

Celebrating Leeuwenhoek's 375th birthday What could his microscopes reveal?

Brian J Ford



On 22 October 2007, Brian J Ford marked the anniversary of Leeuwenhoek's 375th birth with a an illustrated lecture at Cambridge University. Professor Ford showed many of the original images he had obtained, both with original microscopes and with modern replicas, reminding us of the power of a single lens in the right hands. Here he reminds modern microscopists of the images that could be obtained more than three centuries ago.

Antony van Leeuwenhoek was born in Delft, Netherlands, on 24 October 1632. His observations of microorganisms, when he was a middle-aged amateur enthusiast, laid the ground for the modern science of biological microscopy. His career belies those who insist that innovative science is the province of the young, or best done by teams: he worked obsessively alone, often refusing to receive visiting notables who shared his interests, and did not begin his lifetime of endeavour until he was forty years old. Yet – by the time he died, on 30 August, 1723 – he had devoted half-century to diligent research, effectively founding observational microscopy and laying the ground-work for microscopical experimentation.

The baptismal register at the Old Church in Delft would not confirm the above details, because he changed his name. The baptismal register shows that he was originally 'Thonis', but became known as Antony (Antonij in the Dutch) and later adopted the 'van' to indicate his improving social status. He was born the fifth child of seven, but lost his father Philips at the age of five and was sent away to school in Warmond, near Leiden, after his mother's remarriage. Later he was fostered with an uncle in Benthuisen until the age of sixteen, when he moved to Amsterdam and was apprenticed to a draper and became the firm's book-keeper.

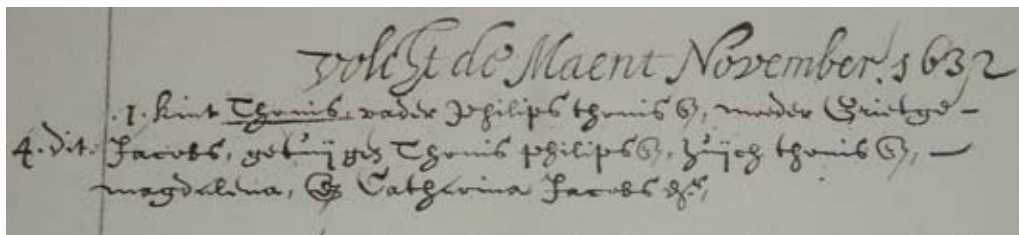


Fig. 1. LEEUWENHOEK'S BIRTH RECORD. The record of Leeuwenhoek's birth states that a child Thonis was born to Philip, son of Thonis sr., his mother Griegte Jacobs, on 4 November 1632. Witnesses were the paternal grandfather, the paternal uncle and two maternal aunts. This appears on the same page of the baptismal register of the New Church in Delft as Johannes Vermeer, the painter whose executor Leeuwenhoek was to become.

By the time he was 21 he had returned to Delft where, on 29 July 1654, he married Barbara de Mey at the New Church. She was three years his senior, and they had three sons and two daughters, all but one of whom died as infants. The surviving daughter was Maria, born on 22 September 1656; she lived with her father and corresponded with the Royal Society after his death, and died aged 89. After twelve years of marriage, Barbara died on 11 July 1666. Leeuwenhoek remarried on 25 January 1671, this time to Cornelia Swalmius, who died in 1694. From that date until his own demise he was diligently cared for by his daughter.

Leeuwenhoek and the Microscope

During 1668 Leeuwenhoek visited London in the course of his business. It was his only visit to England. At the time, Robert Hooke's great work *Micrographia* was at its height of popularity. It had already been reprinted. This was the coffee-table popular book of its time, and contained stunningly realistic images of fleas, lice and stinging nettles – even Samuel Pepys, inveterate playboy and diarist, said that the book so excited him that he stayed up all night with it. Pepys was used to staying up all night, though not normally with a book.

In the past, scholars have argued that, since Leeuwenhoek spoke no English, the book would have remained unknown to him. I have shown that this view can be faulted. First, he often wrote of acquaintances who could translate English into Dutch for him. Second, the specimens that

he first sent to London were exactly the same as specimens described by Hooke, and – clearly beyond coincidence – they were written up by Leeuwenhoek in precisely the same order. Further, Leeuwenhoek clearly took Robert Hooke to task in his descriptions of microscopical structure. "A certain Gentleman," he wrote, was mistaken – and Leeuwenhoek would put him right. The "Gentleman" was, of course, Robert Hooke and it was his descriptions that the Dutchman set out to challenge.

Students of the history of science have drawn attention to the disparity between the beautifully-tooled, grand design of compound microscope that Hooke employed and the diminutive, crude, single-lensed instrument used by Leeuwenhoek. Scholars often talk of these simple microscopes as a 'Leeuwenhoek design'. This can be faulted

too, for the design was actually one of Hooke's. The description is hidden within the Preface to *Micrographia*. Because the pages are un-numbered (and thus could not be formally cited in conventional references) the Preface has been widely ignored – and this has caused researchers to overlook a crucial section.

