

Frontiers of Quantum and Mesoscopic Thermodynamics (FQMT'11)

25 July (Monday) – 30 July (Saturday) 2011, Prague, Czech Republic

<http://conferences.fzu.cz/fqmt/11/>

Topics

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

Detailed Scientific Background and Comments

Recent progress in nanoscale technologies enables the preparation of well defined artificial structures composed of atoms (molecules) in the number range of between several and hundreds and to measure many characteristics of such systems of nanoscale size. At the same time, advances of measurement techniques open the possibility to investigate not only these artificial structures, but also structures of similar nanoscale size occurring in nature, as for example complex molecules, molecular motors in living cells, proteins and viruses.

There is thus a growing demand for an understanding of the laws which govern the behavior of these systems. The development of theoretical concepts for their description and reliable experimental methods is of great importance for investigating these systems and designing new nanostructures with well defined, desired behavior.

Depending on conditions, nanoscale (i.e., nanoscopic or microscopic) systems can demonstrate characteristics of mesoscopic systems. As the name suggests, mesoscopic systems are, by their observed properties, on the borderline between the macro and micro world: contrary to macroscopic systems, fluctuations around average values can play an essential role in their behavior, but similarly to macroscopic systems, which are governed by the laws of classical

mechanics, the behavior of mesoscopic systems is generally determined by large numbers of particles, wherein individuality of particles does not play an important role. Mesoscopic systems have, however, one common characteristic with microscopic systems: their behavior demonstrates quantum mechanical features and their description does not lie within classical physics. Due to their position between the macro and micro world, mesoscopic systems exhibit many surprising phenomena which can lead not only to novel devices, but also to a better understanding of quantum mechanics and the relation between the classical and quantum behavior by sensitive choice of parameters of the studied mesoscopic systems.

An understanding of mesoscopic systems, however, is far from being complete. To find laws governing these systems is a challenging task, due to the complexity of these systems, their 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.

A good understanding of the time evolution of quantum systems, both on the short and long time scale, 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 (e.g., electric and magnetic) time dependent external fields. The theory of non-equilibrium behavior of quantum systems is, however, also far from being 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 (such as Bose-Einstein condensates), limits to “phenomenological” thermodynamic descriptions, and the problem of how to describe properly open quantum systems far from equilibrium (as for example a system under the influence of strong time dependent laser pulses), especially in the case of strong interaction between a small system and reservoirs (contact baths). The conference program will consider experimental as well as theoretical studies of transport and optical properties, including both short time (transient) 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, especially where it is desired to measure and explain short time (transient) behavior.

Time evolution of mesoscopic systems and accompanied decoherence processes are also strongly related to the many body interactions in systems. The strong correlations in systems are, however, far from being understood even in equilibrium. Apart from the properties determined by (electron) charges, spin dynamics of nanoscale systems are also interesting to study, both in terms of basic research and possible applications. 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 (including use of renormalization group), non-equilibrium Green’s function (NGF) methods, and time dependent density functional (TDDFT) or dynamical mean field theory (DMFT).

Another challenging problem related to the conference program is stochastic behavior of quantum 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 in mesoscopic systems, will create an essential part of the conference contributions. Recently, various versions of non-equilibrium 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. Additional important themes of the conference program include: full counting statistics methods based on density matrix as well as non-equilibrium Green's function approaches and especially their use for fluctuations of electron current, systems with strong electron-phonon coupling, spin fluctuations and related dynamics. These studies are of key importance since the fluctuations and noise (in general in a state out of equilibrium) 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 systems is also related to Brownian motion and the physics of molecular motors. This theme brings us to the vast field of biophysics: various versions of molecular motors play an important role in the cells and tissues of living organisms. Again, non-equilibrium processes and the system's environment, together with related dissipation, play a decisive role in the behavior of small (nanoscopic) 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. There are also extensive discussions about the role of quantum physics in the behavior of various nanoscopic systems which are essential for living organisms. For example, there are studies about the role of quantum coherence in photosynthesis. Another phenomenon which can play an important role in living organism is the so-called stochastic resonance, which, perhaps, helps to improve the performance of certain parts of living cells. This opens the question under which circumstances fluctuations and noise, quantum effects, and coherence have positive or negative influence on a cell's performance. 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, and in this regard biomimetics is a quickly developing area of research. Moreover, recently there have been a number of studies related to the possible use of biological molecules and systems for various purposes. Well known are, for example, the recent investigations of various properties of the DNA molecule in relation to data processing and storage.

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 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 (such as well defined temperature) still manifests in various mesoscopic (open) 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. As already indicated, the “best” systems to measure and investigate these problems and questions are mesoscopic systems. Nowadays, various systems of nanoscale size are studied by methods of condensed matter physics and quantum optics, using suitable samples with well defined parameters, to observe the behavior of quantum systems in order to obtain a deeper understanding of quantum physics, as represented by quantum interference phenomena, decoherence processes, entanglement, the uncertainty principle, non-locality and 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, together with a vast number of studies dealing with Bose-Einstein condensation in various systems. An important part of the conference program will be devoted to discussions of the physics of all the above mentioned systems.

Another promising contribution to advance the understanding of mesoscopic systems, and at the same time the foundation of quantum physics, comes from a combination of electron transport and mechanical degrees of freedom in so-called nano-electro-mechanical systems (NEMS), and a combination with light in the case of opto-mechanical systems. These systems not only provide interesting data, they also introduce possibilities of how to measure and investigate other small systems of various origins. Recent progress in technologies and methods of cooling now even allow for investigations which measure directly the transition between classical and quantum behavior of small mechanical oscillators.

Further included in the conference program are the fields of cosmology, gravitation and astroparticle 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.

To summarize, the conference will deal mainly with mesoscopic systems and phenomena which are observed in various 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

various macroscopic quantum effects, such as Bose-Einstein condensation. These finite size open systems are commonly dominated by quantum effects and by strong interactions with their environment. They are often experimentally investigated via, or their performance is based upon, quantum phenomena, including for example decoherence, tunneling or entanglement, optical, transient and transport phenomena. Therefore, an understanding of the foundations of quantum physics and development of a reliable non-equilibrium fully quantum statistical theory are needed for their description. The purpose of the conference is to discuss all the above aspects of mesoscopic systems and to address related fundamental problems which are encountered on the way to understanding the physics of these systems.