Exotic Kondo Effect in Carbon Nanotube Quantum Dot

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We study the Kondo effect in a CNT(left lead)-CNT(QD)-CNT(right lead) structure. Here CNT is a single-wall metallic carbon nanotube, for which 1) the valence and conduction bands of electrons with zero orbital angular momentum (m=0) coalesce at the two valley points **K** and **K'** of the first Brillouin zone and 2) the energy spectrum of electrons with m≠0 has a gap whose size is proportional to |m|. Following adsorption of hydrogen atoms and application of an appropriately designed gate potential, electron energy levels in the CNT(QD) are tunable to have: 1) two-fold spin degeneracy; 2) two-fold isospin (valley) degeneracy; 3) three-fold orbital degeneracy m=0,±1.

This exotic Kondo effect is analyzed within poor-man scaling (in the weak coupling regime) and within the mean field slave boson formalism (in the the strong coupling regime). It is shown that the Kondo temperature T_K for the SU(12) Kondo effect is much higher than in the standard SU(2) Kondo effect. The pertinent tunnel conductance has the similar temperature dependence as for the usual SU(2) Kondo effect. On the other hand, a peculiar result related to the SU(12) symmetry is that the magnetic susceptibilities for parallel and perpendicular magnetic fields display anisotropy with a universal ratio $\chi_{\parallel}/\chi_{\perp} \equiv \eta$ that depends only on the g factors.

The non-linear tunneling conductance at temperature T and source-drain voltage V in the weak coupling regime $T>T_K$ is calculated in perturbation theory with the result,

$$G(V,T) = \frac{\pi^2 N G_0}{ln^2(d(V,T)/T_K)}, \quad N = \frac{2(n^2-1)}{n^3}, \quad G_0 = \frac{ne^2}{2\pi\hbar},$$

where $d(V,T) = \sqrt{T^2 + (eV)^2}$ and $n = 12$. The zero-bias differential conductance is shown in Figure 1, left panel. It is seen that the conductance increases when the temperature decreases which is also characteristic of the standard SU(2) Kondo tunneling through a semiconductor quantum dot [1,2].

On the other hand, a peculiar result related to the SU(12) symmetry [and absent in the ordinary SU(2)] Kondo effect is related to magnetic response. Specifically the magnetic susceptibilities for parallel and perpendicular magnetic fields [with respect to the CNT axis] display anisotropy [3] with a "universal" ratio. In more detail, let us write the magnetic susceptibility tensor as,

$$\hat{\chi} = \mathrm{diag}(\chi_{||}, \chi_{\perp}, \chi_{\perp}),$$

where $\chi_{||}$ or $\chi_{\perp}$ is the susceptibility of the junction for the magnetic field parallel or perpendicular to the CNT axis. The magnetic susceptibility as function of temperature (in the weak coupling regime) is shown in Figure 2, right panel. From this we see that the susceptibility for the SU(12) Kondo tunneling is anisotropic, whereas the susceptibility for the standard SU(2) Kondo tunneling is isotropic [2]. Moreover, it is found that the ratio

$$\frac{\chi_{||}}{\chi_{\perp}} = 1 + \frac{8 g_{orb}^2}{3 g_{spin}^2},$$

is independent on temperature, but only on the spin and orbital g factors. This might be a way to experimentally identify the SU(12) Kondo effect.

References

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[3] H. Ajiki and T. Ando, J. Phys. Soc. Jpn. **62** (1993) 1255.

Figures

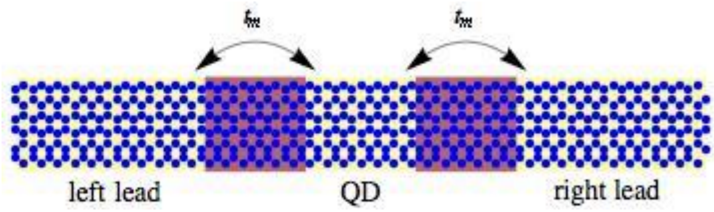

Figure 1: CNT(left lead) - CNT(QD) - CNT(right lead) junction.

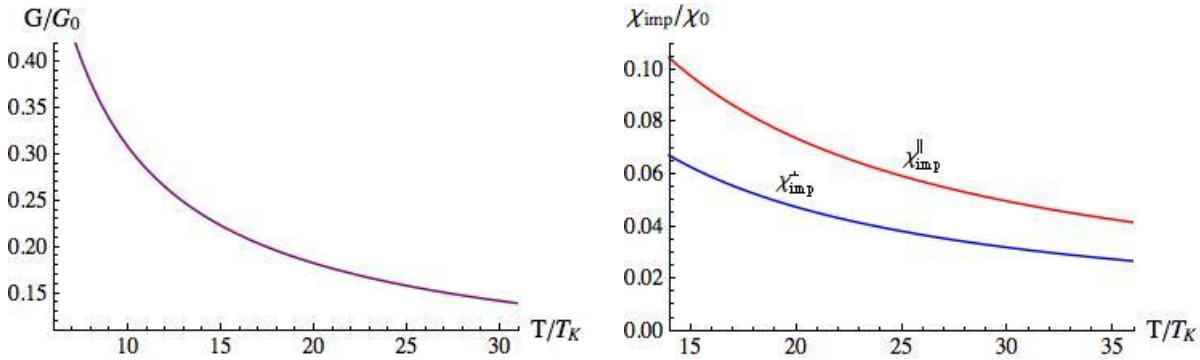

Figure 2: The zero-bias conductance (left panel) and the impurity susceptibility (right panel) as function of temperature in the weak coupling regime [$T>T_K$].