On the 22nd page of the Preface may be found Hooke's own design for a home-made microscope. The description was the

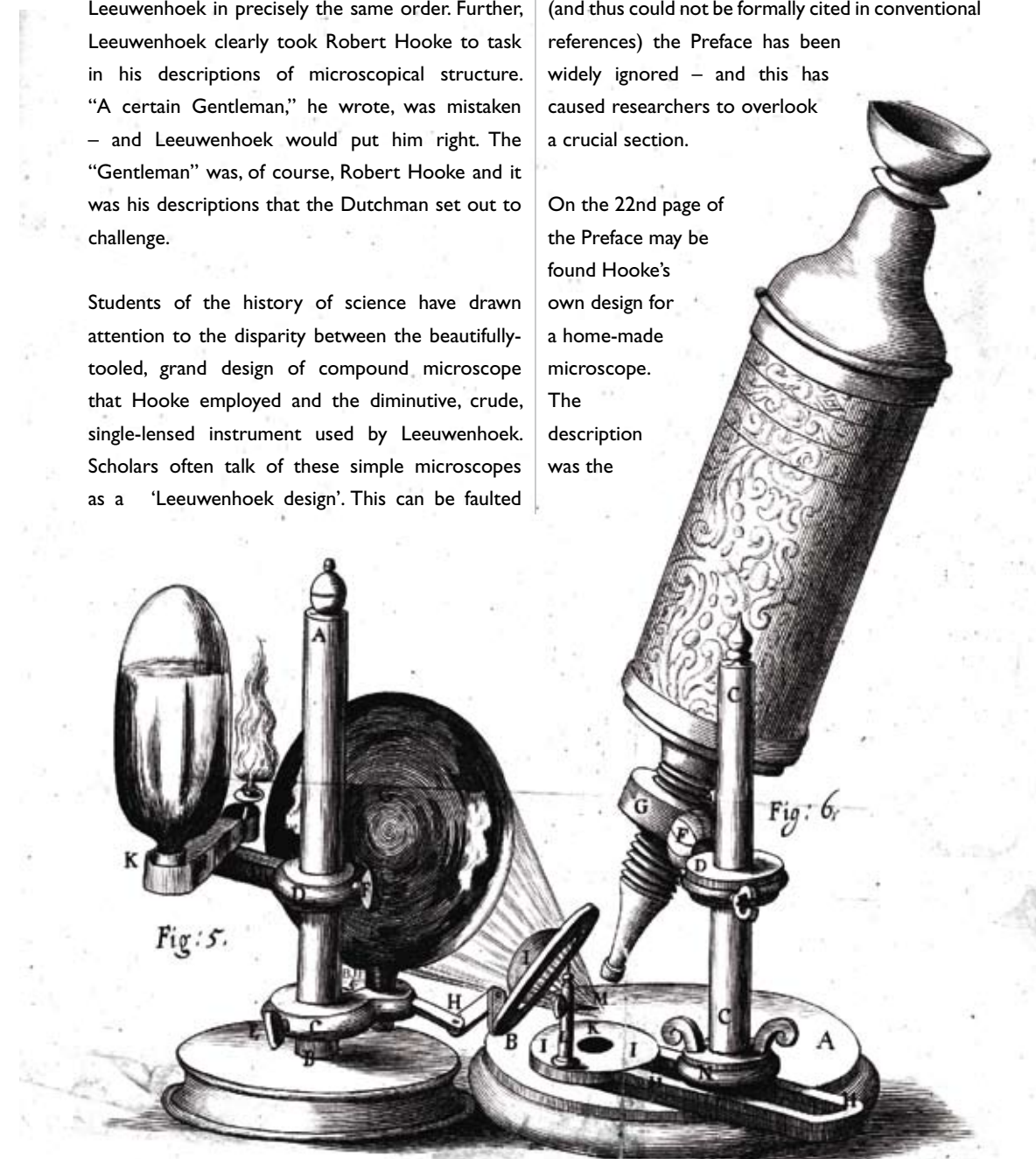


Fig. 2. ROBERT HOOKE'S MICROSCOPE. Hooke's published engraving of his microscope appeared as Scheme I of his great work *Micrographia*. This wooden instrument, covered with tooled leather, was made by Christopher Cock, a London instrument maker. Although a fine object in itself, this compound microscope produced inferior images (Fig 8) and could not have provided the fine images Hooke published (fig 3).

And therefore, if we have one only refraction, it would, *ceteris paribus*, be the best. And hence it is, that if you take a very clear piece of a broken Venice Glass, and in a Lamp draw it out into very small hairs or threads, then holding the ends of these threads in the flame, till they are run into a small round Globul, or drop, which will hang at the end of the thread; and if further you stick several of these upon the end of a Metal plate, with a little sealing Wax, so as that the threads stand upwards, and then with a Whetstone first grind off a good part of them, and afterward on a fine Metal plate, with a little Tripoly, rub them till they come to be very smooth; if one of these be fixt with a little soft Wax against a small hole, prick'd through a thin Plate of Brass, Lead, Pewter, or any other Metal, and an Object, plac'd very near, be look'd at through it, it will magnifie and make some Objects more distinct then any of the great scopes. But because these, though exceeding easily made, are yet very

Fig. 4. THE PREFACE TO MICROGRAPHIA. Robert Hooke's microscope featured a field lens, which helped fill the eyepiece with an image. He knew that compound lens arrays produced inferior results, and on the 22nd page of his unnumbered Preface he observed that, for improved observation: "I took out the middle Glass, and only made use of one Eye Glass with the Object Glass ... the fewer the Refractions are, the more bright and clear the Object." He then went on to provide the design details of what became a Leeuwenhoek microscope.

inspiration for Leeuwenhoek. "Take a very clear piece of a broken Venice glass, and in a Lamp draw it out into very small hairs or threads ..." he wrote. And then, melt them "into a small round globule..." rub them until they become very smooth" before mounting the tiny lenses in a needle-hole in "a thin Plate of Brass ..." and what is the result? A typical 'Leeuwenhoek' microscope. It was, in reality, a Hooke microscope.

