Denisia (2018) **41**:
1–46

The Microcosm under the Microscope: a Passion of Amateurs and Experts

Klaus Hausmann & Hans Machemer

Abstract: This article describes the origin and historical development of amateur microscopy starting with Antonie van Leeuwenhoek (1632–1723), and the changes of its goals in the course of time until the present days.

Key words: microcosm, microscopy, dilettantes, amateurs, autodidacts, experts, historical aspects.

Introduction

Reading the title of this essay may raise a question: Why does a historical review on microscopy find its way into this volume of Denisia, the focus of which is on archives of researchers on protists? Well, there is an easy and hopefully convincing answer. About 400 years ago, a non-scientist, in fact, a naive dilettante discovered the existence of unicells. It is Antonie van Leeuwenhoek, born October 24, 1632 in Delft, Netherlands, where he also died in his nineties (August 27, 1723; Fig 1a). Leeuwenhoek was able to craft a microscope, and, by patient management of illumination and focusing, to discover in droplets of natural water so far unknown miniature living things. They were later called "Animalcula", little animals (Dobell 1932, 1960; Schierbeek 1950–1952; Ford 1991; Meyer 1998) and are today part of the so-called protists. It is this Antonie van Leeuwenhoek, who transformed by his studies and publications, during a busy life, from ultimate beginner into a worldwide highly respected scientist.

Dilettantes and Amateurs

Let us explain at this point, the meaning of the terms of dilettante and amateur. How were they understood in earlier times, and what kind of person do they characterize today?

Since the 18th century, the term of dilettante was borrowed from the Italian dilettare and dilettante, which derives from the Latin verb delectare. This means: to enjoy something. At that time, a dilettante, who spent his time with science or art, did this for sheer fun and not for more earthen reasons such as working for life subsistence. Thus, a dilettante was considered a positive and respected person. Famous representatives of dilettantes in that understanding were the brothers Montgolfier, paper manufacturers and inventors of the hot-air-balloon, or – to give another example – the learned lawman and famous writer Johann Wolfgang von Goethe, who discovered the human intermaxillary bone as well as the metamorphosis of plants. Furthermore, the monk and ecclesial canon Gregor Mendel found the basic rules of genetics; the businessman Heinrich Schliemann was able to find and excavate the ruins of the ancient city of Troja; the priest Sebastian Kneipp established and further developed the therapy of healing by water; the physicist Albert Einstein was a gifted violin player. Last not least, the above mentioned cloth merchant Antonie van Leeuwenhoek entered for the first time the microcosm of unicellular organisms.

Nowadays, a dilettante is thought in the pejorative way, as a non-expert, who does things improperly and badly. Thus he is considered – in contrast to the earlier understanding – to be bungler (Günkel 2000).

The French term amateur is used today in a more positive way. It derives from the Latin word amator (= lover) and designates a person, who does things just for fun – disregarding professional ambitions. An amateur is a layman (from ecclesial Latin laicus = ordinary person; Greek: λαός = people, λαικός = popular); he has no formal education unlike a person with professional training. The term does not focus on specific knowledge since amateurs may reach professional levels. Paradoxically, the adjective amateurish is meant to characterize an imperfect, nonprofessional activity. Wolff & Wittstock (2001) therefore use the term of semi-professionality as intermediate between an amateurish and a professional qualification.

Antonie van Leeuwenhoek

Antonie van Leeuwenhoek arose from a Dutch middle-class family of craftspeople. He had no higher education so that he did not know the Latin, English and French languages. For professional training, he was sent to a cloth merchant in Amsterdam, where he was trained for bookkeeping and treasuring. He returned back to Delft, opened a shop for textiles and married a woman from a more distinguished family. Four out of totally five children from this marriage died at early age; only his daughter Maria survived. She lived unmarried and – after the death of her mother – ran the household of her father.

In 1660 van Leeuwenhoek gave up his business and became an employee of the city of Delft. He proudly bore the title of a "Camer-Bewarder von den Herren Schepens" meaning, he was a city counsellor. His still existing contract tells that his duties were to open and close the council hall, its heating and cleaning; in particular, he was expected to keep silence about the discussion he was involved in (Anderson 2014). The amazingly high yearly salary of 400 guilders did not really correspond to his activity of a janitor.

Fig. 1a-c: Antonie van Leeuwenhoek and his type of microscope. **a** – The portrait shows Antonie van Leeuwenhoek at the age of 54 years (etching by Jan Verkolje [1650–1693], Rijksmuseum Amsterdam, 1686). **b** – The single-lens microscope. **c** – Handling of the Leeuwenhoek-microscope.

Today, it is not easy to understand, how a 28 years old humble cloth merchant was able to achieve such well-paid position. Nepotism may have played a role but there is no direct proof for this. In 1679 he was appointed master of standards in

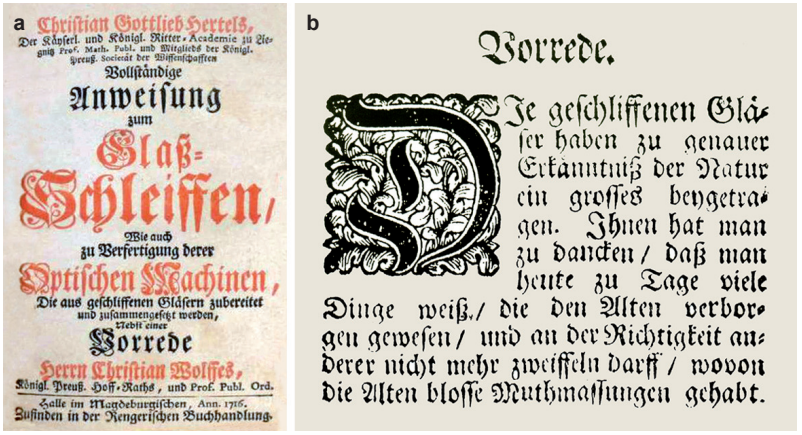


Fig. 2a, b: a – Front page of Christian Gottfried HERTEL's book "Anweisung zum Glaß-Schleiffen" of 1716. **b** – Introduction to this book by Hofrat (Privy Counsellor) Christian WOLFF (1679–1754; SCHRADER 1898).

alcoholic drinks. Before that, he had established the reputation of reliability and circumspection as a land surveyor.

Van LEEUWENHOEK, because of his solid financial status, was able to pursue as a dilettante his hobby of microscopy. It is possible that he was inspired to this activity by the Dutch translation of the bestselling "Micrographia" (1655) of the English universal scholar Robert HOOKE (1635–1703) where the scientific term of "cell" was coined as a basic unit of life and, for the first time, the cellular structure of plants was described. HOOKE used – unlike the dilettante van LEEUWENHOEK – an incident light microscope. This may possibly explain why, so far, the rather tiny unicells had not been discovered by HOOKE.

Antonie van LEEUWENHOEK made his investigation by using microscopes he had built by himself. The guess is of about 500 items. Today, only nine of these devices have been preserved. It is unknown, if and where the remaining microscopes still exist, which had been auctioned in the spring of 1747, 24 years after his death.

These were no compound instruments, as they had been in use already at that time. Rather, they consisted of a miniature, single biconvex lens which was held between two brass plates, analogous to devices for thread-counting as commonly used in the textile trade (Fig. 1b). In other words, they were highly magnifying glasses. These devices had to be kept closely to the eye, with the object fixed at the top of a needle. With these arrangements van LEEUWENHOEK was able to produce magnifications up to amazing 270 times (FORD 1991). Thereby, they clearly surpassed achievements of the early multi-lens – compound – microscopes, which allowed no more than 20 to 30 times magnifications because of deficiencies of their lenses.

There is only a very limited knowledge of the microscopes by van LEEUWENHOEK, who always made a big secret about their construction. Visitors repeatedly expressed their amazement about this secretiveness. In particular, the exact way of lens production is unknown. He is told to have produced them by grinding and polishing, by glassblowing or by glassmelting. While the optics of van LEEUWENHOEK's instruments were obviously excellent, their mechanical properties were rather miserable. By the end of van LEEUWENHOEK's work it was seen that the quality of glass and its grinding is crucial for their use in the microscopic science. In 1716 Christian Gottlieb HERTEL (1683–1743) published his "Anweisungen zum Glaß-Schleiffen" (Instructions for glass grinding) which aroused great attention at that time (Fig. 2; GERLACH 2009).

It is not known at what time exactly van LEEUWENHOEK started his microscopic investigations. There are some hints indicating that this occurred near the year of 1670 because, from that year on, numerous descriptions of his work are documented in more than 300 of his letters. They were written in the Dutch language and addressed to scientists as well as amateurs in the Netherlands as well as to other countries. Beginning in 1673, he sent 190 of these letters,

including recommendations by the physician and researcher Reinier de Graaf (1641–1673), to the "Royal Society" in London, at that time the most famous scientific institution. These letters included numerous illustrations (Fig. 3). They were, under the editorial supervision of Henry Oldenburg (1618–1677), translated into the common language of science, Latin, published in the "Philosophical Transactions of the Royal Society" and thereby accessible to the scientific world. Oldenburg was for many years secretary of the "Royal Society" and thereby a central personality in the community of science of the 17th century.

By these activities, Antonie van Leeuwenhoek had access to the world of science and, thereby, to the important scientists of his time. These had, in the beginning, some reservations about the real existence of his "Animalcula", as indicated in a letter van Leeuwenhoek wrote to the "Royal Society" in 1675 (Fig. 4). However, well established researchers such as the botanist Nehemiah Grew (1641–1712) and the before mentioned universal scholar Robert Hooke confirmed his findings. By the time, the dilettante had grown into an expert, whose discoveries were closely looked at on site (Delft) and acknowledged by distinguished scientists such as Gottfried Wilhelm Leibniz (1646–1716), Constantijn and Christiaan Huygens (1596–1687; 1629–1695) and illustrious personalities like czar Peter the Great (1672–1725), the kings of Poland und Prussia, and the British Queen.

Starting with 1684 van Leeuwenhoek began to publish his letters, in part written in the Dutch language and in part in Latin after translation (1695, 1966 [facsimile reproduction]). His procedures of publishing were apparently quite chaotic so that the non-specialist has some problems in overviewing his complete works. Not until 1932, the 300th anniversary of the birthday of Antonie van Leeuwenhoek the "Royal Academy of Sciences of Amsterdam" and the "Nederlands Tijdschrift voor Geneeskunde" published a critical edition of all of his letters. Schierbeek (1950–1952) presents a complete list of the publications of Antonie van Leeuwenhoek.

A detailed listing of van Leeuwenhoek's single explorations of the microcosm would overextend the present report. Here, it may suffice to emphasize that he discovered a large number of "Animalcula" besides many other things from the living as well as inanimated world. He found the "Animalcula" more or less by chance, when he pursued the question of why pepper bites on the tongue. In order to test this, he softened some kernels of pepper in water, that is, he started so-called infusions, which, after three weeks, were abounding with microorganisms. Until today, the preparation of an infusion is a well-established method of spawning unicells. A whole range of "Animalcula" as described by van

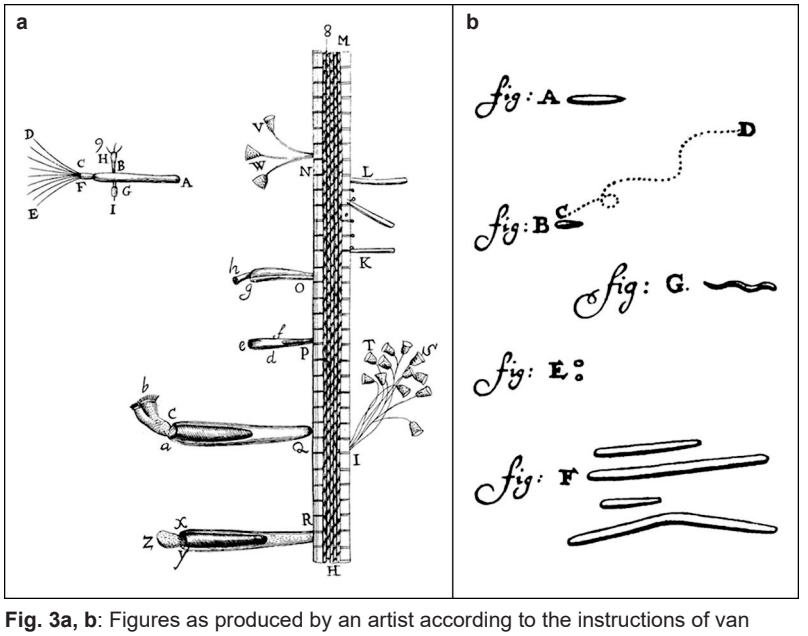


Fig. 3a, b: Figures as produced by an artist according to the instructions of van Leeuwenhoek. **a** – Rotatoria, *Hydra*, and vorticellids, as adhering to a root of the common duckweed, taken from a sample of water from the canal of Delft. **b** – Bacteria from the dental plaque of van Leeuwenhoek. The dotted line (C – D) of Fig. b marks the locomotion of a bacterium.

Leeuwenhoek at his time are easily identified as protists (such as *Anthophysa*, *Coleps*, *Elphidium*, *Nyctotherus*, *Opalina*, *Polystomella* and *Volvox*) as depicted in his drawings (Fig. 3a; Lane 2015). With good reason van Leeuwenhoek is therefore believed to be the founder of protistology.

Amazingly, van Leeuwenhoek was even able to describe bacteria and their motile behaviour (Fig. 3b). According to our present understanding, magnifications larger than 270 times – as

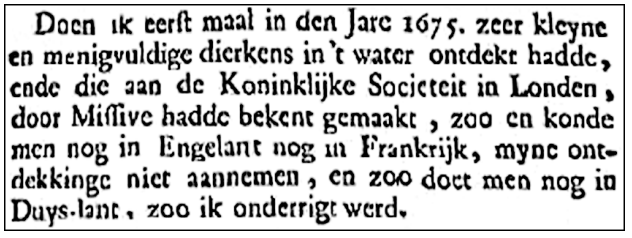

Doen ik eerſt maal in den Jare 1675. zeer kleyne en menigvuldige dierkens in 't water ontdekt hadde, ende die aan de Koninklijke Societeit in Londen, door Miſſive hadde bekent gemaakt, zoo en konde men nog in Engelant nog in Frankrijk, myne ontdekkinge niet aannemen, en zoo doet men nog in Duys-lant, zoo ik onderrigt werd.

Fig. 4: Segment of a letter by van Leeuwenhoek to the Royal Society. The text as translated into English is: "When, in 1675, I had discovered for the first time numerous miniature animals in water, and I had communicated this observation to the Royal Society in London, my findings were accepted, according to my information, neither in England, nor in France, nor in Germany."

mentioned above – would be required. It is speculated, therefore, that he may have achieved magnifications of up to 500 times. Because of these discoveries van Leeuwenhoek is also titled as the "Father of Microbiology". His abilities of discovering things in various ranges of nature, to ask and give answers to an increasing number of scientific questions, made him an authority of the respective scientific community. In 1680, the "Royal Society" in London honoured his intellectual achievements by electing him as "Fellow". This particular appointment was confirmed by a large number of high-ranking honours by various institutions.

Antonie van Leeuwenhoek is an outstanding example of how a layman may transform to an expert in the course of his practical and theoretical studies (Anderson 2014). A portrait of 1707 depicts the meanwhile highly respected scientist at the age of 75 years (Fig. 5).

Transfer of knowledge

The microscopic dimensions were opened up by van Leeuwenhoek, in the first line, to well educated social classes. In general, they were inaccessible to the majority of people and therefore, private persons who practiced microscopy were rare. At the beginning of the 18th century, a few personalities strove to develop understanding of the microcosm for a larger public using common language and easy-to-grasp illustrations. In the following, we demonstrate the beneficial work of three men, who were no experts as such, rather, they were dilettantes in the beginning, who increasingly engaged in microscopy.

August Johann Rösel von Rosenhof

Born at the 30th of March 1705, and christened as August Johann Rösel, he was nobilized by the German Empire to a "von Rosenhof" (Fig. 6; Hess 1889; Geus 2003). Rösel died

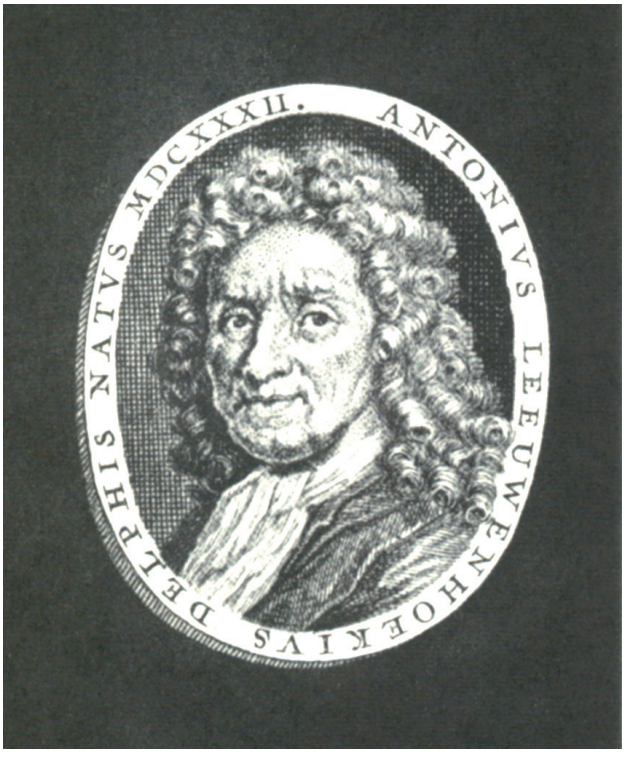


Fig. 5: Antonie van Leeuwenhoek at the age of 75 years (portrait by J. Goeree, 1670–1731).

Fig. 6: Portrait of August Johann Rösel von Rosenhof.


Der
monatlich-herausgegebenen
Insecten-
Belustigung
Erster Theil,
in welchem
die in sechs Classen eingetheilte Papilionen
mit ihrem Ursprung, Verwandlung und allen wunderbaren Eigenschafften, aus eigener Erfahrung beschrieben, und in sauber illuminirten Kupfern, nach dem Leben abgebildet, vorgestellet werden
von
August Johann Rösel,
Miniatur-Mahlern.
Nebst einer Vorrede, in welcher von dem Nutzen derer Insecten gehandelt, was sie seyen gezeiget, und von der Eintheilung dererselben Nachricht gegeben wird.
Nürnberg, zu finden bey dem Verfasser.
Gedruckt bey Johann Joseph Fleischmann.
1746.

Fig. 7: Front page of the first volume of "Insecten-Belustigung" by August Johann Rösel. The addition of "von Rosenhof" to the name occurred by 1753.

