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EXPERIMENTAL DETERMINATION OF THE "SIGN" OF THE DZYALOSHINSKII INTERACTION IN AN ANTIFERROMAGNET

V. I. Ozhogin, S. S. Yakimov, R. A. Voskanyan, and V. Ya. Gamlitskii
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In a two-lattice antiferromagnet (AF) with an AF-structure that is even relative to the principal axis, the expression for the energy of the Dzyaloshinskii interaction (DI) is

$$\mathcal{E}_D = -\vec{\beta}\cdot\vec{m} \times \vec{l} = 2\vec{\beta}\cdot\vec{S}_1 \times \vec{S}_2. \quad (1)$$

Here $\vec{m} \equiv \vec{S}_1 + \vec{S}_2$ and $\vec{l} \equiv \vec{S}_1 - \vec{S}_2$ are respectively the ferro- and antiferromagnetic vectors, $\vec{S}_1$ and $\vec{S}_2$ are the spins of the neighboring ions belonging to different magnetic sublattices of the AF, and $\vec{\beta}$ is a constant vectors whose components characterize the magnitude of the DI. The expression for $\mathcal{E}_D$ should be invariant against an operation (which we shall designate by the letter N) consisting of renumbering the sublattices ($1 \rightleftarrows 2$). But $N\vec{l} = -\vec{l}$, and therefore when the sublattices are renumberd the sign of $\vec{\beta}$ is also reversed: $N\vec{\beta} = -\vec{\beta}$ (this also follows from the microscopic equation derived for $\mathcal{E}_D$ by Moria [2]. It follows therefore that the scalar product $\vec{\beta}\cdot\vec{l}$ is invariant against the operation N, and therefore, in particular, its sign should have a definite physical meaning. We shall demonstrate this, using as an example the most popular AF, hematite (α-Fe_2O_3). By virtue of the known symmetry of the crystal (D^6_{3d}) the vector $\vec{\beta}$ is directed along the C_3 axis [2], i.e., if $z \parallel C_3$, then $\vec{\beta} = (0, 0, \beta)$. Let us consider the easy-axis temperature phase of hematite (at $T < T_M \simeq 262°K$), since in this phase we have in the absence of an external magnetic field $l \parallel C_3$ and therefore $\vec{\beta}\cdot\vec{l} \neq 0$. If we apply an external magnetic field $\vec{H}$ in the direction of the axis $x \perp C_3$ then, as shown in [3, 4], an increase in the field causes not only an increase in the inclination of the moments of the sublattices to the field, but also a rotation of the moments around the field direction. The direction of the rotation is uniquely connected with sign($\vec{\beta}\cdot\vec{l}$), namely, the equilibrium vector $\vec{l}$ is rotated from the z axis counterclockwise (looking in the negative direction of $\vec{H}$) if sign($\vec{\beta}\cdot\vec{l}$) = -1, and clockwise in the opposite case. This follows from the fact that in the equilibrium position the DI energy should decrease the total magnetic energy of the crystal. In addition, this can be seen directly by using the relation

$$I_y I_z = (H_x/H_{eff}^2)\beta_z I_z, \tag{2}$$

which follows from Eq. (9) of [5] (the sign of $I_y I_z$ is invariant against N and is uniquely determined by the direction of rotation of the antiferromagnetism axis, i.e., of the vector $\vec{1}$).

The rotation of the sublattice moments around a magnetic field perpendicular to the

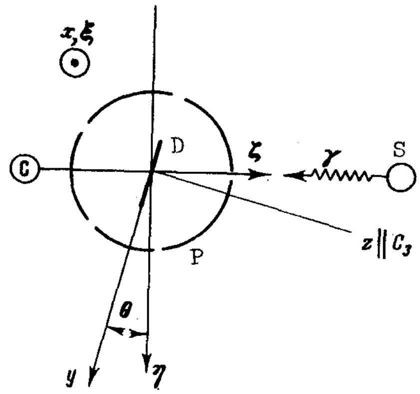

Fig. 1. Experimental setup for the determination of the rotation of the sublattice moments in easy-axis hematite (T < 262°K) around a magnetic field perpendicular to the easy axis; ξ, η, ζ - laboratory coordinate system; x, y, z - coordinate system connected with the crystal axes (z || C_3); S - gamma-quantum source, C - gamma-quantum counter, P - magnet poles, D - projection of sample on the plane of the figure.

