanatic, but displays pronounced coma (Fig. 3). There is a fundamental relationship between the sine condition and the resolving power: the angular separation $2\beta_{min}$ of two separately visible object points (the "weights" on the dumbbell-shaped object $2\Delta y_{min}$ in Fig. 4) must measure at least

(3a)

$$\sin 2\beta_{min} = \frac{1.22 \cdot \lambda}{d}$$

since only then can the diffraction maximum of the one object point coincide with the diffraction minimum of the other, and hence both object points can only just be seen separately (diffraction at a circular pinhole or lens edge; the number 1.22 is connected with the zero point of the Bessel function).

In the microscope, however, the resolution limit $2\Delta y_{min}$ (longitudinal dimension) and not the angular resolution is of prime interest. *R. W. Pohl* provides an amazingly simple derivation of the microscopic resolution limit from the sine condition:

In accordance with Fig. 4, formula (3a) can also be written as follows:

(3b)

$$\frac{2\Delta y'_{min}}{b} = \frac{1.22 \cdot \lambda}{d}$$

According to Fig. 4, the numerical aperture on the image side can be represented as follows:

ful Magnification

(4)

$$n_{BR} \cdot \sin \alpha' = \frac{d}{2b}$$

(In general, the image space is filled with air, i.e. $n_{BR} = 1.0$)

When the sine condition is taken into account,

(5)

$$\frac{n_{OR} \cdot \sin \alpha}{n_{BR} \cdot \sin \alpha'} = \frac{2\Delta y'}{2\Delta y} = \text{const.}$$

the smallest, still resolvable distance between two object points, i.e. the resolution limit $2\Delta y_{min}$, is

$$2\Delta y_{min} = 2\Delta y' \frac{n_{BR} \cdot \sin \alpha'}{n_{OR} \cdot \sin \alpha}$$

$$2\Delta y_{min} = \frac{1.22 \cdot b \cdot \lambda \cdot d}{2 \cdot b \cdot d \cdot n_{OR} \cdot \sin \alpha}$$

(6)

$$2\Delta y_{min} = \frac{0.61 \cdot \lambda}{n_{OR} \cdot \sin \alpha}$$

The reciprocal value of (6) is described as resolving power, which should have as high a value as possible.

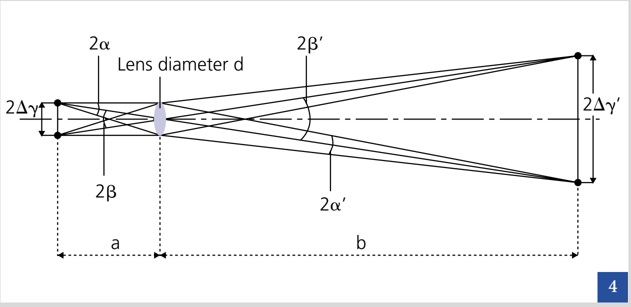
The benefits of immersion

The fundamental resolution formula (6) valid for objects which are not self-luminous states that the resolution limit depends on two factors, namely the wavelength λ and the numerical aperture of the objective. If, therefore, the resolving power is to be increased or the resolution limit minimized accordingly, shorter wavelengths and a larger numerical aperture must be selected.

What should be done, however, if a very specific wavelength or white light must be used and if, with $n_{OR} = 1.0$, the maximum value of 0.95, for example, has already been allocated to the dry aperture? In such cases, immersion objectives are used, i.e. objectives whose front lens immerses (immergere [Lat.]) into a liquid, the optical data of which has been included in the objective's computation. In the special case of homogeneous immersion, the refractive indices of the immersion liquid n_2 and the front lens n_3 have been matched for the centroid wavelength[2)] in such a way that the rays emitted by an object point OP (Fig. 5) pass the immersion film without being refracted and can thus be absorbed by the front lens of the objective. In this case, the numerical aperture has been increased by the factor n_2, i. e. the wavelength and therefore the resolution limit has decreased to $1/n_2$. This means that the numerical aperture of a dry objective and an immersion objective differs by the factor n_2, provided the objectives can absorb rays of the same angular aperture. The standard numerical apertures of immersion objectives are 1.25 (water immersion), 1.30 glycerin immersion) and 1.40 (oil or homogeneous immersion). The values correspond to half the angular apertures α = 56°, 59° and 68°; for dry objectives, the numerical apertures would be reduced to 0.83, 0.86 and 0.93.

Another advantage of immersion objectives over dry objectives is their considerable reduction or even entire elimination of interfering reflected light produced at the front surfaces of the coverslip and the front lens of the objective.

For the sake of completeness, we would also like to mention the immersion technique used to determine the refractive index of isolated solid bodies. The object to be measured is



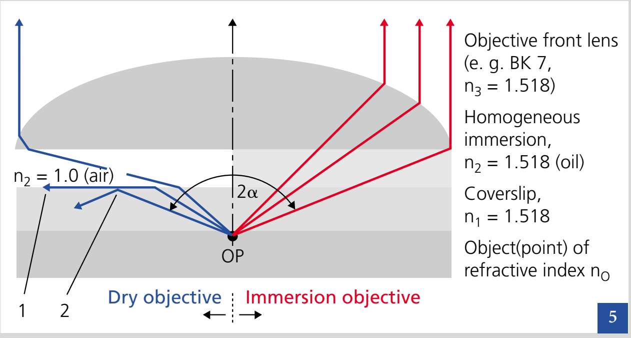


Fig. 4:
The resolving power of the microscope (according to *R.W. Pohl*, 1941)
2Δy object, 2Δy' image,
2α angular aperture on the object side,
2α' angular aperture on the image side,
2β resolvable angle size on the object side,
2β' resolvable angle size on the image side.

Fig. 5:
Influence of the immersion medium on the numerical aperture of the objective.
2α = Angular aperture of the objective (numerical aperture = $n_2 \cdot y \sin \alpha$)
1 = Limit angle of total reflection (= arcsin $[n_2/n_1]$ ≈ 41°) reached; grazing light exit.
2 = Total reflection

embedded in an immersion liquid, the refractive index of which approximates that of the object. Using a heating and cooling stage, the temperature is then varied until the refractive index of the liquid is identical to that of the object. The fact – derived from the Dulong-Petit law – that the temperature dependence of the refractive index of solids is significantly lower than that of liquids is very important here. The refractive index can be determined using either the "Becke line" or, if high accuracies are required, by interferometric means; please see the relevant literature.

Useful magnification

To enable the human eye to see two image points separately, an angular distance 2β of between 2 and 4 arc minutes, or

(7)

$$5.8 \cdot 10^{-4} \leq 2\beta \leq 11.6 \cdot 10^{-4}$$

must exist between these points, according to *Ernst Abbe*. If the lower limit of the overall magnification of the microscope is V_u and the upper limit V_o, where the overall magnification of the microscope V_M equals the quotient of the apparent visual range of 250 mm and the overall focal length of the microscope f_M, the calculation of V_u and V_o is easy:

(8a)

$$\frac{2\Delta y}{f_M} = \frac{2\Delta y\,[\text{mm}]\,V_u}{250} = 5.8 \cdot 10^{-4}\ (= 2')$$

(8b)

$$\frac{2\Delta y}{f_M} = \frac{2\Delta y\,[\text{mm}]\,V_o}{250} = 11.6 \cdot 10^{-4}\ (= 4')$$

with $\lambda = 550\text{ nm} = 5.5 \cdot 10^{-4}$ mm

and

$$2\Delta y_{min} = \frac{\lambda}{2\sin\alpha} = \frac{\lambda}{2\,nA_{Obj}}$$

finally result in

(9a)

$$\frac{V_u \cdot 5.5 \cdot 10^{-4}\,[\text{mm}]}{500 \cdot nA_{Obj}} = 5.8 \cdot 10^{-4}$$

and

(9b)

$$\frac{V_o \cdot 5.5 \cdot 10^{-4}\,[\text{mm}]}{500 \cdot nA_{Obj}} = 11.6 \cdot 10^{-4}$$

or

(9c)

$$V_u \approx 500\ nA_{Obj}$$

and

(9d)

$$V_o \approx 1000\ nA_{Obj}$$

Therefore, the performance of the microscope is meaningfully utilized only if the selected total magnification is no less than 500x and no more than 1000x the numerical aperture of the objective

Our forefathers rightfully termed magnifications > 1000 nA_{Obj} as "empty magnifications" because still smaller object details can no longer be expected to be resolved, which will result in ineffective over-magnification.

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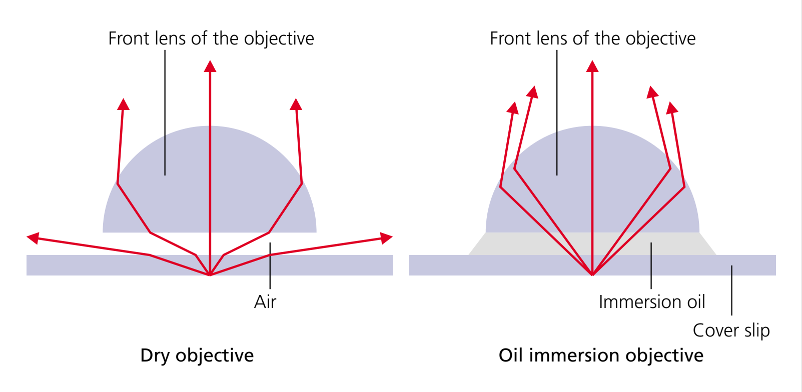
2) Due to the matching refractive indices of the front lens, the immersion liquid and the cover slip, the microscopist first tends not to make any difference between coverslip-corrected (e. g. HI 100x/1,40 ∞/0.17) and non-corrected (e. g. HI 100x/1.40 ∞/0) immersion objectives. This is certainly possible in monochromatic light (centroid wavelength); in polychromatic light, however, immersion liquid and coverslip usually display different dispersions, i. e. the refractive indices depend on the wavelength to a greater or less extent. This effect becomes apparent in the microscope image with chromatic and spherical aberration. Therefore: always carefully note the correction state of the objective!

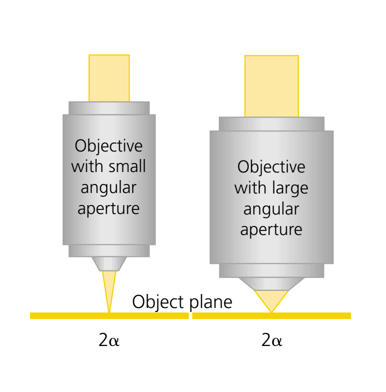
Numerical Aperture

The numerical aperture indicates the resolving power of an objective. Put more simply, the resolving power of an objective depends on how much light of a specimen structure reaches the objective. This amount of light depends on what is called the angular aperture of the objective. The larger the angular aperture, the better an objective will resolve the details of a specimen. However, it is not the angular aperture which is specified on the objective, but the numerical aperture.

The numerical aperture is defined by the formula $A = n * \sin \alpha$ (A: numerical aperture, n: refractive index of the medium between the coverslip and the front lens of the objective, $\sin \alpha$: half the aperture angle of the objective). The formula for the numerical aperture shows that, in addition to the angular aperture of the objective, the refractive index of the medium between the coverslip and the objective is also used for the computation.

In the case of dry objectives, the light rays are refracted away from the perpendicular on entering the air between the coverslip and the objective in accordance with the refraction law. Therefore, strongly inclined light rays no longer reach the objective and do not contribute to the resolution. With oil immersion objectives, immersion oil is inserted between the coverslip and the objective: even strongly inclined light rays reach the objective.





details

Resolving power

The resolving power of an objective is the ability to show two object details separately from each other in the microscope image. The numerical aperture of the objective directly determines the resolving power: the higher the numerical aperture, the better the resolving power.

The theoretically possible resolution in light microscopy is approx. 0.20 µm. The resolving power of an objective is defined by the formula

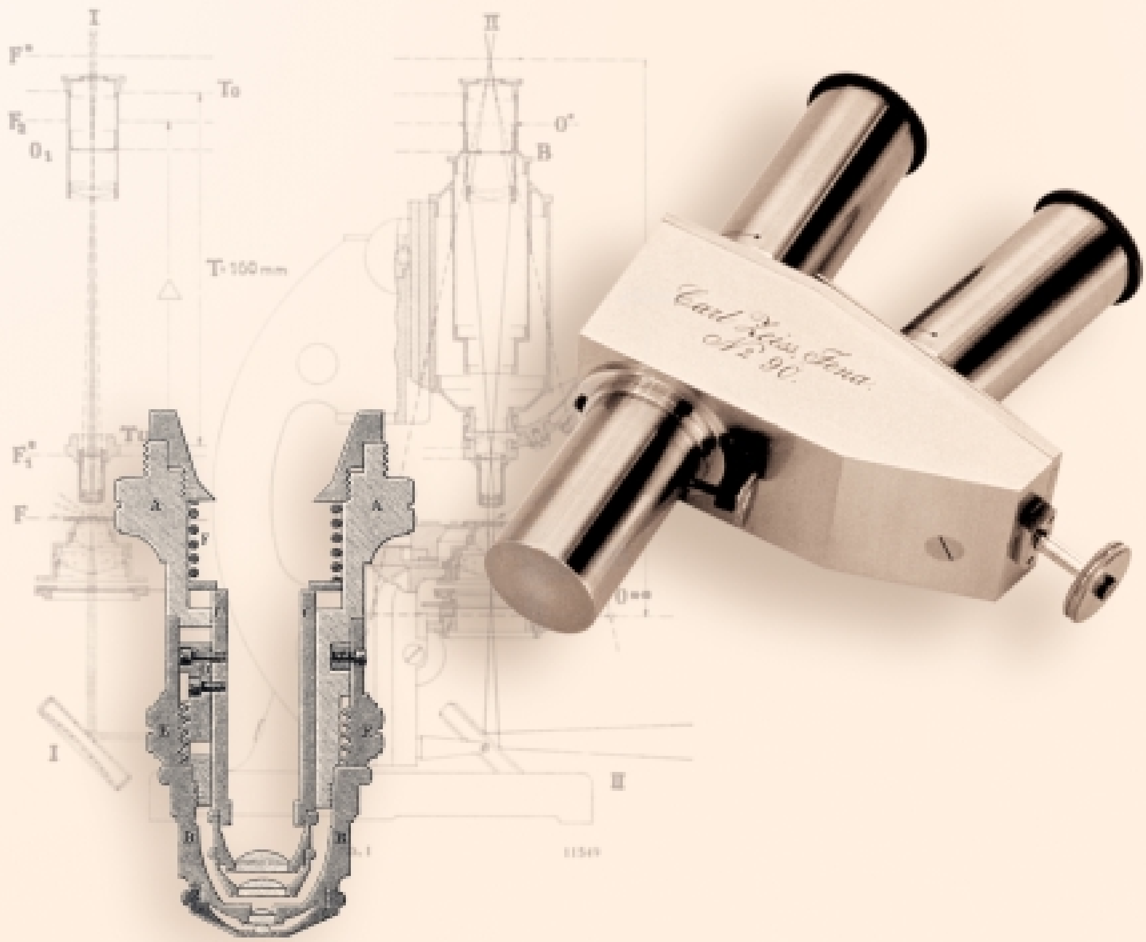
$$d = \frac{\lambda}{2 \times A}$$

d: distance between two image points
λ: wavelength of light
A: numerical aperture of the objective

Refractive index of various media

Refractive index n of the media through which the light ray passes in the beam path of a microscope.

