ANOMALIES IN THE PHYSICAL PROPERTIES OF GADOLINIUM GARNET FERRITE IN THE LOW TEMPERATURE REGION

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The temperature dependences of the magnetic and magnetoelastic properties and of the ferromagnetic resonance parameters of gadolinium garnet ferrite have been measured at low temperatures. It was established that the curves of the temperature variation of the initial susceptibility and of the paraprocess susceptibility have maxima, while minima are found in the curves of coercive force and of the width of the resonance curve. There are also maxima of the paraprocess magnetostriction and of the effect of uniform pressure on the spontaneous magnetization at this temperature. These results confirm Belov's suggestion[2] that low temperature anomalies, corresponding to a sharp change in the magnetic long range order in a sublattice with "weak" exchange interaction, should occur in ferrites possessing compensation points.

1. Measurements of the temperature dependence of the magnetostriction of gadolinium garnet ferrites[1] showed that the magnetostriction isotherms at temperatures above the compensation point Θ_{comp} are of the form usual for "normal" ferromagnets ($\lambda_{\parallel}$ and $\lambda_{\perp}$ are of opposite sign and $\lambda(H)$ exhibits saturation in the isotherms). However, on reducing the temperature below Θ_{comp} a relatively large volume magnetostriction is superimposed on this magnetostriction, as a result of which saturation is not observed in the isotherms, even in strong fields. The slope of the high field parts of the curves increases with decreasing temperature and reaches a maximum in the region of liquid nitrogen temperature. This behavior of the magnetostriction curves resembles that usually observed on approaching a ferromagnetic Curie point.

From an analysis of the results of measurements on the temperature dependence of the spontaneous magnetization of ferrites with a compensation point, Belov[2] deduced that anomalies should appear at low temperatures in such ferrites, corresponding to a rapid change in the long range magnetic order in the sublattice with "weak" exchange interaction (in our case, in the gadolinium sublattice).

2. In order to confirm this conclusion we undertook measurements of the temperature dependence of a number of physical characteristics of gadolinium ferrite in the low temperature range.

It can be seen from Fig. 1 that a maximum in the magnetic permeability μ_0, measured in a weak field ($H = 1.75$ oe), is found at a temperature of 100° K. It can be seen that the coercive force H_c has a minimum in the region of 100° K. The susceptibility due to the paraprocess, χ_p, of gadolinium garnet ferrite was measured in fields from 1,000 to 3,000 oe in the temperature range from 80° K to room temperature. The maximum in the paraprocess susceptibility can also be seen to be at 100° K.

Measurements of the temperature dependence of the width of the resonance absorption curve, ΔH, of gadolinium ferrite were made at 9,400 Mc/sec, by the short circuited waveguide section method, in the temperature range 4 to 560° K. These measurements showed that ΔH is very great at liquid helium temperatures (Fig. 1), then decreases with increasing temperature, reaches a minimum in the temperature region of 90 — 100° K and then increases again with increasing temperature. We should also mention that the magnitude of the resonance field H_r decreases sharply on cooling below 100° K.

The form of the anomalies near 100° K in the temperature dependence of all the properties measured are thus similar to those usually observed in ferromagnets near the Curie point. This indicates that near 100° K a rapid change in the magnetic long range order takes place in the gadolinium sublattice, in agreement with Belov's conclusions.[2]

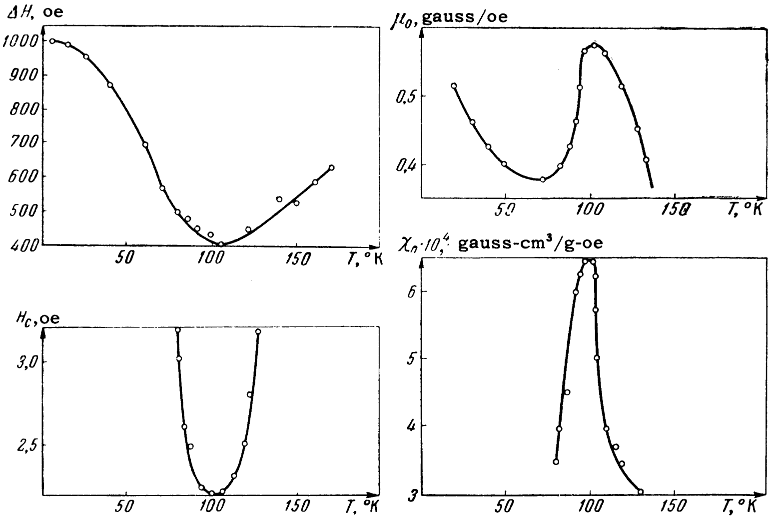

FIG. 1. Anomalies in the temperature variation of some physical properties of gadolinium garnet ferrite at low temperatures.

