

Frequency Dependence of Magnetocrystalline Anisotropy

R. M. BOZORTH, BEATRICE B. CETLIN, J. K. GALT,
F. R. MERRITT, AND W. A. YAGER

Bell Telephone Laboratories, Murray Hill, New Jersey

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IT is well known that the magnetocrystalline anisotropy constant K_1 can be determined both by static measurement of the torque on a single crystal placed in a strong magnetic field, and by measurement of the magnetic field for resonance at microwave frequencies. In experiments on several specimens of nickel-iron ferrites it was apparent that the same value of K_1 was not obtained by the two methods. In order to determine whether the difference was due to chemical composition or to a true frequency dependence, measurements were made by both methods on specimens cut from the same single crystal. The crystal was obtained from Dr. G. W. Clark of Linde Air Products Company; chemical analysis for Ni and Fe indicate that it has the composition $\text{Ni}_{0.76}\text{Fe}_{2.16}\text{O}_4$. The simplest formula preserving these proportions is $(\text{NiO})_{0.70}\text{Fe}_2\text{O}_3$, which calls for metal ion vacancies in the lattice but no Fe^{++} ions. The electrical resistivity of this material at room temperature, however, is $\rho=1$ ohm-cm, and we believe that this low value of resistivity indicates at least the temporary existence of Fe^{++} ions.

Our results, given in Table I, show that the difference

TABLE I. Magnetic anisotropy constant K_1 in ergs/cm³, and anisotropy field $2K_1/M_s$ in oersteds, as dependent on frequency and temperature.

Quantity	Temperature	$\text{Ni}_{0.8}\text{Fe}_{2.2}\text{O}_4$		$\text{Mn}_{1.6}\text{Fe}_{1.4}\text{O}_4$	
		Static	Microwave	Static	Microwave
K_1	20°C	-39×10^3	-43×10^3	-34×10^3	-33×10^3
K_1	-196°C	-42×10^3	-74×10^3	-240×10^3	-233×10^3
$2K_1/M_s$	20°C	-260	-280	-180	-175
$2K_1/M_s$	-196°C	-260	-468	-840	-812

in K_1 is slight at room temperature but marked at -196°C . This difference is the first time to our knowledge that frequency dependence has been observed in a magnetocrystalline anisotropy constant.

The conclusion that Fe^{++} ions are present leads us to believe that this variation of K_1 with frequency confirms the interpretation which some of us have given¹ to relaxation phenomena observed in other crystals where Fe^{++} ions were certainly present. This interpretation starts with the assumption that there are Fe^{++} and Fe^{+++} ions in the crystal on which the valence electrons rearrange easily with a short time constant as suggested some time ago by Verwey.² It is then suggested that these electronic rearrangements occur as the magnetization changes direction, and affect the magnetocrystalline anisotropy constant, so that the value of K_1 will differ depending on whether it is measured at an angular frequency above or below the reciprocal of the

time constant for the electronic rearrangement. The microwave measurements indicate that the reciprocal of this time constant corresponds to 24 000 Mc/sec at about 160°K .

A similar comparison of static and microwave measurements of magnetocrystalline anisotropy on a single crystal of manganese ferrite of composition $\text{Mn}_{0.98}\text{Fe}_{1.86}\text{O}_4$, was made using our static value and the dynamic values deduced by S. Geschwind and J. F. Dillon, Jr. from their microwave measurements at 20° and -196°C , at frequencies of 9300 and 48 000 Mc/sec. These values, also given in Table I, show that K_1 is practically independent of frequency in this material. This indicates that electrons are not free to move so easily from one atom to another in this material as compared with the nickel-iron ferrite.

We are indebted to S. Geschwind and J. F. Dillon, Jr., for permission to quote their results before publication, and to F. J. Morin for the measurement of resistivity.

¹ Galt, Yager, and Merritt, *Phys. Rev.* **93**, 1119 (1954); J. K. Galt, *Bell System Tech. J.* **33**, 1023 (1954).

² E. J. W. Verwey, *Nature* **144**, 327 (1939).

Emission Spectroscopy at Liquid Helium Temperature*

JOSEPH G. HIRSCHBERG

University of Wisconsin, Madison, Wisconsin

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A KOVAR and glass hollow-cathode discharge tube has been operated immersed in liquid helium, to study the emission spectrum of helium. The spectrum was recorded directly from an RCA 1P21 photomultiplier, with a Perot-Fabry interferometer and a 21-foot stigmatically mounted concave grating swept in synchronism.^{1,2} The grating was swept by moving the exit slit, and the Perot-Fabry by varying the interplate gas pressure linearly with time. The entrance and exit slits were curved to concentrate the light into a single interference fringe. Details will be published after further work in improving the signal-to-noise ratio.

The line $\sigma=21\,335\text{ K}$ ($\lambda=4686\text{ A}$) of He II was observed, and the Doppler broadening was found to be sensibly reduced from the amount observed with liquid-air cooling. The splitting arising from the radiation shift³ was clearly shown. In particular, the $3s_3-4p_3$ and $3p_3-4s_3$ pair was almost completely resolved and the $3s_3-4p_3$ and $3p_3-4d_3$ pair was partly resolved.

It was found that a discharge could be not only maintained at this low temperature, but easily started as well. In all, about three liters of liquid helium were consumed in 25 minutes' operation of the discharge. The current averaged 30 milliamperes and the potential difference 250 volts.