optics & photonics focus

Brownian Speedcam

Brownian particles, mind the speedcam! It is now possible to measure the instantaneous speed of a Brownian particle. Not only are these measurements of fundamental importance for statistical physics, they also open up new perspectives for the study of quantum systems.

“Mind the speedcam if you want to avoid a fine!”. Brownian particles must have surely taken heed of this warning, since, until very recently, their speed went unrecorded! The situation has now changed thanks to the work of Mark Raizen’s group at the University of Texas at Austin.

Brownian particles are microscopic particles whose size can range from a few nanometers to several microns. They live immersed in a fluid, either a liquid or a gas, and continuously move due to random collisions with the fluid molecules, which are by far smaller than the particles. The resulting motion is known as *Brownian motion*.

In 1827, Scottish botanist Robert Brown observed under the microscope grains of pollen in water and noticed that they exhibited a jittery motion. For decades, the origin of this motion remained unknown. It was only at the beginning of the twentieth century that physicists, Albert Einstein amongst them, proposed that its origin lay in the collisions between the water molecules and the particles. This physical picture indirectly confirmed the existence of atoms and molecules.

Nowadays, the Brownian motion is of fundamental importance in many branches of science. For example, the mathematical description of the Brownian motion, known as the *Wiener process*, is used to describe mathematically all stochastic phenomena, from the behavior of stock markets to the oscillations of animal populations. As a matter of fact, Brownian particles are often referred to as model systems to address novel concepts in the study of noisy phenomena and statistical physics.

Brownian particles are constantly moving in a random, but still well defined, fashion. This is a consequence of the *equipartition theorem*, one of the fundamental theorems of statistical physics, which states that at thermodynamic equilibrium the average energy is the same for each particle and depends only on the temperature of the system. It follows, therefore, that a Brownian particle should have a very well defined speed.

Prior to the work of Raizen and colleagues it was impossible to experimentally verify this prediction because no one had been able to measure the instantaneous speed of a Brownian particle. It is a fact that the instantaneous speed of a Brownian particle changes extremely fast due to the impact with the fluid molecules. For example, the speed of a Brownian particle immersed in water can change every other nanosecond. Raizen’s experiment “really provides clear evidence and precise measurement of the instantaneous velocity of a Brownian particle,” comments Jun Ye from the National Institute of Standards and Technology and the University of Colorado.

Raizen and colleagues dealt with this problem to an extent by studying a Brownian particle suspended in a gas, rather than in a liquid. This means that the particle undergoes fewer impacts with the fluid molecules and, consequently, changes speed more slowly. However, this was not enough. It was also necessary to develop a new photodetector, capable of measuring the position of the particle as often as 75 million times per second — with a three order of magnitude improvement over previously available systems. Finally, the particle was held in an optical trap: a strongly focused laser beam that can trap a small object.

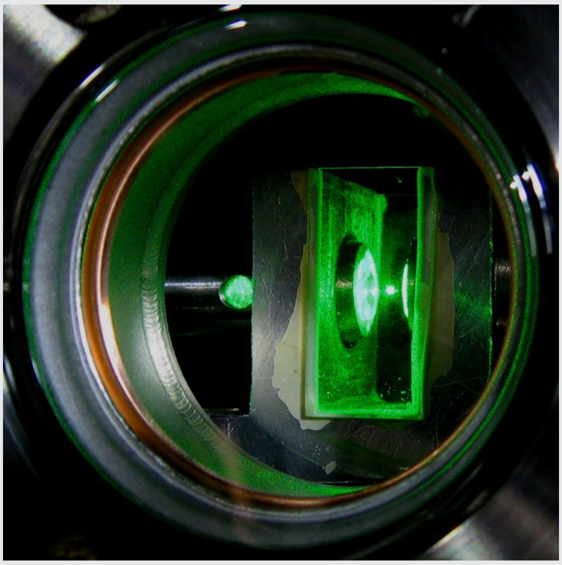

Figure 1: The optical trap and the speed of a Brownian particle. The focused green laser holds a Brownian particle. The scattering from the particle gives information about the instantaneous position of the particle and it is recorded 75 million times per second using a novel photodetector. The position increments tell show the researchers the instantaneous speed of the particle.

However, the experimental demonstration of the equipartition theorem, according to Raizen, was merely an interesting detour on their quest towards the studying of small yet *macroscopic* quantum systems. Indeed, while a *Brownian particle* is *microscopic* by everyday standards, it is indeed a *macroscopic* object compared to atoms and molecules, which are usually the subjects of quantum experiments.

Raizen's aim is to reduce the thermal motion of the optically trapped particle by implementing a feedback cycle on its measured velocity. If this can be implemented on a particle trapped in vacuum, where it would be possible to avoid any decoherence effects arising from the interaction of the particle with the gas molecules, then we might also be able to cool the optically trapped particle down to its quantum ground state.

Similar studies are currently being performed by other groups using mechanical cantilevers. However, Raizen explains that the study of the quantum properties of an optically trapped particle opens up new possibilities. For example, it would be possible to turn off the optical trap once the particle is in the quantum ground state, and to see what happens. Jun Ye agrees that "the system will be a good candidate for studying the quantum behaviors of a mechanical system, as it is isolated from a thermal environment."

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Measurement of the Instantaneous Velocity of a Brownian Particle
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