INVESTIGATION OF THE MAGNETIZATION OF A FERRITE GARNET IN STRONG PULSED MAGNETIC FIELDS

V. E. RODE and A. V. VEDYAEV

Moscow State University

Submitted to JETP editor February 4, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **45**, 415-417 (September, 1963)

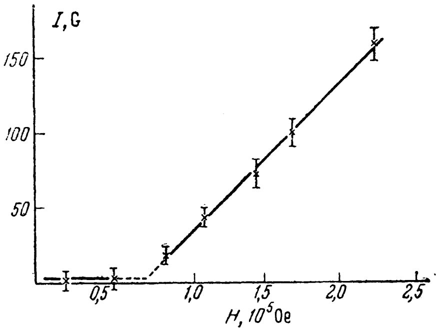
The results are given of an investigation of the magnetization of gadolinium garnet in a pulsed magnetic field of up to 200 kOe at room temperature. It was found experimentally that the ferrite sublattices rotate in sufficiently strong fields and consequently the total magnetic moment of the sample increases considerably. The equilibrium configurations were calculated for a ferrite model with two sublattices at temperatures close to the Curie point. The parameter of the exchange interaction between the Gd and Fe sublattices, $\Theta_{12} = 23 \pm 4$°K, and the effective field acting on the gadolinium sublattice, $H_{eff} = (2 \pm 0.4) \times 10^5$ Oe, were estimated from the experimental data.

In the present work we investigated the magnetization of gadolinium ferrite garnet $5Fe_2O_3 \cdot 3Gd_2O_3$ in pulsed magnetic fields at room temperature. The field intensity reached 220,000 Oe in 6 msec pulses. The field was produced by discharging a capacitor bank of 6800 μF capacitance through a many-turn coil. The working volume of the coil was 1.5 cm^3.

The magnetization of the ferrite investigated was measured by a compensation method with two coils connected in opposition. One of them was used to compensate the magnetic-field signal and the other enclosed the sample. A micrometer movement of the coils made it possible to move them smoothly in the working volume of the coil until the field signal approached zero, which was recorded with a loop oscillograph MP-02. The signal from the measuring coil with the sample was integrated by an RC-circuit and fed to one of the loops of the oscillograph. The coil compensation was checked after each measurement of the sample magnetization. The error in measurement of the magnetization amounted to 7%. It was possible to reduce the error by improving the coil compensation. Simultaneously with measurement of the magnetization we also determined the field intensity at the location of the sample. The field was measured by the usual ballistic method adapted for pulse measurements.[1] Although the solenoid was heated strongly by the discharge, the sample was sufficiently well thermally insulated from the solenoid to keep its temperature practically constant during the pulse, as verified by special measurements.

The results of the investigation of $5Fe_2O_3 \cdot 3Gd_2O_3$ are given in a graph of the dependence of the magnetization on the field (cf. the figure). From this graph it is clear that beginning from fields close to 70,000 Oe the magnetization begins to rise quite rapidly with a differential susceptibility

$$\chi_{diff} = (1 \pm 0.2) \cdot 10^{-3} \text{cm}^{-3}. \qquad (1)$$



Tyablikov[2] has shown that close to 0°K in sufficiently strong and rising magnetic fields

$$(M_{10} - M_{20})/\chi = H_1 < H < H_2 = (M_{10} + M_{20})/\chi$$

the magnetization vectors of the ferrite sublattices rotate and the total magnetization increases in accordance with the law $M = \chi H$, where

$$\chi = M_{10}M_{20}/K\sigma_1\sigma_2. \qquad (2)$$

Gusev[3] has shown that in a wide range of temperatures the susceptibility χ is independent of the temperature and has obtained the following expressions for the critical fields

$$H_1 = (M_1 - M_2)/\chi + \Delta H, \qquad H_2 = (M_1 + M_2)/\chi - \Delta H,$$

where ΔH is a small correction the actual form of which was not given by Gusev.

Our calculations by the method of the energy center of gravity confirm that χ is independent of temperature; in our notation χ has the form

$$\chi = \mu_0^2 N_1 N_2 / \tfrac{1}{2} \sum D_{qj}. \tag{3}$$

Here M_{10}, M_{20}, M_1, M_2 are the saturation magnetizations of the sublattices I and II at zero and nonzero temperatures respectively: N_1 and N_2 are the numbers of electrons in the sublattices I and II; ΣD_{qj} is the sum of the integrals for the exchange interaction between the sublattices I and II, respectively.

