

Determination of the Magnetic Moment of Cr₂O₃ by a Proportional Relation

Yong Jin Kim and Jung Gi Kim

Department of Physics, Hanyang University, Seoul 133-791, Korea

(Received 23 September 1996)

The effective magnetic moment of Cr₂O₃ is determined by assuming that a proportional relation holds between its moment and the effective magnetic moment of hematite determined by the previous derived relaxation expression and the moments of Fe³⁺ ion and Cr³⁺ ion. The result obtained from the relation is found to be given by 0.10 in Bohr magneton which is in good agreement with the value obtained by use of the expression.

1. Introduction

The theoretical expression [1] for determining the effective magnetic moment of the hematite crystalline particle in powder form by using the well-known relaxation theories [2] applied to aqueous solutions with paramagnetic ions is derived. The results of the moment obtained by use of the expression is given by 0.15 in Bohr magneton which is in good agreement with the value of 0.14 in Bohr magneton equivalent to 2.1 emu/c. c. obtained by Hirai [3].

In this study, without owing to the above theories, an attempt is made to determine the effective magnetic moment of Cr₂O₃ by a proportional relation which is based on the assumption that the ratio of the unknown effective magnetic moment of Cr₂O₃ to the known moment of α-Fe₂O₃ is equal to the ratio of the known moment of Cr³⁺ ion to the known one of Fe³⁺ ion. The result of the attempt shows that the moment obtained by use of the relation is in good agreement with the one obtained by use of the expression.

2. Proportional Relation

Since the magnetic property of Cr₂O₃ having the same crystal structure [4] as α-Fe₂O₃ is similar to each other except that the latter possesses so-called parasitic ferromagnetism above the transition temperature [1, 3, 5, 6] of -15 °C and moreover since their corresponding metal ions belong to the transition metal ions, it is assumed that the following proportional relation between the respective effective magnetic moments holds :

$$\frac{(\mu_{eff})_c}{(\mu_{eff})_h} = \frac{(\mu_{eff})_{Cr^{3+}}}{(\mu_{eff})_{Fe^{3+}}} \quad (1)$$

Here μ_{eff} refers to the effective magnetic moment and subscripts of c and h stand for Cr₂O₃ and α-Fe₂O₃ (hematite), respectively. $(\mu_{eff})_h$ in Eq. (1) is given by [1]

$$(\mu_{eff})_h = [15 \epsilon k T < (1/T_1)_h - (1/T_1)_w > / 128 \pi^2 \gamma^2 a \eta N]^{1/2} \quad (2)$$

where ϵ is the minimum distance of approach between the water molecule and the single hematite particle, k the Boltzmann constant, T the absolute temperature, $(1/T_1)_h$ the total contribution to the proton relaxation in water caused by the presence of the hematite crystalline particles, $(1/T_1)_w = 0.27 \text{ sec}^{-1}$ the relaxation in pure water, γ the proton gyromagnetic ratio, a the radius of the molecule, η the viscosity of water and N the number of the corresponding electronic spins per cubic centimeter*. {* This particular expression of "the corresponding electronic spin" is properly explained in reference [1].}

Since the theoretical expression of Eq. (2) is equally applicable to the case of insoluble Cr₂O₃ particles present in water, the expression for $(\mu_{eff})_c$ can be written as Eq. (2) i. e.,

$$(\mu_{eff})_c = [15 \epsilon k T < (1/T_1)_c - (1/T_1)_w > / 128 \pi^2 \gamma^2 a \eta N]^{1/2} \quad (3)$$

where $(1/T_1)_c$ is the total contribution to the proton relaxation in water due to the presence of the Cr₂O₃ crystalline particles.

It is noted that η in Eqs. (2) and (3) must be replaced by the effective viscosity η_{eff} , which is given by [7]

$$\eta_{eff} = \left(\frac{1 + \varphi/2}{1 - 2\varphi} \right) \eta \quad (4)$$

where φ is the volume fraction given by $\varphi = \frac{4}{3} \pi R^3 N_c$. Here R is the average radius of the single crystalline particle used and N_c the number of the Cr₂O₃ crystalline particles per cubic centimeter. It is also noted that each of the crystalline particles is so small to contribute an effective influence on the relaxation that the particle is regarded as a sphere.

