Evidence for Spin-Chiral Edge Transport in HgTe Quantum Wells

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Recommended and a Commentary by Leonid Levitov, MIT

Spin-orbital interaction couples spin degrees of freedom with orbital motion of an electron. Currently, experimentalists are learning how to use it to guide spin flow by charge flow, which leads to many interesting transport phenomena and can possibly bring about some applications in spintronics. The extreme case of spin-orbital interaction is *chiral dynamics*, realized when electron spin polarization is uniquely determined by its velocity. Chiral dynamics locks particle spin to its velocity, making the spin state of a particle moving with a particular velocity fully polarized.

The simplest example of chiral dynamics is provided by the massless Dirac model $H = v\sigma.\mathbf{p}$, where σ are Pauli matrices and $\mathbf{p}$ is momentum. Crucially, since the scalar product $\sigma.\mathbf{p}$ makes spin and momentum parallel, the particles with opposite spins are moving in the opposite directions, in accordance with the time reversal symmetry. Such a Hamiltonian describes, in particular, electrons in a graphene monolayer. However, the role of spin in graphene is played by flavor, or pseudospin, degrees of freedom.

Is it possible to realize chiral dynamics for real spin? The paper by Konig et al., reports achieving this in low density and high mobility HgTe/(Hg,Cd)Te quantum well structures. The electron bands in this material can be modeled by a Dirac Hamiltonian with a mass term that opens up an energy gap in the spectrum. The key property of HgTe structures is that the magnitude and sign of the mass term depends on the composition, which allows to engineer an arbitrary spatial profile of the Dirac mass. In particular, it is possible to create a mass domain wall that, as is well established in theory, must support chiral gapless states propagating along the wall and carrying opposite spins in the opposite directions.

In the experiment the Dirac mass term is made tunable by adjusting the quantum well width. This leads to formation of chiral states at the boundary of a two-dimensional electron system. Transport measurements indicate that the one-dimensional modes, while propagating along the edge, exhibit little or no backscattering and thus are capable of carrying charge and spin in a ballistic, dissipationless fashion. This behavior is similar to transport in the Quantum Hall state, however it requires no external magnetic field.

In the future, the results may help to demonstrate the so-called quantized spin-Hall effect, a phenomenon predicted in this system but so far remaining elusive due to the difficulty of measuring spin current. From a more general theory perspective, the edge states realized in this system provide a fascinating example of a spin-chiral Luttinger liquid which is quite different in its properties from non-chiral Luttinger liquids studied in quantum wires and carbon nanotubes.