Einstein's Theory of Brownian Motion and Diffusion

What is Brownian Motion?

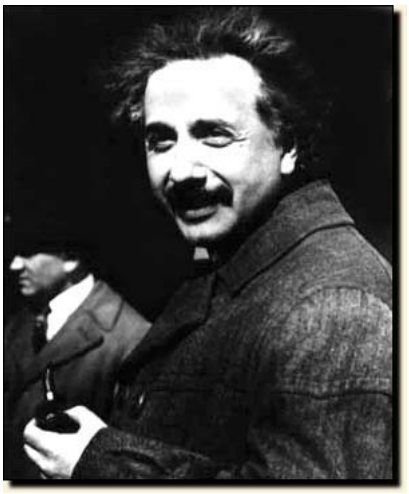
In 1827, Robert Brown, an English botanist, observed under a microscope that pollen grains in water were in a constant state of agitation. He first thought that there might be something 'alive', but proved that was not so by observing the same kind of motion in inclusions in quartz that were millions of years old. He never was able to explain the observations…

Robert Brown

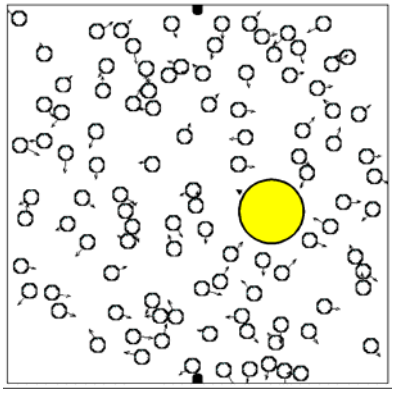
In 1905, Albert Einstein published a theory that turned out through measurements by Jean Perrin to explain Brown's observations. Here is the title and start of the paper:

On the movement of small particles suspended in a stationary liquid demanded by the molecular-kinetic theory of heat

In this paper it will be shown that, according to the molecular-kinetic theory of heat, bodies of a microscopically visible size suspended in liquids must, as a result of thermal molecular motions, perform motions of such magnitudes that they can be easily observed with a microscope. It is possible that the motions to be discussed here are identical with so-called Brownian molecular motion; however, the data available to me on the latter are so imprecise that I could not form a judgment on the question…."

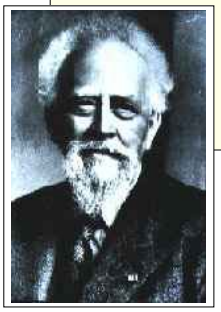


Albert Einstein

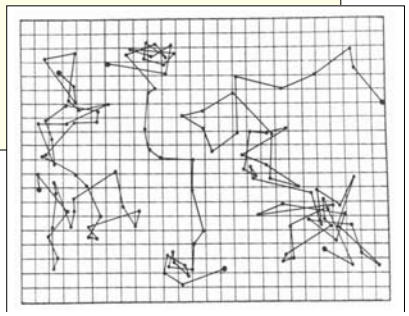


Einstein's statement that thermal molecular motions should be easily observed under a microscope stimulated **Jean Perrin** to make quantitative measurements, culminating in his book The Atoms in 1909.

"I did not believe that it was possible to study the Brownian motion with such a precision."
Letter from Albert Einstein to Jean Perrin (1909).



Jean Perrin



Drawings by Perrin of positions of a particle every 10 seconds, showing stochastic motion due to collisions with water molecules.

Einstein's explanation: The pollen grains are buffeted by collisions with molecules of water moving randomly in all directions (see figure above). Einstein's theory and Perrin's observations showed that the mean distance traveled by a pollen grain (or other microscopic object) subject to random collisions increases as the square root of time:

$$x \sim \sqrt{t}$$

unlike the relation $x \sim t$ for an object in straight-line motion.

Perrin was awarded the Nobel Prize in Physics in 1926

The Nobel Prize in Physics 1926

"for his work on the discontinuous structure of matter, and especially for his discovery of sedimentation equilibrium"

Significance: The concept of atoms and molecules became universally accepted. Perrin deduced an accurate value for Avogadro's number (the number of atoms in a mole). The theory applies to all **diffusion phenomena**: mixing of gases or liquids, atom motion in solids, spread of the black plague, spread of agriculture in Neolithic times, spread of clothing fashions, spread of africanized-bees….

Gary S. Collins, February 2005