Magnetometric Measurement of Susceptibility of Ferro-magnetic Powders.*

By

D. P. Raychaudhuri.

(Received for publication, 25th April, 1935).

Abstract.

Description is given of a convenient magnetometric method for the measursment of the susceptibility of ferromagnetics in a powdered form. Results of measurements on some ferrites are also given. Under certain circumstances the phenomenon of magnetic viscosity is observed for nickel ferrite.

In connection with gyromagnetic experiments on some ferrites, which are available only in a powdered form, it was necessary to measure the magnetic suspectibility of specimens formed by filling a thin walled glass tube about 6 cm long and from 1·4 to 2 mm in diameter under the exact conditions of the experiment.

It was found that unlike case of ferromagnetics obtainable in the form of rods or wires, a definite value cannot be assigned to magnetic constants like maximum permeability, coercive field etc., in the case of ferromagnetics in the form of a powder. The size and shape of the grains, the density of packing, as also

* Read before the Indian Physical Society on 24th April, 1935.

previous magnetic history, play an important role for the latter; and so also the shape of the specimen as a whole. In experiments where the magnetic susceptibility values χ of such substances are required, a very cautious procedure is to be adopted, as otherwise the final results may very largely be vitiated by the uncertainty of these χ values. For rather loosely packed specimens the magnetometric and the ballistic methods generally give different values of χ. In the following a magnetometric method due to Bozorth[1] is described by which χ values for thin cylindrical specimens may very conveniently be determined under conditions exactly similar to those of the main experiment. Some results of measurements are also given.

Two parallel magnets of equal moment and opposite direction, about 6 cm apart, form an astatic pair, which may be used even under unfavourable laboratory conditions. The specimen is so placed that both of its induced poles produce upon the suspended magnetic system equal torques in the same sense about the axis of suspension.

The adjoining Fig. 1 is a diagram of the magnetometer with its electrical connections. The magnets are made of thin steel strips 6 mm x 2 mm x 0·4 mm. They are made to have almost the same magnetic moment and are attached to the ends of a light but rigid frame provided with oil damping. The suspension fibre is of glass. The magnetising solenoids, 25 cm long and 7 cm in diameter are placed with axes vertical on opposite sides of the needle system. The axis of suspension of the needle system lie in the same vertical plane, the needle system lying exactly midway between tne solenoids. These latter are mounted on bases capable of motion towards or away from the needles along horizontal rails fixed to the walls. The carrier for the needle system is also fixed. The solenoids have

[1] Bozorth, *Jour. Opt. Soc. Amer.* *10*, 59 (1925).

the same dimensions and number of turns, and are so connected in series as to exert equal and opposite torques on the needles. In one of the solenoids is placed the specimen accurately centred.

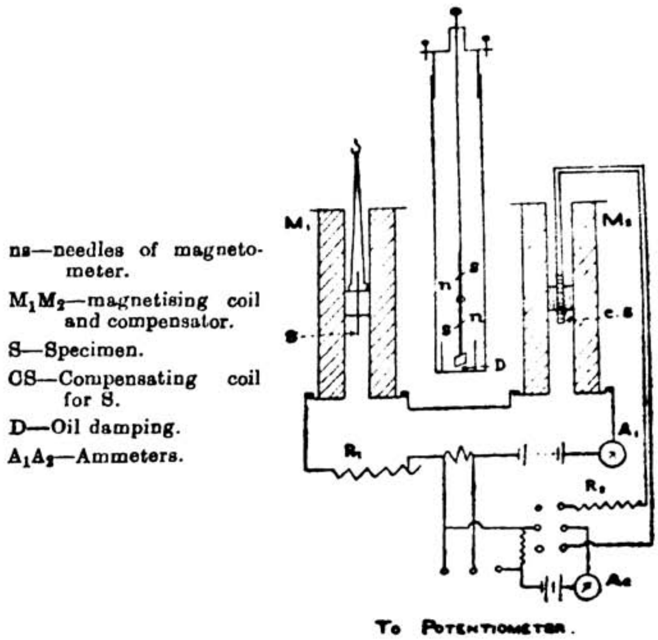

FIG. 1.

For purposes of measurement a current is sent through the magnetising solenoids, which are then adjusted so as to give no deflection of the needles. The zero is checked each time the magnetising current is altered. The deflections are read with a scale and telescope arrangement. Susceptibility is obtained by comparison with a small solenoid having the same dimensions as the specimen, hung exactly at the same place, of known number of turns and with a known current flowing through it. Current is measured with a potentiometer and a standard cell.

Calculation of constants.

