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CRITICAL FOCUS

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The Man Who Gave the Cell Its Nucleus

Robert Brown, the Scottish physician and botanist, named that most familiar object, the cell nucleus. His research showed that the simple microscope had truly come of age.

The brick-built building housing Twentieth Century Fox stood at 32 Soho Square in the center of London. Their mock-Georgian premises had been completed in 1938, and hundreds of staff worked there, linking to the 8 branch offices spread across Britain. The premises are empty now, and due for development, but they were a center for the British entertainment industry.

That same address, 200 years ago, was Robert Brown's home. He was an astonishingly accomplished microscopist, one of the greatest that science has ever known. Brown is the microscopist who identified the cell nucleus, and from whom Brownian Motion was named. In 1826, 200 years ago, he was researching the structure of the angiosperm ovule. He noted the position and nature of the nucleus and the micropyle (the minuscule aperture through which the pollen tube enters), and he noted that the apex of the ovule is where the future embryo would form … this is all detailed microscopy which anyone today would find difficult and demanding.

Pioneering microscopist Robert Brown was investigating orchid histology 200 years ago when he named the cell nucleus. His appearance has been recreated by the author from a marble bust using Dola, ChatGPT, Grok, and Photoshop.

There are three "microscopes of Robert Brown" known to us. One is in the collections at the Royal Botanic Gardens, Kew, in south-east London, popularly known as Kew Gardens; another is at the Linnean Society in Burlington House, Piccadilly; and there is a third in the Universiteitsmuseum Utrecht (UMU), the Utrecht University Museum in the Netherlands. I set out to investigate them all.

BIRTH OF A MICROSCOPIST

Robert Brown was born in 1773 in Montrose, Scotland. His father, the Rev. James Brown, was a Scottish Episcopal clergyman and his mother Helen was the daughter of a Presbyterian minister. The young Robert excelled at school (as the Montrose Academy, it's still there) and won a scholarship to Marischal College of the University of Aberdeen when aged just 14 and, as a child prodigy, he mastered Latin in his teens. Brown enrolled to study medicine at the University of Edinburgh but much preferred botany, and microscopy. He corresponded with William Withering, inventor of a folding microscope, and even discovered a new grass species, *Alopecurus alpinus*. When he was 19 he presented a paper, "The Botanical history of Angus," to Edinburgh Natural History Society. Brown dropped out of his medical course in 1793 without completing his degree. I know the feeling.

Late in 1794 he enlisted in the army with the Fifeshire Regiment of Fencibles, and was soon appointed Assistant Surgeon. The regiment saw little combat, so he had ample time for botanical work and microscopy, studying mosses and cryptogams. In 1798 Brown was dispatched to London to enlist new recruits. His circle of botanical acquaintances introduced him to the Linnean Society, and he was elected an Associate of the Society that same year. He was subsequently introduced to Sir Joseph Banks who was so impressed by his detailed understanding of botany and Latin that he recommended Brown to Captain Matthew Flinders and, in 1801, Brown sailed as naturalist aboard HMS Investigator on a survey of the Australian coast. He personally collected around 3,400 plant species (roughly 2,000 of them new to science), along with insects, birds, and other specimens. Many were lost when his ship was wrecked, but Brown still returned to Britain in 1805 with an enormous haul.

In 1810, he published the first scientific account of Australian plants, *Prodromus Florae Novae Hollandiae et Insulae Van Diemen*, all written in exquisitely detailed Latin. Just the first volume was published in London by Richard Taylor; it failed to sell and Brown abandoned the project for a decade. He then published a further account under the title *Supplementum Primum* in 1830, but the following volumes were never published. Substantial sections later appeared in journals. So impressed was Banks that he appointed Brown to be his personal librarian later that year. He also had him elected a Fellow of the Royal Society at the age of 37; Robert Brown was now a member of the scientific elite.

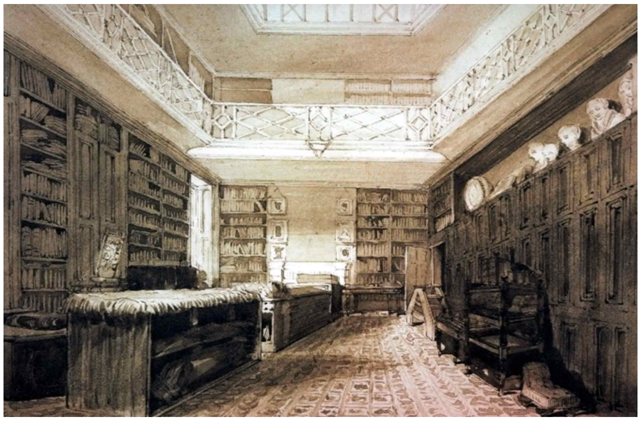
THE LEGACY OF SIR JOSEPH BANKS

When Banks died in 1820 he bequeathed his vast library and herbarium to Brown, along with an annuity so that he could live there for the rest of his life. And so 32 Soho Square became the center of British botany. Fortuitously, just to the south lay the center of London scientific instrument-making; names like Adams, Cary, and Watkins & Hill were clustered around the Strand, with W & S Jones, Ramsden, and the Dollond family a little further away. At No 441 in the Strand was the workshop of Robert Bancks, who specialized in making beautiful little portable microscopes. The building is there to this day, currently housing Coutts Bank with a Jigsaw clothing store at street level – but otherwise unchanged.

Cattle drovers were part of the daily scene in central London, when Robert Brown lived at 32 Soho Square in the 1820s. The ornate entrance to the premises is seen on the left of this engraving, and led to some 20 rooms in large, L-shaped premises.

In the 1820s Robert Bancks was joined in business by his son, also named Robert. Bancks' premises were just half a mile from Soho Square, an easy 10 minute stroll, and it was from Bancks that Brown obtained his portable microscope. It still exists, and can be seen at the Linnean Society's permanent premises at Burlington House in Piccadilly, London. Brown also purchased a smaller instrument with a more powerful lens and with a concentric focusing mechanism from John Dollond, and later purchased from Bancks an improved microscope with a fine focusing control. The lenses were minute, often smaller than red lentils, yet produced images magnifying in the hundreds which I proved to have surprisingly good resolution.

Bancks made microscopes for so many Georgian microscopists, and even the British Royal Family. Bancks held a royal appointment as Mathematical, Optical, and Philosophical Instrument Maker to George, Prince of Wales, who became Prince Regent in 1811; so we know Bancks was an established microscope maker before 1810 (you didn't gain a royal endorsement unless you'd been a faithful provider for many years). The Prince became King George IV in 1820, and his successor was King William IV who also signed up Bancks as provider of microscopes. Leaders of society were expected to understand microscopy in those far-



Robert Brown had responsibility for maintaining this extensive library and the collections at Soho Square. Sir Joseph Banks had collected tens of thousands of specimens, and the published list of all his library books filled five volumes.

