# Mössbauer study of the dynamics of a nuclear spin system under ferromagnetic resonance conditions

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The resonance dependence of the intensity of satellites in the Mössbauer spectrum of $Fe^{57}$ on the static field with the excitation of uniform precession of the magnetic moment of a thin iron specimen was observed. A nonlinear dependence of the precession frequency of the nuclear magnetic moment on the radio-frequency (RF) pumping power was observed.

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Interaction of the electron and nuclear magnetic moments leads not only to a Zeeman splitting of the nuclear sublevels in the effective magnetic field in the nucleus, but also to a number of dynamic effects,[1] which are very large when the frequency of the nuclear magnetic resonance coincides with that of the ferromagnetic resonance[2]; this is experimentally achievable in thin ferromagnets.[3] We investigated the state of the nuclear spin system of $Fe^{57}$ by using the nuclear gamma resonance (NGR) method under conditions of excitation of uniform precession of the magnetic moment of a thin iron specimen than was magnetized in its plane. The method allowed us to simultaneously observe the NGR and monitor the amplitude of the transverse component of magnetization ($M\perp$) by using the Bloch crossed-coil method. After computer processing, we calculated from the NGR spectra the relative intensities of the subordinate absorption bands ($s$ is the satellite area and $S$ is the area of the principal line) that were

  

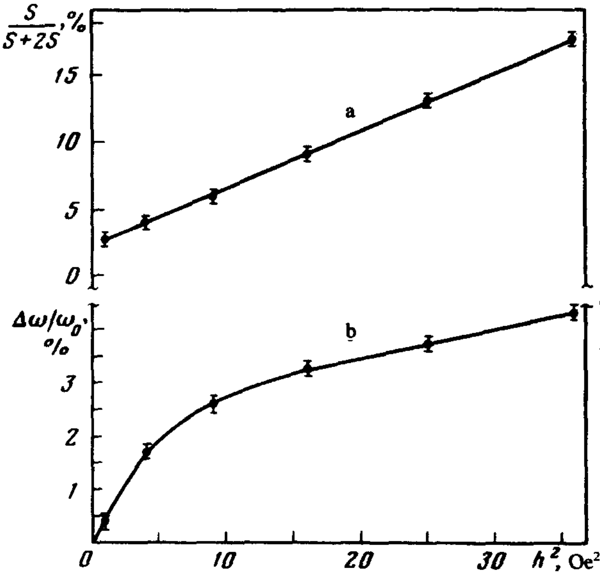


FIG. 1. Dependence of the normalized satellite area (a) and of the relative DFS of nuclear ground state (b) on the RF power input.

located a distance $\Omega$ from the principal lines ($\Omega = 2\pi 62$ MHz is the pumping frequency). The pumping frequency is higher than the frequencies of the nuclear magnetic resonances of the ground and excited $Fe^{57}$ states; therefore, resonance absorption effects can be ignored, and the intensity of the satellites can be examined as only a function of the amplitude of the RF field in the nucleus.[4] The normalized area of the satellites [Fig. 1(a)], in the absence of a static field, is proportional to the power input ($h^2$), i.e., it is proportional to the number of quanta of the RF field; this means that the transitions from the ground state to the excited state of the nucleus are two-quantum transitions via the virtual level. We determined the relative dynamic frequency shift (DFS) $\Delta\omega/\omega_0$ (where $\omega_0$ is the NMR frequency of the unperturbed nucleus and $\Delta\omega$ is the variation of the NMR frequency) of the ground state of the nucleus from the variation of the corresponding intervals between the NGR components of the spectrum. The power dependence of the DFS is shown in Fig. 1(b). As is known,[1] the DFS is a highly nonlinear function of not only the frequency and amplitude of the RF field in the nucleus but also of the projection of the nuclear magnetic moment, which can have different, stable stationary states in a rotating coordinate system and can switch from one state to another by changing the parameters of the coupled electron-nucleus vibrational system. Figure 2 shows the resonance dependences of the amplitude of the transverse component of magnetization (curves 1 and 2), the intensity of the satellites (3 and 4) and the DFS of the nucleus (5 and 6) on the static field intensity for different pumping amplitudes. It can be seen in a comparison of curves 1, 2, 3, and 4 that the NGR method has a higher resolution than the crossed-coil method used by us, and the Bloch method showed no evidence of peculiarities in the 40 to 400-Oe interval of static fields, where the magnetostatic Walker modes with even indices are apparently excited and where a resonance change in the DFS from the static field of up to 14%[5] was observed by us.

The curves 3 and 4 reflect the variation of the transverse magnetic susceptibility

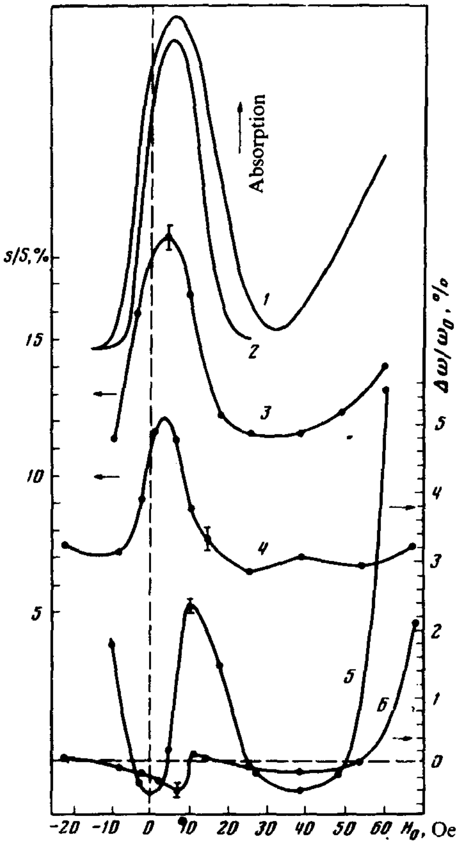


FIG. 2. Dependence of $M\perp$ (curves 1 and 2), of the satellite area (3 and 4), and of the nuclear DFS (5 and 6) on the static field ($H_0$) for different RF field ($h$) amplitudes. (Curves 1, 3, and 5 correspond to $h = 2$ Oe; curves 4 and 6 correspond to $h = 1.4$ Oe; curve 2 corresponds to $h = 10^{-4}$ Oe).

of the sample under ferromagentic resonance conditions and the corresponding variations of the gain coefficient of the RF field in the nucleus.[1,2] It can be seen from the behavior of the DFS (curve 6) that as a result of variation of the natural frequency of the electron system, which[3] is proportional to the static field, there is an abrupt change in the projection sign of the nuclear moment, which is analogous to a 180° change in the phase of the oscillations in the model of two, coupled linear oscillators due to a change in the characteristic frequency of one of the oscillators. However, at a higher power (curve 5) the mechanism of parametric coupling between the electron and nuclear systems apparently is dominant, which leads to a nonlinear dependence of the natural frequency of the nucleus on the oscillation amplitude.[1] Under strong magnetic anisotropy conditions (shape anisotropy in our case), the oscillations of the sample's magnetic moment can be excited parametrically (see Ref. 6, where the excitation of Mössbauer satellites at frequencies of $\Omega$ and $\Omega/2$ was reported in $\alpha$-$Fe_2O_3$—an antiferromagnet with an easy-plane-type of anisotropy).

It should be noted that the amount of splitting of the excited state of the nucleus, within the accuracy limits of the experiment, remains constant, i.e., the average effective field in the nucleus does not change. This also confirms the mechanism of coherent dynamic interaction of the electron and nuclear magnetizations for nuclei in the ground state.

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