Magnetic Properties of the Mixed Garnets $(3-x)Y_2O_3 \cdot xGd_2O_3 \cdot 5Fe_2O_3$†

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Polycrystalline garnets of the form $(3-x)Y_2O_3 \cdot xGd_2O_3 \cdot 5Fe_2O_3$ have been prepared for several values of x ranging from 0 to 3. Lattice constants vary linearly from 12.374±0.005 A for yttrium-iron garnet ($x=0$) to 12.463±0.005 A for gadolinium-iron garnet ($x=3$). Magnetic moments were measured from 77°K to 580°K. For $0<x<0.73$, the magnetization decreases as x increases, the decrease being more pronounced at low temperatures. At $x\sim 0.73$, a compensation point occurs near absolute zero. This compensation point appears at increasingly higher temperatures as x increases beyond 0.73, until it reaches ~287°K for $x=3$. The magnetic moments for the members of the series show reasonable agreement with values calculated on the basis of the Néel theory.

INTRODUCTION

GADOLINIUM-IRON garnet is of particular interest because it has a high magnetic moment at low temperatures and a compensation point near room temperature. Its crystalline and magnetic properties were discovered and reported by workers at Grenoble, France.[1-3] We have prepared polycrystalline samples of mixed yttrium-gadolinium garnets having the formula $(3-x)Y_2O_3 \cdot xGd_2O_3 \cdot 5Fe_2O_3$, where $0 \leq x \leq 3$, in order to study the effects of gadolinium substitution on the magnetic properties. The method of preparation and the measuring techniques are the same as those described previously.[4]

LATTICE CONSTANTS

The lattice constant increases linearly with gadolinium content as shown in Fig. 1. For yttrium-iron garnet ($x=0$), the lattice spacing is 12.374±0.005 A[4] and for gadolinium-iron garnet ($x=3$) it is 12.463 ±0.005 A. Other values for gadolinium-iron garnet are 12.44 A (Bertaut and Forrat)[1] and 12.472 A (Sirvetz and Zneimer).[5]

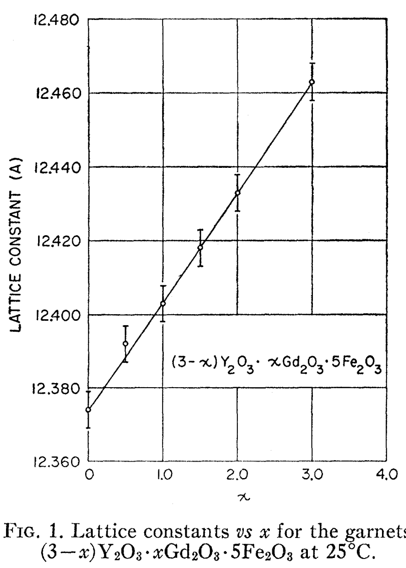

FIG. 1. Lattice constants *vs* x for the garnets $(3-x)Y_2O_3 \cdot xGd_2O_3 \cdot 5Fe_2O_3$ at 25°C.

MAGNETIC PROPERTIES

The unusual magnetic properties of the members of this series are explained by the fact that gadolinium is itself a paramagnetic ion with a spin of $\frac{7}{2}$. The presence of gadolinium in the c-sites of the garnet structure produces a magnetic moment which opposes the net moment due to the interaction between the iron ions of the a-sites and d-sites. Since the temperature dependence of the gadolinium and iron sublattices is different, a temperature may exist at which the net magnetization goes through zero and actually changes sign. This temperature is called a compensation temperature. Although the net magnetic moment vanishes at the compensation point, magnetic order is still present in the crystal lattice.

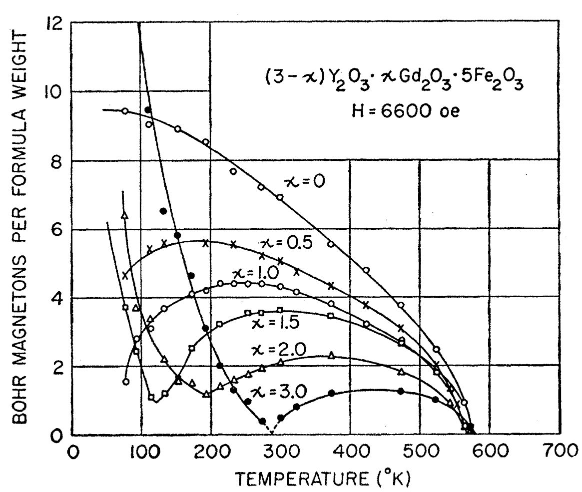

FIG. 2. Saturation magnetization *vs* temperature for the garnets $(3-x)Y_2O_3 \cdot xGd_2O_3 \cdot 5Fe_2O_3$.

