

SOME PROPERTIES OF THE COMPENSATION POINT IN RARE EARTH IRON GARNETS

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Abstract

The present paper describes the study of the lattice constants varying with temperature between 78 and 600 K and the variation of the compensation point temperature as a function of the hydrostatic pressure P up to 1.5 CPa, for several garnet ferrites REIG (RE = Gd – Er). For all compounds, the lattice constant increases with temperature. The corresponding functional dependence can be approximated by third degree polynomial. For Gd, Tb, Dy and HoIG, the corresponding sets of a_i 's below the compensation points differ from those above T_{comp} . It means that the lattice constant depends on temperature in a different way below and above the compensation points. The temperature dependence of the linear thermal expansion coefficient shows a strong anomaly in the compensation point. T_{comp} appears to be linearly growing function of the applied pressure and the derivative dT_c/dP decreases when passing from Gd to Er ($8.4 \frac{K}{GPa}$ for CdIG to $1.2 \frac{K}{GPa}$ for ErIG). For GdIG and HoIG, we have also measured the specific heat vs temperature, and found a weak anomaly in the vicinity of the compensation point GdIG.

The rare earth iron garnets (REIG) have the general formula $[RE_3](Fe_2)(Fe_3)O_{12}$ where RE^{3+} is a rare earth ion [1]. The cations occupy their own sublattices, whose positions differ with respect to their anionic surroundings [2]. The REIGs show ferrimagnetic properties [3]. For RE between Gd and Er, one encounters the compensation point T_c [4]. This very feature has also drawn our attention due to interesting physical properties, seen in the system near T_c .

This paper reports some of our experimental results obtained for polycrystalline samples of garnet ferrites (for RE = Cd, Tb, Dy, Ho and Er), and for comparison, also

of the yttrium garnet. In particular, we have investigated the dependence of the compensation temperature upon the applied pressure up to 1.5 GPa. Besides, we have measured near T_c : 1) temperature dependence of the lattice constants and the linear thermal expansion coefficient; 2) the specific heat and its thermal dependence, but for GdIG and HoIG only.

Bulk magnetization was measured between 80 and 600 K by means of a modified Faraday balance. For all compounds, the minimum of magnetization corresponded to the compensation point. The latter was measured through the „ac” susceptibility technique, and defined as the temperature corresponding to the minimum of the thermal variation of the weak-field susceptibility at constant pressure. By repeating the experiment at different pressures, one can determine the pressure dependence of the compensation temperature, and this, in turn, leads to the determination of dT_c/dp (Fig. 1 and Table 1). T_c appears to be a linear, growing function of the applied pressure and the derivative dT_c/dp decreases when passing from Gd to Er. The change of the compensation point under the influence of pressure is considered to be the result of the corresponding change of exchange interactions [5].

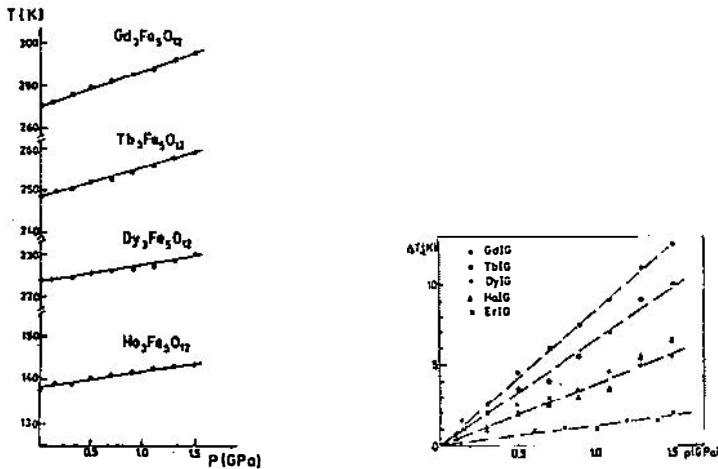


Fig. 1. Variation of T_c with hydrostatic pressure.

