Electron spin resonance theory for carbon nanotubes

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We present a recent theoretical study of electron spin resonance (ESR) in carbon nanotubes [1]. In a typical ESR experiment a static magnetic field is applied and the absorption of radiation with polarization perpendicular to it is measured. Taking the static field along the z-axis, the ESR intensity is proportional to the Fourier transform of the transverse spin-spin correlation function:

$$I(\omega) = \int dt\, e^{i\omega t} \langle S^+(t) S^-(0) \rangle \ , \tag{1}$$

where $\vec{S} = \sum_i \vec{S}_i$ is the total spin operator. If the system Hamiltonian has SU(2) spin symmetry, the ESR spectrum consists of a single δ-peak at the Zeeman frequency, even at finite temperature. Any deviation from that, e.g. a shift or a broadening, is directly connected to the intrinsic spin dynamics, more precisely to the SU(2) breaking interactions. The leading term breaking SU(2) invariance is generally the spin-orbit (SO) coupling.

We derive the form of the SO interaction in single-wall (SWNT) as well as in multiwall carbon nanotubes (MWNT), and study the resulting ESR spectrum by using the low-energy field theory approach. Drastic differences emerge between SWNTs and MWNTs, reflecting fundamentally distinct mechanims of SO coupling.

Most remarkably, in SWNTs the SO coupling only acts in the spin sector and hence does not affect spin-charge separation. As a consequence, the ESR intensity is unaffected by electron-electron interactions, which only act in che charge sector, and can be computed analytically. The resulting spectrum exhibits a double peak, the splitting being intimately linked to the spin-charge separation.

In MWNTs, the dominant mechanism of SO coupling is traced back to the effect of a Rashba-type electric field, due to the inner shells, acting on the outermost shell. The appropriate form of the SO interaction is derived. The resulting ESR spectrum at low temperature exhibits only a single, narrow and asymmetric peak, whose line shape strongly depends on temperature.

[1] A. De Martino, R. Egger, K. Hallberg and C. A. Balseiro, Phys. Rev. Lett. **88**, 206402 (2002);