The Linnean Society moved to these premises in Piccadilly during Robert Brown's lifetime, and remain here today. The layout and design were modified in 1873 but are typical of Victorian England, and are remarkably similar to the original rooms in Soho Square.

off days. How things have changed.

BROWN WELCOMES THE LINNEAN SOCIETY

In 1827 the entire collection that Banks had acquired was donated to the British Museum. Scholars say it comprised some 30,000 specimens, but this is incorrect. Those were just the botanical specimens he'd collected on his voyage in HMS Endeavor during 1768–1771. Bancks had also acquired large amounts from his correspondents, expeditions around the world, and also from his own travels to places like Iceland in 1772. In addition, he had a collection of over 4,000 insect specimens, neatly set and labeled. His library was huge – it was catalogued by Jonas Dryander, and that list alone was published in 5 volumes. The donation to the British Museum was a complex undertaking, and Brown was appointed to be in charge of the collections as Under-Librarian.

It was too much for one person to handle, so Brown appointed John Joseph Bennett, a qualified physician and enthusiastic botanist, as his personal assistant in 1827. He also decided to offer half the building to the Linnean Society. The Society had taken a lease in Gerrard Street, Soho, in 1805 and – since Brown lived just round the corner – they had appointed him as Clerk, Librarian, and Housekeeper. After Banks passed away and the premises passed to Brown, he proposed that the Society might like to move in with him, and so from 1821 the Linnean Society occupied the front half of the building facing Soho Square. They remained there until 1857, when they transferred to their present premises, occupying the wing of Burlington House running west along Piccadilly. The composer Handel once lived there, so did the 6th Duke of Devonshire William Cavendish, after whom your banana was originally named *Musa cavendishii*. The building was remodeled in the 1850s to make it suitable for the learned societies, and the Linnean Society (the oldest organization representing biologists anywhere in the world) was accommodated in the front of the building with the Geological Society, and with the Royal Society across the courtyard. I first lectured in the Royal Society's rooms there in 1965, though they later transferred to larger premises.

Fellows of the Linnean Society would have felt instantly at home in their new premises. The galleried library, though more spacious than in the house in Soho Square, looked much the same when they moved there in 1857. Robert Brown had become the Society's President in 1849, and died in 1858, after serving the Society in various roles for more than 50 years. It is a record that few could equal.

I became a Fellow of the Linnean Society in 1969, served there on Executive Council, and for several years as Zoological Secretary, before being honored with Fellowship *honoris causa* in 2021. Every time I go in to that historic building, approaching 60 years since my election as a Fellow, I am aware that this was the very premises that Robert Brown had once known. It is a humbling and profoundly moving thought.

BROWNS DEMISE AND THE DAWN OF DARWINIAN EVOLUTION

Robert Brown's death left an organizational hole in the Linnean Society that had to be filled. A special meeting of Council was called for July 1, 1858, in or-der to elect a replacement. At around the same time, Charles Darwin had been in contact with the Society about his new theory of evolution. The hypothesis had already been written up in detail by Alfred Russel Wallace, and Darwin was uncertain what to do next. It was decided that Wallace's paper, and Darwin's, should be read to the Society as a joint presentation at the same meeting, and the date agreed was July 1, 1958. So the aftermath of Brown's passing and the launch of Darwinian evolution, as it became known, took place at the same meeting. Their paper was entitled: "On the Tendency of Species to form varieties, and on the perpetuation of varieties and species by natural means of selection . . ." and was read by the Secretary.*

It is interesting to reflect that the theory has ever since been associated with the name of Darwin, while Wallace, who was the first to have written the theory up in detail, has been largely forgotten.

You'd imagine that this startling new theory would immediately attract global attention, but nobody took much notice. Indeed, when the president Thomas Bell delivered his annual review, he reported that there had been nothing of importance presented all year:

> "The year has not, indeed, been marked by any of those striking discoveries which at once revolutionize so to speak, the department of Science on which they bear, it is only at remote intervals that we can reasonably expect any sudden and brilliant innovation which shall produce a marked and permanent impress on the character of any branch of knowledge, or confer a lasting and important service on mankind."

And so one of the best-known scientific theories of all time was dismissed as unimportant … but not for long.

THE LOST MICROSCOPE COMES HOME

After Bell died in Selborne in 1880, his possessions were sold off in a house sale, and the microscope vanished from scholarly view. The purchaser in turn bequeathed his possessions to his daughter, Miss Ida Silver of Reigate, whose neighbor was a sprightly architect named Charles Edgar Salmon, a keen amateur botanist – and a long-standing Fellow of the Linnean Society. He was a well-known expert on flora, studying in particular the sea-lavender *Limonium*. Salmon was the author of the *Flora of Surrey*, and he was excited by Miss Silver's possession of this ingenious simple microscope. There was no doubting its provenance, for a note glued inside read:

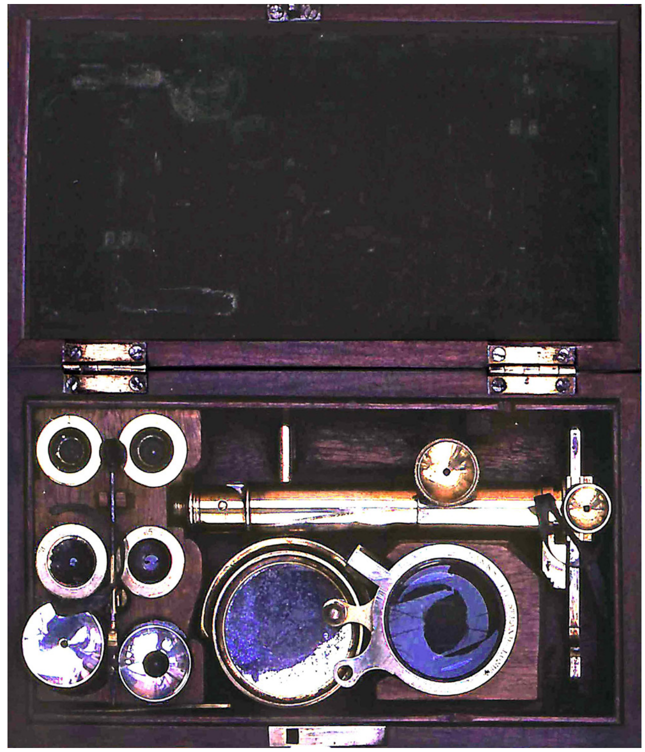
> "This microscope belonged to Robert Brown, and was certainly used by him for many years, until within a short time of his death, which event occurred on the 10th June 1858, in the 85th year of his age. The instrument was given to me, as a memorial of my revered old friend, by his Executor, my friend John Joseph Bennett Sec.L.S. on the 5th day of Feby. 1898. Thomas Bell."

Miss Silver informed Salmon that she had no use for this grubby and uninteresting relic, and she agreed to donate it to the Society, where it rightly belonged.

This portrait of the young Robert Brown was painted by Henry William Pickersgill during the 1830s. It hangs in the meeting room that Brown himself would have known, at the Linnean Society of London in Burlington House.