3. The existence of a relatively large volume magnetostriction by the paraprocess in gadolinium garnet ferrite (in the region of the low temperature magnetic transition) leads one to assume that the exchange interaction between Gd^{3+} ions in the gadolinium sublattice depends strongly on the interatomic distance. Uniform elastic deformations should then exert an appreciable influence on the magnetization of gadolinium ferrite near this transition. We made measurements of the magnetization of gadolinium ferrite at 80° K. The specimen was contained in a bomb in which water was frozen, thus being subjected to a hydrostatic compression on the order of 1,800 atm.

It can be seen from Fig. 2 that the magnetization decreases with increasing pressure, which agree with the sign of the magnetostriction. It follows from simple thermodynamic considerations that the change of volume in the magnetization process at constant pressure (i.e., the volume magnetostriction) is related to the change in magnetization in a field under the action of pressure, by the relation

$$(\partial V/\partial H)_p/V = -(\partial I/\partial p)_H.$$

Our measurements gave

$$(\partial I/\partial p)_H \approx \rho\,(\Delta\sigma/\Delta p)_H = 8\cdot 10^{-9}\,\text{oe}^{-1}$$

(assuming that the density ρ changes little with pressure). From the measurements of magnetostriction[1] we obtained

$$(\partial V/\partial H)_p/V \approx 3\Delta\lambda/\Delta H = 3\cdot 10^{-9}\,\text{oe}^{-1},$$

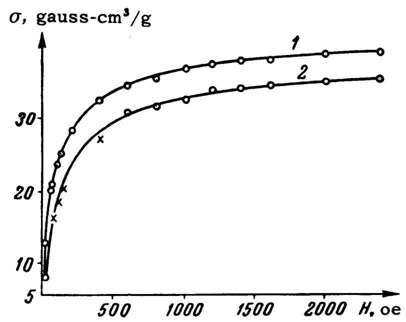

FIG. 2. Magnetization isotherms $\sigma(H)$ of gadolinium garnet ferrite, measured at 80°K: curve 1 – at atmospheric pressure, curve 2 – at a pressure of 1,800 atm.

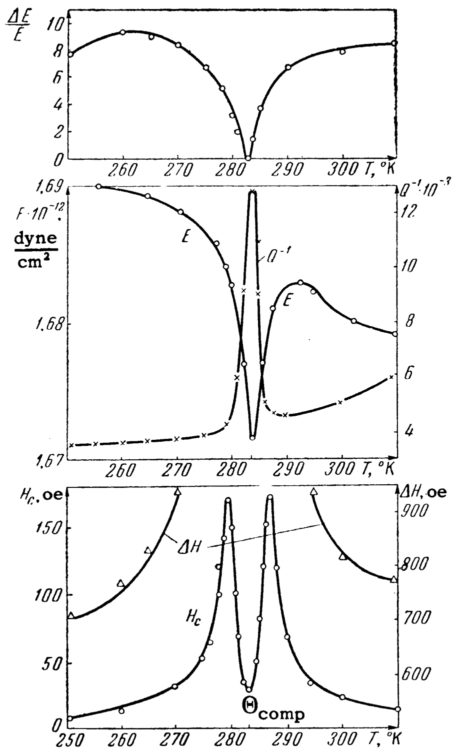

FIG. 3. Anomalies in the temperature variation of some physical properties of gadolinium garnet ferrite at the compensation point Θ_{comp}.

i.e., a value of the same order of magnitude.

4. In conclusion, we show that our measurements have established the existence of sharp anomalies in various magnetic and non-magnetic properties of gadolinium ferrite at the compensation point. It can be seen from Fig. 3 that at Θ_{comp} the coercive force, H_c, and the width of the resonance absorption curve, ΔH, have maxima.[3,4] The internal friction Q^{-1}, measured at $H = 1{,}800$ oe, also has a maximum at the compensation point, while Young's modulus E has a sharp minimum. The ratio $\Delta E/E$ (the ΔE-effect) equals zero at the compensation point. We shall explain the physical nature of these anomalies elsewhere.

In conclusion, the author expresses his thanks to Professor K. P. Belov for his interest in this work and for discussion of the results.

[1] K. P. Belov and A. V. Pedko, J. Appl. Phys. Suppl. **31**, 55 (1960).

[2] K. P. Belov, JETP **41**, 692 (1961), this issue, p. 499.

[3] K. P. Belov and A. V. Ped'ko, JETP **39**, 961 (1960), Soviet Phys. JETP **12**, 666 (1961).

[4] Smith, Overmeyer, and Calhoun, IBM J. Res. Developm. **3**, 153 (1959).

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