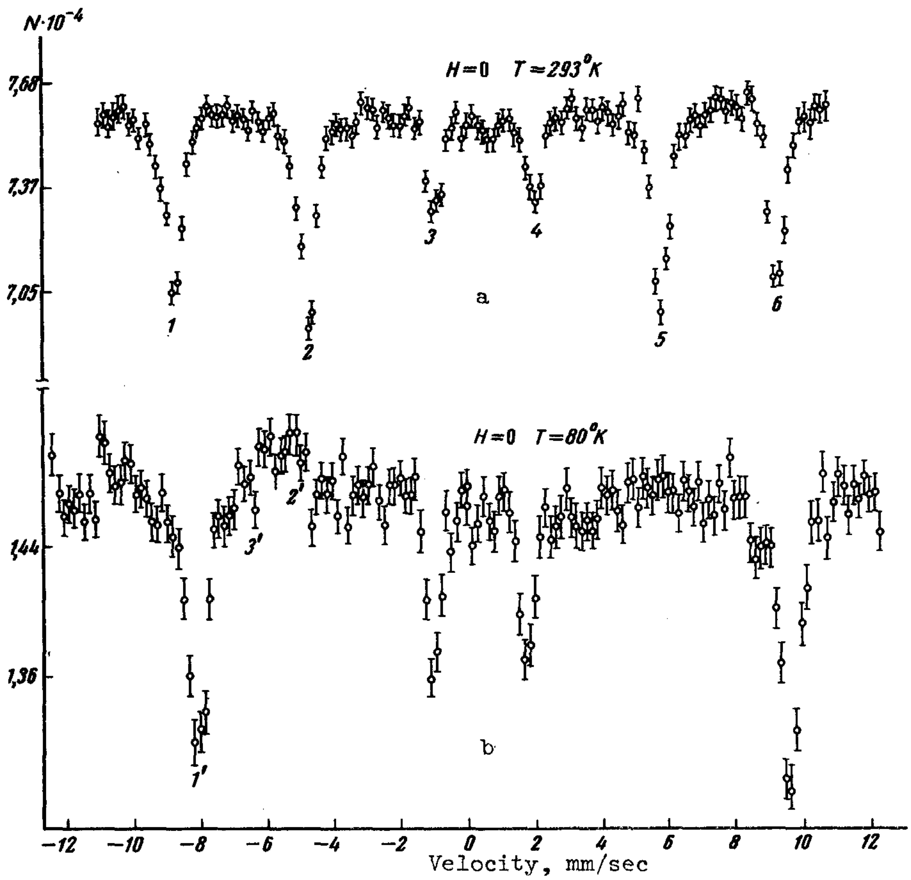

Fig. 2. a, b - results of auxiliary experiment: a - Mossbauer spectrum of single-crystal hematite at T = 293°K, H = 0 and k_γ || C_3 (k_γ - γ-quantum propagation vector), b - the same at T = 80°K.

easy axis can be measured with the aid of the Mossbauer effect, as was done in [6] to study the features of the behavior of hematite in the direct vicinity of the Morin point T_M. To determine the direction of the rotation, the experimental setup must be modified. We have organized an experiment, whose geometry is clear from Fig. 1. A disc of synthetic single-crystal α-Fe_2O_3 (with natural isotope content) 25 mm in diameter, 75 μ thick, and with C_3 axis perpendicular to the plane of the disc, was used as an absorber of the 14.4-keV γ quanta emitted by a source (Co^{57} in stainless steel) of 5 mCi intensity. The counting rate was about 2500 counts/min. The disc was placed between the poles of a magnet in such a way that the field could be applied parallel to the plane of the disc, and the z axis, which is parallel to C_3, was inclined at an angle $\nu = 15°$ to the direction of γ-quantum propagation, perpendicular to the magnetic field.

Figs. 2a,b show the results of an auxiliary experiment, in which the γ-quantum propagation direction was perpendicular to the plane of the disc, and the Mossbauer spectrum of the hematite was plotted at 293° and 80°K in a zero magnetic field. The absence of the second and fourth lines, corresponding to γ transitions with $\Delta m = 0$ in Fe^{57} nuclei, from the spectrum at 80°K shows that the single-crystal has been correctly oriented [7], and the spectrum at 293°K makes it possible to determine the position of the $\Delta m = 0$ lines in terms of the scale of the source velocities.

