

Rethinking Brownian motion with the 'Emperor's New Clothes'

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In the classic fairy tale, "The Emperor's New Clothes," Hans Christian Andersen uses the eyes of a child to challenge conventional wisdom and help others to see more clearly. In similar fashion, researchers at the University of Illinois have now revealed the naked truth about a classic bell-shaped curve used to describe the motion of a liquid as it diffuses through another material.

"The new findings raise fundamental questions concerning the statistical nature of the diffusion process," says Steve Granick, Founder Professor of Engineering, and professor of materials science and engineering, of chemistry, of chemical and biomolecular engineering, and of physics at the U. of I.

Diffusion is critical to processes such as drug delivery, water purification, and the normal operation of living cells. Key to the diffusion process is the manner in which the motion of one molecule affects the motion of another.

"In high school science classes, students are often assigned the task of using a microscope to watch a particle of dust sitting in a drop of water," Granick said. "The dust particle seems alive, moving back and forth, never in the same way. The motion of the dust particle is caused by the random 'kicks' of surrounding [water molecules](#)."

Called "Brownian motion" (after botanist Robert Brown, who noticed it in 1828), this phenomenon of fluids was described by [Albert Einstein](#) in

1905, when he published his statistical molecular theory of liquids.

According to Einstein, if the motions of many particles were watched, and the distance each moved in a certain time were recorded, the distribution would resemble the familiar Gaussian, bell-shaped curve used to assign grades in a science class.

Einstein had it right - almost.

"Like Einstein, we used to think we could describe Brownian motion with a standard bell-shaped curve," Granick said. "But now, with the ability to measure very small distances much more precisely than was possible 100 years ago, we have found that we can have extremes much farther than previously imagined."

In a paper to be published in the *Proceedings of the National Academy of Sciences* Online Early Edition next week, the U. of I. researchers show that Einstein's explanation, commonly cited in textbooks, fails in certain important cases.

The experiments were conducted by precisely tracking the motion of 100-nanometer colloidal beads using fluorescence microscopy.

In one series of experiments, the researchers watched as the beads moved up and down tiny tubes of lipid molecules by Brownian motion. In a second series of experiments, the researchers watched as the beads diffused through a porous membrane of entangled macromolecule filaments, again by Brownian motion.

In both sets of experiments, there were many features in full agreement with Einstein and the bell-shaped curve; but there were also features in significant disagreement. In those cases, the beads moved much farther than the common curve could predict. In those extreme displacements,

diffusion behavior was not Gaussian, the researchers report. The behavior was exponential.

"These large displacements happen less often, but when they do occur, they are much bigger than we previously thought possible," Granick said.

The new findings "change the rules of the diffusion game," Granick said. "Like the emperor's new clothes, now that we know the bell-shaped curve isn't always the right way to think about a particular problem, process, or operation, we can begin to design around it, and maybe take advantage of it. And, we can correct the textbooks."

Source: University of Illinois at Urbana-Champaign ([news](#) : [web](#))

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