Seeing Atoms

Scanning probe microscopes have made false-color snapshots of atomic and molecular landscapes commonplace. So it is more easily forgotten now just how thoroughly invisible the atomic and molecular building blocks of every material have been through the ages. For 25 centuries, a larger class of particles well-known to the allergically afflicted—dust and pollen—provided some of the closest approaches to seeing atoms.

Just how the original atomic theory came to the Greek philosopher Leucippus in the 5th century BC is not known but was attributed by Aristotle in the 4th century BC to Leucippus's student Democritus the comparison of atoms to "motes in the air we see in shafts of light coming through the windows." To Leucippus and Democritus, the seemingly random dance of tiny particles and fibers was a model of atoms in constant motion.

Half a millennium later, in the first century BC, Lucretius, the Roman poet and philosopher who more than any ancient thinker promoted the idea of atoms, had a similarly dusty epiphany. In the dance of dust in sunbeams he too observed a model of the atomic microworld, as he describes in his poetic song to atoms, *De Rerum Natura*, "There you will see many particles under the impact of invisible blows changing their course and driven back from their track, this way and that, in all directions. You must understand that they all derive their restlessness from the atoms." By battering the dust like an unruly crowd, invisible atoms made themselves perceptible to the senses.

Almost 2,000 years later, one of the most striking and direct lines of evidence for the reality of atoms and molecules was unwittingly spotted in London, but went unrecognized for decades.

These observations were made during the summer of 1827 by Robert Brown, a respected Scottish-born botanist working in his laboratory at the British Museum. He began with the simple goal of observing and describing the physical form of pollen grains in greater detail made possible with the then recently improved microscopes. To do this, he collected pollen grains from the plant species *Clarckia pulchella*, suspended them in water on a glass slide, and then viewed each preparation in the microscope. The grains were either cylindrical or oblong and he measured them to be about 1/4000 or 1/5000 of an inch in length.

What diverted his attention, however, was a variety of unexpected motions in each grain that he examined. Not only did he see particles move randomly through the otherwise invisible water, much like "dust motes" suspended in sunlight, but he observed that the grains' shapes often changed as well. A grain would, in his words, undergo "a contraction or curvature repeatedly about the middle of one side, accompanied by a corresponding swelling or convexity on the opposite side of the particle." Sometimes the grains or the smaller particles that often accompanied the grains, which he called molecules (by this he meant the smallest thing he could see in his microscope, not what we now mean by the word) somehow would be sent into a spin. Having convinced himself that tiny currents in the water or mechanical action by the glass slide on the particles were not at work, he concluded that nothing external seemed to be causing these lifelike contortions: The motion was originating within the particles themselves. Like Mexican jumping beans, something appeared to be alive inside.

He found that any kind of pollen grain moved in the same animated way under his microscope. Pollen from plants that he had killed by drowning in alcohol for several days or drying moved with as much liveliness as ever. The same held for pollen and "molecules" from plants that had been dried and preserved for over a century, and the same for scrapings from nonreproductive parts of living and dead plants that seemed to Brown less likely to contain strong doses of a life force, if that was what in fact was causing the motions. He moved to animal tissue, taking tiny particles he called "molecules" from specimens, and looking for the strangely animated motion under the microscope. He always saw the movements but could never discern the cause.

As the summer of 1827 wore on, Brown progressed to samples from minerals and metals that seemed as far from life as possible. He tried scrapings from glass, lava, obsidian, meteorites, nickel, lead, and arsenic. He tried dust and soot particles from the iron, steel, and glass factories. Even particles from a pulverized piece of the Sphinx shed "molecules" that danced before his eyes with as much vitality as the pollen grains that started his research.

The generality of the result finally relieved Brown of his most alarming conjecture—that all of the minute particles from his sources were alive. He could no longer hold that conjecture at all likely. Still, he could not account for these motions, nor did he try to, when he published his observations of "active molecules" in 1828 in the *Philosophical Magazine*, then a widely read forum of scholarly ideas, arguments, and examinations.

Aside from an early rally of letters in the scholarly literature, nothing much came of his observations during his own lifetime—not until 75 years later when Albert Einstein showed in a pivotal 1905 paper that Brown had in hand even in 1827 the most direct evidence—dubbed "Brownian motion"—then available for atoms. Einstein unveiled a theory and a mathematical model for Brownian motion that provided experimentalists with a route to indirectly measure and count these minuscule molecules.

Brown had died half a century earlier, in 1858, not knowing how much would be made of his "active molecules." At the time, Henry Bessemer and others were introducing new steel-making methods that would elevate steel's role from an expensive specialty material to a high volume commodity that would become the backbone of massive structures and mass manufacturing. At the same time, researchers in polymer chemistry were experimenting on cotton-derived cellulose that would lead to celluloid, an early glimpse of the polymeric diversity of species that would transform the look and feel of the future. Every bit of this was due to the atoms that Brown never saw.

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FOR FURTHER READING: J.J. McConnell, *The Concept of an Atom from Democritus to John Dalton*, Edwin Mellen Press (United Kingdom, 1991)—he author quotes from Aristotle's *De Anima*; H.A. Borse and L. Motz, eds., *The World of the Atom*, Basic Books (New York, 1966)—Brown's own account of his 1827 observations are reprinted here; A.D. Winspear, trans., *Lucretius: De Rerum Natura*, The Harbor Press (New York, 1955); A. Pais, *Subtle is the Lord...The Science and Life of Albert Einstein*, Oxford University Press (New York, 1982).

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