

## **Spin-Separation in Cyclotron Motion.**

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**Recommended and a commentary by Bertrand I. Halperin, Harvard University.**

There has been much interest, and theoretical discussion, about the possibility to use spin-orbit coupling to separate the trajectories of carriers of different spin in a two-dimensional semiconductor structure, without the use of a strong magnetic field. Rokhinson et al. have been able to achieve such separation, in a hole-doped GaAs structure, by using the technique of magnetic focusing. The experiment exploits the fact that for holes traveling in a given direction, particles at the Fermi energy have different momenta, associated with two possible spin states. When there is a modest magnetic field perpendicular to the sample, holes with different momenta follow different cyclotron orbits, and their trajectories can be separated. Although the direction of spin quantization will vary as the holes follow their orbits, the variation is adiabatic, so a particle initially in the higher momentum-state remains in the higher momentum-state, etc. The magnetic fields employed in the experiment (of order 0.2 T) are small enough so that the Zeeman energy is negligible compared to the spin-orbit splitting, and only the orbital effects of the magnetic field are important. A theoretical analysis of spin separation by spin-orbit coupling and magnetic focusing, in the context of a 2D electron system, has been presented independently by Usaj and Balseiro [1].

In order to check that the two cyclotron orbits correspond to different spin states, Rokhinson et al. partially close the quantum point contact in front of their detector, and apply a large in-plane field (of order 3.5 T), so that only one spin state can pass. They then see only one peak in the magnetic focusing experiment, rather than two, as only one of the two cyclotron orbits has the correct spin orientation. They argue that even with this large in-plane field, the Zeeman coupling has negligible effect on the hole-trajectories, except when the holes attempt to pass through the point contact.

The separation via spin-orbit coupling, achieved in these experiments, was made possible by the very high quality of the hole-doped samples and lithographic structures, and by the fact that the momentum-splitting due to spin-orbit coupling, which is measured in the experiments, is an order of magnitude

larger than in typical GaAs 2D electron systems. The achievement of spin selection by an in-plane magnetic field in the detector point contact is another noteworthy accomplishment. Although this effect has been observed previously in 2D electron systems, and has been combined with magnetic focusing [2], I believe this is the first time it has been seen in a 2D hole system. As the Zeeman effect of an in-plane field is highly momentum-dependent in a 2D hole system, it is not easy to predict the strength of field necessary to achieve spin filtering with a point contact.

[1] G. Usaj and C. A. Balseiro, Electron Focusing in Systems with Spin-Orbit Coupling, *Phys. Rev. B* 70 (2004) 041301(R); cond-mat/0405061.

[2] R. Potok, J. A. Folk, C. Marcus, and V. Umansky, Detecting Spin-Polarized Currents in Ballistic Nanostructures, *Phys. Rev. Lett.* 89 (2002) 266602.