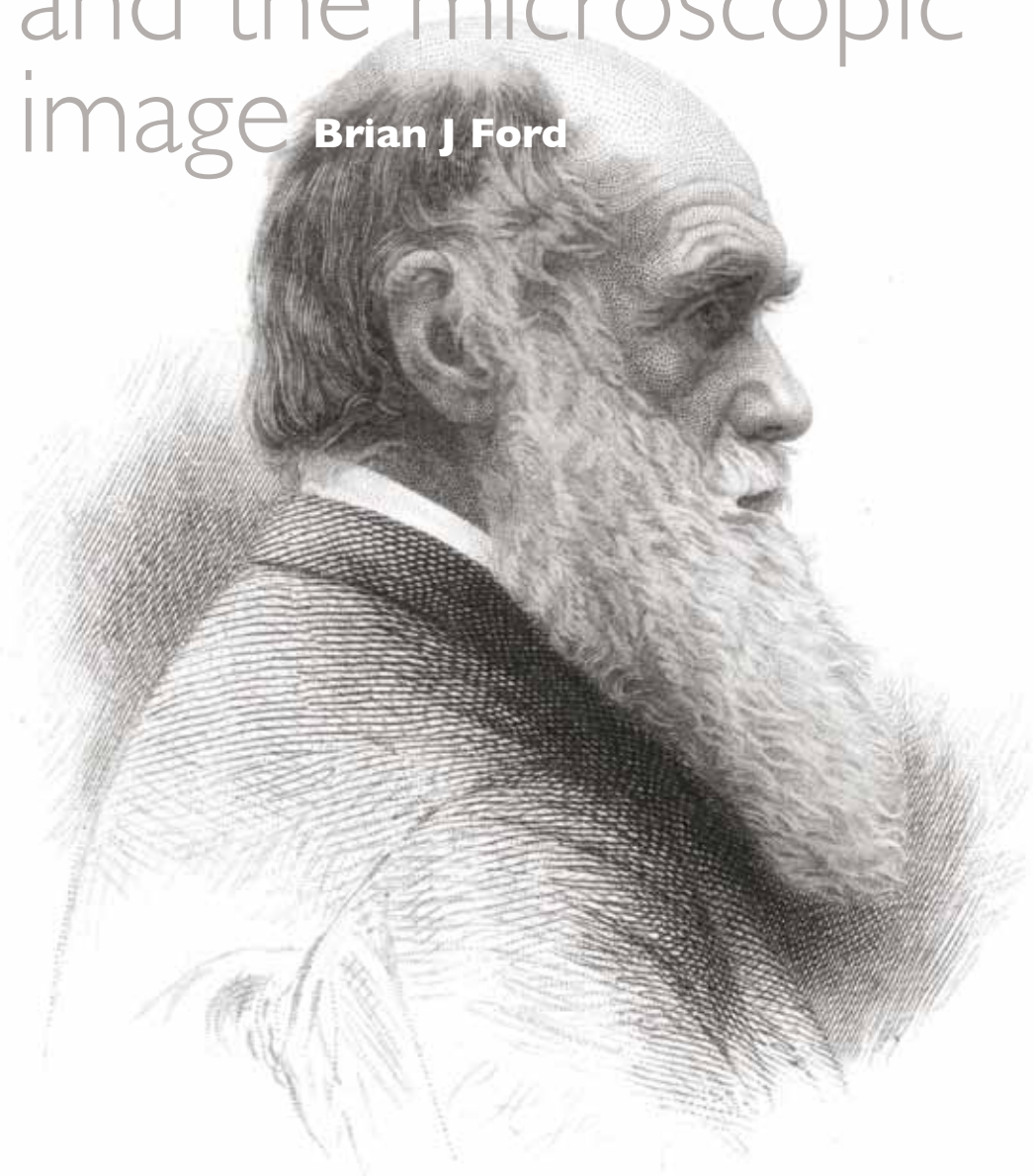


Charles Darwin and Robert Brown – their microscopes and the microscopic image

Brian J Ford



Microscopes were important to many Victorian scientists. Once the brass and glass instruments fitted with achromatic lenses were in vogue, high-resolution optical microscopy would become easily available – but what about microscopy prior to that? There was much useful investigation carried out with microscopes using just a single magnifying lens, indeed many of the fundamental revelations in the biological sciences were made possible by these unsophisticated instruments.

