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INVESTIGATION OF Fe_3BO_6 BY THE NUCLEAR γ RESONANCE METHOD

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The authors of [1] recently established that the compound Fe_3BO_6 is an antiferromagnet with weak ferromagnetism. From measurements of the dependence of the magnetic moment on the temperature they determined the temperature of its transition to the paramagnetic state (508°K) and observed spin reorientation at a temperature 415°K . The crystal structure of this compound is orthorhombic and the space group is P_{nma} [2].

In the present paper we present results of investigation of Fe_3BO_6 by the method of γ resonance spectroscopy in the temperature region $77 - 545^\circ\text{K}$. The Fe_3BO_6 single crystals were grown by the method of spontaneous crystallization from a solution in the melt in the system $\text{PbO} - \text{B}_2\text{O}_3 - \text{Fe}_2\text{O}_3$. The single crystals were in the form of plates with dimensions up to $15 \times 5 \times 0.5$ mm.

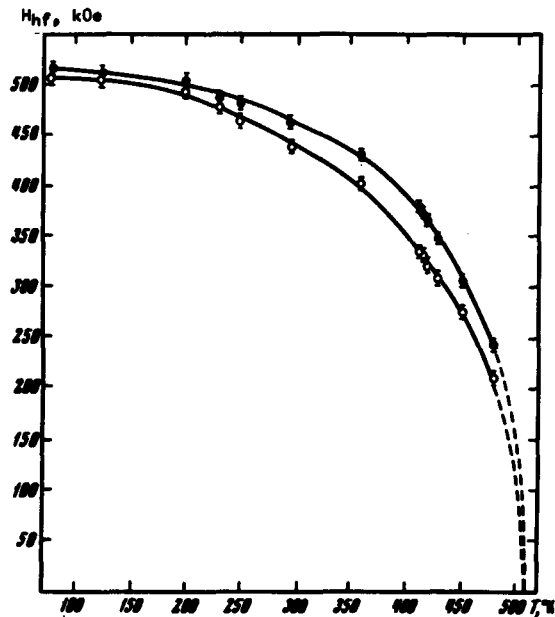


Fig. 1. Temperature dependence of the internal hyperfine magnetic field H_{hf} : o - for the ions Fe(I), □ - for the ions Fe(II).

The Fe_3BO_6 crystal lattice is based on hexagonal close packing of the oxygen ions, with iron ions located in the octahedral voids and boron ions in the tetrahedral voids; it presents an alternation of layers of ions of iron and boron and of ions of oxygen along the c axis. Out of the 12 Fe^{3+} ions in the unit cell, four ions, Fe(I), have each eight magnetoactive bonds with the Fe^{3+} ions in the neighboring layers, and the remaining eight ions, Fe(II), have six bonds each.

The authors of [1] have shown, on the basis of magnetic and Mossbauer measurements on single-crystal Fe_3BO_6 , that at 4.5°K the spins of the iron ions experience a reorientation from the direction [001] to [100].

The Mossbauer investigations were performed by us in a nuclear γ resonance spectrometer based on the AI-256 multichannel analyzer operating in the time regime. The absorber was powdered single-crystal Fe_3BO_6 with thickness 15 mg/cm^2 in terms of natural

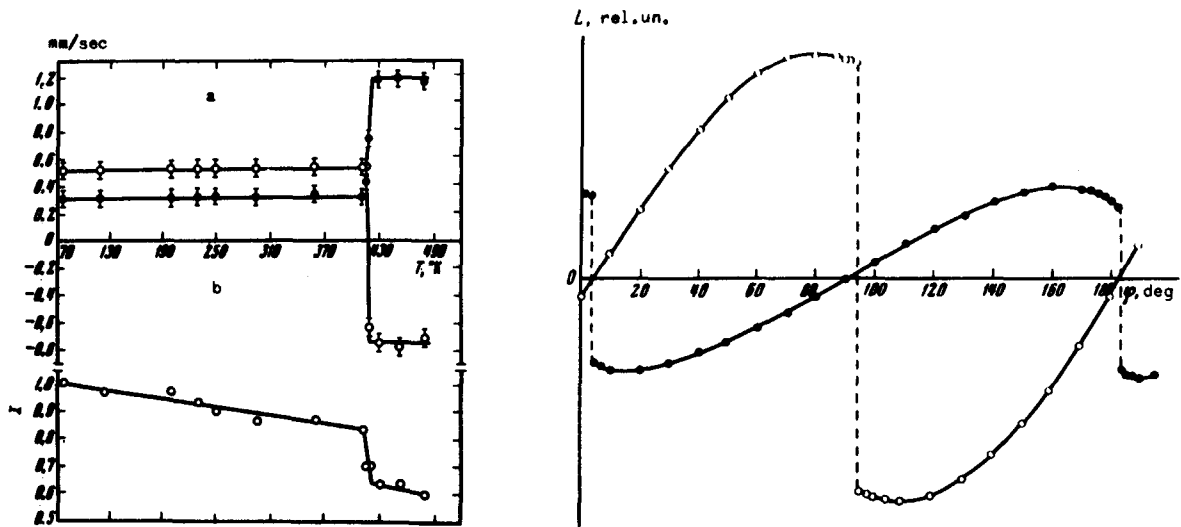


Fig. 2. a - Temperature dependence of the quadrupole line shift: ● - for the Fe(I) ions, ○ - for the Fe(II) ions; b - temperature dependence of the ratio I of the area of the first line of the spectrum at a given temperature to the area of the first line at 77°K.

