Metal-Insulator Transition in Disordered Two-Dimensional Electron Systems

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Recommended with a Commentary by Claudio Castellani, Universita' di Roma.

The existence of a Metal-Insulator transition (MIT) in a two dimensional electron gas at low density is one of the most significant problems which have been around in the last ten years since its discovery in 2d Si-MOSFET by Kravchenko and co-workers [1]. I think there is not yet a theory for that phenomenon. The very interesting paper by PF makes a great step towards a consistent understanding of that problem

The MIT first observed in Si-MOSFET and later in various other 2d heterostructure occurs when the square resistance R is of the order of quantum resistance h/e^2. This suggests the importance of quantum effects, in particular the importance of disorder quantum interference in the presence of strong Coulomb interactions. The theory for describing quantum interference for interacting electrons was introduced by Finkelstein in the early eighties [2]. The relevant dimensionless couplings of the theory are the dimensionless resistance $g = (e^2/\pi h)R$ and the Landau amplitudes, in particular the amplitude γ_2 in the triplet channel which controls the magnetic response of the electron gas. Let me say that it is not obvious a priori that this (essentially hydrodynamic) theory will be of relevance in controlling the transport and the magnetic response (and the various crossovers) in these low densities systems (Si-MOSFET and heterostructure near the MIT) with Fermi energies comparable with (or at least not very smaller than) temperature.

Indeed attempts to apply the Finkelstein theory to the 2d MIT were received with scepticism. Let me recall that the two loop RG equations derived by Kirkpatrick and Belitz in the large γ_2 limit provides a MIT fixed point with γ and χ_s diverging in the same way (so that it can be interpreted as a diverging effective mass) [3]. $\gamma = c_v/T$ is the specific heat ratio and χ_s is the spin susceptibility.

The main criticism to the old RG eqs was that already at one loop they were providing a diverging γ and even a more diverging χ_s also in the metallic phase while there is no experimental evidence for that.

FP are now deriving the two loop RG eqs in the limit of large valley degeneracy n_ν. The theory appears to be much more under control in this limit. Notice that the RG eqs are changed also at one loop with respect to the old result. The MIT fixed point has the same features than the old one (equally diverging γ and χ_s). The big difference is in the metallic phase. Eventually γ and χ_s diverge everywhere in the metallic phase , but in a much weaker way ($|logT|$) than at the transition. This is a big improvement with respect to the old theory, in agreement with what is provided by the experimentalists on χ_s. The metallic phase is however not really satisfying, in the sense that the theory now produces a perfect metal (zero resistivity $\simeq 1/|logT|$) while the old theory did allow for a zero temperature finite conductivity.

A main point for assessing the validity of the PF proposal would be the comparison with experiments of the theoretical predictions for the magnetoconductance with in plane magnetic field. This is an issue also for the experimentalists since the results of two main groups (Kravchenko and Pudalov) are still controversial on that. Other important issues are the determination of temperature dependence of χ_s, and the assessement of the relevance of band degeneracy. A lot of work still to do.

In conclusion the large n_ν analysis of FP provides a “reasonable” fixed point for the MIT which appears to be consistent with the experiments in the sense that at fixed T χ_s is enhanced by approaching the MIT. However it seems to me that the general understanding of the MIT will stay unclear as far as the nature of metallic phase of dirty interacting electron escapes a proper description (it would possibly result in a non Fermi liquid phase). This also requires further work, both by theoreticians and experimentalists.

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[2] A.M.Finkel'stein, Sov. Phys. JETP **57**, 97 (1983).

[3] T.R.Kirkpatrick and D.Belitz, Rev. Mod. Phys. **66**, 261 (1994); C.Castellani et al., Phys. Rev. B **57**, R9381 (1998)