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**NASA TECHNICAL  
MEMORANDUM**

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(NASA-TM-X-71535) HIGH-FIELD  
MAGNETIZATION OF Dy<sub>2</sub>O<sub>3</sub> (NASA) 5 P HC  
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HIGH-FIELD MAGNETIZATION OF Dy<sub>2</sub>O<sub>3</sub>

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## SUMMARY

The magnetization of powdered samples of  $\text{Dy}_2\text{O}_3$  has been measured at temperatures between  $1.45^\circ$  and  $4.2^\circ$  K, in applied magnetic fields ranging to 7 Teslas. A linear dependence of magnetization on applied field is observable in the high-field region, the slope of which is independent of temperature over the range investigated. The extrapolated saturation magnetic moment is  $2.77 \pm 0.08$  Bohr magnetons per ion.

## INTRODUCTION

The magnetization of a simple paramagnetic material is given by

$$M = Ng\mu_B J \left[ B_J \left( \frac{Jg\mu_B H}{kT} \right) \right] + \alpha(H) \quad (1)$$

$N$  is the number of magnetic ions per cubic centimeter,  $g$  is the spectroscopic splitting factor,  $J$  is ground state total angular momentum quantum number, and  $\mu_B$  is the Bohr magneton. The function  $B_J(Jg\mu_B H/kT)$  is the Brillouin function, and  $\alpha(H)$  is a term which arises when the ground state magnetic energy levels have been perturbed by the presence of nearby upper energy levels (ref. 1). The contribution to  $M$  from the second term  $\alpha(H)$  is independent of temperature if the separation between the ground state and the nearest excited state is large compared to  $kT$ . This contribution to the magnetization is known as van Vleck paramagnetism. A standard perturbation calculation yields (ibid).

$$\frac{\alpha(H)}{H} = \frac{2N \left| \langle J' | \mu_o | J \rangle \right|^2}{\Delta E} \quad (2)$$

where  $J'$  refers to an excited state of the system,  $\mu_o$  is the magnetic moment operator, and  $\Delta E$  is the separation between the ground state and excited energy levels. Van Vleck paramagnetism is usually small, and can be difficult to observe in the low field region. At magnetic saturation, however,

$$M = Ng\mu_B J + \alpha(H) = \text{const} + \alpha(H) \quad (3)$$

and observation of  $\alpha(H)$  can become relatively easy.

## EXPERIMENTAL METHODS

The compound was obtained from a commercial supplier in powder form. A portion of the sample was tightly packed into one of two hollow phenolic cylinders which were wound with nearly identical 750 turn pick-up coils. The pick-up coils were connected in series opposition to one another, and the difference voltage was applied to the input of an integrator. This arrangement automatically eliminated the large background emf caused by the changing magnetic field itself. The measurements were made by suspending the cylinders side-by-side in a helium bath at the center of a 10 centimeter (4") diameter bore, water-cooled solenoid capable of producing magnetic fields in excess of 7 Tesla. A schematic diagram of the experiment is shown in figure 1. The sample was 0.8 cm in diameter and 5.2 cm in length with a density of  $3.32 \text{ gm/cm}^3$ .

## RESULTS AND DISCUSSION

The magnetization of  $\text{Dy}_2\text{O}_3$  (Néel temp -  $1.2^\circ \text{ K}$  (ref. 2)) as a function of applied magnetic field is shown for several temperatures in figure 2. The high field data indicate a contribution to the magnetization which is linear with a slope independent of temperature. From figure 2,  $\alpha(H) = 0.133 \times 10^5 H$  (H in Tesla). Westrum and Justice (ref. 3) found from specific heat data that the separation between the ground state magnetic energy level, which is a Kramer's doublet, and the first excited level, also a Kramer's doublet, is  $75 \text{ cm}^{-1}$ . Using this value in equation (2) yields  $\langle J' | \mu_0 | J \rangle = 3.04 \times 10^{-20} \text{ ergs/gauss}$ . ( $N = 10.7 \times 10^{21} \text{ ions/cm}^3$  for the sample used.) This rather large value for the off-diagonal term indicates appreciable mixing of the states of the system.

