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This Month in Physics History

Einstein and Brownian Motion

Photo Credit: American Institute of Physics
Einstein and his first wife with their first-born son.

Photo Credit: American Institute of Physics
The Patent office in Bern.

In March of 1905, a young patent clerk in Switzerland named Albert Einstein submitted a groundbreaking paper extending Planck's 1900 notion of quanta to the wave/particle dual nature of light. It was published in the *Annalen der Physik*. In May the journal received another paper from Einstein. This time, his subject was the kinetic theory of gases, but the paper was equally groundbreaking in its conclusions.

In the 19th century, physicists had refined the kinetic theory of gases, which described heat as an effect of the nonstop agitated motion of atoms. Along with the American physicist J.Willard Gibbs, Ludwig Boltzmann used the kinetic theory to resolve the so-called "reversibility paradox" in physics. This arose from the second law of thermodynamics, which dictates that most natural processes are irreversible, in seeming contradiction to the Newtonian mechanics of atoms.

Bolztmann reinterpreted the second law as statistical, rather than absolute. He reasoned that there are so many atoms and molecules that make up something as small as an ice cube, for example, that it is extremely unlikely—although not impossible—for the molecules in a melted ice cube to return from the disorder of a liquid to their original orderly arrangement. The statistical improbability of those molecules doing so, however, was the source of the seeming irreversibility observed in nature.

While a student at the Zurich Polytechnic Institute, Einstein met a young Serbian woman, Mileva Maric, the only woman in his physics class. Einstein's family opposed any talk of marriage, even after Mileva gave birth to a daughter (who was apparently given up for adoption). The pair finally married in 1903 after Einstein got his job at the Patent Office. Their first son was born in 1904. [A second followed in 1910.]

Einstein was supposedly unaware of Boltzmann's work when he began independently deriving the second law of thermodynamics from 1902 to 1904 to develop his own form of statistical mechanics. He used mechanics, atoms and statistical arguments to formulate a "general molecular theory of heat."

Einstein developed this statistical molecular theory of liquids for his doctoral dissertation at the University of Zurich. In a separate paper, he applied the molecular theory of heat to liquids to explain the puzzle of so-called "Brownian motion".

In 1827, the English botanist Robert Brown noticed that pollen seeds suspended in water moved in an irregular "swarming" motion. Einstein then reasoned that if tiny but visible particles were suspended in a liquid, the invisible atoms in the liquid would bombard the suspended particles and cause them to jiggle. Einstein explained the motion in detail, accurately predicting the irregular, random motions of the particles, which could be directly observed under a microscope.

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When Einstein's paper first appeared in 1905, the notion of atoms and molecules was still a subject of heated scientific debate. Ernst Mach and the physical chemist Wilhelm Ostwald were among those who chose to deny their existence. They argued that the laws of thermodynamics need not be based on mechanics, which dictated the existence of invisible atoms in motion. Ostwald in particular advocated the view that thermodynamics dealt only with energy and how it is transformed in the everyday world. [He and his followers were known as "energeticists" as a result.]

However, by May 1908, Einstein had published a second paper on Brownian motion providing even more detail than his 1905 paper, and suggesting a way to test his theory experimentally. That same year, a French physicist named Jean Baptiste Perrin conducted a series of experiments that confirmed Einstein's predictions. Perrin wrote that his results "cannot leave any doubt of the rigorous exactitude of the formula proposed by Einstein," and his work later earned him his own Nobel Prize in Physics, in 1926.

Eventually the experimental evidence supporting Einstein's theory of Brownian motion became so compelling that the naysayers were forced to accept the existence of material atoms. His fundamental work on applying statistical methods to the random motions of Newtonian atoms also led to his insights into the photo electric effect, through the discovery of a critical connection between his statistical theory of heat and the behavior of electromagnetic radiation. This was the first step in his goal to unify the two fields. Thus far, the electromagnetic theory developed by James Clerk Maxwell in the late 19th century had resisted all attempts to reduce it to mechanical processes. Einstein set out to do just that.

Next month: Special Relativity

See the special exhibit on Albert Einstein's life and work by the American Institute of Physics:
http://www.aip.org/history/einstein/

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