Instantaneous ballistic velocity of suspended Brownian nanocrystals measured by upconversion nanothermometry

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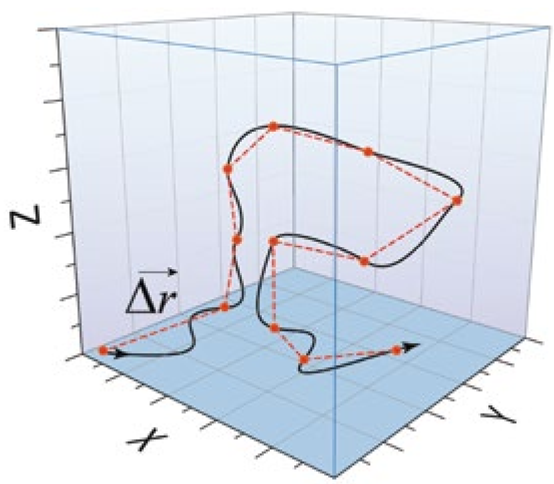
Understanding Brownian motion, the random movement of microscopic particles in liquids and gases (Figure 1), provides an intimate insight into a microscopic world and enables answering questions on how substances interact with each other at different time ranges. The conceptual implications of Brownian motion impact almost every field of science and even economics, from dissipative processes in thermodynamic systems, gene therapy in biomedical research, artificial motors and galaxy formation to the behavior of stock prices. Using conventional techniques, it has been challenging to measure Brownian motion due to the rapid and random movements of the particles at the very short time scale of 10-10 s (namely, ballistic regime). Since Brownian motion is extremely sensitive to the variation of temperature, nanothermometry (capable of monitoring thermal fluctuation at the nanoscale) is a tool that may be used for studying such motion of nanoparticles.

We demonstrated the use of upconversion nanothermometry for measuring the instantaneous ballistic velocity of nanoparticles with different sizes and shapes (Figure 2). Measuring the instantaneous Brownian velocity of these tiny particles, however, has proved to be a daunting task, as evidenced by the seminal work of Einstein in 1905. Our work has verified Einstein's prediction made in 1907 that the instantaneous Brownian velocity is independent of the particle size and shape under infinite dilution conditions. Better understanding of Brownian motion of suspended particles in non-equilibrium systems would have an invaluable impact in a wide range of scientific fields. For example, it allows improved understanding of thermal conductivity, convective heat and mass transfer in various types of nanofluids.
Upconversion nanocrystals may be dispersed in various solvents, providing a versatile platform for investigating the ballistic Brownian motion in non-equilibrium systems and related phenomena, without the stringent constraints associated with optical tweezers. The newly developed technique may be used to achieve a better understanding of fluid properties. It may also be extended into biological systems to understand the transport of molecules and cells.



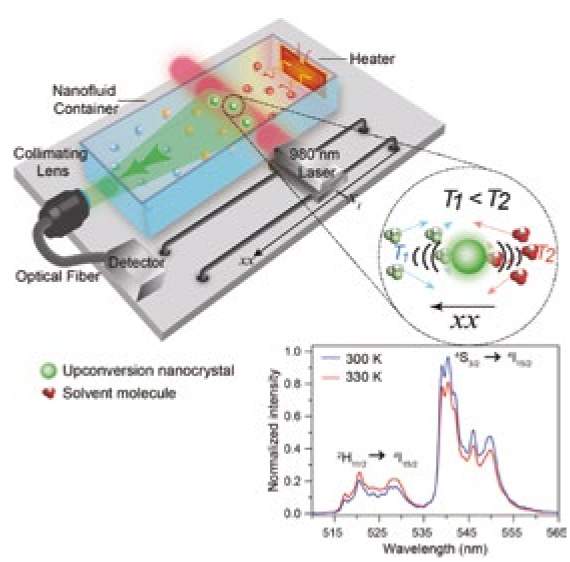


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FIGURE 1
3D trajectory of a single Brownian nanoparticle, indicating the effect of the temporal resolution on the measurement of the instantaneous velocity in the ballistic regime.

FIGURE 2
Schematic of the experimental set-up for upconversion measurements of the nanofluids. A collimating lens collects the upconversion emission generated at different positions by moving a 980-nm laser along the x direction and the signals are guided to the detector by an optical fiber. The inset shows the solvent-mixing effect arising from the Brownian motion of the nanoparticle located at the interface between the cold (T1) and hot (T2) regions of the nanofluid. The emission spectra of the water-based nanofluid under 980 nm excitation is also presented for 300 and 330 K.