*In Victorian England, it was normal for a secretary to read a paper, rather than the author. There were reasons for this – most scholars lived outside London (even abroad), so they couldn't attend in person. Travel by horse was slow, troublesome, and expensive. Some scholars were elderly, ill, shy, or simply not eloquent speakers. The secretary (or a designated reader) would be a skilled and experienced orator who could deliver the text clearly and audibly in a large room. At the Royal Society, for example, a long-standing rule (from 1752 onward) required that every paper must be read aloud at a meeting before it could be considered for publication in the *Philosophical Transactions*. This was traditionally done by the secretary or another officer.

Robert Brown's first Bancks microscope was in a sad state in the 1970s. It was dirty, the coarse focusing control was seized, the stage had been bent out of alignment, and the silvered Lieberkühn mirrors were dull and oxidized.



In restoring the microscope to usable condition, it was carefully cleaned, the lenses were gently polished and the hardware meticulously realigned. The mahogany box was waxed, and the little instrument could once again be used.

She drafted a neatly handwritten note to the Linnean Society on January 19, 1922:

> "By the kindness of Mr. Salmon, I have much pleasure in offering Mr Brown's microscope to the Linnean Society should they care to accept it. Its credentials are in the box with it. At the sale of Mr. Bell of Selbourne's effects, it was bought by my father & so its history since the original owner is accounted for."

Salmon brought it into the Society the very next day. This was the microscope with which Brown had investigated the cell nucleus, the naked ovule of gymnosperms, and what we now know as Brownian Motion. It's a scientific instrument of immense importance.

In spite of this, the Society was unimpressed. Achromatic optical instruments were what every self-respecting microscopist aspired to use, and simple microscopes with their single lenses were dismissed as insignificant and irrelevant. This instrument was designated as a lowly dissecting microscope, of little use to any serious investigator. Its return came at a propitious time, since the Society was celebrating the centenary of the recognition of the cell nucleus by Robert Brown, and an exhibition was being prepared. The microscope was put on display, with a dismissive little note:

> "Brown's…microscope, which agrees with his description of the one with which he made his epoch-making discoveries, is surprisingly simple, being little more than a dissecting-microscope."

The Linnean Society won't be commemorated as being first to recognize the scientific importance of what takes place. Evolution? Insignificant. Brown's microscope? Primitive. It reminds me of Dick Rowe, the head of Artists and Repertoire at Decca Records in 1962, sitting in the London studio with a cigarette dangling from the corner of his lips and listening to demo tapes. He is the man who concluded: "The Beatles have no future in show business". Perhaps Dick Rowe should have joined the Linnean Society. He'd have felt perfectly at home.

A MICROSCOPIST SHOWS INTEREST

For my schoolboy thesis in botany I had chosen to study *Osmunda regalis*, the Royal Fern. It's a statuesque and majestic species with hemidimorphic fronds, the sporangia being confined to the tips of the fronds rather than nestling on the underside, with spreading branches and a substantial rhizome. At the age of 17, I went to London and arranged to visit John O'Grady, the Linnean Society's long-serving Clerk, to browse their collections. It was my first contact with that august body. The list of acknowledgements and references in my thesis contains an entry: "I. Manton, *Problems of Cytology and Evolution in the Pteridophyta*, Cambridge, 1950." Even in my teens, I had adored Manton's work, for she was just so darned ingenious. I knew she was a Fellow of the Linnean Society, and I was astonished to find that she and I would eventually become colleagues.

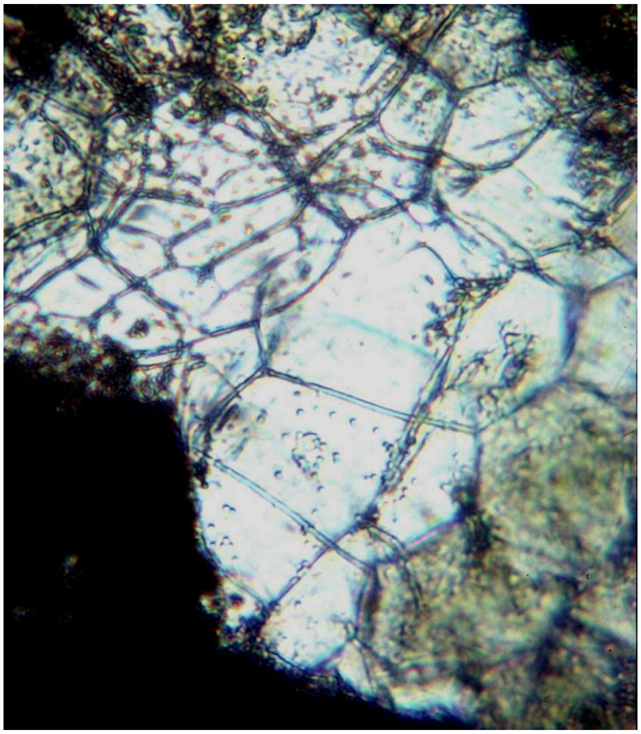
Irene Manton should be much better known, since she was one of the greatest microscopists of her time. She was born in 1904 and brought up in a huge house in central London with domestic staff (cook, housemaid, and parlor maid). Like many women scholars of her time, she remained resolutely unmarried. Whereas marriage was the overwhelming societal norm for most Edwardian women, it was considered that serious scholarly or academic pursuits conflicted directly with the expectations of a wife. Teaching positions in girls' schools and university roles required women to be single, and women were frequently expected (often contractually obliged) to resign if they were to marry. This "marriage bar" persisted in education and other professions through the 1920s. A woman scholar who married risked losing her livelihood, institutional affiliation, or research opportunities.

Although there were late Victorian colleges established for women academics, like Girton and Newnham at Cambridge, which provided a "private space," and a freedom that domestic married life often denied, many pioneering women academics associated with these colleges had to remain single to pursue their work. The "New Woman" archetype of the period—independent, educated, and career-focused—was customarily confined to women who chose to remain single, and Manton resolved early on that marriage was not for her.

It is probably just as well; many people found her rude, argumentative, and uncompromising, though she was also generous to a fault, and devoted herself to nurturing younger scientists. As new microscopical technologies emerged, she moved from classical cytology to UV microscopy, and then was quick to adopt cutting-edge electron microscopy, mastering each new technique with superlative skill. In 1949, she set her heart on acquiring an electron microscope for her department at Manchester University, a Philips EM 100, and to ensure the grant went through she said she'd buy it herself and mortgage her home if they didn't agree. They did.

Cytoplasmic streaming is particularly noticeable within the enlarged staminal hairs of *Tradescantia virginiana*. Brown discovered this phenomenon in 1830. The cytoplasmic bridles within each cell show continual movement.

