Spin-polarization induced tenfold magnetoresistivity of highly metallic two-dimensional holes in a narrow GaAs quantum well.

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Recommended with a Commentary by Steve Kivelson, Stanford University.

More then ten years ago, a set of unanticipated phenomena were reported associated with the two dimensional electron gas (2DEG) in high mobility Si MOSFETs with low electron density (large r_s) and an unusually large distance to the metallic gate. So as to have a name that does not presuppose the answer, the associated set of phenomena have come to be called, somewhat awkwardly, "the apparent metal insulator transition in the 2DEG." The "apparent transition" refers to a dramatic change from metal-like (increasing) to insulating-like (decreasing) temperature dependence of the resistivity triggered by a small change in density near a critical density. The apparent transition was not the only surprise: for example, on the metallic side of the transition, at temperatures low enough that electron-phonon scattering is negligible, strong changes in the resistivity, ρ, as a function of the temperature and magnetic field were observed, where the pre-existing theory of disorder scattering of weakly interacting quasiparticles leads to the expectation of small variations of ρ, generally with the opposite sign to those observed. These experiments and their extensions have, by now, been reproduced by several groups using devices from more than one source, so there is no doubt about their validity.

The theoretical activity triggered by this discovery has been intense and the ideas proposed have been diverse and creative. What has not been clear, until recently, is to what extent these phenomena can be attributed to specific details of these Si MOSFETs – the existence of a valley degeneracy, some special features of the impurity scattering in these particular devices, etc. The recent paper of Gao *et al*, which is the culmination of a set of studies of the properties of the 2D hole gas in high mobility GaAs-GaAlAs heterostructures, definitively settles this issue. The geometry of the GaAs heterstructure is rather different than the Si MOSFET, although it shares the feature that any metallic gate (ground-plane) is far from the 2DHG in units of the spacing between particles. There is only one relevant hole band, in contrast with the two electron bands in the Si devices. There are corresponding differences in the form of the spin-orbit couplings. In both systems, the disorder is, by some measure, weak (so that despite the large r_s, the electrons or holes are not strongly localized), but in detail, the sources of disorder are quite different. Yet clearly similar behaviors are observed in the two classes of device. Thus, in my opinion, the case is now clear that the phenomena in question are intrinsic, and probably universal features of the 2DEG at large r_s (strong correlations) with sufficiently weak disorder.

While there is much of interest reported in the new paper of Gao *et al*, the most dramatic new findings concern the behavior of the system well on the metallic side of the transition, where ρ is small compared to the quantum of resistance (by as much as a factor of 75!). Here, were a simple Fermi liquid picture valid, corrections to the Drude conductivity are readily computed in powers of $1/k_F l$; the results are well controlled, clear, and, in my opinion, totally at odds with observation. On raising the temperature from the base temperature (roughly 20mK) to temperatures of order the Fermi temperature, the resistivity rises more or less linearly by a factor of 2 or 3. As a function of increasing in-plane magnetic field, $B_{||}$, at fixed, low temperature, ρ rises roughly linearly, and then becomes field independent above a characteristic magnetic field, B*. Finally, for $B_{||} > B^*$, the dominant temperature dependence of ρ is quenched, leaving a much weaker T dependence of the opposite sign, which is at least crudely consistent with weak localization. All these same features are seen on the metallic side of the apparent transition in Si MOSFETs, as well, although in the existing data, the magnitude of the resistance is never as small as in the experiments of Gao *et al*, probably because the Si devices are not, by some measure, as clean.

In addition to the universality of the phenomenon, there seem to be three clear conclusions that can be drawn. 1) The fact that the $B_{||}$ dependence of ρ saturates for B > B* implies that the only important effect of the magnetic field is to polarize the electron spins – they are fully polarized for $B_{||} > B^*$. 2) This same observation implies that the anomalous metallic temperature dependence of ρ is a consequence, in some manner, of fluctuations of the spin degrees of freedom, which are quenched for $B_{||} > B^*$. 3) The fact that these phenomena have become increasingly clear as the mobility of pGaAs heterostructures has improved, suggests that the phenomena have a collective origin, better understood by considering the limit of strong correlations with vanishing disorder than the opposite limit.

I have discussed these results with my friends. The standard response is, "Big deal, it's useless for nano-topological bio-computing." Indeed, I think it is a big deal.