Hidden secrets in the Royal Society Archive

B. J. FORD, FLS

Archives are always considered as written records, but I believe we should now regard them as artefacts with their own intrinsic microscopical value. As objects in their own right they offer new and highly significant areas of study.

In 1981 I began a systematic survey of the Leeuwenhoek correspondence at the Royal Society. The intention was to examine the documents for non-archival residues, spores, pollen grains, or perhaps (as was said at the start of the work) 'hairs from Leeuwenhoek's head'. The investigation revealed an extraordinary bonus in the form of a series of nine specimen packets which had been sent to London by Leeuwenhoek during the late 17th century. All but one still contained specimen material. These included fine plant sections, thicker serial 'slices', specimens of bovine optic nerve and desiccated algal films.

The sections were examined by optical and scanning electron microscopy and proved to be of a standard that is comparable to many present-day preparations. The optic nerve material could be reconciled with the surviving drawings made by Leeuwenhoek's limner (Leeuwenhoek did not prepare drawings himself), and the algal material was amenable to reconstitution with sterilised water. Microscopy revealed intimate traces of Leeuwenhoek, including blood cells still detectable on the razor-cut sections, and it has been possible to identify some of the species which he described in his letters. A unique insight was gained into the origins of the modern era of biological microscopy.

The conclusion is that archives must be construed as physical objects, amenable to microscopical or analytical examination, being a resource greater than that of the facts they may record. Archivists should be prepared to conserve collections in ways that preserve their physical nature, for microscopical traces upon the surface, or chemical constituents from the time of origin, may prove important in unravelling the past. Encapsulation or cleaning can remove vital traces of historical evidence.

A selected bibliography of publications on the Leeuwenhoek specimens is appended.

Keywords: Leeuwenhoek — history of science — microscope — specimen — microslide — Hooke — Redi — de Graaf — Malpighi — lens — resolution.

LEEUWENHOEK'S WRITINGS

Antony van Leeuwenhoek (1632-1723) founded the discipline of microbiology. There had been microscopists prior to his time, for the compound microscope had

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been in existence at least since the end of the 16th century. However, Leeuwenhoek was the first person to construct reliable high-power microscopes, capable of resolving organelles and bacteria. His career in microscopy commenced in 1673, and several notable microscopists had been active during the preceding decades. The fields they investigated embraced many areas of interest (Hall, 1989). These included:

Human histology

Capillary circulation in the lung (Malpighi, 1661a, b)
Haematology and general organ microscopy (Malpighi, 1665, 1666)

Entomology

Insect morphology (Power, 1664; Hooke, 1665)
Anatomy (Swammerdam, 1669; Malpighi, 1687)

Embryology

Rana (Swammerdam, 1669)
Callus (Malpighi, 1687)

Botany

Plant histology (Grew, 1672; Malpighi, 1687)

However, the work encompassed by these investigators centred on the examination of familiar objects, such as an enlarged flea, or the structural details of pollen. Leeuwenhoek's fascination was for objects that are only discernible with a microscope, and to minimise constructional complications (coincidentally reducing chromatic and spherical aberration) he confined himself to the simple microscope. He began his career as a microscopist when aged 40, yet went on to devote 50 years to establishing the modern era of microscopical biology. In many respects, Leeuwenhoek was a pioneer of today's scientific era.

Leeuwenhoek spoke no other language than Dutch, and the language of his era was close to that of the present-day Boers. South African scholars find the language of Leeuwenhoek far easier to read than do modern scholars based in Europe. His inability to read foreign languages does not mean (as many have asserted) that he had no access to texts in other tongues. In his letters there are many allusions to the foreign-language books of his day, including: Willis's *Cerebri anatome* (1664), the 1665/7 *Micrographia, etc.* of Hooke, Swammerdam's *Historia insectorum generalis* of 1669, Redi's influential *Esperienze intorno alla generazione degl' insetti* of 1668, his *Experimenta circa generationem insectorum* (1671), de Graaf's *De Mulierum Organis Generationi* (1672), Grew's *Comparative anatomy of trunks* (1675) and Willoughby's *Historia piscium* of 1686. Leeuwenhoek knew many individuals who were able to translate, and noted the death of a translator in some of his writings.