The cell itself, its nucleus, sperm cells and bacteria, fungal spores, pollen grains and microfungi, were all discovered using simple microscopes. Some devoted microscopists showed extraordinary enterprise and sheer technical skill in unravelling the microscopic realities of life. The naked ovule of the gymnosperms is characteristic of the group, and this diminutive reality was meticulously unravelled in the early nineteenth century by the distinguished Scottish botanist Robert Brown (1773-1858)¹.



The Banks Design

A range of well-designed simple microscopes was made by the firm of Robert Banks (later Banks & Son) in central London during the late Georgian era. These brass instruments were small enough to fit into a modest wooden box that could go into a coat pocket and the best soda-glass lenses magnified little more than 100x. We know that Brown owned several microscopes in his lifetime, and some have survived. There is a microscope in the collections at the Linnean Society of London, where I serve as Honorary Surveyor of Scientific Instruments, and another example with an engraved silver plate at the Herbarium at Kew Gardens, Surrey.

The Linnean Society microscope was found among the items from a house sale in Dorset of items owned by Thomas Bell (1792-1880) who had inherited it on Brown's death. In 1922 it was given to the Society by Miss Ida M Silver. Here we may discern the

traditional attitude that conventional scientists have traditionally shown to the simple microscope, for it was quickly dismissed as being 'surprisingly simple, being little more than a dissecting-microscope'.² The view was that something as diminutive as a cell nucleus could not be resolved by so ordinary a microscope. As we can see from the accompanying micrographs, a single lensed microscope, used properly, is clearly sufficient for the task.

We can conclude that Brown's microscope at Kew is of later date since it has a more complicated design of double stage and an ingenious fine-focussing control near the base of the body pillar. The lid of the box bears a silver plate on which the following words are engraved:

The microscope used for years
BY ROBT. BROWN F.R.S. in Soho Square
Given to me by J. J. Bennett F.R.S. 12 Feby 1859
J. E. Gray

The design was also made by Bancks for Charles Darwin (1809-1882). An example survives at Down House, Kent, where Darwin lived between



Fig. 1. Together after almost three centuries: four simple microscopes by Bancks, manufactured in London in the early 1800s. First is the Robert Brown microscope at Kew, fitted with fine focussing and bearing its commemorative silver plate. Next is that of Sir William Hooker, who used it in writing his *Musci Exotici* (1820), then George Bentham's microscope which still bears the tiny cutting marks from his plant dissections and, unusually, features a substage condenser lens. On the right is Brown's Linnean Society microscope.



Fig. 2. Robert Brown's microscope at the Linnean Society with the stage forceps holding a specimen of the snowdrop *Galanthus*. The flower lying alongside is the orchid *Cymbidium*, for it was in the orchids that Brown first identified the cell nucleus. The focussing control (centre) is useful only for coarse adjustment. A cork insert within the cylindrical body supports the lens pillar (top) and allows fine focussing movements.

1842 and his death in 1882. The house became a girls' school – Downe House – in 1907 and was later opened as a Darwin museum in 1929. In 1996 work began to restore the property to the state it was in when Darwin lived there, and it has since been comprehensively re-equipped with

contemporaneous artefacts and memorabilia – among which is the Banks microscope.

There are other examples at Kew. The former deputy keeper at the Herbarium, Gren Lucas, took me to examine an example in their collections made for George Bentham (1800-1884), alongside a microscope made for Sir William Hooker (1785-1865). Banks was well connected, for they made instruments for the British Royal family. A compound microscope made in 1815 was described by the Royal Microscopical Society and bears the inscription 'Banks, Inst. Maker to the Prince Regent, 44 Strand, London'. Hooker's microscope bears a dedication to: 'His Royal Highness The Prince of Wales'. The Prince of Wales became Prince Regent in 1811, so we can deduce that this microscope was made prior to that date.