Air n = 1.000
Glass n = 1.513
Oil n = 1.516



Highlights from the History of Immersion

details

Immersion oil

In the beginning, natural cedar oil was used. Gradual thickening leads to alteration of the refractive index over time. Exposed to air, it turns to resin and becomes solid.
Nowadays, synthetic immersion oil with a constant refractive index is used. It does not harden in air and can therefore be stored longer.

Robert Hooke (1635-1703) was the first to discuss the technique of immersion: "that if you would have a microscope with one single refraction, and consequently capable of the greatest clearness and brightness, spread a little of the fluid to be examined on a glass plate, bring this under one of the globules, and then move it gently upward till the fluid touches and adheres to the globule." His "Lectures and Collections" from 1678, published in his book "Microscopium" in the same year, thus marked the beginning of oil immersion objectives.

Sir David Brewster (1781-1868) proposed the immersion of the objective in 1812. Around 1840, *Giovanni Battista Amici* (1786-1868) produced the first immersion objectives that were used with anis oil and had the same refractive index as glass. However, this type of immersion was not yet used to increase the aperture, but more to correct chromatic aberration. *Amici* had already recognized this problem during *Brewster*'s time. Because microscope slides were very expensive at the time, microscopists in the 19th century did not yet accept oil immersion. *Amici* gave up on oil immersion and converted to water immersion. A short time later in 1853, he built the first water immersion objective and presented it in Paris in 1855.

In 1858, *Robert Tolles* (1822-1883) built his first water immersion objective which had two exchangeable front lenses: one for working under dry conditions, the other for water immersion.

Approximately 15 years later in 1873, he constructed his famous 1/10 objective for homogenous immersion. *Edmund Hartnack* (1826-1891), who in 1859 presented his first water immersion objective, also added a correction ring for the first time. *Hartnack* sold around 400 models over the next five years. By 1860, many German microscope manufacturers offered water immer-

details

Glycerin

1,2,3 propanetriol – is the most simple tertiary alcohol. The Greek word glykerós means "sweet". The viscous, hygroscopic, sweet-tasting liquid boils at 290 °C and freezes at 18 °C. Glycerin can be mixed with water and lower-order alcohols. A mixture of water and glycerin is used in microscopy for immersion. It is mainly used in UV microscopy as glycerin transmits UV light.

Objectives

sion lenses, including *Bruno Hasert* in Eisenach, *Kellner* in Wetzlar, *G&S Merz* in Munich and *Hugo Schroder* in Hamburg. *Hartnack*'s immersion lenses, however, were considered the best.

At the "Exposition Universelle" in 1867 in Paris, *Ernst Grundlach* (1834-1908) presented his new glycerin immersion lens, claiming that he developed the lens because he wanted to use an immersion medium with a higher refractive index than water.

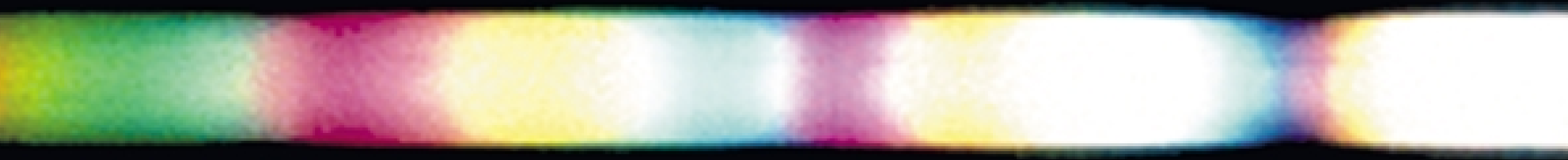
In 1871, *Tolles* once again presented something new: he used Canada balsam as an immersion medium for homogenous immersion. His discovery that Canada balsam has the same refractive index as the crown glass that was standard at the time remained unused until *Ernst Abbe* discovered a suitable liquid in 1877. The Zeiss Optical Works in Jena also produced initial water immersion objectives in 1871. In 1872, *Carl Zeiss* introduced the *Abbe* water immersion objective. Three objectives were offered in the Zeiss catalog at the time, all with an aperture of 180°. They had different working distances, but also a numerical aperture of 1.0. Objective no. 3 was equipped with a correction ring.

In August 1873, *Robert Tolles* built a three-lens objective for homogenous immersion in balsam with a numerical aperture of 1.25. It was the first homogenous immersion system for microscopes to be recognized at the time. In the same month, he produced his first objective for glycerin immersion with a numerical aperture of 1.27.

In August 1877, *Carl Zeiss* began building *Abbe*'s oil immersion objectives which later became known as "homogenous" immersion. The design of the Zeiss oil immersion objectives was influenced by the work of *J. W. Stephenson,* which *Abbe* emphasized in a lecture to the Jena Society for Medicine and Natural Science in 1879.

In 1879, *Ernst Abbe* published his "On New Methods for Improving Spherical Correction" in the "Royal Microscopical Society" magazine. In this article, *Abbe* described the optics he used in his 1873 experiments. He also added that homogenous immersion systems make it possible to achieve an aperture at the limits of the optical materials used and available at the time. *Robert Koch* was one of the first to utilize the Abbe oil immersion objective and the Abbe condenser system for research purposes. In 1904, *Carl Zeiss* manufactured its 10,000th objective for homogenous oil immersion.

From the History of Microscopy: Abbe's



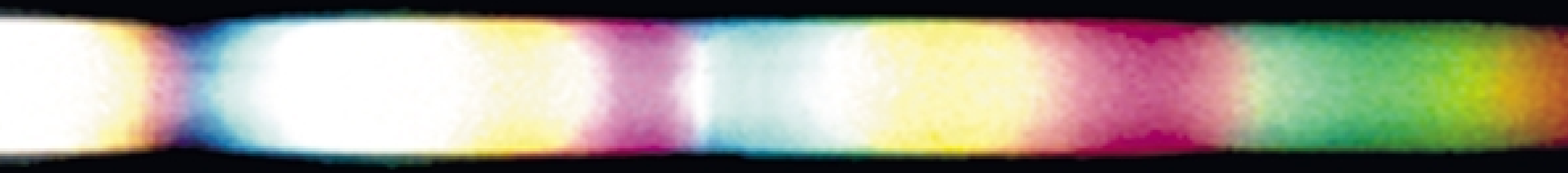
The history of microscopy started around 1590 with Dutch spectacle makers. The first "simple" microscopes date back to *Antony von Leeuwenhoek* (1632-1723) and his contemporaries. *Leeuwenhoek* built microscopes with a single, small lens displaying magnifications of up to 270x. This enabled him to discover protozoa (single-celled organisms) as early as 1683. The "combined" microscopes are attributed to the Englishman *Robert Hooke* (1635-1703), who is known to have used these for the first time. "Combined" microscopes consist of an objective lens and an eyepiece. *Hooke* already recognized the importance of microscope illumination at that time. However, the aberrations of both microscope types impaired precise observation. Nevertheless, they formed the base of the pioneering microscopic discoveries in the 19th and 20th centuries.

Until 1866 – the year when the cooperation between *Carl Zeiss* and *Ernst Abbe* began – microscopes, and the microscope objectives in particular, were made by trial and error, resulting not only in some microscopes with outstanding optical performance, but also in some with less desirable features. *Carl Zeiss* (1816-1905) and *Ernst Abbe* were aware that optimum and – above all – consistent performance would only be possible on a sound theoretical basis. The first calculations were made of the geometric beam path. To improve correction, *Abbe* used lower apertures than those of the objectives made by Zeiss until then. The results were not really satisfactory: fine specimen structures remained blurred, and their resolution was less good than that obtained with the old objectives with a wider angular aperture.

Abbe's key theory on microscope image formation

In the end, it was *Carl Zeiss* who recognized the importance of a solid theoretical basis and who initiated and also financed *Abbe*'s research. The major breakthrough for the building of microscopes came with the theory of microscope image formation from *Ernst Abbe* (1840-1905). After countless calculations and experiments, *Abbe* realized that it is the diffraction image in the back focal plane of the objective that is decisive for image formation. In 1873, he wrote: "No microscope permits components (or the features of an existing structure) to be seen separately if these are so close to each other that even the first light bundle created by diffraction can no longer enter the objective simultaneously with the non-diffracted light cone."

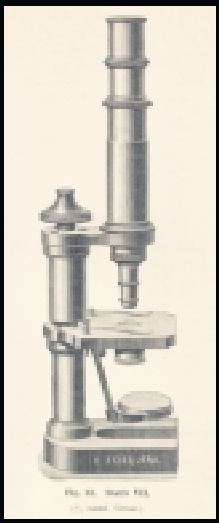
Diffraction Trials



This is also the core of *Abbe*'s theory of microscope image formation. His theory, based on the wave characteristics of light, shows that the maximum resolution is determined by half the wavelength of the light used, divided by half the numerical aperture.

Abbe's theory of image formation and resolution limits was rejected by many biologists and mainly by microscopists in England, who were too biased by the old microscopy technique of using strongly magnifying eyepieces, a method known as empty magnification.

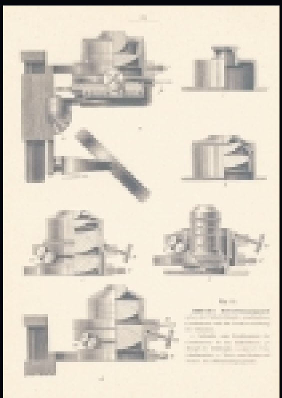
Finally, *Abbe* was able to prove his theory with a system of experiments he first demonstrated using the **ZEISS Microscope VII**. *Robert Koch* used the same **Microscope VII** for his discovery of the tuberculosis bacterium.



Microscope stand VII.

Microscope stand I.

Cover page of brochure on the diffraction apparatus.



Abbe's illumination apparatus.

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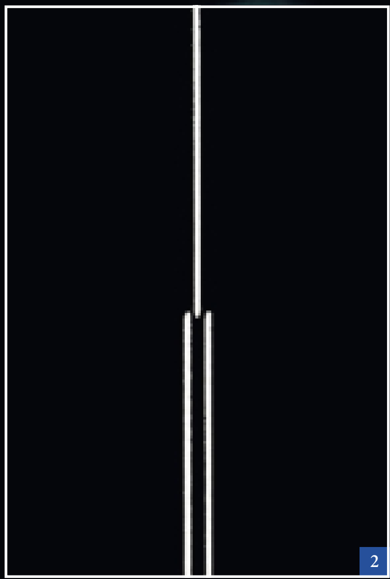

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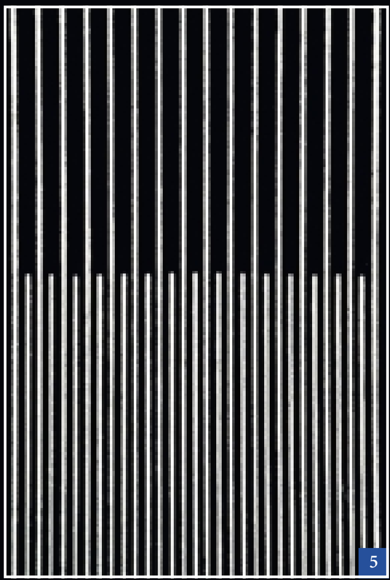

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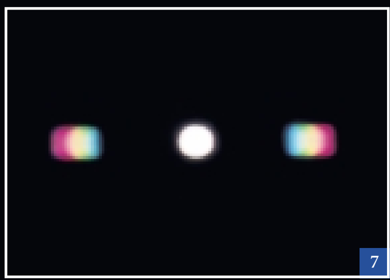

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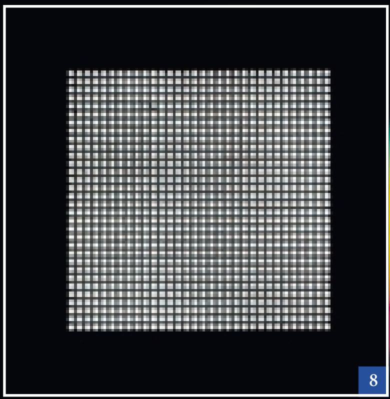
Diffraction experiments

Even today, diffraction experiments still play a major role in training courses in microscopy, and make a major contribution to the understanding of modern microscopy techniques. *Abbe* created almost 60 experiments to prove his theory of image formation. A diffraction plate with various objects engraved in the form of lines and dots is used as a specimen. The condenser is removed so that the light source lies at infinity and can be made to adopt a point-shaped structure by closing the luminous-field diaphragm (Fig. 1). Removal of the eyepiece or the use of an auxiliary microscope permits viewing of the images produced in the back focal plane of the objective.



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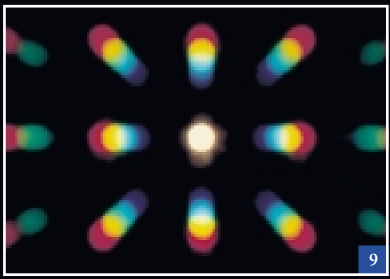

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Fig. 10:
Abbe's diffraction apparatus b.

Single slit

With a single slit (Fig. 2), a light strip (Fig. 3) appears in the back focal plane of the objective, which is perpendicular to the optical axis and displays the point-shaped light source in the center. This light strip is produced by the diffracted light waves at the edges of the slit.

