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Robert Brown, Brownian Movement, and Teeth Marks on the Hatbrim*

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ABSTRACT

Dr. Daniel H. Deutsch, writing with the over-confidence you might expect from a denizen of Pasadena, California, is reported in the August *Scientific American* as refuting Robert Brown's observations of the "active molecules" to which he (posthumously) gave his name.

An abstract in *Bulletin of the American Physical Society* argues that there are a dozen reasons why Brownian Movement

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(dubbed "motion" in Deutsch's paper) could not have been observed by Robert Brown himself.

In refutation it is shown that some of the objections make no sense; that some of those that do, require experimental procedures which Brown himself undertook; that basic assumptions on microscope design are erroneous; and that the literature on microscopy has been consistently misunderstood.

Robert Brown's microscopes are shown to have been sophisticated, capable of surprizingly high magnifications, and well suited to the resolution of fine detail.

If they do not reveal Brownian Movement the author (subject to a reciprocal commitment from the direction of Pasadena, California) would eat his hat.

INTRODUCTION

The departure from my program–listed title (1) for which I apologise, has been necessitated by a lamentable calumny perpetrated on a very great microscopist. The factor which prevents him from standing here, defending his own work, is his death on June 10, 1858. But we cannot allow a logistical detail like that to stand in the path of setting the record straight.

Scientific American, as some of you may have heard, has begun to publish a latter-day version of those satirical columns we used to find in the 1960s. The exemplar of the genre is their current article on Robert Brown (2). He is familiar to most of us as the originator of the concept known as Brownian Movement, the unceasing agitation of small suspended particles in a fluid medium. Brown, in fact, did more fundamental work than that. He is also the man who named the cell nucleus. This element of cell detail had been observed by Leeuwenhoek in the 17th century (it appears in the drawings that accompanied his letters to the Royal Society) but Robert Brown attached to it the name we know today.

In the 1820s, when observing orchid tissue (Figure 1), he noted that in the center of many of the cells was a small discoid or elliptical body (3). He went on to say:

"This areola, or nucleus of the cell as perhaps it might be termed, is not confined to the epidermis, being also found...in many cases in the parenchyma or internal cells of the tissue." He added that it appeared in many other species of plants, too, and

Figure 1. Epidermal cells of Allium *are here imaged with darkground illumination, the mirror being obliquely aligned on Brown's microscope at Kew. The nuclei are easily seen, whilst the smaller particles are of bacterial dimensions. This appearance would likely be compatible with the image demanded by Brownian Movement demonstrators.*

from that coinage our modern use of the term originated. Brown also discovered the naked ovule of the gymnospermae, the evergreen conifers, a characteristic form of reproduction. The term derives from *gymnos*—naked, and *sperma*—seed. The microscopical behaviour of these plants during reproduction was elucidated by Brown using his simple microscope (Figure 2) and published in 1828. Figures 3-5 show his microscope and two photomicrographs taken through his microscope.

I do not know if any of you are familiar with, or related to, Dr. Daniel H. Deutsch of Pasadena, California, but he has published a list of objections to Robert Brown's observations of the motion which bears his name (4). We shall examine these in turn. You will see that he suggests Robert Brown saw—not real Brownian movement at all—but nothing more than tiny perturbations in the liquid medium. The Deutsch report is generous enough to recommend that we do not disenfranchise Brown;

Figure 2. Robert Brown's microscope at Kew represents a type similar to that produced by Bancks (see Figure 3). But there is an added feature: the substage mirror housing is mounted on a rotating collar which enable lateral lighting to be more easily utilised. Brown dispensed with a substage condenser, preferring a double-sided mirror instead. The lens unit is shown in its fitted position here.

nobody is actually suggesting the withdrawal of the term "Brownian movement" from current use.

