Magnetic Resonance in αFe_2O_3

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Magnetic resonance experiments performed on αFe_2O_3 confirm the existence of a highly anisotropic, weak ferromagnetism which disappears below −15°C. The anisotropy energy has been studied as a function of orientation.

I. INTRODUCTION

With the use of fields up to 24 000 gauss, αFe_2O_3 single crystals were studied by magnetic resonance at 1.25-cm wavelength. A range of temperatures, including the Morin transition at −14°C,[1] was investigated. A strong line was observed above this transition, which is probably a ferromagnetic resonance due to the "parasitic ferromagnetism" of Néel.[2] We were able to study in some detail the marked anisotropy known to be exhibited by this ferromagnetism.[3–5] However, we unexpectedly found that this anisotropy does not vary appreciably with temperature near the transition at −14°C, but rather that all observable resonances simply disappear completely below this temperature. It seems, then, that these observations do not, as had been hoped, indicate that the ferromagnetism turns, with the antiferromagnetism, from the basal plane to the (magnetically) hexagonal axis at this temperature. Thus we do not confirm Néel's hypothesis[2] on this point, although our measurements do not necessarily exclude this hypothesis.

The resonance fields were studied as a function of the orientation of the external field with respect to the crystal. These observations have been fitted to a phenomenological ferromagnetic anisotropy energy. The *ad hoc* character of this fitting must, however, be emphasized; in view of the rather mysterious nature of all the phenomena in this substance it is not even certain that such a description of them is correct.

II. OBSERVATIONS

A number of flat plates parallel to the basal plane were grown. They were rather impure, analyzing about 3 percent Fe^{++}. The one used in most experiments was about 21 square mm in area and about 0.35 mm thick. The single plate gives a strong resonance at room temperature (losses several times the nonmagnetic losses in a cavity of $Q\sim 2000$) at a field which is about 2300 gauss when the dc and rf fields are both perpendicular to the hexagonal axis. The half-power full width of the line was 600 gauss, and the line is plotted in Fig. 1. The position of the peak varied roughly as

$$H_{\text{res}}=(2270+60\sin 6\varphi)\text{ gauss} \quad (1)$$

as the angle φ between the dc field and some undetermined direction, both in the plane perpendicular to the axis, is varied. This rather small anisotropy has not been observed previously.

The very low resonance field (for a g factor of 2 it should be 8600 gauss) confirms the large anisotropy observed previously for the parasitic ferromagnetism.[3,4] We note that the usual magnetization of αFe_2O_3, of the order of a few emu/cc, can lead to macroscopic demagnetizing fields of at most a few hundred gauss so that we can neglect any ordinary demagnetizing effects. The usual formula,[6] assuming that the small anisotropy in the plane [Eq. (1)] can be neglected, is

$$H_0^2=H_{\text{res}}(H_A+H_{\text{res}}). \quad (2)$$

Here H_0 is the normal resonance field, H_{res} the observed resonance field, and H_A the anisotropy field. This equation gives for the anisotropy field (if we assume $H_0\simeq 8600$ gauss):

$$H_A\cong 30\,000\text{ gauss}. \quad (3)$$

The resonance field was observed at room temperature as a function of the angle between the field and the basal plane in order to find out more about the anisotropy energy. If one writes the anisotropy energy as

$$U_A=MH_Af(\sin\theta), \quad (4)$$

where θ is the angle between the magnetization and the basal plane, the resonance fields are given by the

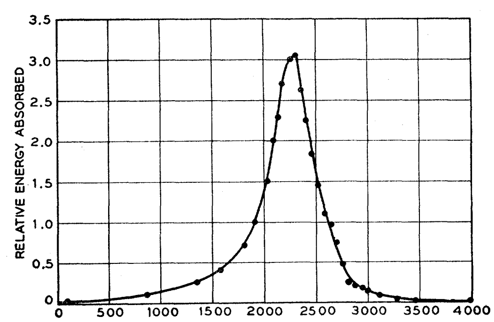

FIG. 1. The absorption line in the "normal" position (H parallel to hexagonal plane).

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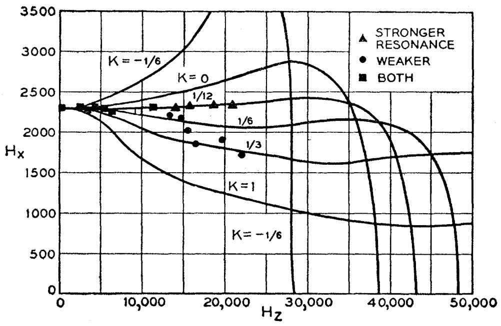

FIG. 2. H_x *vs* H_z for resonance: theoretical curves and experimental points.