Fig. 3. Dependence of the torque on the angle ϕ between the direction of the weak ferromagnetic moment and the external field: ○ - 295°K, ● - 433°K.

iron, and the source was Co^{57} in Pt with activity 8 mCi.

The absorption spectra in the temperature interval from 77°K to the Curie point constitute a superposition of two well-resolved six-line spectra corresponding to the two magnetically-nonequivalent positions of the Fe^{3+} ions. The ratio of the intensities of these two spectra is close to 1:2, i.e., it coincides with the ratio of the number of Fe(I) ions to the number of Fe(II) ions in the unit cell. The Curie temperature of the investigated single crystals, measured by the nuclear γ resonance method [3], is $508 \pm 0.5^\circ\text{K}$. The magnetically nonequivalent positions of the Fe^{3+} ions are characterized by different magnitudes and temperature dependences of the internal hyperfine magnetic fields H_{hf} acting on the iron nuclei. $H_{\text{hf}}(\text{I})$ for Fe(I) ions is larger in magnitude in the entire temperature interval than $H_{\text{hf}}(\text{II})$ for the Fe(II) ions (Fig. 1).

The temperature dependence of the shift of the spectral lines due to the quadrupole interaction is shown in Fig. 2a for both types of iron ions, Fe(I) and Fe(II). It is seen from the figure that the reorientation of the spins of the iron ions covers a temperature region 5 - 6°K centered at 417°K. The quadrupole shift of the spectrum lines in this region experiences a sharp change, and reverses sign for the Fe(II) ions. The reorientation temperature, determined by us from measurements of the torques in the (010) plane in a field of 10 kOe is 417°K. The torque curves of the single-crystal Fe_3BO_6 before and after the reorientation are shown in Fig. 3. The spectrum obtained above the Curie point (at 544°K) represents a superposition of two doublets with an intensity ratio 1:2. The quadrupole splitting at this temperature amounts to 2.16 ± 0.06 mm/sec for the ions Fe(I) and 1.14 ± 0.06 mm/sec for the ions Fe(II).

The presence of reorientation of the spins of the Fe^{3+} ions makes it possible to use this phenomenon to determine the direction of the electric field

gradient (EFG) with polycrystalline samples. It is known that in the presence of hyperfine magnetic interaction the quadrupole shift of the excited levels of the iron nuclei is determined by the expression

$$\Delta E_m = (-1)^{|m_1|+1/2} \frac{e^2 q Q}{4} \frac{3 \cos^2 \theta - 1}{2},$$

where m_1 is the magnetic quantum number, e the electron charge, q the gradient of the electric field acting on the nucleus, Q the quadrupole moment of the nucleus, and θ the angle between the direction of the magnetic field and the EFG axis. The change of the measured quadrupole shift of the lines in the case of spin reorientation is due to the angle multiplier. From the values of the quadrupole shift before and after the reorientation and from the value of the quadrupole splitting in the paramagnetic region, it is possible to determine, apart from the sign, the angles θ between the EFG axis and the two crystallographic directions, under the assumption that the quadrupole interaction has a weak temperature dependence. This calculation determines, in addition, the sign of the quadrupole interaction constant, since

$$3 \cos^2 \theta > 0. \quad (1)$$

The calculation of the angles of the EFG axis, performed from the obtained experimental data, has shown that for the ions Fe(I) the EFG axis makes an angle 49° with the [001] direction and an angle 33.5° with the [100] direction. Condition (1) is satisfied here for $e^2 q Q > 0$. For the ions Fe(II) the EFG axis makes an angle of 81° with the direction [001] and an angle 29° with [100]. The condition (1) is satisfied in this case for $e^2 q Q < 0$. Such a difference between the directions of the axes and magnitudes of the EFG is apparently connected mainly with the nonequivalence of the surrounding of the Fe(I) and Fe(II) ions in the second coordination sphere.

Figure 2b shows the dependence, normalized to 77°K , of a quantity proportional to the probability of the resonant absorption, estimated from the areas of the first lines of the spectra. In spite of the qualitative character of the estimate, it is seen from the figure that the probability experiences a jump in the region of the spin-reorientation temperature. Since the probability of the resonant absorption characterizes the connection between the resonant nucleus and the crystal lattice, the dependence shown in Fig. 2b offers evidence of a change of the elastic properties of the crystal lattice Fe_3BO_6 on going through the spin-orientation temperature.

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MECHANISM OF ACCELERATION OF IONS ON THE FRONT OF IONIZATION OF A GAS BY A RELATIVISTIC ELECTRON BEAM

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It was reported recently that when strong-current relativistic electron beams are injected in a gas the ions are captured and accelerated on the gas ionization front [1]. This phenomenon is of interest as one of the promising