The microscope used by Charles Darwin on the voyage of the *Beagle* was recommended to him by Robert Brown³. This is believed to be the microscope at Down House. The voyage commenced in



Fig. 3. Bancks, the name of the manufacturer, is engraved on the circular stage of George Bentham's microscope at Kew. The specimen here is a Parisian preparation of a female *Pulex*, the flea. Note (top right corner) the small cutting marks visible on the brass block. Bentham, a distinguished botanist, would have dissected floral structures in his studies, and here we have first-hand evidence of such work with this instrument.



Fig. 4. The Linnean Society microscope packed in its case. Mahogany is used to make the case which is divided into sections and the lid of which is lined with bottle-green velvet. The main body and lens arm remain assembled during storage. Six lens holders (left) include two silvered Lieberkühn reflectors. The simple lenses magnify between 32.5x and 170x and provide remarkably clear images.

December 1831, and we could assume that the microscope was made earlier that year. Thus, even though the instruments themselves are not dated, we can infer through these means approximately when they were produced.

The Microscopes

The photographs were taken at the author's laboratory, where the microscopes were examined and put through their paces. The images show the way the microscopes were constructed. A hollow cylindrical body pillar supported a circular stage into which a disc of glass could easily be fitted. In this form the instrument was known as a botanical microscope. Other users, more interested in studying living pond organisms, ordered a version supplied with a concave watch-glass in which a little water could be held. These were known as aquatic microscopes – the instruments in both applications were otherwise the same.

Above the stage, supported by a transverse bracket, was a lens fitted into a circular holder the size of a small coin; beneath it was a (typically two-sided) substage mirror. The lens bracket was held in a plug

of cork held within the body pillar, which allowed the supporting rod to be gently slid in and out at will. The bracket allowed the lens to be moved across the stage plate so that the entire area was easily covered.

Many of the designs by Bancks featured a rack and pinion coarse focussing adjustment. Some were fitted with a concentric fine-adjustment control, and occasional models also bore a substage condenser lens. The lenses for transmitted-light microscopy were fitted in a conventional holder, in which a perforated steel cup caused the lens to be somewhat stopped down in an attempt to limit aberrations and increase contrast. Those intended for the examination of solid specimens (opaque surfaces, or floral structures) were fitted into a concave silvered Lieberkühn reflector.



Fig. 5. Fixed within the lid of Hooker's simple microscope is this copper-engraved paper label. The Prince of Wales relinquished his title in 1811, which allows us to infer that the microscope was manufactured prior to that date. The label identifying the owner as Sir William Hooker is signed 'Sir J.D. Hooker GCSI & C'. William and Joseph Dalton Hooker, father and son, were distinguished directors of Kew Gardens and raised the status of Kew to one of international renown.

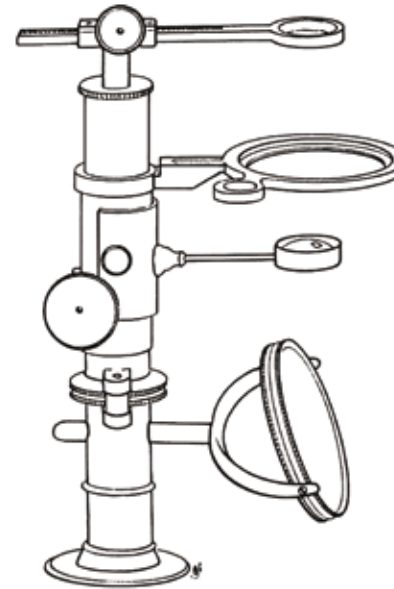


Fig. 6. Charles Darwin's microscope was the subject of this line drawing made by the author at Down in 1982. It is a refined version of the Bancks design, featuring a fine adjustment control on the body pillar and a substage condenser lens. An on-line search for microscope image J970114 shows photographs of this instrument in its present-day condition, in which the arm supporting the substage lens now appears to be missing.



Fig. 7. Component parts of the Linnean Society microscope are here displayed in disassembled state. The stage assembly (left) and body components (below) can be identified. The six lenses (top) are held in place within the brass lens holders by retaining cups; and the aperture of the smaller lenses, being of higher power, were all restricted by means of perforated steel stops. Although this reduces resolution, it significantly increases image contrast.