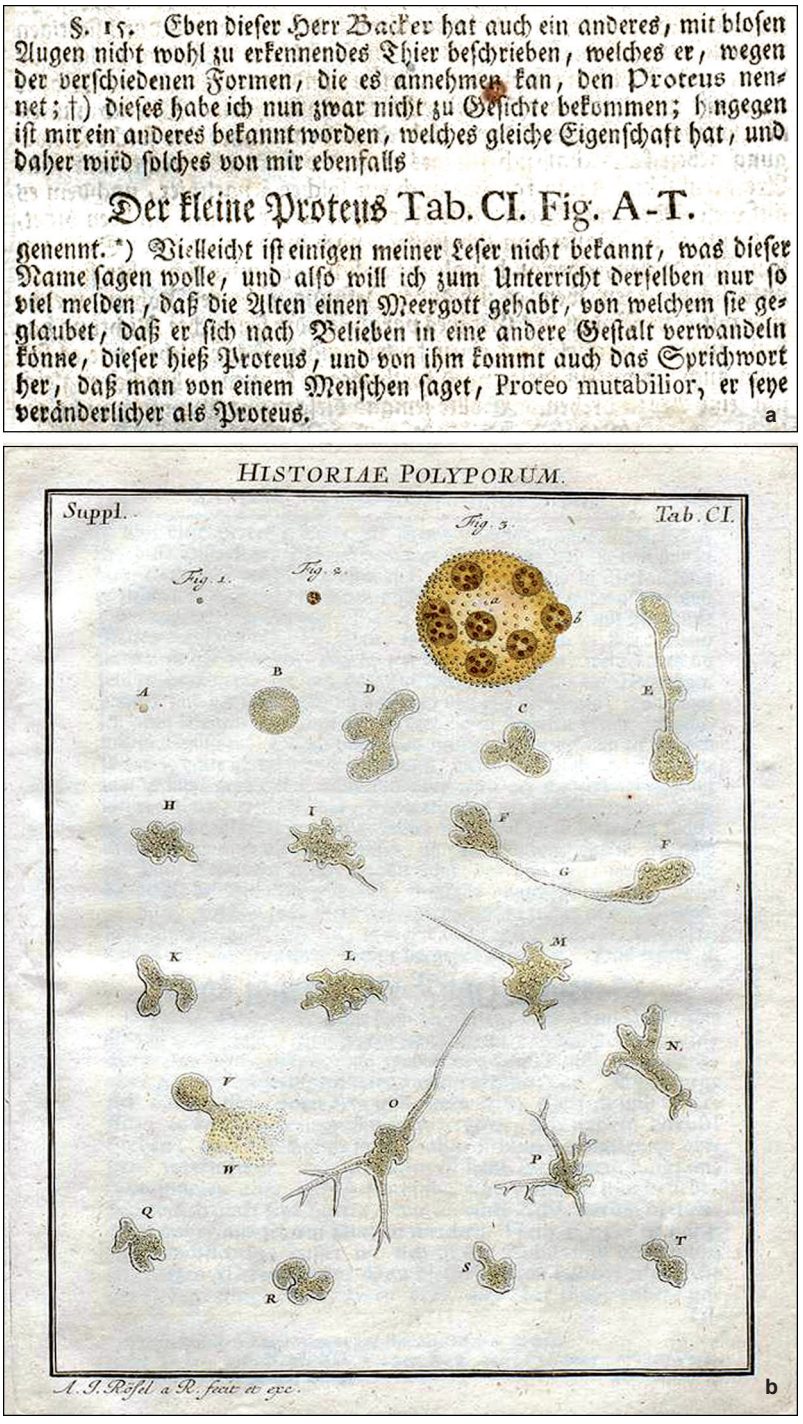
at 27th March 1759 in Nuremberg, Germany. He absolved an apprenticeship as a painter, worked at the court in Copenhagen for two years and thereafter returned back to Germany. As a portrait artist, miniaturist and engraver, he achieved some prosperity. He was influenced by the famous works on insects by Maria Sybilla Merian (1647–1717) and decided to produce similar art work on insects, although he was not yet trained as a scientist.

Between 1730 and 1740 he seriously studied insects and gradually became a natural scientist who was, among experts in particular, appreciated as an entomologist. He was able to depict meticulously insects and so precisely that until now species can be identified from his illustrations. Rösel is therefore deemed a pioneer of modern entomology. He wrote four books on insects, illustrated with numerous coloured copperplate prints, and titled "Der monatlich herausgegebenen Insecten-Belustigung Erster (Zweiter, Dritter, Vierter) Theil". These books appeared from 1746 to 1761 (Fig. 7; Rösel von Rosenhof 1755). The last book appeared posthumously and was edited by his son-in-law Christian Friedrich Carl Kleemann (1735–1789). In that edition Kleemann wrote a vita of his father-in-law, Rösel von Rosenhof, from which we know that his contemporaries were not pleased to learn that he was predominantly engaged in invertebrate studies. His plans were considered as useless and ridiculous pipe dreams. He should not waste his precious time on picturing noxious and repulsive creatures which obviously derived their lives from the arch-enemy of goodness, not the creator spirit. Rösel's "Insecten-Belustigung" well documents that the author was able to keep off that degrading gossip (Gerlach 2009).

In these fascinating publications for laymen the microscopic dimension is not often represented. Rösel used, in the first line, low magnifications

for his investigations. For microscopists, in particular protozoologists, an interesting detail is found in his third volume: Here, the author describes a creature, so far unknown as being an amoeba, as "Der kleine Proteus" (the small proteus) (Fig. 8). The extensive text by Rösel reveals some kind of helplessness in producing an accurate drawing of this newly discovered organism. Any time, when he looked again through his microscope, the organism's outline was different from before. Viewed in this light, his naming of Proteus was justified. According to Greek mythology, Poseidon, the ruler of the seas, was the master over Proteus; this god was held to be much inclined to the female gender so that his numerous sexual liaisons had consequences: ten extramarital children as told by the traditions. In order to escape from hairy adventures, Proteus managed to transform to various guises: a lion, a snake, a leopard, a boar, a tree, and even water.

In this third volume of Rösel's books we find, besides small water insects, an extensive description of freshwater polyps. In addition, much attention is also given to bryozoans and various ciliates.



§. 15. Eben dieſer Herr Backer hat auch ein anderes, mit bloſen Augen nicht wohl zu erkennendes Thier beſchrieben, welches er, wegen der verſchiedenen Formen, die es annehmen kan, den Proteus nennet; †) dieſes habe ich nun zwar nicht zu Geſichte bekommen; hingegen iſt mir ein anderes bekannt worden, welches gleiche Eigenſchaft hat, und daher wird ſolches von mir ebenfalls

Der kleine Proteus Tab. CI. Fig. A-T.

genennt. *) Vielleicht iſt einigen meiner Leſer nicht bekannt, was dieſer Name ſagen wolle, und alſo will ich zum Unterricht derſelben nur ſo viel melden, daß die Alten einen Meergott gehabt, von welchem ſie geglaubet, daß er ſich nach Belieben in eine andere Geſtalt verwandeln könne, dieſer hieß Proteus, und von ihm kommt auch das Sprichwort her, daß man von einem Menſchen ſaget, Proteo mutabilior, er ſeye veränderlicher als Proteus.

a

HISTORIAE POLYPORUM.

Suppl. Tab. CI.

Fig. 1. Fig. 2. Fig. 3.

A. J. Rösel a R. fecit & exc.

b

Fig. 8a,b: „Der kleine Proteus". **a** – Clipping from page 622 of the third volume of Insecten-Belustigung. **b** – Table 101 lively illustrates the changes in shape of the "kleiner Proteus" (small proteus). Today, we call this amoeboid movement.

Martin Frobenius Ledermüller

Martin Frobenius Ledermüller (* 20 August 1719 in Nuremberg, Germany, † 16 Mai 1769, ibidem) lived a much varied life (Müller 1985). His basic education was given by home tutoring and later attending a high school in his home town. At the age of fourteen years, and contrary to Ledermüller's inclinations, his father pressed him to learn the profession of a trader in "Spezereien" (spices). After three years, the father yielded to the insistence of his son and


Martin Frobenius Ledermüllers,
Hochfürstlich-Brandenburg-Culmbachischen Justiz-Raths, wie auch der Kayserlichen Akademie der Naturforscher und der Deutschen Gesellschaft zu Altdorf Mitglieds,
Mikroskopische
Gemüths-
und
Augen-Ergötzung:
Bestehend,
in
Ein Hundert nach der Natur
gezeichneten
und mit Farben erleuchteten Kupfertafeln,
Sammt
deren Erklärung.
Gedruckt auf Kosten des Verfassers
von Christian de Launoy.
1761.

Fig. 9: Front page of "Gemüths- und Augen-Ergötzung" by Martin Frobenius LEDERMÜLLER of a 1761 book edition.

allowed him to dedicate himself to the writings of a notary. In 1739 he began to study philosophy and law at the University of Jena, Germany. But already one year later his implacable father coerced him to return to Nuremberg. On his way back, LEDERMÜLLER entered service with various armies but finally returned home to Nuremberg. Here, his father confronted him with hard charges so that he took refuge with a friend in the small German town of Römhild. After a temporary occupation as a secretary he passed in 1749 in Nuremberg the examination of notaryship. 1749 he became a "Sollizitator" (lawyer's clerc) at the town hall and 1751 procurator at the town court and registry office (until 1760).

LEDERMÜLLER very soon dedicated himself to microscopic studies. He published his first results on "Saamenthiergen" (spermatozoa) in two small papers, which evoked a very positive public response. This encouraged him to write his most important work "Mikroskopische Gemüths- und Augen-Ergötzung" (Fig. 9) which appeared in three partial deliveries (LEDERMÜLLER 1761). In 150 copper-engravings coloured by hand, LEDERMÜLLER communicated to his readers a widely diversified insight into the live and inanimate aspects of nature. For good reason LEDERMÜLLER is therefore called a popularizer of the microscopic dimensions.

Altogether, we find only a few unicellular organisms in his "Ergötzungen" such as stentors and vorticellas, which, however, are identified without any doubt (Fig. 10).

It is interesting to note that LEDERMÜLLER used a so-called sun or solar microscope in his investigations, which also served as a projector (Fig. 11a). In a dark-painted room this instrument was fixed at a wall in such a way that rays of the sun were guided by a mirror to the microscope. Thereby, several persons were able to observe the microscopic preparations at the same time.

When a frame covered with parchment paper was placed between the microscope and the projection screen, it was possible to make a drawing of the preparation (Fig. 11a, top left). Beyond that, LEDERMÜLLER constructed additional appliances for drawing pictures of microscopical structures, which presumably were useful for the practitioner (Fig. 11b).

LEDERMÜLLER was an introverted but open-minded natural scientist. Nevertheless, his self-educated achievements in the field of descriptive biology did neither earn him an academic title nor an academic position. His state of health worsened with rising age, following a work accident in earlier years. It is reported that he opened a vial containing preserved animals; the poisonous gases which leaked out deteriorated lastingly his health. LEDERMÜLLER was depressed at old age. By the end of his life, he became intolerable toward anybody including himself.

Fig. 10: Table 83 of "Gemüths- und Augen-Ergötzung" titled "Noch einige andere Schlammthierchen, so unter dem Namen gesellschaftlicher Polypen, bekannt sind" (Some more mud animalcules as being known as gregarious polyps). Ciliates can be identified undoubtedly.

Otto Fridrich Müller

Otto Fridrich Müller (* 11 March 1730 in Copenhagen, Denmark, † 26 December 1784, ibidem?) stuied theology and became, at the age of 23 years, "Master of the Court" under Johann Sigmund Graf von Schulin (1694–1750), with whom he traveled a lot. In 1769 Müller was appointed "Advisor" and keeper of the archives at Copenhagen. With these positions, he was not an examined academician.

In 1767 he settled at Copenhagen and married a wealthy lady. Being a private scholar he devoted himself, as an autodidact, to the study of worms according to the schemes of Carl von Linné (1707–1778) who had organized the system of invertebrates (Günkel 2000).

Müller started the first systematic investigations of the infusoria, including the protists as well the bacteria and rotatoria. In 1773 his comprehensive study of the infusoria was published. His widow posthumously published "Animalcula Infusoria Fluviatilia et Marina" (Fig. 12; Müller 1786), a book which is a source of reference until today. Otto Fridrich Müller is an example of how an autodidact offered his findings exclusively to scientists.

Deadlocks and further developments of microscopy

In the ongoing 18th century the progress of scientific microscopy was rather stagnant. After an initial tide of discoveries and accompanying euphoric responses, new questions and issues, using technically rather deficient microscopes, did not show up straightaway. At the same time, methods of preparation were still rudimentary.

This does not mean that there was no further progress in technology. However, it should be kept in mind that instruments were used in the first line for amusement, implying that attention was given more to external design than to performance (Fig. 13; Ernst-Abbe-foundation, 2013). A gorgeous instrument was best suited to reflect the wealth of its owner. As a consequence, trends of that age favoured the appearance and – to a much lesser degree – the optics and mechanics of the instruments (Gloede 1986; Gerlach 2009). Serious advancements started, however,

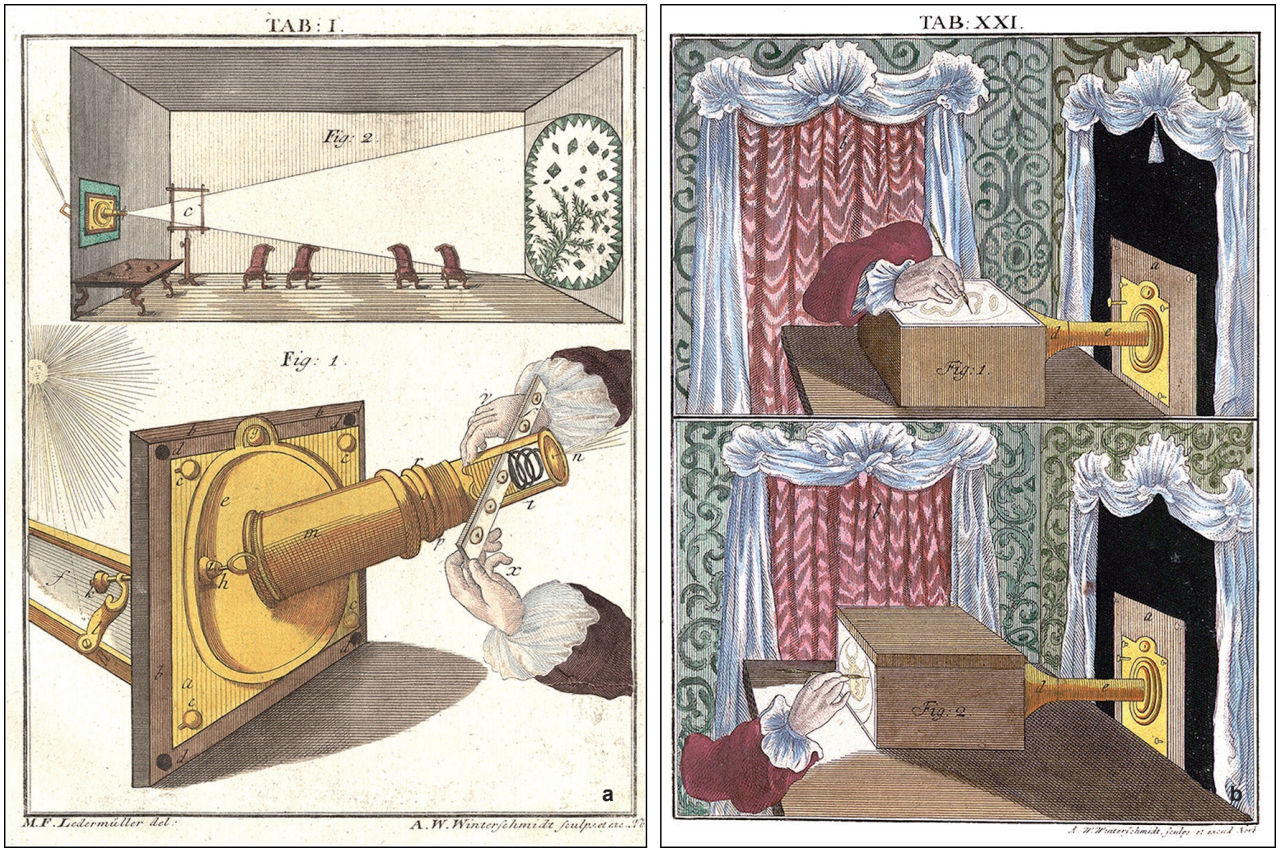


Fig. 11a,b: Microprojection and appliances for drawing. **a** – Using a solar microscope allowed the demonstration of microscopic preparations to a number of persons (see chairs) **b** – Two versions of devices for drawing.

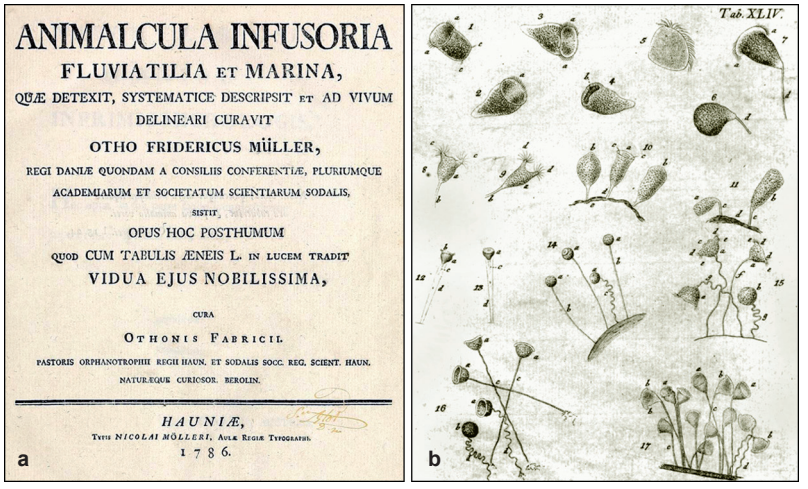

ANIMALCULA INFUSORIA
FLUVIATILIA ET MARINA,
QUÆ DETEXIT, SYSTEMATICE DESCRIPSIT ET AD VIVUM
DELINEARI CURAVIT
OTHO FRIDERICUS MÜLLER,
REGI DANIÆ QUONDAM A CONSILIIS CONFERENTIÆ, PLURIUMQUE
ACADEMIARUM ET SOCIETATUM SCIENTIARUM SODALIS,
SISTIT,
OPUS HOC POSTHUMUM
QUOD CUM TABULIS ÆNEIS L. IN LUCEM TRADIT
VIDUA EJUS NOBILISSIMA,
CURA
OTHONIS FABRICII.
PASTORIS ORPHANOTROPHII REGII HAUN. ET SODALIS SOCC. REG. SCIENT. HAUN.
NATUR.EQUE CURIOSOR. BEROLIN.
HAUNIÆ,
TYPIS NICOLAI MÖLLERI, AULÆ REGIÆ TYPOGRAPHI.
1786.
a
Tab. XLIV.
b

Fig. 12a,b: **a** – Front page of O. F. MÜLLER "Animalcula Infusoria Fluvatilia et Marina". This is still an important work for the present-day protozoologists. **b**.– An example of illustration from this book.

by the end of the 18th century. Microscopes were continuously improved and eased useful in the progress of research. These technical developments will not be further detailed in the present overview.

Microscopy for everybody

We will now ask if, and in which way, a larger proportion of the public was able to participate in the discovery of the microscopically small world.

A cartoon from William HEATH (1794–1840) of the year 1828 illustrates that people had some understanding of miniature organisms in bodies of water (Fig. 14). A bizarrely decorated British lady loses her countenance, when she glances through the microscope: She discovers what kind of water is used for preparation of her tea. Her cup dumps down, and she grimaces for a yell. What terrifies her is shown in the right part of the picture: A microscopic section of the Thames water contains a multitude of fantastic unicells, fish,

Fig. 13a, b: Splendour microscopes. **a** – A baroque device after Duc de CHAULNES, around 1760. **b** – A Japanese instrument of the 19th century.

Fig. 14: A cartoon by W. HEATH, 1828, illustrating a "Monster Soup", as the Thames waters were commonly called.

Das Mikroſkopiſche Aquarium in Berlin.

Zu den bisher beſtehenden ſogenannten Naturanſtalten, wie ſie jetzt in allen größern Städten ſo verbreitet und beliebt ſind, den Zoologiſchen und Botaniſchen Gärten und den Aquarien ſüßen und ſalzigen Waſſers, iſt ſeit 2 Jahren durch das Mikroſkopiſche Aquarium in Berlin ein neuer Zweig, eine höchſt weſentliche Ergänzung hinzugetreten. In allen dieſen Anſtalten

Fig. 15: Beginning of a newspaper report on the "Mikroskopische Aquarium" of the 10th February 1877.

crustaceans, worms and strange fabulous beasts. The trigger of this graphic satire had been two long articles of the "Times" on the 16th and 19th January 1828.

A report of the "Illustrirte Zeitung" (Illustrated News) of the 10th February 1877 (TEICHERT & HAUSMANN 1994) is particularly interesting. Under the headline "Das Mikroskopische Aquarium in Berlin" it tells about an establishment comparable to the so-called "Naturanstalten" of a big city, the Zoological and Botanical Gardens, and the Aquariums (Fig. 15). Here, the magistrate of Berlin had supplied some rooms of the "Alte Münze" (Old Mint) for the "Mikroskopische Aquarium". In the beautiful dome hall and three more connecting rooms, about fifty microscopes were set up on long rows of tables (Fig. 16). The reporter writes as follows: "Neben jedem Mikroskop befindet sich ein Zettel mit dem Namen und einer kurzen Beschreibung des Geschöpfs, das man beim Hineinblicken wahrnimmt. Ein Stuhl bei jedem Instrument soll den Beschauer veranlassen, sich mit Ruhe der Durchmusterung des Bildes hinzugeben, dessen Anblick meist umso interessanter wird, je mehr man sich in die Einzelheiten vertieft." (A slip of paper near each microscope gives the name of the creature which appears upon looking through the ocular. A chair invites the observer to take time for viewing the scenery which becomes increasingly interesting with intensified observation of the details).