LEEUWENHOEK'S RESEARCH

Leeuwenhoek has also been dismissed as a mere 'dilettante', his microscopes being described as primitive, whilst the suggestion has often been made that his specimens would have been crudely prepared and of inferior technical quality. A

summary of earlier attitudes towards Leeuwenhoek's working methods appeared in Ford (1981). The review published as Folkes (1724) implies some degree of condescension. Becking (1924) described Leeuwenhoek as an immortal dilettante, while Sachs (1875) dismissed him as inconsequential. Leeuwenhoek's individualism has been discussed by van der Star (1981).

A study of his writings certainly reveals some conceptual limitations. For example, we may see evidence of a globalist understanding of organic structure, a view that has frequently been cited as evidence of his observational inadequacies. In truth, these are limitations of the tyro working in new fields and should not divert us from appreciating his contributions in other key respects. His importance as an experimental biologist is clear from his many letters, most of them sent to the Royal Society of London and preserved in their archival collections. There can be little doubt that Leeuwenhoek was a pioneer of experimental biology, as well as the greatest 17th century pioneer in observational microscopy. Most interestingly, the publication of scientific findings on the specimens (Ford 1981-99 and others, see chronological bibliography in Appendix 1) has resulted in widespread present-day endorsement of Leeuwenhoek's pioneering endeavours.

Leeuwenhoek's work reveals that he was able to construct experimental procedures which were, within their historical context, rational and proved to be repeatable. He was never loath to fly in the face of current opinion (over the question of spontaneous generation, for instance) or to adapt a previously held belief in the light of new evidence. However, one crucial aspect of his work remained a mystery: namely, how good was he as a practical microscopist? Previously published comments had all concluded that his specimens must have been inferior. Some commentators published conclusions without a scientific basis for their findings:

'No preparations from the seventeenth century have survived, for it is almost certain that they all were only of a temporary kind, for viewing on one occasion only ... The detail visible in the usual dry mounts is minimal, and they are prepared with little finesse [having] so little resemblance to life that scientific interpretation is almost impossible.' (Bracegirdle, 1978).

In each respect, such claims have now proved to be unfounded. Leeuwenhoek's fine specimens were not temporary preparations, for he left the specimen attached to its microscope for prolonged periods, returning from time to time to make further inspections. They were certainly not for viewing on a single occasion. It was amongst the archives of the Royal Society that I discovered his surviving specimens, untouched for over three centuries. They reveal the considerable technical finesse which Leeuwenhoek brought to the preparation of his specimens. Although they are all dry preparations, they are amenable to microscopical examination and have revealed many crucial details of the way he worked.

The letters are preserved in custom built bindings in the archive strong-room of the Royal Society of London, and I am grateful to the President and Council for full access to them. Transcriptions of the letters to the Society, and to Leeuwenhoek's other correspondents, are still being published (Leeuwenhoek, 1939-present). It is anticipated that the considerable volume of correspondence will be

published in English and Dutch by 2000. It is worthy of reflection that the time taken for the publication of the correspondence will be over a decade longer than it took Leeuwenhoek to originate it.

LEEUWENHOEK'S SPECIMENS

During a programme of research on the origins of microscopy, the President of the Royal Society, Sir Andrew Huxley and the Archivist, Mr Leslie Townsend, were kind enough to encourage me to inspect the original letters with a view to looking for microscopical evidence of the circumstances of their compilation. Leeuwenhoek's first letter was sent to Royal Society by de Graaf in 1673. The manuscript