The microscope was purchased with its components neatly fitted into sections of a velvet-lined hardwood storage box. The biconvex lenses typically ranged in magnification from 20x to 160x and were hand-ground from beads of soda glass. When assembled and ready for use, the microscope was screwed into a boss set into the lid of the box. The whole instrument could fit into a coat pocket and, though exacting to use, this type of microscope is a pleasing and efficient design. Until the larger achromatic compound instruments were available, this type of microscope was perfectly fitted to the task⁴.

The Microscopic Image

Robert Brown first noticed the ubiquity of the cell nucleus when examining orchid tissues in 1828. He was not the first to observe nuclei, for they were figured by Leeuwenhoek in 1682. Examining fish blood through his microscope, erythrocytes of which are nucleated, Leeuwenhoek correctly noted 'that some of them enclosed in a small space a little

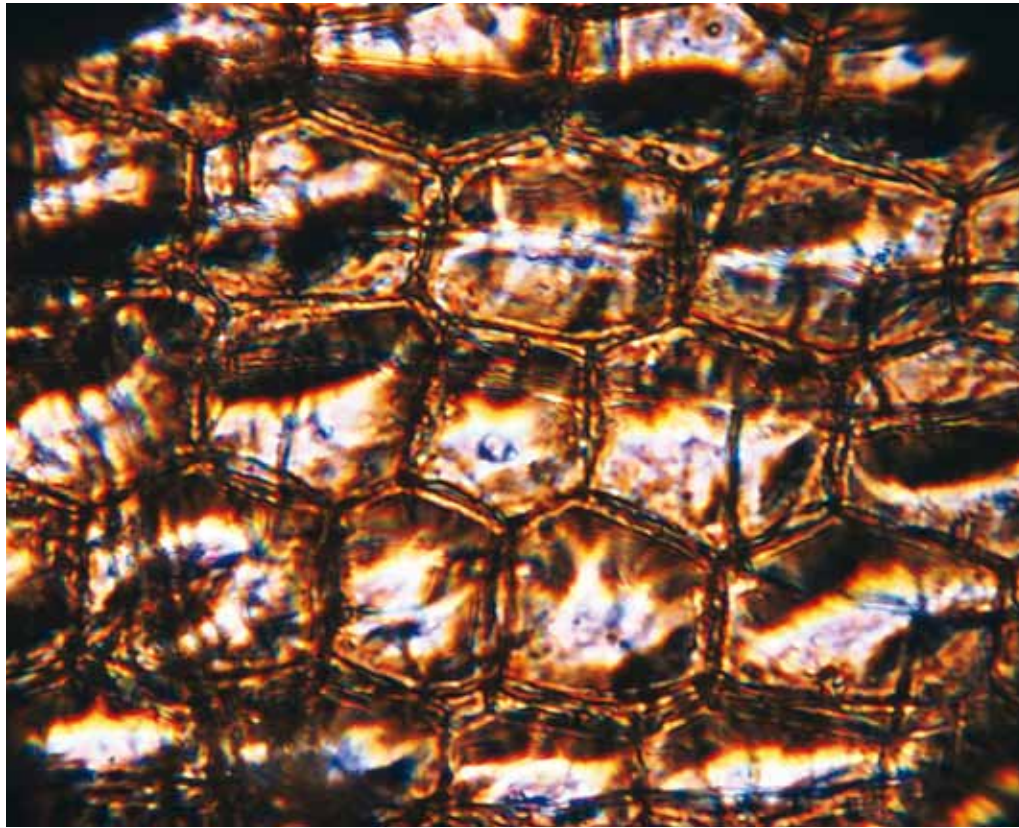


Fig. 8. When crudely dissected with the forceps included with the Linnean Society microscope (see right centre of previous figure) the tissues of an orchid leaf are here imaged through the Brown's No 2 lens, magnifying 75x. The cellular structure is clearly visible, and the nuclei (centre) are also apparent. Chromatic aberration, though clearly visible in this image, does not greatly detract from the structures that the microscopist wishes to observe. Field width 250 μ m.

