

SPIN DYNAMICS IN KONDO SYSTEMS AT LOW TEMPERATURES

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The theory of the electron paramagnetic resonance (EPR) of localized moments (LM) in Kondo systems at low temperatures ($kT \ll \omega$, ω , the resonance and external frequencies) is presented, having taken into account the dynamic nature of the exchange coupling between LM and conduction electrons (CE). The obtained EPR parameters of Kondo systems, which are valid at arbitrary temperatures, static magnetic fields and frequencies are studied at different conditions of the dynamic coupling of spin systems of LM and CE. The experimental data on EPR studies of the Kondo system Au:Yb are discussed.

1. INTRODUCTION

The investigation of static and dynamic characteristics of Kondo systems at low temperatures by means of EPR techniques has become an object of growing interest in recent years (1). This is due to the fact that unlike other experimental techniques, EPR investigations make it possible to study independently in the same experiment the Kondo anomalies in the static susceptibility and in the rate of transverse spin relaxation of LM. But increasing of the effectiveness of relaxation processes in spin subsystems of LM and CE due to s-d exchange with decreasing temperature to the Kondo temperature T_k leads to the emergence of a coupled motion of magnetic moments of impurities and CE in the Kondo system (2). Under these conditions, the spin subsystems of LM and CE are characterized by the summary dynamic response. The aim of the present work is the microscopic investigation of the spin dynamics of LM in Kondo systems at low temperatures taking into account the dynamic nature of the exchange interaction.

2. CALCULATION OF THE SUMMARY RESPONSE

The properties of LM and CE in a Kondo system in an external DC H_0 and a weak AC $h(t)$ magnetic fields are described by the Hamiltonian (2,3)

$$H(t) = H_0(t) + H_{es} + H_{eL} .$$

Here $H_0(t)$ is the Hamiltonian of LM and CE in the external magnetic fields; H_{es} and H_{eL} determine the interaction of CE with LM and nonmagnetic impurities, respectively.

Following the non-equilibrium statistical operator method (3) and confining ourselves to the linear approximation in the deviation of the spin subsystems from the equilibrium state and to first order terms in concentrations of impurities, after temporal Fourier transformation we obtain for the total response of LM and CE

$$\chi(\omega) = (c_s a_e - c_e b_e + c_e a_s - c_s b_s) (a_s a_e - b_s b_e)^{-1}$$

The parameters a_i, b_i, c_i ($i=s,e$) are defined by the expressions:

$$a_i = \omega_i' - \omega - \theta_i \Xi_{ij}(\omega) - \Xi_{iL},$$

$$b_i = \lambda \chi_j (\Xi_{jL} - \omega_j) + g_i \theta_i \Xi_{ij}(\omega) / g_j ,$$

$$c_i = \chi_i (\omega_i' - \Xi_{ij}(\omega) - \Xi_{iL}) + g_i \chi_j \Xi_{ji}(\omega) / g_j ,$$

where

$$\omega_i' = \omega_i (1 + \lambda \chi_j) , \quad \theta_i = 1 + \lambda \chi_i g_j / g_i ,$$

$$\Xi_{ij}(\omega) = \text{Re} \Xi_{ij}(\omega) + i \text{Im} \Xi_{ij}(\omega) , \quad (ij=se, es, eL) ,$$

$$\chi_i = \langle M_i^z \rangle / H_i^i , \quad H_i^i = H_0 + \lambda \langle M_j^z \rangle , \quad \langle \dots \rangle = \text{Tr}(\dots \rho) ,$$

ρ is the equilibrium statistical operator; λ is the molecular field constant; M_i ($i=s,e$) is the operator of the spin magnetization.

The imaginary parts of the kinetic coefficients $\Xi_{ij}(\omega)$ define the transverse relaxation rates of spin magnetizations of LM and CE, caused by the s-d(-f) exchange and spin-orbit scattering of CE on nonmagnetic impurities. The real parts $\Xi_{ij}(\omega)$ determine shifts of the resonance frequencies of LM and CE.

Using the temperature Green's func-