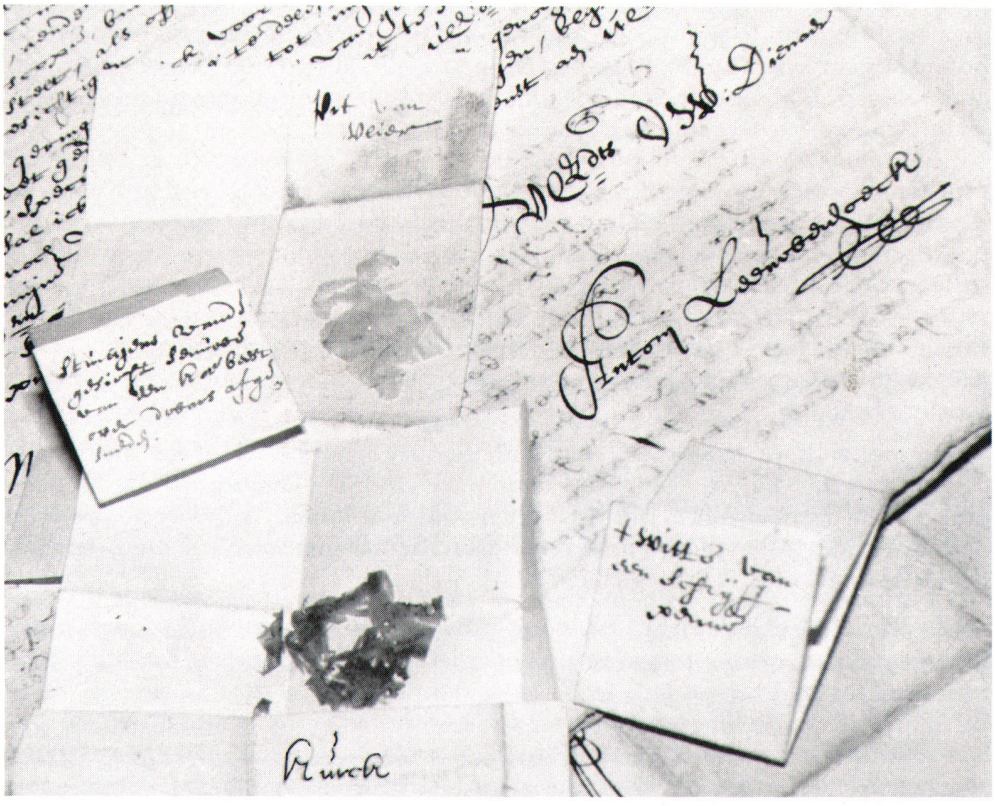

FIGURE 1. A Leeuwenhoek letter and its specimens. This letter, from the archive files of the Royal Society, was sent to London by Antony van Leeuwenhoek on 1 June 1674. An unmarked envelope had been pasted to the reverse of the final page, in which four paper packets were found. On opening, three proved to contain original specimens prepared by Leeuwenhoek's hand. The photograph shows the opened packets of elder-pith (centre) and cork (below). Slices of bovine optic nerve were found in a third packet (left), whilst material from a writing quill (lower right) was missing. Five further packets were found attached to later letters.

has long since been lost. It was published in *Philosophical Transactions* **VIII** (94), 6037-6038 as: 'A Specimen of some Observations made by a Microscope, contrived by M. Leeuwenhoek in Holland, lately communicated by Dr. Regnerus de Graaf'. The illustrations were published some time later, in **VIII** (97), 6116-6119. In it he took the unnamed Robert Hooke to task for some of the descriptions published in *Micrographia, etc.* (Hooke, 1665). It is clear that Leeuwenhoek was much influenced by this influential book, which had been a talking-point during his only visit to London in 1668.

When I inspected the letter of 1 June 1674, the final folio seemed to be weighed down by a small envelope pasted to the reverse (Leeuwenhoek, 1674). On cautious inspection, it proved to contain four labelled specimen packets (Fig. 1). One, identified as containing white from a quill pen, was empty. Two others contained fine sections of elder pith (Fig. 2) and cork (Fig. 3), whilst a fourth contained transverse slices of the dried optic nerve of a cow. These were not known to the translators of the published *Collected letters,* for (as Sir Andrew explained to me) the Dutch scholars had been provided only with microfilm copies of the letters. No photographer would be interested in a blank paper envelope pasted to a page, and so the packet I found had not been noted when the translations were done.