But the objections listed in the article I find quite extraordinary. They perpetrate the view against which I have fought for many years, namely this arrogance as a feature of modern science. There is a belief that nowadays we can do things which of course could not have been possible in those unrefined, far-off and primitive times. Yet, as I have shown elsewhere, the images that can be obtained even with a Leeuwenhoek lens are not so different from those you would obtain with the best optical microscope available today.

From the picture in *Scientific American* you might be tempted to envision Brown as an irascible and thick-necked individual. But, when an active botanist in middle-age, he can be seen (cover) as a dashing, handsome figure; something of a socialite, even a gossip, who maintained a lively and distinguished group of friends (5). Among the people to whom he showed the phenomenon of Brownian movement, as it became known, were Ferdinand Bauer, the gifted illustrator, Darwin (who wrote of the occasion in his old age), Sir Everard Home, the surgeon who plagiarised the Hunterian manuscripts and lost the Royal Society's collection of Leeuwenhoek microscopes; from America came Thomas Horsfield of Bethlehem, Pennsylvania. Also in the group were William Wollaston, who invented the lens that bears his name, and Peter Mark Roget, author of the famous *Thesaurus*.

Robert Brown traveled widely and explored Australia and Tasmania, returning with over 4,000 species to identify; he then established the first national botanical collection in Britain at the original British Museum(6). His work on the "active molecules" was a side-light to this endeavor.

By his own private account, the work was carried out between June through August 1827 and he had the work printed in the form of a pamphlet by Richard Taylor of Red Lion Court in London's Fleet Street. A further account of the phenomenon was appended, dated in the printed form as July 28, 1829. In this short essay Brown listed the workers who may have observed the effect prior to his own studies (7).

The unwarranted slur on Brown's name was originally published as an abstract in the *Bulletin of the American Physical Society,* a bulging volume not unlike a telephone directory. I should say that my presentation here is inevitably hastily compiled since my attention was drawn to it by an article in the current issue of *Scientific American* and I saw it just a few days before I flew out to the States. But the University Library at Cambridge keeps such publications and I was able to consult the list of objections raised in that short account. Let us deal with them separately:

1) His system was too noisy

Nonsense. I have used Brown's microscopes and they function in complete silence if properly oiled. There is no noise at all. Dr. Deutsch cannot have referred to signal noise, I am sure; microscopes are not analogous to electronic systems.

2) He did not use cover glasses

Brown makes it clear that he used uncovered specimens, but he compensates for this effect in some of his experiments by mounting droplets of his specimen liquids emulsified inside oil, thus producing a sealed preparation.

3) They were not yet invented

Not so. Sliders made from ivory and utilising discs of talc or mica to retain the specimen have been known since the first half of the 17th century. These fine, rounded products acted as a "coverslip" and had been in use for one-and-a-half centuries by the time Brown was active.

4) His field of view was very small

It was limited, true; but smallness of field is no limitation to the would-be student of Brownian movement and in any event the visual cone (numerical aperture) was not as limited as Deutsch seems to imply.

5) His particles were much too large

Robert Brown hesitates to give firm dimensions. But, using an engraved graticule, he calculates that his earliest observations (they date from the Fall of 1826) concerned particles "from nearly 1/4,000th to 1/5,000th of an inch in length" (about 5-6 µm). Later he estimates the size of subsequently-observed particles to be 1/15,000th to 1/20,000th of an inch (1.2-1.8 µm). In a footnote he states that further work reduced the size of the smallest particles to less than 1/30,000th of an inch. This is about 0.8 µm, therefore, less than one micron.

6) His particles were much too light, pollen

This error is frequently made in writing about Robert Brown. Most textbooks say he observed Brownian movement of pollen grains, but he did not. As his account clearly emphasises, he was observing minute granules *within* pollen grains. Whereas pollen may be between 20 and 50 µm in diameter, the granules within them are at least one order of magnitude smaller. Brown recommends the pollen of the gramineae, where "the membrane of the grain of pollen is so transparent that the motion of the larger particles within the grain was distinctly visible", but cites a host of other plants in which the same observation was confirmed.

