Spin-current and spin accumulation in 2d spin-orbit coupled systems with impurities
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AND

Spin-Hall effect in a disordered 2D electron-system.
Authors: R.Raimondi and P.Schwab

Recommended with a commentary by Alexander Punnoose, Bell labs and Chandra Varma, Bell labs and University of California, Riverside.

Spin-orbit interactions offer the possibility of manipulating the spins in a semi-conductor through applied electric fields. This has inspired the burgeoning interest in *spintronics*. It has also led to some rather intricate theoretical analysis of spin-Hall effects in two-dimensional heterostructures with Rashba spin-orbit coupling in which an electric field applied in the $\hat{x}$ direction in the plane leads to a spin-current in the direction $\hat{y}$ in the plane with spins polarized in the direction $\hat{z}$. The spin-conductivity σ_{xy}^{z} in the pure system at zero frequency can be deduced to have the value $e/8\pi$. The important question is whether this result is stable to impurity scattering (and particle-particle scattering). Several papers, referred to in the two papers above, have come to the intriguing result that such a universal value is preserved at low frequencies ω compared to the scattering rate $1/\tau$. Doubtless many experimentalists are designing experiments to test such a surprising prediction. The prediction is surprising because it is independent of the spin-orbit scattering rate Δ without which there is of-course no coupling between the spin and the electric-field. It is also independent of impurity scattering like for example the universal values in the quantum Hall effects. Such miracles have occurred in physics before but a conservation law or topological property always underlies them. No such general property has been offered yet as an explanation.

The two papers recommended above have looked at the problem systematically with apparently different methods and on the crucial point of the universality of the spin-hall conductivity they agree and also with some results of Inoue et al. (ref. 10). While the first paper examines the frequency dependence also, the second concentrates on the dc limit. The result is that in the limit of small $\omega\tau$, $\sigma_{xy}^{z} \propto \omega\tau$, so that it vanishes in the dc limit. Only in the high frequency limit, $1/\tau << \omega << \Delta$ is the result the universal value $e/8\pi$. For the dirty case, $1/\tau >> \omega >> (\Delta\tau)^2/\tau$, it is proportional to $(\Delta\tau)^2$ even in the high frequency limit. These results are obtainable with very careful use of the theoretical artillery. They are also not such as to hold promise for new spintronic technologies.

The theoretical problem is rather complicated even for the non-interacting problems of the models treated. There is no continuity equation for spin-density analogous to charge-density for finite spin-orbit coupling. So spin-current is not unambiguously defined. There is no way to measure it; what can be measured is spin-polarization at the ends of the sample. For that reason the first paper examines the problem for a finite sample and then generalizes the result for large sample size. Even the spin accumulation they obtain is not large enough to be interesting. The paper use the Keldysh formalism to derive the transport equations, presumably because lack of conservation laws make one worried about writing down a Boltzmann type equation for transport directly. There arise important issues of vertex corrections of impurity scattering, the questions of q -limit versus ω -limit, questions of going from finite length calculations to infinite length of sample keeping ω fixed and other arcana of transport which have been well understood only for ordinary transport. Now we await a more detailed paper explaining the intricacies of the calculations and possibly, if the authors or others have the stomach for it, calculating the corrections due to interactions.