Bulletin of Pure and Applied Sciences.
Vol.38 D (Physics), No.2,
July-December 2019 P.55-59

Print version ISSN 0970 6569
Online version ISSN 2320 3218
DOI: 10.5958/2320-3218.2019.00009.5

Original Research Article

Available online at www.bpasjournals.com

Kondo Box Effects by Varying Coupling between Dots and Chain

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Received on 19.07.2019
Accepted on 03.10.2019

ABSTRACT We have studied the Kondo box effect by varying the coupling between the dots and the chain. The physics of a Kondo box can be realized in systems of two impurities coupled between them by a finite number of non-interacting sites. Finite size effects can take place together with a magnetic interaction between the impurities of the Ruderman-Kittel-Kasuya-Yosida type. We have found that when Kondo effect is present, the fourth order Ruderman-Kittel-Kasuya-Yosida interaction between the impurities is mediated by the electrons of the non-interacting sites, which are participating simultaneously in the Kondo screening of each impurity. It was also found that other types of magnetic interactions arised such as the Kondo correlated or super exchange interactions. Using vibrational wave functions it was predicted that the interaction between the impurities was mainly due to an interference-enhanced hybridization that generated Kondo doublet states. We analysed a double quantum dot system simultaneously connected to metallic leads and between themselves through a finite number of non-interacting sites. The impurities in such as system are coupled to and interact through a non-interacting linear chain that consisted a quantum box, whose electrons participated in the Kondo's screening. Thus there is interplay between a bulk continuous Konodo regime and a two impurity Kondo box. We also analysed the transport properties for different values of number of sites of the non-interacting linear chain and for different couplings of the quantum dots with it. The results were valid for temperatures below the characteristic single impurity Kondo temperature. The obtained results were in good agreement with previously obtained results

KEYWORDS Kondobox, coupling, quantum dot, impurity, non-interacting, Kondo screening.

INTRODUCTION

When the charge on the quantum dot is close to an odd integer, the Kondo effect takes place and it resulted in transmission through the system at temperatures below the kondo temperature for gate voltages that did not incorporate extra charge into the quantum dot. Hewson [1] studied that electrons in the quantum dot leaded to form a spin singlet, which is one of the clearest benchmarks of the kondo effect. Anderson [2] presented the system that constituted an experimental realization of the single-impurity Anderson modesl. Alexander et al., [3] showed that two quantum dots directly coupled between them amounted to an experimental realization of the two impurities Anderson model. Glazman et al., [4] and NG et al., [5] predicted the occurrence of the Kondo effect in a single quantum dot device and its subsequent experimental observation by done by Goldhaber et al., [6]. Jayatilaka et al., [7] and Hamad et al., [8] studied theoretically several single, double quantum dot and multiple quantum dots devices or systems with atoms or molecules acting as magnetic impurities. It was experimentally studied by Neel et al., [9] and Bork et al., [10]. Cornaglia et al. [11] and Anda et al., [12] showed kondo resonance and kondo peak with a very narrow dip at the Fermi level which is representative of a two stage kondo regime. Jayaprakash et al., [13] predicted that this system could suffer a quantum phase transition which involves a non Fermi liquid fixed point. Malecki et al., [14] studied these transitions in the two impurities Anderson model.

METHOD

We have used finite-U slave-boson field approximation for our work. By introducing in the Hamiltonian a set of bosonic operators which incorporate into the system underlying the kondo regime. These operators, l_i, $p_{i\sigma}$ and d_i, with i corresponding to the i^{th} impurity are responsible for projecting the system on a state of zero, single and double occupation on the impurity and are introduced by the hybridization of the fermion which creates (annihilates) on electron with spin σ in the i^{th} impurity

$$f_{i\sigma}^{\dagger} \to Z_{i\sigma}^{\dagger} f_{i\sigma}^{\dagger}$$

where

$$Z_{i\sigma}^{\dagger} = \left[1 - d_i^{\dagger} d_i - p_{i\sigma}^{\dagger} p_{i\sigma}\right]^{-\frac{1}{2}} \left(e^{\dagger} p_{i\sigma} + p_{i\sigma}^{\dagger} d_i\right) \times \left[1 - e_i^{\dagger} e_i - p_{i\sigma}^{\dagger} p_{i\sigma}\right]^{-\frac{1}{2}}$$

is an operator that in the mean field approximation, becomes a parameter $\overline{Z}$ that reproduces correctly the results expected in the non-interacting limit. U=0 and is responsible for the renormalization of the connection of the impurities to non-interacting linear chain and to the metallic leads. It was observed that this parameter became less than 1, $\overline{Z}$ < 1 as the system enters in to the kondo regime.

An Anderson Hamiltonian composed of three terms $H = H_0 + H_t + H_{lcc}$. The first contribution carries the local physical information of the quantum dots and is given by

$$H_0 = \sum_{\substack{i=\alpha;\beta \\ \sigma}} \in_i f_{i\sigma}^{\dagger} f_{i\sigma} + \sum_{i=\alpha;\beta} U f_{i\downarrow}^{\dagger} f_{i\downarrow} f_{i\uparrow}^{\dagger} f_{i\uparrow}$$

where $\in_i$, U and $f_{i\sigma}^{\dagger}\left(f_{ir}\right)$ represent the local energy state, the electron – electron coulomb interaction and the operator that creates $\in_i = 0$. The local energy of the dots is tuned by a gate potential Vg that, for simplicity was considered to be the same for both quantum dots.

