Current research programmes include the following:

NITheP National Institute for Theoretical Physics

Quantum Transport and Mesoscopic Physics

Often the phenomena predicted by quantum mechanics are very delicate. Unwanted influences from the environment in which a quantum system finds itself cause its wavefunction to collapse. Furthermore, the full implications of quantum mechanics are often hard to verify because they occur at small length scales and low temperatures.

However, in the last three decades, experimental physicists have become ever more adept at controlling conductors and semi-conductors at the nanometer scale and to shield the electrons inside these devices from their environment. Aspects of quantum mechanics that were previously thought to belong to the realm of ``thought experiment'' have been demonstrated in actual current and voltage measurements. A beautiful example is the Aharonov-Bohm effect. (See the figure.) Thus the sub-field of condensed matter physics known as Quantum Transport came into being. It involves the study of the world of small electronic devices, in search of surprising and/or useful quantum effects.

Recent experimental developments that strongly influence our theoretical work in this field were the discovery of two-dimensional sheets of carbon (graphene) and of topological insulators. These materials contain electrons that behave as if they are ultra-relativistic particles even though typical velocities are orders of magnitude less than the speed of light. Our current research combines the relativistic quantum mechanics of these new systems with the physics of the quantum Hall effect and that of localization by disorder. This leads to surprising consequences, such as a Quantum Hall effect without Landau levels, and metals that conduct electricity better the higher the density of impurities.

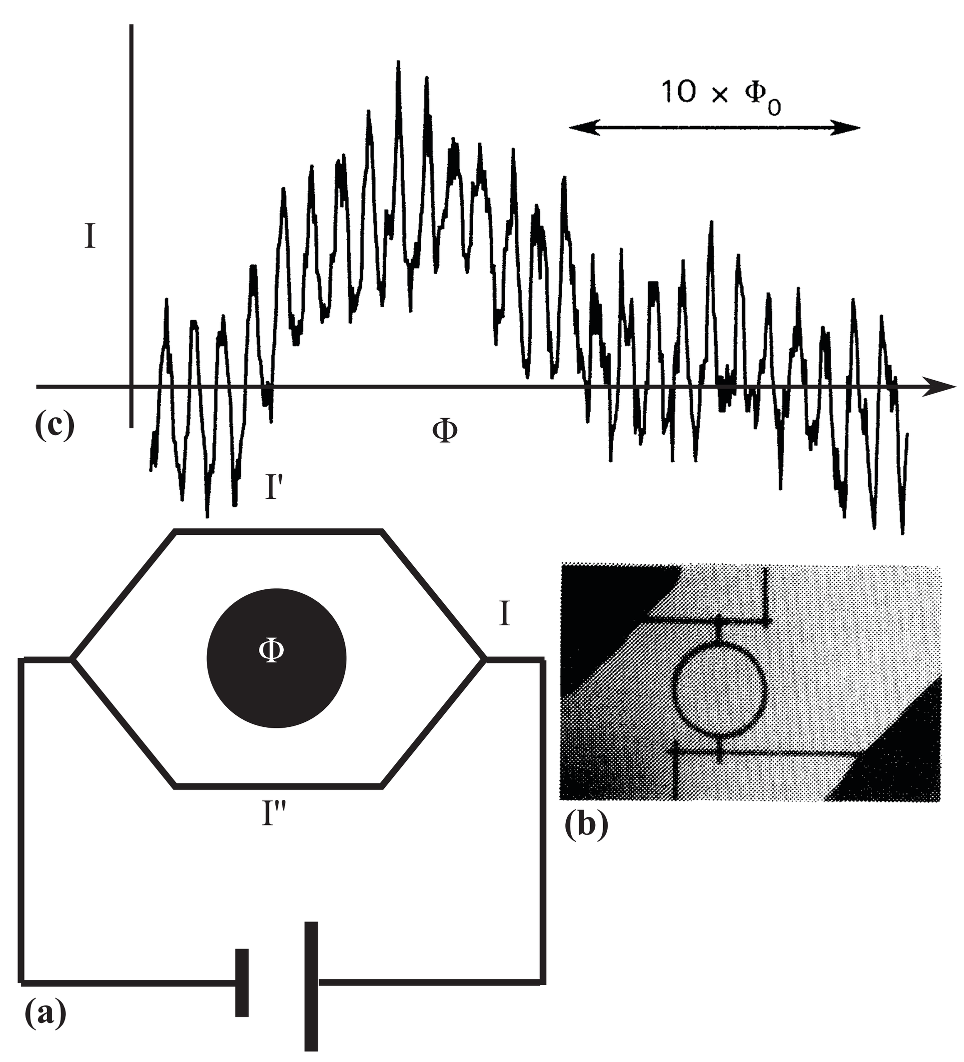

Figure 1: A famous quantum transport experiment: The Aharonov-Bohm effect [from Webb et al, PRL (1985)].

(a) Two parallel currents I' and I'' are threaded by a thin solenoid with magnetic flux Φ. The magnetic field is confined to the region in the black disk. The electrons in the wires experience no magnetic field. Classically, the total current is I=I'+I'' independent of Φ. However quantum mechanics predicts that the current oscillates as Φ is varied, with period Φ0=h/e.

(b) The experimental setup. The metal ring has a diameter of a few micrometers.

(c) The measured current oscillates as Φ is varied, in accordance with the quantum mechanical prediction.

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