Letters to the Editor

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Thermal and Electrical Conductivities of Carbon Materials

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IN a previous note,[1] the large difference in thermal conductivity (1:100) between so-called amorphous carbon and graphite was attributed to the difference in crystallite sizes. Experiments have been carried out to test this relationship by measuring the physical changes and crystallite sizes for coke specimens. These were prepared from pitch coke (0.5 percent ash) manufactured at the Yahata Steel Company and widely used for the production of electrodes in Japan. After prebaking at 1300°, each sample was heated in an electric furnace at different temperatures over a range from 1500° to 2700° for 20 min. The results are shown in Fig. 1. It can be seen that the curves for the thermal conductivity

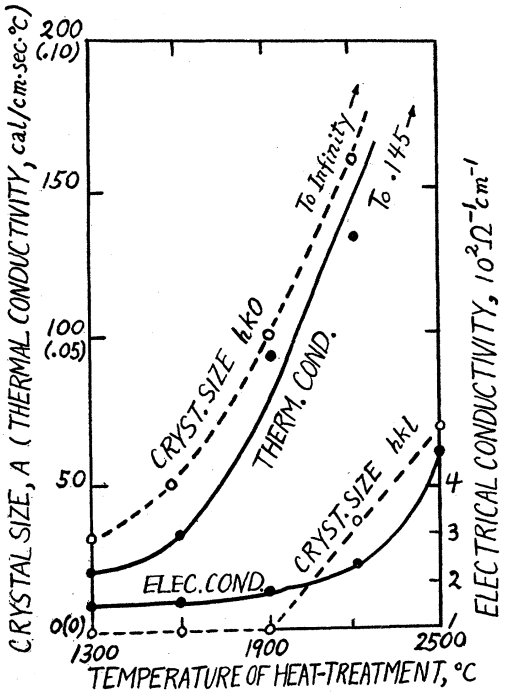

FIG. 1. Changes of crystal size and of electric and thermal conductivities by heat treatment at different temperatures.

and for the crystallite size in the *hk*0 direction are nearly parallel to each other and both show a rapid rise with temperature even in the region where the electrical conductivity remains constant. Inasmuch as the *hk*0 size represents the (mean) diameter of the layers in a crystallite, this resemblance means that the lattice waves which carry the heat current are scattered by the crystallite boundaries with the mean free path being proportional to the layer diameter. On the other hand, the curve for the electrical conductivity appears to correspond to that representing the temperature dependence of the crystallite size in the *hkl* direction. Since the *hkl* size is related to the degree of the change from the randomly oriented layer structure to the regular three-dimensional one, the electronic waves which carry the electric current are scattered by the irregular potential caused by the random neighboring layers.

So-called amorphous carbons having a completely random layer structure may therefore be supposed to have electrical resistivity independent of crystallite size, as long as the layer diameter in a crystallite is sufficiently large. After heating at temperatures in the range from 1500° to 1900°, solid carbon samples, prepared from pitch coke, formaldehyde resin, or charcoal, show nearly the same and constant resistivity, 3.6, 3.6, and 2.3Ω cm (in the fiber direction).

Though a number of experiments on the crystallite growth of carbon have been carried out by others, these new relations found for solid samples seemed worth mentioning.

[1] S. Mizushima and J. Okada, Phys. Rev. **82**, 94 (1951).

Ferromagnetic Resonance in Copper Ferrite

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THE ferromagnetic resonance absorption in a single crystal of copper ferrite was studied from −195°C to *ca* +470°C at 24,000 Mc/sec, and the resonance phenomena in some sintered polycrystalline specimens were also studied.

The *g*-factor, the first-order magnetocrystalline anisotropy K_1, and the saturation magnetization M_s were determined from the resonance data as functions of the temperature.

The crystals were grown by a method similar to that by which crystals of manganese zinc ferrite and cobalt zinc ferrite had been grown previously.[1] A mixture of 8.0 g of Fe_2O_3, 4.0 g of CuO and 12 g of borax was kept at 1200°C for 3 hours in a platinum crucible and slowly cooled at a rate of 1°C/min till 900°C; then the current to heat the furnace was turned off, and the sample was cooled to room temperature in the furnace.

We were afraid that the specimen obtained in this manner might have tetragonal symmetry; but since its deviation from

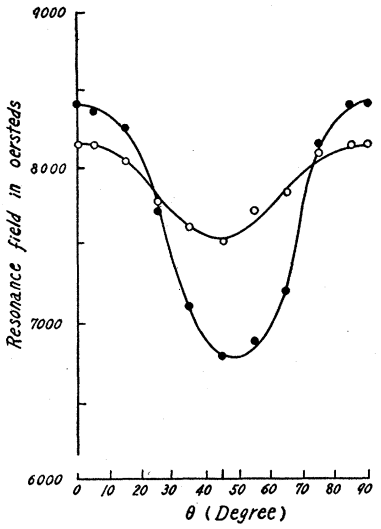

FIG. 1. The resonance field as a function of crystal orientation; θ equals the angle in the (100) plane between the static field and the cube edge; the open circles denote the results at room temperature and the solid circles denote the results at liquid nitrogen temperature.

cubic symmetry might be negligibly small, we assumed the crystal symmetry to be cubic for the calculation of K_1 and g.

The measuring procedure was the same as in the earlier experiments,[2] so it is omitted here.

The single crystal was so mounted as to make the (100) plane consistent with both the directions of the rf field and the dc magnetic field. The resonance field was observed as a function of crystal orientation at room and liquid nitrogen temperatures, as shown in Fig. 1.