The main experiment was performed in the described geometry (Fig. 1) at 198°K, the cooling being effected in a magnetic field of 23 kOe to prevent formation of AF domains on the inhomogeneities of the crystal on going through the Morin point T_M[8]. We measured the change of intensity of one of the $\Delta m = 0$ lines when the 23 kOe field was applied along the positive and negative x axes (Fig. 1). An acceptable accuracy was ensured by the accumulated large number of counts (∿200,000) at each source velocity. To eliminate errors due to the possible instability of the electronic circuitry, the count at the top of the $\Delta m = 0$ line was monitored periodically (every 30 sec) against the other characteristic points of the spectrum (points 1' and 3' in Fig. 2b).

The result of the experiment does not depend on the direction of the field in which the sample is cooled, and is shown in Fig. 2c. The decrease of the intensity of the $\Delta m = 0$ line

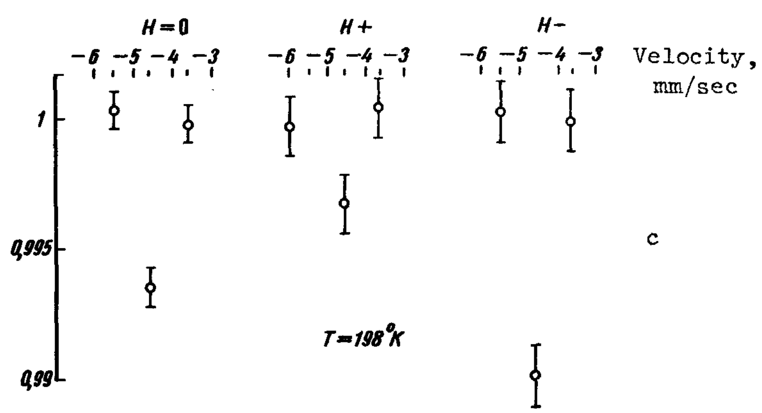

Fig. 2. c - results of main experiment: change of Mossbauer spectrum of single-crystal hematite upon application of a magnetic field in the geometry of Fig. 1. Temperature T = 198°K.

following application of a field H_x = +23 kOe indicates that the magnetic moments of the sublattices are inclined in this magnetic field away from the C_3 axis towards the γ-quantum propagation direction. At H_x = -23 kOe, the deflection is in the opposite direction. This leads to the conclusion that in easy-axis hematite

$$\text{sign}(\vec{\beta}\cdot\vec{1}) = -1 \quad (3)$$

Knowing the dependence of the intensity of the Δm = 0 line on the angle θ between the direction of the magnetic field at the nucleus and the direction of γ-quantum propagation ($I_{\Delta m=0} \sim \sin^2\theta$), it is possible to determine from the data of Fig. 2c the value of $|\theta|$ at $|H_x|$ = 23 kOe, and with it also one of the quantitative characteristics of the hematite, namely $(H^2_{eff}/\beta)_{T=198°K}$ = 110 ± 30 kOe. Similar results were obtained also at a sample temperature 243°K (the magnitude of the effect was correspondingly larger).

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OBTAINING A VISIBLE IMAGE OF RADIO EMISSION IN THE MILLIMETER BAND

A. P. Bazhulin, E. A. Vinogradov, N. A. Irisova, and S. A. Fridman
P. N. Lebedev Physics Institute USSR Academy of Sciences
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Obtaining visible images in millimeter radio waves is an important physical and technical problem. Solution of this problem would make it possible to transmit images of objects using radio waves of this band, and would help to investigate the interaction between millimeter waves and various substances or objects; it would also greatly facilitate studies of the structures of fields of various oscillating systems. Special notice should be taken of the promise offered by this method for the simulation of electromagnetic fields of large-scale reflecting, scattering, or transmitting systems, usually employed in the long-wave band. By obtaining the picture of the distribution, it would be easier to adjust and tune apparatus in quasi-optical systems. Possibilities exist also for the realization of defectoscopy and introscopy in the millimeter band.

Photometry of the obtained photographs would apparently yield the quantitative characteristics of the field distributions.

We obtained visible images of the intensity of the electromagnetic field of radiation with wavelengths λ = 1.7 - 2.5 mm, and photographed these fields. The images were obtained