Scientific session of the Division of General Physics and Astronomy of the Academy of Sciences of the USSR (29 May 1991)

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A scientific session of the Division of General Physics and Astronomy of the Academy of Sciences of the USSR was held on 29 May 1991 at the P. L. Kapitza Institute of Physics Problems of the Academy of Sciences of the USSR. The papers listed below were presented at this session:

1. S. L. Brazovsky. Conducting (and superconducting?) carbon.

2. G. V. Kozlov, A. A. Mukhin, A. Yu. Pronin, and A. S. Prokhorov. Spin-flipping transitions and dynamic properties of rare-earth weak ferromagnetics.

A brief summary of one paper is presented below.

G. V. Kozlov, A. A. Mukhin, A. Yu. Pronin, and A. S. Prokhorov. *Spin-flipping transitions and dynamic properties of rare-earth weak ferromagnetics.* High-frequency properties of rare-earth orthoferrites ($RFeO_3$) in submillimeter wave band were studied experimentally and theoretically and the main types of dynamic behavior of strongly interacting paramagnetic (R) and antiferromagnetic (Fe) subsystems were elucidated.

The transmission spectra of $RFeO_3$ (R = Ho, Er, Yb, Dy, Gd) were measured on a submillimeter BWO (backward-wave oscillator) spectrometer "Epsilon"[1] in $\nu = 100$–1000 GHz frequency range at $T = 4.2$–300 K. The temperature dependences of resonance frequencies, linewidths, and contributions to static magnetic permeability of the AFMR modes of the Fe-subsystem and R-modes, determined by electron transitions in a rare-earth ion (REI), were obtained. The effects of strong interaction between AFMR and R-modes were discovered, which are most conspicuous in the domain of spin-flipping (SF) and phase transitions (PT) and determine qualitatively different behavior of AFMR-modes ($HoFeO_3$, $ErFeO_3$, $YbFeO_3$).[2]

R-modes, connected with electric He dipole transitions, which give a significant contribution (about 30%) to the permittivity ε_{zz} of crystals with a decrease in temperature, were discovered in TmFeO along with the R-modes, determined by magnetic dipole electron transitions in Tm^{3+}.[2,3]

A theory was developed which makes it possible to describe from unified positions the observed variety of dynamic properties of orthoferrites with different types of rare-earth ions (REI). The basis of the theory is the description of the linear dynamics of the R-subsystem made with the help of generalized dynamic susceptibilities with respect to the alternating external field and anisotropic exchange field of the Fe-subsystem. Dynamic susceptibilities are determined by the spectrum and wave functions of REI in the crystal line and exchange fields.

The Fe-subsystem is described with the help of Landau-Lifshitz equations in which exchange fields from the R-subsystem are taken into account. Within the framework of the approach employed here it was possible to describe quantitatively in a consistent manner both the static properties (for example, the presence of orientation transitions) and the dynamic properties of the orthoferrites under investigation (behavior of the frequencies of coupled vibrations of the Fe- and R-subsystems and mode contributions to static magnetic permeability). It was shown that the AFMR-mode behavior strongly depends on REI spectrum in a crystal line field, symmetry of the ground state of REI and peculiarities of its interaction with the Fe-subsystem.

As an illustration Fig. 1 gives temperature dependences of the frequencies of coupled vibrations of the Fe- and R-subsystems for the case when the R-subsystem is described by a two-level approximation (quasidoublet), and when with a decrease in temperature a spin flipping of a weak ferromagnetic moment from the c-axis (Γ_4) (to the a-axis (Γ_2) is realized in the system. The mechanism of spin flipping is due to anisotropy of exchange splitting of a REI ground quasidoublet, i.e., its increase during the transition into the Γ_2 phase. In this case the system has 4 magnetoactive modes: 2 AFMR-modes and 2 R-modes, corresponding to two nonequivalent positions of the REI.

The nature of the behavior of the modes of coupled vibrations differs significantly according to the relation between the characteristic frequencies of AFMR- and R-modes. In the case when the quasidoublet splitting is great ($\Delta_R > h\nu(\mathrm{Fe}) = h\gamma(2H_E H_A(\mathrm{Fe}))^{1/2}$), we have the usual behavior of the quasiferromagnetic AFMR mode (ν_1), i.e., its softening at the PT points [Fig. 1(a)]. In the opposite case when the quasidoublet splitting is small, the picture is more complex [Fig. 1(b)]. At the high-temperature end of spin flipping (T_1) the AFMR frequency ν_1 does not soften at all, while the corresponding R-mode ν_4 softens. Here at the

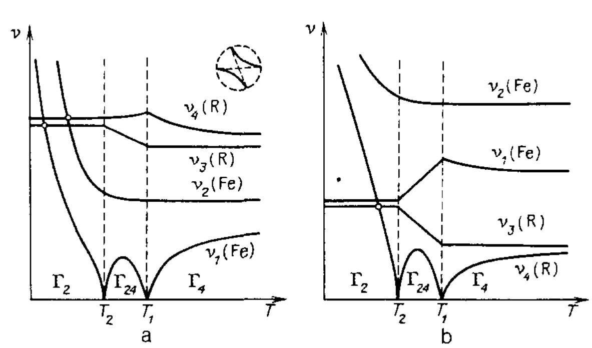

FIG. 1. Temperature dependences of the resonance frequencies in $RFeO_3$ at spin flipping $\Gamma_4 \to \Gamma_{24} \to \Gamma_2$. (a) $-\Delta_R > h\nu(\mathrm{Fe}) = h\gamma(2H_E H_A(\mathrm{Fe}))^{1/2}$; (b) $-\Delta_R < h\nu(\mathrm{Fe})$.

