BROWNIAN MOTION

In 1827, the Scottish botanist Robert Brown looked through a microscope at pollen grains suspended in water, and discovered what we now call *Brownian Motion*. It was an unintentional discovery. He was not looking for the effect that now bears his name, but was, rather, curious about reproduction. He wanted to know about the detailed mechanism by which pollen grains impregnate the female ovule.

In a pair of papers published in the *Philosophical Magazine* he writes about his investigations.[1] His story is remarkable for its candor, reporting failures along with successes, all in extraordinary detail. It is as if he were inviting his readers to participate with him in his researches. He begins the first paper by describing his "microscope", actually a simple lens:

> The observations, of which it is my object to give a summary in the following pages, have all been made with a simple microscope, and indeed with one and the same lens, the focal length of which is about $\frac{1}{32}$nd of an inch.*
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> * This double convex Lens, which has been several years in my possession, I obtained from Mr. Blancks, optician, in the Strand. After I had made considerable progress in the inquiry, I explained the nature of my subject to Mr. Dollond, who obligingly made for me a simple pocket microscope, having very delicate adjustment, and furnished with excellent lenses, two of which are of much higher power than that above mentioned. To these I have often had recourse, and with great advantage, in investigating several minute points. But to give greater consistency to my statements, and to bring the subject as much as possible within the reach of general observation, I continued to employ throughout the whole of the inquiry the same lens with which it was commenced.

A lens of this focal length would have a magnification (as a hand lens) of about 300. Brown had discovered that certain plants contained pollen grains that were oblong, rather than spherical. He thought that the peculiar shape of the grains would enable them to be tracked so that he could see what role they played in the process of impregnation. He writes:

> My inquiry on this point was commenced in June 1827, and the first plant examined proved in some respects remarkably well adapted to the object in view. 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 $\frac{1}{4000}$th to about $\frac{1}{5000}$th 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; their motion consisting not only

[1] Phil. Mag. **4**, 161 (1828), and Phil. Mag. **6**, 161 (1829).

> of a change of place in the fluid, manifested by alterations in their relative positions, but also not unfrequently of a change of form in the particle itself; a contraction or curvature taking place repeatedly about the middle of one side, accompanied by a corresponding swelling or convexity on the opposite side of the particle. In a few instances the particle was seen to turn on its longer axis. These motions were such as to satisfy me, after frequently repeated observation, that they arose neither from currents in the fluid, nor from its gradual evaporation, but belonged to the particle itself.

Brown writes that he then looked at pollen grains from related plants:

> In extending my observations to many other plants of the same natural family, namely *Onagrariæ*, the same general form and similar motions of particles were ascertained to exist, especially in the various species of *Œnothera*, which I examined.

He later writes:

> Having found motion in the particles of the pollen of all the living plants which I had examined, I was led next to inquire whether this property continued after the death of the plant, and for what length of time it was retained.
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> In plants, either dried or immersed in spirit for a few days only, the particles of pollen . . . were found in motion equally evident with that observed in the living plant; specimens of several plants, some of which had been dried and preserved in an herbarium for upwards of twenty years, and others not less than a century, still exhibited the molecules or smaller spherical particles in considerable numbers, and in evident motion . . .

Brown thought that his observed motion of the pollen grains (which he termed "peculiar") might possibly be used as a test to indicate the existence of a male sexual organ, and so looked at grains from the genus *Equisetum*, in which the existence of sexual organs was thought not to exist. However, as he writes:

> . . . this motion was still observable in specimens both of Mosses and of *Equiseta*, which had been dried upwards of one hundred years.
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> The very unexpected fact of seeming vitality retained by these minute particles so long after the death of the plant would not perhaps have materially lessened my confidence in the supposed peculiarity [as a test for the male organ]. But at the same time I observed, that on bruising the ovula or seeds of *Equisetum* . . . I so greatly increased the number of moving particles, that the source of the added [particles] could not be doubted . . . My supposed test of the male organ was therefore necessarily abandoned.

Brown then went on to examine "various products of organic bodies . . . extending . . . even to pit-coal", continuing to find that even these particles moved. He then turned to "silicified" wood, and then to window glass, and finally to a variety of mineral substances (travertine, stalactites, lava, obsidian, pumice etc.) and even to metals (manganese, nickel, plumbago [graphite], bismuth, antimony and arsenic). In each case, whenever he could reduce a substance to a powder sufficiently fine that it could be suspended in water, he observed the constant motion of the particles.

In the second of his two papers Brown takes on his critics and others who apparently made observations similar to his own. There must have been considerable conjecture regarding the causes of the motion of the particles, whether such motion might be evidence for "animation", or life. Although Brown refuses to guess why the particles move, he forcefully asserts that the motion of the particles cannot be taken as evidence that they are alive, or "animated". He writes:

> In the first place, I have to notice an erroneous assertion of more than one writer, namely, that I have stated the active Molecules to be animated . . .
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> The result of the inquiry at present essentially agrees with that which may be collected from my printed account, and may be here briefly stated in the following terms: namely,
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> That extremely minute particles of solid matter, whether obtained from organic or inorganic substances, when suspended in pure water, or in some other aqueous fluids, exhibit motions for which I am unable to account, and which from their irregularity and seeming independence resemble in a remarkable degree the less rapid motions of some of the simplest animalcules of infusions. That the smallest moving particles observed, and which I have termed Active Molecules, appear to be spherical, or nearly so, and to be between 1/20,000th and 1/30,000th of an inch in diameter; and that other particles of considerable greater and various size, and either of similar or of very different figure, also present analogous motions in like circumstances.
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> I have formerly stated my belief that these motions of the particles neither arose from currents in the fluid containing them, nor depended on that intestine motion which may be supposed to accompany its evaporation.

It was not until much later that the phenomenon that Brown observed was understood. In a famous paper [2] published in *Annalen der Physik* in 1905, Albert Einstein developed the theory of *Brownian Motion.*

Curiously (but typically), Einstein deduced Brownian motion without knowing about the experimental observation. In his 1905 paper he wrote

> In this paper, it will be shown that according to the molecular-kinetic theory of heat, bodies of microscopically visible size suspended in a liquid will perform movements of such a magnitude that they can be easily observed in a microscope, on account of the molecular motions of heat. It is possible that the movements to be discussed here are identical to the so-called 'Brownian molecular motion'; however, the information available to me regarding the latter is so lacking in precision, that I can form no judgement in the matter.

In a subsequent paper published the following year, Einstein noted

> Soon after the appearance of [Einstein, 1905] I was informed [that] physicists—in the first instance, Gouÿ (of Lyons)—had been convinced by direct observation that

[2] Einstein, A. "Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen", *Ann. Phys.* **17**, 549 (1905). For a later summary (in English), see A. Einstein, "Investigations on the theory of the Brownian Motion", published by Dover in 1956.

> the so-called Brownian motion is caused by the irregluar thermal movements of the molecules of the liquid. Not only the qualitative properties of the Brownian motion but also the order of magnitude of the paths described by the particles correspond completely with the results of the theory. I will not attempt here a comparison [with] the slender experimental material at my disposal.

Many years later, in his letter to Michele Besso (6 January 1948), Einstein reminisces that he had

> deduced [Brownian motion] from mechanics, without knowing that anyone had already observed anything of the kind.

— Summary by Peter Scott, with some material relating to Einstein by B. M. Gammel