In our experiments the critical field $H_1 = 70{,}000$ Oe was considerably greater than the value 5000 Oe which was expected for the ferrite garnet investigated. We note that if the dependence of the magnetization on the field is extrapolated to zero field intensity, the magnetization does not fall to zero, as would be expected from the theoretical formula $M = \chi H$. It seems to us that this discrepancy between the theory and experiment is concealed in neglecting the magnetic anisotropy energy in calculations. Such calculations have not yet been carried out for ferrites, but they have been done for antiferromagnets.[4,5] For pure antiferromagnets $M_1 = M_2$ and consequently $H_1 = 0$ but H_1 is represented by $H_c = \sqrt{2H_E H_A}$, where H_E is the effective exchange field and H_A is the anisotropy field. In the case of $5Fe_2O_3 \cdot 3Gd_2O_3$ the quantity H_c reaches several tens of thousands of oersted and agrees with our experimental data. The field H_c seems to delay the beginning of the sublattice rotation. However the value of the susceptibility χ_{diff}, related to the sublattice rotation, should not be affected strongly by the anisotropy field because this field is much smaller than the effective exchange field. Following what was said above, we may estimate the exchange energy in the first approximation using the formula (3) for χ_{diff}, deduced without allowing for the anisotropy energy.

From the value of χ_{diff} in Eq. (1) we may estimate the magnitude of the exchange energy between the gadolinium and iron ions and the parameter $\frac{1}{2}(\Sigma D_{qj})$ which occurs in Eq. (3). To be able to use the formulas deduced above for a ferrite model with two sublattices, we shall consider only two lattices in gadolinium garnet: one consisting of only the gadolinium ions at dodecahedral interstices, and the other formed by iron ions in octahedral and tetrahedral interstices. In our case this is quite permissible since the negative exchange interaction $Fe^{3+}-O^{2-}-Fe^{3+}$ is much greater than the applied field energy and the exchange interaction $Fe^{3+}-O^{2-}-Gd^{3+}$. Consequently the system $Fe^{3+}(a)-O^{2-}-Fe^{3+}(d)$ behaves as one sublattice with a saturation moment of $10\mu_0$ per molecule.

The formula (3) may be transformed into

$$\chi = \sqrt{N_1 N_2}\, \mu_0^2 / k\Theta_{12}. \tag{4}$$

Here Θ_{12} is the exchange energy on the temperature scale. Comparing this expression with the experimentally determined value in Eq. (1) and assuming that $N_1 = n_1 N$ and $N_2 = n_2 N$ ($N = 1.54 \times 10^{21}$ cm^{-3} is the number of $5Fe_2O_3 \cdot 3Gd_2O_3$ molecules; $\mu_0 n_1 = 42\mu_0$ is the magnetic moment of the six gadolinium ions in each molecule; $\mu_0 n_2 = 10\mu_0$ is the magnetic moment of $(6-4) = 2$ iron ions), we find

$$\Theta_{12} = 23 \pm 4^\circ \text{ K}.$$

Using this value and the formula given by Vlasov,[4]

$$\mu_0 H_{\text{eff}} = \sqrt{\mu/\lambda}\, \Theta_{12} ky,$$

where $\mu/\lambda = 2/6 = 1/3$ is the ratio of the numbers of magnetic ions in the sublattices, we can estimate the effective field acting on the gadolinium ion sublattice:

$$H_{\text{eff}} = (2 \pm 0.4) \cdot 10^5 \text{ Oe},$$

which is quite close to the field value 2.3×10^5 Oe, obtained in experiments on exchange resonance.[6]

[1] Rode, Vedyaev, Kraĭnov, and Talyzin, PTÉ No. 3, 146 (1963).

[2] S. V. Tyablikov, FMM **3**, 3 (1956).

[3] A. A. Gusev, Kristallografiya **4**, No. 5, 695 (1959), Soviet Phys. Crystallography **4**, No. 5, 655 (1960).

[4] K. B. Vlasov, Izv. AN SSSR, ser. fiz. **16**, 339 (1954).

[5] A. Ts. Amatuni, FMM **3**, 411 (1956).

[6] S. Geschwind and R. L. Walker, J. Appl. Phys. Suppl. **30**, 163S (1959).

Translated by A. Tybulewicz
78