Double slit

The double slit (Fig. 2) enables observation of the interference phenomenon: the image of the light source is located in the center, while bright and dark sections extend to the right and left in a regular sequence (Fig. 4). The bright sections display characteristic color fringes (spectral colors). *Abbe* designated this image in the back focal plane of the objective as the diffraction spectrum.

Line grid with 16 µm grating constant

In the produced diffraction image of the 16 µm line grid (Fig. 5), the image of the light source, also called the zeroth maximum, and the first and second order secondary maxima are clearly separated from each other and imaged much more sharply (Fig. 6) than is the case in Fig. 4. Furthermore, it is also evident that blue light is less diffracted than red light.

Line grid with 8 µm grating constant

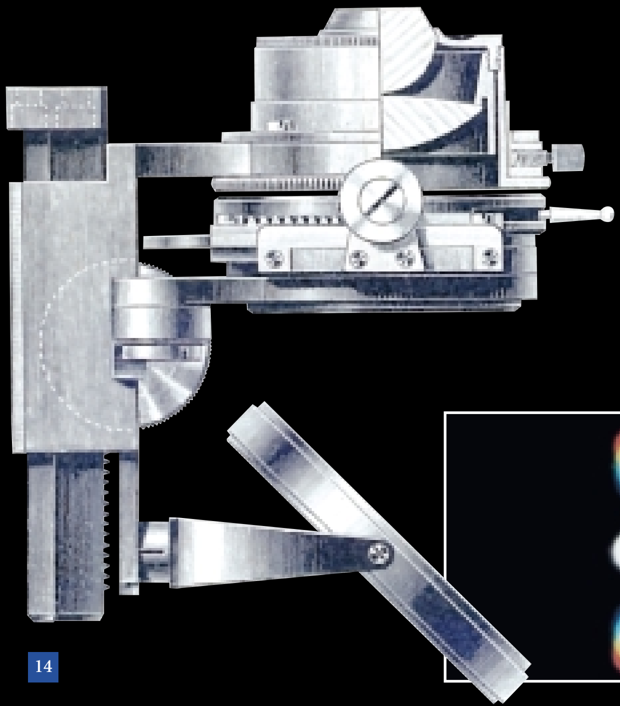
In the diffraction image of the 16 µm line grid (Fig. 5), the 1st secondary maximum is twice as distant from the 0th maximum, and the 2nd secondary maximum is no longer visible at all (Fig. 7). From this, *Abbe* concluded that the closer the structures – or lines in this case – the more the light waves are diffracted, explaining why the 1st maximum in the 8 µm grid is twice as distant from the 0th maximum as in the 16 µm grid.

Point grid

In the diffraction image of the point grid (Fig. 8), the respective primary diffraction spectrum (Fig. 9) can be seen in the back focal plane of the objective. From this, *Abbe* concluded that each specimen forms a specific diffraction image of the light source.

Influencing the diffraction image

If an intermediate component with a slit is inserted between the objective and the nosepiece (Fig. 10), in which various stops can be inserted, parts of the diffraction image can be faded out. For more precise orientation, the intermediate component can be rotated through 360 degrees. This means that the primary diffraction image is changed by artificial means.



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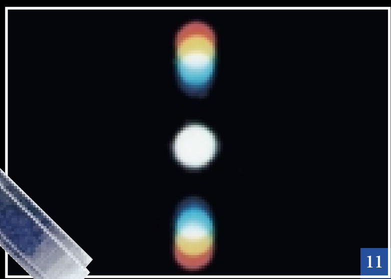

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Point grid

From the diffraction image of the point grid (Fig. 9), the 0^{th} and the first secondary maxima in the horizontal axis are faded out via the slit. In the intermediate image, a line grid then appears in the perpendicular direction (Fig. 11), and at an angle of 45° when the slit is oriented diagonally (Fig. 12). A particularly remarkable feature of the artificially produced 45° grating is that the lines are closer to each other than in other images. This is bound to be the case because the secondary maxima in the 45° diffraction image are further away from the 0^{th} maximum than in the perpendicular or horizontal diffraction images.

With these experiments, *Abbe* finally showed that the image in the microscope is created in the space between the primary diffraction image (back focal plane of the objective) and the intermediate image plane through interference of diffracted light waves.

In a further experiment, *Abbe* demonstrated why the resolution formula is

$$d = \frac{\lambda}{2n \sin \alpha} \qquad 2 \times n \times \sin \alpha =$$

numerical aperture.

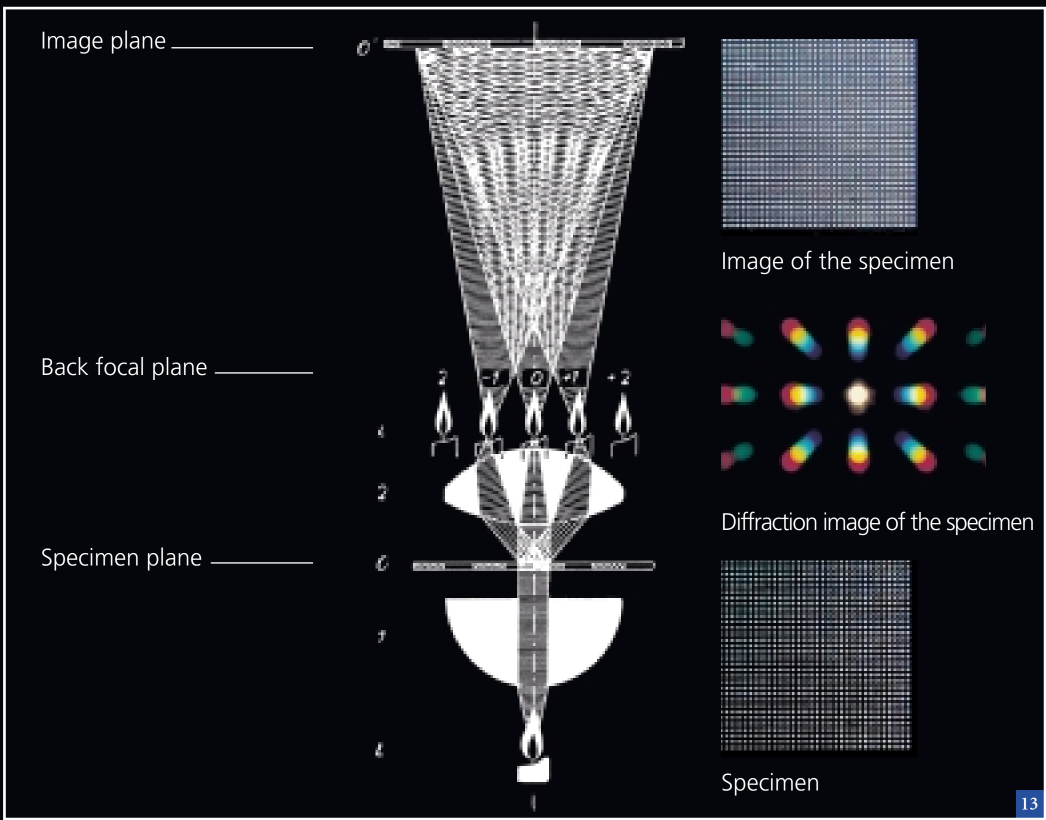
Abbe pushed the point-shaped light source to the edge (known as oblique illumination): therefore, the 1^{st} secondary maximum can be twice as distant as in straight illumination, i. e. the distance d between two points or lines can be twice as small. On this basis, *Abbe* had already developed the illumination apparatus with focusing condenser in 1872 (Fig. 14). In today's microscopy, we use unilateral oblique illumination to achieve full resolution with the maximum condenser aperture.

The theory of microscope image formation and its practical implementation defined the resolution limits and thus enabled the scientific construction of microscopes. *Abbe* could then concentrate on the correction of spherical and chromatic aberration. He realized that this requires the development of special glass materials. His collaboration with the glass maker *Otto Schott* (1851-1935) started in 1879, and the first Apochromat objectives featuring high color fidelity were already launched in 1886.

In 1893, *August Köhler* (1866-1948) developed his illumination technique with separate control of luminous-field diaphragm and condenser aperture on the basis of *Abbe*'s results. *Köhler* also developed the microscope with ultraviolet light, which was primarily built to increase the resolution by a factor of 2 relative to green light. Finally, the phase contrast technique from the Dutch physicist *Frits Zernike* also is attributable to manipulation in the back focal plane of the objective.

With his theory and experiments, *Ernst Abbe* decisively shaped the development of microscopy in the 19^{th} and 20^{th} centuries. Numerous Nobel prizes are directly or indirectly connected with microscopy. *Abbe* himself was twice nominated for the Nobel prize. Pioneering examinations in cell and molecular biology would not have been possible without modern light microscopy. Metallography would probably not have achieved its current status without microscopy, and semiconductor technology would probably not even exist at all.

[Heinz Gundlach, Heidenheim]



The Science of Light

The importance of light is emphasized in the First Book of Moses in the Bible: "In the beginning, God created the heaven and the earth. And the earth was without form, and void; and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters. And God said, Let there be light: and there was light. And God saw the light, that it was good: and God divided the light from the darkness." Without light life is impossible. Light plays an important role in our lives. And the question of the "nature of light" is one that we have always endeavored to answer.

Besides mechanics, optics would seem to be the oldest field in which scientific work has been conducted. The Babylonians, on the basis of their experience, were already applying the law of the rectilinear propagation of light around 5000 BC in the use of astronomical instruments.

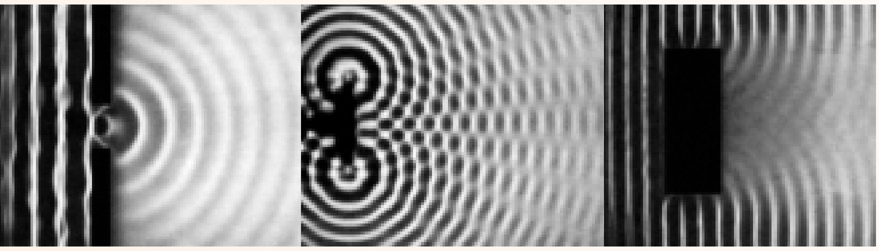
There is evidence of scientific study in the field of optics in Greece in the 6^{th} century BC: here the emphasis was on explaining the effect the visible object had on the eye. The various schools developed ideas that differed from each other to a greater or lesser extent and were generally rather imprecise.

The predominant theory in Ancient Greece was the extramission theory, which can presumably be traced back to *Pythagoras* (570/560-480 BC) and was later supported in particular by *Euclid* (around 300 BC) and *Ptolemaeus* (around 100-160 AD). The extramission theory assumed that we are able to see as a result of hot rays that emanate from our eyes towards an object. The resistance these rays meet with when they reach the cold object causes them to be sent back, enabling the information they have gathered to reach the eye. The ability of many animals to see at night was put forward in support of this theory.

Aristotle (384-322 BC), in particular, had a different view. He believed that light is not something physical that moves between the object and the eye, but rather that the process of seeing is the result of the effect the object has on the eye by means of the medium between them ("the transparent").

In addition to the process of seeing in itself, the Greeks also studied the laws of geometric optics. It seems that *Plato* (424-347 BC) was aware of the law of reflection and he described the reflection of concave and cylindrical mirrors. The mention of oars bending in water indicates that the phenomenon of refraction was also familiar. The playwright *Aristophanes* (445-385 BC) described the effect of burning glasses (glass lenses or glass globes filled with water). *Ptolemaeus*, who summarized the entire optical knowledge of the ancient world and systematically examined the refraction of light, is perhaps the most important optical scientist of that time.

During the Middle Ages, Christianity was not particularly open to science. It was the Arabs who not only collected and translated the ancient writings but also made their own scientific contributions. The most important Arab scientist was *Abu Ali Al-Hasan Ibn Al-Haitham* (965-1040), also known as *Alhazen*,



who wrote more than 200 works on optics, astronomy and mathematics. His principal work, the "Book of Optics", contained descriptions and explanations regarding light and vision.

From the 12th century, the main scientific focus shifted geographically from the East back to the West of the known world. Initially, however, only the works of *Alhazen*, *Ptolemaeus* and *Euclid* were translated and summarized. There is evidence that *Roger Bacon* (1214-1294), a Dominican monk, studied the camera obscura, which he recommended for observing solar eclipses. *Bacon* also predicted the development of eyeglasses and the telescope. Eyeglasses were apparently invented in Italy at the end of the 13th century.

At first, however, it was not known how they functioned exactly, since people did not know how the eye saw, nor how lenses worked. *Giovanni Battista della Porta* (1535-1615) compared the eye with a camera obscura. *Father Franciscus Maurolycus* (1494-1575) recognized that defective vision was caused by the incorrect curvature of the lens.

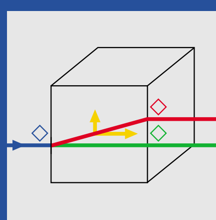
Johannes Kepler (1571-1630) is regarded as the founder of modern optics. He succeeded in correctly explaining how the camera obscura and the eye worked, including the lens and the retina. *Thomas Harriott* (1560-1621) was supposedly the first person to discover the law of refraction.

In 1637, *Rene Descartes* (1596-1650) derived a theory relating to the Law of Refraction in his work "La Dioptrique". He was one of the first to attempt to explain all optical laws and phenomena on the basis of the mechanical properties of the light source and the transparent medium. The work of *Johannes Marcus Marci de Kronland* (1595-1667) and *Francesco Maria Grimaldi* (1618-1663) gradually brought us closer to the wave theory of light, which was then supported emphatically by *Robert Hooke* (1635-1703). At the same time as *Hooke*, the Jesuit priest *Ignace Gaston Pardies* championed the theory of the wave nature of light. Nevertheless, it is *Christiaan Huygens* (1629-1695), with the Huygens' principle that was named after him, who is regarded as the true founder of the wave theory of light.

In *Huygens*' famous principle, every point on a forward-moving wavefront is seen as a source of new waves. He used this principle to develop the wave theory of light. With a new method (1655) for the grinding and polishing of lenses, *Huygens* achieved an improvement in optical performance. This enabled him to discover the moon of Saturn and to make the first exact description of the rings of Saturn. To observe the night sky, *Huygens* developed the pendulum clock with an exact time measure. In 1656 he invented the Huygens telescope. He developed theories about centrifugal force in circular motion. These helped the English physicist *Sir Isaac Newton* to formulate the law of gravitation. In 1678 *Huygens* discovered the polarization of light through birefringence in calcite.

