Letters to the Editor

PUBLICATION of brief reports of important discoveries in physics may be secured by addressing them to this department. The closing date for this department is five weeks prior to the date of issue. No proof will be sent to the authors. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents. Communications should not exceed 600 words in length and should be submitted in duplicate.

Suspension of Particles in Liquid Helium

K. L. CHOPRA AND J. B. BROWN

Department of Physics, University of British Columbia, Vancouver, B.C., Canada

(Received July 17, 1957)

IT would clearly be very useful in many studies of the properties of liquid helium to be able to suspend, in the liquid, fine particles which would render visible the detailed motion of the fluid. Studies of the onset of turbulence similar to the classical ones of Reynolds should be interesting in the case of liquid He II, where on the one hand the viscosity becomes vanishingly small with correspondingly high Reynolds numbers, while on the other hand Landau's theory suggests that the superfluid component should be capable only of irrotational motion. It would be interesting also to examine a rotating vessel of the liquid for the vortex structure suggested by Onsager[1] and Feynman,[2] or the laminar structure considered by London, and by Landau and Lifshitz. Further, it might prove possible with such suspensions to make visible the Brownian movement in a Bose-Einstein fluid.

Of course the extremely small viscosity ($\sim 10^{-5}$ poise) of liquid helium renders difficult the suspension of even very small particles for any length of time unless their density is as near as possible that of the liquid (0.146 g/cc). Solid hydrogen is lighter than liquid helium, however, and it was therefore decided to attempt to condense fine particles from a mixture of hydrogen and some heavier gas.

The use of deuterium with hydrogen to make such particles has been found to be practicable. It is also economical as compared with using neon, for example. Essentially the apparatus consists simply of flasks and taps to release a burst of about 100 cc of a mixture of 5.55 cm Hg partial pressure of deuterium, plus 5.0 cm Hg pressure of hydrogen, measured at room temperature, into the liquid helium in a cryostat at a temperature of about 1.4°K and a pressure of 2 mm Hg. However, to obtain fine particles the 8-mm diameter german silver tube conducting the condensable gas mixture down into the cryostat has been lined with a spiral constantan heater about 40 cm long, and while the burst of gas is being admitted heat is supplied electrically at several watts for a few seconds. Without this heating, the cloud emerges in a gelatinous form, while particles as small as 1000 microns or less are obtainable when the heat is supplied.

The particles have a tendency to stick to glass surfaces, as well as to aggregate in clusters. Silvering the Dewar wall and grounding it, as well as irradiating the liquid with a $\frac{1}{2}$-curie Co^{60} source have not been effective in preventing the sticking. It is observed that while the particles tend to stick in He II, in He I they appear to be quite free, possibly because of stirring of the liquid by small bubbles.

Using the suspension of particles to indicate the motion of the fluid, we have observed and measured acoustic streaming[3] in liquid He II. To the eye, the particle motion appears turbulent in He I, but along stream lines in He II. The velocity is surprisingly independent of temperature and is proportional to the square root of the driving pressure (sound intensity) to the lowest values measurable. Thus a tentative conclusion is that the flow in He II is probably turbulent. The details of these experiments will be published shortly.

[1] L. Onsager, Nuovo cimento 6, Suppl., 2, 249 (1949).
[2] R. P. Feynman, in *Progress in Low Temperature Physics*, edited by C. J. Gorter (North Holland Publishing Company, Amsterdam, 1955), Vol. 1, Chap. 2.
[3] L. N. Liebermann, Phys. Rev. 75, 1415 (1949).

Magnetization of Ilmenite-Hematite System at Low Temperatures

R. M. BOZORTH, DOROTHY E. WALSH, AND A. J. WILLIAMS

Bell Telephone Laboratories, Murray Hill, New Jersey

(Received August 12, 1957)

NAGATA,[1] Akimoto,[2] and Ishikawa[3] have shown that some of the compositions in the series $FeTiO_3 - Fe_2O_3$ have strong ferromagnetism, although the end members are both paramagnetic. Akimoto's measurements were made on natural specimens at room temperature, and for one composition were extended to helium temperatures. Our present report refers to materials prepared from Fe_2O_3, TiO_2, and metallic Fe, and measured from room temperature to 1.3°K in fields to 11 000 oersteds. The data permit evaluation of the Bohr magneton numbers per mole of $Fe_{1+x}Ti_{1-x}O_3$ as a function of composition; these are shown in Fig. 1.

$FeTiO_3$ is known[4] to have alternate layers of Fe and Ti ions perpendicular to the rhombohedral axis, with plane layers of O ions between adjacent metal ion layers, each of which is not truly planar but somewhat puckered. We assume with Li[5] that the Fe ion layers are composed of Fe^{2+} ions which are antiferromagnetically coupled within each layer and have the magnetic structure known to exist in Cr_2O_3.[6]
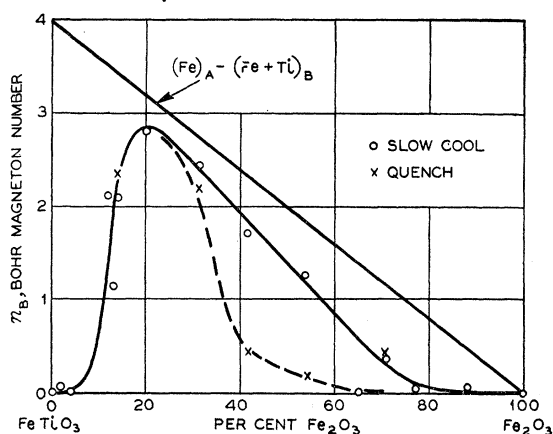
FIG. 1. Bohr magneton numbers per molecule of $Fe_{1+x}Ti_{1-x}O_3$ of series (points) as compared with model given in text (straight line).