Table 1. Compensation temperatures and their variation with pressure

| Compounds | T_c (K) | dT_c/dp /K/kbar/ | $\frac{1}{T_c} \frac{dT_c}{dp} / \frac{1}{kbar}$ |
|-----------|-----------|--------------------|--|
| GdIG | 286 | 0.84 | $2.94 \cdot 10^{-3}$ |
| TbIG | 249 | 0.66 | $2.65 \cdot 10^{-3}$ |
| DyIG | 223.5 | 0.39 | $1.74 \cdot 10^{-3}$ |
| HoIG | 138 | 0.35 | $2.54 \cdot 10^{-3}$ |
| ErIG | 80 | 0.12 | $1.50 \cdot 10^{-3}$ |

Temperature dependent X-ray diffraction measurements were performed by means of the DRON-3 diffractometer, radiation: $\text{CuK}_{\alpha 1}$. An evaporation cryostat was used, equipped with temperature controller ± 0.3 K within the range of 78 K to 450 K. Figure 2. shows temperature dependence of the „a” lattice constant. For all compounds, this constant increases with temperature. The corresponding functional dependence can be approximated by third degree polynomial:

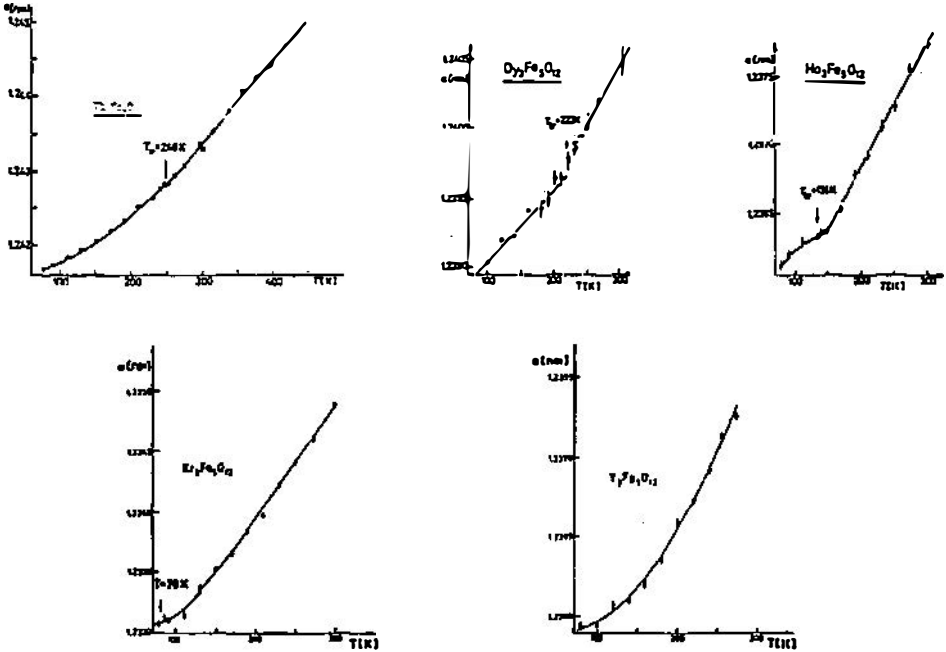


Fig. 2. Lattice constant „a” vs temperature for REIG, for GdIG see [6].

$$a(T) = a_0 + a_1 T + a_2 T^2 + a_3 T^3 \quad (1)$$

Least-squares fitted values of the coefficients a_i are listed in Table 2.