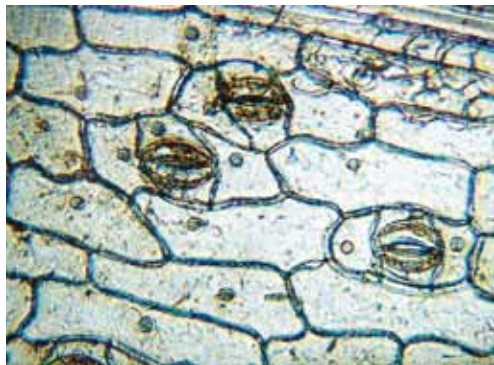


Fig. 9. Epidermal peels can be prepared from orchid leaves, and this unmounted fresh specimen is well resolved by Brown's No 2 lens. Not only are the epidermal cells clearly delineated, but the nuclei are clearly seen within each cell. Three stomata are also visible in this field of view. The microscope, when appraised by microscopists at the Linnean Society in 1930, was dismissed as being too primitive for Brown to have studied nuclei⁵. This micrograph substantiates his observations. Field width 250 μ m.

round body or globule'. Although he did not relate them to structures observable elsewhere in nature, Leeuwenhoek unambiguously recorded nuclei.⁵

Brown's description of the nuclei in orchid tissues goes further: 'In each cell of the epidermis of a great part of this family, especially of those with membranous leaves, a single circular areola, generally somewhat more opaque than, the membrane of the cell, is observable . . . This areola, or nucleus of the cell as perhaps it might be termed, is not confined to the epidermis, being also found, not only in the pubescence of the surface, particularly when jointed, as in *Cypripedium*, but in many cases in the parenchyma or internal cells of the tissue, especially when these are free from the deposition of granular matter'.⁶

We can envisage how Robert Brown might first have observed the nucleus by dissecting surface parenchymatous tissues from a leaf of the orchid *Cymbidium* and examining the tissues, unmounted,