The average magnetic field over the specimen may be calculated in the ordinary way from the dimension of the magnetising coil and the length of the specimen. Let

$2l$=length of the solenoid.

r_1, r_2, r=the inner, outer and average radii of the solenoid respectively.

n =number of turns of the solenoid.

d=length of the specimen.

The coil may be considered as an infinite solenoid with two magnetic poles $\pm\frac{nia}{10}$ at the two end surfaces, (a=area of the end). The field at an axial distance from the middle of the coil is

$$H=0{\cdot}4\pi ni-\frac{nia}{10}\left[\frac{1}{(l+x)^2}+\frac{1}{(l-x)^2}\right]$$

This expression on averaging over the length of the specimen gives

$$H=0{\cdot}4\pi ni\left[1-\frac{2r^2}{4l^2-d^2}\right]$$

which on averaging again over the radial thickness gives

$$H=0{\cdot}4\pi ni\left[1-\tfrac{2}{3}.\frac{r_1{}^2+r_1r_2+r_2{}^2}{4l^2-d^2}\right]$$

This is the expression for the average magnetic field over the specimen.

The balancing coil may be considered as a long thin solenoid, the effect of a single layer of which on the astatic system is the same as that of a magnet of pole strength

$$m_o = \frac{\pi n i l}{10} \cdot \frac{\rho^2}{(l^2 + \rho^2)^{\frac{1}{2}}}$$

where $2l$ = length of the coil and ρ its radius, and polar distance

$$l_o = (l^2 + \rho^2)^{\frac{1}{2}}$$

For multiple layer

$$m_o = \frac{\pi n i l}{10} \sum_1^p \frac{\rho_m^2}{(l^2 + \rho_m^2)^{\frac{1}{2}}}$$

and $$l_o = \frac{\sum_1^p \rho_m^2 (l^2 + \rho_m^2)^{\frac{1}{2}}}{\sum_1^p \rho_m^2}$$

the summation extending over all the layers, p in number.

Let the effect of the specimen at the needle be approximated by a pair of poles m'_o at a mutual distance of $2l'_o$. Under the condition of the experiment the horizontal field produced at the needles by m_o and m'_o are equal. If $l_o = l'_o$ then $m_o = m'_o$. In such a case the intensity of magnetisation of the specimen $I = m_o/A$ where A = cross sectional area of the cylindrical specimen.

The value of l'_o is uncertain and changes with the intensity of magnetisation. The error due to it is minimised by placing the specimen at a distance from the needle where the torque exerted is a maximum, the dimensions being so chosen as to give a flat maximum. At the position of maximum torque the rate of change of torque with change of position of pole is zero, while for positions near by the change of torque is very small. The position for the specimen was calculated[2] for different di-

[2] Bozorth, *loc. cit.*

mensions of the needles and their distance apart so as to give a flat maximum.

The effect of the compensating solenoid at the specimen was calculated and taken account of.

The above instrument was used for measuring the magnetic susceptibility of a number of ferrites in connection with gyromagnetic tests made on them. The ferrites of Mn, Co, Cu and Zn were prepared by Holgerson's dry method in which the oxides are taken in the requisite proportion and heated to a high temperature for a sufficient length of time. In our case the temperature was about 1000°C and duration of heating 20 hours. Fe_3O_4 and $NiO.Fe_2O_3$ were prepared by the wet method.

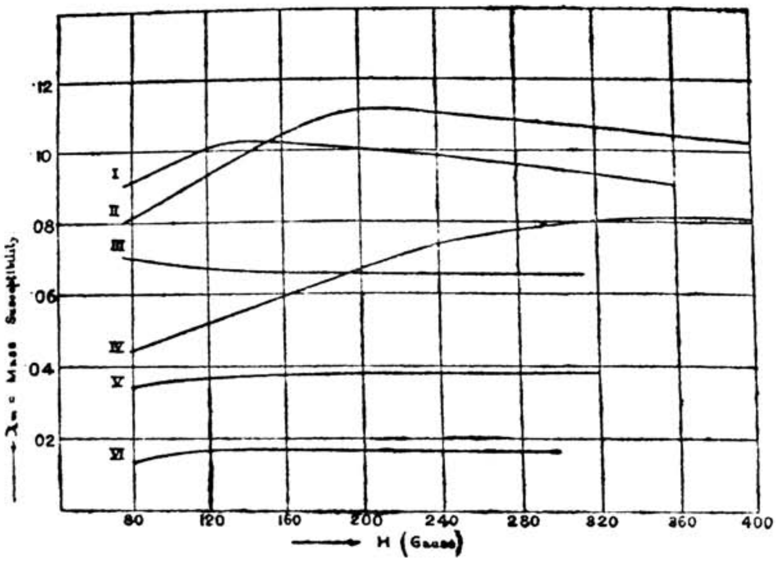

FIG. 2.