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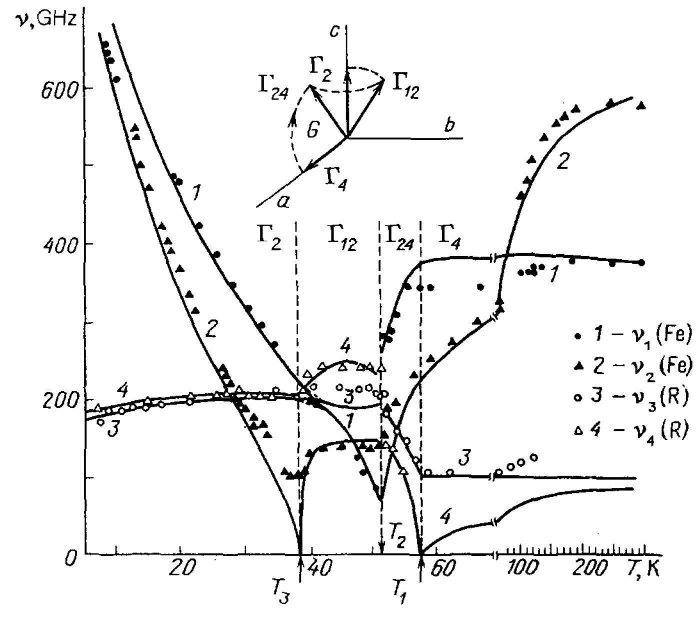

FIG. 2. Temperature dependences of the resonance frequencies in $HoFeO_3$ involving spin flipping. Symbols–experiment, solid lines–theory.

second end of the flipping (T_2) the frequency of the AFMR-mode softens.[2]

Both situations considered above are most clearly realized in $TmFeO_3$ and $YbFeO_3$. In $TmFeO_3$, where the splittings of Tm^{3+} levels in the crystal line field and the corresponding frequencies of the R-modes are comparatively high ($\geqslant 17\,\mathrm{cm}^{-1}$), the quasiferromagnetic AFMR mode (ν_1) softens at both boundaries of spin flipping $\Gamma_4 \to \Gamma_{24} \to \Gamma_2$ with the corresponding contributions of this mode to the magnetic permeability ($\Delta\mu_x$, $\Delta\mu_z$) diverging. And in $YbFeO_3$ at the same spin flipping instead of the AFMR-mode (ν_1), the R-mode (ν_4) softens, which is connected with the transitions inside the ground doublet of Yb^{3+}.

The modes have a more complex behavior at PT in $ErFeO_3$ and $HoFeO_3$. It was shown that in $ErFeO_3$ the observed softening of the AFMR-mode ν_1 at PT $\Gamma_4 \to \Gamma_{24} \to \Gamma_2$ is determined by its strong interaction with the excited states of Er^{3+} in the crystal line field, and the interaction with a low-lying R-mode, due to the splitting of the ground Er^{3+} doublet, determines the presence of gaps at the PT points. In $HoFeO_3$, where spin flipping is of a complex character ($\Gamma_4 \to \Gamma_{24} \to \Gamma_{12} \to \Gamma_2$), both AFMR-modes soften and, moreover, one of them (ν_1) is characterized by a strong interaction with a low-lying R-mode and the other (ν_2) with higher lying excited states of the Ho^{3+} ion (Fig. 2).[4]

Taking the indicated effects into account numerical calculations of resonance frequencies of orthoferrites were carried out and the main parameters of their magnetic interactions (anisotropy constants, R–Fe exchange parameters, and so on) were determined.

[1] A. A. Volkov, Yu. G. Goncharov, G. V. Kozlov, S. P. Lebedev, and V. I. Mal'tzev, Prib. Tekh. Eksp. **2**, 236 (1984), [Instrum. Exp. Tech. (USSR)].
[2] A. A. Mukhin and A. S. Prokhorov, Trudy IOFAN **25**, 162, (1990).
[3] G. V. Kozlov, A. A. Mukhin, A. Yu. Pronin, A. S. Prokhorov, V. Zhelezny, and Ya. Pettzel't, Pis'ma Zh. Eksp. Teor. Fiz. **52**, 890 (1990) [JETP Lett. **52**, 264 (1990)].
[4] A. M. Balbashov, G. V. Kozlov, S. P. Lebedev, A. A. Mukhin, A. Yu. Pronin, and A. S. Prokhorov, Zh. Eksp. Teor. Fiz. **95**, 1092 (1989), [Sov. Phys. JETP **68**, 629 (1989)].

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