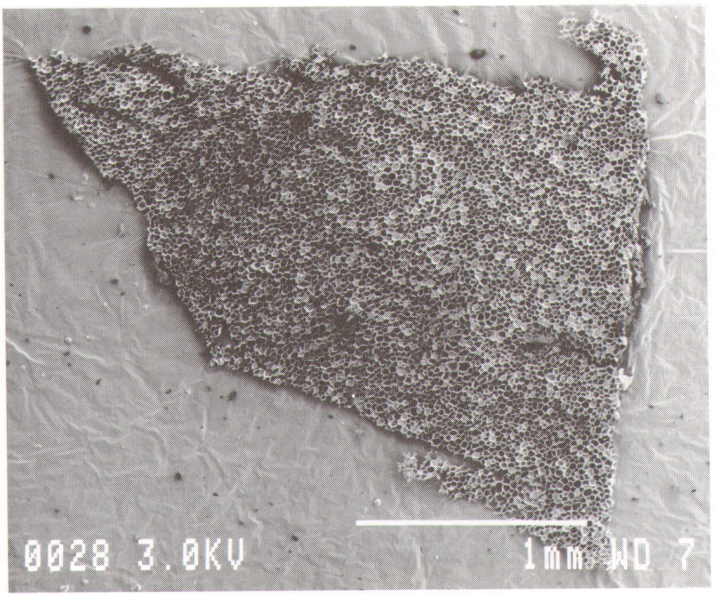

FIGURE 2. *Sambucus nigra* L. cortex sectioned by Leeuwenhoek in 1674. The botanical sections found in these specimen packets were of exceedingly high quality, well matched to the demands of modern microscopy. This scanning electron-micrograph under a Jeol JSM 840A reveals Leeuwenhoek stepped method of sectioning plant material. He allowed the blade of a shaving razor to rise during cutting, until the material became too friable to hold together. The blade was then directed to cut deeper, rising again until a further thin region was obtained. Cellular material found on the specimens has proved to reveal further details of Leeuwenhoek's working.