† Presented at the 1959 Washington meeting of the American Physical Society [Bull. Am. Phys. Soc. Ser. II, 4, 241 (1959)].

[1] F. Bertaut and F. Forrat, Compt. rend. **242**, 382 (1956).
[2] R. Pauthenet, Compt. rend. **242**, 1859 (1956).
[3] R. Pauthenet, Compt. rend. **243**, 1499 and 1737 (1956); also J. Appl. Phys. **29**, 253 (1958).
[4] Elmer E. Anderson, J. Appl. Phys. **30**, 299S (1959).
[5] M. H. Sirvetz and J. E. Zneimer, J. Appl. Phys. **29**, 431 (1958).

Figure 2 shows plots of the temperature variation of the magnetic moment for several values of x in the temperature interval from 77°K to 580°K. The magnetic moment is expressed here in Bohr magnetons per formula weight. Note that yttrium iron garnet (YIG) has no compensation point but that one appears when gadolinium is added. Theoretically, a compensation point should exist for this series only when $0.73<x\leq 3$. Thus the curve for $x=0.5$ should not have a compensation point. Although the "dips" shown in the curves for $x>1.0$ do not appear to go to zero, it has been definitely determined that they are true compensation points. A cylindrical rod of the sample was suspended between magnet poles and it was observed to rotate through 180° as the sample was alternately cooled and warmed through the compensation temperature.

The fact that the curves do not touch the axis is probably due to the lack of experimental points in the vicinity of the compensation temperature.

The magnetic moments of the yttrium-gadolinium garnets fit the Néel theory rather well. Using the three sublattice model and assuming antiparallel *c-d* and *a-d* interactions, one may write

$$\mu=2(3\mu_c+2\mu_a-3\mu_d) \qquad (1)$$

for the magnetic moment per formula weight at a given temperature. If the *c*-sites contain both Gd^{3+} and Y^{3+} ions in the ratio x to $3-x$, then the $3\mu_c$ term becomes $x\mu_{Gd^{3+}}$ since the moment of yttrium is zero. Assuming further that *a*- and *d*-sites contain only Fe^{3+} in the garnets considered here, Eq. (1) becomes

$$\mu=2(x\mu_{Gd^{3+}}-\mu_{Fe^{3+}}). \qquad (2)$$

From the data shown in Fig. 2, we have at 77°K: for $x=0$, $\mu=9.38$; and for $x=3$, $\mu=14.87$. Using these values in Eq. (2), it follows that

$$\mu(77°\mathrm{K})=8.08x-9.38. \qquad (3)$$

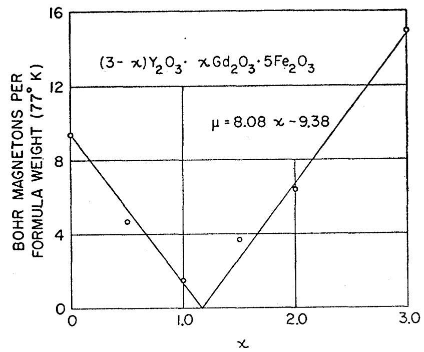

FIG. 3. Saturation magnetization *vs* x for the garnets $(3-x)Y_2O_3\cdot xGd_2O_3\cdot 5Fe_2O_3$ at 77°K. The lines represent values predicted by the Néel theory; experimental values are shown by circles.

A plot of the absolute value of μ *vs* x at 77°K is shown by the straight lines in Fig. 3. Experimental values are shown by the circles. Note that the agreement with the Néel theory is good.

PERMEABILITY AND LOSSES

Preliminary measurements have been made of the initial permeability and magnetic losses from dc to 2 kMc/sec at several different temperatures. Results to date indicate that all the garnets of this series lack the electron diffusion-type loss mechanism proposed by Epstein and Frackiewicz for YIG.[6] A report of the permeability and losses will be the subject of a future paper.

ACKNOWLEDGMENTS

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[6] D. J. Epstein and B. Frackiewicz, J. Appl. Phys. 30, 295S (1959).