One might object to Deutsch's comments by pointing out that "lightness" has nothing to do with Brownian movement; but we can content ourselves with the simpler observation. The nature of pollen is not the problem; Robert Brown was observing what went on inside.

7) Or they were too heavy, even rocks

Brown was an exemplary investigator, and when he saw Brownian movement in a range of organic specimens, he speculated as to their relationship to life itself. Were these the seat of movement in macroscopic species? He set out to disprove that view by observing minerals. But not, as our friend from Pasadena, California suggests, rocks. Rather, Brown ground minerals to a considerable fineness—the particles he studied were small enough to remain (in his own words) "temporarily suspended in water". *Rocks*! indeed.

8) Evaporation of the liquid produced movement of the particles

It is many months since I last visited Pasadena, California, and I confess the levels of presumption I then observed did not reach such dizzying heights. Of course, evaporation can produce movement, an observation Daniel H. Deutsch includes in his own "discoveries" on the subject. Dr. Deutsch is behind the times—165 years behind the times, to be precise. Robert Brown observed evaporation as a cause of movement and carried out an ingenious experiment to disprove it. In Brown's words, "this experiment consists in reducing the drop of water containing the particles to microscopic minuteness... and immersing it in a transparent fluid of inferior specific gravity, with which it is not miscible..." He mixed some particle-containing water with almond oil by vigorous shaking, producing samples "from 1/50th to 1/2,000th of an inch in diameter (about 10-500μm)" and observed that the movement of the particles within each water droplet continued as before:

"The motion of the particles takes place with undiminished activity, while the principal causes assigned for that motion, namely evaporation, and their mutual attraction and repulsion, are either materially reduced or absolutely null."

Not only had Robert Brown anticipated the objection now raised, but he neatly disproved it by experiment.

9) He confirmed his findings with the then best achromatic microscope

Oh no he didn't—he had a colleague do it for him. Brown asked "Mr. Dollond (to use his) best (compound) achromatic microscope" for that purpose. This refers to George Dollond (1774-1852) whose maternal uncle Peter Dollond (1730-1820) had made a fine triple achromatic objective lens in 1764. A third Dollond, John (1706-1761), was Peter's father and he had demonstrated achromatism in experiments during the Spring of 1757. But Robert Brown used simple, not compound, microscopes (8).

10) A proper compound achromatic microscope was invented a few years later

But achromatic microscopes were not necessary to make such observations. Here we are witnessing an example of current scientific presumption of a kind widespread in modern thinking and not peculiarly associated with the denizens of Pasadena, California. Technicians seem convinced that their predecessors could not have achieved what they did. As I have shown elsewhere, even a lens hand-made by Leeuwenhoek more than a century earlier could generate images of fibrillar structures less than one micron in thickness. Simple microscopes produced images better than many we see from modern microscopes, and Brown's techniques would have been quite sufficient for the demonstration of his "active molecules" at work.

11) The new achromatic microscope acted like an inverted pendulum and required complete redesign

As far as one can understand this it is wrong. I showed, with painstaking care, that the compound microscopes were based on designs for their single-lensed predecessors. The account appeared in *Single Lens, Story of the Simple Microscope* which Dr. Deutsch apparently obtained in 1985. The extensive re-design is something of a myth.

And as for the "inverted pendulum"... if anyone can offer a suggestion as to the interpretation of that cryptic phrase I shall be relieved to read it, for it makes no sense to me.

12) Cover glasses were invented later to hold samples fixed and prevent evaporation

We have dealt with this before, I guess. Cover glasses that held the specimen date back long before Brown. An example was published in Italy as long ago as 1686, when sliders had been invented. And Brown himself showed how to make preparations free of evaporation as long ago as 1828. No marks here, Dr. Deutsch.