At the sight of a colony of *Vorticella* the reporter raves: "Schon der erste Blick in eins jener Messingrohre versetzt uns in eine andere Welt. Ist das ein Tulpenbeet, welches wir vor uns sehen? An durchsichtigen, sanftgebogenen Stielen hebt

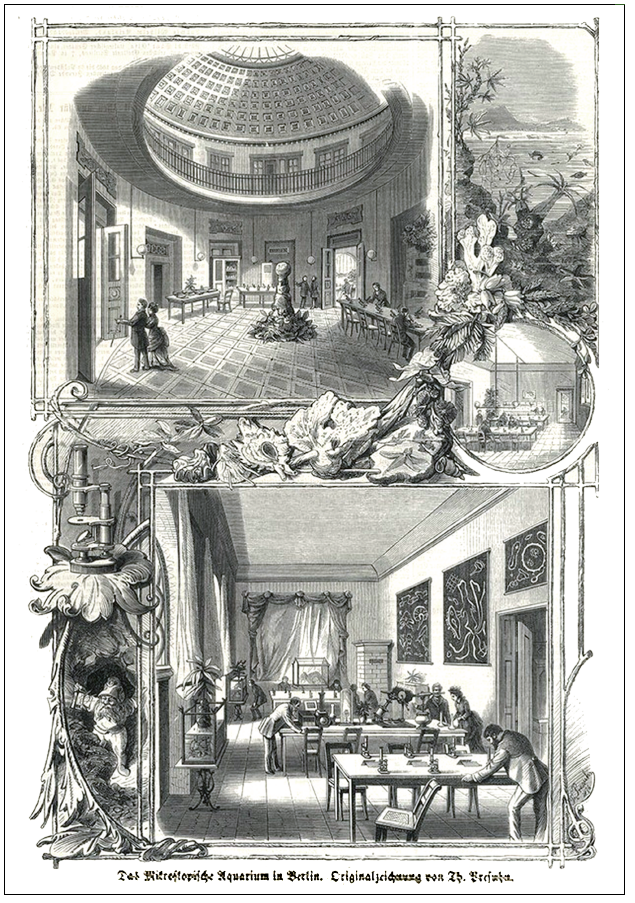


Fig. 16: Interior of the "Mikroskopische Aquarium" of a contemporary illustration.

Blume neben Blume sich empor, zwar farblos weiß, aber in durchsichtiger Klarheit, an ihrem Saum kleine Wellen schlagend – da plötzlich schnellt es zusammen und die ganze Gesellschaft mit ihm, um bald darauf langsam wieder in korkenzieherartigen Windungen emporzuwachsen. ... Die Blütenkelche unserer vermeintlichen Tulpen sind Thierchen mit Mund, Speiseröhre und Magen, und die kleinen Wellen, die sie mit Hülfe ihrer Wimperhärchen erzeugen, dienen nur dazu, um die genannten Organe zu füllen." (Already at first glance through those brass tubes we are taken away to a strange world. Do we see a bed of tulips? Flower by flower rises on transparent, gently bent stalks, without colour, but with shining lucidity. Small waves are seen moving along the margins. All of a sudden the community flips to contracture and then again grows up the corkscrew way. The calyces of the alleged tulips are miniature animals, equipped with mouth, gullet, and stomach, and the waves are generated by cilia which serve to fill the organs mentioned before).

Today, we can well imagine that the onetime visitors of the "Mikroskopische Aquarium" were fascinated in a similar way.

The report ends optimistically: "Wie jene älteren, die Zoologischen Gärten und später die Aquarien, aus einzelnen Centren beginnend, allmählich über alle größern Städte sich verbreitet und sich daselbst die Anerkennung und Liebe des gebildeten Publikums gewonnen haben, so wird gewiss auch das Mikroskopische Aquarium zu Berlin, vielleicht schon durch unsere Beschreibung, überall das verdiente Interesse finden und die Veranlassung werden, auch dieser Art von Naturanstalten eine weitere Verbreitung zu geben." (The Microscopic Aquarium will surely win the appreciation and love of the educated public, as did those older zoological gardens and aquariums. These started from single centres as well, and gradually expanded to become part of all larger cities. We do hope that our description will induce such well-deserved interest and may further serve to propagate this type of institution.)

Unfortunately, this forecast did not become reality. Until today, there is no such educational facility neither in Berlin nor in any other city of the German-speaking countries (Hausmann & Hülsmann 1988; Lötsch 1998).

Worldwide societies of microscopy of the 19th century

By the end of the 19th century the time had come in Germany for foundations of large scientific societies which still persist until today. In biology, the "Deutsche Botanische Gesellschaft" and the "Deutsche Zoologische Gesellschaft" were founded (1882 and 1890, respectively). However, at this time, only a few friends of nature convened to practice microscopy for

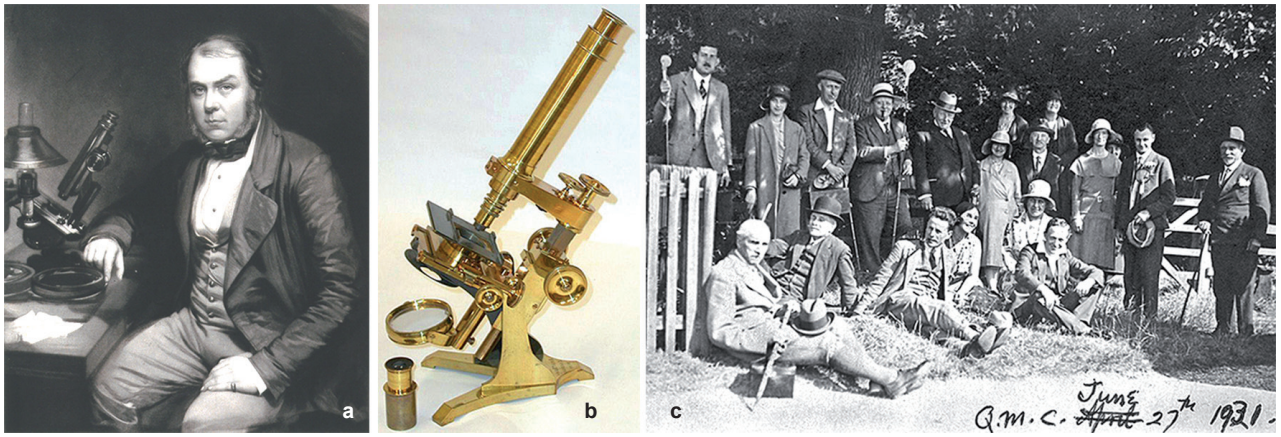


Fig. 17a-c: **a** – The "Quekett Microscopical Club" was named after the Victorian practitioner and popularizer of microscopy, John Thomas Quekett. **b** – His microscope is today owned by the Club. **c** – Photograph of an excursion of 1931.

sheer enthusiasm. This did not happen until the early 20th century.

In the European foreign countries the amateurs and enthusiasts were more ahead, when, for example, they founded the "Quekett Microscopical Club" in London as early as 1865. They named their club after the Victorian John Thomas Quekett (1815–1861; Fig. 17), a practician and popularizer of microscopy. Until these days this club is active and enjoys, after more than 150 years, a buoyant team of members (Bracegirdle 2016).
In 1873 the "Postal Microscopical Society" was founded, which is a union of microscopists all over England. These persons receive a box of 12 microscopic slides every three weeks. They dispatch these preparations to the next society member at the end of that period by the postal service. This club still exists, amazingly, after more than 140 years.

Early federations of amateur microscopists occur in overseas as well. The "New York Microscopical Society" dates back to the year of 1877 and continues to enjoy great popularity. Presumably, some more unions of hobby microscopists were established in the 19th century, but they did not reach far beyond their domains or did not exist very long.

Raoul Heinrich Francé: a mediator par excellence

Raoul Heinrich Francé (* 20. May 1874, Altlerchenfeld near Vienna, Austria, † 3. October 1943, Budapest, Hungary) was able to popularize knowledge about the microcosm like hardly any other person (Fig. 18; Müllerott 1961; Aescht 1993; Henkel 1997; Roth 2000). Francé, the son of a bank employee, very early studied analytical chemistry and micro-technology, although his father coerced him to be trained in his own profession. At the age of sixteen years he became the youngest member of the "Königlich-Ungarische Naturwissenschaftliche Gesellschaft" (Royal Hungarian Society of Natural Science). When he had finished the academy of commerce in 1897, he catched up on his "Abitur" certificate (school-leaving exam) and studied medicine for eight semesters, disregarding the wish of his father. Thereafter, he became a scholar of the Hungarian protozoologist, Professor Géza Entz (1842–1919) at "Technical University of Budapest". During this time, he made fourteen botanical expeditions. Entz provided him an assistantship with the botanist, Professor Julius Klein, which made him independent of financial support by his father. From that time on, his work was characterized by the overall view of medicine, zoology, and botany.

Fig. 18: A portrait of Raoul Heinrich FRANCÉ.

In the following period, FRANCÉ worked on algae, flagellates, turbellarians and geologic questions. During this time, he was infected in the Hungarian swamps with malaria, a disease from which he suffered all his life. In addition, he had problems with tuberculosis. Thus, FRANCÉ had a labile health condition which, however, did not affect his creative energy. His monograph on Craspedomonaden (choanoflagellates), published in 1897, made him a well-known specialist among researchers in protists and is an important reference until today.

An early attempt of obtaining a doctorate failed because, as is told, the official professorate intended to teach the young whizz kid the lesson that anything in life should take time. Since he experienced restrictions by the university, he eventually turned his back to it (HENKEL 1997). In 1901 FRANCÉ, as a freelance writer in Munich, Germany, became one of the first staff of "Kosmos". He founded the "Mikrokosmos" and acquired an enthusiastic readership by these and other popularizing activities. An amazingly productive phase of life continued until his death.

In the beginning, writings such as "Streifzüge im Wassertropfen" (Wanderings through a Water Droplet) (Fig. 19a; FRANCÉ 1907), "Die Kleinwelt des Süßwassers" (The Small World of Freshwater) (Fig. 19b; FRANCÉ 1910) and "Das Leben im Ackerboden" (Life in Soil) (Fig. 19c;

Fig. 19: Covers from three among a large number of publications by FRANCÉ, addressing hobby microscopists in particular.

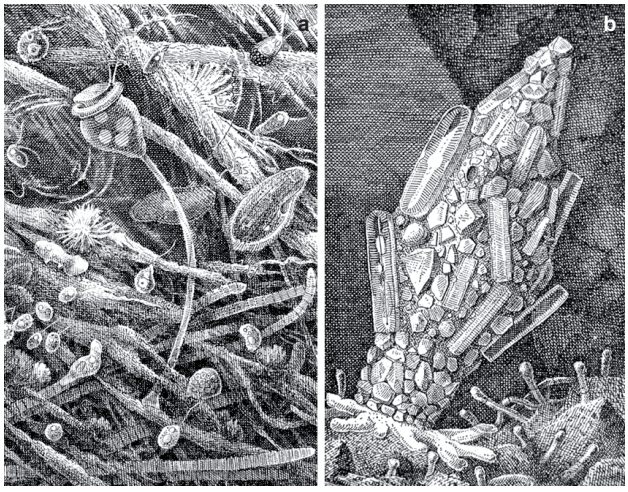


Fig. 20a,b: **a** – FRANCÉ's special drawings of microscopic animals as found in the waste waters of a sugar-beet factory. **b** – Testate amoeba from the soil.

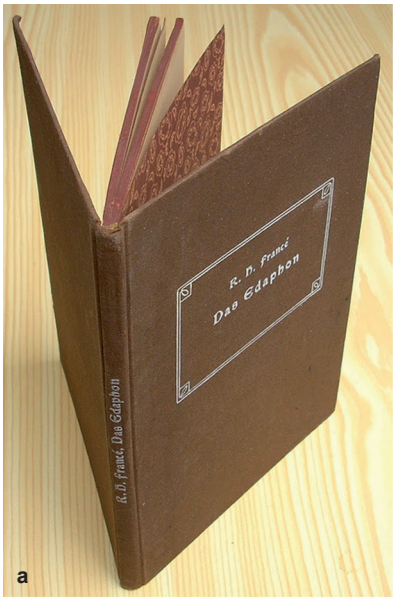
reproductions of his graphics, he developed a new technology of ink drawing on paper in the manner of copper engravings (Fig. 20).

It is difficult to imagine today the excitement of the readers of FRANCÉS books. At the turn of the century, the burgeoning, educated middle class was eager to know and understand science. Countless cultural associations were founded in cities and small towns. The book "Streifzüge im Wassertropfen" (Fig. 19a), as an example, appeared in early 1907 and was so enthusiastically received that the thirteenth edition came out as early as in July of the same year.

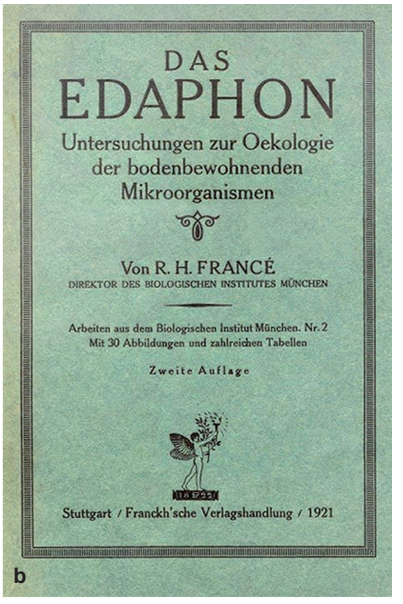
FRANCÉ understood the signs of his times and founded in 1907 the "Deutsche mikrologische Gesellschaft (DMG)", whose defined goal was the popularisation of the microscope. This society allegedly had 2,000 members in all of Germany within a few months, and 4,000 members in central Europe after short time. In 1907 FRANCÉ also founded the "Mikrokosmos", the "Zeitschrift zur Förderung wissenschaftlicher Bildung" (Journal for the Promotion of Scientific Education) (Fig. 21). FRANCÉ revealed a so far unknown facet of nature, when he thoroughly explored the common soil, which had been thought of as largely lifeless. He was a pioneer in discovering a hierarchy of small organisms which were comparable to those in various waters. For this biocoenosis he coined the name of "Edaphon" (as derived from Greek ἔδαφος = soil). His book "Das Edaphon – Untersuchungen zur Oekologie der bodenbewohnenden Mikroorganismen" (The Edaphon – Investigations on the Ecology of Soil-dwelling Microorganisms) (Fig. 22) appeared in 1913. Until today, it is considered a classic of soil ecology, and was repeat-

Fig. 21a-c: "Mikrokosmos", issue 3 and 4: **a, b** – of the first volume. **c** – with declaration of objective and purposes of the "Deutsche mikrologische Gesellschaft".

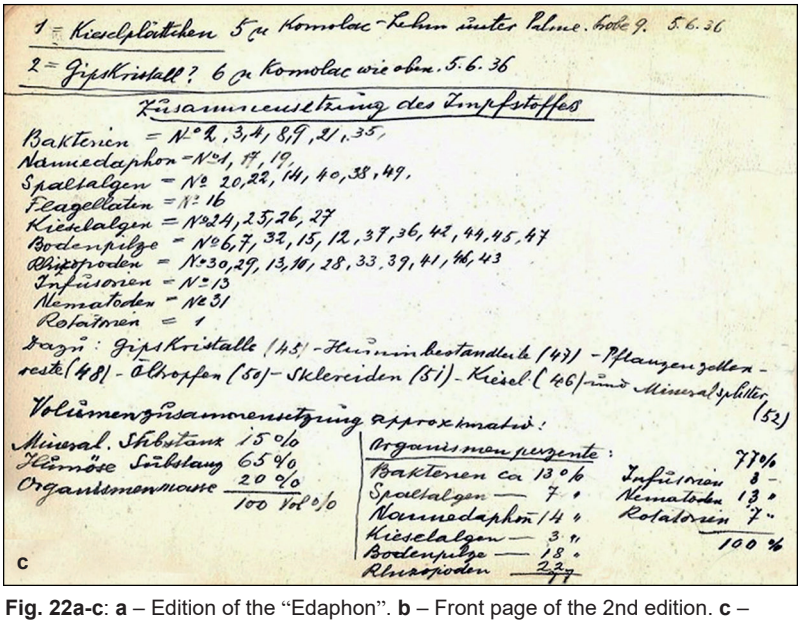
FRANCÉ 1922), specifically addressed the hobby microscopists. These volumes were illustrated by the author himself. In order to improve the



a



b



c

Fig. 22a-c: **a** – Edition of the "Edaphon". **b** – Front page of the 2nd edition. **c** – From the sketchbooks of Raoul Heinrich Francé (1936) are shown first handwritten descriptions of how soil may be inoculated with all groups of organisms.

edly reprinted, lately in 2012. The lasting effects on popular science of Raoul Heinrich Francé's activities to the good of amateur microscopists can hardly be overestimated.

We do not intend to go into more detail about the professional and private life of Francé, but we like to mention that he devoted himself to philosophical topics in his later years and was able to sustain his creative energy. He bequeathed a remarkable oeuvre: His more than 60 books were translated into 22 languages. The total edition in German language exceeded three million copies. In hundreds of essays he dealt with topics which are up to date still today (Aescht 1993; Pichler 2016).

Mikrokosmos: 1907–2014

Raoul Heinrich Francé launched and initially published the journal "Mikrokosmos" in the "Franckh'sche Verlagshandlung", Stuttgart, Germany, as the medium of the "DMG" (German Micrological Society). Two years later the editor and the publisher clashed on economic interests of the company. According to historical sources, mischievous fliers and advertising were written and distributed by the publisher and led to a definite breakup. Thereupon, the publisher once more edited the three starting volumes of the "Mikrokosmos" – allegedly because of the great resonance and demand. The revising editor was Hanns Günther (1886–1969; a pseudonym, actually Walter de Haas; Hilz & Schwedt 2002) (Fig. 23a). The revision essentially consisted of an elimination of any contribution by and reference to Francé. On the other hand, in the same volume of "Mikrokosmos", with all works by Francé erased, the publisher insisted to advertise the 4th volume of "Handbücher für die praktische naturwissenschaftliche Arbeit" of the series "Die Bibliothek des Mikroskopikers", written by Raoul Heinrich Francé. The latter person, for his part, was also active. He founded a counter-journal "Die Kleinwelt" (The Small World) with the publisher Huber in Munich, Germany,

which, however, was much less successful than the "Mikrokosmos".

In 1909 Dr. Adolf Reitz (1884–1964) accepted the editorial work of the "Mikrokosmos", which continued to be published in the "Franckh'sche Verlagshandlung". The change of editorship was not declared by the company. The editorship changed in 1913 to the then revisor Hanns Günther, and again this was not declared by the "Mikrokosmos", which continued to appear in the same publishing company. A few years later (1917) Dr. Georg Stehli (1883–1951) took charge of the position of editor. Also this change was not commented by the "Franckh'sche Verlagshandlung".

Georg Stehli now took care of the journal for three decades (Fig. 23b). His achievements of life are to be admired. He was completely deaf and was able to communicate with readers, authors and colleagues only by writing or by reading the lips. When Dr. Dieter Krauter (1926–2007) took over the editorship in 1951 as a recent graduate, this occurred presumably for reasons of age of Georg Stehli.

Dieter Krauter surpassed all earlier colleagues regarding his time as editor. He published the journal for 41 years, and ended his career only for age. Even as a retiree he continued to support the "Mikrokosmos". While the editorship by Dieter Krauter drew to a close, the "Franckh'sche Verlagshandlung" considered the cessation of the "Mikrokosmos", chiefly because of financial reasons.

By coincidence, Dr. Klaus Hausmann, Professor of Zoology and head of the working group "Protozoologie" at the "Freie Universität Berlin", got to know about these considerations. Since he had been feeling close to this journal for decades and was an author already for many years, he was not willing to accept the vanishing of this traditional organ of publishing. Finally, the "Gustav Fischer Verlag", Stuttgart, Germany, – no longer on the market today – responded to Hausmann's concern. Hausmann took care of the editorial work of the journal, apart from his university job, and was initially supported by the botanist Dr. Bruno P. Kremer of the "Universität zu Köln", Germany, as coeditor. Kremer retired from editorship after some time.