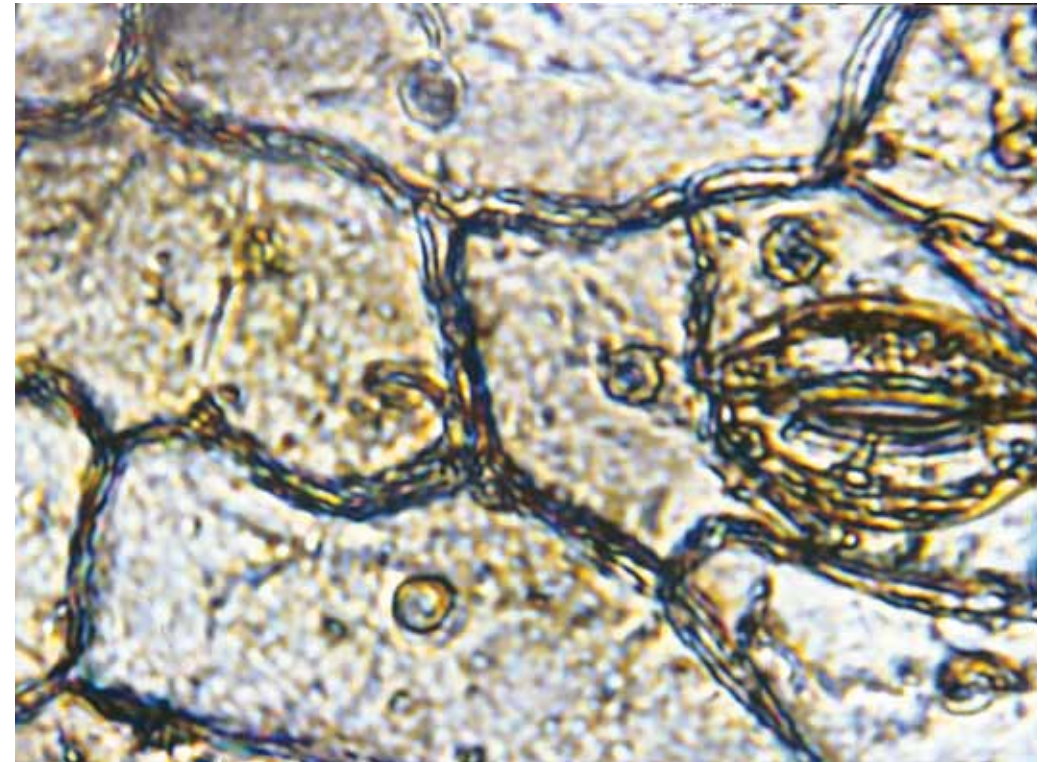


Fig. 10. The central portion of the specimen shown in Fig 9 is here imaged through Brown's No 1 lens, which magnifies 170x. Chromatism is visible in the form of fringes of yellow or blue which appear around diminutive structures within the field of view. The elimination of these spurious colours drove the development of achromatic doublets, though observations made by the simple microscope are not greatly perturbed by this chromatic aberration. Field width 130 μ m.



Fig. 11. Brown's double-sided microscope mirror gave him the use of a concave reflector with which to focus light onto the plane of the stage. With the illuminating beam set off-centre, dark ground microscopy is facilitated. Brown discovered the phenomenon of cytoplasmic streaming within the staminal hairs of *Tradescantia*, and the effect is demonstrated with spectacular clarity using this form of illumination and Brown's No 3 lens. Field width 1500 μ m.

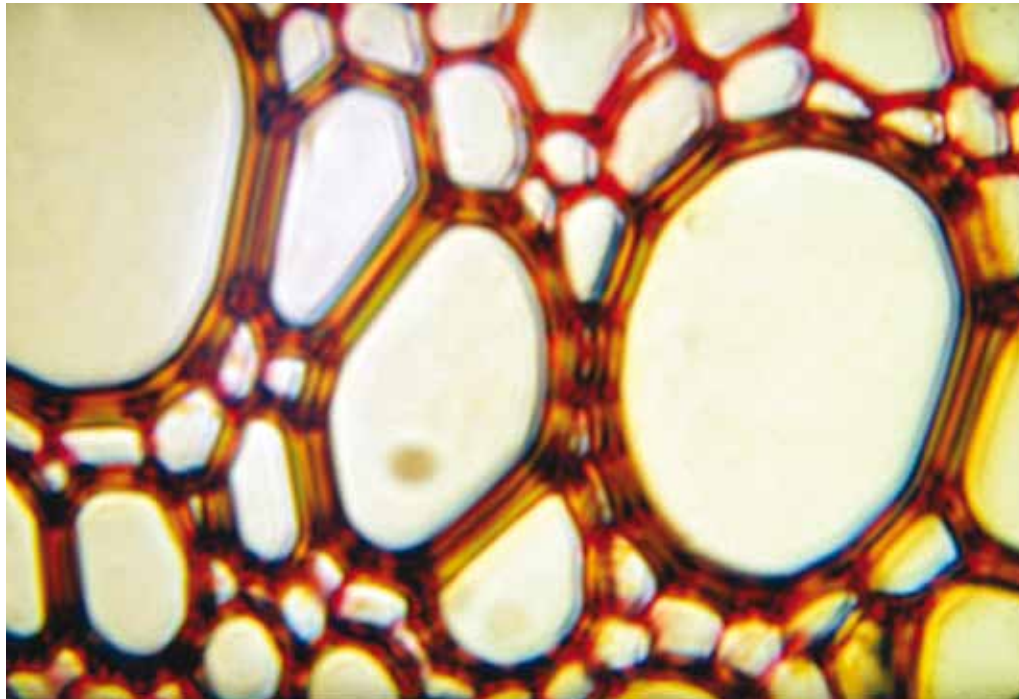


Fig. 12. This detail from the central portion of a single-lens micrograph shows a Victorian transverse section of *Cycas* xylem (as in Fig. 14) stained with safranin and mounted in Canada balsam. Chromatic aberration takes the form of the fringes from the red and blue extremities of the visible spectrum (centre). The intrusion of these colours does not materially affect the structural details of the image. Field width 130 μm .