Table 2. Values of the coefficients a_i for REIG, $a_1 \cong 0$ for $T < T_c$, for all REIG.

| Compounds | for $T < T_c$ | | | for $T > T_c$ | |
|-----------|---------------|----------------------|------------------------|---------------|----------------------|
| | a_0/A | a_2 | a_3 | a_0 | a_1 |
| GdIG | 12.4526 | $3.46 \cdot 10^{-7}$ | $-5.27 \cdot 10^{-10}$ | 12.4349 | $1.19 \cdot 10^{-4}$ |
| TbIG | 12.4155 | $2.36 \cdot 10^{-7}$ | $-1.10 \cdot 10^{-10}$ | 12.4000 | $1.12 \cdot 10^{-4}$ |
| DyIG | 12.3878 | $3.19 \cdot 10^{-7}$ | $5.64 \cdot 10^{-10}$ | 12.3771 | $9.38 \cdot 10^{-5}$ |
| HoIG | 12.3577 | $3.91 \cdot 10^{-7}$ | $-4.98 \cdot 10^{-10}$ | 12.3497 | $9.32 \cdot 10^{-5}$ |
| ErIG | 12.329 | $3.40 \cdot 10^{-7}$ | $-3.88 \cdot 10^{-10}$ | | |

For GdIG, TbIG, DyIG and HoIG, the corresponding sets of a_1 's below the compensation points differ from those above T_c . This means that the lattice constant depends upon temperature in a different way below and above the compensation point. The effect becomes more spectacular if the linear expansion coefficient a_a is analysed (Fig. 3). For the compounds mentioned above a_a shows a complex temperature dependence below T_c which points to possible anomalies for below T_c , while it remains constant above T_c . For ErIG, there is a discontinuity in the a_a coefficient close to T_c , which continues growing for $T < T_c$.

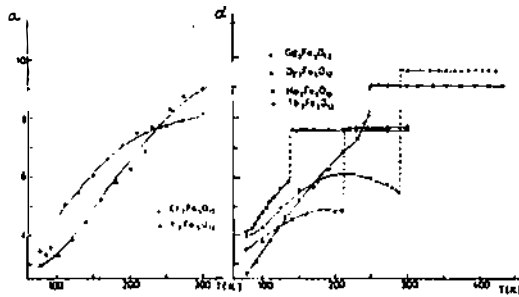


Fig. 3 Temperature dependence of linear expansion coefficient a_a .

For GdIG and HoIG, the specific heat was measured around T_c , no anomaly is seen at the T_c of HoIG. Specific heat of GdIG vs temperature (Fig. 4) has been described by polynomials third to fifth degree. In the first series of measurements, all these polynomials show the saddle points at 276 K. The third, fourth and fifth degree polynomials in the second series of measurements show the saddle points at 278, 274, 274 K, respectively. For all polynomials, standard deviations are 6 J/moleK/ for first, and 4 J/moleK/ for the second series of measurements. As the convex shape of the specific heat curve cannot be maintained in a wider temperature interval, the specific heat in the temperature region $T > T_c$ is expected to become again concave, which should be confirmed in a continuation of this measurement at temperatures above 305 K, when the anomaly would show more pronounced. Thermodynamic theory [7] anticipates, and the experiment [6]

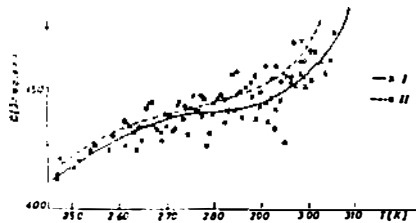


Fig. 4. Specific heat of GdIG near T_c vs temperature.

shows the existence of two more phase transitions, besides the transition in the compensation point, symmetrically arranged around the compensation point of GdIG, which on ce more asks for further measurement of specific heat at higher temperatures. Earlier noticed anomaly of specific heat in ErIG [8] is much more pronounced than the one in GdIG, described here, which can be considered as due to a much greater temperature distance of the compensation from the „low-temperature Curie-point“ in GdIG than in ErIG [3]. Anomaly of the specific heat of GdIG becomes more pronounced to the earlier known [9] specific heat measurements of YIG, which has not been shown.

According to the reported experimental results, there is a phase transition at the compensation point, as a number of physical properties undergo non-typical changes at T_c . Our results concerning anomalous behaviour of a macroscopic quantity, without the magnetic field applied, are the first experimental evidence, in the case of linear expansion coefficient, of this kind.

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