Naturally, the readers of "Mikrokosmos" were concerned of a possible "scientification" of the journal. This turned out to be unfounded. Still,

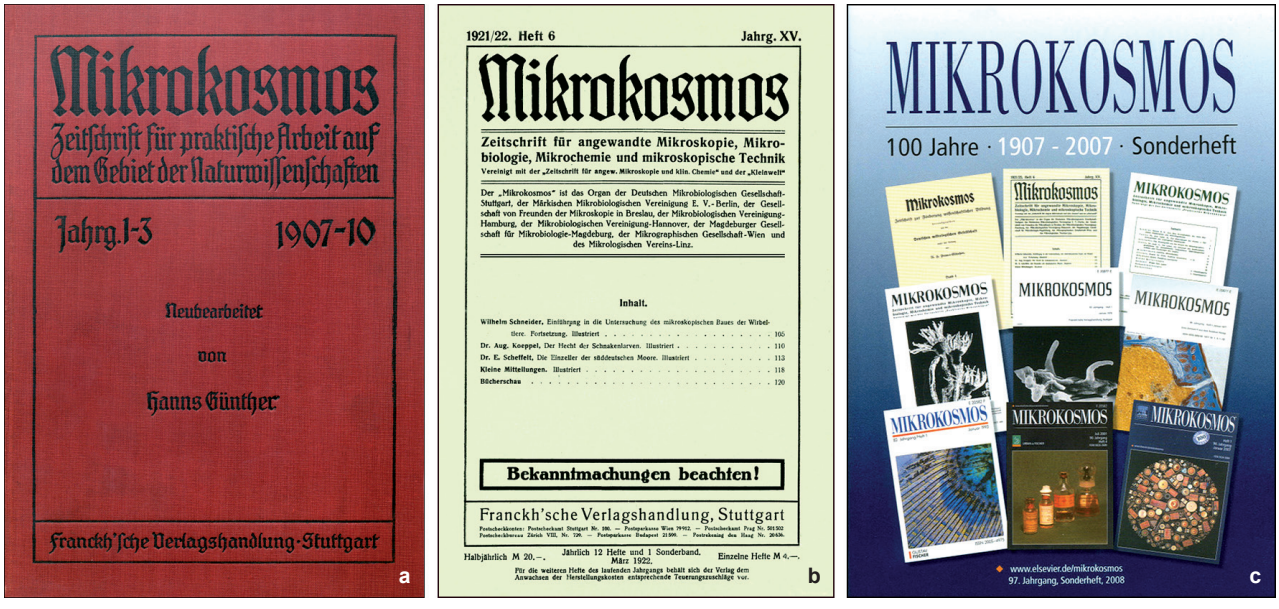


Fig. 23a-c: Title pages of "Mikrokosmos". **a** – Re-edition of journal in red linen with no reference to Francé. **b** – Issue 6 of volume 15). **c** – Special edition at the centennial.

the contents of the issues were characterized, as ever before, by manuscripts of readers of the journal and thereby primarily amateurs. The "Mikrokosmos" enjoyed loyal authors and readers, but the number of subscribers declined continuously because of the range of age of the subscribers. On the occasion of the 100th anniversary of its foundation (2007), a special edition of the "Mikrokosmos" looked back to the preceding decades, and a cautious forecast was given.

Meanwhile, the scenario of publishers changed due to various sale events, which also affected "Mikrokosmos". Thus, the journal eventually appeared under the worldwide giant among publishers, "Elsevier". Klaus Hausmann cont-inued as the responsible editor. Still, the ever lasting goal of the journal since its foundation, the bridging of science and interested laymen, had top priority. While incoming manuscripts and good articles were encouraging, the "Elsevier" company nevertheless decided to terminate the journal by the end of 2014 for explicitly economic reasons. A follow-up publisher was not in sight, and so, after more than 100 years, the end of this unique scientific journal of the German language area was definite.

The 20th century: a flowering period of associations in the German-language area

The "DMG" as founded by Francé in 1907 still exists as a vital "Mikrobiologische Vereinigung München (MVM)". This association considers itself as the oldest association of microscopists in Germany. Strictly speaking, it did not exist between 1919 and 1923, so that the present "MVM" started by 1923. Naturally, ups and downs occur during a long period of time. During the war time of 1914 to 1918 the "DMG" disintegrated because of internal disputes, and also because of the loss of club assets by inflation. However, by the 6th February 1923, in midst of the inflation, fourteen amateurs of microscopy in the area of Munich started again under the name of "Mikrobiologische Vereinigung München". They continued in the "MVM" what had been written once in the statute of the "DMG", "vor allem den Gebrauch des Mikroskopes volkstümlich zu machen, die Kenntnis der kleinsten Lebewesen und des feinsten Baues der Pflanzen und Tiere dem allgemeinen Verständnis zu erschließen, alle Freunde des Mikroskops zu gemeinsamer Arbeit zusammenzufassen sowie ihnen zum Austausch ihrer Erfahrungen und Präparate zu verhelfen" (in particular to popularize the use of the microscope, to develop general knowledge of the microorganisms and the fine structure of plants and animals, to unite all friends of the microscope for joint work, and to support the exchange of their experience as well as preparations).

Interestingly, this re-foundation was a concerted action. Within the same month, the "Freie Vereinigung von Freunden der Mikroskopie" started in Berlin from the "Märkische Mikrobiologische Vereinigung" (founded 1909), a union of microscopists, which unfortunately does not exist anymore.

The Munich association achieved acclaim and growth of membership due to numerous publications of members in the "Zeitschrift für wissenschaftliche Mikroskopie", the "Mikrokosmos", and the "Mikroskopie für Naturfreunde". On the 10th anniversary in February 1933, an anniversary issue appeared, which was completely designed by the Munich members. The "MVM" had a flowering period. Membership ranged between 35 and 60. The evening lectures and slide presentations were not rarely attended by more than 100 visitors.

After the chaos of World war II, the 38th issue of the "Mikrokosmos" appeared in 1948. In 1950 the club activities of the "MVM" also revived. Membership tripled from 22 to 65 between 1980 to 1995. This is remarkable because many groups of the so-called education sector experienced a dramatic loss of membership.

In 2007, the then 50 members celebrated the jubilee by an exhibition in the renowned "Museum Mensch und Natur" in the large side wing of the palace of Nymphenburg. Here, the current activities and the history of the association were shown in word and picture. Some short video films gave insights into the microworld.

Approximately at the time of establishment of the "DMG", that is in 1910, the "Mikrographische (later: Mikroskopische) Gesellschaft Wien (MGW)" was founded. The declared objective was "die Verbreitung naturwissenschaftlicher Kenntnisse über die Welt des kleinsten Raumes mit Hilfe des Mikroskops" (the dissemination of scientific understanding of the tiniest space by means of the microscope). It was the great upswing of natural science in the past centennials together with the desire of wide sections of the population to gain insight into the rich and beautiful world of the invisible. This generated a large community of enthusiastic microscopists and was implemented by numerous registrations. The annals of the "MGW" tell it: "Den unmittelbaren Anstoß zur Gründung des Vereines bewirkte ein Vortrag des bekannten Forschers und Verfassers zahlreicher gemeinverständlicher naturwissenschaftlicher Werke, Raoul Heinrich Francé, in der Wiener Urania" (The direct impulse of founding the association came from a lecture given by the well-known researcher and author of numerous books in popular scientific language, Raoul Heinrich Francé, in the Urania of Vienna). His lecture dealt with the "miracle world of the microscope".

Following World War I, the activities of the "MGW" declined considerably. The members successfully attempted to continue operations as far as possible under the circumstances. The "MGW" most suffered from the uncertain conditions of the immediate postwar time. However, after that time the society saw a renewed flowering. It even survived World War II. The activities continued in spite of heavy bombing of Vienna; amazingly there was even an increase in attendance of courses and lectures.

What we show here by the example of the "Mikrobiologische Vereinigung München", occurred in similar ways during the past decades: Societies were founded 1911 in Hamburg, Germany, 1933 in Antwerp, Belgium, 1946 in Zurich, Switzerland, and later in many other places.

Today it is easy to communicate with friends of microscopy. You can find like-minded people is cities such as Berlin, Bremen, Cologne, Constance, Darmstadt, Göppingen, Hagen, Hamburg, Hannover, Munich, Stuttgart, Tübingen, Vienna, Würzburg and Zürich (Fig. 24; Henkel & Hausmann 2008). Not to forget in this context are the most active and highly regarded sections of some Adult-Education-Centres or societies of natural sciences such as those in Bremen, Cologne or Hagen. Now, it is possible to find links in the internet connecting to associations of microscopists and micro-panels.

During the last decades weeks for microscoping have been offered in Germany at varying intervals, for instance the "Limnologiewochen" at Bodman (Lake of Constance), the weeks

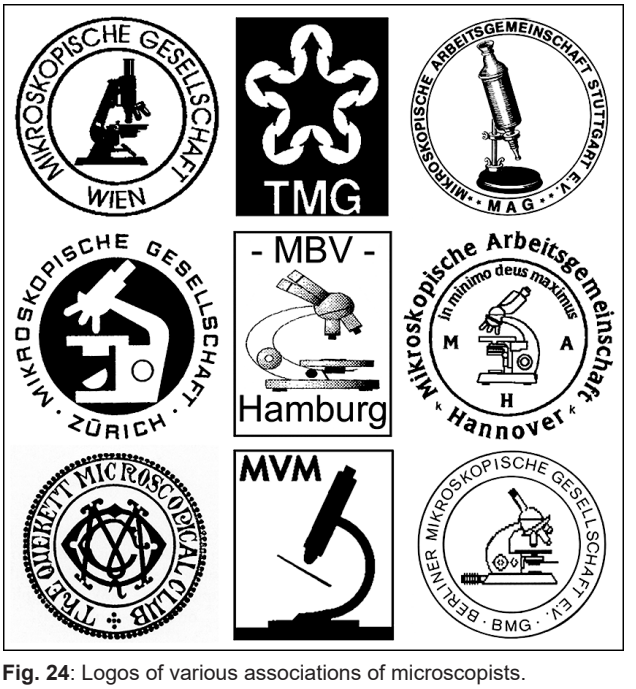


Fig. 24: Logos of various associations of microscopists.

Fig. 25a, b: Microscopy in practice. A "weekend of information" was organized at the Berlin Botanical Garden by the "Berliner Mikroskopische Gesellschaft". **a** – Demonstration of a high-end microscope by Klaus HAUSMANN. **b** – Practicing microscopy by junior scientists.

at "Kloster Heiligkreuztal" organized by the microscopists of Stuttgart, the meetings of the Working Group Microscopy Hannover at Wohldenberg, the Berlin Weeks of Microscopy as well as excursions to Helgoland, Hiddensee, and the lower valley of the Oder river. These crosstown and crossregional activities well contribute to cohesion of the microscopists.

As a rule, such week activities serve, to a large part, what is called in colloquial German "Tümpeln" (screening ponds for organisms using plankton nets). Numerous amateur microscopists love to look for unicells in water samples. In this context, the book "Leben im Wassertropfen" (Life in the Water Droplet) by Heinz STREBLE and Dieter KRAUTER is on the market since 40 years and considered "the" field guide (meanwhile in its 13th edition).

Some societies of microscopists organize – at varying intervals – public exhibitions which invite the visitors to practice microscopy themselves (Fig. 25). This is a way to open the small world of microscopy to a wider public. And again, it is not the professional microscopists, but the enthusiasts and dilettantes, who organize and carry out these activities.

Large-scale transfer of knowledge

In earlier times models of microscopically small organisms were produced as visual aids for academic teaching and for botanical and zoological museums. Here, the decimeter-scale glass models by BLASCHKA deserve to be mentioned in the first line. Unfortunately, a large part of these – originally several thousand – models got lost in the course of decades. In some university collections such as the Humboldt University of Berlin and the Eberhard-Karls-University of Tübingen, or in the world-famous museums of natural history (Cambridge, Ithaka, London, New York, Pisa, Vienna) a larger number of items may be admired (Fig. 26). Until today, the models are witnessing the unbelievable beauty and perfection of nature.

These realistic models were created by the glassblowers Leopold BLASCHKA (* 27 May 1822 in Český Dub (Böhmisch-Aicha), Czechia, † 3 June 1895 in Dresden, Germany) and his son

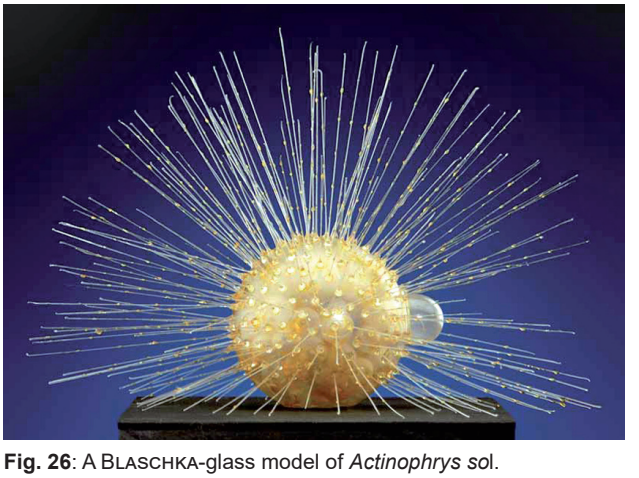


Fig. 26: A BLASCHKA-glass model of *Actinophrys sol*.

Fig. 27a,b: Porträts of **a** – Leopold Blaschka and **b** – Rudolf Blaschka (about 1895).

Rudolf (* 17 June 1857 in Dresden, Germany, † 1 May 1939, ibidem) (Fig. 27). The son Rudolf began to work in his father's shop at the age of thirteen years. These men created some thousand models of unicells, marine invertebrates and botanical objects, which were shipped to about 70 countries of essentially all continents (Europe, America, India, Japan and Australia) (Koch & Koch 2007).

Rarely, you will find larger sculptures of protists in the public, and if, they may not be recognized as representing unicellular organisms. As an example, in the Berlin Botanical Garden a 1.20 meter bronze sculpture arises from the centre of a pond representing the euglenoid *Lepocinclis tripteris*, which, in the absence of a written explanation, is occasionally misinterpreted as a potato chip (Fig. 28).

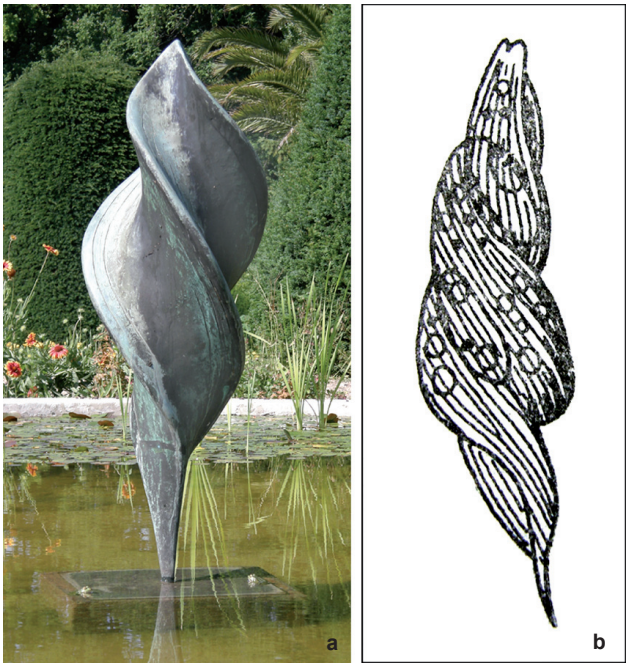


Fig. 28a,b: Natural art. **a** – Sculpture of the euglenid *Lepocinclis tripteris* in the Botanical Garden of Berlin. **b** – Drawing of the 50 µm long flagellate for comparison.

Once in a while, a web search may lead to an encounter of artists, who create large sculptures of protists. As an example, the Englishman Alan Ross of Herforeshire comprises a wide range of biological topics starting with fishes, amphibians, reptiles, over to insects, flowers, up to abstract human bodies. Unique in his collection are two radiolarians (1.8 meter and 2.5 meter, respectively) and a 1-meter diatom (Fig. 29).

In Sanxiang Township, Zhongshan City, Guangdong Province, China, there exists a park, which displays more than hundred sculptures made of sandstone, granite or marble. These pieces of art represent giant, true-to-nature copies of foraminiferans, which

Fig. 29: Large sculptures by Alan Ross depicting protists. **a** – Radiolarian. **b** – Diatom.

Fig. 30: Professor Shouyi ZHENG created graceful models of foraminiferan shells which have sizes of several decimeter.

are reminding in some way of works by Henry MOORE. Initiator of the exhibition is Professor Dr. Shouyi ZHENG (* 20. Mai 1931 in Manila, Philippines), a female scientist, now close to 90 years of age, who went to China at the age of 25 years. In the city of Qingdao, Institute of Oceanography, she worked on foraminifera as a member of the "Chinese Academy of Science" until her retirement in 1980. Beyond her retirement, she still continues her activities in her former institute.

Mrs. ZHENG showed a great number of models of foraminifera of the size of a palm of a human hand (Fig. 30). Templates were foraminiferans from all over the world, from five oceans and from countries such as America, Cuba, France, Italy, Russia, New Zealand and – of course – China. These models were created primarily for academic teaching, but also for interested people in general.

The history of this impressive park is not well known. Obviously, a high-ranking person of the international scientific community, being much impressed by the models of Mrs. ZHENG at the occasion of a laboratory visit, suggested to create a park for the wider public. Thereupon, Shouyi ZHENG, a lady of amazing energy, was able to convince the relevant politicians of her home town Zhongshan that the idea of a "Park of Foraminiferans" must be put to reality. Thus, a number of stone masons was busy during a period

Fig. 31: The sculpture park of foraminiferans in Zhongshan, China.

of five years, under the strict supervision of the lady scientist, to create sculptures according to nature. Of course, this installation represents more than a sheer illustration for academicians.

The park, embedded into a hilly environment of the size of several acres, has grown to become a great attraction of the local people, in particular of school classes. At the same time, the park receives international acknowledgement. It gives an example, how the small world under the microscope, using impressive models, may be made accessible to wide parts of the population (Fig. 31).

Challenges of microscopy and art

Considering the Chinese park of foraminifera, it is obvious that a scientifically exact, true-to-nature representation on the one hand, and an artistic reproduction which is easy to grasp on the other hand, are not easy to separate from each other. A layman who looks for the first time through a microscope, may think that his observations of a particular preparation are from a world of wonders. Why should we be surprised that some people and their artistic productions are abiding, more or less visibly, in this zone of transition?

Many amateur microscopists are deeply gratified by making aesthetically rewarding photographs of the microscopic world and transforming those to large-scale pictures. They display them in their home or in exhibitions, and eventually offer them for sale. In most cases, however, this activity is a demanding hobby, and only in rare cases the artist is able to generate a lasting income from selling microscopic pictures.

From autodidact to internationally renowned photographer

It sounds rather fabulous, but for Manfred P. Kage (* 4 October 1935 in Delitzsch, near Leipzig, Germany), this is reality: He can make his living using the microworld (Kage 2014–2016). He loved structures in nature already as a child. About sixty years ago, the trained engineer of chemistry decided to engage in professional microphotography. What started humbly in a flat of Winnenden (Wurttemberg, Germany) in 1959, continued 1972 as "Institut für wissenschaftliche Fotografie" (Institute of Scientific Photography)

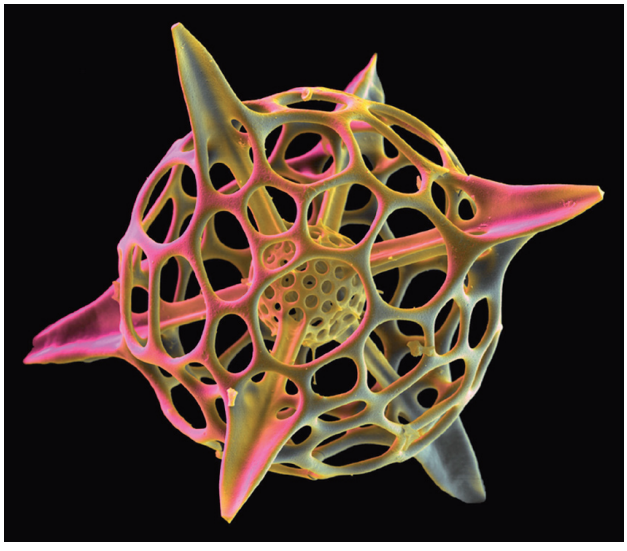


Fig. 32: Globe-in-globe radiolarian skeleton exhibited by scanning electron microscopy (SEM).

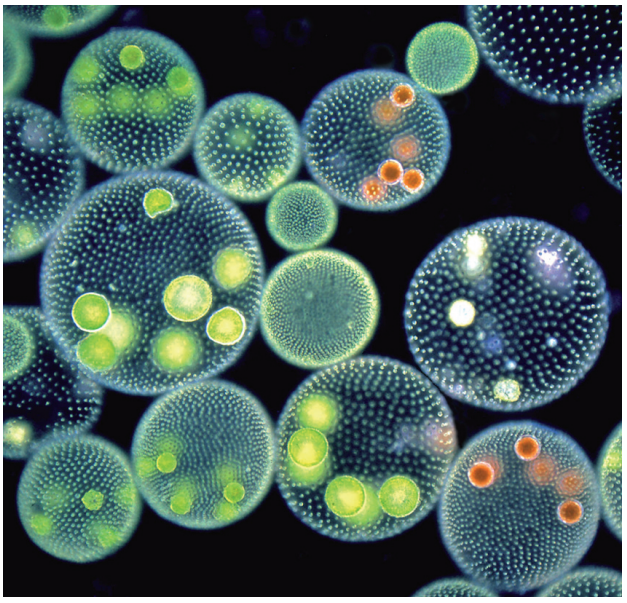


Fig. 33: The green alga *Volvox* in dark-field microscopy.