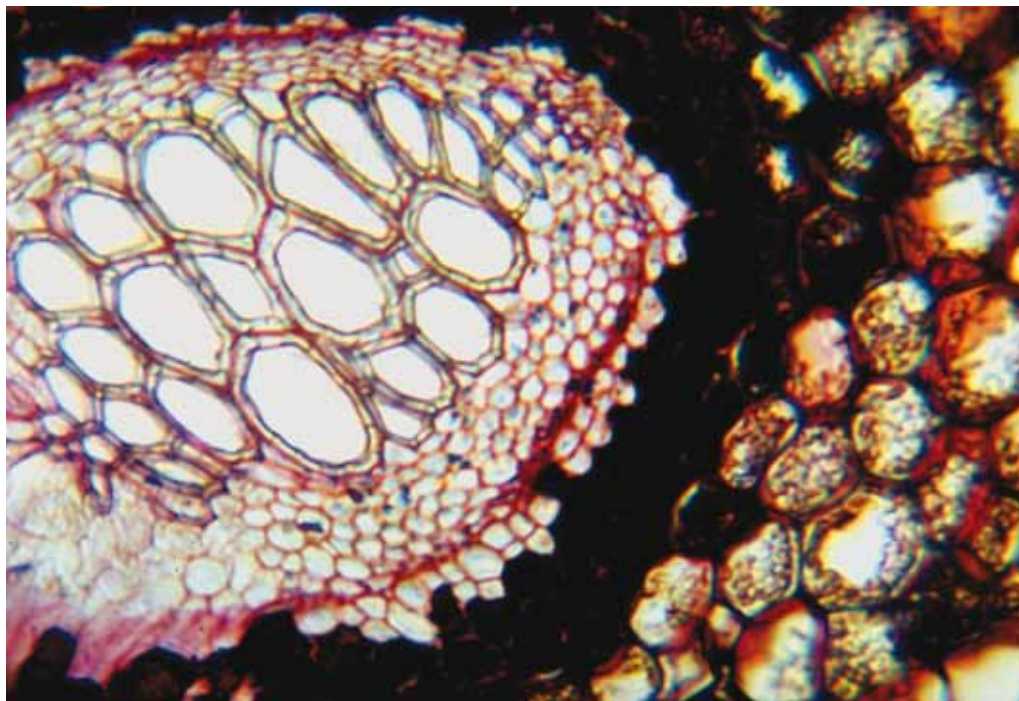


Fig. 13. Histological details are well resolved with the single lens microscope. In this transverse section of *Osmunda* root, hand-cut by the author as a schoolboy, the middle lamella in the vessel walls can be resolved in surprising detail. The smallest cells are approximately 20 μm across, and although spherical aberration can be seen towards the periphery, the clarity of the image towards the centre of the field of view is remarkable. Field width 130 μm .