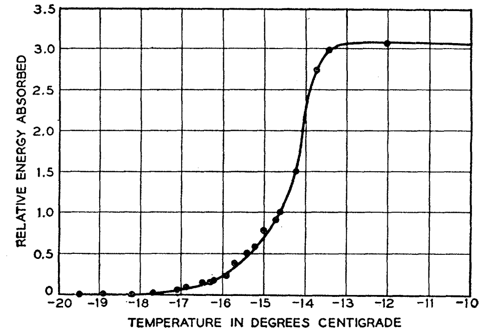

FIG. 3. Peak intensity in the "normal" position as a function of temperature.

equations

$$\frac{M_{z0}}{M_{x0}}=\tan\theta=\frac{H_z-H_Af'/2}{H_x},$$
$$H_0^2=H_x^2\sec^2\theta+H_AH_x\cos\theta(\tfrac{1}{2}f''). \tag{5}$$

Here θ is the angle of the static magnetization with the basal plane, given that the external field is H_x, H_z (x is in the plane, z along the axis). We assume that

$$f(\sin\theta)=\sin^2\theta+K\sin^4\theta, \tag{6}$$

and the components of the resonant field H_z and H_x are plotted against each other for a number of values of K in Fig. 2.

The observed behavior of the resonance as the angle between H and the basal plane was increased was the following: until H was 70° or more from this plane, the resonance shifted in such a way that H_x was approximately constant, thus deviating appreciably from the behavior for $K=0$ at the higher angles. The maximum intensity did not change much; the breadth increased proportionally to the central field, as one would expect. At the higher fields and angles, a second resonance slowly split off from the main one toward lower fields. The intensities indicated that the two new resonances had both been part of the original one: the intensities of the smaller, larger, and single peaks were in the ratio 0.3:1.2:1.5. The resonant fields seem to fit (5) with $K=1/12$ for the larger peak and about $\frac{1}{3}$ for the smaller peak.[7] The lower peak seems to be shifted where it is closer to the higher one; this may be the usual effect of being on the side of the other peak, for which we have not corrected. The two peaks are plotted as triangles for the stronger, circles for the weaker on Fig. 2. Note that the second peak, in spite of its lower resonant field, fits an anisotropy energy which is *higher* at the axis.

The effect of varying the temperature was surprisingly small. At no temperature from −50°C to room temperature could any signal at all be detected, up to 19 000 gauss, with the dc field along the axis. At all temperatures at which a signal could be detected in the plane position of H, the field was 2300±50 gauss. The intensity of this resonance varied sharply at the lower transition point, as shown in Fig. 3, disappearing below it as mysteriously as does the parasitic ferromagnetism, without shifting or broadening appreciably.

One very minor effect was observed near the transition. It was found that the lower one of the two resonances at high angles θ shifted noticeably to lower fields in the transition region. This effect was difficult to pin down quantitatively but was definitely there, since at some orientations in which, at room temperature, no absorption whatever was observed, absorptions as high as 1/10 to 2/10 of the usual maximum showed up in the region −14 to −16°C. These phenomena occurred only at the angles closest to the axis and at the highest fields. A rough estimate of the effect of temperature on line position would be that, whereas at $H_z=10\,000$ no shift could be observed, in the region $H_z=15\,000$–$20\,000$ the value of H_x for resonance is 500–1000 gauss lower than previously. Unfortunately, according to our formulas such behavior indicates a *higher* total anisotropy energy, if anything. We repeat that when H was accurately parallel to the axis, no signal was ever observed; computations show that this condition eliminates larger negative values of K from consideration and thus indicates that the position parallel to the axis is always highly unfavorable energetically.

We should like to acknowledge helpful suggestions from F. J. Morin on growing the crystals and to thank J. P. Wright for performing the analysis of the crystals for Fe^{++}.

[7] A possible alternative explanation of the double peaks is that the basal planes of two portions of the test specimen may not have been accurately co-planar. A difference in orientation of about 1.5 to 2.0° would be required to account for the observations. Hematite is known to exhibit this type of crystal habit. Unfortunately, the crystal was broken before this hypothesis could be checked.