Impossible Observations

For centuries, scholars have described the detailed etchings in Hooke's great book and concluded that they were based on observations made with his compound microscope. It became clear to me at the outset that this could not possibly be true. Compound microscopes of the seventeenth century were made with relatively crude lenses, and lenses in train magnify aberrations and imperfections more than images. I have used such instruments, and have always found that they could not generate images of the clarity that Hooke portrayed.

Look at his famous drawing of the louse, for example: apart from the armour-plated arthropod carapace (which you can see with a hand-lens) it is the detail that astounds: the fine chitin hairs on each appendage; the details of the eye and claws. Yet these features are not resolved by his compound microscope – Robert Hooke's published plates contain details that, if he used his famous microscope, were invisible. This extraordinary paradox has been conveniently ignored for centuries. So, what is the answer?

Hooke clearly used a single-lens, simple microscope to observe these diminutive details. If you make a simple microscope in the way he described in his Preface, then such details can easily be seen. Most present-day commentators conclude that these microscopes were made with a melted bead-lens, but this is not true either. Hooke clearly explained that you melt glass

Fig. 3. CULEX PIPPIENS STUDIED BY HOOKE, projecting chitinous hairs that are so vividly portrayed are below the resolution of his desk microscope (fig 2) which is an enduring paradox. The author concludes that he used simple microscopes of the type he described in his Preface (fig 4) to fill in such fine detail.