Fig. 34: Front pages of the so far published "KAGEs fantastische Mikrowelten".

in the "Castle of Weißenstein", Lauterstein. KAGE had a kind of elusive enthusiasm to design an incredibly versatile institution of microphotography in those historical, 500 years old walls. His deep knowledge of optics and techniques of microscopy emerged, step by step, largely by self-study. At that place, you may meet with an unbelievable multitude in devices of microphotography, as is told in and referred to in the internet.

If, as a visitor of the "KAGE Company", you wish to change from one to the next method of microscopy, you just change the workplace. During a brief visit it is hard to know the origin of the instruments. In part, they are aged pieces being top-ready however for high-quality professional use. There are systems and technologies, which are unfamiliar today. Who would be able, for instance, to operate the interference contrast microscopy by JAMIN-LEBEDEFF? This is no problem in the KAGE-castle. There are numerous cabinets and showcases, rich sources of optical accessories, and a fully equipped shop of precision mechanics, all accessible for repair and development.

The "Institut für wissenschaftliche Fotografie" does not accumulate historical devices only. There are as well top-quality microscopes of today's generation, such as digital photography and techniques of image processing. The fully operative darkrooms for analogue photography have been largely replaced by high-performance computers.

Since the very beginning of activities in the "Schloss", a scanning electron microscope (SEM) has been a central tool. This was uncommon at that time when SEMs occurred in research laboratories rather than in private labs. Manfred KAGE did the step of transforming objects of SEM from black-and-white to colour. He was able to introduce a gamma discriminator and colour filters naming the result "SEM-Color" (Fig. 32). Nowadays, the computer-supported colouration of SEM-pictures is a standard of producers. At that time, it was a pioneering accomplishment, – one out of many innovations by KAGE.

Again Manfred KAGE was one of the first providers of large-scale (DIN A0 plus) transparencies of microscopic crystals from chemical substances for light boxes at trade fairs. These boxes were the predecessors of the multi-monitor displays which then attracted much attention as being equipped by KAGE with top-quality micrographs. Sure, this does not sound too exciting today but it was a top achievement at that time. Today, there is hardly an institution in the German-language area, or even worldwide, which would be comparable to the "KAGE-Schloss".

The KAGE-productions entered a large number of school books and contributed to a timely and lifelike representation of the microscopic dimensions (Fig. 33). There are, for instance, special books on the generation of integrated circuits (chips), which KAGE was able to put into effect in cooperation with the corresponding companies. For the interested layman KAGE

Fig. 35: The colpodid ciliate *Bresslauides* as seen in SEM. Note occasional preservations of ciliary waves due to instantaneous fixation of the cells.

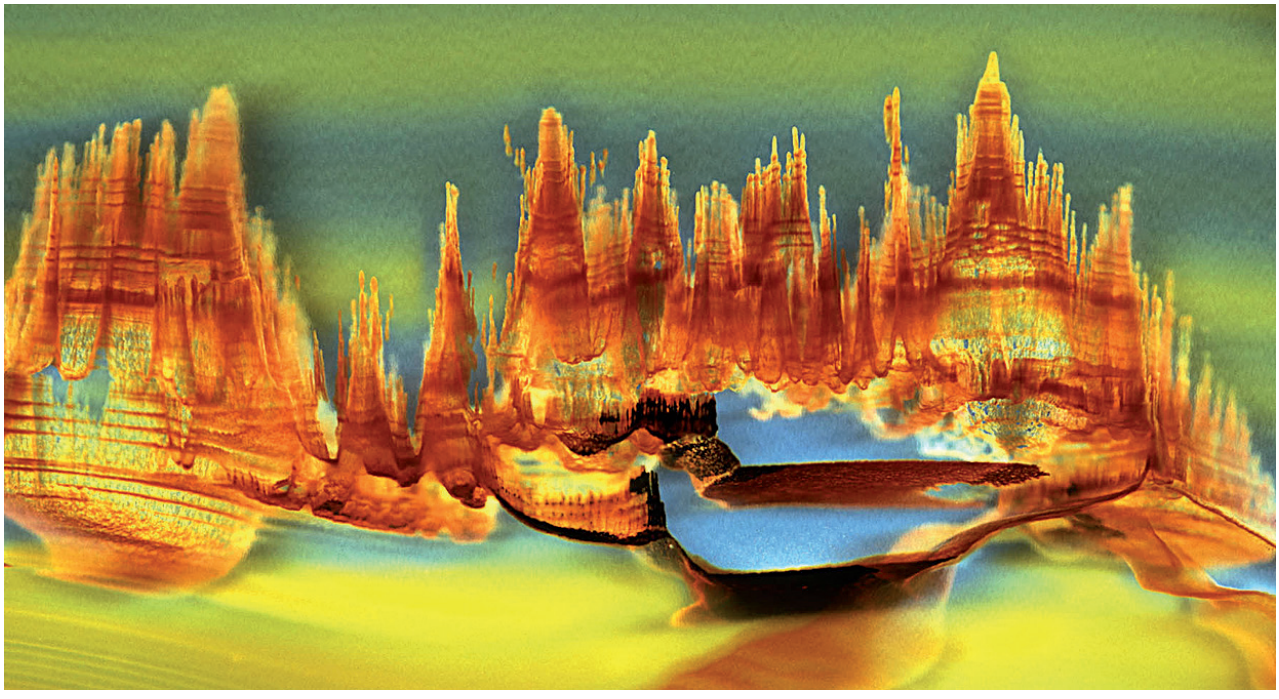


Fig. 36: Slice of landscape agate as seen in combined incident and transmission illumination. Note the "landscaping" distribution of colourful crystals.

started the book series "KAGEs fantastische Mikrowelten" (KAGEs Fantastic Micro-Worlds) (KAGE & KAGE 2010, 2012, 2013, 2014) (Fig. 34).

Beyond the production of micrographs the "Institut KAGE" engaged in the U-matic technology and established a special studio for exposure and processing of videographs of eminent quality. This technology is obsolete today but was, in those days, the ultimate of video documentation. Meanwhile these documents have all been transformed to current digital formats and are employed in TV productions to visualize processes in the microscopic dimension. A considerable number of promotions by films as well as documentations of relevant activities in science is based on this material (Fig. 35).

Manfred KAGE was repeatedly honoured in the course of his life. As an example, we here mention the "Kulturpreis 2012", which is the most distinguished award by the "Deutsche Gesellschaft für Photographie".

For the record, we should like to emphasize that for Manfred KAGE the processing of micro-objects is a challenge for achieving both, the technically optimal representation of facts and its combination with a considerable artistic aspect (Fig. 36).

Decorative arrangements, an art sui generis

Looking at "Legepräparate" (decorative arrangements of little things), in particular so-called "Salonpräparate", the impression is that such arrangements are kind of an amusement for lovers of the microscopic "Augenergötzung" (delight of eyes) but surely no objective among scientists. This is true for the salon preparations as shown here (Fig. 37). During the 19th century it was fashionable in upper-class circles to organize regular meetings of artists, philosophers and scientists. These salons were arranged by the lady of the house, whose social prestige rose with such arrangements. At the same time, a respected field of activity was opened. There were discussions and demonstrations of exotic rarities, among them the salon preparations mentioned above. Artistic layers of decorations were shown exhibiting beautiful geometric patterns or even compositions of diatoms,

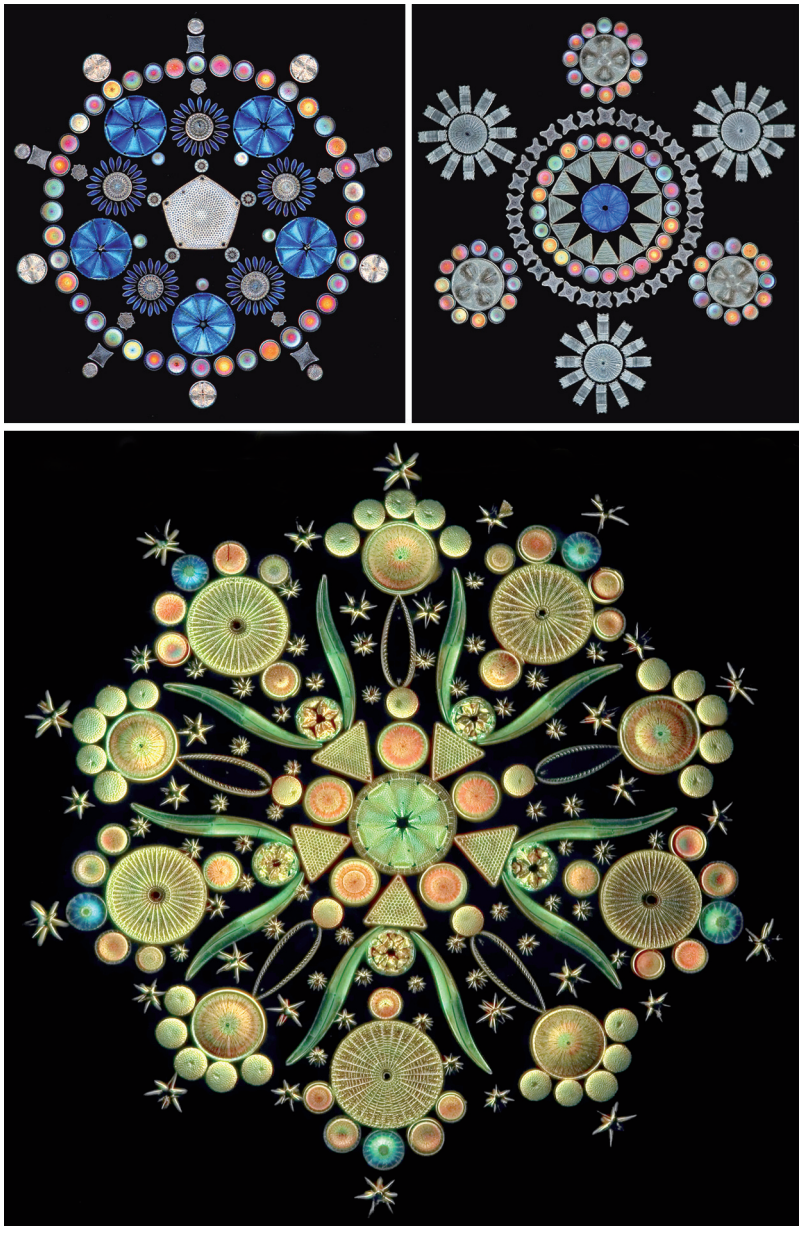


Fig. 37: Examples of geometric "Salonpräparate" of diatoms.

scales of butterflies and small pieces from marine animals. The patterns were viewed by means of highly decorated microscopes at weak magnification. Thereby, single elements may have appeared in marvellous interference colour (Kranz 2009).

We may ask if these activities were just for fun. Originally, the "Legepräparate" were circular (Fig. 38), later rectangular plates of types (Fig. 39), and eventually, serving scientific needs, plates for testing purpose (Fig. 40) .

Circulars and plates of types such as test-diatoms served for identification of species, or they were used for tests of resolution power of microscope objectives (Fig. 40). Using the known lattice pitches of special well identified diatoms, the resolution of any microscope was verified without further equipment.

Johann Diedrich Möller (* 15 March 1844 in Wedel, Germany, † 29 October 1907, ibidem); was a master of this method (Rienitz 1994). During his school time, he was already interested in optics. Trained as a painter, he was able to work privately in the shop of the optician Hugo Schröder (1834–1902) during his free time. In 1864 he established a shop of his own in his parental home which was the beginning of the today's company "J. D. Möller Optische Werke in Wedel (Holstein)". Möller initially produced lenses, prisms and projection pictures for "Laterna Magica". When he succeeded to construct a microscope by himself, he manufactured microscopic preparations as the major source of his income (Rosenbauer 2003; Burba 2007). He also produced salon preparations for amateur microscopists (Burba 2009), plates of types of diatoms, and testing arrangements for scientific use, advertising them in the print media (Fig. 41). These preparations received high professional acclaim and his productions were awarded with numerous medals. The climax was the „Universum Diatomacearum Moellerianum" in 1890, displaying 4026 species of diatoms in 133 rows on a plane of 6 x 6,7 millimeters (Burba 2009; Kranz 2009). Today only a few

Fig. 38: Circular preparation of radiolarians in darkfield illumination.

preparateurs can master the art of professional laying, Their objects may be still obtained from specialist shops. There are even a few private persons, such as Klaus-Dieter KEMP, a German born micro arrangeur from Blautannen, England (HAUSMANN 1996), who can design and manufacture "Legepräparate" according to special ideas, even – if asked for – a bicycle (Fig. 42).

The microcosm represented in gold, silver and plastics

There have always been people desiring to unite science with art. A prominent representative of these visionaries is Professor Dr. Ernst HAECKEL (* 16 February 1834 in Potsdam, Germany, † 9 August 1919 in Jena, Germany) who published his fascinating "Kunstformen der Natur" (Art Forms in Nature) (HAECKEL 1899–1904) and presented the beauty of nature to a wide public. Some more recent persons walk in the steps of this doyen trying to demonstrate the

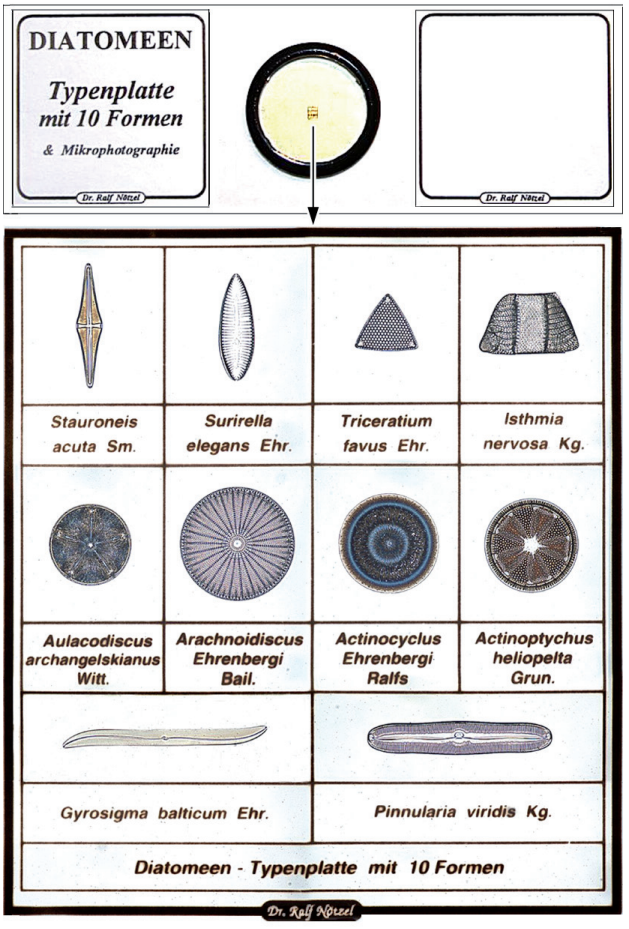


Fig. 39: Type plate of diatoms.

harmony of science and art. An example is Robert KRAUS (* 20 March 1965 in Dorfen, east of Munich, Germany) whose vita includes the studies of biology, diploma, doctoral thesis on cactuses with a research year in Chile, and assistantship at the Ludwig-Maximillian

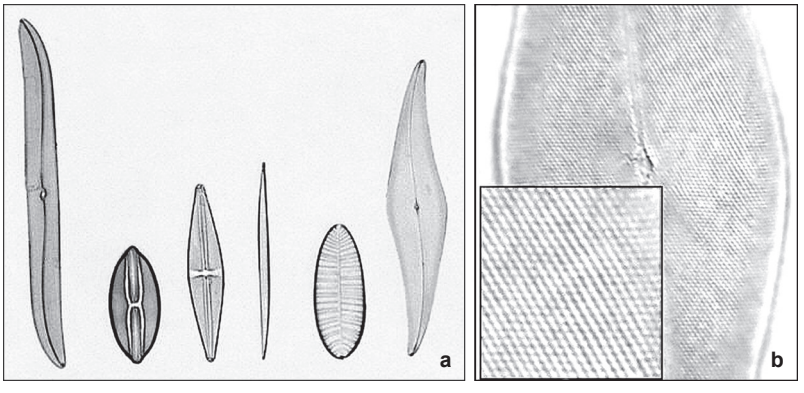


Fig. 40a,b: Typical diatoms for testing purposes. **a** – From left to right: *Gyrosigma balticum*, *Navicula lyra*, *Stauroneis phaenicenteron*, *Nitzschia sigmoidea*, *Surirella gemma*, *Pleurosigma angulatum*. **b** – High magnification of *P. angulatum* exhibiting well resolved microstructures (inset).

Fig. 41a,b: Advertisements of microscopic preparations in the nineteen fifties, as published in "Mikrokosmos". **a** – Target: amateurs. **b** – Target: scientists.

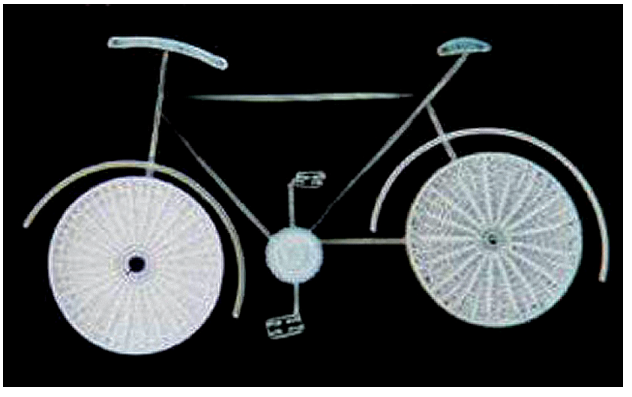


Fig. 42: An artful miniature "bicycle" constructed by Klaus-Dieter KEMP of the diatoms *Arachnodiscus* and *Nitzschia*.

University in Munich. Thereafter, with great enthusiasm, he returned to Chile and became Assistant Professor at the Universidad de Concepción. Regretting this premature step, KRAUS soon returned to Munich deciding to turn his back to the university. He then was a guide in nature travelling and expeditions in South America for several years. He was not fully satisfied with these activities, remembering his artistic abilities. He learned the basic techniques of goldsmith crafting, in particular the lost wax casting process. Since 2000, he acts as a freelance artist producing "Edlen Schmuck nach Vorbildern der Natur" (fine jewellery after models in nature). His motives are manifold, from microscopic details up to the macrocosm, from macromolecules, delicate diatoms, amoebas and radiolarians (Fig. 43) over delicate leaves, cross sections of plant stems, to sharks and whales to be crafted into necklaces, ear rings and brooches. Biological structures are metamorphosed to art from the finest materials such as gold, silver, gems, nacre and wood. His maxim is that the expert must be able to immediately identify his handcrafted piece of art (Fig. 44). A certificate documents the natural model.

Going quite different ways Kimberly FALK (* 25 August 1964, Spokane, WA, USA) creates art

Fig. 43a-d: Various protist gems by Robert KRAUS. **a** – Amoeba *Gephyramoeba* spec. **b** – Dinoflagellate *Ceratium hirundinella*. **c** – Amoeba *Mayorella vespertilio*. **d** – Coccolith of the flagellate *Eimiliania huxleyi*.

Fig. 44a-d: Further pieces of protist jewellery by Robert KRAUS. **a** – Radiolarian *Saturnalis circularis*. **b** – Radiolarian *Heliodrymus dendrocyclus*. **c** – Foraminiferan *Lagena auriculata*. **d** – Foraminiferan *Pavonia flabelliformis*.

of comparable result. This graduated biologist builds her wax models by 3D-printing technology to produce the cast (Fig. 45). The creative step of handcrafted modeling is replaced in part by the computer.