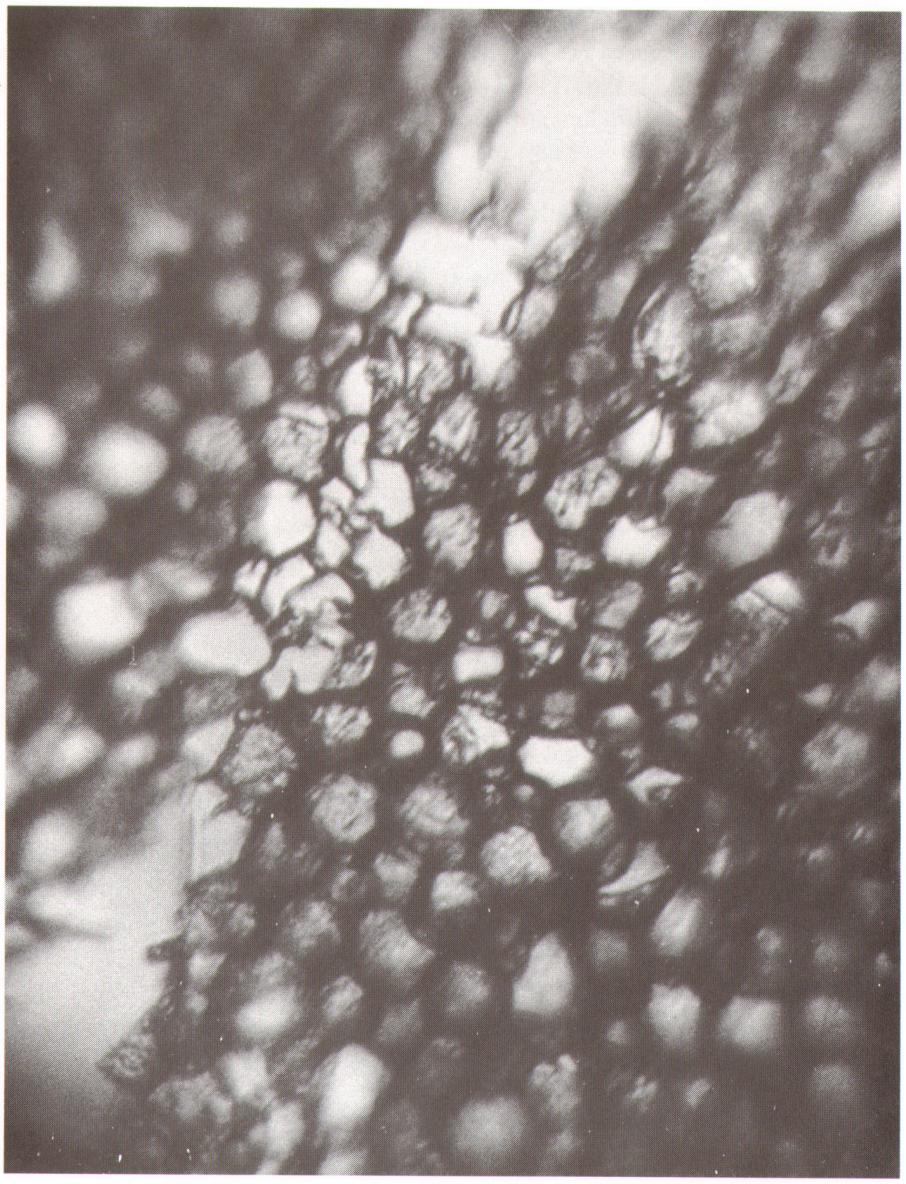

FIGURE 3. Leeuwenhoek's view of his original section of *Quercus suber* L. At the Museum for the History of Science at the University of Utrecht, the late Professor Peter Hans Kylstra was kind enough to arrange for the author to take micrographs of the specimens through their original Leeuwenhoek microscope. The lens has a focal length of 0.94 mm and magnifies × 266 (van Zuylen, 1981). The finest structures visible are occasional phycomycete hyphal contaminants. Measurement under the scanning electron microscope revealed that the finest such structures that can be resolved by the Leeuwenhoek lens are 0.7 μm wide, testimony to the capacity of single lenses to resolve fine detail.

Clifford Dobell had noted that packets of specimens were attached to this letter, though he made no investigation of what the packets contained. Their presence was also noted by F. J. Cole when he wrote on Leeuwenhoek's research (Cole, 1937), though once again they remained uninvestigated.

The next set of specimen packets which I found were attached to the letter of 2 April 1686 (Leeuwenhoek, 1686). In this letter he had written:

'I have thought fit to put some cotton seeds, which I have had by me for over a year, and which are so old that their greenish colour has already faded, in water for one night, after which I removed from them their tough rind, being their first; and then their soft membrane, being their second envelope; and separated the leaves a little from one another. Eight or nine of these seeds, from which the young cotton tree takes its origin, I send you herewith. On these a sharp eye will recognize, even without any magnifying lens, not only the four distinct leaves, together with that part which will become the root and stem; but one will also be able to see the small spots on the leaves.'

Leeuwenhoek took some of the soaked cotton seeds and

'cut one of them into twenty-five to twenty-six round slices, and the other into twenty-eight to twenty-nine round slices, which too I send you herewith.'

Leeuwenhoek's outer layer is the seed coat proper; the soft membrane is the endosperm which surrounds the embryo itself. Leeuwenhoek was wrong to refer here to 'four distinct leaves', however. Within the cotton seed are two cotyledons. These are folded against each other and dried specimens are liable to break unless handled with extreme care. It is probable that his manipulations separated the convoluted structures into four separate parts. His description of 'small spots' is an example of acutely accurate observational microscopy; these are the glandular structures on the leaves which contain brown or violet secretions.

