

From a broken integrability to thermalization in quantum many-body systems

POPULAR SCIENCE SUMMARY

The concept of temperature is familiar to everyone of us. Behind this casually sounding term there is a quite astonishing concept of physics. Complex systems, such as the air surrounding us on a winter day or a hot plate of an oven, each consist of unbelievably large number of particles entangled in complicated motion or vibrations. The systems are complicated, but for what matters in most purposes can be characterized by a handful of parameters such like temperature or pressure. The powerful concept behind this massive reduction of complexity is thermal equilibrium and a process leading to it, namely thermalisation.

Ubiquity of the concept of thermal equilibrium should be contrasted with complicated dynamics of each particle of the system. Indeed from the microscopic point of view of the quantum theory, the motion of particles is governed by equations of motion and the future state of the system is determined fully by the initial information. For the thermalization to happen, this initial information has to be somehow lost such that effectively the system can be indeed described just by few parameters. The standard understanding of the thermalization relies on two assumptions. First is the ergodicity. Namely, an ergodic system is such that consequently explores all the possible states conforming to the conservation of energy. Whereas for classical systems governed by the Newton's law of motion the ergodicity is enough to argue in favour of thermalization, for real quantum dynamics it is not enough and we need a stronger notion of the eigenstate thermalization. This hypothesis tells that for every reasonable quantity that we can measure, its value, up to some small fluctuations, is determined by the energy of the state. Since energy is related to temperature this indeed guarantees that when a system thermalizes its properties depend on the temperature and not on some microscopic information.

This conceptual understanding of thermalization in quantum many-body systems is hard to put on more quantitative grounds. In practice one would like to take a specific model and answer whether it thermalizes, and if it does not, what is the obstacle. If it does thermalize, how this process happens in time. These are all fundamental questions about non-equilibrium dynamics which in the same time are very hard to address for interacting quantum many-body systems. It is very difficult to set up computations or numerical simulations in such systems that would allow to answer these questions. Fortunately, there is a class of models in which situation is somehow simpler.

In this project I would like to study quantum integrable models. These are very special theories of interacting particles. They are special because beside energy there are other similar quantities that are conserved in time. This makes it easier to follow the dynamics in such models. On the other hand, the presence of conserved quantities means that the standard eigenstate thermalization hypothesis does not work anymore. Indeed usual observables in such theories depend not only on the energy of the state but also on values of other conserved quantities. This has an effect that quantum integrable models do not thermalise to a standard thermal equilibrium. Instead they often thermalise to a generalized equilibrium which is determined not only by temperature but also by generalized temperatures related to other conserved quantities.

Whereas purely integrable models do not thermalize, once their dynamics is slightly perturbed, a window of opportunity for the thermalisation opens. The aim of this project is to study exactly such situations. This setup has a great benefit of underlying integrable model, which allows us to write equations for the time evolution of the generalized temperatures. From this point of view the question of thermalization and associated timescales can be simply deduced from those equations. The weakly perturbed integrable models are also important from a practical, experimental standpoint. In most situations where quantum integrable models appear, such like ultra-cold atomic gases or magnetism of special compounds, integrability breaking interactions are present. The methods developed in this project will provide quantitative predictions for thermalisation in such situations.