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BOOK OF ABSTRACTS

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New experimental tools in microfluidics

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Abstract: Contemporary experiment in fluid mechanics evidently moves from large scale problems to micro or even nanoscale phenomena, to accomplish our desire to elucidate mechanisms driving living nature. Experiments at such scales found new exciting approaches, some of them touching molecular limits, where assumption of continuous and deterministic description becomes questionable. At short time and length scales diffusion governed by Brownian motion becomes the most efficient transport mechanism. Whereas its analysis is apparently simple in case of ideal spherical objects, understanding complex behavior of long, deformable objects is far from being complete. Examples of experimental techniques allowing us to monitor and control behavior of single micro objects conveyed by flow will be given.

1. Introduction

It is generally understood, that the main difference between macro- and nano-scale mechanics originates from rapidly increasing surface to volume ratio along with the decreasing of object size. The fluid phenomena that dominate liquids at this length scale are measurably different from those that dominate at the macroscale [1]. Some experimental examples we may gain observing the mother nature, some of them has been recently proposed using completely new for fluid mechanics techniques, like fluorescent microscopy, atomic force microscopy, and optical tweezers.

Most of microfluidic problems concern multiphase flow, suspensions of micro and nanoparticles, cells or macromolecules (proteins, DNA, etc). Understanding and properly interpreting fluid-particle interaction is crucial for interrogating such systems [2]. One of the basic optical tools is based on Brownian motion. The local and bulk mechanical properties of a complex fluid can be obtained by analyzing thermal fluctuations of probe particles embedded within it.

Thermal fluctuations generated by molecules are not only noises, it has been demonstrated that such fluctuations are fundamental to the function of biological systems. Preferential binding of ligands to one of the spontaneously fluctuating structures of proteins leads to activation or deactivation. This mechanism appears essential for a long scale evolutionary development of leaving species, and at short time scale to create signaling paths for early immune response of individual cells. Hence, looking at the “bottom” of our fluid mechanics, there is no place for steady, unique and predictable modelling. Rather, by analogy to quantum mechanics, we have to talk about the most probably evolution of the analyzed system. As an illustration of the difficulties, in the following we cope with two intriguing problems, kinematic boundary conditions in micro and nano scales flow, and mobility of nano-objects suspended in liquids.

New experimental tools largely help in understanding transport phenomena at nanoscales. In the presentation we give few examples of problems appealing for new theoretical and numerical models embracing continuous flow modelling with molecular scale phenomena.

2. Slip velocity

The physics of hydrodynamic slip may have different origins. Purely molecular slip is clearly relevant in case of gases and relatively easy to demonstrate there. Its observation in liquids became challenging. Classical microscopy used for nanoscale observation has resolution

limited by the light wavelength of about 500 nm micrometers. Evaluating diffraction disks the measured position of particle coordinates in plane perpendicular to the optical axis can be improved by order of magnitude. However, resolution in depth, along optical axis, remains very low (tenths of micrometer), and is defined solely by focal depth of the microscope lens. Total Internal Reflection Microscopy (TIRF) helps to bypass some of these limitations offering possibility to locate objects position with resolution of about 20 nm. Laser light illuminating object undergoes total internal reflection at an interface between investigated medium (liquid) and the wall (glass), and part of the light penetrates into the medium parallel to the interface with an intensity that decays exponentially with the normal distance from the interface. This evanescent wave illumination has been used extensively in the life sciences. Recently it was rediscovered in microfluidics for near wall flow measurements. The main advantage of the method is possibility to reduce the depth of focus of the acquisition system [3]. Hence, it became possible to obtain images of particles, which are in the direct vicinity of the wall. In our recent study of the Brownian motion of fluorescent particles observed close to the wall, the deviation of the particle diffusion rate has been interpreted as an evidence of the hydrodynamic slip.

3. Tackling particle in flow

Detailed experimental analysis of interactions of individual particle conveyed in flow is very difficult. Recently, a new optical tool, so called Optical Tweezers (OT) expanded our traditional instrumentation creating possibility for undisturbed measurements of forces and position for suspended micro particles in picoNewton and nanometer scales. Dragging, towing single particle allows to perform precise analysis of forces involved by liquid environment, wall interactions, and particle-particle interactions. One of the fundamental problems of single particle mobility, namely ballistic regime and effects of inertia creating time dependent recirculation of surrounding liquid molecules, could be proven using OT. Electronic way of signal analysis allows for thermal motion of particle trapped by OT to be evaluated with MHz sampling frequency and displacements below 1 nanometer. In our preliminary study OT developed at IPPT have been used to analyze Brownian motion of trapped polystyrene particle [4]. It appears that already at sampling times of 10 kHz diffusion becomes influenced by ballistic regime of molecular interactions.

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