The digital documentation of data allows a scaling up of graphic editions such as production of Christmas tree decorations made of white plastic (Fig. 47). Or you may order from the artist a china box and cover shaped as a dinoflagellate to store sweets. The American artist Kimberly FALK studied biology and graduated on a topic in plant physiology. In 1997 she moved to Jena, Germany, for private reasons and was a scientific member of the "Max-Planck-Institut für Chemische Ökologie". When she abandoned this career as a mother of two daughters in 2010, she nevertheless decided to pursue the scientific track. So she specialized on computer-generated illustrations and animations for scientists, who like to visually enhance their lectures and presentations. She also engaged in 3D-printing technology for creating jewellery. The major provider of ideas was Ernst

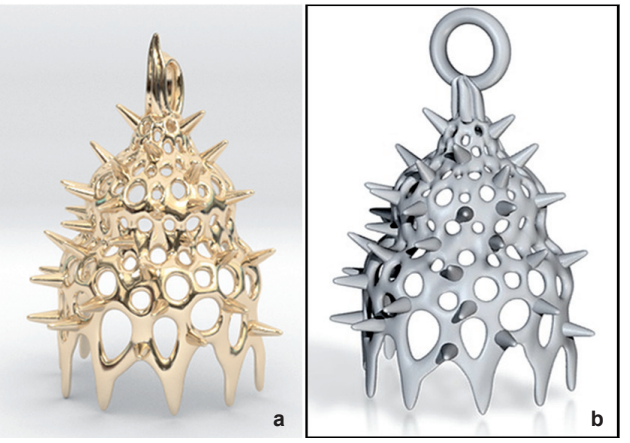


Fig. 45a,b: 3D-printing principle of producing jewellery from protist models. **a** – Kimberly FALK employs digital data of the radiolarian *Calocyclas* to generate a golden piece of decoration. **b** – The same digital source may be used for printing larger items of white plastics.

HAECKEL with his "Kunstformen der Natur", which is no surprise with her residence at Jena.

Anybody searching the worldwide internet will meet with persons, who produce pieces of art from microscopic observations which they are able to transform. Rarely, these artist and their high-quality creations are known transregionally. Comparable to microphotography, there are only a few, who can make a living out of their activities.

Fig. 46a,b: Radiolarians as plastic Christmas tree decorations: **a** – *Anthocyrtium* and **b** – *Spumellaria*.

Bacteriality, a novel art form

Finally, we would like to present an artist, whose productions do not tell, at first glance, how they are related to microscopy. Wolfgang GANTER (* 22 June 1978 in Stuttgart, Germany), does not

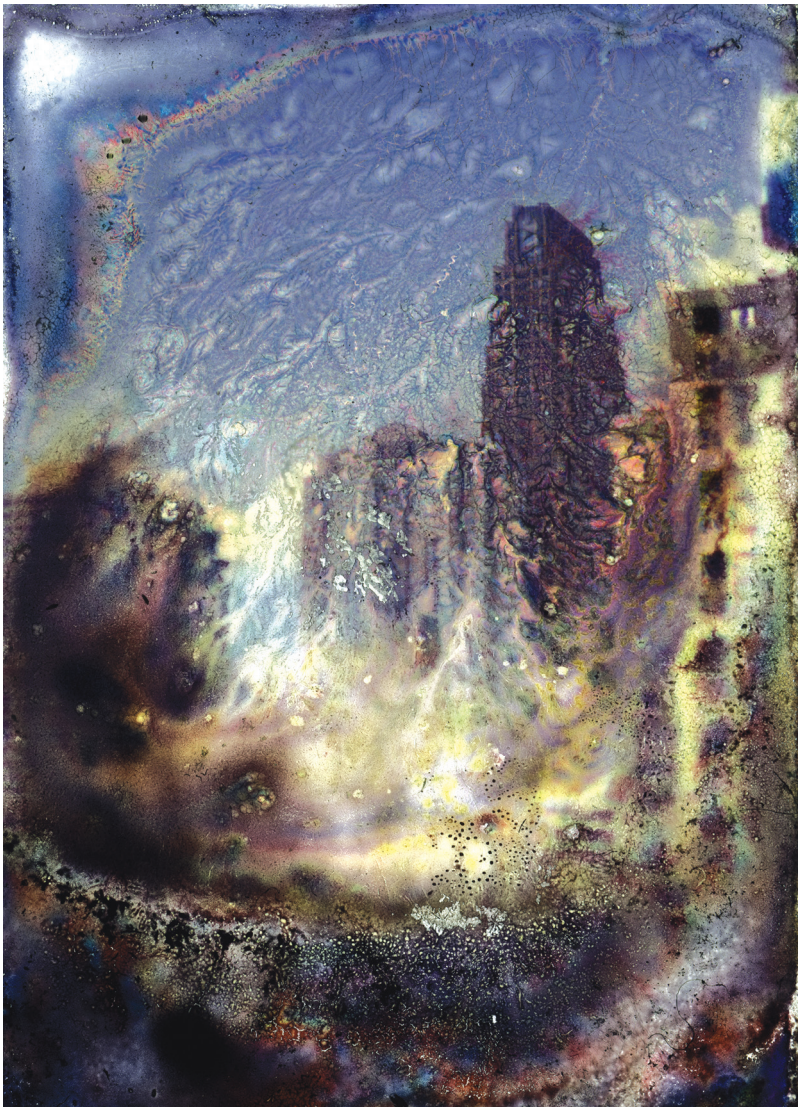


Fig. 47: Microbial creations of art: The gloomy impression from bacterial decomposition may be associated with paintings by William TURNER or Claude MONET.

involve himself into microscopy to translate observed things into art. To the contrary, he is using bacteria, microscope, computer and plotter just for tools comparable to colours, brush and scraper as used by other artists.

Wolfgang GANTER lives and works in Berlin since 2006. He studied at the "Staatliche Akademie der Bildenden Künste Karlsruhe", Germany, was honored by stipends and won numerous awards. He successfully presents his works in national and international galleries and exhibitions.

The artist collects slides since a couple of decades, which are then estranged artificially. It is a goal of his work to transform his templates, actually, to destroy them by bacterial degradation. The resulting artwork is a matter of square meters. The incredible resolutions of these pictures cannot be achieved with a conventional scanner. It is rather the result of microscopic photography. The entire slide is subdivided, after bacterial treatment, into hundreds of single photographs at relatively low magnification, but very high resolution. These separate pictures are then put together again using a conventional stitching computer program. A professional pigment printer plots the recomposed giant picture. As a final step, the picture is put on top of a wooden box and sealed with a crystal clear plastic surface. The result is overwhelming to the viewer.

It is unknown, what is going on with the slides in the presence of the bacteria. The bacterial species are unknown; they may occasionally give rise to red and watery eyes of the artist. Unknown is also the special influence Wolfgang GANTER takes in this process. There remain open questions.

GANTER names his art "Bakterialität", and calls the result of his performance a "casus coactus", that is, a "forced coincidence", which, as a contradiction, may not happen at all.

The results of bacterial decay of slides are so diverse and multifaceted that a representative summary of GANTER's oevre cannot be given in this report. Therefore, we present only two examples of his work which may allow us to perceive the

Fig. 48: Microbial artistics: The original picture's message of the transparency has been transformed by bacterial activity to a new abstract image.

range of his results. First of all, with the motive of the slide being essentially preserved, there are strong variations in colour intensity. The various monochrome layers of colour of a colour slide appear to be left essentially intact but modified in intensity. This does not apply, however, to other cases, where the colour sheets appear as being modified suggesting new intervening sheets with structures of their own. Again, the original picture can only be conjectured. Colours and contours may be imagined (Fig. 47). Finally, there are results of bacterial pictures, which do not tell anything of the former slide. There appears an original abstract picture (Fig. 48). It exists a great variety of modifications and alternatives between the two examples presented here.

Building a large bridge

It may be a unique event worth mentioning that microscopy, in particular protistology, was able to enter the "sacred space". The "Kulturinitiative Narrenschyff" of Linz opened in October 2011 the exhibition "GEN 7" under the essential participation of the Austrian artist Walter Gschwandtner. This exhibition took place in a church, where, instead of the common altarpiece, a large picture of the ciliate protozoon *Metopus* was installed (Fig. 49).

"GEN 7" relates itself to the bible, Genesis 7. Here, the story is about the construction of Noah's arch. Consequently, a huge arch had been mounted at the ceiling of the church inspiring archaic associations. The project was respectfully accepted by the interested visitors of the exhibition. An unprepared worshipper may have been irritated, in particular because of the huge ciliated animal, *Metopus* as altarpiece (Foissner 2012).

Fig. 49: A large-scale altarpiece of the ciliate *Metopus*.

From autodidacts to recognized scientists

There have always been scientists who were active in research as well as in popular science. On the other hand, there were laymen who were able to focus on a particular question in protistology or a specific group of unicells. They worked their way into the material as autodidacts, that is in the absence of a university background and acquired a special knowledge for which many professionals might envy them. Even more, they did not keep their results of research for themselves but published them in high-ranking organs of science. Thereby, they opened them to the science community so that they are useful for reference until today. Looking on the past and the present century a number of such personalities are found in the German-language area.

Alfred Kahl

The first to tell is Alfred Kahl (* 18 February 1877 in Warwerort, Germany), † 20? November 1946 in Hamburg?, Germany). We do not know much about his family and his living environment. He was married and had a daughter called Lucia. He was a teacher in an Elementary School and later in a Gymnasium with the subject English, French and natural science. At fifty years of age he published his first 241-page monograph on ciliates in "Archiv für Protistenkunde" (Kahl 1926). In the introduction he explains his motive for these investigations as follows: "Die Anregung zu dieser Arbeit verdanke ich Herrn Prof. Dr. E. Reichenow vom Tropeninstitut zu Hamburg; zwar nicht unmittelbar, sondern durch Vermittlung meiner Tochter, die als Studentin mehrere Semester an den Vorlesungen wie an den praktischen Übungen des genannten Herrn über Protistenkunde teilnahm. Die außerordentlich interessanten Berichte und Präparate, die sie mit nach Hause brachte, wie auch die Literatur ... fesselten mich als alten Biologen sehr und erregten in mir den Wunsch, mich selbständig in dieses Gebiet zu vertiefen" (I owe the incitement to this work to Professor Dr. E. Reichenow of the Tropical Institute Hamburg, that is, not directly, but by the intercession of my daughter, who, as a student, participated in the lectures and practical courses on protistology of this gentleman. She carried home most interesting reports and preparations as well as literature. I was, as a long-standing biologist, enthralled by these things and desired to delve into that subject matter on my own).

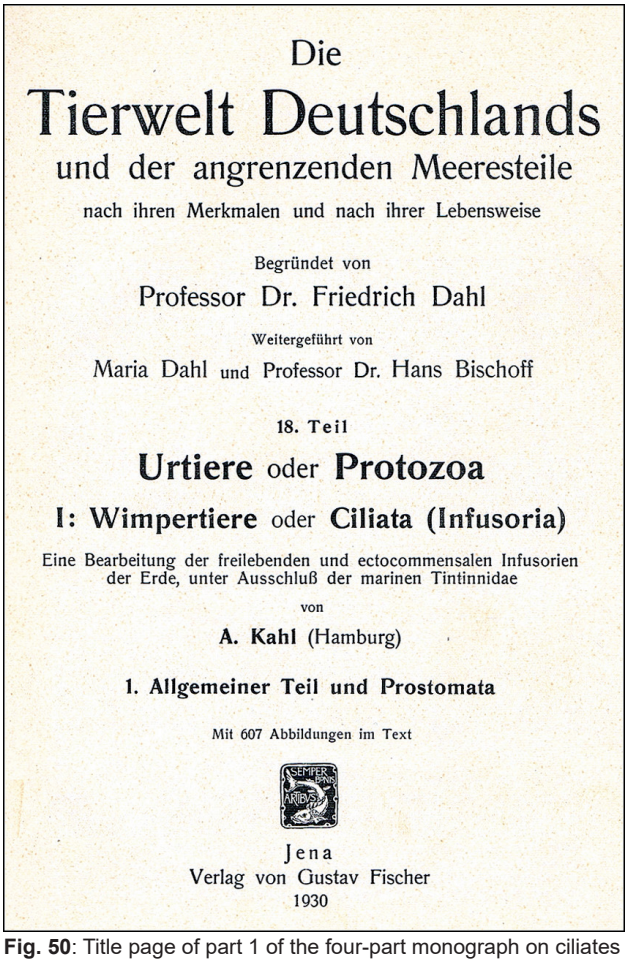

Die
Tierwelt Deutschlands
und der angrenzenden Meeresteile
nach ihren Merkmalen und nach ihrer Lebensweise
Begründet von
Professor Dr. Friedrich Dahl
Weitergeführt von
Maria Dahl und Professor Dr. Hans Bischoff
18. Teil
Urtiere oder Protozoa
I: Wimpertiere oder Ciliata (Infusoria)
Eine Bearbeitung der freilebenden und ectocommensalen Infusorien der Erde, unter Ausschluß der marinen Tintinnidae
von
A. Kahl (Hamburg)
1. Allgemeiner Teil und Prostomata
Mit 607 Abbildungen im Text
Jena
Verlag von Gustav Fischer
1930

Fig. 50: Title page of part 1 of the four-part monograph on ciliates by Alfred Kahl.

Kahl started in 1924 to fish with a plankton net in ponds and ditches of the immediate environment. Within three quarters of a year, he internalized the techniques of cell catching and drawing on paper, which were essential for his investigations. Within no more than ten years Kahl published 21 comprehensive papers, predominantly in the

"Archiv für Protistenkunde". His monograph "Urtiere oder Protozoa. Wimpertiere oder Ciliata (Infusoria). Eine Bearbeitung der freilebenden und ectocommensalen Infusorien der Erde, unter Ausschluß der marinen Tintinnidae" (Kahl 1930, 1931, 1932, 1935) (Urtiere or Protozoa. Ciliata (Infusoria). A compilation of free living and ectocommensal Infusoria excluding the marine Tintinnidae) is a special highlight. This work continues to be an important reference for species identification until today (Fig. 50).

Around 1934/1935 Alfred Kahl abruptly ended his publishing activities for so far unknown reasons. There are speculations that he was frustrated from derogatory criticism by academic colleagues and referees of his manuscripts (Foissner & Wenzel 2004). His further history is not known.

Friedrich Hustedt

Friedrich Hustedt (* 15 December 1886 in Bremen, Germany, † 1 April 1968, ibidem) was the oldest out of seven children of the carpenter Carl Heinrich Hustedt. After eight years of elementary school he began an education for teacher at the "Seminar" in Bremen which he ended Easter 1907 with his first examination. During his time at the "Seminar" he was introduced into the world of algae by the phycologist Ernst Lemmermann (1867–1915), one of his teachers. Hustedt practiced teaching until 1939; he was primarily an art teacher, later he worked as a headmaster. He liked to work on freshwater diatoms, which he collected from the rivers and estuaries in areas of North Germany. As soon as 1927, 41 years old, he received the title of "Doctor honoris causa" (Dr. h. c.) by the Halle University for his anatomical investigations of diatoms.

The "Amt für Bodenforschung" (Office of Soil Research) had recognized the importance of his work for basic research of geology and approved his leave of absence from school service, so that he was able to fully engage himself to his research. As an autodidact he succeeded with the novel challenges, and was soon on a par with his colleagues.

Hustedt created the largest private collection of diatoms of his time which he completed by findings of friendly collectors. After his school era, he started a lifelong study of diatoms and identified about 2,000 new species. Some special abilities met in his personality: his remarkable sense of identification of form, his prominent talent for drawing, his good sense of systematics and his everlasting readiness for work. They all contributed to his huge and hardly imaginable achievements (Behre 1970; Garbary & Wynne 1996).

The results of his wide research were published in professional journals. Besides his original papers he also contributed to summarizing reports. Here, the volume VII of "Die Kieselalgen" (Hustedt 1936) as part of the "Kryptogamen-Flora" by Gottlob Ludwig Rabenhorst (1806–1881)

Fig. 51a-c: **a** – Preparations by Hustedt. **b** – Front page of book by Friedrich Hustedt on diatoms. This book appeared as part of "Kryptogamen-Flora" by Rabenhorst. **c** – The title of "Kieselalgen (Diatomeen)" is part of the series "Einführung in die Kleinlebewelt" (Introduction into the Microbial World) by Hustedt and applies primarily to amateurs.

(Fig. 51b) is worth mentioning; it is still in use today. HUSTEDT wrote the volume "Kieselalgen (Diatomeen)" in the series of "Einführung in die Kleinlebewelt" especially for hobby microscopists (Fig. 51c; HUSTEDT 1956).

With advanced age HUSTEDT made sure that his opus would survive after his retirement. He therefore sold his collection of diatoms to the Bremen City on the condition that, after his death, this collection should be made accessible to interested scientists. In 1965 such workplace, the current "Friedrich-HUSTEDT-Zentrum für Diatomeenforschung", was established at the "Institut für Meeresforschung" in Bremerhaven, which became part of the "Alfred-WEGENER-Institut (AWI)" in 1986.

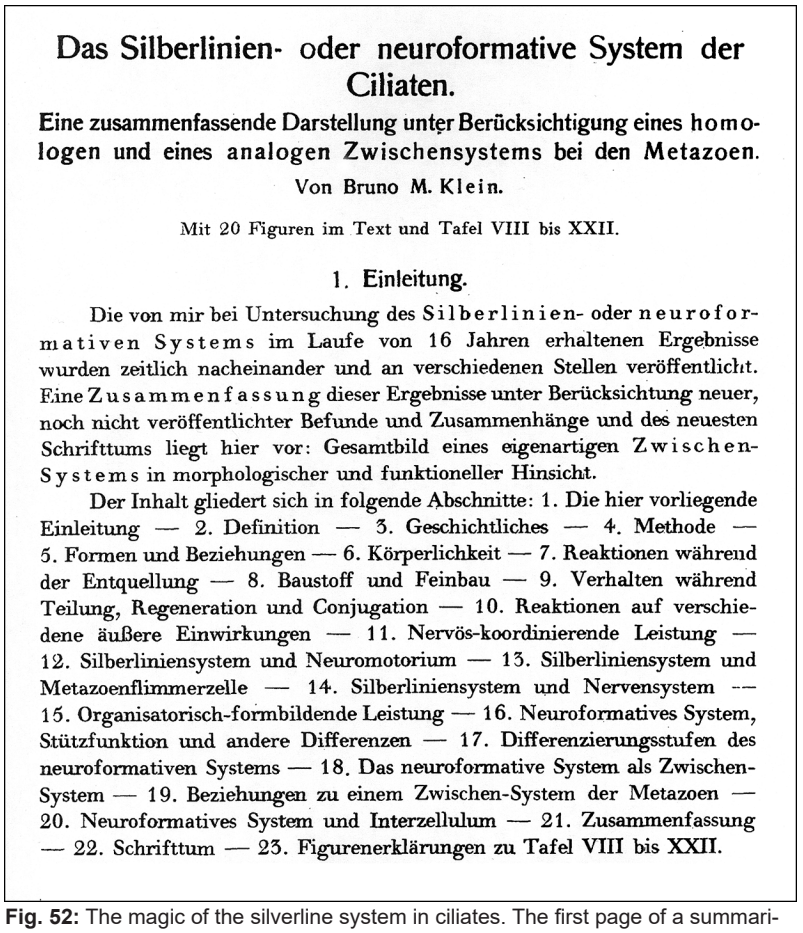
Meanwhile, this "Centre" is worldwide one of the largest and most precious collections of diatoms. HUSTEDT's collection of the "Centre" has been not only complete for more than 50 years but continuously grows by contributions from researchers of diatoms from all over the world, including donations of complete estates. Naturally, also probes of "AWI" scientists taken from their expeditions on the German oceanographic research ship "Polarstern" are given to the collection. Meanwhile, more than 100,000 preparations and 50,000 probes of diatoms are stored in carefully shelved wooden boxes. The "Centre" also houses a substantial special library. In the last years the "Centre" invested in establishing a database of diatoms. Today, informations are be easily obtained from internet about a particular species, its discoverer, the site of discovery, the native ecology, its size and appearance.

Bruno Maria KLEIN

Bruno Maria KLEIN (* 19 August 1891 in Vienna, Austria, † 16 August 1968 in Wördern, near Vienna, Austria) was "eine sensible, künstlerisch begabte und wissenschaftlich hochaktive Persönlichkeit, deren vielfältige Neigungen und Interessen immer in das intensive Bestreben mündeten, dem Verständnis der Dinge und Vorgänge in der Natur durch intensive eigene Beobachtungen und Experimente näher zu kommen" (a sensitive, artistically gifted and scientifically most active personality, who focused his manifold inclinations and interests to the insatiable desire for understanding nature and its processes by own observation and experiments). With these words Josef EISELT characterizes Bruno Maria KLEIN (EISELT 1969), who in his boyhood already knew his ultimate goal, "researcher of nature". His father, Adalbert KLEIN, a specialist of security-technology at the "Artistisch-technische Staatsnotenatelier" of Vienna, gave him, at the age of fourteen years, the gift of a microscope, which opened to the boy undreamt-of worlds. Without a graduation of the middle school KLEIN initially worked as a trainee at a trader of animals dreaming of the profession of photographer, artist and journalist in this occupational field. These plans ended due to the chaos created by World War I.