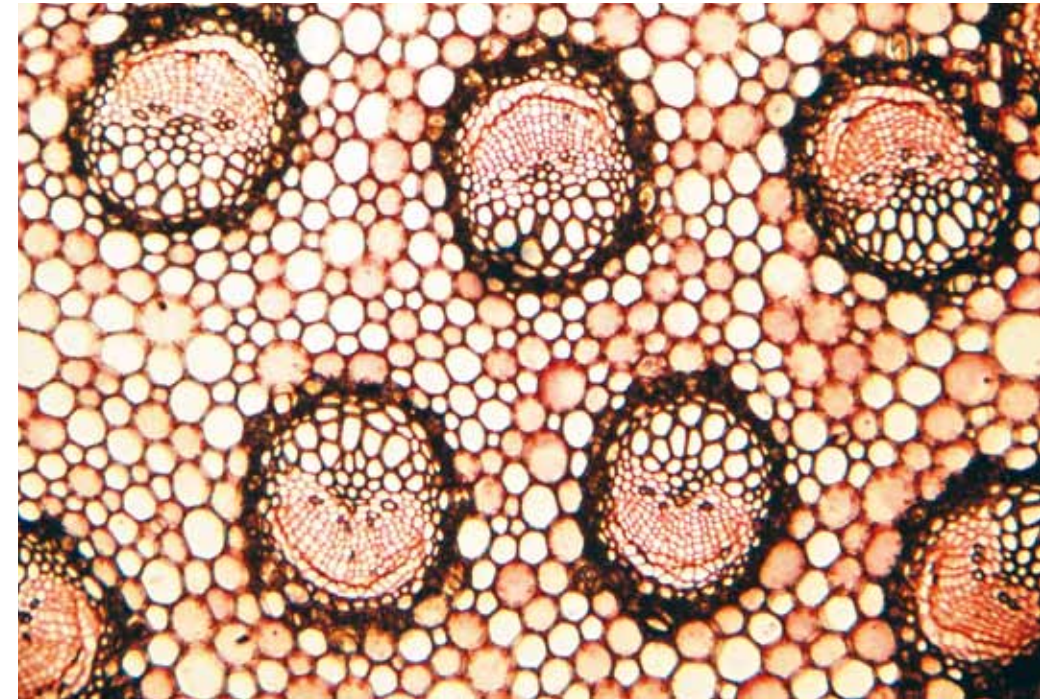


Fig. 14. Vascular bundles of *Cycas* in transverse section provide a suitable test object for the simple microscope (see also Fig. 12). These show off the Linnean Society microscope at its best. With careful adjustment of the substage mirror and meticulous focussing, the larger xylem vessels and smaller components of the phloem can be compared with the medullary tissues that make up the bulk of the plant. An image of this sort compares favourably with one obtained in a modern microscopical laboratory. Field width 250 μm .

with the Linnean microscope. Within each cell the nucleus can be clearly discerned. The appearance of the nuclei is clearer if we break a leaf partly across, and strip from the upper surface a lamina of the epidermis. Under a lens of higher power the structure of the cell, its nucleus, and the stomata can be clearly discerned.

It is important to note that the chromatic aberration that is believed to militate against observational clarity was, in reality, an insignificant problem to the pioneering microscopist using single lenses. Close examination of these images does reveal the existence of chromatism, but it is insufficient to interfere with our interpretation of the image. Many modern-day photomicrographs, taken with sophisticated state-of-the-art microscopes, show worse results. On occasion, when speaking on the behaviour of cells, I have used one of these Georgian-era images to illustrate a point. Nobody has ever asked afterwards why the picture was

clearly inferior to the others, all of which were taken with modern microscopes.

We can use the instrument to examine Victorian botanical preparations, and others of more modern vintage. As the accompanying micrographs testify, the results are astonishingly clear. In publishing photomicrographs, I have in recent years optimised optical values using Adobe Photoshop CS prior to submission of the images. This is because a colour cast, or a slight loss of contrast, can be instantly corrected. The purist argument (that this is not the image as recorded) can be challenged, since the observer makes such corrections instinctively when examining an image. It can be contended that the optimisation of the image allows one to view images in juxtaposition with each other, freed from the intrusion of an obvious change of gamma-value or colour balance between adjacent photomicrographs.

However, in the case of the images in this paper, no correction has been used. The images have been scanned at high resolution from 35 mm Kodachrome 64 originals. What you see is what we got. Although some of the micrographs show significant chromatic aberration, the images are remarkably clear and do not hinder the elucidation of anatomical detail. The impetus towards achromatism was essentially to demonstrate whether the colours shown by structures near the limits of resolution were real or artefactual.

It has long been held that obscuring, rainbow-hued colours prevented useful microscopy with a simple microscope. However, as the results in the accompanying pictures demonstrate, this is a misconception. In the hands of the enthusiast, a simple microscope could have provided the pioneers with excellent images of the subjects that they were the first to examine.

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Brian J Ford recreated Robert Brown's microscopical discoveries in a series of demonstrations reported in journals including *New Scientist*⁷ and *Nature*⁸. He brought together four microscopes from the early years of the 19th century, and all made by the same manufacturer, to put them through their paces. Professor Ford's studies of orchid cell nuclei, as visualised by Brown in 1828, won the 2009 photomicrography prize sponsored by the pH2 Company at the Inter Micro conference held in July in Chicago (see Fig. 9). He lives in Cambridgeshire and is based at Gonville and Caius College, University of Cambridge.



Photograph by Joe Barabe, Chicago, USA