In 1973, Irene Manton was appointed the Linnean Society President. She was the first woman to hold that position and for me, it was so exciting to have a microscopist in that leading role. For the first time, the little Robert Brown microscope was suddenly an object of interest. Manton's microscopist colleague W.S. Burnett took the first photograph of the microscope itself. He documented its neglected and damaged condition after decades of misuse and poor storage (pitted brass, bent parts, torn velvet lining in the case, etc.). Burnett worked with the Society's administrator John O'Grady to describe and record the historic microscope. Manton personally examined the instrument and noted that it needed minor repairs to become usable. Her technician successfully took micrographs through one of the



Orchid parenchyma was well displayed by the No 1 lens of Brown's Bancks microscope. It magnifies 170× and resolved particles of bacterial dimensions, the smaller components oscillating randomly in typical Brownian motion.

lenses—most notably, clear images of onion epidermal cells showing distinct nuclei. This proved that the old instrument could still resolve fine cellular detail, despite its age and condition. The pioneers really could see what they claimed, and it was clearly a mistake for scholars to dismiss their primitive instruments as useless.

A MICROSCOPE REBORN

Throughout the busy seventies the topic lay fallow. I was so busy with research ranging from blood coagulation and plant physiology to locusts and the reconstruction of human skeletal remains. Several of my books came out too, including volumes on the microbiology of food and the role that microbes play in our daily lives. I published many articles in the journals, most frequently in *New Scientist* and *Nature*, and also hosted my own weekly science series for the BBC, Science Now.

But as the decade ended, I realized that 1982 was approaching and that would mark the 150th anniversary of Robert Brown's publications on the cell nucleus. The Linnean Society may have dismissed his microscope when marking the centenary, but this time we should celebrate it in all its delicate precision. I put the point to the Kodak Bursary scheme, and they generously awarded me a grant with which I was able to purchase an Olympus OM2n 35 mm camera with all the necessary accessories. It was reported in the press, and it opened a new door.

With the Society's eager agreement, I took the instrument back to my laboratory with a single aim – to restore the microscope to how it would have been when used by Robert Brown. Over the following weeks, and in between a varied catalogue of other scholarly preoccupations, it was carefully disassembled and each part was delicately cleaned.

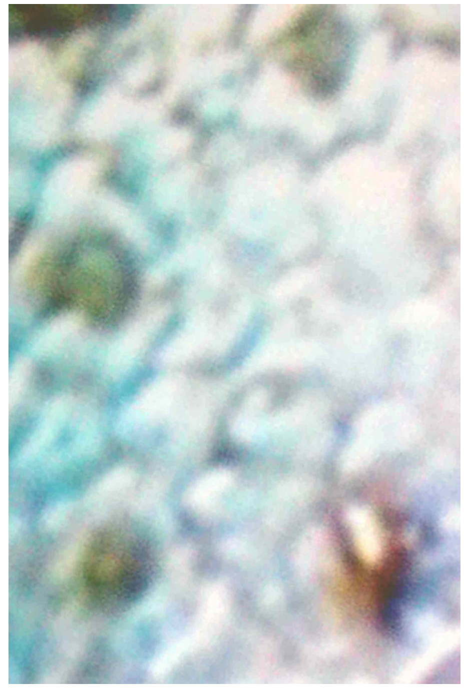
Now the microscope had been restored to full function, as it had been when Brown had used it, and I could at last glimpse breathtaking detail through its bright, clean lenses. The next task was to measure and calibrate the optics. Two were substantial lenses of low power, one magnifying 6× that was housed in a brass holder the size of a cent, designed for transmitted light, and another of 8× mounted in a Lieberkühn reflector intended for top-down illumination. Both gave clear images with remarkably little aberration. Indeed, I have seen worse results produced by modern equipment. Then there were three more biconvex lenses, all progressively smaller in diameter, and each about twice as powerful as its predecessor. I determined them to magnify 32.5×, 75×, and 170×. The resolution of the most powerful lens was approximately 0.5 µm – it could have resolved bacteria, and the perforations of test-objects like the diatom *Coscinodiscus*.

Brown, however, wasn't interested in microbes. What preoccupied his attention was the microscopical structure of plants, most importantly his recognition of the cell nucleus. Brown was not the first to see it; Antony van Leeuwenhoek had published studies of cells with their nuclei clearly mentioned in 1682. On cells, Leeuwenhoek wrote: "It seemed to me that some of them enclosed in a small space a little round body or globule." Brown had seen them too. Indeed, after repeatedly noticing them, he had recognized that they were everywhere in life; the point of his discovery was realizing that all typical cells have a nucleus. His microscope, which the Linnean Society officials had casually dismissed in 1932, was well able to resolve nuclei.

WHAT COULD ROBERT BROWN OBSERVE?

What of his studies of stomata, the respiratory pores on the leaves of vascular plants and bryophytes? Brown studied them, and they were well within the capacity of this microscope. He was able to observe plant tissues, including the naked ovule of the gymnosperms, without any problem. And the discovery

The cell nucleus was first granted its name when Brown was observing orchid tissue. I studied *Cymbidium* epidermis with the No 2 lens of the Bancks microscope. The nuclei and stomata were well resolved, confounding Linnean Society sceptics.



In its documentary series entitled "Cell," the BBC had Adam Rutherford narrate their attempt to capture similar images with the same instrument. Despite their lavish technical budget, the microscopical results were disappointing.

of cytoplasmic streaming was well within his scope. Charles Darwin was acquainted with Robert Brown, indeed he had a Bancks microscope for his own research, and in 1831 he went to see Brown to discuss microscopy. Brown showed him an intriguing demonstration he had recently observed, the streaming of cytoplasm within the giant staminal cells of *Tradescantia*. Darwin could see the movement clearly, and pressed Brown for an explanation. He wouldn't say what it was. "That," he told Darwin, "is my little secret."

It remained so. Robert Brown made little of his findings, referring only briefly to the movement of cytoplasm within cells in his publications on nuclei, where he wrote of the staminal hairs of *Tradescantia virginiana* and observed that the granular matter within each cell appeared in constant motion, streaming in various directions. It was a key observation, though he never published it as a paper.

SEDULOUSNESS, SCHOLARSHIP, AND STUDY

We are told that Brown purchased his first microscope around 1820, though that cannot be correct. As early as 1810 he had been publishing microscopical observations of orchids.

Brown himself wrote that all his observations had been made with the same simple microscopes he had "obtained from Mr. Bancks, optician, in the Strand." That's where the Bancks microscopes were produced and sold between 1796 and 1820, so the dates fit well.