Christian Huygens (1629-1695)
Dutch astronomer, mathematician, physicist and clockmaker.

Birefringent calcite.



Stazione Zoologica Anton Dohrn, Naples,

Stazione Zoologica
Anton Dohrn

Fig. 1:
Group of researchers at the Stazione Zoologica at the end of the 19th century.

Since its inception, the zoological station has been devoted to basic research in biology for all its inter-disciplinary activities – from evolution and molecular biology to ecophysiology. The station celebrated its 125th anniversary in 1998. Named after founder, financier and first director, *Anton Dohrn*, the center took 18 months to complete, finishing in September 1873. Located in Naples, Italy, the station served as an example for many other marine biological centers and institutes. This renowned list includes Woods Hole in the USA and Misaki in Japan, as well as the Kaiser Wilhelm Institutes which later became the Max Planck Institutes. A novelty when the station was founded, its internationality was fostered and ensured by influential scientists at the time, *Charles Darwin* and *Rudolf Virchow*, among others.

Naturalists as well as philosophers have always shared a fascination for life under the sea. This curiosity, scientific observation and legends passed down through the years, led *Pliny the Elder* (23-79 A. D.) to pen Naturalis Historia. It attracted attention to sea life, an unending source of wondrous (Mirabilia) and fantastic monsters, a place of mystery and a constant source of life and beauty. To the German science scene in the 19th century, which was marked by men such as *Alexander von Humboldt*, the ocean was a place of elementary life forms and a symbol of the endless search for knowledge.

Marine life became the focus of interest of all those who recognized the philosophy of nature. Appearing in the "protoplasmic theory of life", initial forms of cell theory looked for "elementary forms of matter", the "primordial mud" teeming with one-celled organisms, in the depths of the oceans. The new generation of biologists from the 1850s and 1860s was well versed in "natural philosophy" and in Darwinism. They viewed the ocean as a source of knowledge and as an experiment of life. In the second half of the 19th century, the wealth of life forms, particularly simple forms, caused many scientists to see the oceans as a source of biological models, experimental objects and as a metaphor for fundamental biological problems such as the organizational plan of life, embryogenesis, general physiology, evolution and phylogeny.

Johannes Müller (1801-1858), considered the founder of physiology and theoretical biology, raised interest in marine organisms for the understanding of fundamental biological problems. The concept of marine biology research published by *Müller* was a means of explaining the fundamental biological concept. The station's first boat carried his name as an indication of its purpose. It was used to gather marine plants and animals.

First marine institutes

Zoologist and parasitologist *P. M. van Beneden* from Leuven, Netherlands founded the first marine laboratory in Ostende 1843. Similar initiatives in North America emphasized the need for such research institutes: *Louis*

Italy

Agassiz founded the Anderson School of Natural History in 1873; Johns Hopkins University the Chesapeake Zoological Laboratory in 1878. The Woods Hole Oceanographic Institution opened in 1892.

However, these were all university and institute field stations. They can also be split up into two categories: centers such as Naples were dedicated to research and practical training, while French and American institutes were used primarily for teaching.

Deciding on Naples

During his stay at the zoological center in Messina, *Anton Dohrn* realized that a permanent laboratory structure was required to study ocean life. This is where his dream of a "full house" for ocean research started: instant and permanent availability of instruments, laboratory stations, laboratory services, chemicals, books and much more.

The diversity of life in the Gulf of Naples, the size of the city and its international reputation contributed to *Dohrn*'s decision to locate his center in Naples. With a mixture of imagination, willpower, diplomatic skill, luck and some friendly help from other scientists, artists and musicians, he was able to remove any doubts, uncertainties and misunderstandings, and convince the city to donate a piece of land directly beside the sea: a piece of land at one of the most beautiful places in Naples – Park Ville Reale. He promised to finance the zoological center himself. *Dohrn* knew exactly what he wanted. The cornerstone was laid in March 1872 and construction of the station was completed in September 1873. He and his father paid for two-thirds of the construction costs. The remainder was financed by loans from friends. Although the center had just opened its doors, the first scientists headed to Naples in September 1873. The official inauguration was on April 14, 1875 and *Anton Dohrn* signed the contract with the City of Naples.

Anton Dohrn's idea of independence

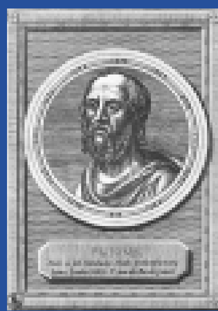
In order to increase the internationality of the center, and to ensure the economic – and therefore political – independence and freedom of research, *Anton Dohrn* introduced a series of innovative measures to finance projects. The system for renting work and research space deserves to be mentioned first. For an annual fee, partners such as universities, governments, private institutions, and even individuals were permitted to send a scientist to Naples for one year. Everything needed for unlimited research was available. Scientists could even use the knowledge of station employees. Everyone was free to pursue their projects and ideas. The fast and free exchange of ideas, methods, techniques and instruments, as well as the contact between scientists from different cultures, was decisive for the success of the system. In 1890, for example, 15 countries rented 36 tables for one year. More than 2,200 scientists from Europe and America had worked at the center by the time of *Dohrn*'s death in 1909.

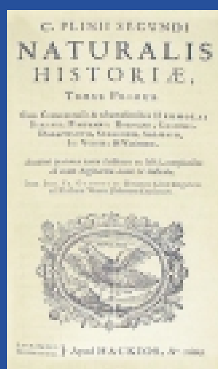
Internationality increased as a result of scientific publications. These included Notes from the Zoological Station in Naples (1879-1915), which later became the Pubblicazioni della Stazione Zoologica di Napoli (1924-1978) and has appeared as Marine Ecology since 1980. The Zoological Annual Report (1880-1915) also appeared for a short time. The Fauna and Flora of the Gulf of Naples monograph is still considered an outstanding work today.

The station's technical setup

The station has always provided scientists with state-of-the-art research equipment which was acquired either as a gift or at a very low price. The latest developments from Ca*rl Zeiss* were used, tested and presented to the guest scientists. *Ernst Abbe*, one of *Anton Dohrn*'s few close friends made it possible for the station to purchase Zeiss microscopes and other optical instruments at cut-rate prices. Station employees not only assisted in the optimization of the instruments, but also aided in distribution to the international science community. Employees and guest scientists constantly improved the scientific methods, techniques and instruments provided to the station.

Gaius Plinius Secundus, better known as *Pliny the Elder* (Latin: *Plinius maior*), an ancient author and scientist, is best known for his scientific work Naturalis Historia. He was born around 23 A. D. in Novum Comum and died on August 24, 79, in Stabiae. The Naturalis Historia (occasionally Historia Naturalis) comprises a comprehensive encyclopedia of natural sciences and research. It is the oldest known complete systematic encyclopedia. The Naturalis Historia consists of 37 books with a total of 2,493 chapters. The bibliography cites almost 500 authors, including 100 primary and almost 400 secondary sources.

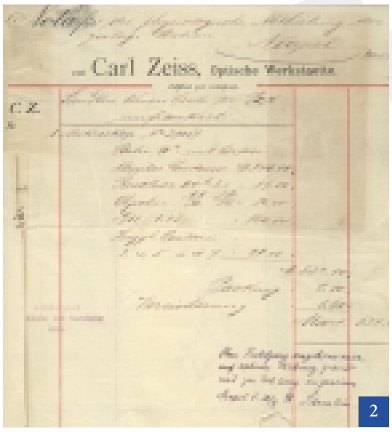




Well-known visitors

The zoological station has never had its own research project. The structure of the center always reflected the interests of its guests. According to statements by *Theodor Boveri*, *Dohrn* always had an eye open for the importance of the different scientific aspects and their interaction in the overall scheme of things. This was the only way to attract the best scientists of the time to Naples.

Nobel Prize winner *Fridtjof Nansen* was accepted by *Dohrn* in 1886 although he did not have a financial agreement with Norway. *Nansen* "found" a new field of interest: hotly debated by physiologists and histologists at the time, the relationship between ganglion cells and nerve fibers, the nature of nerve impulses and brain functions at a cellular level later became a traditional field of interest. A visit by *Robert Koch* to Naples in 1887 convinced *Dohrn* of the necessity of establishing a bacteriological laboratory. Developmental biology examinations on sea urchins were first conducted by *Theodor Boveri* in 1889 and later by *Otto Warburg*.


Carl Zeiss, Optische Werkstätte

C. Z.

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Fig. 2:
Delivery note/invoice for **Microscope Stand IV[a] No. 29057** from April 20, 1898.

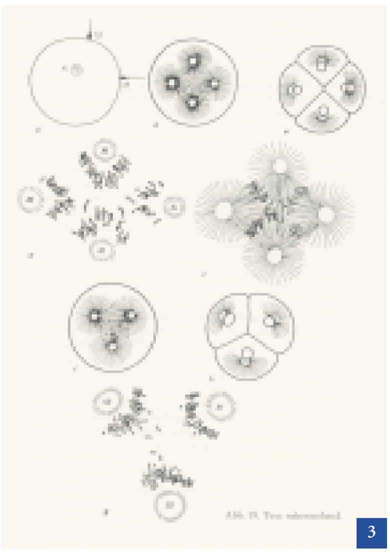
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Fig. 3:
Theodor Boveri (1862-1915): the development of doubly (di-sperm) fertilized sea urchin eggs.

Art and culture in a scientific facility

The significance of the zoological station extends far beyond pure scientific aspects. It is also known for its humanitarian values and its cultural climate. For the majority of the many guest scientists, the "Naples experiment" was an impressive mixture of new research, human experience, acquiring new methods and the exchange of ideas and cultural differences. The zoological station is the only institution in the world where science, art and music were integral elements of a unique project, the complementary halves of a dream, from the beginning. The architectural design and the technical-scientific equipment are a perfect match. Art and music were an essential element of cultural life in the 19th century. *Dohrn* wrote to *E. B Wilson* in 1900: "Phylogeny is a subtle thing. It requires not only the analytical powers of the researcher, but also the constructive imagination of the artist. Both must balance each other out, otherwise it does not succeed."

The Stazione Zoologica organism

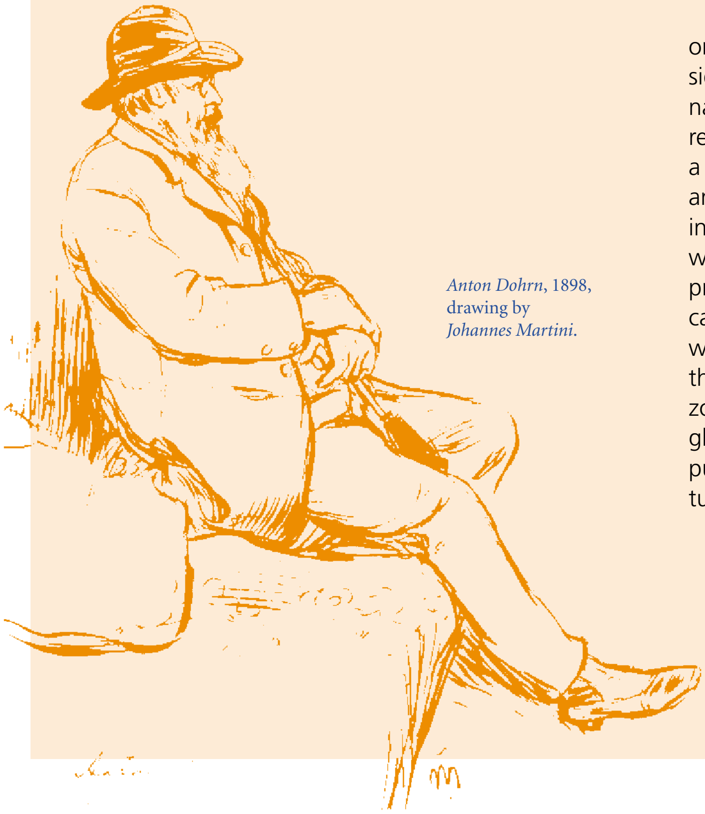
To this day, many complementary facts contribute to the uniqueness of the station: the high level of scientific activity, the active and constant exchange of information with the international scientific community, the flexible organizational structure and the associated independence of political and academic institutions, the incomparable library, the availability of state-of-the-art instruments, the cultural atmosphere and the creative dialogue between different cultures. Tradition and innovation have merged right from the beginning of the station and enabled the Stazione Zoologica "organism" to survive until now. The zoological station has been officially called "Stazione Zoologica Anton Dohrn" since 1982 and has almost 300 employees.

www.szn.it

Felix Anton Dohrn

***Anton Dohrn* founded the zoological station in Naples in 1870. For decades it was the leading international center for marine research.**

Anton Dohrn was a zoologist and one of the first outstanding researchers of phylogeny. He came from a well-to-do family in the German city of Stettin. In his early childhood, he learned that art and science coexist and interact: his father *Carl August* (1806-1892) corresponded with artists, poets and scientists such as *Alexander von Humboldt* and *Felix Mendelsohn*. His children were required to "know their Goethe", be knowledgeable about music and share his passion for science.

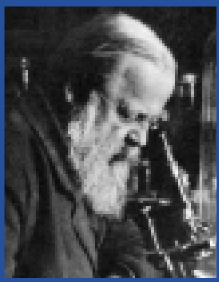


Anton Dohrn, 1898, drawing by *Johannes Martini*.

Dohrn studied in Königsberg, Bonn and Jena under *Rudolf Virchow*, *Ernst Haeckel* and *Carl Gegenbaur*. Following his studies in medicine and zoology, he became interested in the theories of *Darwin*. In 1870, he founded the zoological station for the research of marine fauna in Naples, Italy, one of the first marine research centers. He also studied the phylogeny of arthropods based on embryological and comparable anatomical data. Building on his insights, he was the first to suggest that vertebrates evolved from annelids. Furthermore, he described the "principle of the change of functions".

Dohrn earned his doctorate in 1865 in Breslau. He qualified as a lecturer in 1868 in Jena and taught zoology until 1870. From 1874 until his death, he was director of the marine research station in Naples, Italy (Stazione Zoologica di Napoli). In 1874 he married 16 year old Marie de Baranowska.

