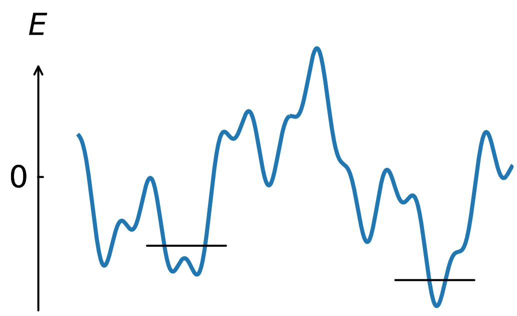
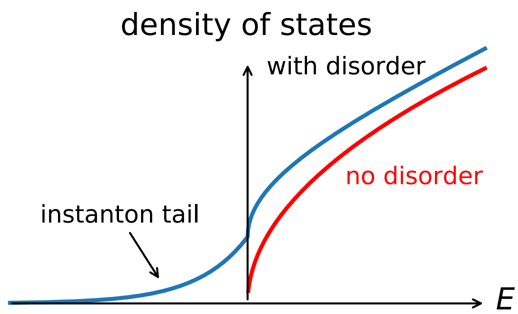
Master project: Instantons in disordered semiconductors

Background: Perturbation theories in quantum mechanics and quantum field theories are somewhat problematic since they are not convergent but asymptotic, which means that they have a convergence radius of zero with a maximum number of terms that improve the solution before it gets worse. Historically, this problem was first pointed out by Julian Schwinger, who discussed quantum electrodynamics where electrons interact via a repulsive Coulomb interaction. He gave a physical interpretation of the breakdown of perturbation theory by noting that a theory in which the electron interaction changes sign (i.e., attractive rather than repulsive) is not sensible: A cloud of electrons would not form a thermodynamically stable state but simply implode and collapse on itself. Within quantum field theory, there is a beautiful framework that links the divergence of large-order terms to saddle-point configuration of the action that are known as instantons.

Instanton solutions are not just abstract concepts in quantum field theories, however, and they are often important to describe experimental situations. For example, they determine the density of states (i.e., the number of states at a given energy) in disordered semiconductors: The problem here is to describe the energy levels of electrons in the presence of impurities in the material, which can be modelled by a random potential (as sketched in the left figure). This potential traps states at energies inside the excitation gap in a semiconductor (horizontal bars in that figure), and the distribution of these disorder-induced states are given by instanton configurations that are linked to an optimal form of the disorder potential (right figure).





Project proposal: The aim of the project is to develop the path integral representation of the density of states in a disordered semiconductor, and to compute the instanton solution. There are several open problems that can be tackled within this framework related to the effect of boundary conditions and specific geometries and the shape of the disorder potential.

The project is ideal for someone with a background in quantum field theory. Some knowledge of complex analysis is essential. The work is mostly analytical but requires the occasional solution of simple nonlinear differential equations, which must be done numerically. Office space in the physics department is available.

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