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Direct observation of Aharonov-Casher phase

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Recommended with a Commentary by Bertrand I. Halperin, Harvard University

Spin-orbit coupling in a two-dimensional electron system can be varied by applying a voltage V_G to a gate, which modifies the asymmetry of the confining well. If the spin-orbit coupling can be varied over a sufficiently large range, this could lead to oscillations in observable quantities, as a function of V_G, arising from spin-dependent phases for different electron paths leading to the same final point, in an interference experiment.

The preprint by König et al. reports the observation of such oscillations in the conductance through ring structures, fabricated from HgTe/HgCdTe quantum wells. The most important spin-orbit induced phase difference expected in this geometry is the so-called Aharonov-Casher phase. Application of a perpendicular magnetic field B to the same ring structures give rise to Aharonov-Bohm oscillations, and variations in the conductance due to both V_G and B give additional support to the authors' identification of the spin-orbit effect.

The HgTe system is remarkable because of its large spin orbit coupling, as well as its small carrier mass and large g-factor, associated with its small band gap. The group at Wurzburg that conducted these experiments has learned to make high quality microstructures from these materials, which opens up a very promising avenue for other experiments where spin-orbit coupling can be used to manipulate electron spins.

The ring structure shown in the preprint has an average radius of 1μm and an arm-width of 300 nm, with a carrier density of 1.5×10^{12} cm^{-2}. By studying Shubnikov-de Haas oscillations in a Hall bar adjacent to the ring, the authors find that the spin-orbit coupling and the difference between the spin populations can be tuned to zero at $V_G \approx -2.57$ V, whereas voltages of +4 V or –6 V lead to spin populations that differ by approximately 6% of the total density. Aharonov-Bohm and Aharonov-Casher oscillations were shown for V_G in a narrow range of 0.04 V around the symmetric point, with -12 mT $< B < 12$ mT. Oscillations in the conductance were of the order of ±1% on a background of ≈ 23 e^2/h. The pattern of maxima and minima was found to be in qualitative agreement with calculations based on a highly simplified model, in which there is only a single conduction mode contributing in each branch of the ring. It is not entirely clear why this model works so well.