Soon after the end of the war the parents of KLEIN died. A friend of his, the zoologist Otto WETTSTEIN (1892–1967), advised him to apply for the post of a dissector at the "Museum of Natural History" in Vienna. He was able to begin with this training by January 1921. His first assignment was the production of ink paintings of moulting in mammals. Because this work was very successful, KLEIN soon was assigned with illustrations for science. After some period of time, he shifted to the Herpetological Collection and became a lifetime civil servant by 1927.

With this position his old dream of researcher awoke again. In the evening, the daily duties in the "Museum" done, he privately devoted himself to microscopy. Originally, the neurohistology and applications of the silver staining method after Camillo GOLGI and Santiago Ramón y CAJAL were in the centre of his interest. In 1926, following intuition, he applied a 2% solution of silver nitrate to dehydrated ciliates and induced a chemical reduction by daylight. His first object



Das Silberlinien- oder neuroformative System der Ciliaten.

Eine zusammenfassende Darstellung unter Berücksichtigung eines homologen und eines analogen Zwischensystems bei den Metazoen.

Von Bruno M. Klein.

Mit 20 Figuren im Text und Tafel VIII bis XXII.

1. Einleitung.

Die von mir bei Untersuchung des Silberlinien- oder neuroformativen Systems im Laufe von 16 Jahren erhaltenen Ergebnisse wurden zeitlich nacheinander und an verschiedenen Stellen veröffentlicht. Eine Zusammenfassung dieser Ergebnisse unter Berücksichtigung neuer, noch nicht veröffentlichter Befunde und Zusammenhänge und des neuesten Schrifttums liegt hier vor: Gesamtbild eines eigenartigen Zwischen-Systems in morphologischer und funktioneller Hinsicht.

Der Inhalt gliedert sich in folgende Abschnitte: 1. Die hier vorliegende Einleitung — 2. Definition — 3. Geschichtliches — 4. Methode — 5. Formen und Beziehungen — 6. Körperlichkeit — 7. Reaktionen während der Entquellung — 8. Baustoff und Feinbau — 9. Verhalten während Teilung, Regeneration und Conjugation — 10. Reaktionen auf verschiedene äußere Einwirkungen — 11. Nervös-koordinierende Leistung — 12. Silberliniensystem und Neuromotorium — 13. Silberliniensystem und Metazoenflimmerzelle — 14. Silberliniensystem und Nervensystem — 15. Organisatorisch-formbildende Leistung — 16. Neuroformatives System, Stützfunktion und andere Differenzen — 17. Differenzierungsstufen des neuroformativen Systems — 18. Das neuroformative System als Zwischen-System — 19. Beziehungen zu einem Zwischen-System der Metazoen — 20. Neuroformatives System und Interzellulum — 21. Zusammenfassung — 22. Schrifttum — 23. Figurenerklärungen zu Tafel VIII bis XXII.

Fig. 52: The magic of the silverline system in ciliates. The first page of a summarising presentation by KLEIN of 1943. Note KLEIN's suggestions of a neuroid function of these cortex structures.

was *Chilodon uncinatum,* which revealed an overwhelming result. A delicate black pattern of lines had appeared which covered the entire cell surface. He called it the "Silberliniensystem" (silverline system). KLEIN interpreted this network as a primordial neuroid differentiation for coordination of ciliary activity and therefore called it "neuroformatives System". From today's perspective the discovery of the silverline system is most valuable for identifications of ciliates, although the neuroid properties of the silverlines could not be confirmed. KLEIN much invested himself into this system in the following years and studied its properties during cell division, conjugation, development, regeneration and in deformities. He published his results in "Mikrokosmos" and corresponding journals. His 280-page review paper "Das Silberlinien- oder neuroformative System der Ciliaten" (Fig. 52) gives an impressive record of his scientific activities (KLEIN 1943). Since KLEIN did his experiments primarily in ciliated protozoa, he became a superb expert of ciliates. The University of Vienna honored his scientific opus by investing him with the honorary doctorate of the Faculty of Philosophy on the 28th January 1952. In the same year, the "American Society of Protozoologists" appointed him to honorary membership.

In addition to his publications on his silverline research, KLEIN reported on a multitude of biological topics in the organs of popular science. His oeuvre includes a total of more than 150 publications (AESCHT 1994b).

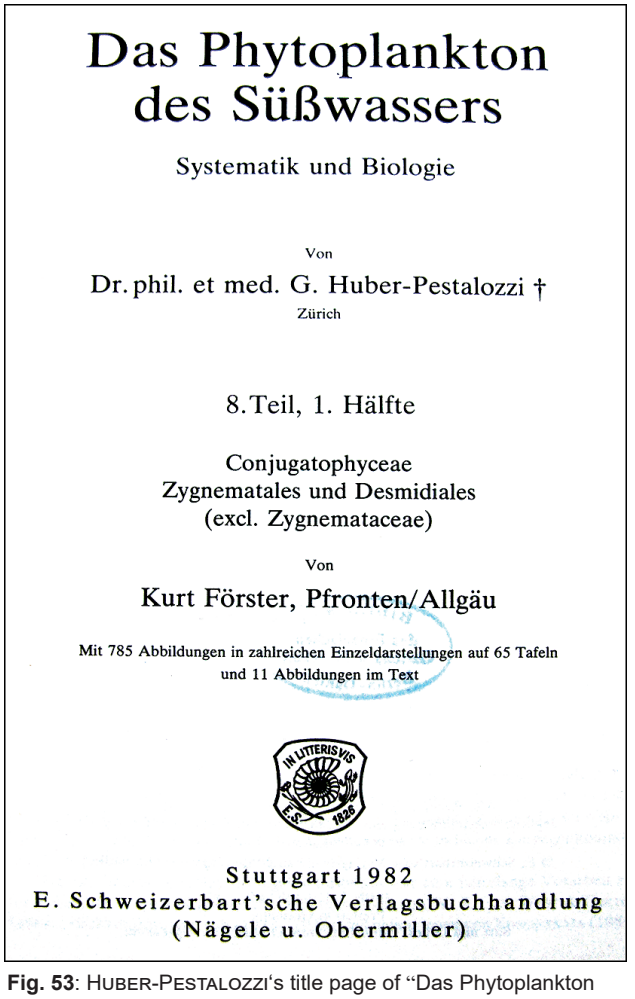
Unfortunately, hard misfortunes overshadowed the end of his life. Just before his retirement he suffered a retinal detachment, which ruined his plan of fully devoting himself to scientific microscopy. Thus, by the end of 1965, he began his retirement as a broken man. Later on, he increasingly suffered from a weak heart condition. In spite of this he continued to write manuscripts, correspond with colleagues, and attempted to organize his estate. After the decease of his wife Adelheid, his longtime house keeper, Anna HOKE, made his old life bearable until he died on the 16th August 1968.

Kurt FÖRSTER

Kurt FÖRSTER was born as the youngest son of a cloth merchant on the 17th January 1918 in Troppau, Sudetenland. Five years of elementary school were followed by three years of secondary school and eight semesters at the "Staatliche Ingenieurschule in Mährisch-Schönberg (Sudetenland)". He was an engineer in machine

works until the beginning of World War II. By the end of the war, as an engineer of the air force, he was imprisoned by the Americans but was soon released to the Sauerland, Germany, where he worked in a stone quarry. After years of occupational insecurity and unemployment, he started a 2nd academic education which he finished successfully and earned him tenure at the "Berufsschule" (professional school) of Pfronten (East-Allgau, Germany).

Besides his bread-and-butter job he increasingly expanded on his passion for the desmids (Desmidiaceae). By the time he acquired most expensive optical devises. Soon, he had a workroom reflecting his pronounced sense of order, precision and aesthetics. In an obituary the writing is: "FÖRSTER hat seine Arbeiten ingenieurmäßig mit Akribie und Akkuratesse abgewickelt. Wohlgeordnet, wohlorganisiert lagen sein Erfahrungsschatz und das Wissen anderer in gebundenen Sonderdrucken, Karteien und Bildtafeln stets griffbereit. Gewissenhaft wurde jede taxonomische Entscheidung mit diesen Daten verglichen und nach langem Erwägen dann endgültig festgelegt. Seine Zeichentechnik war sehr ausgefeilt. Man sieht, dass FÖRSTER Technisches Zeichnen für Metallberufe unterrichtete." (As an engineer, FÖRSTER worked meticulously and with accuracy. His experience and knowledge materialized in well-bound reprints, file cards and plates on his desk. Any determination in taxonomy was scrupulously tested with these data and finally determined. He had a highly refined way of drawing. From this it is seen that FÖRSTER had taught technical drawing for metalworking professions.) (Anonymus 1983).


Das Phytoplankton des Süßwassers

Systematik und Biologie

Von

Dr. phil. et med. G. Huber-Pestalozzi †

Zürich

8. Teil, 1. Hälfte

Conjugatophyceae
Zygnematales und Desmidiales
(excl. Zygnemataceae)

Von

Kurt Förster, Pfronten/Allgäu

Mit 785 Abbildungen in zahlreichen Einzeldarstellungen auf 65 Tafeln
und 11 Abbildungen im Text

Stuttgart 1982
E. Schweizerbart'sche Verlagsbuchhandlung
(Nägele u. Obermiller)

Fig. 53: HUBER-PESTALOZZI's title page of "Das Phytoplankton des Süßwassers" (Phytoplacton of freshwater), part 1, of the series on Conjugatophycea written by Kurt FÖRSTER.

With the number of his publications rising – 28 in total – the autodidact Kurt FÖRSTER was eventually formally recognized in scientific circles. In appreciation of his contributions to the collections of the cryptogamic flora of the "Forschungsinstitut Senckenberg" he was 1974 an honorary member of the Phycologic Section of this internationally renowned institution. Citation from the laudatio: "FÖRSTER konnte sich durch zähen Fleiß und mit großem Idealismus in über dreißigjähriger, ununterbrochener Arbeit als unangefochtener Kenner der Desmidiaceen in die kleine Gruppe der immer seltener werdenden taxonomisch forschenden Spezialisten einreihen." (FÖRSTER was able, due to his persistent diligence and great idealism during more than thirty years, to join the ranks as an undisputed expert of the desmids in the small group of increasingly rare specialists of taxonomy.)

FÖRSTER retired by the 1st May 1976 as a "Gewerbeoberstudienrat" (Senior Master on Industry). He was now able to continue, with high intensity, his work on a book started

in 1973 and representing his legacy, the monograph on conjugatophyceae, 1982 (Fig. 53). The first volume appeared in the series "Das Phytoplankton des Süßwassers" by Gottfried Huber-Pestalozzi as editor. While Förster worked on the second part of this monograph, he suffered and eventually died of an inflammatory bowel disease at the 21st March 1983 in the hospital of Reutte, Austria. He remains ever-present in science, in particular by his guide book on conjugatophycea.

Rupert Lenzenweger

Rupert Lenzenweger (* 1 März 1931 in Ried, Innkreis, Austria) lived a protected childhood in a single-family house with a large garden. Very early his interest for nature awoke and was further intensified, when he, at the age of eleven years, received a small microscope of his own. His time on the elementary school was normal, and he finished his further school education with his high-school diploma of a "Humanistisches Gymnasium". According to his parent's recommendations, he became a bank employee, a profession not corresponding to his inclinations, but practiced until his retirement in 1991.

Apart from his profession, he was an enthusiastic microscopist with emphasis on Desmidiacea. This continued beyond his retirement. Starting in 1970, his activities until today are evident from more than 100 papers in special journals on taxonomy. Furthermore, he published more than 50 contributions in "Mikrokosmos" and a multitude of reports on popular science. He loved to guide excursions with hobby microscopists. During 1996 to 2003, he published his major opus, a four-volume "Desmidiaceenflora von Österreich" (Fig. 54; Lenzenweger 1996, 1997, 1999, 2003). As a result of these extraordinary activities Rupert Lenzenweger was awarded the title of Professor by the Austrian Federal Ministry of Science and Research.

Fig. 54: Front covers of the 4-volume edition of "Desmiaceenflora von Österreich" by Rupert Lenzenweger.

Autodidactic ciliatologists of our days

Undoubtedly there are, in these days, many autodidacts around, who seriously deal with specific groups of protists, ask questions about them and thereby compile valuable scientific informations (Aescht 1994b; Bahls 2015). To name but a few from the German-language area are the learned carpenter Josef Dieckmann (Münster, Germany), the computer scientist Peter Eigner (Schrötten, Austria), the gymnasium teacher Dr. Hans-Jürgen Voss (Gladbeck, Germany) and the chemist Dr. Martin Kreutz (Constance, Germany). The latter should be mentioned in particular because he established the biodiversity by photographic records of the microscopic world of a freshwater biotope in

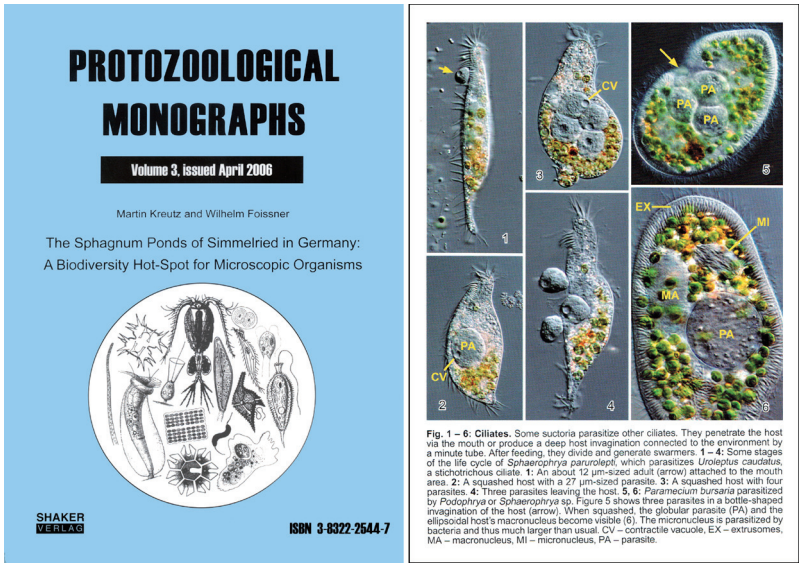


Fig. 55: Cover and representative high-quality page of the book by Martin KREUTZ and Wilhelm FOISSNER (2006).

the Lake Constance region, the "Simmelried". Encouraged by and in cooperation with Professor Dr. Wilhelm FOISSNER of the University of Salzburg, Austria, a book appeared (KREUTZ & FOISSNER 2006), which was received with cheers by laymen as well as experts. The main reason for this positive response is the extraordinary quality of the microphotographs, which have no equal in the professional literature (Fig. 55).

Diversity among amateurs

The present compilation does not claim completeness but intends to give examples of the activities and works of some individuals of our time and area. Professor Dr. Theodor BUTTERFASS (1926–2015) of the Botanical Institute of the Johann Wolfgang GOETHE-Universität, Frankfurt, Germany, demonstrated in his review of 1987 "Self-taught botanists of German tongue" how diverse the numerous autodidacts of Botany were during the 19th and 20th century (BUTTERFASS 1987).

His collection itemizes 115 autodidacts according to their major profession: 62 elementary-school teachers, twelve lawmen, ten clergymen, eight businessmen including bank employees, booksellers or publishers, three engineers, three gardeners, three railwaymen, two bakers, two artists, one classical philologist, one maker of horse-drawn carriages, one miller, one musician, one postal clerk, one typesetter, one watchmaker and three other persons. Of these 115 individuals four worked on unicells, especially algae. This listing is a praise of human diversity.

Public relations activities are important

It might be argued that in these times of extensive information, it is needless to give an access to the world of small dimensions to the wider public. This does not apply, at least to the German-language area, where microscopic associations attract attention at the information desks of public institutions such as Zoological and Botanical Gardens or other larger museums. An example is the special exhibition by Dr. Erna AESCHT "Die Urtiere – Eine verborgene Welt", Biology

Fig. 56a,b: **a** – Collage of protists as cover of catalogue of exhibition "Die Urtiere" (Protists) which was curated by Erna AESCHT. **b** – SEM of a mosquito on the book cover of "Die fantastische Welt des Unsichtbaren" (The Fantastic World of the Invisible) by Oliver MECKES und Nicole OTTAWA. The illustration was artificially coloured.

Centre of the Oberösterreichisches Landesmuseum, Linz, Austria, which was an eye-opener of visitors for the invisible world (Fig. 56; AESCHT 1994a). Much effective are also high-standard book publications such as "Die fantastische Welt des Unsichtbaren" of the biologists and photographers of science, Nicole OTTAWA and Oliver MECKES (Fig. 56; MECKES & OTTAWA 2002).

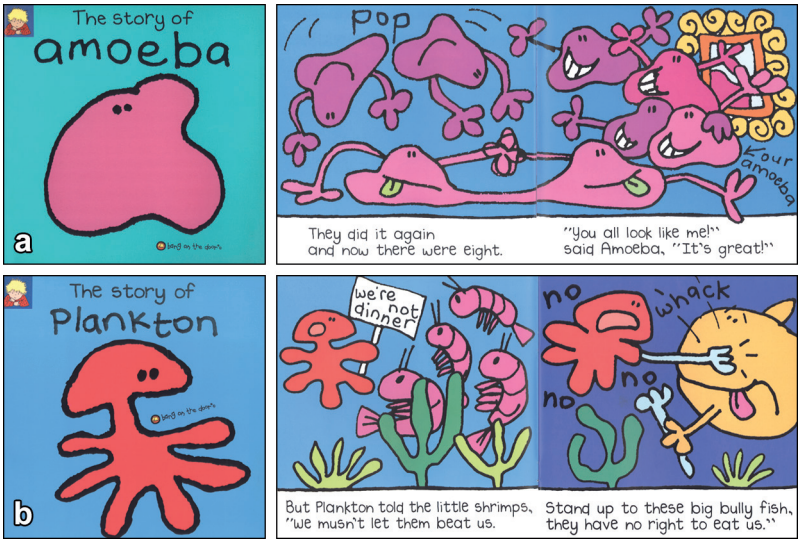


Fig. 57: Representative pages of innovative cartoon-type picture book on amoebas and plankton.

In view of the multitude of film reports as broadcasted by the media, it is hard to understand, why the microcosm does not play the role it certainly deserves. Is it true, as maintained by some producers, that the average person is unwilling to watch reports from the microscopic world for more than a few minutes?

Last but not least: children's microcosm

It takes a thorough research of the international book market to identify publications about microscopy designed for children. A few do show up indeed. There are colourful books for smaller kids, where a youngster paging through the picture book may not understand that those fabulous creatures live in the micro-world (Abb. 57; STRINGLE 1999, 2000). Some lovingly illustrated books such as "Die Abenteuer im Wassertropfen" or "Caroline im Wassertropfen" (Abb. 58; AFONKIN 1991; KIRSCH & OELSCHLAEGER 1990) do in fact carry off the young reader into the realm of the small, in particular of the world of unicells. The informed adult person likes to see that the easy writing includes many correct details and correlations. The "Junior researcher of nature" is able to find suitable reference books

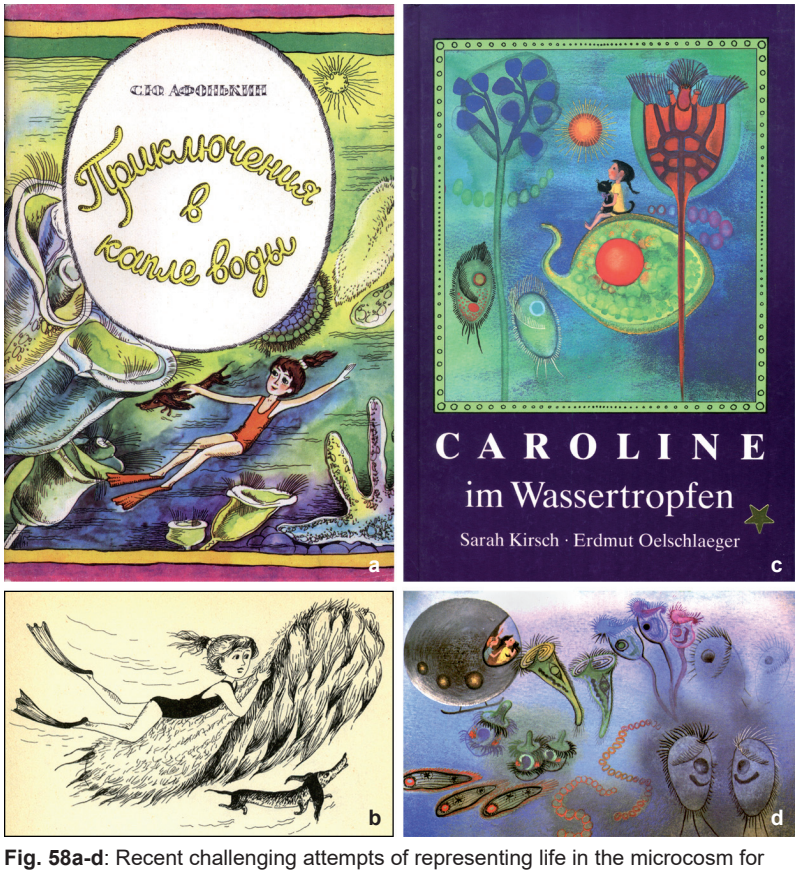


Fig. 58a-d: Recent challenging attempts of representing life in the microcosm for children's books. A Russian author shows a little girl and her dog immersed in a water droplet (**a**) and experiencing thrilling adventures such as riding on a hypotrich ciliate (**b**). In the German-language book "Caroline im Wassertropfen" (**c**) a little girl and an older boy cross the microcosm by submarine, accompanied by a friendly professor (**d**).

