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SATURATION MAGNETIZATION OF POLYCRYSTALLINE IRON

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16. Abstract

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SUMMARY

The magnetic moment per gram $\sigma(H_I, T)$, where H_I is the internal field and T is the temperature, has been measured for a polycrystalline iron sphere with the vibrating sample magnetometer. The instrument was calibrated by using a method utilizing the high permeability of an iron sphere. The spontaneous moment $\sigma(0, T)$ was obtained from plots of $\sigma(H_I, T)$ as a function of H_I for temperatures from 4.2 K to room temperature. The value of the spontaneous moment $\sigma(0, T)$ at 298.9 K was 217.50±0.4 electromagnetic unit per gram. The extrapolated moment $\sigma(0, 0)$ at absolute zero from a plot of $\sigma(0, T)$ as a function of $T^{3/2}$ was 221.7±0.4 electromagnetic unit per gram.

INTRODUCTION

In the calibration of different types of instruments used to make magnetic measurements, many investigators use a sample of iron or nickel as a standard and assume the literature values of the saturation magnetization for these samples. The values determined by Weiss and Forrer (ref. 1) for iron and nickel have been used by many. Danan, Herr, and Meyer (ref. 2) report along with their determination of the saturation of iron and nickel the important previous data of other authors. Discrepancies between the results of Danan (ref. 3) and Weiss and Forrer (ref. 1) prompted Arajs and Dunmyre (ref. 4) to examine the saturation of iron and nickel at room temperature. These inconsistencies were also noticed by Arrott and Sato (ref. 5). Because of the widespread use of iron and nickel for this purpose, accurate values for their saturation are needed. It was felt important to recheck some of these values. This report presents the results of a study of the magnetization of iron from 4.2 K to room temperature.

EXPERIMENTAL PROCEDURE

If an isotropic ferromagnetic sphere is placed in a uniform magnetic field, the magnetization and the internal field for the sphere will be uniform. The internal field H_I depends on the applied field H_A in the following way:

$$H_I = H_A - \frac{4\pi d}{3} \sigma(H_I, T) \tag{1}$$

where $\sigma(H_I, T)$ is the magnetization per gram at a temperature T and internal field H_I. Here, d is the density in grams per cubic centimeter. The factor $4\pi/3$ is the demagnetization factor for a sphere. For a soft magnetic material such as iron, the internal field H_I will be near zero in applied fields for which the magnetization is not close to saturation. Then neglecting H_I in equation (1), we obtain

$$\sigma(H_I, T) = \frac{3}{4} dH_A \tag{2}$$

This enables one to calibrate the moment measuring apparatus independently of a standard since the uniform applied field can easily be measured.

In this study the magnetic moment of the polycrystalline sphere was measured by using a commercially built vibrating-sample magnetometer with a modified pickup coil system designed to eliminate image effects (ref. 6). Fields of up to 3.4 teslas were applied to the sample with an iron-core electromagnet. The sample was attached to a glass-fiber epoxy extension of the drive system of the magnetometer and placed in a liquid-helium Dewar between the pole pieces of the magnet. Temperatures from liquid-helium temperature to room temperature could be maintained by using a temperature controller and were measured with a copper-constantan thermocouple. The uniform magnetic field of the electromagnet was measured to ±0.1 percent with a rotating-coil gauss meter.

The apparatus was calibrated by using a polycrystalline iron sphere weighing 0.2887 gram. Measurements at low fields indicated that, for values larger than 0.25 tesla, the internal field in the sample was not sufficiently close to zero to justify use of equation (2). Therefore, for calibration purposes only, data at 0.2 tesla and below were used. Image corrections were made as indicated in reference 6. Numerous measurements were made of the magnetization of the iron sample for applied fields from 0 to 3.4 teslas with the result that the short-term (16-hr) reproducibility for the magnetometer was better than ±0.2 percent. Because of long-term drifting, the apparatus was calibrated each day that measurements were made. The total error was set at ±0.2 percent for the measured magnetic moment.

RESULTS AND DISCUSSION

The magnetic moment per gram $\sigma(H_I, T)$ as a function of the internal field H_I at 298.9 K for the polycrystalline iron sphere is shown in figure 1. An expanded scale with a suppressed zero was used for $\sigma(H_I, T)$ to show the high-field region in detail. The increase in scatter of the data above 1.2 teslas is due to the increase in electrical noise at the pickup coils. This noise was produced by the larger currents in the coils of the electromagnet. This scatter is well below the ±0.2 percent limit of error. Similar plots were made by using the data taken at seven different temperatures from room temperature to liquid-helium temperature.

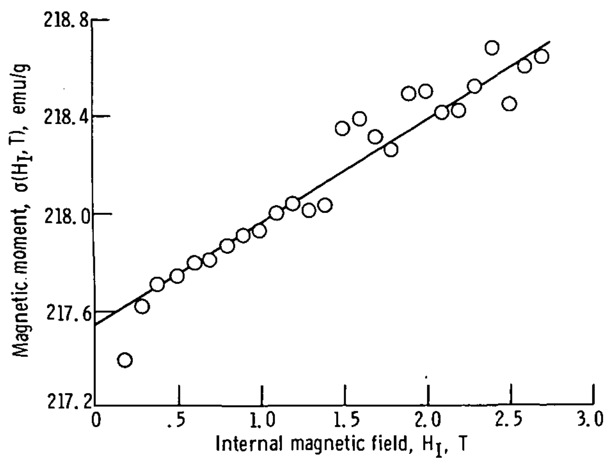

Figure 1. - Magnetic moment of iron at 298.9 K as function of internal magnetic field.