3. Results and Discussion

To determine the effective magnetic moment of μ_{eff} , N must first of all be calculated as the following ways: Since the edge length [4] of the rhombohedron unit cell of Cr₂O₃ is 5.38 Å, and the angle of the unit cell is 54° 50', the volume of the cell designated by V_0 is roughly given by $V_0 \doteq 1.26 \times 10^{-23} \text{ cm}^3$. The volume of the single particle of Cr₂O₃ in powder form designated by V_c is approximately given by $V_c \doteq \frac{4}{3} \pi R^3$. Since there are two corresponding electronic spins in the unit, the number of the spin in the volume of the single particle designated by N_c is roughly given $N_c \doteq 2(V_c/V_0)$. Here N is now given by $N = N_c N_e$.

The following experimental results are used only for whether Eq. (1) is valid: For given $R = 10^{-4} \text{ cm}$, $(1/T_1)_w = 0.27 \text{ sec}^{-1}$, $N_c = 9.20 \times 10^7 \text{ \#'/c. c.}$ and $N_e = 7.00 \times 10^{10} \text{ \#'/c. c.}$, $(1/T_1)_c$ is measured to be given by $(1/T_1)_c = 0.40 \text{ sec}^{-1}$. N and η_{eff} are calculated to be given by $N = 6.44 \times 10^{18} \text{ \#'/c. c.}$ and $\eta_{\text{eff}} = 0.01$, respectively, along with the above given formulae. Substituting these values into Eq. (3), $(\mu_{\text{eff}})_c$ is found to be given by $(\mu_{\text{eff}})_c = 0.10$ in Bohr magnetons. $(\mu_{\text{eff}})_{\text{Fe}^{3+}} = 5.9$

Now, substituting $(\mu_{\text{eff}})_h = 0.15$ in Bohr magneton [1] in Bohr

magneton [9] and $(\mu_{\text{eff}})_c = 0.10$ in Bohr magneton into Eq. (1), $(\mu_{\text{eff}})_{\text{Cr}^{3+}} = 5.9 \left(\frac{0.10}{0.15} \right) \doteq 3.9$ in Bohr magneton which is the same as the effective magnetic moment of Cr³⁺ ion obtained by relaxation experiments [9].

Conversely, putting the above given values into Eq. (1) to find $(\mu_{\text{eff}})_c$, it is found to be given by $(\mu_{\text{eff}})_c = 5.9 \left(\frac{3.9}{5.9} \right) \doteq 0.10$ in Bohr magneton which is in good agreement with the value calculated by use of Eq. (3). It is concluded that Eq. (1) is proven to be valid.

References

- [1] Yong Jin Kim and Jung Gi Kim, J. Korea Mag. Soc., **4**, 282 (1994).
- [2] A. Abragam, "The Principles of Nuclear Magnetism", Oxford at the Clarendon Press (1962) pp. 244-304.
- [3] A. Hirai, J. A. Eaton, and C. W. Searle, Phys. Rev., **B3**, 68 (1971).
- [4] R. W. G. Wyckoff, "Crystal Structure", **1**, Interscience Pub. Co., Inc., New York 1948.
- [5] Yin Yuan Li, Phys. Rev, **101**, 1450 (1956).
- [6] Akira Tasaki and Shuich Iida, J. Phys. Soc. of Japan, **16**, 1967 (1961).
- [7] A. Einstein, Ann. Phys., **34**, 591 (1911).
- [8] John R. Kalafut, Paramagnetic Surface Dependence on Spin-Lattice Relaxation Times of Protons, Master Thesis, Univ. of Delaxware (1962) P. 42.
- [9] N. Bloembergen, E. M. Purcellnd, Phys. Rev., **73**, 679 (1948).