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Analysis of hydrodynamic interactions of single particles by the use of optical tweezers.

Ever since humanity discovered the microscope, people where fascinated with the complexity and dynamics of the small world that seems to coexist with what they normally see around them. As the technology evolved, microscopes became much more sophisticated, possible magnifications became much higher with the development of new technics (such as fluorescent microscopy, electron microscopy, atomic force microscopy). As people are able to look deeper in to the surrounding matter, the micro- and nano world they see exhibits more and more phenomena that don't exist in the macro everyday world. One of the first discovered differences was the random movement of small objects in fluid, now called Brownian motion after name of Robert Brown, the botanists who first observed this phenomenon. Later Albert Einstein has shown that observed behavior of small particles is due the thermal motion of bombarding them molecules, giving clear evidence that atoms and molecules really exist. His formula describing stochastic movement of ideal sphere suspended in viscous fluid works perfectly up to now. But since we are able to look deeper into the matter, we may find differences between theoretical calculations and experimental measurements. This happens because nanoscale particles are usually far from being ideal, smooth spheres with well-defined geometry. In addition they interact with surrounding fluid, ions and other molecules create specific layers on their surface. Depending on the kind of ions and their concentration in the fluid, the thickness of such additional layer can be of the order of nanoparticle radius, changing friction parameters responsible for damping stochastic motion of observed particles. This is especially evident in complex fluids which are typical for biological systems such as cellular interior. It is worth to underline that at such scales diffusion, hence thermal fluctuations, are the only mechanisms available to transport selected molecules responsible for keeping biological matter alive. Hence, its proper description is vital for all biomolecular models.

Recent advances of high speed electronics permits to look with higher precision on the thermal motion of particles. It was found that at short time and space scales colloids motion is no longer random but becomes ballistic, hence their diffusion no longer obey Einstein’s equation. Now, as it often happened in the history of science, the current theoretical models have to be validated and calibrated in order to accurately described phenomena that govern single, nanosized colloidal particles suspended in a fluid. Fortunately, technology keeps up with the demand for newer and even more precise equipment that allows us to have deeper look in to the nano-world of fluid mechanics. A device called Optical Tweezers can trap and manipulate micrometer and smaller sized objects using the power of focused laser light. Beam of laser light is capable of either inducing or sensing the movement of the object with great precision, sometimes reaching a fraction of an angstrom resolution (that is a fraction of a hydrogen atom diameter!). As a nanomanipulator, optical tweezers are the only device capable of applying (or measuring) forces in the femtonewton range.

The purpose of this project is to explore the mechanisms of interactions of single colloidal micro and nanoparticles suspended in a fluid using new tools available now. This will be done using a recently constructed, at IPPT PAN, Optical Tweezers coupled with the Atomic Force Microscope (OT/AFM). This device allows us to preform measurements of both movement and forces with great precision and resolution and thanks to the AFM module we can accurately define the structure of the particle that is used in the experiment. This equipment will be used to evaluate effects of different ions interacting with particles. Both the type of ion and its concentration in the fluid will be changed in order to obtain comprehensive results. Since Optical Tweezers allow to measure forces acting on a single particle, the interactions between two colloids will also be measured again in different solutions of ions in the fluid. The measurements of a particle near flat wall will be done in a very similar way, additionally the walls surface will be modified to make it either hydrophobic of hydrophilic. The hypothesis of nanoscale slip flow at the fluid-solid boundary will be verified.

Another advantage of Optical Tweezers in favor of other instruments, yet still very rarely exploited, is that it can also preform measurements with great temporal resolutions, reaching the ranges of tens of nanoseconds. By preforming measurements of single particle motion with very high acquisition rates we will be able to measure its displacements in the ballistic regime. This is important in order to address the problem of calibrating and validating theoretical models used in molecular dynamics simulations. Those, kind of simulations are able to predict the behavior of a system on an atomic level, but due to the enormous amount of needed computations, the usual time scales of them are only in the range of picoseconds. It makes comparison with typical experimental data questionable. Thanks to high temporal resolution of the Optical Trap we will be able to deliver data at time scales comparable with that of molecular dynamics, permitting direct validation of simulation results.