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Relaxation of Nuclei Spins of Ions with Fluctuated Valence in Magnetic Materials

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As a rule, nuclear magnetic relaxation in magnetic solids is considered like non-magnetic solids based on the "rigid" lattice model. In this case the nuclear interactions cannot influence on longitudinal (spin-lattice) relaxation. On the other hand, the increase of longitudinal relaxation rate as a result of magnetic isotope enrichment has been observed experimentally in ferromagnetic YIG films [1]. The phenomenon when nuclear interactions influence on spin-lattice relaxation is well known in liquids [2]. In this case molecular motion modulates nuclear interactions and gives a relaxation process, which depends on both nuclear interactions and lattice dynamics.

We propose to consider the effects of changing valency as reason for modulation the nuclear interactions in magnetic solids. It is known, that the appearance of hetherovalent impurities is possible in YIG lattice. As a result of valency compensation, some Fe^{3+} ions change it valency to Fe^{2+} or Fe^{4+}. It was shown, that iron ions of changed valency migrate in some region near impurity from one lattice position to another [3]. This means the valency of ion, which occupies a lattice position depends stochastically on a time. As a reason for such changing valency for a case of YIG films of work [1], let us consider the non-controlled technological impurities, which appear during film grows.

Taken into account that the NMR frequency depends on valency of ion to which this nucleus belong, the Hamiltonian of nuclei I and S at different lattice sites we can write in the form

$$\mathcal{H}_0 = -\omega_I I_Z - \omega_S S_Z + 2d(2I_Z S_Z - I_X S_X - S_Y I_Y)] .$$

Here $\omega_{I,S}$ are the NMR frequencies of nuclei I and S, d - dipolar interaction constant. Let us assume that NMR frequency ω_S is the stochastic function of a time and fluctuates between ω_S and values ω_I. The interaction Hamiltonian for this model system has the form

$$\mathscr{H}_0 = -\omega_I I_Z - \Delta(t) S_Z + 2d(2I_Z S_Z - I_X S_X - S_Y I_Y)],$$

where $\Delta(t)$ is a stochastic function of time and can be equals to ω_I or ω_S.

Using the standard procedure [2] we have obtained the expressions for spin-lattice (T_1^{-1}) and spin-spin (T_2^{-1}) relaxation rates

$$T_1^{-1} = \frac{\Omega}{\omega_I^2 + \Omega^2} d^2, \quad T_2^{-1} = \frac{\omega_I}{\omega_I^2 + \Omega^2} d^2 .$$

where $\Omega = \left((\omega_I - \omega_S)/2\right)^2 \tau_c$ and τ_c is the correlation time which describes the fluctuation of resonance frequency of nucleus S. The dipole interaction constant d in equation for T_1^{-1} shows that nuclear interactions really influence on longitudinal relaxation. The modulation of Suhl-Nakamura interactions by changing valency must be taken into account too to get a correspondence between theory and experiment.

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