The magnetic susceptibility of an MnO single crystal

T.R. Mcguire, R.J. Happel

To cite this version:


HAL Id: jpa-00236062
https://hal.archives-ouvertes.fr/jpa-00236062
Submitted on 1 Jan 1959

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
THE MAGNETIC SUSCEPTIBILITY OF AN MnO SINGLE CRYSTAL

By T. R. McGuire and R. J. Happel, Jr.,
United States Naval Ordnance Laboratory, White Oak, Maryland, U. S. A.

Résumé. — On trouve que la susceptibilité magnétique d’un monocristal de MnO obtenu par fusion dans une flamme, est identique à celle de la substance en poudre. Pourtant, la variation de sensibilité avec le champ est plus prononcée et se prolonge dans la région paramagnétique.

Abstract. — The magnetic susceptibility of an MnO single crystal grown by flame fusion was found to be similar to the powder material; however, the magnetic field dependence of the susceptibility was larger than the dependence for the powder and in addition extended into the paramagnetic region.

Magnetic susceptibility measurements of MnO powder made by Bizette, Squires and Tsai [1] showed strong magnetic field dependence of the susceptibility below 116 °K (the Néel temperature), an effect which was interpreted by Néel [2] and also Van Vleck [3] as one of the characteristics of antiferromagnetism.

We have made measurements on a small piece of MnO single crystal which weighed 68.7 milligrams. The specimen was grown by Prof. W. H. Bauer of Rutgers University by the flame fusion method and made available to us by the M. I. T. Lincoln Laboratory (1). Because of the small size of the sample we were not able to determine the chemical composition but an X-ray Laue photo-

graph by Miss S. W. Greenwald showed that the sample is a single crystal. The agreement of its magnetic properties with powder data, both in magnitude and temperature dependence, lead us to believe that the composition is nearly stoichiometric.

The magnetic measurements were made by a force method [4]. Preliminary data taken in the antiferromagnetic region indicated that the susceptibility was isotropic. Fig. 1 and fig. 2 show the susceptibility plotted as a function of temperature and in fields up to 8 500 Oe.

Fig. 1. — Magnetic susceptibility as a function of temperature. The dotted line for \( H = 0 \) is the projection of the slopes found in fig. 2.

Fig. 2. — The magnetic susceptibility in fields 4 100 to 8 860 Oe.
to 16,400 oersteds. The data are plotted in fig. 3 and in fig. 4. It is seen in fig. 4 that for the lowest magnetic fields there is a slight falling off of the curve. Since this effect was not observed in earlier measurements (fig. 2), we believe it is an experimental error in calibration against the platinum standard. Our relative error comparing data at different temperatures is estimated at ±1%, but absolute values compared over a period of time are only good to ±2%.

The susceptibility of the MnO is isotropic and this result is similar to that found by Singer [5] for annealed NiO single crystals. The field dependence of the susceptibility of the MnO crystal is larger than that found for the powder material and there is some field dependence even in the paramagnetic region. In fields up to 16,400 oersteds and at 77 °K the susceptibility is approximately linear in H and there is no hysteresis effect.

From neutron diffraction studies by several investigators [6], [7], it has been determined that spins lie in ferromagnetic (111) planes. Theoretical work by Kaplan [8], also Keffer and O'Sullivan [9], lead to the interpretation that a very strong anisotropy $K_1$ holds the spins in this plane, but that a much smaller anisotropy $K_2$ exists in the (111) plane. Also applicable to MnO is the uniaxial case with a single anisotropy constant $K$ which Nagamiya [10] has discussed.

The above theories give an equation of the following form for low magnetic fields:

$$
\chi_\| \propto \chi_{11} + (\chi_\perp - \chi_{11}) \left( \frac{2}{3} + ak^2 \right) \text{ for } h^2 \ll 1
$$

where $\chi_{11}$ and $\chi_\perp$ are the susceptibilities parallel and perpendicular to the spin axis, $\chi_\|$ is the powder or measured value, and $h = H/H_c$. The critical magnetic field $H_c$ causes the spins to switch to a crystallographic direction closer to $\chi_\perp$. For $a = 2/15$, $H_c = [2K_1(\chi_\perp - \chi_{11})]^{1/2}$; when $a = 1/45$, $H_c = [6K_2/(\chi_\perp - \chi_{11})]^{1/2}$. Using our data for 20 °K we obtain, $\chi_\perp = 87.6 \times 10^{-6}$ emu/gm, $H_c = 24,000$ oersteds and $K = 1.1 \times 10^8$ ergs/cc for Nagamiya's uniaxial case, while $\chi_{11}$ is 87.1 and $H_c = 14,700$ oersteds, and $K_2 = 1.5 \times 10^4$ ergs/cc for the Keffer-O'Sullivan conditions. The values of the anisotropy obtained from our data are smaller than obtained previously [7] from the powder data. It is interesting that the calculated value of $\chi_\|$ (at 20 °K) is about $87 \times 10^{-6}$ and this is the same value used for the powder data by Keffer.

The isotropic susceptibility is interpreted to mean that antiferromagnetic domains are present causing the spin axis to average out to the polycrystalline value in a manner similar to the NiO case [5]. Néel [11] has suggested that domain wall motion might contribute to the field dependence of the magnetic susceptibility and it cannot be excluded in this case, especially since differences between powder and single crystal must be accounted for.

The field dependence observed in the paramagnetic region may be due to short range order, which has been reported from neutron diffraction results [6]. According to the interpretation of Wangness [12], short range order in this temperature region (116 °K to 250 °K) in MnO also has the effect of decreasing microwave resonance absorption [13].
Further experiments are necessary before more definite conclusions can be stated concerning the most appropriate values of $H_e$ and $K$.

*Note added at time of presentation.* It has been found that the measurements made at 20 °K are not reproducible. This is now being studied.

REFERENCES


DISCUSSION

*Question by S. Foner.* — Although the purity of of this MnO crystal appears to be better than 95 % MnO, this data should be taken with some caution. Our measurements on a part of this crystal showed that the magnetic moment at 4.2 °K was not a linear function of applied field. Furthermore, it appeared that the susceptibility increased as the temperature was decreased from about 70 °K to 4.2 °K.

Such results disagree with the behavior of “simpler” antiferromagnets (see our contribution to this Colloque, p. 336). We have observed that Mn$_3$O$_4$ becomes ferrimagnetic at about 50 °K. An impurity of a few percent of Mn$_3$O$_4$ in this material would be sufficient to produce the observed effects.

*Mr. McGuire.* — We have tried to estimate the amount of ferromagnetic impurity in this sample from measurements at liquid helium temperatures (fig. 5). The curve marked 1st run is after the initial cooling and shows a steep positive slope much greater than a 77 °K. All subsequent measurements followed the curve marked 2nd run which has the form typical of a ferromagnetic impurity. Using the standard Honda-Owen method the impurity concentration was found to be .01 gms per cm$^3$ (assuming Mn$_3$O$_4$ as the impurity). This concentration value is probably somewhat low since the impurity might not be saturated and further there is the problem of separating the antiferromagnetic behavior from the effect of the ferromagnetic impurity. For temperatures at 77 °K and above the susceptibility measurements were reproducible and there was no evidence of a ferromagnetic impurity.

---

![Figure 5](image-url)