After the investigation, each set of the seed specimens was packed in its own wrapper and neatly labelled in ink. The *Collected letters* **VI:** 11 published a footnote to Leeuwenhoek's descriptive letter which did not recognize the packets for what they were. The editors recorded that the 'slide' Leeuwenhoek sent to the Royal Society is 'no longer in the library'. At the time, a 'slide' would not, of course, have existed; and the correspondent was equally wrong to imagine that the material was missing. The translations were done from microfilm copies of the original letters, and the small packets which Leeuwenhoek had used to contain his specimens were pasted adjacent to his signature.

The packets were present all the while, but the image they presented to the camera deluded the translator into thinking Leeuwenhoek had drawn 'rectangles' at the end of his account. The images were, in fact, the outlines of the folded paper packets, unopened for three centuries. The use of the term 'slices' draws a neat distinction between these portions of plant material and the fine sections which Leeuwenhoek had earlier prepared of cork and elder pith, *q.v.* and his decision to introduce the concept of the serial technique has had many later examples in the realm of experimental biology.

At the time of his active period it was believed that 'heavenly paper' descended from time-to-time to the earth's surface, as though messages from a divine source.

Some small fragments were sent to Leeuwenhoek by a correspondent in Courland on the south coast of the Baltic. The specimens took the form of blackened fragments of a papery substance and were contained in a square of folded paper. The handwriting on the envelope suggests that the correspondent was not accustomed to writing in the Latin alphabet.

Leeuwenhoek examined the specimens when they arrived at his home in Delft (Leeuwenhoek, 1687). In the letter dated 17 October 1687 he wrote:

'I had not had this supposed paper in my house for half an hour before I had (with the aid of the microscope) formed such a clear impression of it, that I concluded it was a plant which had come forth from the water. And moreover, I took it for sure that, if it were true that it had fallen from the sky onto the field, then this substance must first have been driven up into the air (by a cloud which we call a whirlwind). But I much prefer to believe that, due to heavy rains or melting snow . . . the water from a marsh or from ditches had flooded some piece of land, and that the water had left this green plant, from which the supposed paper is made, behind on a greensward or a field with young corn, with the result that the sun and wind caused the plant to become dry and stiff, so that it took on to some extent the look of charred paper.'

The specimen packet was sent by Leeuwenhoek to London with this letter, and the 'heavenly paper' was the seventh of the nine specimen packets which I found hidden amongst his correspondence. When Leeuwenhoek examined the specimen, he concluded that it was not paper at all. This 'plant' material, as he correctly designated it, had originated as a mass of algal growth floating in water. He emphasises this in the following extract from the letter of 17 October 1687:

'I concluded that I had often seen this substance in large quantities in stagnant waters, such as ditches and excavated ground; but what puzzled me was how I could possibly make this Substance, or green plant, turn into a blackened mass. This green plant is often called felt, but more often slime, by the common person.'

Leeuwenhoek was alluding to colonies of chlorophyte algae (such as *Spirogyra* and *Zygnema*) which occur in fresh water. He set about testing his hypothesis, by making some heavenly paper of his own. The letter continues:

'I bethought myself to go to some swampy fields, situated not far from our City; but on reflection that the canals which run around our City have sluice-gates in two distinct places, in order that the daily current of water should run, not around, but through the City, I went to where the water in the City canal had least movement, and where I saw the slime in abundance.

Of this slime I have taken some and laid it on several pieces of thick paper, and dried the same in front of the fire; and I saw that where it lay very thick, it changed by itself from a clear green into a blackish substance; and where it was quite thin it retained its green colour. Furthermore, I once again examined the so-called burnt paper, and now I saw very distinctly that it was one and the same substance, and of the same composition. For, when I examined the green substance, just as I had taken it from the water, through an ordinary microscope, I imagined seeing that these very thin, thread-like parts, which by far exceed a hair in thinness, were round, and that their membrane was very transparent, and that they were filled with green globules ...'

