Frontiers of Quantum and Mesoscopic Thermodynamics (FQMT'15)

27 July (Monday) – 1 August (Saturday) 2015, Prague, Czech Republic

http://fqmt.fzu.cz/15/

Topics

- Foundations of quantum physics
- Quantum measurement, entanglement and coherence
- Quantum optics
- Quantum many body physics
- Non-equilibrium statistical physics
- Quantum thermodynamics
- Dissipation, dephasing, noise and decoherence
- Macroscopic quantum behavior, e.g. cold atoms, Bose-Einstein condensates
- Topological states of quantum matter and quantum phase transitions
- Physics of quantum computing and information
- Mesoscopic, nano-electromechanical and nano-optical systems
- Biological systems, molecular motors and quantum biology
- Cosmology, gravitation and astrophysics

Scientific Background

Recent progress in technologies has led to enormous improvements of measurement and observation techniques, both at microscopic as well as macroscopic scales, which allow us to measure many characteristics and observe many features of various systems. These include not only very small artificial structures, but also structures occurring in living cells, as for example complex molecules, proteins and molecular motors. At the same time, nanoscale technologies enable the preparation of well-defined artificial structures composed of atoms (molecules) in the number range of between several and hundreds and to create enormous diversity of systems with well-defined inner parameters and external fields which can influence them. They can be studied by methods of condensed matter physics and quantum optics in details to observe the quantum phenomena in order to obtain a deeper understanding of quantum physics, as represented by quantum interference phenomena, entanglement, the uncertainty principle, non-locality and quantum measurement.

All these developments have brought new questions and challenges for the understanding the behavior of various systems and structures, both of natural and of artificial origin. They have also opened a vast arena for better tests of foundations of theories, hypothesis, and models, which are being used to improve our understanding of the world around us.

In this situation, it is advantageous to discuss experiences from different fields of physics which are studying various aspects of microscopic and macroscopic systems, both from the point of view of theory and experiments, in order to design new possible tests leading to better understanding of foundations. The FQMT15 conference will be focused on foundations of quantum physics, quantum many body physics, and non-equilibrium statistical physics. As for systems which enable the study of these foundations, the conference will deal mainly with mesoscopic systems.

There are several good reasons for using mesoscopic systems to improve our understanding of foundations. Various systems can exhibit mesoscopic features depending on inner parameters of these systems and interactions with their environment. Typical mesoscopic systems can be of nanoscale size composed from atoms (molecules). In addition, e.g., nuclear matter itself can exhibit mesoscopic behavior. Due to their position between the macro and micro world, these systems exhibit many surprising phenomena which can lead to a better understanding of quantum mechanics, many-body physics, and the relation between the classical and quantum behavior by sensitive choice of parameters.

The understanding of mesoscopic systems is a challenging task by itself, due to their complexity, diversity, and the fact that these systems are on the borderline between different disciplines (i.e., physics, chemistry, and biology) where the diverse dynamic behavior of these systems and corresponding various methods of their description (individual and statistical, microscopic and macroscopic, classical and quantum) meet. These (often open) systems are commonly dominated by quantum effects, by topology of their structures and states, and by strong interactions with their environment. They are often experimentally investigated via quantum optical and transport phenomena, or their performance is based upon quantum effects, including quantum coherence, entanglement and tunneling. The development of theoretical concepts for their description and reliable experimental methods is of great importance for investigating these systems, testing theories and designing new nanostructures with well defined, desired behavior.
The conference will deal mainly with phenomena which are observed in structures and materials such as carbon allotropes (e.g., graphene and carbon nanotubes), quantum wires and dots, microcavities, single molecule nanomagnets, various structures in living cells, as well as specific arrangements featuring cold atoms which can exhibit macroscopic quantum effects and which can be used for testing methods of quantum many-body theory. In addition systems exhibiting topological states of quantum matter will be discussed.

A good understanding of the time evolution of quantum systems is essential for an explanation of many experiments pertaining to mesoscopic systems. They must be often treated as non-equilibrium, open systems in which their behavior is influenced not only by their inner parameters, but also by properties of their environment and time dependent external fields. The theory of non-equilibrium behavior of quantum many-body systems is, however, far from complete. There are lasting and extremely important problems related to modern technologies, including questions of irreversible behavior of real systems in comparison with reversible microscopic laws, emergence of classical macroscopic behavior from microscopic quantum behavior and macroscopic quantum systems, limits to “phenomenological” thermodynamic descriptions, and the problem of how to describe properly open quantum systems far from equilibrium, especially in the case of strong interaction between a small system and reservoirs.