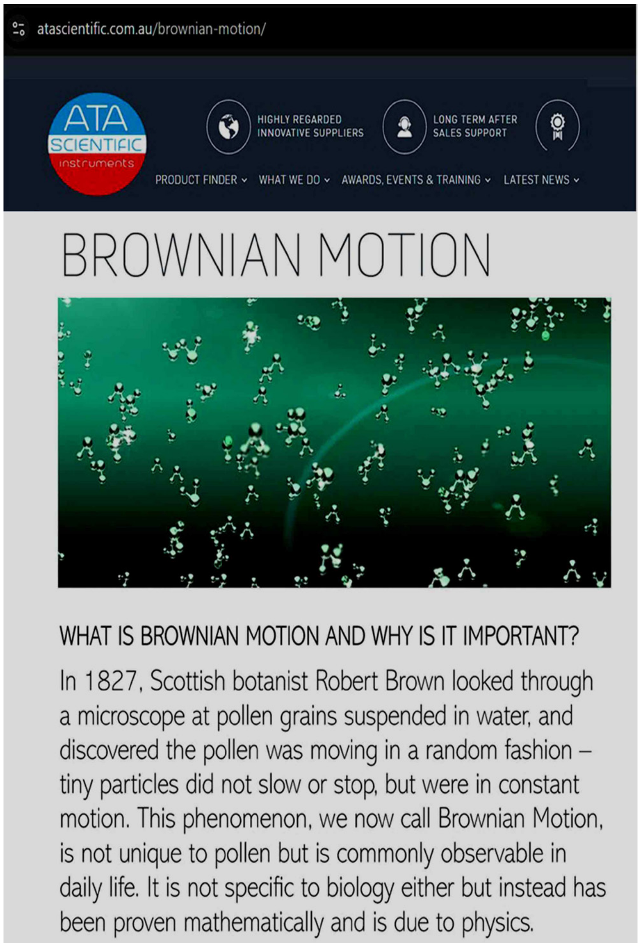
Without doubt, the Linnean Society instrument must have been purchased far earlier than scholars assume.

A MICROSCOPE PUT THROUGH ITS PACES

The observations that Brown recorded, using the Bancks microscope that Miss Silver so thoughtfully returned, have long been doubted. Looking at Brown's neglected, grubby little microscope in its battered box might not inspire confidence, but it need not have deserved derision. (Ford, Brian J. "Did Physics Matter to the Pioneers of Microscopy?" *Advances in Imaging and Electron Physics*, 158, pp. 27–87, 2009).

It was surely more than a "simple dissecting microscope", though I still had to prove the point. I set out to capture images of the principal specimens Brown had claimed to observe. The orthodoxy of the time was that early investigators were bumbling and unskilled. As I explained in a much earlier article, a BBC television science program had the presenter, Adam Rutherford, describing how microscopists had been "eagerly tearing up plants to study their anatomy." Microscopists like Brown were diligent and devoted and I had even shown that sections cut by Leeuwenhoek in the 1600s were better than many you'd see today. Nobody was into "tearing"; those pioneers were much cleverer than we think (Ford, Brian J. "Breaking the Myths of Microscopy, *The Microscope*, 62:2, pp. 63–73, 2014).

It was time to put the microscope to the test. It gleamed and glistened softly under the lights as I carefully selected the lenses, one by one, to examine



Since my publications gained currency, most major reference sources have recently corrected their entries, but not all. Some 40% still get it wrong. Reference books rarely obtain their information from primary sources – they copy from each other. Once an error is live, it's difficult to have it corrected.

botanical specimens in search of nuclei. Brown might well have studied genera of Australasian orchids like *Caladenia*, *Pterostylis*, or *Prasophyllum*, which were not available, so I had peeled abaxial leaf epidermis from young leaves of *Cymbidium*. You can easily observe epidermal cells (with their nuclei) in all angiosperms, though monocotyledonous plants are renowned for clearly delineated epidermal cells, and in genera like *Tradescantia* and *Dracaena* they are spectacularly large and clear.

THE NUCLEUS REVEALED

I mounted the peels in a minimal film of distilled water, eschewing a coverslip in deference to Brown's likely methods, and set the camera's light measurement to automatic for the first exposures. The camera was clamped firmly in position, and then came the moment of truth – to see exactly what Brown had seen. Technicians at BBC television later tried the same experiment (with the same instrument), with profoundly unsatisfactory results; but I was accustomed to those early microscopes and, more importantly, was experienced at how to correctly optimize both focus and illumination. I have to say, the results were just so easy to obtain. They were breathtaking, and spectacular.

I could clearly discern cell structure with Brown's No 3 lens, magnifying no more than 32.5×. Under the No 2 lens at 75×, the field of view covered some 20 epidermal cells, and the nuclei were plain to see in each. That is what Brown had claimed; this is what Brown had seen for himself. With his No 3 lens magnifying 170×, there was room within the field for only some four cells, within which you could glimpse mitochondria, as well as nuclei. I ensured we had stomata in each frame. The images were clear, and – although there is always chromatic aberration – it did not detract from what we were perusing. These were remarkable images, and I sat a long while watching them, knowing that's exactly what Brown had once seen. And then? The film cassette was mailed away for processing, and it would be ten days before they were seen again. These days, we forget that had to happen.

BROWNIAN MOTION REVIVED

It was Brownian Motion (Brownian Movement, it used to be called) that proved to be the most demanding demonstration of all. Most sources said that Robert Brown observed the movement of pollen grains. That is not what he said. He made his observations unambiguously clear in his original paper of 1828:

> "This plant was *Clarckia pulchella*, of which the grains of pollen, taken from antheræ full grown, but before bursting, were filled with particles or granules of unusually large size, varying from nearly 1/4000th to about 1/3000th of an inch in length, and of a figure between cylindrical and oblong, perhaps slightly flattened, and having rounded and equal extremities. While examining the form of these particles immersed in water, I observed many of them very evidently in motion..."

There you have it: he was not describing the movement of pollen grains (which Brown measured to be about 1/300th inch) but the grains within them that were less than ten times smaller (measuring 1/3,000th inch). Indeed, as Brown had made clear, he eventually observed particles ten times smaller again, and only 1/30,000 inch in size, only 0.85 μm, which is smaller than bacteria. He was right. I have observed pollen of the same *C. pulchella*, and the smaller particles are all around 1 μm in size.

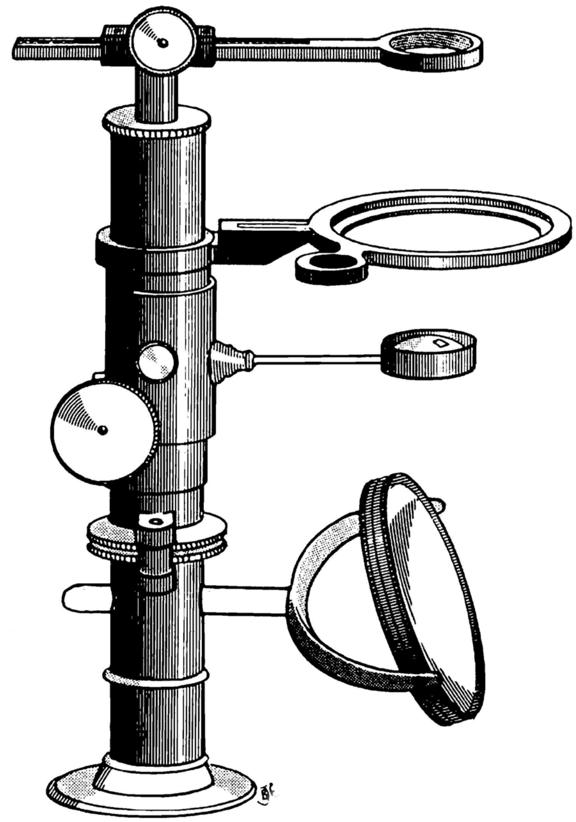
I took that same lens in its perfectly formed holder and prepared some pollen from *C. pulchella*. Carefully adjusting the illumination, I brought the specimen gently into focus … and the pollen was well resolved, indeed too large for a single pollen grain to fit into the field of view. Within each, I could make out those tiny particulates, all vividly agitated in Brownian Motion, the smallest of which were of bacterial dimensions. It was an unforgettable experience. Nobody had seen this with the microscope since Robert Brown made his remarkable discovery two centuries ago. I confirmed the observations with some further micrographs, and settled down to prepare the results. The point had finally been proved.