Despite his nationality and cultural origins, *Anton Dohrn* received considerable support from the British natural science tradition during the realization of his dream of founding a marine biology laboratory. At the annual meeting of the British society in 1870 in Liverpool, a committee was founded with the intention of promoting the foundation of zoological stations in different regions of the world. In fact, it was this committee that increased the fame of *Dohrn*'s zoological station in Naples in the English-speaking world with regularly published reports and articles in Nature.



Felix Anton Dohrn

Born December 29, 1840,
in Stettin,
Died September 26, 1909,
in Munich

"...not only that *Abbe* provided new instruments at a very low price, or even donated them, he also received suggestions from there, the control of the practice, the critical thoughts of experience. The station was also a place where foreign researchers were introduced to and acquired Zeiss equipment, and then announced the splendor of superior German workmanship in their home countries. The station was almost a type of ideal export warehouse and *Dohrn* was delighted to write to *Abbe* that *Balfour* acquired this apparatus and he wants one for everyone..."

Theodor Heuss was friends with *Dohrn*'s son *Boguslav* who, on the 100th birthday of the great natural scientist in 1940, requested that Heuss write a comprehensive summary of the life work of *Anton Dohrn*.

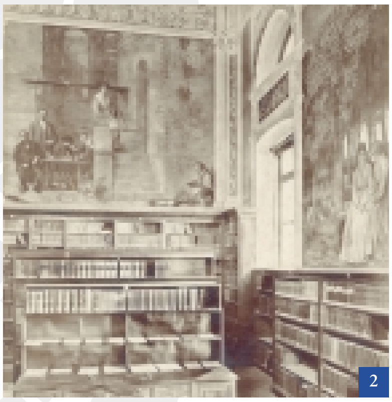
From "*Anton Dohrn*: A Life for Science"
by *Theodor Heuss* (1940)

Fig. 1:
View of the hall of frescoes at the Stazione Zoologica *Anton Dohrn*.

Fig. 2:
Desk in front of the east wall of the hall of frescoes with the “La Pergola” fresco.

The Hall of Frescoes

An unexpected treasure is hidden above the aquarium and between the labs, technical equipment and offices at the Zoological Station in Naples: the Hall of Frescos, a room *Anton Dohrn* dedicated to music and entertainment.



Two German artists, *Hans von Marées*, and sculptor and architect *Adolf von Hildebrand*, decorated it with a fresco cycle that plays a unique role in the history of 19th century art.

Hans von Marées (1837-1887) was one of the most influential German artists in the second half of the 19th century. He developed an idealistic style of painting with clarity of form focused on people. As a painter he was attracted to the world of the antiques. As an art theoretician, he worked together with *Adolf von Hildebrand* (1847-1921), the leading sculptor of his time, on the theory of pure visibility.

Following his studies and training in Berlin (1853-1855) and Munich (from 1857), and travels to Italy, Spain and France (1864-1866), *Marées* completed the frescoes in Naples which represent a high point of his work. They are the result of his meeting with friends of *Anton Dohrn*, with the world of the antiques and the sunny life on the Mediterranean.

Hilderbrand studied in Nuremburg and Munich. In 1867 he accompanied his teacher, *von Zumbusch*, to Rome. From 1872 to 1897, he lived in Florence and focused his work on the sculpture of the Italian Renaissance. With his marked tectonic talent, he created fountains and monuments.

Christiane Groeben, *groeben@szn.it*
www.szn.it

Bella Napoli

During his trip to Italy in 1786, *Johann Wolfgang von Goethe* also made a stop in Naples: "Everyone is on the street, sitting in the sun, as long as it shines. The Neapolitans believe they are living in paradise," he wrote in February 1787.

Naples is well known, beloved and popular and attracts many visitors. It is a city with its own character, a city of enchantment, entrapping everyone in its spell with the beauty of the sea, the magic of history, the extraordinary architecture and its friendly people.

The city was founded sometime in the 8th century B. C., most likely by inhabitants of the Greek Cumae colony. In the 17th century, Naples boasted 300,000 citizens, making it the second largest European city after London. Today, Naples (Greek: nea polis: New City, Italian: Napoli) is the third largest city in Italy after Rome and Milan, and is the largest city in southern Italy. It is the capital of the Campania region. The city currently has approximately one million inhabitants; together with the suburbs around three million. It is situated halfway between Mount Vesuvius and another volcanic region, the Campi Flegrei (Phlegraean Fields) on the Gulf of Naples.

Science quickly found a home in the city: in 1224, *Friedrich II von Hohenstaufen* founded the University of Naples. For some, it is the loudest, most polluted and chaotic city; for others it is the most beautiful and lively. Five and six story apartment buildings existed as early as the 16th century. It was the largest city in Europe and space was at a premium. Scholars came to the city at all times to revel in its artistic splendor.

Naples is considered the birthplace of pizza. The recipe for a margherita has remained unchanged since the 16th century: topped with only tomato sauce, mozzarella and basil, the pizzaiolo places the culinary delight into the wood-burning brick oven. Three minutes later, it is ready to eat and the next one takes its place.

details

See Naples and die

"See Naples and die," is an expression often used when someone is completely mesmerized by the beauty of something they have seen.
It is based on the Italian saying "Vedi Napoli e poi muori".
In Italian it has a funny double meaning. It is a play on words with the name of a city, "Muori", that is located just beyond Naples which can only be seen upon leaving, and the verb form "muori", meaning to die. Enjoying a favorable climate, Naples is a special place: the Italians consider it a piece of heaven on earth, while the Germans and French saw it as the center of sorcery and black magic until the 19th century.

Fig. 1:
Menu from 1907 with the Stazione Zoologica.

Fig. 2:
The Stazione Zoologica around 1873.

The Zebra Fish as a Model Organism for

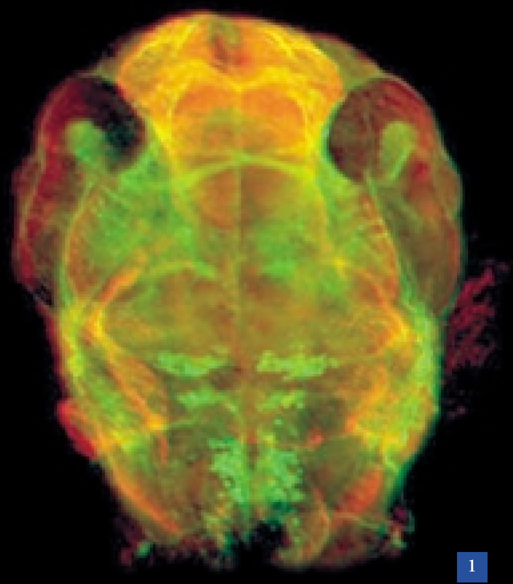


Fig. 1:
3-day-old zebra fish in red and green fluorescence: antibody labeled axon populations and GFP motor neurons **NeoLumar S 1.5x** 150x magnification.

Specimen:
Prof. M. Bastmeyer, Dr. M. Marx, Friedrich Schiller University Jena, Germany.

Photo:
Dr. M. Zölffel, Carl Zeiss.

The zebra fish (danio rerio) is very easy to breed, requiring only three days to develop from an egg into a free-swimming larva. As the zebra fish remains transparent throughout its entire developmental period, it is an ideal organism for examinations of vertebrate organ development under the microscope. Examinations on zebra fish models lead to a better understanding of organ development of "man the vertebrate" and his diseases.

In cancer research

The zebra fish has already replaced the well-established model organism – the mouse – in cancer research: the mouse has a longer developmental cycle and the ontogenesis stages are less translucent than in the zebra fish. Until now, mice were used that develop cancer cells (e. g. leukemia) caused by genetic mutations. These cells are transfected with GFP using molecular biology techniques. The extremely powerful **SteREO Lumar.V12** fluorescence stereo microscope enables scientists to optimally view and research the progression of the disease.

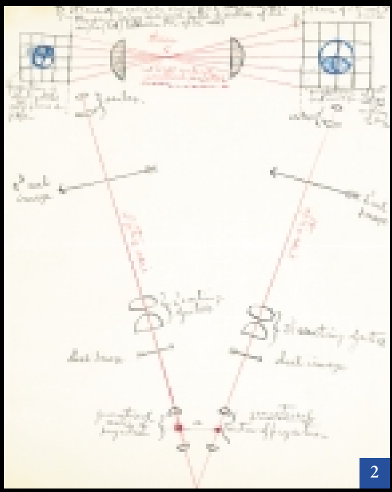
For retinal diseases

Degenerative changes to the retina are genetic diseases in people that cause photosensitive receptor cells to die. This is one of the most common causes of blindness in humans. Zebra fish suffer from similar genetic eye diseases. The development of the fish eye and the activation of the nerve fibers in the zebra fish's eye are very similar to the human eye. The short development period of the zebra fish permits observation of these degenerative retinal processes with the **SteREO Discovery.V12** and **Lumar.V12** high-resolution stereomicroscopes as if in slow motion, thus enabling better research into the cause of blindness and possible treatment methods. The eyesight of zebra fish larva is examined using a special test. The stereomicroscope makes it possible to examine the developing eyes of blind as well as normally sighted fish and also compare them to each other.

The First Stereomicroscope Came from Jena

It all started at the Weimar Courtyard in Jena in 1892. Under the leadership of *Ernst Abbe* and developmental biologist *Ernst Haeckel*, this was the regular meeting point for science employees from the university and the Zeiss Works. At one of these gatherings, American zoologist *Horatio S. Greenough* expressed his wish for a "binocular microscope that renders true 3D images."

Carl Zeiss set to work on fulfilling this wish and constructed the first industrially manufactured stereomicroscope at the end of 1897 – the Greenough double microscope.



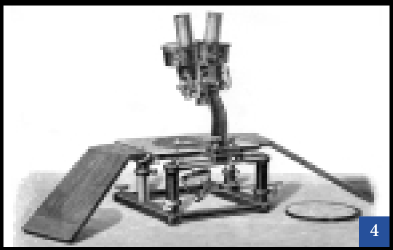


Fig. 2:
Sketch of *Greenough*'s idea for a binocular microscope that renders true 3D images.

Fig. 3:
The Greenough double microscope from Carl Zeiss.

Fig. 4:
Dissecting microscope following the design of *Paul Mayer*.

Fig. 5:
SteREO Lumar.V12.

It had two tubes tilted towards each other at a convergence angle of 14 degrees with objective lenses at the lower ends. Carl Zeiss ensured that the axes on the two lenses were in one plane, i.e. they actually intersected. Porro erecting prisms were used between the lenses and the eyepieces. These prisms ensure that images are upright and unreversed, i. e. the images can be viewed as they are in reality. This was also a demand from Greenough and the guarantee of a true orthoscopic impression when looking through the stereomicroscope, or dissecting microscope as it was called back then.

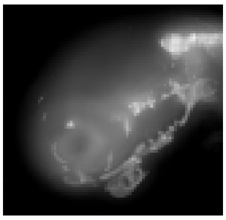
The invention of the stereomicroscope at Carl Zeiss was an essential contribution to the rapid upswing in the still young developmental and marine biology: the Greenough stereomicroscope enabled exact research into the lifecycle of many invertebrates (e. g. polyps, bristle worms, snails) for the first time. It also contributed considerably to the most important discoveries in developmental biology and genetics of the early 20th century (*Wilhelm Roux*, *Hans Spemann*, *Thomas Hunt Morgan*).

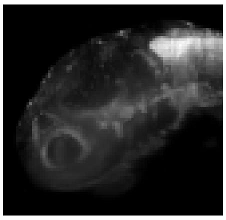
Today, the **SteREO Lumar. V12** is setting new standards for the fluorescence microscope examination of complex issues related to developmental genetics in biological and clinical research.

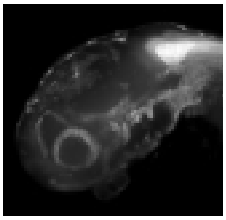
[*www.zeiss.de/micro*]

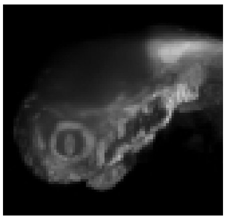
The new high-tech microscope procedure, SPIM (Selective Plane Illumination Microscopy), permits fascinating insights into living organisms and makes it possible to observe processes – even those in deep-lying tissue layers. The new development has its roots in the theta microscope from the 1990s which was designed for examinations of large specimens with high 3D resolution. The fundamental light microscopy principle is fluorescence detection at an angle of 90° relative to the illumination axis. SPIM now unites the technology of the targeted illuminated plane in the specimen with the theta principle, thus permitting optical cutting.

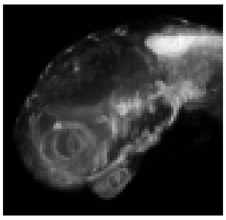
SPIM – A New Microscope Procedure



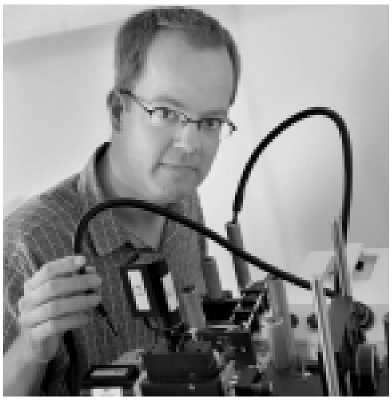




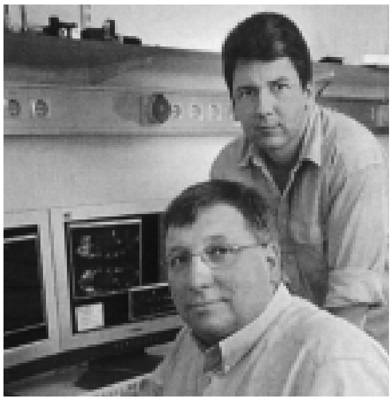




In the SPIM procedure, the specimen is no longer positioned on the microscope slide as usual, but in a liquid-filled specimen chamber which allows it to remain viable during the measurement. Rotating the specimen changes the illumination and detection axes relative to the specimen, permitting better detection of previously hidden or covered areas. Complex development processes such as formation of the eyes and brains of fish embryos or other specimens can be observed and documented.



Jan Huisken,
European Molecular
Biology Laboratory (EMBL).



Ernst Stelzer (front)
and Jim Swoger,
European Molecular
Biology Laboratory (EMBL).