His account adds that he observed 'joints' in the filaments. These were the transverse septa which divide one cell from the next in line. Leeuwenhoek later collected algal material from a water cistern used to irrigate a small garden near his home, which he dried down in a similar fashion. In this case, the papery specimen he obtained retained its green colour. He sent samples of the results to the Royal Society. The packets were among those I found to have survived intact, and both were made available for microscopical examination. His technique of drying fresh aquatic algal matter means that he was also bequeathing to a 20th century microscopist some desiccated samples of the same specimens which he studied during his research. Reconstitution of the material has restored many of the organisms to a lifelike appearance, and has enabled us, for the first time, to identify in Leeuwenhoek's own material some of the aquatic types he described in his letters.

Many of our problems in the history of science result from reference to derivative sources, rather than to primary archive material. We can trace one interesting example through the literature on Leeuwenhoek's observations of *Hydra*. The original commentary was republished in Baker (1743). Baker's third figure (p. 94) is a reproduction of the third figure in Leeuwenhoek's account. Interestingly, Leeuwenhoek's original submission had shown a diagram of *Hydra* with eight tentacles, increased by the engraver to nine by the time it appeared in *Philosophical Transactions* in 1703. This was corrected to the original eight in Baker's version, strongly suggesting that he referred, not to the published version but to Leeuwenhoek's original correspondence in drawing up his account.

CONCLUSIONS

The letters Leeuwenhoek sent to London have been indexed and bound into volumes. Translators have had recourse to microfilm copies of the original correspondence, and relatively few research workers have had access to the original documentation. In consequence, packets of original specimens have survived to the present day. These have illuminated many points of interest concerning Leeuwenhoek's productive research. It has been possible to reconcile reconstituted specimen material with his descriptions, and to identify some of the species he observed (mites of the genus *Tyrophagus,* for example). The high quality of his scientific expertise has also been determined, allowing us to dismiss suggestions that his specimens would have been of poor quality or hard to observe.

There is always a danger that the over-enthusiastic conservation of documentary collections could lose such important artefacts (Fig. 4). If archives are left without cleansing or rearrangement, clues can be obtained to the conditions under which researchers carried out their work. Spores, pollen-grains and other microscopical contaminants are removed through many techniques of conservation. These are important strands of evidence in building up an entire picture of a programme of research from the past. For example, some blood cells were detected on Leeuwenhoek's sections of elder pith. Since he utilised a shaving razor to cut this material, it is probable that these cells originated from Leeuwenhoek himself. Genetic sampling methods are rapidly advancing, and could be used in the future to analyze DNA from cells or hairs residing on documents.

FIGURE 4. The specimens today, preserved for future scholarship. Following scientific investigation the portions of specimen material were returned to the Royal Society. Each was packed in a secure container and is now in storage after being formally accessed. Fourteen aluminium stubs of gold-sputtered specimens were annotated and packed in a specially adapted box (left). The plant sections used for optical microscopy were enclosed in acid-free paper packets (left), and samples from the specimens of 'heavenly paper' — correctly shown by Leeuwenhoek to be dried algal films — were left adherent to standard 76 mm × 26 mm microscope slides (centre). Care has been taken to avoid contamination, a convention it is hoped will be applied in future investigations.

The lesson is simple: archives are more than their literary content. The paper of which they are composed may have microscopic traces attached. In some cases the material may take the form, as in this case, of specimens prepared by the research worker for the interest of other investigators. Cases in the future may centre on microscopic contaminants which throw important light on their origins. Conservators need to bear this in mind when maintaining document collections. Washing, or chemical denaturing agents, could destroy vital clues of interest to the analyst.

The packets attached to the Leeuwenhoek letters were clearly of little interest to archivists. In the hands of the enthusiastic microscopist, they have revealed much of the origins of the modern era of biological microscopy. Their survival was a matter of chance, which — with proper insight — we could turn into a certainty for archivists in the future.

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B. J. Ford, Rothay House, Mayfield Road, Eastrea, Cambridgeshire, PE7 2AY, UK.