My final experiments were to demonstrate cytoplasmic streaming in the giant staminal cells of *Tradescantia virginiana*. This was an easy matter. The cells are large enough to be glimpsed by the naked eye, and the slowly swirling contents could be clearly observed with the Bancks microscope. Job done.

Robert Brown also examined in detail the processes of fertilization in the gymnosperms, but I had no intention of essaying that. It's an exceedingly difficult process to observe, even with a present-day achromatic instrument, and I knew I wouldn't be capable of doing justice to it. This is no false modesty; I have long been known as a nifty microscopist, but there are limits. Brown was better at manipulating such things than me, so I opted to let his supremacy stand.

SPREADING THE WORD

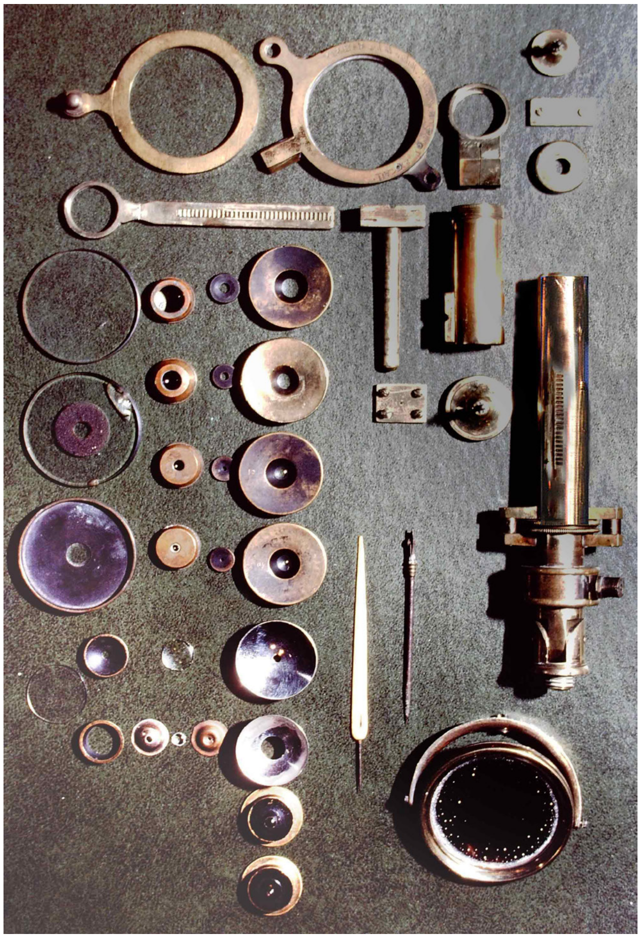
I could at last reveal all to associations like the Quekett Microscopical Club and the Linnean Society, where my lecture demonstrations attracted a packed house, also at the Inter/Micro conference in Chicago and at Brandeis University in Waltham, MA. I arranged a conference at Downe House, Darwin's former home, at which my good friend Stephen Jay Gould came to speak, where I also presented my research. There is much about Brown, Bancks, and Leeuwenhoek in my book *Single Lens, the Story of the Simple Microscope* (New York: Harper & Row, ISBN 0060153660, 1985). My articles appeared in journals ranging from *Nature* and the *Journal of Biological Education* to the *British Medical Journal*, with a later account in this journal (Ford, Brian J. "Brownian Movement in *Clarkia* Pollen, a Reprise of the First Observations," *The Microscope*, 40:4, pp. 235–241, 1992). The research even featured prominently in the popular press.



Robert Brown's later Bancks microscope is preserved in the museum at London's Kew Gardens. I prepared this line illustration in tribute to the engravers of the nineteenth century. Note the substage condenser lens and the concentric fine-focusing control at the base of the main pillar.

Robert Brown had been vindicated. So many of the popular resources always insisted Brown had witnessed the motion of pollen grains. I had now confirmed what he had written: the motion was of minute particles within the pollen, not the entire pollen grains. By this time, my research had extended further. The President of the Royal Society, Sir Andrew Huxley, had expressed enthusiastic support for my scientific investigations into the microscopy of Antony van Leeuwenhoek, whose specimens I had discovered in their archives. I had received some further funding from the Royal Society and bodies including the American Microscopical Society. The research was fast gaining momentum.

The problem remained that so many resources had



The complexity of this exquisite little brass instrument is revealed by a snapshot of its component parts when disassembled. There are six ground biconvex lenses, two of them fitted into silvered Lieberkühn reflectors. The magnifications range from a 12× macro lens to a fine doublet that magnifies 160×.

stuck to the jiggling pollen paradigm, despite that fact that it was obvious pollen was orders of magnitude too large to manifest any form of Brownian Motion. I watched a BBC television program hosted by an Iraqi physicist, Jameel Sadik Al-Khalili (popularly known as Jim) where he sprinkled powdery pollen onto the surface of a jar of water while announcing that Robert Brown had seen the pollen grains dancing about "almost as though they were alive." In San Francisco, at their marvelous Exploratorium, I learned that "A random movement of pollen grains suspended in water was observed by botanist Robert Brown." For a decade I was science contributor to *Encyclopaedia Britannica* and they had it wrong, too; it took me five years to have them correct the mistake.

Even though *Nature* had published my findings, they made the same elementary error in their "Year of Physics" supplement, which included a paper by Giorgio Parisi stating that "... the observation of pollen grains in water — now known as brownian motion — also heralded a revolution in physical thought." (Parisi, G. " Brownian Motion," *Nature*, 433, p. 221, 2005). *Science-Sparks* still stated: "Robert Brown... noticed pollen grains moving around randomly in water under a microscope," in June 2023, while *Atascientific* has: "Pollen grains suspended in water ... was moving in a random fashion." The 2003 update to *LibreTexts* has "Tiny pollen grains suspended in still water moved about in complex paths," while *Brainly.in* still speaks of "Pollen grains moving randomly in water." Once a fact is printed in a work of reference, others copy it. Encyclopedias don't obtain their information from original sources, often they steal them from other encyclopedias.