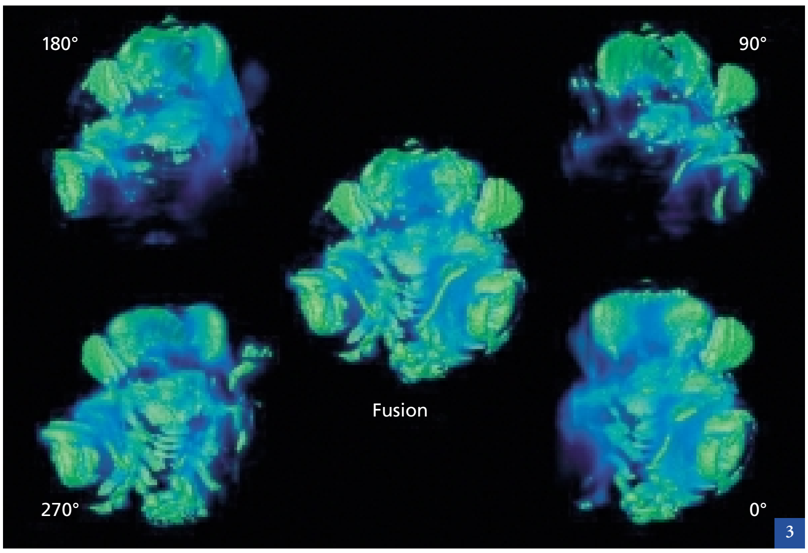
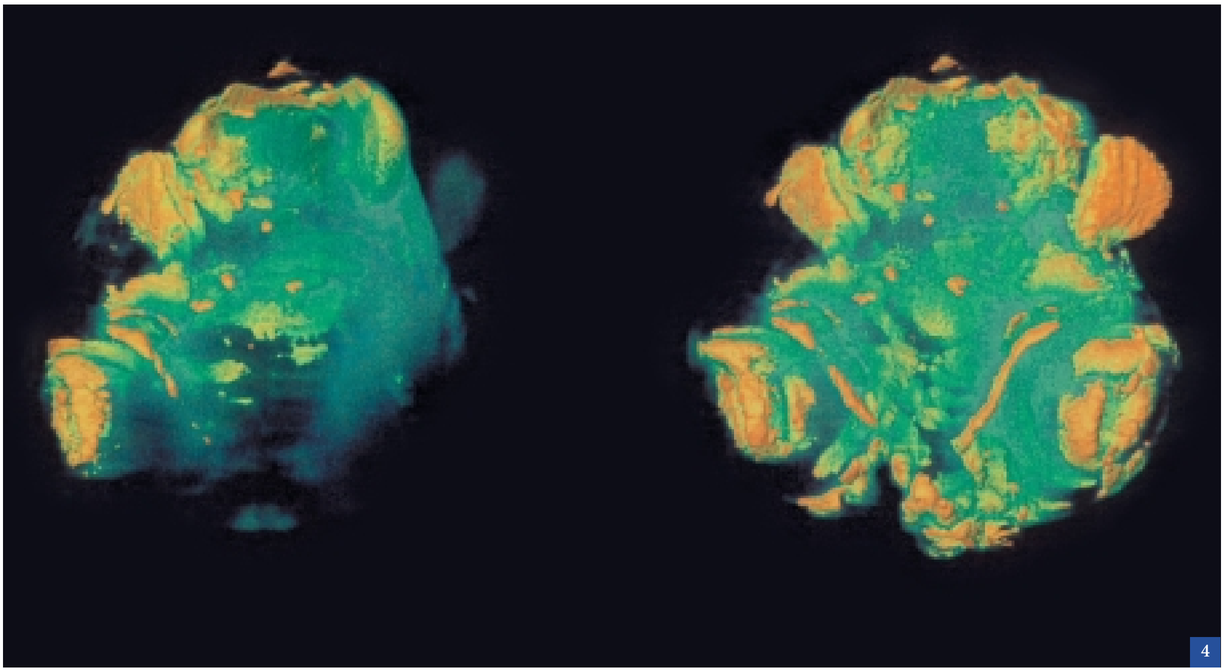


Fig. 1:
Medaka fish.

Fig. 2:
Pictures of Medaka fish embryos, head region, different perspectives. The last (or fifth) picture in a series shows the fusion of the data sets.

Fig. 3:
3D display of the picture series from Fig. 2. Display in various exposure angles. The center image shows a section through the fusion of the data set.



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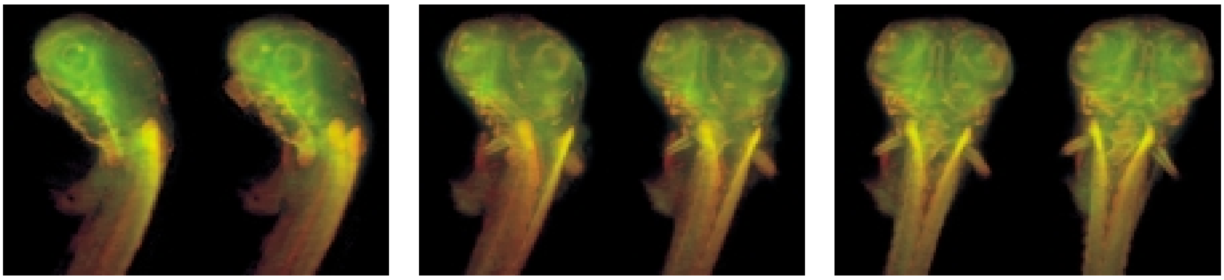
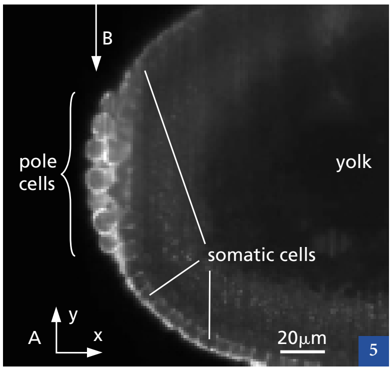
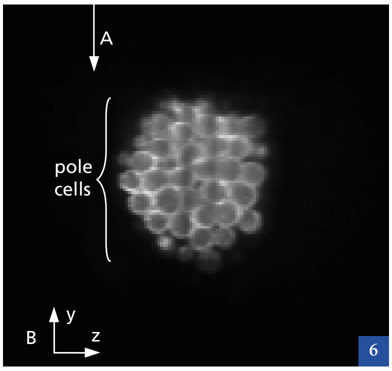
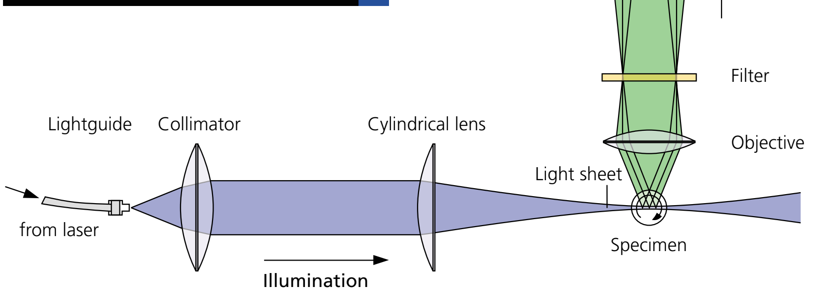


In the SPIM method, which is based on the theta principle, the specimen is illuminated from the side and not from above through the objective lens as before. With the traditional configuration, researchers obtained excellent resolution in the microscope slide, but the resolution perpendicular to the slide is worse. With the SPIM procedure, an extremely thin “light sheet” is generated in the specimen so that an optical sectional image is created. A special feature of SPIM is that only one plane is illuminated and observed at a time unlike in conventional or confocal microscopes in which the entire specimen is exposed for each plane. For example, if 100 planes have to be recorded, the radiation exposure to the specimen is reduced to 1% of what was previously required. This advantage can be used to significantly increase the period of observation. The sectional images can be recorded from several sides by moving or rotating the specimen. This makes hidden regions visible, allowing researchers to delve deeper into the tissue. The entire process is very fast and the image information generated can be pieced together using appropriate software to form a high-resolution 3D image. It is the perfect complement to confocal and multiphoton 3D imaging systems.

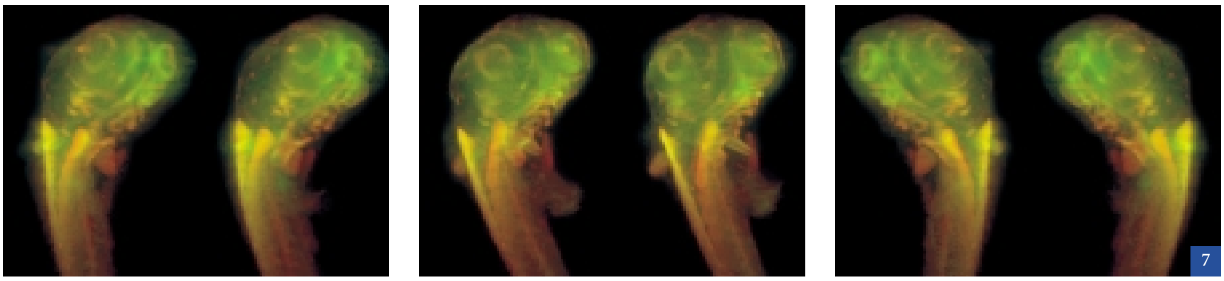
www.embl.de/ExternalInfo/stelzer
www.zeiss.de/micro







SPIM Principle:
beam path and optical components.



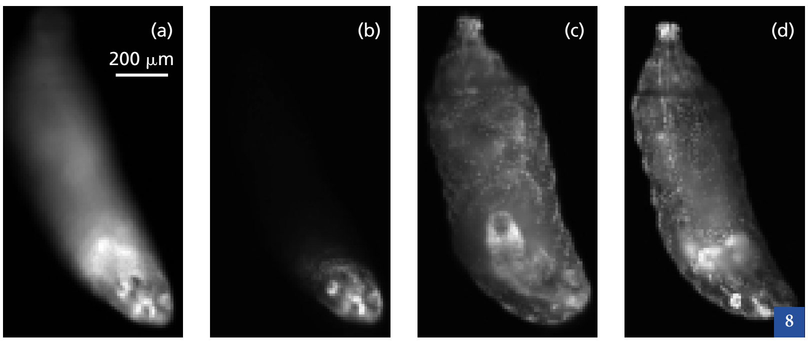


Fig. 4:
Three-dimensional image rendition of the picture series from Fig. 5: left 180°, right fusion.

Fig. 5:
Drosophila embryo, pole cells, x-y plane.

Fig. 6:
Drosophila embryo, pole cells, y-z plane.

Fig. 7:
Picture series of Medaka fish embryos from various perspectives.

Fig. 8:
Drosophila larva:
(a) Traditional image
(b) Theta illumination of a single plane
(c) Image stack
(d) Image stack rotated 180° around the vertical axis.

The Scourge of Back Pain – Treatment Methods and Innovations

Fig. 1:
The ergonomic design of the surgical microscope allows the surgeon to work in an extremely comfortable position over longer periods.

Back pain is among the most common health complaints in industrialized countries. More than 30 million people in Germany alone suffer from chronic or occasional back pain – tense muscles in the neck and shoulder regions, pinched nerves or dislocated vertebra.

Over the long term, spinal pain can considerably affect the quality of life, and not just the elderly suffer. Signs of wear on the spinal column can already be seen from the age of 30 and onwards. The rise in the number of patients with spinal pain and the simultaneous cost pressures in healthcare are leading to numerous innovations in treatment methods.

Carl Zeiss recently discussed this with *Dr. H. Michael Mayer*, one of the leading spine surgeons and medical director at the Orthozentrum in Munich.

Dr. Mayer, what developments and changes have you noticed in recent years concerning spine diseases?

The range of spine diseases has changed so that now primarily older people have to undergo surgery on the spine. There are many different types of disease that occur mainly in old age, such as a narrowing of the spinal canal, degenerative scoliosis and constriction of the nerve canals. Increasing life expectancy has resulted in many more patients with symptoms of wear on the spine who require treatment and surgery than in the past.

What is the significance of this rise in the number of patients for spinal surgery and what are the consequences?

As a result of this development, spinal surgery is becoming more and more important, leading to a constant increase in the surgical possibilities. With new techniques, e. g. artificial discs or minimally invasive surgery, it is now possible to intervene at a much earlier stage with innovative methods that are designed to preserve the mobility and dynamics of the spine, particularly with symptoms of wear.

Considering the cost pressures facing the healthcare sector, what opportunities and innovations are particularly important from your point of view?

Any procedure that is considered minimally invasive is particularly important, i. e. all microsurgical and endoscopic procedures. In fact, we have been using minimally invasive methods in Germany for 15 years. However, it was only after healthcare reform that the positive effects had their full impact. Patients are released earlier from the hospital, i. e. the more gentle the operation, the shorter the stay and the faster the patient can be rehabilitated.

What is required for minimally invasive surgery?

There can be no minimally invasive surgery without visualization systems. Minimally invasive surgery is only possible if optical aids are available, e. g. a surgical microscope. Through tiny incisions, these instruments pro-

Fig. 2:
The **OPMI® Vario/NC33** was developed exclusively for minimally invasive procedures on the spine.

facts

Spinal column

Combined with a complex muscle system the S-shaped spinal column not only provides the body a support beam to walk upright, but also a high degree of mobility and elasticity. The entire spinal column consists of seven cervical, twelve thoracic, five lumbar, five sacral vertebrae and the coccyx consisting of three or four vertebrae. The vertebras are separated by discs which work as a buffer, thus enabling mobility of the back. The spinal column also contains a spinal canal in which the very sensitive spinal cord is located. This connects the brain with the body's organs (peripheral nervous system).

Minimally invasive surgery

Unlike open surgery, minimally invasive techniques avoid using a large incision. Surgical instruments, e. g. a surgical microscope, require a small incision of around 2 cm. The new techniques deliver a range of advantages, including reduced pain, smaller scars and cost savings resulting from shorter hospital stays.

vide us with the necessary light and magnification – even in the depths of the thoracic and lumbar vertebrae. That is what is required. Without it, you cannot perform minimally invasive surgery.

What are the advantages of minimally invasive surgery to patients?