Fig. 59a,b: Dictionaries for older kids (**a**) and reference books for explanations of the microcosm (**b**).

by experts, who were able to give answers for the insatiable curiosity of children. At the same time a high-quality standard of production was maintained (Abb. 59; Brockhaus 2013; Meckes & Ottawa 2002). Hopefully, the supply of such publications will increase significantly in the future.

Prospects

"Et parvis quoque rebus inest sua saepe voluptas" (even the small has often its delight). Ledermüller put this motto on top of the third part of his "Mikroskopische Gemüths- und Augen-Ergoezung" (Fig. 60). The motto holds as well for today and for the future for many microscopists, younger as well as older amateurs and experts. This very popular epigraph traces back to the Italian physician, Girolamo Fracastoro (1476–1553), who, in 1530, wrote this line in his noteworthy didactic poem on causes and effects of syphilis (Fracastoro 1530).

Acknowledgment

We would like to give cordial thanks to Wolf-Henning Kusber, Botanischer Garten und Botanisches Museum, Berlin, Germany, and to Dr. Erna Aescht, Oberösterreichisches Landes-museum, Linz, Austria. They helped in our search of literature and gave valuable hints at some people mentioned in this report. We also thank Professor Dr. Øjvind Moestrup, Laboratory of Phycology, University of Copenhagen, Denmark, and Professor Dr. Weibo Song, Institute of Evolution and Marine Biodiversity of the Ocean University of China, Qingdao, China, for important information. Dr. Alan Warren, Natural History Museum London, UK, kindly gave support in acquisition of a book. We thank Dr. Jürgen Ibs from Lübeck, Germany, for his critical revision as historian of an earlier version of the manuscript.

Postscript

This article is a translation of Klaus Hausmann's four-part publication "Der Mikrokosmos: Gleichermaßen attraktiv für Amateure wie

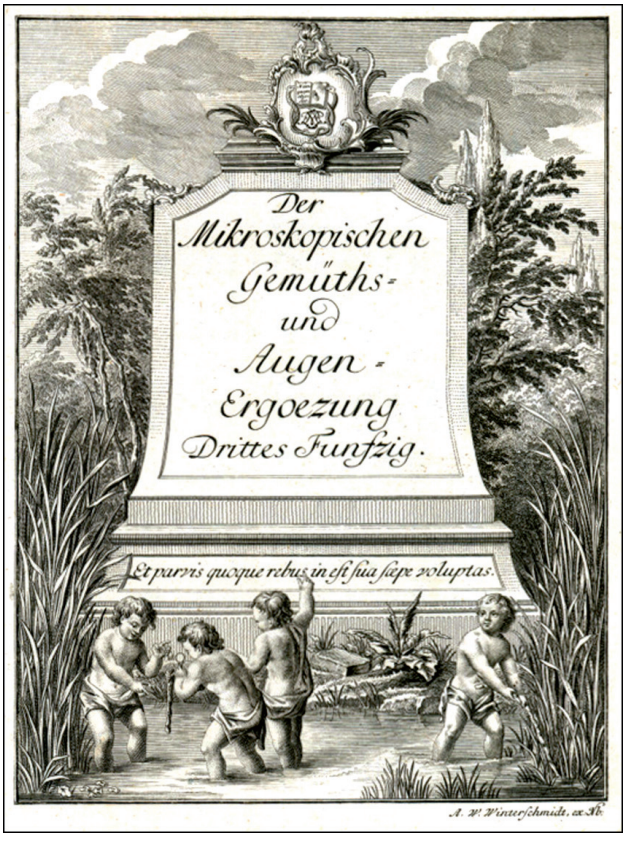


Fig. 60: Copper engraving of the third part (1761) of Ledermüller's "Mikroskopischen Gemüths- und Augen-Ergoezung" (Microscopic Delights of Mind and Eyes).

für Experten" (Hausmann 2017). The author and the co-author HM have a long practice of scientific cooperation. The present manuscript results from this rewarding tradition. While KH extensively and deeply involved himself in the history of microscopy, HM profited from reading and learning about this interesting matter. The translation by HM is a bow of respect and gratitude to KH. The author KH insisted on HM's co-authorship. The reader may thereby acknowledge the good spirit between two enthusiastic scientists.

References

Aescht E. (1993): Biographie. In: R. H. Francé – Leben und Werk. — Tagungsband zum Francé-Symposium in der Universität Salzburg am 22./23.10.1993.

Aescht E. (Hrsg.) (1994a): Die Urtiere – eine verborgene Welt. — Katalog des OÖ. Landesmuseums **71**: 7–278.

Aescht E. (1994b): Die Erforschung der Urtiere (Protozoen) in Österreich. — In: Aescht E. (Hrsg.): Die Urtiere – eine verborgene Welt. Katalog des OÖ. Landesmuseums **71**: 7–79.

Aescht E. (2013): Der Sammlungsbereich "Wirbellose Tiere" (ohne Insekten) am Biologiezentrum Linz: 2003–2012. — Beitr. Naturk. Oberösterreichs **23**: 207–236.

Anderson D. (2014): Still going strong: Leewenhoek at eighty. — Antonie van Leeuwenhoek **106**: 3–26.

Anonymus (1983): Ein Leben für die Zieralgen – Zum Gedenken an Kurt Förster. — Naturwiss. Arbeitskr. Kempten **26**: 1–6.

Afonkin S.J. (1991): Priklucheniya v kaple vody. — Karelija, Petrosavodsk.

Bahls L.L. (2015): The role of amateurs in modern diatom research. — Diatom Research **30**: 209–210.

Behre K. (1970): Friedrich Hustedts Leben und Werk. — Beiheft Nova Hedwigia **31**: XI–XXII.

Bracegirdle B. (2016): The Quekett Microscopical Club 1865–2015. — Quekett Microscopical Club, London.

Brockhaus (2013): Der Kinder Brockhaus – Eine Reise ins Unsichtbare. Die Welt unter dem Mikroskop. — F. A. Brockhaus, München.

Burba M. (2007): Johann Diedrich Möller (1844–1907) – Über die Kunst, Diatomeen zu legen. — Mikrokosmos **96***:* 7–17.

Burba M. (2008): Die größte Typenplatte der Welt und ihre Herstellung. — Mikrokosmos **97**: 321–327.

Burba M. (2009): Mikroskopische Salonpräparate – Naturschönes und Kunstschönes auf kleinstem Raum. — Mikrokosmos **98**: 70–75.

Butterfass Th. (1987): Self-taught botanists of German tongue. — Ber. Deutsch. Bot. Ges. **100**: 347–371.

Dobell C. (1932, 1960): Antony van Leeuwenhoek and his „Little Animals". — Bale, Sons & Danielsson and Constable and Co, London.

Eiselt J. (1969): Dr. phil. h. c. Bruno M. Klein † — Ann. Naturhistor. Mus. Wien **53**: 25–34.

Ernst-Abbe-Stiftung (2013): Schatzkammer der Optik. Die Sammlungen des Optischen Museums Jena. — Druckhaus Gera, Gera.

Foissner W. (2012): Ein Ciliat als Altarbild und Protisten in der Oper. — Mikrokosmos **101***:* 82–84.

Foissner W. & Wenzel F. (2004): Life and legacy of an outstanding ciliate taxonomist, Alfred Kahl (1877–1946), including a facsimile of his forgotten monograph from 1943. — Acta Protozool. **43***:* 3–69.

Ford B.J. (1991): The Leeuwenhoek Legacy. — Biopress, Bristol.

Förster K. (1982): Conjugatophyceae. Zygnematales und Desmidiales (excl. Zygnemataceae). In: Huber-Pestalozzi G. (Hrsg.): Das Phytoplankton des Süßwassers. Systematik und Biologie. — Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart.

Fracastoro G. (1530): Syphilidis sive morbi gallici libri tres. — In: Wöhrle G. (Hrsg., Übers.) (1993): Lehrgedicht über die Syphilis; 2. Auflage. Harrassowitz; Wiesbaden.

Francé R.H. (1897): Der Organismus der Craspedomonaden. (A craspedomonadinák szervezete). — Kir. M. Természettudományi társulat, Budapest.

Francé R.H. (1907): Streifzüge im Wassertropfen. — Franckh'sche Verlagshandlung, Stuttgart.

Francé R.H. (1910): Die Kleinwelt des Süßwassers. — Theod. Thomas, Leipzig.

Francé R.H. (1913): Das Edaphon – Untersuchungen zur Oekologie der bodenbewohnenden Mikroorganismen. — Verlag der mikrologischen Gesellschaft, München.

Francé R.H. (1922): Das Leben im Ackerboden. — Franckh'sche Verlagshandlung, Stuttgart.

Garbary D.J. & Wynne M.J. (eds) (1996): Prominent phycologists of the 20th century. — Lancelot Press, Hantsport.

Gerlach D. (2009): Geschichte der Mikroskopie. — Verlag Harri Deutsch, Frankfurt.

Geus A. (2003): Rösel von Rosenhof, August Johann. — Deutsche Biographie **21**: 738–739.

Gloede W. (1986): Vom Lesestein zum Elektronenmikroskop. — VEB Verlag Technik, Berlin.

Günkel N.G. (2000): Dilettanten als Könner – Amateure in der Mikroskopie. — Mikrokosmos **89**: 143–150.

Haeckel E. (1899–1904): Kunstformen der Natur. — Verlag des Bibliographischen Instituts, Leipzig.

Hausmann K. (1996): Der Diatomeen-Mikro-Arrangeur von Blautannen, England: Klaus-Dieter Kemp. — Mikrokosmos **85**: 107–110.

Hausmann K. (2017): Der Mikrokosmos: Gleichermaßen attraktiv für Amateure wie für Experten, Teile 1–4. — Mikrokospie **4**: 3–12, 61–71, 119–130, 180–188.

Hausmann K. & Hülsmann N. (1988): Faszinierender Mikrokosmos. — In: Klös H. G. & Lange J. (Hrsg.): Tierwelt hinter Glas. Das Zoo-Aquarium Berlin. arani/Haude & Spencer, Berlin.

Henkel K. (1997): Die Renaissance des Raoul Heinrich Francé. — Mikrokosmos **86**: 3–16.

Henkel K. & Hausmann K. (2008): Mikroskopische Gesellschaften und Vereinsleben. — Mikrokosmos **97**: 24–26.

Hertel C. G. (1716): Vollständige Anweisung zum Glaß-Schleifen: Wie auch zur Verfertigung derer Optischen Machinen, die aus geschliffenen Gläsern zubereitet und zusammengesetzt werden, Nebst einer Vorrede Herrn Christian Wolffes. — Rengersche Buchhandlung, Halle.

Hess W. (1889): Rösel von Rosenhof, August Johann. — Allgemeine Deutsche Biographie **29**: 188–189.

Hilz H. & Schwedt G. (2002): Zur Belustigung und Belehrung – Experimentierbücher aus zwei Jahrhunderten. Deutsches Museum. — GNT Verlag, Diepholz.

Hooke R. (1655): Micrographia: or some Physiological Descriptions of Minute Bodies made by Magnifying Glasses. With Observations and Inquiries thereupon. — Martyn & Allestry, London.

Hustedt F. (1936): Die Kieselalgen. — In: Rabenhorst L.: Kryptogamen-Flora von Deutschland, Österreich und der Schweiz. Akademische Verlagsgesellschaft Leipzig.

Hustedt F. (1956): Kieselalgen (Diatomeen). Einführung in die Kleinlebewelt. — Kosmos-Verlag, Stuttgart.

Kage C. (2014–2016): Manfred P. Kage – Ein Leben für die Mikroskopie, Teile 1–5. — Mikroskopie **1**: 210–218, **2**: 44–52 + 97–108 + 154–166, **3**: 106–117.

Kage C. & Kage M. (2010): KAGEs fantastische Mikrowelten. — Manuela Kinzel Verlag, Göppingen.

Kage C. & Kage M. (2012): KAGEs fantastische Insektenwelten. — Manuela Kinzel Verlag, Göppingen.

Kage C. & Kage M. (2013): KAGEs fantastische Kristallwelten. — Manuela Kinzel Verlag, Göppingen.

Kage C. & Kage M. (2014): KAGEs fantastische Wasserwelten. — Manuela Kinzel Verlag, Göppingen

Kahl A. (1926): Neue und wenig bekannte Formen der holotrichen und heterotrichen Ciliaten. — Arch. Protistenkd. **55**: 197–438.

Kahl A. (1930): Urtiere oder Protozoa. I. Wimpertiere oder Ciliata (Infusoria). Eine Bearbeitung der freilebenden und ectocommensalen Infusorien der Erde, unter Ausschluß der marinen Tintinnidae. 1. Allgemeiner Teil und Prostomata. — Tierwelt Dtl. **18**: 1–180.

Kahl A. (1931): Urtiere oder Protozoa. I. Wimpertiere oder Ciliata (Infusoria). Eine Bearbeitung der freilebenden und ectocommensalen Infusorien der Erde, unter Ausschluß der marinen Tintinnidae. 2. Holotricha außer den im 1. Teil behandelten Prostomata. — Tierwelt Dtl. **21**: 181–398.

Kahl A. (1932): Urtiere oder Protozoa. I. Wimpertiere oder Ciliata (Infusoria). Eine Bearbeitung der freilebenden und ectocommensalen Infusorien der Erde, unter Ausschluß der marinen Tintinnidae. 3. Spirotricha. — Tierwelt Dtl. **25**: 399–650.

Kahl A. (1935): Urtiere oder Protozoa. I. Wimpertiere oder Ciliata (Infusoria). Eine Bearbeitung der freilebenden und ectocommensalen Infusorien der Erde, unter Ausschluß der marinen Tintinnidae. 4. Peritricha und Chonotricha. — Tierwelt Dtl. **30**: 651–886.

Kirsch S. & Oelschlaeger E. (1990): Caroline im Wassertropfen. — Verlag Junge Welt, Berlin.

Klein B.M. (1943): Das Silberlinien- oder neuroformative System der Ciliaten. Eine zusammenfassende Darstellung unter Berücksichtigung eines homologen und eines analogen Zwischensystems bei den Metazoen. — Ann. Naturhistor. Mus. Wien **73**: 56–336.

Koch H. & Koch H. J. (2007): Blaschka – Gläserne Geschöpfe des Meeres. — Dölling & Galitz Verlag, München.

Kranz H. (2009): Diatomeen im 19. Jahrhundert. Typenplatten und Salonpräparate von Johann Diedrich Möller. Abhandlungen des Naturwissenschaftlichen Vereins in Hamburg (NF) 41. — Goecke & Evers, Keltern.

Kreutz M. & Foissner W. (2006): The *Sphagnum* ponds of Simmelried in Germany: A biodiversity hot-spot for microscopic organisms. — Protozoological Monographs **3**: 1–267.

Lane N. (2015): The Unseen World: Reflections on Leewenhoek (1677) 'Concerning Little Animals'. — Phil. Trans. R. Soc. B **370** – 20140344.

Ledermüller M.F. (1761): Mikroskopische Gemüths- und Augen-Ergötzung: Bestehend in Ein Hundert nach der Natur gezeichneten und mit Farben erleuchteten Kupfertafeln, Sammt deren Erklärung. — Christian de Launoy, Nürnberg.

Leeuwenhoek A. van (1695, 1966 Faksimile): Arcana naturae detecta. — H. Krooneveld, Delphis Batavorum (Delft), Culture et Civilisation, Bruxelles.

Lenzenweger R. (1996): Desmidiaceenflora von Österreich, Teil 1. — Bibliotheka Phycologica **101**: 1–157.

Lenzenweger R. (1997): Desmidiaceenflora von Österreich, Teil 2. — Bibliotheka Phycologica **102**: 1–216.

Lenzenweger, R. (1999): Desmidiaceenflora von Österreich, Teil 3. — Bibliotheka Phycologica **103**: 1–218.

Lenzenweger R. (2003): Desmidiaceenflora von Österreich, Teil 4. — Bibliotheka Phycologica **111**: 1–87.

Lötsch B. (1998): Gibt es Kunstformen der Natur? Radiolarien, Haeckels biologische Ästhetik und ihre Überschreitung. — Stapfia **56**: 339–372.

Meckes O. & Ottawa N. (2002): Die fantastische Welt des Unsichtbaren – Entdeckungen im Mikrokosmos. — Gruner + Jahr, Hamburg.

Meckes O. & Ottawa N. (2003): Der Mikrokosmos – Für Kinder erklärt. — Gruner + Jahr, Hamburg.

Meyer K. (1998): Geheimnisse des Antoni van Leeuwenhoek. — Pabst, Lengerich.

Müller G.H. (1985): Ledermüller, Martin Frobenius. — Neue Deutsche Biographie **14**: 43.

Müller O.F. (1786): Animalcula infusoria fluviatilia et marina. Havniæ (Copenhagen).

Müllerott M. (1961): Francé (eigentlich Franzé), Rudolf (Raoul) Heinrich. — Neue Deutsche Biographie **5**: 313–314.

Pichler F. (2016): Raoul Francé und sein Werk zu Natur und Leben. Eine kommentierte und illustrierte Bibliographie. — Schriftenreihe Geschichte der Naturwissenschaften und der Technik **32** (Universitätsverlag Rudolf Trauner, Linz).

Rienitz J. (1994): Möller, Johann Dietrich. — Neue Deutsche Biographie **17***:* 645–646.

Rösel von Rosenhof A. J. (1755): Der monatlich herausgegebenen Insecten-Belustigung Dritter Theil. — J. J. Fleischmann, Nürnberg.

Rosenbauer K. A. (2003): Mikroskopische Präparate. Hersteller und Lieferanten. Eine Zusammenstellung aus zwei Jahrhunderten. — GIT Verlag, Darmstadt.

Roth R.R. (2000): Raoul H. Francé and the doctrine of life. — 1st Books Library, Bloomington.

Schierbeek A. (1950–1952): Antoni van Leeuwenhoek, zijn leven en zijn werken, 2 volumes. — De Tijdstroom, Lochem.

Schrader W. (1898): Wolff, Christian. — Allgemeine Deutsche Biographie **44**: 12–28.

Streble H., Krauter D. & Bäuerle A. (2017): Das Leben im Wassertropfen. Mikroflora und Mikrofauna des Süßwassers. — Ein Bestimmungsbuch, 13. Auflage. Franckh-Kosmos Verlag, Stuttgart.

Stringle B. (1999): The story of plankton. — David Benett Books, London.

Stringle B. (2000): The story of amoeba. — David Benett Books, London.

Teichert G. & Hausmann K. (1994): 1875: Mikroskopieren für jedermann. — Mikrokosmos **83**: 129–133.

Wolff F. & Wittstock O. (2001): Latein und Griechisch im deutschen Wortschatz – Lehn- und Fremdwörter, 6. Auflage. — VMA-Verlag, Wiesbaden.

Addresses of authors:

Univ.-Prof. Dr. Klaus Hausmann
Rothenburgstr. 27b
12165 Berlin
Germany

formerly:
Free University of Berlin
Institute of Biology / Zoology
WG Protozoology
E-mail: hausmann@zedat.fu-berlin.de

and

Univ.-Prof. Dr. Hans Machemer
Franz-Mörchen-Weg 15
59969 Hallenberg
Germany

formerly:
Ruhr University Bochum
Institute of General Zoology
and Neurobiology
WG Physiology of Excitable Cells
E-mail: machemerhs@web.de

Index

The numbers in **bold type** refer to pages with illustrations.