Frontiers of Quantum and Mesoscopic Thermodynamics 2026 - FQMT'26

26 July – 1 August 2026, Prague, Czech Republic

https://fqmt.fzu.cz/26/

Scientific Background

The FQMT'26 program will be focused on conceptual and experimental challenges of non-equilibrium statistical physics, quantum thermodynamics, foundations of quantum mechanics, quantum field theory, metrology, physics of fundamental constants, physics of gravitation, quantum many body physics, quantum optics, physics of quantum information, and biophysics.

Recent advances in technologies have led to an enormous boost in the possibility of creating new, well-defined structures. At the same time, measurements, sensors, imaging and other observation techniques at microscopic, mesoscopic and macroscopic scales have enabled us to measure or observe both natural and artificial structures at various space scales.

With the increasing refinement and use of quantum sensors and simulators, these advances have also opened the way to a deeper understanding of complex quantum phenomena and the related foundations of quantum physics and information.

In addition, various methods allow us to investigate not only equilibrium features of complex many body systems, but also time evolution of these systems (which are in general far from equilibrium) at different time scales. This increasing ability to study subtle details of the dynamics of systems yields new versions of old questions and creates new challenges in many fields of physics.

At the FQMT'26, special attention will be paid, for several reasons, to mesoscopic systems. Various systems, of natural and artificial origin, can exhibit mesoscopic features depending on inherent inner parameters and interactions with their environment. Typical mesoscopic systems are of nanometer size, enabling fast developing nanoscale technologies for the preparation of structures with well-defined inner parameters, providing an enormous diversity of systems subject to interaction with the external environment. Nanoscale structures include not only very small artificially prepared structures, but also structures occurring in living cells, as for example complex molecules, proteins and molecular motors. Such systems lie on the border between different disciplines where the 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. 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 classical and quantum behaviors by sensitive choice of parameters.

A good understanding of the time evolution of both classical and quantum systems is essential for an explanation of many observations and experiments of contemporary physics. Observed systems must often be 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. Important problems include such questions as irreversible behavior of real systems in comparison with reversible microscopic laws, emergence of classical macroscopic behavior from microscopic quantum behavior, charge (electron), spin and heat transport, limits to "phenomenological" thermodynamic descriptions, and the problem of how to properly describe open quantum systems far from equilibrium, especially in the case of strong interaction between a small system and reservoirs. Various versions of classical as well as quantum fluctuation and fluctuation-dissipation theorems can play an important role in these developments.

Non-equilibrium processes and the system's environment also play a decisive role in living organisms and there are many questions to be answered before we fully understand the laws which govern the performance of the structures 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. It is thus vital to work on a better understanding of active matter physics. There are also questions about the role of quantum physics in the behavior of various systems which are essential for living organisms, i.e., under which circumstances quantum effects, coherence, fluctuations, and noise can influence a cell's functions.

For quickly developing areas of neurosciences, biology of living cells and immunology the understanding of physics of neural and immunological networks as well as their parts, neural and immunological synapses, is vital. This is complemented by studies of artificial neural networks structures, cerebral organoids and detailed simulations of their behavior. All these interrelated issues are moreover related to the physics of information and the field of artificial intelligence.

Another challenging problem is stochastic behavior of considered systems caused either by their innate features of the systems or by noise related to the studied systems being open. Studies of temperature and quantum fluctuations, as well as quantum noise, dephasing and dissipation are of key importance, since these phenomena are closely related to the performance and the reliability of both artificially created nano-devices and "nano-engines" as well as natural "engines", as are for example molecular motors and processes in cells in general. Behavior of molecular motors is 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 pumps, heat engines or refrigerators 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.

In general, the above problems arise in dissipation, dephasing and decoherence processes, and, on a very basic level, 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. It is also essential for developing a suitable description of small quantum systems and their applications. This applies particularly to studies of light-matter interactions, cold atoms and molecules, quantum optics and physics of quantum information and 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. Various quantum (two-state) systems are nowadays intensively studied in the hope that their parameters and related dynamics will be suitable for quantum computers.

Many of the above-mentioned problems are also important for cosmology, gravitation and astrophysics, for the reason that these areas of investigation are strongly related to non-equilibrium statistical physics, many body physics, foundations of quantum physics, physics of quantum measurement, physics of the quantum vacuum, macroscopic quantum phenomena and also, mainly due to measurement methods used for observation and detection, to quantum optics, condensed matter physics, and physics of mesoscopic systems. In addition, the methods developed within these fields can help us in better understanding of fundamental constants. These methods have also enabled the recent advances of various tests of quantum gravity (including e.g. quantum equivalence principle) and are therefore important for our better understanding of the Universe.

In summary, further experimental as well as theoretical studies of short to long time dynamics (via transport as well as optical properties) and the influence of initial and boundary conditions are needed. To understand better dynamics as well as equilibrium properties of classical and quantum systems, both theoretical and experimental experiences from such seemingly different, but in fact strongly correlated, fields as condensed matter physics, quantum optics, plasma physics, nuclear physics, physics of quantum information and computing, chemistry, biophysics and astrophysics, will be discussed during the conference program.