Homogeneous Dynamical Susceptibilities of Dilute Magnetic Alloys

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The four longitudinal and four transverse dynamical susceptibilities for zero wave number of the coupled system of conduction electrons and impurity spins in metals are discussed within the s–d model. The susceptibilities are expressed in terms of two well-behaved relaxation functions which are then calculated in lowest order perturbation theory. As a result closed expressions for the dynamical susceptibilities are found valid for all frequencies, magnetic fields, and temperatures under the restriction that Kondo anomalies are quenched. A Bloch equation description is found to be valid in the transverse case, whereas in the longitudinal case large deviations from the Bloch-type behavior may occur (provided the bottleneck is broken) whenever the thermal energy is small compared to the Zeeman energy of the impurities. However, these anomalies do not cause a breaking of the bottleneck.

1. INTRODUCTION

The dynamical properties of a system of randomly distributed spins in a metal coupled to the conduction electrons via the exchange interaction are usually discussed in terms of relaxation times and g shifts. This has been done, e.g., by Hasegawa who used a coupled set of phenomenological Bloch equations to calculate the dynamical susceptibility of such systems. The treatment of Hasegawa fails to properly take into account relaxation proceeding towards the instantaneous local equilibrium polarizations. A modified version of the Hasegawa equations which correctly describes this point

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for the special case of equal $g$ factors of the conduction electrons and local spins has been given by Cottet et al.\textsuperscript{2} A correct version of the general linearized coupled Bloch equations can be found elsewhere.\textsuperscript{3,4} It has been derived microscopically within the $s$–$d$ model together with explicit expressions for the relaxation frequencies and line shifts. This theory as well as others\textsuperscript{5} is restricted to the low-field regime, i.e., the Zeeman energies of the local spins, and the electrons have to be small compared to the thermal energies.

An attempt to generalize the low-field and low-frequency calculations into the nonclassical regime has been made by Orbach and Spencer,\textsuperscript{6} who employed a decoupling procedure in the set of equations for the correlation functions. Recently, Giovannini and Orbach\textsuperscript{7} gave a discussion of the transverse conduction electron susceptibility in terms of the conduction electron self-energy, which should apply to the extremely nonclassical regime. They have reported dramatic anomalies for the quasiparticle damping and for the frequency dependence of the susceptibility. However, their results will be shown to be seriously in error.

One may expect that the dynamical susceptibilities in the nonclassical regime no longer can be represented in terms of constant relaxation times. The kinetic equation approach should break down in this case. Therefore we employ a different technique which has been developed\textsuperscript{8} in connection with the problem of relaxation of a single spin in a metal. In this paper we calculate the four longitudinal and the four transversal susceptibilities of the $s$–$d$ model for small exchange coupling well above the Kondo regime. Within these restrictions we find closed expressions for the correlation functions for all fields, temperatures, and frequencies. Explicit formulae for the various relaxation times are obtained for all values of the impurity spin in the complete range of temperatures and magnetic fields whenever the concept of a relaxation time makes sense. A detailed discussion of the results is given in Section 5.

2. GENERAL FORMULAE

The Hamiltonian of a system of $N_i$ localized impurity spins in a metal interacting with the conduction electrons is given within the $s$–$d$ model by

$$H = H_s + H_d + H_{sd}$$

(1a)

where $H_s$ is the Hamiltonian of the noninteracting electrons

$$H_s = \sum_{p\sigma} E_p \sigma c_{p\sigma}^* c_{p\sigma}$$

(1b)

$H_d$ is the free spin Hamiltonian

$$H_d = -h_d \sum_n S_n^0$$

(1c)