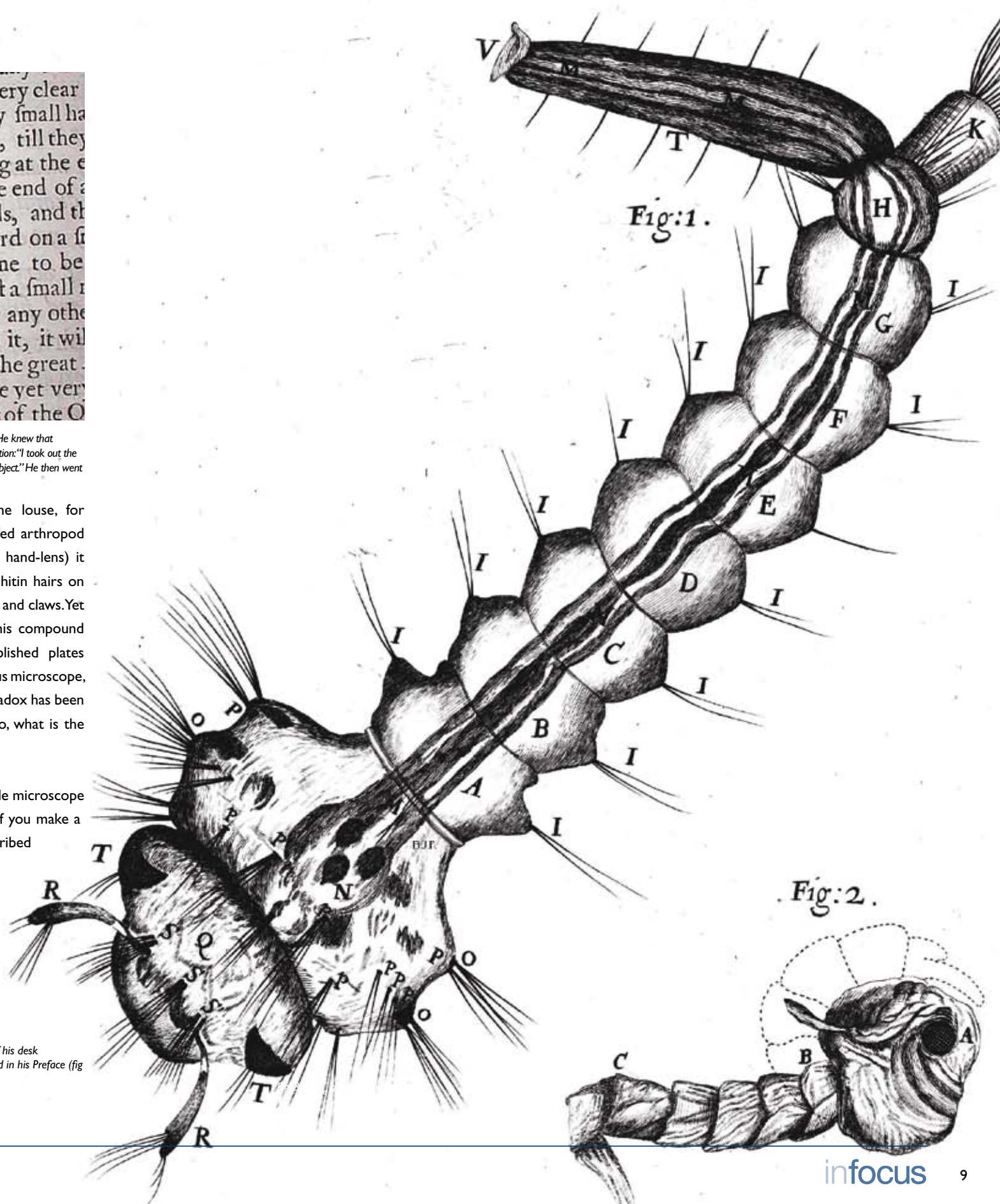




Fig. 5. LEEUWENHOEK MICROSCOPE IN BRASS. For many years this brass Leeuwenhoek microscope has been on display in the foyer of the Technische Universiteit, Delft, Netherlands. Although it has no surviving lens its construction is typical of the microscopes with which historians are familiar. The body plates measure 22 x 26 mm. This microscope was once owned by the Haaxman family, descendants of the Leeuwenhoek family. In 1929 it was purchased by the Nederlandsch Historisch Natuurwetenschappelijk and was subsequently placed on indefinite loan to the Department of Microbiology in Delft.



Fig. 6. A SILVER MICROSCOPE FROM MUNICH. Many of the microscopes were made by Leeuwenhoek from silver, which is easier by far to manipulate and shape. This example is in the Deutsches Museum in Munich, Germany, and has a specimen pin made from forged iron. Although not usually published, this is the kind of microscope that Leeuwenhoek bequeathed to the Royal Society. They were still used for critical microscopy into the nineteenth century before being lost.



Fig. 7. LEEUWENHOEK MICROSCOPE IN CLOSE-UP. The brass microscope at Antwerp measures 28 x 47 mm and Ford photographed it in close-up to show the details of the stage, focussing and lens assembly. This is No 2 in the microscope collection of the Royal Antwerp Zoological Society and doubts have been raised about its authenticity. It appeared without provenance in the private collection of Dr Henri van Heurck around 1900, which makes its exact origins unclear.

threads to obtain a bead of glass, and then grind off the projecting 'tail' with a jeweller's abrasive paste. The result is not a bead at all, but is a plano-convex lens. Such lenses (with the plane aspect adjacent to the specimen) offer good resolution and are certainly greatly superior to a compound lens array. Hooke, and others, used prettily decorated, hand-tooled compound microscopes shod in shagreen and made of lustrous hardwood because they were objects of desire. They were executive toys; status symbols. A simple microscope was no more than a hand-made lens the size of a pin-head mounted in a crude metallic plate, which would not impress anyone.

However, the evidence is clear. Only with a tiny, single-lens microscope could Hooke have discerned the details he published in his printed plates. To Leeuwenhoek, who was a loner and an obsessive enthusiast, there was nothing to be gained by standing a grand instrument upon his desk. He rarely invited anyone to view his working methods in any event, and sight of his specimens was what mattered to him more than the intricacy of the instrument. For him, there were two advantages



Fig. 8. ROBERT HOOKE'S VIEW OF A FLEA. Using a Christopher Cock microscope from the seventeenth century we obtain this view of *Pulex*, the flea. Although the general outline of this 3 mm long insect is well enough conveyed, the finest fibrillar structures resolved are $>20\ \mu\text{m}$ in breadth. The fine hairs Leeuwenhoek portrayed in his studies (fig 3) are down to $2\ \mu\text{m}$ in diameter, proving that he must have had extensive recourse to the simple (i.e. single-lens) microscope for these fine studies

of Hooke's design: these little microscopes were cheap, and easy to make; and they revealed the ultimate in detail.

Unimaginable Revelation

My good friend the late Dr J van Zuylen of Zeist in the Netherlands painstakingly examined the surviving