The spontaneous magnetic moment $\sigma(0, T)$, which is the magnetization per gram of a single-domain particle at a temperature T, is one quantity that can be obtained from these data. One method of doing this involves extrapolating the linear high-field portion of the data in a plot of $\sigma(H_I, T)$ against H_I to $H_I = 0$. Another method suggested by Arrott (ref. 7) and Belov (ref. 8) requires plotting $\sigma^2(H_I, T)$ against $H_I/\sigma(H_I, T)$ and extrapolating the high-field portion of the data to $H_I/\sigma(H_I, T) = 0$ to obtain $\sigma^2(0, T)$. These two methods become equivalent for a material in which the high-field susceptibility is sufficiently small, that is, so small that $p(H_I)H_I << \sigma(0, T)$, where $p(H_I)$ is the high-field susceptibility. We have used both methods at several temperatures on the iron data, and well within the limits of error they yield the same values for the spontaneous moment. For all temperatures investigated, the spontaneous moment $\sigma(0, T)$ was determined from plots of $\sigma(H_I, T)$ as a function of H_I. The spontaneous moment and the high-field suscep-

TABLE I. - SPONTANEOUS MOMENT AND HIGH-FIELD SUSCEPTIBILITY FOR VARIOUS TEMPERATURES OF IRON

Temperature, K (a)	Spontaneous moment, $\sigma(0,T)$, emu/g (b)	High-field susceptibility, $p(H)$, g^{-1}
298.9	217.5	4.3×10^{-5}
253.8	217.5	6.5
200.5	218.9	5.8
200.5	219.0	6.9
152.2	219.8	7.7
100.7	220.6	7.1
51.0	221.5	8.2
4.2	222.0	10.2

[a]Accuracy, ±0.2 K.
[b]Accuracy, ±0.4 emu/g.

tibility $p(H_I)$ obtained in this way are given in table I. From the table it can be seen that the value for $\sigma(0,T)$ at 298.9 K is 217.5±0.4 electromagnetic unit per gram. Arajs (ref. 4), also using a polycrystalline iron sphere, obtained a value for $\sigma(0,T)$ at 298 K of 217.1±0.2 electromagnetic unit per gram, which agrees well with our value. The values for $\sigma(0,T)$ were plotted against $T^{3/2}$ (fig. 2). A least-squares fit of these data extrapolated to $T = 0$ gives a value for the absolute moment $\sigma(0,0)$ of 221.7±0.4 electromag-

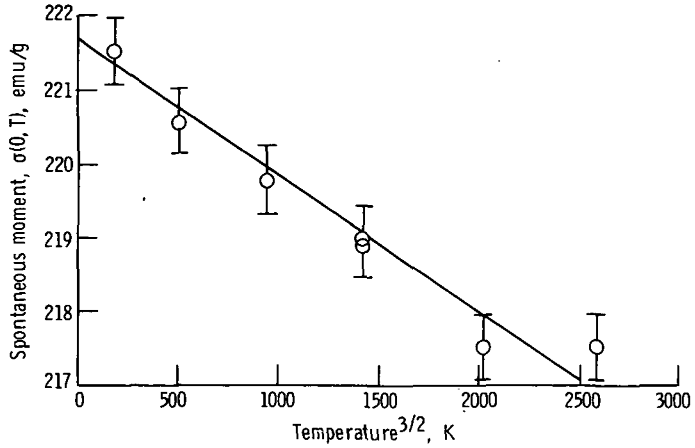

Figure 2. - Spontaneous moment of iron as function of temperature to 3/2 power.

netic unit per gram. It has been shown (ref. 2) that for a ferromagnetic metal the magnetization $\sigma(H_I, T)$ varies as

$$\sigma(H_I, T) = \sigma(\infty, T)\left(1 - \frac{a}{H_I} - \frac{b}{H_I^2}\right) + p(H_I) \tag{3}$$

where a/H_I, b/H_I^2, and $p(H_I)$ involve, respectively, contributions of the internal demagnetizing fields, homogeneous rotations, and paramagnetic terms. When $p(H_I)$ is linear in H_I, a plot of $\sigma(H_I, T)$ against H_I extrapolated to $H_I = 0$ by using the high-field data yields, according to equation (3), a $\sigma(\infty, T)$ which is the same as the $\sigma(0, T)$ of table I. Thus, $\sigma(\infty, T)$ is the magnetization of a single domain at a temperature T. Danan, Herr, and Meyer (ref. 2) calculate a mean value of 221.71±0.08 electromagnetic unit per gram for $\sigma(0, 0)$ for iron based on the results of four previous investigators. Our value agrees well with this quantity. Danan (ref. 2) reported a value of 221.17 electromagnetic units per gram calculated from measurements made at 293 K. The fact that this value is lower than the values found by other authors might be due to the method of calculating $\sigma(0, 0)$ from room-temperature data.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, February 16, 1972,
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