Physicists track the random walks of ellipsoids, test 'lost' theory of Brownian motion

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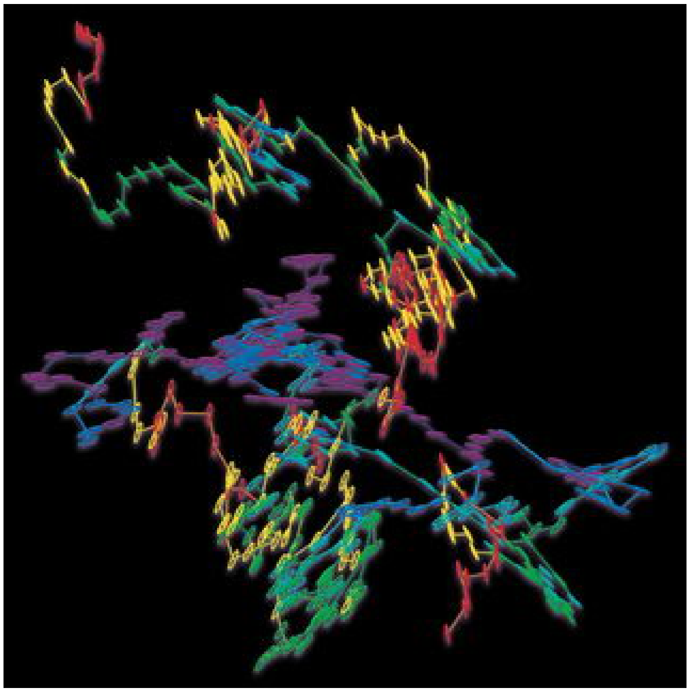

Twenty seconds of a measured random walk trajectory for a micrometer-sized ellipsoid undergoing Brownian motion in water. The ellipsoid orientation, labeled with rainbow colors, illustrates the coupling of orientation and displacement and shows clearly that the ellipsoid diffuses faster along its long axis compared to its short axis.

Research carried out at the University of Pennsylvania has definitively measured and described the Brownian motion of an isolated ellipsoidal particle, completing a path laid out by Einstein 100 years ago when he first described rotational Brownian motion for spheres in water.

Brownian motion, the tiny random movements of small objects suspended in a fluid, has served as a paradigm for concepts of randomness ranging from noise in light detectors to fluctuations in the stock market. Using digital video microscopy, the researchers directly observed the twisty "random walks" arising from the combined effects of random rotations and displacements of ellipsoids in water.

"Brownian motion arises from the aggregate effect of the random collisions of many molecules with suspended objects. It is such a profound and fundamental phenomena that, as a physicist, I want to learn everything about it," said Arjun Yodh, professor in Penn's Department of Physics and Astronomy in the School of Arts and Sciences. "Our work explored the movement of rod-like particles in order to understand how their spinning motion affects the displacement or translation of their centers."

As Einstein predicted in his 1906 paper, the rotation of spherical particles does not affect their translation. On the other hand, the rotation of non-spherical particles affects their translation, and, since most Brownian particles are not spherical, they experience cross-talk between translation and rotation.

The findings of the Penn group, reported in the journal *Science*, rediscovered ideas about rotational-translational coupling first published by French physicist Francis Perrin in the 1930s, ideas that were apparently "forgotten" by the science community. Perrin's father, Jean Perrin won the Nobel Prize in 1926 for the first experimental observations confirming Einstein's theories about Brownian motion.

"One of the exciting aspects of this work is the precise agreement between a relatively simple theory and experiments. We developed the theory at Penn but later found many of our results in the forgotten French papers by Perrin," said Tom Lubensky, professor and chair of Penn's Department of Physics and Astronomy and co-author of the *Science* paper. "Perrin's work is largely unknown today, at least in part because experiments to verify it could not be done in his time."

The Penn researchers employed state-of-art digital imaging technology and computer image analysis for their experiments. Using a charge-couple device camera, they recorded the orientations and positions of a single, micrometer-sized plastic ellipsoid particle suspended in water at a sequence of times.

The experiments confirmed the theory's curious description of how an ellipsoid's random motions are different from those of spherical particles. On average, particles undergoing Brownian motion do not move very far. For example, in one second, the largest number of particles will stay very close, say within one micron, of their starting point; a smaller number will move between one micron and two microns; a still smaller number will move between two microns and three microns, and so on. A plot of the number of particles traveling specific distances yields the famous bell-shaped or Gaussian curve from statistics. The Penn researchers found that the same experiment, carried out on ellipsoidal particles, produces a curve that is not Gaussian.

"Since ellipsoids are longer than they are wide, they experience more water resistance going in one direction than the other," said Yilong Han, a post-doc in Yodh's research group. "These effects are larger in two-dimensions than in three, and the coupling of the rotational movement -- spinning -- with the translational movement -- the distance traveled -- give rise to the weirdly non-Gaussian behavior we observed."

Source: University of Pennsylvania

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