The conference program will consider experimental as well as theoretical studies of transport and optical properties, including both short as well as long time dynamics and steady state transport. Due to possible abrupt changes of system dynamics caused either by sudden changes of external fields or by quick switches ("quantum quenches"), it is also important to discuss the influence of the initial conditions on the dynamics of non-equilibrium quantum systems. Time evolution of quantum systems and accompanied decoherence processes are also strongly related to the many body interactions in systems. The conference program will include discussions of the latest development in the competitive, and at the same time complementary, approaches used for the description of many body systems out of equilibrium, as represented by various density matrix methods, non-equilibrium Green's function (NGF) methods, time dependent density functional (TDDFT), dynamical mean field theory (DMFT) or time dependent density matrix renormalization group theory (DMRG).

Another challenging problem related to the conference program is stochastic behavior of systems caused either by innate features of the systems or by noise related to the fact that the studied systems are open. Quantum and temperature fluctuations, as well as quantum noise, dephasing and dissipation will create an essential part of the conference contributions. Recently, various versions of non-equilibrium fluctuation and fluctuation-dissipation theorems for quantum systems have been discussed. The conference aims at supporting investigations in this direction in order to improve our understanding of these theorems, their use and relations between their various versions for classical and quantum systems. These studies are of key importance since the fluctuations, dissipation and noise are closely related to the performance and the reliability of both artificially created nano-devices as well as natural "engines", as are for example molecular motors in cells.

Stochastic behavior of small (nanoscopic) systems is also related to Brownian motion and the physics of molecular motors. This theme brings us to the vast field of biophysics. Non-equilibrium processes and the system's environment play a decisive role in the behavior of small structures of living organisms and there are many important questions to be answered before we fully understand the laws which govern the performance of the nanoscopic structures which are essential for life. In this regard, it appears one of the necessary conditions for the proper performance of cells is that their dynamics be based on far from equilibrium states and related nonlinear non-equilibrium transport. After some break, there are again also extensive discussions about the role of quantum physics in the behavior of various small systems which are essential for living organisms. This opens the question under which circumstances quantum effects, coherence, fluctuations and noise have positive or negative influence on a cell's performance. Therefore, the conference will pay also a special attention to quantum biology, which is now a re-emerging field dealing with quantum aspects of biological systems.

All the above questions are important not only for an understanding of living organisms, but also for studies of artificially prepared structures which are motivated by nanobiology. In this regard, biomimetics is a quickly developing area of research, which is closely related to the FQMT'15 program.

Performance of molecular motors and the field of biomimetics are associated with more general considerations related to thermodynamics and the use of various mesoscopic structures. Among the central themes of classical thermodynamics are the concepts of "temperature", "system", “reservoir”, and “engine”. Due to quantum features of mesoscopic systems, it is necessary to deal with quantum thermodynamics to discuss possible quantum heat engines based on features of mesoscopic (molecular) systems. The task of quantum thermodynamics is to provide a good “phenomenological” frame for the “macroscopic” description of open mesoscopic systems coming from more detailed studies of non-equilibrium quantum statistical physics of open systems and the foundations of quantum mechanics. The central question which will also be discussed during the conference is under which conditions the thermodynamic behavior still manifests in various small systems.

In general, the above problems are related to questions of the description of dissipation, dephasing and decoherence processes, and, on a very basic level, to the foundations of quantum mechanics and related theories of quantum measurement. A better knowledge and insight into the foundations of quantum physics is essential for a proper formulation of the fundamental laws of physics with regard to Bell inequalities and quantum gravity. It is also essential for developing a suitable description of small quantum systems and their applications. This applies particularly to quantum optics investigations and physics of quantum computing, where questions of quantum interference, entanglement and decoherence processes, together with knowledge of time scales governing the dynamics of the studied systems, are essential and mutually beneficial. This can be well documented by various examples from the physics of quantum computing, information and metrology and the physics of cold atoms. An important part of the conference program will be devoted to discussions of the physics of all the above mentioned systems.

Further included in the conference program are the fields of cosmology, gravitation and astro-particle physics, for the reason that these areas of investigation are strongly related to the foundations of quantum physics, physics of quantum measurement, macroscopic quantum phenomena (e.g., magnetization) and also, mainly due to measurement methods used for observation and detection, to quantum optics, condensed matter physics, and physics of mesoscopic systems.