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EFFECT OF RADIO-FREQUENCY MAGNETIC REVERSAL ON THE γ-RESONANCE SPECTRA OF FERROMAGNETS

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The effect of magnetic reversal in a sample induced by a radio frequency field on the γ-resonance spectrum is considered. It is shown that as a result of change of direction of the effective field at the nucleus during magnetic reversal magnetic hyperfine structure lines disappear from the γ resonance spectrum and new lines appear, whose positions correspond to frequencies that are multiples of frequency of the applied field. A new interpretation of some of the experimental facts based on the calculations is proposed.

A number of recent theoretical and experimental papers are devoted to investigations, by γ-resonance spectroscopy, of the effect of radio-frequency fields on magnetic materials[1-10]. The action of a radio-frequency field on a multidomain sample causes a displacement of the domain walls. If this wall displacement is much smaller than the wall thickness, then an appreciable ($\sim 10^3$) enhancement of the external RF field occurs for the nuclei situated inside the wall[11]. Mittin[1] has shown that strong RF fields give rise to additional "γ-photon" transitions that produce additional satellite lines in the γ-photon" transitions that produce additional satellite lines in the γ-resonance spectra. The strongest distortion of the spectrum occurs, as shown by Gabriel[3], at frequencies corresponding to transitions between the sublevels of the ground and excited states of the Mössbauer nucleus.

On the other hand, it is of interest to consider the case when the RF field moves the domain wall a distance much larger than its thickness, or even reverses the magnetization of the sample completely. Then the time of reorientation of the magnetic moment of an atom over which a domain wall passes can be neglected, and the field direction at the nucleus can be assumed to be reversed jumpwise. We present here a calculation of the γ-resonance spectrum for this case. The results of the calculations allow us to explain, from a new point of view, certain existing experimental results.

We consider two domains separated by a domain wall assumed to be, for simplicity, of the 180-degree type. We choose the z axis in the magnetization direction of one of the domains, and the y axis normal to the wall. The Hamiltonian of a nucleus located at a point with coordinate y is given by

$$\mathscr{H} = -g\mu_N H_{\text{eff}} \hat{I}_z \varepsilon_y(t), \tag{1}$$

$$\varepsilon_y(t) = \begin{cases} -1 & y > y_1(t) \\ +1 & y < y_1(t) \end{cases}. \tag{2}$$

Here g is the gyromagnetic ratio, μ_N is the nuclear magneton, H_{eff} is the effective field at the nucleus, $\hat{I}_z$ is the projection of the nuclear spin on the z axis, and $y_1(t)$ is the coordinate of the domain wall. The usual expression for the probability of absorbing a γ quantum of energy E on going from the ground state to an excited one is given by the formula

$$W(E) = \operatorname{Re} \int_0^\infty \exp\left[i(E - E_0)t - \Gamma t\right] \sigma(t)\, dt,$$

$$\sigma(t) = \frac{2}{\Gamma} \operatorname{Sp}\left[\hat{\mathscr{H}}_\gamma{}^+ \rho \exp\left(i\int_0^t \hat{\mathscr{H}}\, dt\right) \hat{\mathscr{H}}_\gamma \exp\left(-i\int_0^t \hat{\mathscr{H}}\, d\bar{t}\right)\right], \tag{3}$$

where $\hat{\mathscr{H}}_\gamma$ is the Hamiltonian of the interaction of the γ quantum with the nucleus, and ρ is the density matrix. Substituting here the Hamiltonian from (1), we obtain

$$W(E) = \sum_k C_k \operatorname{Re} F\{-\Gamma + i(E - E_0); -iE_k\}. \tag{4}$$

Here C_k is the relative probability of the k-th transition, $E_0 + E_k$ is the energy of the k-th transition, and Γ is the line half-width. We put $\xi = -\Gamma + i(E - E_0)$; $\eta = iE_k$, and then

$$F\{\xi; \eta\} = \int_0^\infty \exp\left[\xi t + \eta \int_0^t \varepsilon_y(t')\, dt'\right] dt. \tag{5}$$

We shall henceforth omit the arguments ξ and η.

Let t_1 be the time in which $\epsilon_y(t)$ changes in value from from -1 to $+1$, and let τ be the time during the period T when $\epsilon_y(t) = +1$ (Fig. 1). Expression (5) must be averaged over t_1, i.e., over the initial phase of the RF field, since the instant t = 0, which is connected with the start of the excited-state decay, is random:

$$F(\tau) = \frac{1}{T}\int_0^T F(\tau; t_1)\, dt_1 = -\frac{1 - \tau/T}{\xi - \eta} - \frac{\tau/T}{\xi + \eta}$$
$$-\frac{1}{T}\left(\frac{1}{\xi + \eta} - \frac{1}{\xi - \eta}\right)^2 \frac{\left(1 - e^{(\xi+\eta)\tau}\right)\left(1 - e^{(\xi-\eta)(T-\tau)}\right)}{1 - e^{\xi T + \eta(2\tau - T)}}. \tag{6}$$

The time τ in (6) is different for the different nuclei in the domain. Let the number of nuclei characterized

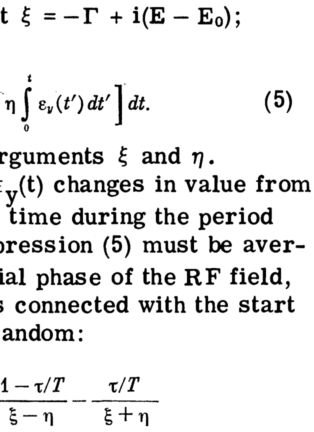

FIG. 1. Reversal of the sign of the field at the nucleus when a domain wall passes over it.

by the time τ be described by the distribution function $\varphi(\tau)$. Then the averaging over the nuclei takes in the general case the form

$$F=\int_0^T F(\tau)\varphi(\tau)\,d\tau. \qquad (7)$$

The concrete form of the function $\varphi(\tau)$ depends on the law of motion of the domain wall.