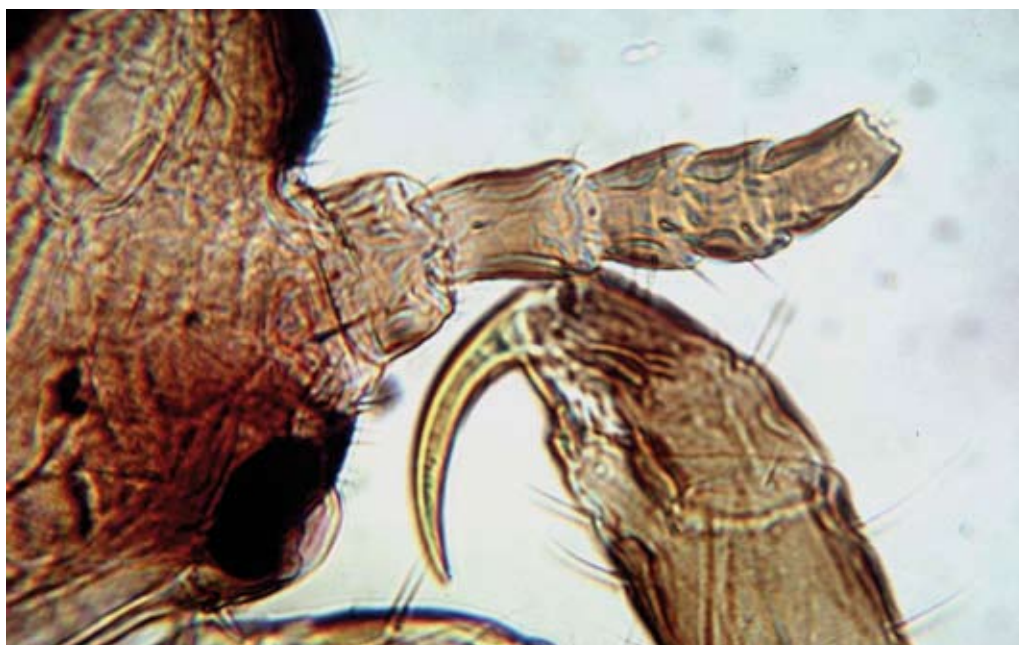


Fig. 9. THE SINGLE LENS VIEW OF A LOUSE. In this view through a simple microscope Ford selected a field covering the eye, anterior appendage and antenna of *Pediculus*, the head-lice. The lens, ground from spinel by the late Horace Dall, shows the best image that single lenses can generate. The lens of the louse eye is graphically revealed and the finest chitinous hairs resolved are $<2\ \mu\text{m}$ in thickness. Note that chromatic aberration has only minimal effect on image quality. The image width is $800\ \mu\text{m}$.

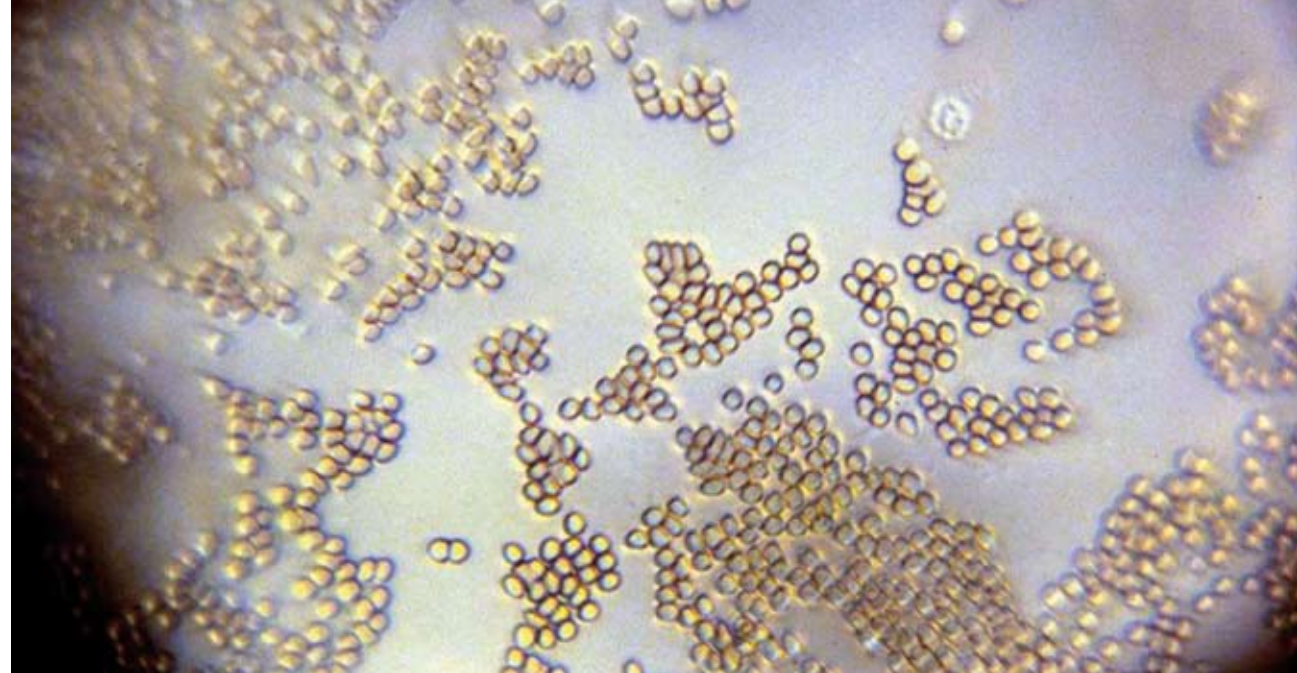


Fig. 10. HUMAN BLOOD CELLS AND THE LEEUWENHOEK MICROSCOPE. Utrecht University Museum holds the best of the surviving Leeuwenhoek microscopes, the lens of which was calibrated by J. van Zuylen in *Proceedings of the RMS* 18 (2): 118-124 (1983). Its magnification was found to be 266x and to put it to the test the author resorted to an unstained smear of his own blood on a coverslip. The results give vivid images of erythrocytes (mean diameter $7.2\ \mu\text{m}$) and (above right, centre) a granulocyte polymorph nucleus is clearly revealed. The nuclear lobes are approximately $2\ \mu\text{m}$ in diameter. Field width $325\ \mu\text{m}$.

