université de BORDEAUX

LOMA UMR5798 Laboratoire Ondes et Matière d'Aquitaine

Master 2 Internship

Brownian Motion at Extreme Scales

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In LOMA (Laboratoire Ondes et Matière dôAquitaine) we created a consortium of researchers for investigating the Brownian Motion of nano- or micro-particles in various set of fronts:

A- Brownian Motion at short time scales,
B- Glass phase transition in confinement of an optically trapped glassy particle,
C- Levitating ultra-sensitive sensor controlled by the laser light.

The pioneering works of Arthur Ashkin (2018 Nobel Prize), in the 1970s through to the mid-1980s, on the optical control and manipulation of dielectric particles have led to major advances in cold atomic physics and biophysics.[1] By tightly focusing a laser beam, he showed how to trap a particle in liquid or how to levitate a particle in vacuum with the scattering optical force (i.e. radiation pressure force).

A- Einstein thought that no one could ever be able to measure the (hydrodynamic) instantaneous velocity of a Brownian particle, this has however been realized in liquid and gas environments with an optically tweezed particle.[2] These investigations have revealed the transition between the diffusive and the ballistic regime. Our goal is to understand the Brownian motion at shorter time scales and with better spatial resolutions, where water compressibility is probed by the trapped particle. For instance, a Brownian particle of 9 µm necessitates a temporal resolution better than 3 ns and a spatial resolution of 1 am/Hz$^{1/2}$. Several methods are envisaged to reach this goal. One of them is to adapt our femtosecond pump-probe spectroscopic set-up. Another alternative is based on the scattered light by the particle measured by cross-correlation with avalanche photodiodes with time resolution of 4 ps. Our approach should allow observing the impact of compressibility of water on Brownian motion at short time scale and going far further than state of the art experiment limitations. Finally, this proposal could be a starting point for investigations of other non-equilibrium physics phenomena at the nanoscale. The development of experimental devices, if successful, could lead to technical valuations.

Notably, it is only recently that the gradient force has been used to trap dielectric particles in vacuum (B, C).[2] Since then, many theoretical propositions have emerged and are related to ultra-weak force sensing and tests of quantum mechanics foundations.[3]

B- We propose to study the unresolved problem of vitreous phase transition. According to Philip W. Anderson (1977 Nobel Prize), the deepest and most interesting problem in condensed matter physics is probably the glassy transition. Indeed, vitreous materials are ubiquitous in nature, and the glass transition discussions involve many areas of physics and are of great importance in the industry. Despite the intense interest in the slowing dynamic that accompanies the formation of a glass, a complete microscopic theory does not exist yet. Recently, the supposed existence of a characteristic length scale for cooperative rearrangement has attracted considerable interest in an alternative approach: the study of confined glass. The correlation length scales emerging in these systems appear to be much larger than molecular sizes, which greatly intrigues the community. Interestingly, one of us predicted the existence of a critical radius of 10 nm for polystyrene below which the nanoparticle will remain in a liquid state at all temperatures. We propose to tackle the problem of glass transition by studying the behavior of optically trapped glass particles (silica or polystyrene) in vacuum.

C- The emerging field of levitating optomechanics focuses on mesoscopic systems that are extremely well isolated from the environment and therefore offers unique tools for testing fundamental theories of physics and for developing next generation of versatile platforms that support sensor detection technologies. All these ingredients will help to reach the fundamental sensitivity regime of the quantum oscillator and to approach sensitivity in force of the order of zeptoNewton. We also aim to study the possibility of using our system as an inertial sensor (gravimeter). The levitation of more massive particle (micrometer) and the use of low-stiffness optical trap improve the sensitivity to an applied force. For the measurement of an ultra-weak external force, we plan to use optical feedback on the power of the trapping laser beam to cool the center-of-mass motion of

[1] A. Ashkin, Optical Trapping and Manipulation of Neutral Particles Using Lasers, World Scientific Publishing (2006).
[2] T. Li *et al*., Science **328** (2010) 1673 ; R. Huang *et al*., Nature Physics **7** (2011) 576.
[3] J. Bateman *et al*., Nat. Commun. **5** (2014) 4788 ; D. Moore *et al*., Phys. Rev. Lett. **113** (2014) 251801.

particle. The measurement of feedback gain making it possible to bring the particle back to the bottom of potential well under the action of the destabilizing external force constitutes a direct and real-time measurement of this same external force.

According to its affinity the student chooses one of the presented topics, the candidate may however participate to the other projects in reason of their overlapping in terms of concepts and instrumentation.

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