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Ballistic motion of a Brownian particle

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interviewed make comments like "that's how science works," "this is . . . part of the structure of being scientists," and "part of this . . . is just endemic." Physicists described a desire to be open rather than secretive, but they found that the distinctions between theft and priority of discovery were ambiguous.

Competition seems to be the main driver of those ambiguous practices, according to the physicists we interviewed. They reported seeing physicists get highly competitive as funding and opportunities, especially for basic research, become scarcer. Over the past 20 years, the US has fallen from 2nd to 10th place in R&D investment as a percentage of GDP.[5] Physicists have only limited options for improving funding, but they can still control and minimize gray-area issues that result from it.

The physics community needs to establish a greater dialog on how to teach ethics to students and reaffirm ethical practices for research scientists. Creating a physics-specific curriculum for responsible conduct of research would be beneficial. Materials and case studies from the American Physical Society already exist to help with that task (see http://www.aps.org/programs/education/ethics, and the article by Kate Kirby and Frances Houle, PHYSICS TODAY, November 2004, page 42). In addition, ethics discussions about gray areas should continue in seminars and at conferences so faculty can also participate. By having greater exposure to gray-area problems and their effects, researchers and faculty members will be more likely to reevaluate their own practices in the future.

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Letters

Ballistic motion of a Brownian particle

Mark Raizen and Tongcang Li (PHYSICS TODAY, January 2015, page 56) describe a remarkable experimental observation of short-time ballistic motion for a single Brownian particle in an optical trap. Readers of their Quick Study may be surprised to learn that "the measurement Einstein deemed impossible" was accomplished nearly 25 years ago by Jixiang Zhu and coworkers,[1] for an ensemble of untrapped Brownian particles. In that case, the long-time motion is diffusive, which is the actual problem considered by Albert Einstein, instead of bounded, the situation studied by Raizen and Li. In the 1992 work by Zhu and coauthors, dynamics down to the scale of 1 Å and 25 ns were probed by a dynamic light-scattering technique in which particle motions cause infinitesimal Doppler shifts in multiply scattered light that are resolved by intensity interferometry. Zhu and coworkers were thus able to capture both motion deep inside the short-time ballistic regime and the predicted long-time tail in the crossover to diffusion.

This work contains plenty of intriguing physics. Related ballistic-to-diffusive behavior can be found in the transport of electrons in conductors, phonons in solids, and photons in opaque media. But perhaps even more prominent in physics today is the nature of an intervening subdiffusive plateau that develops for disordered liquids, colloids, bubbles, grains, and so forth that are on the verge of jamming.

For the Raizen–Li case of a single harmonically bound Brownian particle, it is possible to construct a mechanical analogue. A single centimeter-scale sphere driven stochastically in a horizontal plane by a turbulent but sub-levitating upward flow of air obeys not just equipartition and the Maxwell–Boltzmann speed distribution, but also the Langevin equation with colored noise satisfying the fluctuation–dissipation relation.[2] Therefore, the system has truly thermal behavior, but with a huge effective temperature, and the essence of Einstein's challenge is seen with the naked eye.

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■ **Raizen and Li reply:** We are aware of the excellent work by Jixiang Zhu and coauthors, which we referenced in a recent review article.[1] Zhu and his team used dynamical light scattering to measure the mean square displacement $\langle \Delta r^2(t) \rangle$ of concentrated particles at short time scales and from it determined the velocity autocorrelation function. A more recent experiment with optical tweezers reported a similar result.[2] Neither of those prior experiments could resolve the instantaneous velocity of a Brownian particle, the topic of the 1907 paper by Albert Einstein. We stand by our assertion that the experiments reported in the Quick Study are the first such measurements.

The other work mentioned by Douglas Durian (his reference 2) examined the mechanical motion of a Ping-Pong ball in turbulent airflow. The researchers observed that the ball behaved like a Brownian particle and is a beautiful simulation with a macroscopic system. The effective temperature is on the order 10^{17} K, so that clearly is not the case discussed by Einstein, in which the Brownian motion is directly caused by the thermal fluctuations of molecules at the actual temperature of the system.

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Historical note on fiber bundles

C. N. Yang, in his clear review of Maxwell's equations and gauge theory (PHYSICS TODAY, November 2014, page 45), reports that his colleague mathematician James Simons exclaimed, "[Paul] Dirac had discovered trivial and nontrivial bundles before mathematicians." Remarkably, however, in 1931, the same year that Dirac discovered his monopole, Heinz Hopf discovered its fiber-bundle equivalent, now known as the Hopf fibration of the 3-sphere.[1]

Although Eli Lubkin pointed out the bundle structure of the Dirac monopole[2] in 1963 and Tai Tsun Wu and Yang provided a widely read description,[3] Andrzej Trautman apparently first noted its identification with the Hopf fibration[4] in 1977. Trautman's 1967 lectures at King's College London introduced some physicists to the mathematical equivalence of gauge theories and fiber-bundle theory, but not until 1970 were those lectures published.[5] Yang notes that the equivalence came as a shock to both physicists and mathematicians in the 1970s.

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Correction

February 2015, page 8—The headline for the second letter should read, "Discovering the ozone hole." ■