Transport through quantum dots: Making semiclassics quantitative

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It is still a puzzle how much classical information is, under certain circumstances, contained in quantum mechanics. The electric current through conductors with very large coherence lengths (ballistic transport) is clearly ruled by quantum mechanics. Nevertheless, ballistic electron transport shows unambiguous signatures of classical trajectories. Transport through mesoscopic devices, so called quantum billiards, proves to be of great importance for our understanding of the classical-to-quantum correspondence and quantum chaos. Semiclassical mechanics may provide the bridge that connects classical paths with quantum properties. Path interference of classical paths has been used previously to explain qualitative features of ballistic transport. Quantitative agreement, however, has not been reached. We show that classical paths alone are indeed insufficient to account for quantum interference effects. The missing link are quantum paths arising from diffraction at the cavity lead junctions. We present a novel diffraction theory that yields good quantitative agreement with quantum mechanics.

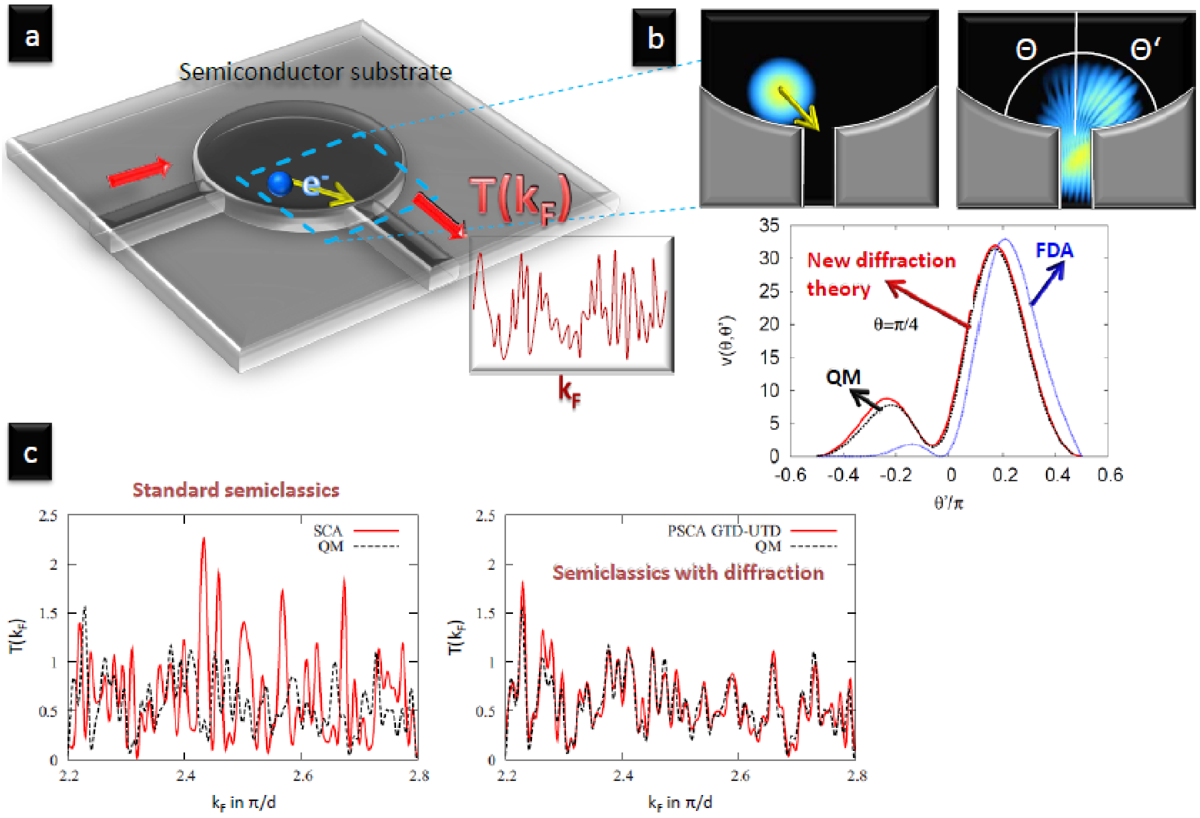

Figure:

(a) Schematic sketch of a circular quantum billiard within a semiconductor heterostructure. Electrons move ballistically inside the cavity. The conductance $T(k_F)$ as a function of the Fermi wavenumber k_F (energy) shows a strongly fluctuating interference pattern – a signature of the quantum nature of ballistic electron transport.

(b) Back-diffraction of electrons at the cavity-lead junction is an essential process for electron transport in quantum billiards. We found a new analytic diffraction theory for the back-diffraction coefficient $v(\Theta,\Theta')$ in very good agreement with quantum mechanics (QM) in contrast to the Fraunhofer diffraction approximation (FDA).

(c) Within Feynman's picture, conductance fluctuations are the result of electron-path interference. The standard semiclassical theory which takes into account only classical paths is unable to reproduce conductance fluctuations quantitatively. Inclusion of diffraction and the additional paths resulting from diffraction into a semiclassical theory results in quantitative reproduction of conductance fluctuations $T(k_F)$ as a function of k_F (measured in π/d where d is the width of the lead). We compare to quantum mechanical results (QM).