We have recorded lower perioperative morbidity with microsurgery, i. e. as a result of the minimally invasive access, there is less pain and blood loss, as well as shorter waiting times, hospital stays and rehabilitation periods. The techniques and instruments permit surgeons to work much more accurately and safely with fewer complications than with the naked eye.

Who else benefits from this type of spinal surgery?

Everyone involved benefits, first and foremost the patient, surgeon and the assistant. This procedure allows the surgeon to work more safely. Assistants profit because they generally see what the surgeon sees and can learn more easily through onsite teaching. Even the entire OR team benefits, including the nurses, as everyone is able to see exactly what is happening. Most of all, when you project the image onto a monitor or the wall everyone is able to see exactly what the doctor is doing. There is really no one who does not benefit one way or another.

How common is this type of operation?

Unfortunately, it is not as common as we would like. It goes without saying that microsurgery is much more common at neurosurgery centers than in orthopedic or spine trauma centers. Going from the number of signups for the courses that we conduct here in cooperation with Zeiss and the feedback from the many international guests at our hospital, it is obvious that it is not very widespread and there is a very high need for training.

What can be done so that more doctors, clinics and patients can benefit?

It is really just a lot of hard legwork. On the one hand, surgeons have to convince other surgeons of the benefits of microsurgery and minimally invasive surgery. This works best in the OR where they can see up close how this type of surgery works. On the other hand, there must be courses available, preferably cadaver workshops, in which the participants can actually practice these techniques and see for themselves how advantageous they really are. I don't know anyone that has looked through a microscope, or has operated with a microscope, and then later returned to traditional surgery.

How do you think spinal surgery will develop?

Spine surgery is a relatively crisis-proof, specialized field which will continue to grow. Within the surgical disciplines, it is one of the most dynamically growing specialized fields. This can be seen indirectly in the growth rates of the medical technology industry, the number of spine implants sold per year and the new procedures being developed. Further growth is expected, primarily because more and more surgeons are looking to sub-specialize. If you look at the number of knee specialists and hip specialists around the world, then look at the number of spinal column specialists, you can see that there is a significant gap.

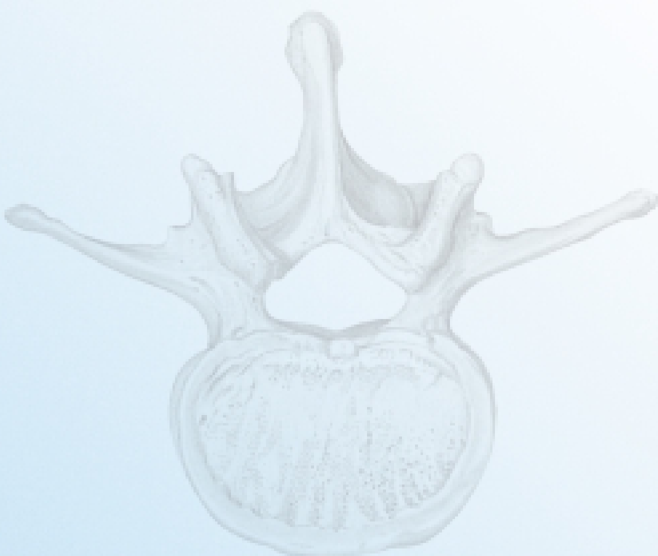
What do you envision for the future?

It goes without saying that surgeons want still more flexibility. The image of the surgical incision should be visible regardless of the position of the surgeon's head or the position of the monitor.

It is possible to virtually project digitized images using head-mounted displays, in eyeglasses or even in space (augmented reality). Augmented reality uses certain technology to create a virtual, 3D image in space. This technology is currently used primarily in advertising films, but it is theoretically possible to use it for surgery.

For example, you have a patient and look at the body's interior through a certain opening. If you could project what you see inside to the surface of the body, it would be as if you were working with a normal open wound. You work in the direction you are looking and the interior of the body is projected on the patient's skin or onto a monitor. This is, of course, something for the future that I think would increase comfort for the surgeon as well as the acceptance of minimally invasive surgery. It would be an ideal surgical technique.

Dr. Mayer, thank you very much for an interesting and informative interview.



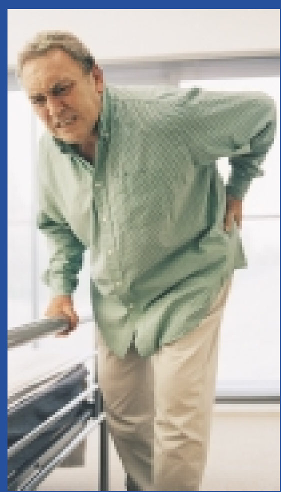
facts

Intervertebral disc

The intervertebral discs work as a buffer between each vertebra and maintain their spacing. The plasticity of the discs enables them to reduce the stress that affects the back caused by movement and strong forces. With increasing age, the fluidity of the disc deteriorates, thus reducing its elasticity. Nowadays, it is possible to implant artificial discs when severe signs of wear appear. Biocompatible disc prostheses implanted between the vertebra help to restore the natural anatomy of the body while preserving the mobility of the back.

Constriction of the spinal canal

Spinal canal stenosis is a narrowing of the spinal canal. Various diseases can appear depending on where the stenosis is. Most of them are associated with severe pain, organic malfunctions and numbness in the extremities.



Spinal canal stenosis can also be congenital. It can also result from bone diseases, injuries or degenerative changes, through tumors on rare occasions. Discs degenerate considerably faster as the result of improper posture and biomechanical stress. Discs and tissue narrow the spinal canal. Spinal fluid builds up causing painful irritation of the spinal cord.

ZEISS in the Center for Book Preservation

Books stacked pile-high, plans and files as far as the eye can see! Diffusing the air with the delicate mixture of smells – old leather, linen, bookbinding glue, paper, printer's ink and patina – that usually greets experts when they enter historic libraries and archives. However, we are not inside one of those venerable old buildings; we are actually in an extremely modern building north of Leipzig, the "Center for Book Preservation" (ZFB).

The ZFB originated from the two central archives, the Deutsche Bücherei and the Deutsche Bibliothek, which were amalgamated in Leipzig after the reunification of Germany. Since 1998, it has offered, as an independent institution, comprehensive services for the expert preservation of the valuable collections of books held in libraries, archives and museums. The center is able to draw on what may well be unique experience in the area of paper restoration and combines this knowledge with research into and the development of new methods for preserving large quantities of books efficiently and rationally, a service for which there is considerable demand worldwide.

The work of the ZFB is known internationally among experts in this field. In general, however, the center carries out its work and services largely outside the public domain. This changed suddenly in the fall of 2004 when the ZFB contributed, using methods that it had developed, to saving one of the most valuable and historically irreplaceable collections of books to have been preserved in Germany. What happened?

On the night of September 2, 2004, a devastating fire destroyed large parts of the historic Herzogin Anna Amalia Library building in Weimar. Residents from that part of the town, employees and several hundred spontaneous helpers formed a human chain to save more than half of the treasures – autographs and books – from the burning Unesco world-heritage site. Around 50,000 volumes from the library, passed from hand to hand, were rescued unscathed in this way. A further 30,000 escaped the inferno, damaged to a greater or lesser extent.

First deep-frozen, then dried and saved

The latter, already singed by the fire and soaked by the water used to extinguish it, were given an initial emergency home at the ZFB. Here they were sorted and classified according to the extent of the damage: from Group One, virtually intact, to Group Six, almost completely destroyed. The treatment began with temporary storage in large cold chambers. Here, wrapped in muslin or fleece, and at a temperature of minus 20 degrees Celsius, each soaking wet book was transformed within

a short time into a solid block of ice. This prevented any further distortion and stopped the spread of mold spores; what is more, it allowed the center to gain valuable time. Although the institute worked in three shifts, the careful and expert damage limitation process needed time more than anything else. Who would expect to be faced with tens of thousands of books, the survival of which hung in the balance from one hour to the next?

In the second stage of the process, the books were freeze-dried – a method for which the ZFB has developed its own system for extracting the moisture from the books. If they were simply left to dry out naturally, the inks, colors and glues would run. The pages would stick together and become distorted and brittle. Additional, even more harmful problems would be added to the existing damage. Instead of this, freeze-drying prevents the moisture in the book block from thawing again in the conventional sense once it has turned to ice. It ensures that the ice escapes as a gas, that is to say, in a dry form.

A quantity of books weighing up to a tonne is locked in a low-pressure chamber, the internal temperature of the cooling pipes in the condenser is lowered to minus 196 degrees Celsius and the air pressure, which is normally around 1,000 millibars, is reduced to below 6 millibars. Rather than melting, under these conditions the ice begins to "evaporate". In this consistency it can simply be removed by suction. Normal air pressure is restored in the chamber and the temperature is gradually raised to plus 20 degrees Celsius. Depending on the number and format of the books stored, the treatment process is often finished after only 3 days or fewer. The books are thoroughly dried out.

The last stage of the treatment process is the manual removal of any remaining dirt. Below the suction systems of the work cubicles, installed in rows, ZFB employees turned the pages one at a time and, using paintbrushes and fine brushes, carefully removed the mixture of dust originating from the fire ashes and lime plaster that the water used to extinguish the fire had washed from the shelves, ceilings and walls of the burning rooms into the books. With this after-care process, the ZFB's rescue operation and task were complete.

The patients treated in this way have now arrived back in Weimar, where the experts and restorers of the Anna-Amalia library are faced with the difficult decision of which further rehabilitation measures to carry out and with what priority.

One thing is for sure: it will take many years and require considerable financial support before the unique, historic, cultural heritage that this collection represents is open once again to academics and the public. And, even then, the evidence of the fire will never be completely erased.

Fig. 1:
Damaged books from the Herzogin Anna Amalia Library in Weimar.

Fig. 2:
Mass-deacidification in which the books are soaked in an alkaline, non-aqueous solution. The treatment capacity totals over 100 tons a year.

Acid corrosion, the greatest concern and threat

After this spectacular emergency operation, the ZFB returned to its "normal fields of activity" in the area of book preservation, where rescues following fire damage actually, or rather thankfully, form the exception.

It is not bookworms, bark beetles, mold or improper handling that present the main threat to books as historic cultural possessions. When asked about the main issues in book preservation, *Dr. Manfred Anders*, CEO of the ZFB, named acid corrosion, which already threatens a good two thirds of all historically and culturally important collections of books, newspapers and documents worldwide, as the greatest problem.

As a result of the growing demand for paper, experiments began using all kinds of ingredients as early as the 17th and 18th centuries to make the diminishing source materials for paper manufacture go further, and to improve the glue and quality of finish. Today it is the acids in the glue which, combined with environmental influences, destroy the paper. They degrade the fibrous substances and cellulose which guarantee the mechanical stability of the books. The pages become fragile and brittle. This aging process is autocatalytic, meaning that it accelerates itself. Only efficient mass-deacidification is able to counteract this deterioration. The ZFB has developed what it calls the Papersave process for this purpose. During this process, books are saturated in an alkaline, non-aqueous solution and deacidified. In this way their life expectancy is extended by a factor of 4 to 5. Although mass-deacidification (Papersave process) as a conservation treatment is able to delay damage, it is unable to reverse it. In addition, therefore, the ZFB also deals with all kinds of restoration measures: correcting ink corrosion, carrying out paper stabilization, fighting against mold and performing all forms of damage limitation – from recording the problem to remedying it – to the extent that these measures are possible on the basis of the latest research, findings and techniques. This has achieved amazing results – a scarcely decipherable hand-written musical notation by Beethoven, the virtually disintegrated first edition of a Luther bible as well as the plans for a Schinkel building drawn by the architect himself have been protected against further decay.

Naturally, all decisions regarding how and with which methods the various deterioration processes can best be countered are preceded by thorough analyses of the actual and aging condition – using NIR spectroscopy, for example. It almost goes without saying, therefore, that Zeiss is present in the Center for Book Preservation, acting in some ways as a partner, with instruments for expert scientific examination, measurement and determination of methodology.

But why go to all this effort when everything can be recorded on microfilm and digitized, a task that, inci-

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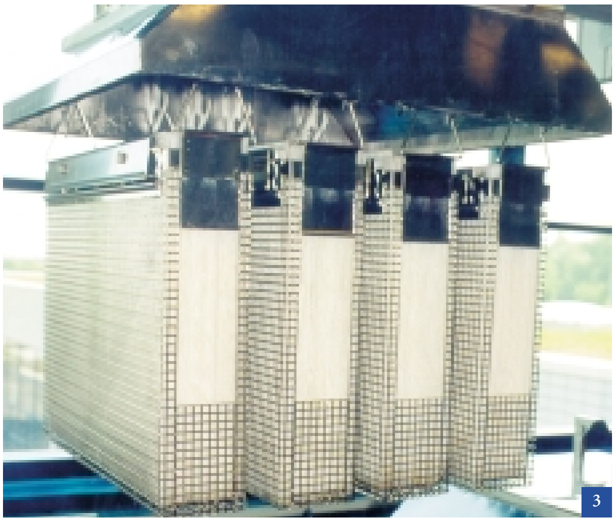

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Fig. 3:
Aqueous fungicide treatment to kill mildew.

Fig. 4:
Removal of ash and lime.

Fig. 5:
Paper deterioration caused by acid.

dentally, is usually carried out in the ZFB in parallel to the restoration measures?

Heritage is an ongoing duty

Viewing words, sentences, images and drawings on a screen alone is just not the same as still being able to hold in your hand the pieces of paper on which, centuries ago, a good proportion of what forms the basis of our history and culture today was written down, drawn or printed. In any case, the passage of time and events have already destroyed or ruined much of this. What still remains should not be seen as a problem that we have inherited but as a duty, and the effort of preserving it must be regarded as being worthwhile, even for our own sakes.

Manfred Schindler
manfred.schindler@msw.de

details

Microscopy

Books have many different enemies: mice, bookworms, light, micro-organisms and acid. Recording the damage that a book has suffered always forms the starting point of a comprehensive strategy for book preservation. Microscopes, especially stereomicroscopes, are frequently used in the restoration of books to analyze the book's "state of health" before work begins on it: a record is made of the book materials and images of the damage.

Liposcelis divinatorius, for example, is a minute, wingless type of book louse that lives between the pages of books. It prefers to live in a moist, warm environment and feeds on mildew, starch, organic glue, fabric, paper, silk and leather. Its natural predator is the book scorpion.

