Speed and Spin-Orbit: New Results in Carbon Nanotubes

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We will present two new results on the fundamental properties of electrons in carbon nanotubes. The first concerns the degeneracy of electronic states in nanotubes. The electronic states in defect free tubes are widely believed to be four-fold degenerate due to independent spin and orbital symmetries. Here we report measurements demonstrating that the spin and orbital motion of electrons are coupled in clean NTs, thereby breaking all of these symmetries. This spin-orbit coupling is manifested experimentally as a splitting of the four-fold degeneracy for a single electron in ultra-clean quantum dots. The coupling favours parallel alignment of the orbital and spin magnetic moments for electrons and anti-parallel alignment for holes. Our measurements are consistent with recent theories that predict the existence of spin-orbit coupling in curved graphene and describe it as a topological effect in NTs. Our findings have important implications for spin-based applications of NTs, necessitating new design principles for the realization of qubits in NTs and providing a mechanism for all-electrical control of spins in NTs.

The second experiment is the first terahertz electrical measurements of single-walled carbon nanotube transistors. Significantly, a ballistic electron resonance is directly observed in the time-domain with a picosecond-scale period corresponding to the roundtrip transit of an electron along the nanotube. The electron velocity is measured to be constant and equal to the Fermi velocity, suggesting that the single-particle modes dominate the electron transport in quasi-metallic carbon nanotubes. Initial evidence is also reported for the observation of the plasmon mode. These results are important not only for carbon nanotube based THz applications, but also demonstrate a powerful new tool for directly probing picosecond electron motion in nanostructures.

References

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[2] "Coupling of Spin and Orbital Motion of Electrons in Carbon Naanotubes," F. Kuemmeth, S. Ilani, D.C. Ralph, and P.L. McEuen, Nature 452, 448 (2008).