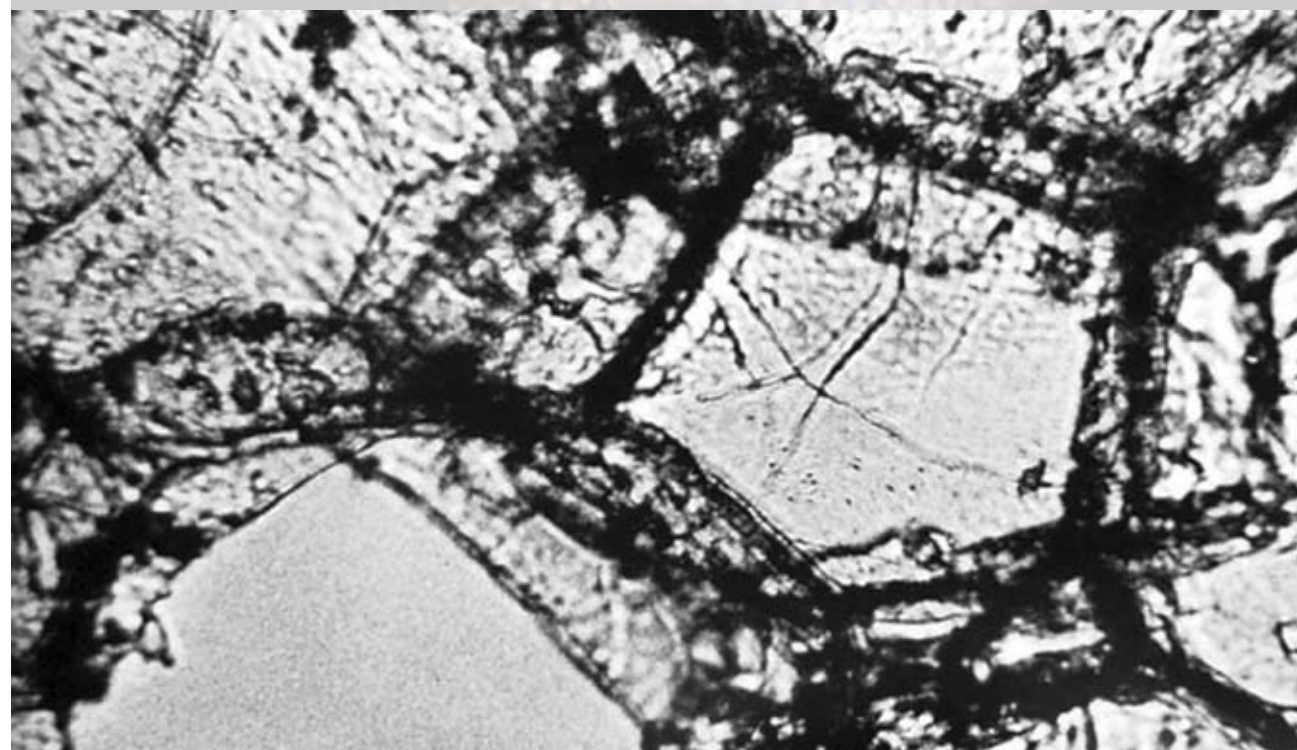


Fig. 12. LEEUWENHOEK'S ELDER -VIEW WITH MODERN MICROSCOPE. The same area of *Sambucus medulla* was selected for examination through a Leitz Dialux microscope with 25 x Fluotar objective and 200 mm bellows on the Olympus OM2n 35 mm camera. The maximum resolution of a conventional modern microscope is around $0.2\ \mu\text{m}$, and thus we can see that Leeuwenhoek's instruments were less than a factor of four less efficient. This is without parallel in the history of scientific instrumentation. Field width $200\ \mu\text{m}$.