I. $CuO. Fe_2O_3$,	$\rho = 2·65$
II. Fe_2O_3,	$\rho = 1·42$
III. $MnO. Fe_2O_3$,	$\rho = 2·45$
IV. Fe_3O_4,	$\rho = 1·08$
V. $NiO. Fe_2O_3$,	$\rho = 1·42$
VI. $2ZnO, Fe_2O_3$,	$\rho = 2·48$

It is found that χ depends on quite a large number of factors. Higher temperature and longer heating raises the value of χ. After a sample has been prepared the effective χ depends on the size of particles and density of packing. For tight packing particle size has lesser effect. Different samples prepared by the same wet process do not give identical values of

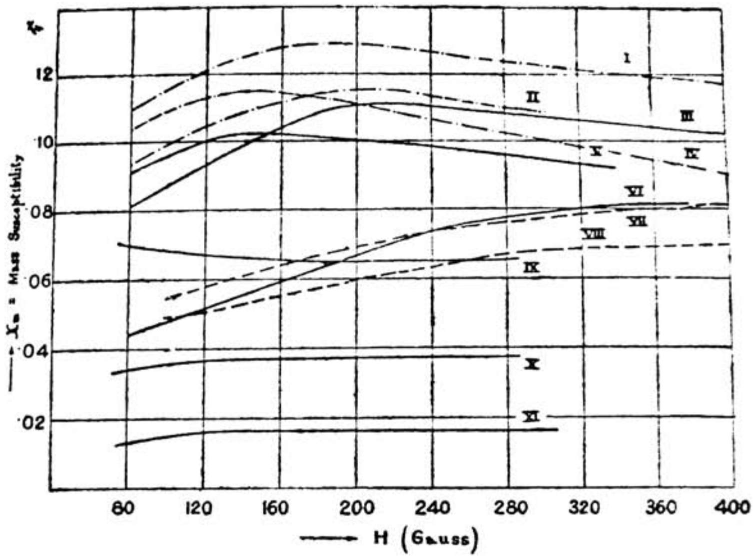

FIG. 3.

I. Fe_2O_3, $\rho=1{\cdot}67$ (H. & W.)
II. Fe_3O_4, $\rho=1{\cdot}73$ „
III. Fe_2O_3, $\rho=1{\cdot}42$ (D. R.)
IV. $CuO.\ Fe_2O_3$, $\rho=3{\cdot}02$ (H. & W.)
V. $CuO.\ Fe_2O_3$, $\rho=3{\cdot}65$ (D. R.)
VI. Fe_3O_4, $\rho=1{\cdot}08$ „
VII. Fe_3O_4, $\rho=1{\cdot}68$ (W. & B.)
VIII. Fe_3O_4, $\rho=1{\cdot}07$ „
IX. $MnO.\ Fe_2O_3$, $\rho=2{\cdot}45$ (D. R.)
X. $NiO.\ Fe_2O_3$, $\rho=1{\cdot}42$ „ (4 hrs. heating at 500°C)
XI. $2ZnO.\ 3Fe_2O_3$, $\rho=2{\cdot}48$ (D. R.)

ρ = packing density.

H. & W. = Heroun and Wilson, Proc. Roy. Soc., *41*, 100 (1928).
W. & B. = Welo and Baridich, Phys. Rev., 25, 58 (1925).
D. R. = This author.

χ even when the details of the process and other conditions remain the same. Generally there are small variations due apparently to undetermined causes. The larger the size of the microcrystals formed on precipitation and the higher the temperature of precipitation, the higher is χ generally.

For the purpose of gyromagnetic experiments the substance, finely powdered in an agate mortar, was packed to different degrees of tightness in a thin-walled copper tube about 2 mm in diameter and 6·5 cm in length. The value corresponding to the packing density of the specimen used in the gyromagnetic experiment could be found from these data by interpolation.

The results of some of the measurements are represented graphically in the adjoining figures. Some of the results of other authors are incorporated for comparison.

An observation made on nickel ferrite may be mentioned. This substance was investigated at different stages of formation. When heated to 550°C for 4 hours, the maximum χ value attained was about ·034. When this powder was taken in a tube of diameter 8 mm it showed magnetic viscosity for all degrees of packing. The same phenomenon was not observed when it was heated to a higher temperature, or when the diameter of the specimen was much smaller, say, 2 mm. The connection between magnetic viscosity and the formation of microcrystals is being further investigated.

In finding χ the demagnetising factor N was taken to be constant, and equal to that for a long thin ellipsoid of ratio of axes = 65 : 2. Owing to the small value of intensity of magnetisation this produces no perceptible error.

University College of Science :
Calcutta.