Molecular-scale electronics and mechanical analogues of spin torques

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When a spin-polarised current impinges on a magnetic island, an imbalance between incoming and outgoing fluxes of spin angular momentum generates a spin torque on the island. In this talk, I describe a molecular-scale, mechanical analogue of this effect, which arises when an electrical current impinges on a chiral nanotube. In this case, the outgoing electron 'wind' acquires an angular momentum and by Newton's third law, exerts a mechanical torque on the chiral nanotube. This effect occurs, for example, in a double-wall carbon nanotube (CNT), in which a current flows from the outer achiral CNT to the inner chiral CNT. For reasonable area of overlap between the inner and outer CNTs, it can be shown that the current-induced torque is sufficient to overcome the mutual friction and therefore the inner CNT will rotate.

With a view to optimizing the design of such a 'windmill' and to maximizing the internal magnetic field generated by chiral currents, I present analytical results for the group-velocity components of an electron flux through chiral carbon nanotubes. Chiral currents are shown to exhibit a rich behavior and can even change sign and oscillate as the energy of the electrons is increased. It is found that the transverse velocity and associated angular momentum of electrons are a maximum for nonmetallic CNTs with a chiral angle of 18 degrees. Such CNTs are therefore the optimal choice for CNT windmills and also generate the largest internal magnetic field for a given longitudinal current. For a longitudinal current of order 10^{-4} A, this field can be of order 10^{-1} T, which is sufficient to produce interesting spintronic effects and a significant contribution to the self-inductance.

Since an electrical current can produce mechanical rotation, it is reasonable to expect that mechanical rotation of an outer CNT relative to an inner CNT can induce an electron current. When the outer tube is chiral, such devices indeed act like quantum Archimedes screws, which utilize mechanical energy to pump electrons between reservoirs. Results will be presented for the pumped charge from one end of the inner tube to the other, driven by the rotation of a chiral outer nanotube. Such a device is found to be an efficient electron pump, whose pumped charge can be greater than one electron per 360 degrees rotation.

References:

Carbon nanotube Archimedes screws, L. Oroszlany, V. Zolyomi and C. J. Lambert, ACS Nano,7363 (2010)

Oscillating chiral currents in nanotubes: A route to nanoscale magnetic test tubes, C.J. Lambert, S.W.D. Bailey, and J. Cserti, Phys. Rev. B78 233405 (2008)

Carbon Nanotube Electron Windmills: A Novel Design for Nanomotors. S.W. D. Bailey, I. Amanatidis and C. J. Lambert, Phys. Rev. Lett. 100, 256802 (2008)