

Chapter 5. Coulomb Repulsion and Resonant Tunnelling

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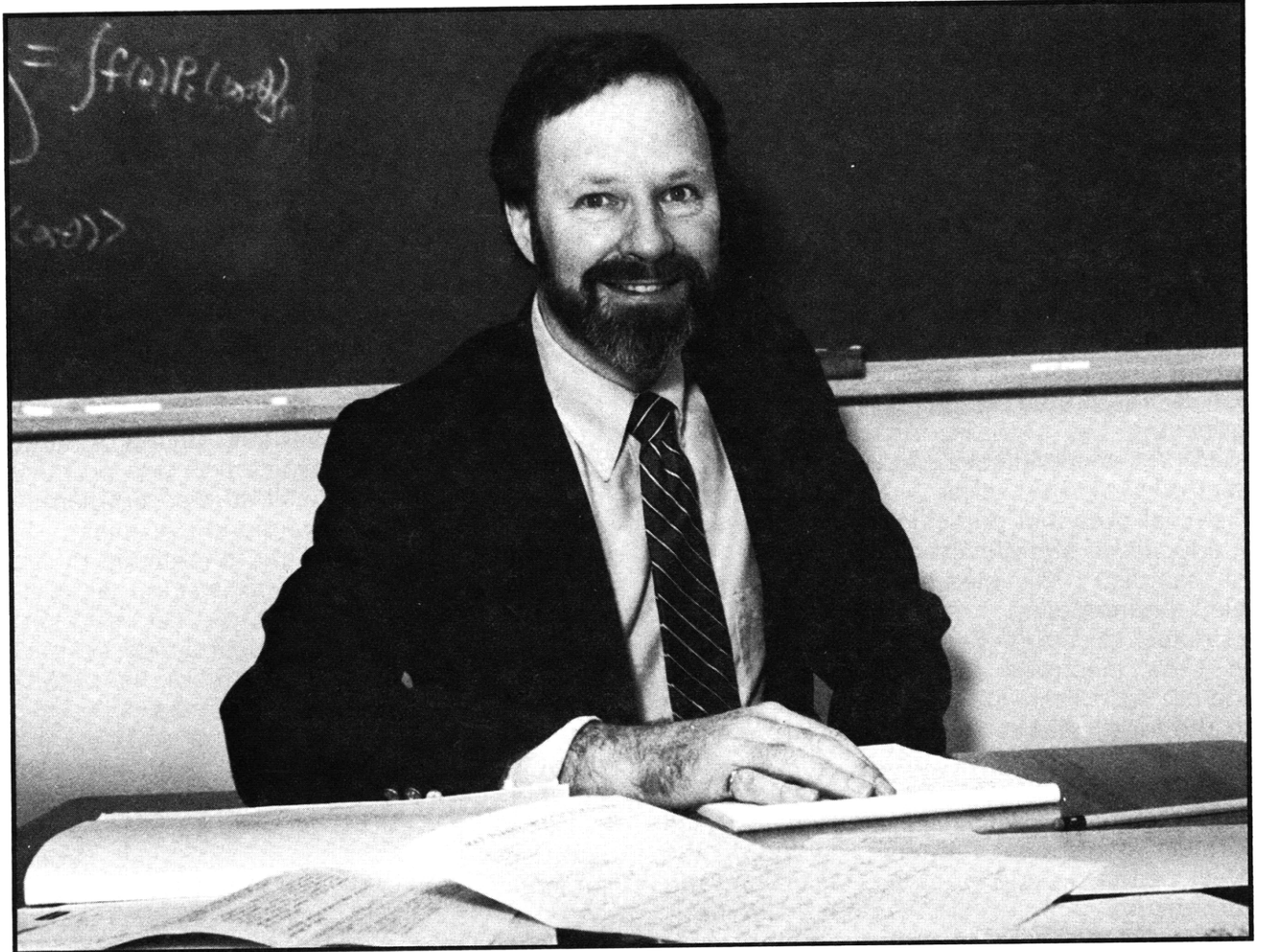
When a Si-MOSFET is taken to low temperature (typically 1K and below), it is found that temperature independent conductance peaks appear as a function of gate voltage when the gate voltage is below threshold. In this regime, the electronic states in the device are localized and the experimental observation is interpreted as being due to resonant tunnelling, a process where an electron quantum mechanically tunnels from one electrode to the other when the electrochemical potential coincides with the energy of a localized state located near the middle of the sample. The theoretical description of this phenomenon has previously been restricted to single particle wave functions, i.e., the electrons were assumed not to interact with each other. In fact, an electron on the localized site strongly repels the addition of a second electron due to the Coulomb repulsion of doubly occupying a single state. We have formulated the problem of resonant tunnelling including the effect of the on-site Coulomb repulsion, and our results are different from the non-interacting theory in several important ways, which are amenable to experimental tests.

The question of Coulomb repulsion is intimately related to the question of interference between the tunnelling of electrons of opposite spins. In the non-interacting theory,

each spin component tunnels independently. In particular, when a magnetic field H is applied, the up and down spin levels are split by Zeeman energy $2\mu_B H$ and the resonance is predicted to split into two. When interaction is included, the two spin components are intimately coupled, because the spin up and down electron cannot simultaneously occupy the localized state without paying a large energy cost. We recognize that this problem is closely related to a well-studied problem in many-body physics, the Kondo problem. In particular, we find that the line-shape of the resonance peak is not Lorentzian, as predicted by the simple theory, but is asymmetric with temperature dependence on only one side of the line. Furthermore, we predict that the resonance should not be split by a magnetic field, but should be shifted, and that it should change its line-shape to another asymmetric but temperature independent form. This latter prediction of no splitting has already been observed experimentally. It will be very interesting to fabricate devices to look for the peculiar line-shape predicted by this theory.

Publication

Ng, T.K., and P.A. Lee, "On-Site Coulomb Repulsion and Resonant Tunnelling," *Phys. Rev. Lett.* 61:1768 (1988).



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