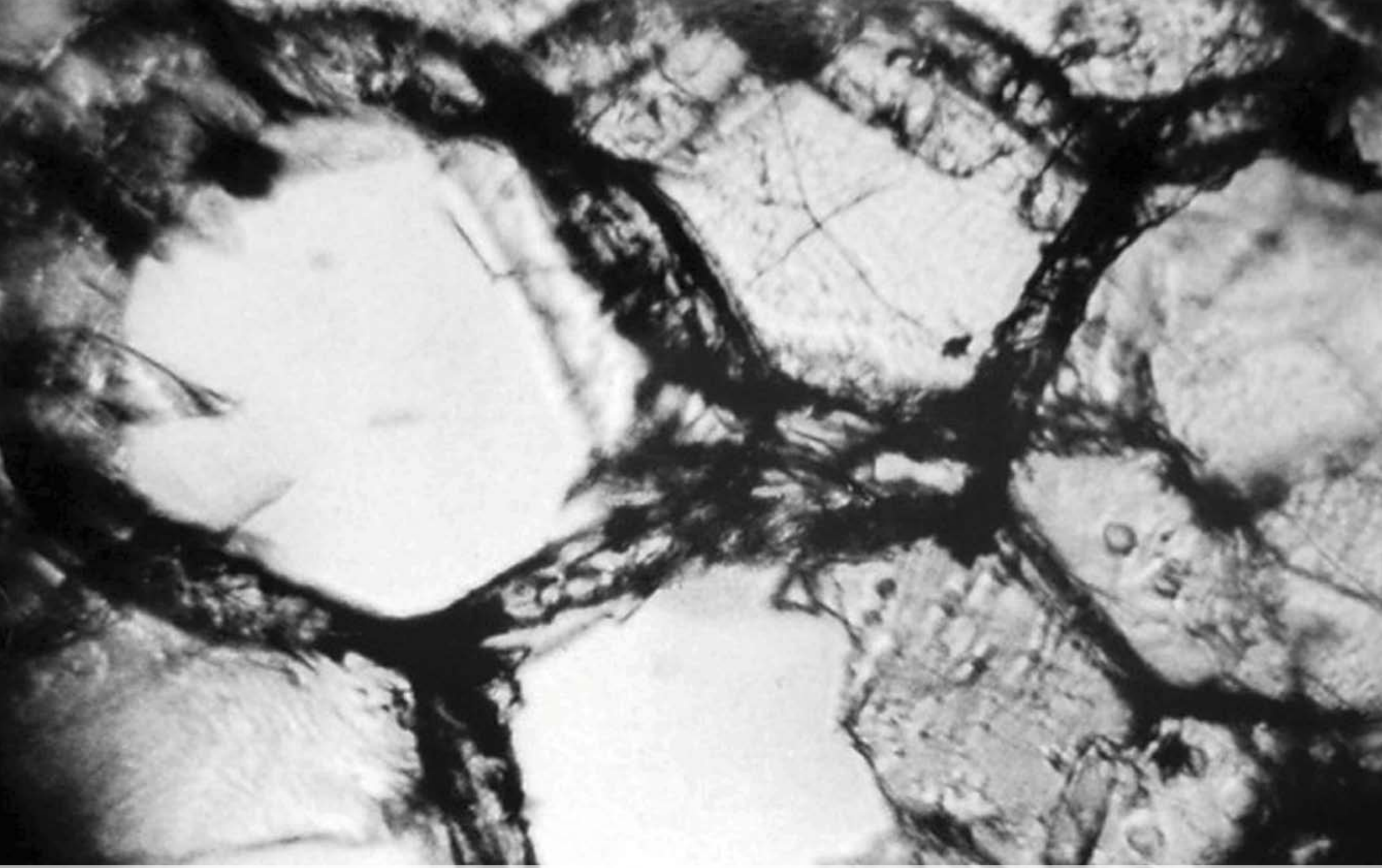


Fig. 11. LEEUWENHOEK'S ELDER SECTION – THE VIEW FROM THE 1600s. Cells of the pith of elder *Sambucus nigra* were studied by Leeuwenhoek in sections he cut with a shaving razor in 1674 and mailed to the Royal Society of London. Here we view them through the Utrecht microscope. Each cell is approximately 80 μm across, and the fine phycomycete hyphae that are visible (resulting from three centuries of storage) are 0.7 μm in breadth. They are clearly resolved by this diminutive lens, its aperture only 0.7 mm in diameter. Field width 200 μm .



Fig. 13. SPIRAL BACTERIA AND THE SINGLE LENS. Leeuwenhoek's work on living bacteria has attracted much scepticism. It seems impossible to many commentators that such diminutive specimen could be satisfactorily resolved by a single lens. The spinel lens has here been used to resolve living cells of *Spirillum volutans* that were found in a pond containing abscised beech leaves. The results are surprisingly good, and substantiate Leeuwenhoek's observations. Each bacterial cell is 20 μm in overall length. Field width 200 μm .

Leeuwenhoek lenses and published his findings in the Proceedings of the RMS (1983).

There would be nothing to gain by reprising his definitive investigations of the focal length and resolution of the lenses, and his findings remain the last word in this field. However, the data themselves – for all their relevance to the fine standards of production that Leeuwenhoek achieved – do not address the question that all microscopists pose: what could early microscopes reveal to the observer?

Commentators like to claim that Leeuwenhoek had secret techniques, or that he exaggerated what he saw; even that his claims lack basis in fact. I decided to take the specimens that he described in his voluminous writings and subject them to single-lens microscopy. There has never been any serious doubt that Leeuwenhoek could perceive microbes

in the general sense, since ciliates are visible to the naked eye. We cannot doubt that he saw living cells, since they can be seen without a microscope in the staminal hairs of *Tradescantia virginiana*, or on the sun-lit surface of a *Begonia* leaf.

In a tour of European museums to see the known Leeuwenhoek microscopes, I took some photomicrographs through the surviving Leeuwenhoek microscope at the University Museum of Science in Utrecht, Netherlands, using both colour transparency and black and white negative 35 mm film. This microscope is the most powerful of those that survive, and is too important for anything other than gentle and non-invasive investigation. I restricted myself to taking pictures of Leeuwenhoek's original specimens of elder-pith (in b/w) and of a fresh and unstained smear of my blood (in colour). What about bacteria? His descriptions, in which he used items like a fine sand-grain or the

breadth of a human hair as reference objects, claim that he saw creatures of bacterial dimensions and some of the published drawings feature a range of minute organisms.

For studies of these specimens, including living bacteria, spermatozoa, and botanical material, I used single lenses made in more recent times. These have similar optical properties to single lenses of more ancient provenance. To show the very best image that could be obtained, I brought in lenses ground from the low-dispersion mineral spinel by the late Horace Dall of Luton. Horace was a great friend and an enthusiast for optics who also made mirrors for Sir Patrick Moore. His tiny lenses offered a chance to experience the ultimate in resolution that is possible with a single magnifier.