13) To see real Brownian motion in water at 350X requires approximately 1 μ/particles, with a density close to 1.00 and a very rigid closed system free of vibrations.
It's "Brownian movement" or *motion*; his lenses could magnify more than 350X, though less would suffice; it is not "μ" but "μm" these days; density does not matter; the system does not have to be "closed" nor free from vibrations (though Brown's pollen grains *were* a closed system, and he was well able to overcome vibratory movements).

I have had one advantage clearly denied to the inhabitants of those darkest corners of California, namely the use of Robert Brown's microscopes. I have been fortunate enough to use them in my own laboratory.

That is no small privilege, for at the time of the 1951 exhibition at the Festival of Britain in London, the organisers wrote to the Linnean Society (where the microscope of Robert Brown resides) and asked if they could display it in the Dome of Discovery. They were refused permission, the microscope being said to be too precious to allow out on loan. I remain honored that the learned Society was kind enough to allow me to take it away, to recreate his observations on the nucleus (9,10).

ROBERT BROWN'S MICROSCOPES

Brown had several microscopes (Figures 2,3), and I have described them in outline elsewhere. To suggest they were "primitive" is a most insulting suggestion. The instruments were made by Bancks of London, a father-and-son company, and they boasted a range of sophisticated accoutrements. Among these are concave mirrors, a substage condenser, fine-focussing and a reclining body pillar. A microscope made for Brown by Dollond gave magnifications far higher than might be supposed with one lens calibrated at 480X. (This is always referred to by Americans as "four-eighty ex" which misreads as a letter the final mathematical character. It should be pronounced "four-eighty times". Could it be that such a misstatement traditionally originated in Pasadena, California? One hesitates to make such a suggestion, but you cannot be sure.)

Suggestions that these microscopes generated poor images, and that microscopists of old were unable to create viable experimental procedures, are now shown to be unsafe (10). I do not know whether Robert Brown's existing microscope at the Linnean Society (Figure 2) does reveal Brownian movement. But it is clearly a superb little microscope, and the experiments I have thus far carried out testify to its ability to reveal particles of the order of size demanded (Figures 1,4,5).

The abstract by Dr. Daniel H. Deutsch of Pasadena, California has been dignified by the editorial reportage offered by *Scientific American*. Dr. Deutsch has not only read my book, but says he has a foot high stack of papers which, (to cite his exact word) lead him to his "discovery".

Were indignant microscopists to find themselves in the vicinity of Pasadena, California, with an unfenced tall cliff or an unguarded mine-shaft close by, then I trust nothing would persuade them to avenge the noble name of our distinguished Scottish predecessor, Robert Brown. However, this article clearly launches a challenge. If a Bancks microscope—as used by Brown—cannot demonstrate Brownian movement then I will eat my hat.

If it can be done, though, I'd like Daniel H. Deutsch, of Pasadena, California, to eat his.

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Postcript

Finally, is it correctly "movement" or "motion"? The latter term is used by Deutsch; it was one of several used by Brown, and indeed I have referred to it myself. The term is correctly "Brownian Movement", however, according to the many definitive sources. These include: *Oxford English Dictionary* (1933), p.1137; *Van Nostrand Scientific Encyclopedia* (4th Edition), p. 245; *Chambers Science and Technology Dictionary* (1988), p. 116. In the interests of consistency, I bow to their authority; whether this applies to Pasadena, California remains to be seen.

Figure 3. A Bancks microscope in operation. The lens unit is fitted, and two ivory specimen sliders are shown in use. The microscope gives clear images of particles below 2 microns in diameter.

Figure 4. No. 65—Guard cells and epidermal structures associated with stomata show in this epidermal peel preparation mounted in water on a mica disc, just as Brown would have done in the 1820s. The image compares well with modern micrographs.

Figure 5. No. 4—Oblique illumination produces this striking image of staminal hairs from Tradescantia virginiana. *In this species Brown first observed cytoplasmic streaming. The particles within the cytoplasmic bridles are down to 1 micron across.*