BROWNIAN BACKLASH

My observations were criticized by Daniel H. Deutsch of Pasadena, CA, in 1991 with a range of curious objections. Deutsch insisted that Brown's system was too "noisy," that he was wrong not to use coverslips, that his field of view was "too small," and that his particles were "much too large." He argued that his specimens were "much too light, pollen" or "too heavy, even rocks" and insisted that it was the evaporation of liquid that produced movement of the particles, concluding that a "rigid closed system free of vibrations" was what you needed to prove the point. He concluded – without the merest whiff of sense in any of it all – by inventing that Brown must have used a compound microscope to confirm his findings, adding that an achromatic compound microscope acted like an inverted pendulum … and so he rambled on.

I responded with courteous, but firm, explanations of why he'd not understood the topic, and the controversy soon became international. The response was extraordinary. In the Netherlands, it was reported extensively in their top quality newspaper *NRC Handelsblad*, in the US, in journals ranging from *Science News* to the *Bulletin of the American Physical Society* and *Scientific American*, while in the UK, *The Economist* and *New Scientist* were reporting the affair. Scholars in the USA from Arizona State University, the American Physical Society in New York, Massachusetts Institute of Technology, Boulder CO, and, in Norway, Netherlands, Sweden, several in London, and others in Dalhousie University in Canada, and from Austria, all sent letters of support. I even devoted one of my annual microscopy symposia presentations to the research ("An Evening with Brian: The Proof of Brownian Movement," Inter/Micro 92, McCrone Research Institute, Chicago, July 13, 1992).

EINSTEINIAN EPILOGUE

Robert Brown never called the phenomenon "Brownian" anything. Scholars do not name phenomena after themselves. Henry Heimlich popularized the Heimlich maneuver and went to great lengths to ensure that his name was attached to it, though I can't think of anyone else so immodest. Brown wrote of "active molecules" and their "rapid oscillatory motion." So where did the term Brownian first appear?

The earliest printed example I have found is in a paper by a German mathematician and microscopist, Christian Wiener, in a paper entitled "Erklärung des Atomistischen Wesens des Tropfbar-flüssigen Körperzustandes, und Bestätigung desselben durch die Sogenannten Molecularbewegungen" (An explanation of the atomistic nature of the liquid state of bodies, and its confirmation through the so-called molecular motions) published in *Annalen der Physik und Chemie*, 118, pp. 79–94, in 1863. Wiener writes of "Brown'sche Bewegung" (Brownian motion).

The first person to publish a paper with "Brownian" in the title that I can find was William M. Ord, a surgeon and part-time microscopist, who published a paper entitled "On some Causes of Brownian Movements" in the *Journal of the Royal Microscopical Society*, Series 2, 2, pp. 656–662, 1879. In 1888, a French microscopist named Louis Georges Gouy affirmed that the irregular motion was real and intrinsic to the liquid, and he went to great lengths to show that it was not caused by external factors like vibrations, convection currents, light, temperature fluctuations, even mechanical perturbance.

Albert Einstein took it further. He modeled each suspended particle as being hit randomly by countless water molecules, and derived the diffusion equation for the probability distribution of the position of a particle. Most importantly, he showed that the mean squared displacement of the particle grows linearly with time:

$$\langle x^2 \rangle = 2Dt$$

where the diffusion coefficient (D) is given by:

$$D = \frac{kT}{6\pi\eta r}$$

where k is Boltzmann's constant, T is temperature, η is the viscosity of the suspending fluid, and r is the radius of the particle. Wiener had shown how Brown's idea of molecular bombardment could work in practice; now Einstein turns that into a quantitative and predictive formula that connects the observable quantities of displacement, viscosity, temperature, and the microscopical particles. Einstein could relate the degree of the movement to fluid viscosity and particle size.

Brown's ideas were conjecture; Wiener's became qualitative; Einstein had made it quantitative. His momentous paper was published as "Über die von der Molekularkinetischen Theorie der Wärme geforderte Bewegung von in Ruhenden Flüssigkeiten Suspendierten Teilchen" (On the Movement of Small Particles Suspended in Stationary Liquids Imposed by the Molecular-kinetic Theory of Heat) in *Annalen der Physik*, 17, pp. 549–560, 1905. Although his paper was on Brownian Motion, he didn't use the term; he wrote of "Brownsche Molekularbewegung" (Brownian Molecular Motion) once and only tentatively — calling it "so-called" and admitting that he didn't have good enough data to be sure it matched his theoretical predictions.

CLONING LOUIS PERRIN

Louis Perrin, a French mathematician, used an ultramicroscope to demonstrate Brownian Motion. His specimens were illuminated by a bright arc lamp constrained through a narrow slit normal to the plane of observation. Perrin chose uniform spherical particles, mainly of gamboge, suspended in water or other liquids. He measured the mean squared displacement of the particles over time (verifying Einstein's formula) and measured the vertical distribution of particles under gravity. By preparing nearly identical-sized particles through fractional centrifugation, he was able to obtain very accurate data. Perrin repeatedly calculated Avogadro's number from his observations and concluded that it lay between $6.4–7.2 \times 10^{23}$ — remarkably close to our accepted value of 6.022×10^{23}.

He published his results as a lengthy memoir titled "Le Mouvement Brownien et la Réalité Moléculaire" in *Annales de Chimie et de Physique*, 8th series, 18, pp. 5–114, 1909. The English translation by Frederick Snoddy appeared in London as a 90-page book titled *Brownian Movement and Molecular Reality*, from Taylor and Francis in 1910.

I have a copy in my library. It's bound in gray cloth and is a handsome little volume. Then suddenly, another copy appeared in the mail, sent over by none other than Daniel H. Deutsch of Pasadena. I was then sent a third by my great friend, the late James B. McCormick of Chicago, who was sure I'd appreciate it as

Microscope	Lens	Magnification	NA (dry)	Resolution (μm)
Linnean Society	Lens #1	170×	0.55 – 0.70	0.48 – 0.61
Linnean Society	Lens #2	75×	0.35 – 0.45	0.75 – 0.96
Linnean Society	Lens #3	33×	0.20 – 0.30	1.12 – 1.68
Linnean Society	Lens #5	6×	0.08 – 0.12	2.80 – 4.20
Linnean Society	Lieberkühn 1	8×	0.12 – 0.20	1.68 – 2.80
Linnean Society	Lieberkühn 2	25×	0.15 – 0.25	1.34 – 2.24
Kew Herbarium	High-power	160×	0.50 – 0.65	0.52 – 0.67
Kew Herbarium	Low-power	65×	0.30 – 0.40	0.84 – 1.12
Kew Herbarium	¾	131×	0.40 – 0.55	0.61 – 0.84
Kew Herbarium	2	69×	0.30 – 0.40	0.84 – 1.12
Kew Herbarium	Low Power	12×	0.10 – 0.15	2.24 – 3.36

Likely optical performance of the Bancks microscopes. We can approximate the numerical aperture (NA) from the refractive index of the convex lenses, all carefully ground and polished from soda-lime glass and then mounted in circular holders turned from brass and milled with steel pinions for the focusing mechanism.