In αFe_2O_3, which has the same kind of crystal structure, the orientation of magnetic dipoles is known[7] to be different; each layer of Fe^{3+} is ferromagnetic in itself, alternate Fe^{3+} layers being antiferromagnetic to each other.

When Fe_2O_3 goes into solid solution in $FeTiO_3$, Nagata[8] and Néel[9] have proposed that the magnetic structure is similar to that in Fe_2O_3, alternate layers being antiferromagnetic to each other. Nagata has suggested specifically that, in the solid solution containing $\frac{2}{3}FeTiO_3+\frac{1}{3}Fe_2O_3$, the alternate layers are $Fe_{1/6}^{2+}Fe_{2/3}^{3+}Ti_{1/6}^{4+}$ and $Fe_{1/2}^{2+}Ti_{1/2}^{4+}$, with some Ti^{4+} in each layer. Li predicts that the layers will contain alternately Fe ions and Fe+Ti ions (alternate ion layers containing only Fe ions). The predicted moment is then 8/3 Bohr magnetons. If the same substitution of Fe for Ti ions in the $FeTiO_3$ structure should occur throughout the whole range from $FeTiO_3$ to Fe_2O_3, the moments would correspond to the straight line of Fig. 1, although some departure from this line could occur, depending on the distribution of Fe^{2+} and Fe^{3+} ions.

The observed moments of Fig. 1 show, as one would expect, that a threshold amount of Fe_2O_3 must be added to $FeTiO_3$ before the weak antiferromagnetic coupling in the Fe layers of $FeTiO_3$ (Néel point[10] 60°K) is broken down by the stronger antiferromagnetic coupling between layers as it exists in Fe_2O_3 (Néel point[11] 950°K). When the Fe_2O_3 arrangement becomes stable, at about 15 molecular percent Fe_2O_3, ferrimagnetism occurs and the observed net magnetic moment comes close to the theoretical value.

On the Fe_2O_3-rich side, one would expect that the addition of rather large amounts of $FeTiO_3$ would be necessary to produce ferrimagnetism, because the first Ti ions could go equally well into Fe layers with moments oriented in either direction and would therefore contribute a net moment of zero.

When the molecular ratio $FeTiO_3/Fe_2O_3$ is near one, specimens quenched from 1200°C show a much lower moment than those slowly cooled. Careful examination of the 42 molecular percent material by x rays shows a homogeneous solid solution in each case. It is supposed that at high temperatures the arrangement of the different metal ions is more nearly random, and that this arrangement is partially preserved on quenching, so that the net moment is lower.

[1] T. Nagata, Nature 172, 850 (1953).
[2] S. Akimoto, J. Geomag. Geoelect. 6, 1 (1954).
[3] Y. Ishikawa and S. Akimoto, J. Phys. Soc. Japan 12, 834 (1957).
[4] T. F. W. Barth and E. Posnjak, Z. Kryst. 88, 265 (1934).
[5] Y. Li, Phys. Rev. 102, 1015 (1956).
[6] B. N. Brockhouse, J. Chem. Phys. 21, 961 (1953), and reference 11.
[7] Shull, Strauser, and Wollan, Phys. Rev. 83, 333 (1951), and reference 11.
[8] T. Nagata, J. Geomag. Geoelect. 5, 168 (1953); Proceedings of the International Conference on Theoretical Physics, Kyoto and Tokyo, September, 1953 (Science Council of Japan, Tokyo, 1954), p. 714.
[9] L. Néel, in Advances in Physics (Taylor and Francis, Ltd., London, 1955), Vol. 4, p. 191.
[10] H. Bizette and B. Tsai, Compt. rend. 242, 2124 (1956); C. H. Shomate, J. Am. Chem. Soc. 68, 964 (1946).
[11] American Institute of Physics Handbook (McGraw-Hill Book Company, Inc., New York, 1957), pp. 5–226.

Optical Absorption in p-Type Indium Arsenide

FRANK STERN AND ROBERT M. TALLEY

United States Naval Ordnance Laboratory, White Oak, Maryland

WE have observed a distinct absorption peak in p-type indium arsenide on the long-wavelength side of the intrinsic optical absorption edge, and attribute this peak to transitions between the light- and heavy-hole bands. We also observe a small absorption peak at 0.055 ev with an absorption constant of 40 cm^{-1} above the free carrier absorption. This peak is found in several samples of InAs, both n type and p type, and we attribute it to lattice absorption.

The absorption constant curve shown in Fig. 1 was obtained at room temperature on a sample 38 microns thick. Material taken from the same portion of the melt as the optical sample had a Hall constant of 70 cm^3/coulomb at 78°K,[1] indicating a hole concentration of 10^{17}/cm^3. The absorption peak at 0.18 ev in Fig. 1 is thought to arise from transitions between the valence bands generally labeled 1 and 2 in the case of germanium[2]; the rise in absorption at 0.085 ev is attributed to free-carrier absorption. Transitions from the split-off valence band (band 3) to the light-hole and heavy-hole bands give absorption at energies above the intrinsic edge at room temperature, which was not resolved.