The number of Bohr magnetons per ion  $p_{\text{eff}}$  at saturation is given by

$$p_{\text{eff}} = gJ = \frac{M(H) - \alpha(H)}{N\mu_B} \quad (4)$$

and from the data,  $p_{\text{eff}} = 2.77 \pm 0.08$ . (Hund's rules predict  $p_{\text{eff}} = 10$  for the free  $\text{Dy}^{+++}$  ion.) In the case of extreme anisotropy, such that  $g_{\perp} = 0$  and  $g_{\parallel} = 2g_L \langle J_z \rangle$ , where  $g_L$  is the free-ion Lande splitting factor, the effective moment for a powdered solid is given by

$$p_{\text{eff}} = \frac{g_{\parallel} J'}{2} \quad (5)$$

where  $J' = 1/2$  is the effective ground-state spin, and  $\langle J_z \rangle$  is the original azimuthal quantum number of the ground state doublet. In this

case,  $g_{\parallel} = 5.54 \pm 0.2$ , so that  $\langle J_z \rangle = 4.15 \pm 0.15$ . Since  $\langle J_z \rangle$  must have half-integer values, the result indicates only that  $g_{\parallel}$  is probably greater than  $g_{\perp}$ , but that  $g_{\perp}$  cannot be neglected entirely. Studies of single crystal samples (which are difficult to prepare) will be necessary to completely characterize the magnetic anisotropy of the compound.

#### SUMMARY OF RESULTS

Saturation magnetization measurements of powdered samples of  $\text{Dy}_2\text{O}_3$  yield a value of  $2.77 \pm 0.08$  Bohr magnetons per ion. The saturation region has a positive, temperature-independent slope equal to  $0.133 \times 10^5$  (for H in Tesla). The compound appears to be anisotropic, but may not be strongly so.

#### REFERENCES

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3. Westrum, Edgar F. Jr.; and Justice, Bruce H.: Thermophysical Properties of the Lanthanide Oxides. III. Heat Capacities, Thermodynamic Properties, and Some Energy Levels of Dysprosium (III), Holmium (III), and Erbium (III) Oxides. J. Phys. Chem., vol. 67, Mar. 1963, pp. 659-665.

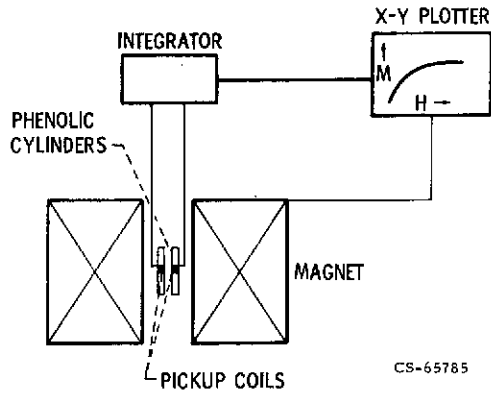


Figure 1. - Schematic diagram of magnetization measurement technique.

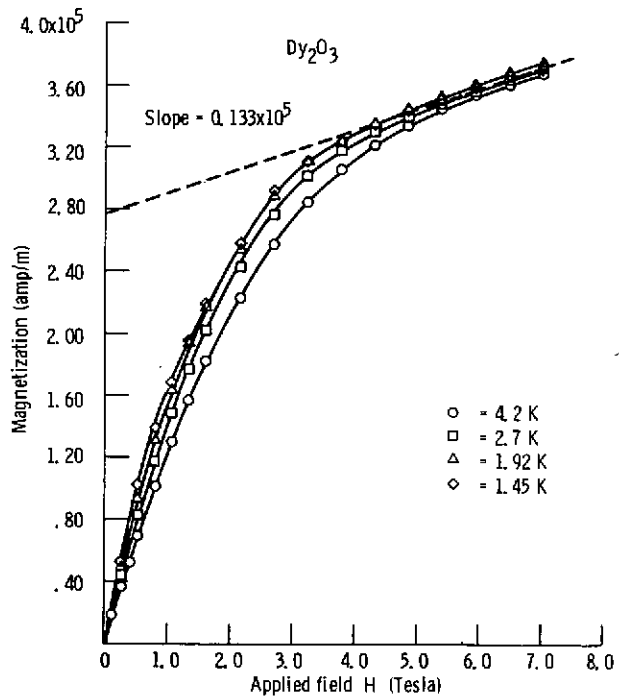


Figure 2. - Magnetization of powdered samples of  $Dy_2O_3$ .