We shall henceforth consider the case when the intensity of the external RF field is such that the time of total magnetization reversal of the sample is less than the period of the field. For all the nuclei in the sample, the field directions is reversed during each half-period, $\varphi(\tau) = T^{-1}\delta(\tau/T - 1/2)$, and the averaging of (7) reduces simply to a substitution of T/2 for τ in (6).

We consider two limiting cases, $T \to \infty$ and $T \to 0$.

$$\text{As } T\to\infty \quad \left(\nu=\frac{1}{T}\to 0\right) \quad F\to-\frac{1}{2}\left(\frac{1}{\xi+\eta}+\frac{1}{\xi-\eta}\right),$$

$$\text{and as } T\to 0 \quad \left(\nu=\frac{1}{T}\to\infty\right) \quad F\to-\frac{1}{\xi}. \qquad (8)$$

Substitution of these limiting values in (4) yields in the former case a spectrum of six lines, corresponding to a constant field H_{eff} at the nucleus, and in the latter case a single line corresponding to $H_{eff} = 0$. This result is physically understandable: at frequencies much higher than the nuclear Larmor precession frequency, the nucleus is under the influence of only a zero average field.

Figure 2 shows the calculated spectra corresponding to intermediate values of the frequency ν. The necessary numerical parameters were taken from the experimental spectra of metallic iron. As seen from Fig. 2, with increasing frequency the spectrum becomes distorted, the initial peaks drop out, and new peaks appear at positions corresponding to multiples of the applied-field frequency. The relative intensities of the peaks depend on the frequency, and at high frequencies there remains only one central peak, as follows from the limiting formulas (8).

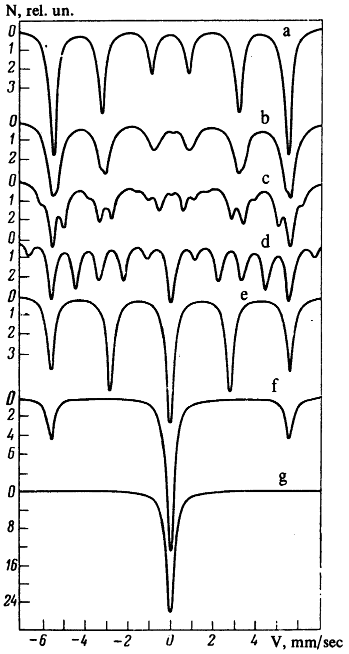

FIG. 2. Influence of the sample magnetization reversal on the γ-resonance spectrum of α-Fe: a—initial spectrum, b—g—ν = 3.1, 6.3, 12.5, 31.5, 63, and 125 MHz, respectively.

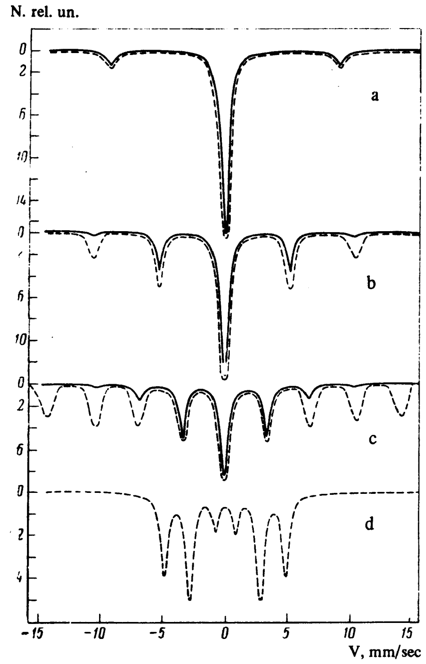

FIG. 3. Influence of RF field of intensity ~15 Oe on the γ-resonance of permalloy (42% Ni). The dashed lines show the experimental spectra obtained in [9], and the solid ones the calculated spectra: a—c—ν = 106, 60, and 39 MHz, respectively, d—initial spectrum.

Recently Pfeiffer[9] obtained γ-resonance spectra of a permalloy (with 42% Ni) foil exposed to an RF field of ~ 15 Oe. His experimental spectra are shown in Fig. 3. He attributes the side peaks to magnetostriction phenomena. The relative intensities of the side peaks should then depend on the amplitude of the atom displacement in the γ-quantum emission direction. In this experiment, however, the sample magnetization remains in the plane of the foil, and there is no change in the sample dimensions, hence no atom displacement in a direction perpendicular to the plane of the foil. On the other hand, the spectra observed in this experiment can be explained on the basis of the calculation made above. Comparing the calculated spectra with the experimental spectra of Fig. 3, we see that the agreement is satisfactory, in spite of the crudeness of the model, in which only 180-degree walls are taken into account. It can thus be assumed that the appearance of side peaks in the γ-resonance spectra of magnets acted upon by RF fields strong enough to cause magnetization reversal is directly connected with the reversal of the direction of the effective field at the nucleus when a domain wall passes over it.

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