

Optical trapping of objects is among the most exciting applications of a laser. Started by Arthur Ashkin in 1970s it brought manifold of intriguing discoveries in physics, chemistry and biology. Among the most exciting applications in physics one can point out the laser induced cooling and realization of Bose-Einstein condensation in atomic vapors (Nobel prize in 1997 for Stephen Chu, Claude Cohen-Tannoudji and William Daniel Phillips). In chemistry and biology one can mention a single molecule force spectroscopy, with studies of a single DNA being the one of the most recognizable achievements.

More than 30 years after realization of the first optical tweezers there are still a lot of exciting effects and basic studies realized today. The nonequilibrium thermodynamics and Brownian motion of single particle trapped with highly intense laser light is not fully described and its understanding may potentially lead to very interesting new discoveries such as microscopic engines with efficiency higher than the Carnot engine. In standard optical tweezers a single Gaussian laser beam is used to trap and manipulate objects. The degree of control of optical forces can be greatly increased by controlling both the key parameters of the beam and the particles. The alignment and light induced motion of a particle can be better controlled in an optical trap when beam shape, phase or polarization are not trivial, e.g. using cylindrical vector beams known also as structured light. Three dimensional vector structure of an optical field can carry momentum, spin and orbital angular momentum which might be transferred from light to the trapped object.

One of the objectives of the project is to push forward our understanding of the Brownian motion of particle, when its temperature differs significantly from the temperature of the surrounding medium. This will be modeled using numerical methods allowing for simulations of random effects, such as Monte Carlo method for stochastic motion simulations. The main contribution of the research into this topic will be simultaneous measurement of forces acting on the particle in optical trap, its Brownian motion frequency and its temperature. The temperature measurements in nanoscale is a nontrivial task. In this project nanoparticles doped with rare earth ions will be used to achieve this goal. The color of light emitted from some of rare earth ions (luminescence spectra) depends on its temperature, this effect allows for very accurate measurements of the nanoparticle temperature in a wide range. Proper understanding of the nanoparticle Brownian motion in nonequilibrium state and experimental realization of the temperature measurement may in future allow for mapping of local properties of cytoplasm inside living cell, what is crucial for understanding of the cell aging process or development of diseases, such as an Alzheimer's disease.

Another aim of the project is to align or spin trapped nanoparticles in any desired direction. This will be realized by focusing light beam of special structure of its intensity, polarization and phase, so called vector beams. Focused vector beams are known to create very complicated electromagnetic field, e.g Möbius strips-like. The nanoparticle motion in appropriately design potential energy landscape might be very complicated. In theory focusing of vector beams may allow for rotation of the trapped particle in any possible direction, but experimental realization of this task require careful preparation of the beam and very good focusing. Manipulation of the particle in the real time requires also fast sequential changes of the vector beam.

The project connects statistical physics with the most advanced measurements of temperature in nanoscale, nontrivial distribution of electromagnetic field, and spin-orbit angular momentum coupling. The results will enrich human knowledge about the thermal nonequilibrium, stochastic motion and light matter interaction in nanoscale. They will also allow for future progress of basic science realization of particle motion in nontrivial nanoscopic potential energy landscape, with possible scaling into cosmologic problems and general relativistic theory. The development of technical method of the single nanoparticle optical trapping and simultaneous temperature measurement may find technological application in local mapping of hydro- and thermos-dynamic properties in nanoscale.