I looked into Brownian Motion. What was interesting is that my own library copy was genuine; the others were fake. Deutsch had produced a small number of exact copies of the original. There was no indication that they were copies (no editorial note saying they had been scanned, or were being re-issued) but they were clearly modern copies. They had pristine bindings; mine was worn. The printed pages of my copy showed the indentations of letterpress; the new copies lacked that key feature.

So the Brownian Motion saga was interleaved with curious controversies. The original coinage, as "Brown'sche Bewegung," was in German, not English; my own recreations of Brown's observations were challenged by Daniel H. Deutsch who cited reasons that had been painstakingly disproved by publications since 1863, and we now had copies of Louis Perrin's superb book that Deutsch had privately printed and put in circulation.

ANOTHER MICROSCOPE EMERGES

Robert Brown needed a better instrument, and a later Bancks design incorporated an intricate fine focusing control at the base of the main pillar. Like its predecessor, it is housed in a polished wooden case, this one bearing an engraved silver plate engraved with these words:

> 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

This commemorative plate attests to the microscope's long-term ownership and use by Robert Brown at his residence in Soho Square, London. It records that, after Brown's death in 1858, it was given by J.J. Bennett (Brown's successor as Keeper of the Banksian Collections) to John Edward Gray, the Keeper of Zoology at the British Museum. It is now in the museum collections at Kew Gardens.

Kew is a remarkable place, housing over 50,000 species of plants – more than any other botanical center anywhere in the world – and dotted with huge Victorian glasshouses, some over 60 feet (20 meters) tall. I say "Victorian" but the originals had cast iron ribs from the mid-1800s that were deteriorating, so during the 1980s they were all replaced with extruded stainless steel. The carefully cast curved glass panels were all substituted by modern tempered glass … so not a trace of the original glasshouses remains. Those we see today are identical-looking replicas, for the originals have been thrown away. Just don't tell anyone I said so.

Sir George Taylor had been the director when I started going to Kew with my parents as a child. I once saw him showing distinguished dignitaries around a glasshouse and remember it well. Once I had been elected to Fellowship of the Linnean Society, I found myself working with Gren Ll. Lucas who was deputy keeper of the Herbarium at Kew Gardens. Gren was full of enthusiasm for my research and he invited me to review the Bancks microscopes in the Kew museum. Since 1988, their director had been Sir Ghillean Prance, a good friend, with whom my wife Jan and I have such pleasant memories of staying in his Dorset home. Kew had several Bancks microscopes on display.

The Kew team were eager for me to check out their Robert Brown microscope, so I took it to my laboratory to see how it was made. It was of familiar Bancks design, though with advanced features, including doublet lenses and that ingenious fine-focus control near the base of the main pillar, while the substage mirror was double-sided (plane on one side, concave on the other). This exquisite instrument had been curated and conserved, so no restoration work was required, and I settled down to calibrate the lenses. The highest-powered magnifier was rated at 160×, and there was an intermediate high-power lens magnifying 131×. It produced sharp and clear images, with surprisingly little chromatism, and I put it through no further tests. A principle on which I had decided when working on Leeuwenhoek was that these microscopes have an inherently limited life, so we should never subject them to more investigation and manipulation than absolutely necessary in the interests of scholarship.

Kew had two other Bancks instruments. One had belonged to Sir William Hooker, who had been Director of Kew from 1841-1865 and was a great friend of Brown's. The other was the microscope of George Bentham, a Linnean Society president whose prodigious *Flora Australiensis* of 1878 ran to 7 volumes. I could detect that he had cut sections of his botanical specimens, because the small brass block at the top of the microscope was riddled with tiny cuts. He'd used a carbon-steel scalpel of some kind and the forensic evidence remained.

A PUZZLE OF GEOGRAPHY

There was one final Robert Brown microscope to address. Knowing of my interest in Robert Brown, the Director of the Utrecht museum, my good friend Peter-Hans Kylstra (who had been so supportive of my Leeuwenhoek research) sent me a cryptic little message. They had a third Brown microscope. I went to see it at once. It stood in a glass case, unambiguously labeled "Microscope of Robert Brown."

"Do you know where this microscope came from?" I asked. Peter shook his head, and said that would be in the records, so I asked to inspect them. He asked his ever-obliging assistant to bring us the original printed catalogue and the hand-written accessions book. Perhaps they held an answer. And he asked her in English – it's salutary to reflect on how many of the Dutch speak English better than the English.

The hand-written ledger was most interesting, and there was my answer. It did not list what we'd been told. Instead of "Een microscoop van Robert Brown" (A Microscope of Robert Brown), it said "Een microscoop folgens Robert Brown" which means "A Microscope after Robert Brown." It was his kind of instrument, but not his own. The printed list was the original catalogue by P. H. van Cittert, published in 1934. And there it was, dignified and immortalized in print: a microscope "folgens Rob. Brown" – *following* Robert Brown. It was not Brown's microscope after all, but one like it. The enduring mystery was solved.

BANCKS – POWER BEHIND THE THRONE

What of the men who made the microscopes? We know little of them, though their handiwork is abundant, even today. Robert Bancks started in business with his brother Anthony and reference works record their existence; Lowndes's *London Directory* (1797) lists "Bancks Robert, Optician, 440, Strand" and *Holden's Triennial Directory* (1805) has "Bancks Rob., Optician, 441, Strand" – not due to a move to different premises, but because the houses were re-numbered.

This microscope is in the Utrecht University Museum in the Netherlands. It was made by John Dollond of London and described as "a microscope of Robert Brown." When I searched the original, handwritten accessions book, I could see it was entered as "a microscope after Robert Brown." It was not his.

Anthony had quit by this time, and Robert Jr. joined; in 1829 they were listed as Bancks & Son at 119 New Bond Street, a more upscale neighborhood about 1½ miles away. The son died in 1830, but the father continued trading under the "& Son" name in New Bond Street until he retired around 1834.

Bancks Sr. was an extraordinary man. We have encountered his simple microscopes used by Robert Brown, and also by Hooker, Bentham and Darwin; yet Bancks also produced barometers, telescopes, sundials, and even experimented with gas lighting and electricity. His instruments were signed variously as Bancks, Banks, R. Bancks, or Bancks & Son, though it's best to stick to Bancks – that's how his name appears on formal documents, and it avoids confusion with Sir Joseph Banks.

He did not only make simple microscopes, but made more advanced instruments with screw-in doublet and triplet lenses, and some with a body tube. He even produced merchandise – a pack of playing cards with the company featured on the back of each card. Brian Stevenson, Professor of Microbiology at the University of Kentucky College of Medicine in Lexington, KY, has compiled a remarkable page online that illustrates some of these remarkable achievements (https://microscopist.net/Bancks.html).

Of Bancks we know very little, but his legacy remains. And Robert Brown? The public may not know much about him, but he bequeathed to us a term at the bedrock of today's cell biology and remains a role model to every modern microscopist.

Next time you speak of the cell nucleus, just remember his name. ■