Slave boson comes from the constraints

$$e_i^\dagger e_i + \sum_\sigma p_{i\sigma}^\dagger p_{i\sigma} + d_i^\dagger d_i - 1 = 0$$

and

$$f_{i\sigma}^\dagger f_{i\sigma} - p_{i\sigma}^\dagger p_{i\sigma} - d_i^\dagger d_i = 0$$

That is imposed on the boson operators in order to eliminate the non physical states, assuring that impurity is occupied with zero, one or two electrons and establishing a correspondence between boson and fermions. They are incorporated into the Hamiltonian through the Lagrange multipliers λ_1^i and $\lambda_{2\sigma}^i$.

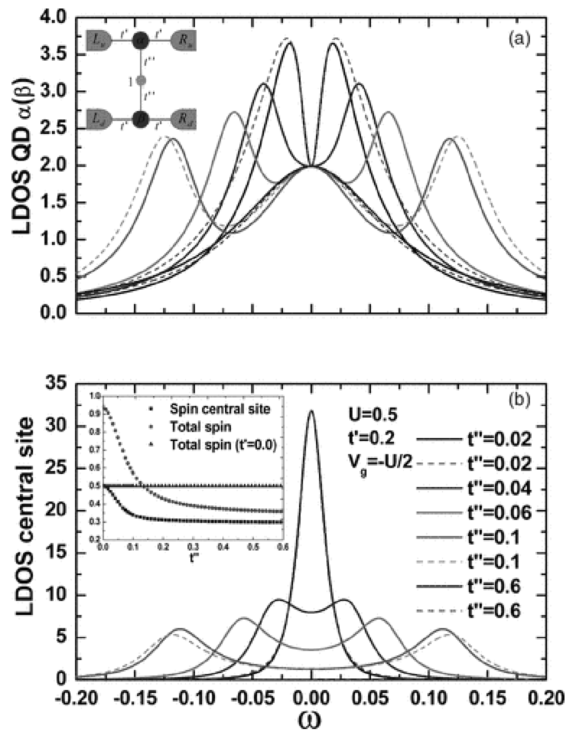
RESULTS AND DISCUSSION

In graph we have presented the local density of state calculated in the quantum dots and in the non-interacting central site, obtained the gate potential V_g adjusted in the particle-hole symmetric position $V_g = -\frac{U}{2}$ it can be easily identified two quantum regimes in the system. The first, for $t'' \lesssim 0.04$, in which we observed a peak with a narrow dip just at the Fermi level, is characterized by the existence of two energy scales that correspond to two kondo temperature T_{k_1} and T_{k_2}.

These energy scales naturally emerged and are associated with the widths of the dip and of the peak in the local density of state of the quantum dots. In this regime the particles and hence the spins are equally distributed in the three quasi degenerated molecular energy states that exist next to $Ef = 0$.

Then the first kondo temperature can be thought of as coming from the partial screening of the quantum dots spin by the free spin allocated at the central non-interacting site. The remanet spin is then completely screened by the leads, characterizing the second kondo temperature. This kondo temperature behavior is that the non-interacting linear chain showed, for low values of t'', a resonance in the local density of state just at the Fermi level. Then there is a free spin allocated this level that screens the spins at the quantum dots. The width of this resonance is similar to the width of the dip in the local density of state at the quantum dots.

When there is a peak with narrow dip in the local density of state of the dots, a magnetic field applied at the central non-interacting site produced the disappearing of the dip and the single kondo peak was recovered. The external magnetic field freezes the spin by opening a spin dependent Zeeman splitting at the central site, eliminating its screening capabilities the recovering of the central kondo peak as the central dip disappeared was a confirmation of this process and of the role played in the inter dot site. The obtained results were compared with previously obtained results of theoretically and experimentally observed result and were found in god agreement.



Graph 1: LDOS calculated (a) in the QDs and (b) in the noninteracing site 1 as a function of the energy ω for N=1 case, and for different magnitudes of the connection t″ between the dots and the non-interacting central site at $V_g = -U/2$.

CONCLUSION

We have presented the kondobox effect by different coupling between the dots and the chain. The interdot chain strongly influenced the transport across the system and the local density of states of the dots. The two kondo temperature regime is manifested as a peak with a dip in the local density of state, rather than only kondo resonance that results from the sum of two peaks with different widths, each one reflecting its corresponding kondo temperature as proposed. As chain was increased, the weight of the state at the Fermi energy was spread along the odd sites of the non-interacting linear chain, reducing the weight of the local wave function, which is directly connected to the dots. This effect reduces the splitting of the two kondo peaks and hence the width of dip decreases. When chain and small coupling between the interdot chain and the dots, a state with two coexisting kondo regimes developed. For magnetic interactions in systems, we have evaluated the spin-spin correlation through a multi configurational Lanczos calculation. The results showed that the correlation between the dots and the central site is anti-ferromagnetism, while between them a ferromagnetic correlation is established. The obtained results were in good agreement of previously obtained results.

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