Popular summary

Anisotropy implies the lack of equivalence between the spatial directions of a system from the point of view of its physical properties. The most standard anisotropic systems are crystals and liquid crystals, as contrasted to gases and liquids which typically are isotropic. Anisotropy may appear spontaneously in a physical system as a result of a phase transition.

Physical systems exhibit incredibly interesting behavior at phase transitions, where a tiny change of a control parameter (e.g. temperature or pressure) causes drastic variation of its properties (such as density, compressibility, resistivity, or magnetic susceptibility). Phase transitions are often accompanied by strong fluctuation effects and the related phenomenon of scale invariance, which means that the system behaves in a very similar way independent of the length scale of the observation. In such conditions anisotropy often turns out to be an irrelevant factor. This happens because the system is dominated by large-scale fluctuations, which are insensitive to its microscopic details, including the existence and properties of a microscopic lattice structure (or its absence). For this reason broad classes of systems may be successfully described by simple models defined in the continuum (without reference to any lattice), the so-called effective field theories. A single effective field theory may serve as a correct description of a variety of completely distinct systems (such as classical fluids and a class of magnetic crystals; or helium, a class of liquid crystals and at the same time a class of magnetic crystals). This amazing phenomenon, known as universality, found its fully correct description only in the second half of the XXth century. Since then it remains a topic of intense research in many contexts of condensed-matter physics as well as high-energy physics and cosmology. In standard situations universality implies that microscopic anisotropies are irrelevant. It however does not always have to be the case. One counterexample (out of many) is provided by high-T_c copper-based superconductors. Due to their strongly anisotropic, layered structure, the important physical properties are tied to the crystal layers, such that the system may be treated as a set of independent two-dimensional entities. Another very interesting counterexample is provided by the so-called Lifshitz points, where three thermodynamic phases (such as paramagnetic, ferromagnetic and antiferromagnetic) coexist. Due to unusually strong fluctuation effects these systems evaded a fully complete theoretical analysis and their accurate description constitutes an open problem till today. The Lifshitz points are predicted to occur in numerous physical systems including magnets, liquid crystals, metals as well as ultracold gases, both at zero and finite temperatures.

Since 1970s a novel point of view on the many-body problem known as ”renormalization theory” has been developed. It emphasizes the role of the scale Λ associated with observation performed on the system, which may be continuously varied between the microscopic and macroscopic ranges. One may consider a family of equivalent (i.e. corresponding to the same physical system) descriptions, each of which is associated with a distinct value of Λ. By continuously changing Λ one interpolates between the microscopic level of description (known in the analyzed problem) and the macroscopic description (which we look for), via the so-called renormalization flow. This way of thinking led to a solution of some of the key XXth century problems in condensed matter physics (description of the critical phenomena) and revealed amazing connections between statistical physics and the theory of elementary particles.

The present project addresses theoretically situations where anisotropies play an essential role, using primarily the modern tools of renormalization theory. Of our focus are both anisotropic effective field theories, which describe the Lifshitz points present in different physical contexts; as well as systems of interacting fermions and bosons, the description of which starts from a microscopic level.