Discoloration of paper and parchment is usually the sign of an infestation by micro-organisms (mildew, bacteria). These are usually single-cell organisms, which can be seen under the microscope. Dye stuffs, excreted by the micro-organisms, turn paper green, brown, red, yellow and black, while parchment is more likely to show purple marks. These marks remain even after the perpetrator has died. However, colored spots also occur if the paper has been attacked by micro-organisms in its structure.

Carl Zeiss Archive Aids Ghanaian Project

Figs 1-5:
GansMens Clinic, Kumasi

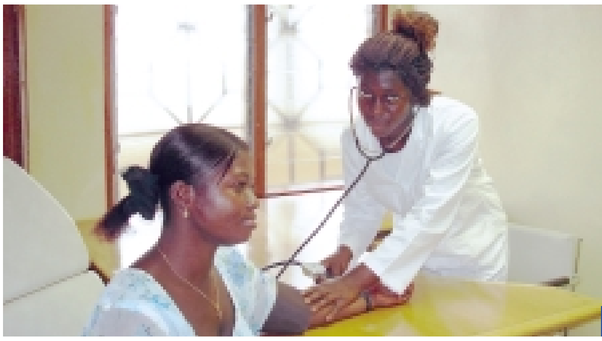
Fig. 4:
PM2K Photometer

Without the help of the well-organized archive system at Carl Zeiss AG, the laboratory at the "GansMens Clinic" in Kumasi, Ghana would not yet be complete. An ideal instrument by Ghanaian standards, an older Zeiss photometer – PM2K – was available in Vienna, but an English version of the user manual was not to be found – in Vienna or any other office. The Carl Zeiss archives were called on for help. *Dr. Dieter Brocksch*, Manager of Technical Information, was able to provide the desired manual in a short time. The photometer has been in use since April 2005 following its transport to Ghana with other medical instruments shortly before Christmas 2004.

A clinic for Ghanaians

Albert and *Monika Mensah Offei* have been working on the construction and setup of the GansMens Clinic in Kumasi using thier own financial resources since 1997. *Albert Mensah Offei* is Ghanaian and decided along with his Austrian wife to create this clinic with high quality medical service, equipment, patient care and hygiene for his fellow countrymen. It enables access to medical care, preventive care (e. g. for children, young people and pregnant women) and the creation of qualified jobs and further education of medical personnel in a region lacking sufficient medical resources.

The formal requirements for start-up were met with the completion of construction in 2003 and certification in fall 2003. The opening of the clinic's own lab followed the start of operations in early 2005 under the leadership of a general practitioner. Approximately 30 % of all patients suffer from malaria. Diarrhea, hepatitis, typhoid, diabetes, HIV and other infections are also common ailments. In addition to preventive examinations for pregnant women – anemia is very common – the clinic has a small operating room including an intensive care unit, a children's department (8 beds), 6 patient rooms (20 beds), a maternity ward with a midwife and 8 beds. The goal of the gynecologist who is also responsible for the maternity ward is to reduce the still high mortality rates of both mother and newborn. Training of high school graduates is done together with the Okomfu Anokye Teaching Hospital in Kumasi. Young



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people who are unable to finance their professional education, particularly women, use this training to increase their chances of finding a job later.

Recycling medical technology

All instruments at the GansMens Clinic have undergone extensive checks by Med Tech Plus in Vienna. The procurement of user manuals in the local language is the final link in the chain of adaptation and adjustments that has to be completed for the instruments to fit into the respective local infrastructure and continue to be used for years to come. Med Tech Plus used altered technological solutions to ensure sustainability (e. g. a microscope with a mirror for sunlight illumination and an adapter for use with car batteries for laboratory doctors who work without power. The three pillar strategy at Med Tech Plus has proven its value since 1986: recycling and ecological recycling management, meaningful job training for the long-term unemployed, repair and re-use to benefit undersupplied regions of the development cooperation.

Instruments that have been sorted out are collected and repaired. Caritas, Horizont 3000, Ökg, Global 2000 and Care are among the list of well-known partners. Many other organizations that value robust instruments adapted to the requirements of the respective countries and projects have been able to find instruments at Med Tech Plus for their health projects in Nicaragua, Cuba, Peru, Uganda, Kenya, Nigeria, Albania and the Ukraine. Adjusted for ease of use, sturdy and equipped with spare and wear parts, these "old instruments" have low operating costs and serve well in the mobile care clinic for rape victims in Bosnia, at the accident hospital in Timisoar, in the children's clinic at the Univeristy Hospital in Lugansk or in the Health Project in Ngorongoro, Tanzania – and now at the GansMens Clinic in Kumasi.

Peter Gluchi, Med Tech Plus, Vienna.
www.medtechplus.at

100 Years of Brock& Michelsen

Carl Zeiss
Exclusive Partner

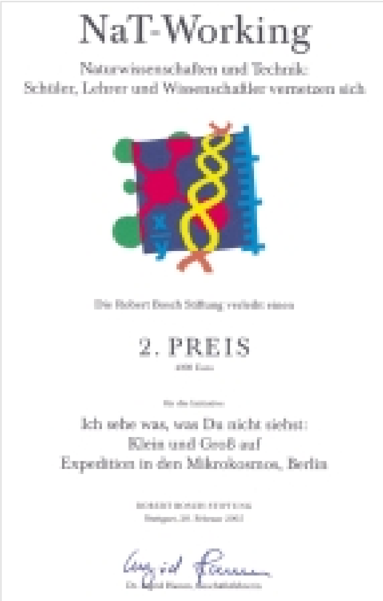
Fig. 1:
Knud Michelsen and *Peter Brock* in 1953 looking through a standard microscope.

Fig. 2:
Festivities for the 100th anniversary (left to right: *Dr. Norbert Gorny, Gregers Brock* and *Jørgen Brock*).

On April 1, 1905, a 20-year-old salesman, *Knud Michelsen*, and a 22-year-old precision mechanic, *Peter Brock*, opened P. Brock & Co. in Copenhagen. The company later became Brock & Michelsen Opto-mechanical Institute and Workshop. Having early contacts with Carl Zeiss in Jena, Brock & Michelsen became the company's general representative in Denmark in 1921, making Brock & Michelsen Carl Zeiss' longest-serving active representative outside Germany. Approximately 60 employees support products ranging from microscopes and the various medical systems to products from semiconductor production technology.

[www.brockmichelsen.dk
www.zeiss.dk]

Award for NaT Working Project



The 4th NaT Working Symposium took place at the German Cancer Research Center in Heidelberg from February 27 to March 1, 2005.

Five awards were distributed among the 60 sponsored projects. The NaT Working Project, "I see what you don't see: small and large on an expedition to the microcosm" from *Birger Neuhaus* and his team from the Carl Zeiss Microscopy Center from the Humboldt Exploratorium at the Museum of Natural History in Berlin finished second and received an award of 4,000 euros.

Fig. 1:
The overjoyed winner with *Dr. Ingrid Wünning* from the Robert Bosch Foundation, and *Karsten Schwanke*, meteorologist and television presenter.

Fig. 2:
At the exhibition booth.

details

NaT Working

The Robert Bosch Foundation initiated NaT Working. The program is intended to arouse students' interest in natural sciences and technology. One promising way of accomplishing this is to establish and maintain personal partnerships between teachers, students and scientists and engineers active in research. Internships for students and teachers in the researchers' labs, summer schools, student congresses or game-like practical projects during leisure time are among the sponsored activities. Particularly outstanding projects are presented with an award once a year.

www.bosch-stiftung.de/natworking

Humboldt Exploratorium Berlin

Exploring nature and discovering new things is the greatest motivation for scientists. The Humboldt Exploratorium offers young people the opportunity of participating in the joy of scientific discovery. The Exploratorium and Humboldt University in Berlin owe their name to *Alexander von Humboldt* – a multi-talented natural scientist who was a geologist, zoologist and botanist in one – and his brother *Wilhelm*.

www.humboldt-exploratorium.de
www.naturkundemuseum-berlin.de

Digital Pathology: MIRAX SCAN

The demands on medical diagnostics are continually increasing. Whether clinical labs, research service providers or pharmaceutical companies, time and cost pressures are high. Customers want maximum quality and growing efficiency. A large number of external factors impacts work processes in pathology today: competition amongst clinical facilities has long been a part of the picture. Borderline cases often lead to legal disputes. Everyday clinical life must ensure compliance with legal guidelines. Health authorities are increasingly demanding more from pharmaceutical research. Lab standards are becoming more challenging. To top it off, the amount of work is also increasing. High throughput is no longer the exception. Time and technology are always in high demand.

Quality and efficiency of the diagnosis

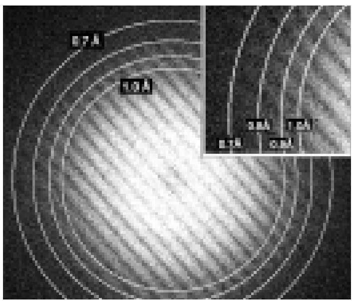
MIRAX SCAN unites optics and technology from Carl Zeiss with IBM's experience in digital archiving. The integrated systems solution for digital pathology enables absolute concentration on the essentials – the diagnosis. High-resolution digital data sets, digital slides, enhance the quality and efficiency of the evaluation of the findings. **MIRAX SCAN** automatically generates digital slides for up to 300 specimens in one run – even in uninterrupted overnight operation.
The diagnosis and report are right on the monitor which does not have to be at the same location as the scanner. The data and results are transmitted directly via the internal network or the Internet. The sections can be seen as a whole.
Immuno-histological specimens are digitized before the specimens fade. Several specimens can be observed at the same time, current and previous sections can be compared quickly and directly. The diagnosis process can also be documented on the section and can be traced at any time.
All archive data is directly available on the network: a real time savings during complex evaluation processes and when comparing different specimens. The pathological findings can be immediately integrated into the patient's electronic file and quickly accessed.
As soon as the section specimens are available, **MIRAX SCAN** does the rest with its powerful optics. The results can be seen on the monitor with the same excellence as through the microscope.

MIRAX SCAN

UHRTEM

UHRTEM, the latest generation of ultra-high resolution transmission electron microscopes from Carl Zeiss, made the breakthrough in sub-Angstrom image resolution (0.8 Angstroms, or 0.08 mm). This milestone was achieved using the newly developed 200 kV field emission **UHRTEM**. The instrument developed in partial cooperation with CEOS GmbH in Heidelberg is equipped with electron-optical components to correct aberrations, electron-beam monochromatization and energy-filtered imaging. **UHRTEM** is a special development for the sub-Angstrom characterization of advanced materials and module structures from innovative nanotechnology.
www.smt.zeiss.com

Sub-Angstrom **UHRTEM** with revolutionary suspension on the microscope column.



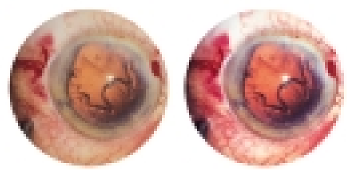
Young's edge zone sample provides an insight into the usability of image resolution of 0.8 Angstroms. An area of the image section is displayed at a resolution of 0.7 Angstroms.

Superlux™ Eye Xenon Illumination

With the innovative **Superlux™ Eye** xenon illumination, Carl Zeiss provides ophthalmic surgeons with a white light that meets even the highest demands. This clearly improves working conditions for ophthalmic surgeons: more realistic colors, increased contrast, better detail recognition and enhanced quality of videos resulting from the higher color resolution. Compared with standard halogen illumination, **Superlux™ Eye** is also easier to service.
Xenon illumination is nothing new to surgical microscopes in other disciplines – neurosurgery and ENT surgery, for example. However, until now, it was considered too dangerous for ophthalmology as the light hitting the retina must not be too strong. It can lead to tissue damage. Carl Zeiss rose to the challenge and optimized xenon for ophthalmology. With **Superlux™ Eye** illumination, the UV portion below 408nm is filtered, making it just as safe as halogen illumination. Compared to halogen, however, **Superlux™ Eye** has more advantages: it has a significantly lower IR portion which reduces the thermal exposure to the cornea and other tissues, making operations on the eye even more safe and gentle.

www-zeiss.de

OPMI® VISU 210



Carl Zeiss Optics in Nokia Mobile Phones

Carl Zeiss has supported Nokia, the global market leader in mobile communications, since the end of April 2005, with the integration of Carl Zeiss optics into Nokia camera phones. In the future, this will enable users of high-end cell phones to record, save, show and print images and videos with even better quality. The Nokia N90 is the first product with integrated ZEISS optics from this partnership: it is a mobile phone with a 2 megapixel camera and the smallest **Tessar** lens in the world.

www.zeiss.de/photo
www.nokia.com

Masthead

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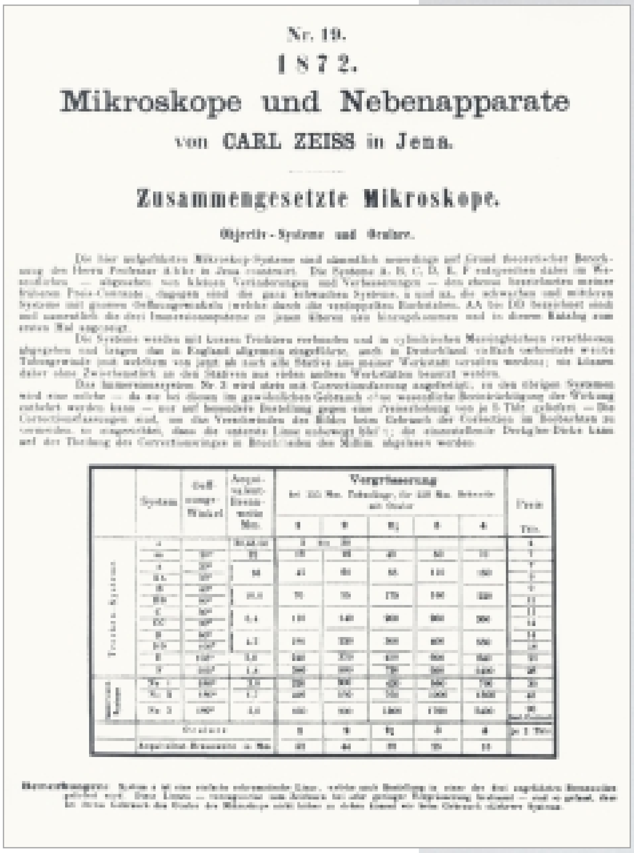
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