Reprising the Birth of Microscopy

The results have shown how remarkably clear are the images created by single lenses. Freed from the burden of image degradation imposed by additional magnifying elements in the light path, they allow one to produce results that are crisp and clear. Spherical aberration is not a limiting factor. What is more to the point, neither does chromatic aberration detract greatly from the clarity of the results.

Popular accounts have dismissed the images generated by pre-achromatic microscopes as being blurred and indistinct, surrounded by rainbow-hued fringes that made observation impractical. As the resulting photomicrographs reveal, this is simply untrue. The images reveal a certain chromatism,



Fig. 14. A SIMPLE MICROSCOPE RESOLVES GIARDIA. In a letter to the Royal Society dated 1681, Leeuwenhoek sent vivid descriptions of the intestinal protest parasite *Giardia*. There was no accompanying drawing to record what he saw. At a conference on *Giardia* in Amsterdam it was proposed that Ford should attempt to reprise the observations with a modern replica simple microscope. The binucleate cells and their flagella are clearly resolved. As with the other micrographs in this paper, the contrast and brightness of images have been normalised using Adobe Photoshop CS. Field width 110 μm .



Fig. 15. TAKING MICROGRAPHS WITH THE LEEUWENHOEK MICROSCOPE AT UTRECHT During the original experiments with the Utrecht microscope the author was assisted by Dr Robert Frederick (left). The Leeuwenhoek microscope was lain on a specially-constructed holder made from plastic and mounted to the Olympus OM 2n 35 mm microscope. This was fitted on an early nineteenth century photomicrographic stand. The photographs figs 12 and 11 were with this device.

it is true, but modern micrographs are often as bad or even worse. The real benefit of chromatic correction, which was introduced in the 1830s, was not so much image clarity as the elimination of spurious tints that appeared in small features. Were some cytoplasmic inclusions really lilac-hued, or pale yellow? The achromatic microscope confirmed that, in life, they were really colourless.

Leeuwenhoek wrote that he first became intrigued by looking at chalk cliffs, and wondering what caused their whiteness (needless to say, the microscopy of chalk cliffs had been described by Hooke in

Micrographia). The first time Leeuwenhoek became interested in microscopic life was after a boat trip across a lake that was rich in visible growths of algae, for that led him to the astonishing revelation of unimaginably rich populations of microbes hidden in the world about us. In his busy life he recognised the nucleus, recorded Brownian motion, studied living sperm, and discovered Hydra.

There is one important final distinction to draw between Hooke and Leeuwenhoek. Robert Hooke confined himself largely to magnifying what was already familiar – he drew gigantic gnats, magnified

moss, hairs the size of logs. Leeuwenhoek's legacy was different. Using Hooke's design of a single-lensed microscope, he went on to unveil the microbial universe. Leeuwenhoek gave us our first glimpse of the world of living cells and microorganisms that are commonplace today. He was not the father of the microscope (microscopes of a sort had been in existence since the 1590s) but he was assuredly the midwife of microbiology.

Hooke's great book, although it was not the first to account for microscopy, was the first devoted to detailed studies of familiar objects and *Micrographia* is certainly the first work of popular science as we would define the term today. But for Leeuwenhoek, the challenge was high-power microscopy. The microscopes he made could allow him to visualise micro-fibrils down to 0.7 μm in diameter – that is within a factor of four of the resolution of the great glass and brass microscopes that were to follow.

Leeuwenhoek's achievements are unparalleled in microscopy, and marking his 375th birthday can give us all a chance to reflect on the magnificence of his achievements.

FURTHER READING

Dobell, Clifford, 1932, *Antony van Leeuwenhoek and his "Little Animals"*, London: John Bale, Sons & Danielsson [available in reprint, 1960, New York: Dover Publications Inc].

Ford, Brian J., 1991, *The Leeuwenhoek Legacy*, Bristol: Biopress & London: Farrand Press.

Fournier, Marian, 1996, *The Fabric of Life, Microscopy in the Seventeenth Century*, Baltimore & London: The Johns Hopkins University Press.

Hooke, Robert, 1665, *Micrographia*, etc., London: Martyn & Allestry [available in reprint, 1961, New York: Dover Publications Inc., and on CD-ROM 1998, Palo Alto: Octavo Editions].

Ruestow, Edward G., 1996, *The Microscope in the Dutch Republic, the Shaping of Discovery*, Cambridge: University Press.

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Brian J Ford

Rothay House, Mayfield Road, Eastrea,
Cambridge PE7 2AY

Email: mail@brianjford.com



Brian J Ford was elected to Fellowship of the RMS in 1962 and has been publishing papers with the Society since 1965. His work on the history of microscopy led him to develop techniques for the reconstruction of the earliest experiments, and

the results have shown that the early instruments were capable of providing images of unexpectedly high quality. His papers in this field have been published internationally, and his books include *The Revealing Lens* (1973), *Optical Microscope Manual* (1973), *Single Lens, Story of the Simple Microscope* (1985), *Leeuwenhoek Legacy* (1991) and, for children, *Using the Digital Microscope* (2002). Ford is Visiting Professor at Leicester University, a Fellow at Cardiff University and former Fellow at the Open University. This paper was first delivered as a PowerPoint presentation, with video examples of microorganisms through a single lens, at the Cambridge Society for the Application of Research at Churchill College, Cambridge.