TABLE I. Measurements on copper ferrite.

Temp. (°C)	M_s (gauss/cc)	K. (ergs/cc)	g	g^a
−195	315	-2.06×10^5	2.20	2.17
−150	310	−1.80	2.13	2.13
−100	305	−1.43	2.09	2.08
− 50	295	−1.01	2.06	2.05
15	280	−0.63	2.04	2.04
50	250	−0.43	2.04	2.05
100	220	−0.24	2.07	2.05
150	180	−0.16	2.01	2.05
200	165	−0.10	2.01	2.05
250	135	−0.07	2.03	2.05
300	110	−0.04	2.04	2.05
350	80	−0.02	2.04	2.06
400	60	−0.01	2.05	2.06
450	30	—	2.05	2.06

[a] Determined by the resonance experiment on a polycrystalline spherical specimen.

The saturation magnetization M_s at various temperatures was calculated from the resonance data for polycrystalline spherical and disk-formed specimens. Substituting these values of M_s in Kittel's formula, g and K_1 were calculated from the resonance field for both the [100] and [110] directions parallel to the static field. The results are given in Table I. In the table, the g-factors determined for a spherical polycrystalline specimen of diameter 0.8 mm are also listed.

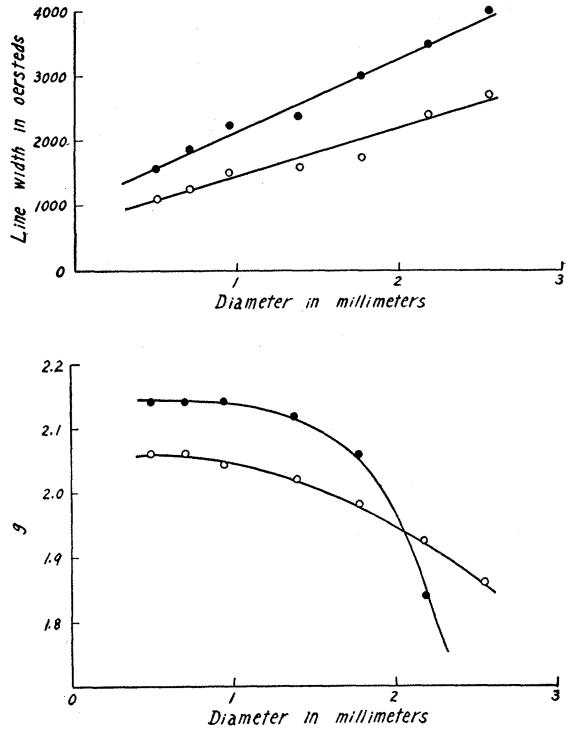

FIG. 2. The half-linewidth and apparent g-factor of various spheres at room and liquid nitrogen temperatures; the open circles denote the results at room temperature and the solid circles denote the results at liquid nitrogen temperature.

K_1 did not change its sign in the whole temperature region, contrary to the cases of nickel ferrite,[3] manganese zinc ferrite and cobalt zinc ferrite,[2] for which K_1 changes sign at *ca* −160°C, −100°C and +70°C, respectively.

The g-factor increases in value below room temperature with falling temperature, similar to the inclination of g-factors in other ferrites[4] when plotted against temperature; but it shows an almost constant value above room temperature up to the Curie point *ca* +470°C, at which temperature the resonance disappeared.

To determine the g-factor in polycrystalline specimens, the size effect was studied for various spheres whose diameter varied from 2.6 mm to 0.5 mm, and a similar effect was observed to that found in other ferrites by Yager and his co-workers[5] and recently by the writer.[6] Figure 2 shows the half-linewidth and apparent g of various spheres at room and liquid nitrogen temperatures. An interesting effect was found, that is, g at a low temperature was smaller than g at room temperature for a very large sphere, and the discrepancies of the half-linewidth between room temperature and a lower temperature became smaller as the size of the sphere approached zero.

Details of the present experiment will be published in Science Reports of the Research Institute of Tôhoku University.

[1] T. Okamura, Phys. Rev. **85**, No. 4 (1952).
[2] Okamura, Kojima, and Torizuka, Sci. Repts. Research Inst., Tôhoku University, 4, No. 1 (1952).
[3] D. W. Healy, Technical Report of Harvard University, No. 135 (1951).
[4] T. Okamura and Y. Torizuka, Nature **168**, 162 (1951).
[5] W. A. Yager and F. R. Merritt, Phys. Rev. **81**, 477 (1951).
[6] T. Okamura and Y. Kojima (to be published in Sci. Repts. Research Inst., Tôhoku University).

The β-Spectrum of RaD

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THE radioactive decay of RaD has been investigated by introducing it in the form of lead tetramethyl vapor into a proportional counter. Excellent proportionality was obtained (as checked by the line width obtained from superimposed external sources) using dry lead tetramethyl at a pressure of a few mm together with methane and argon, to a total pressure of one atmosphere. The counter was 75 cm long and 9 cm in diameter and was provided with a window for calibration with an external source. The amount of lead tetramethyl that sticks to the counter wall during the course of an experiment (not more than 4 hours) was found to be very small.

The pulse distribution, obtained with a single channel pulse analyzer, is shown in Fig. 1, for an experiment in which 2 mm of lead tetramethyl vapor gave a total counting rate of about 3000/sec.

Other work[1,3] has shown that a 46.7-kev γ-ray occurs in about 70 percent of disintegrations, and is highly converted (97 percent). If this γ-ray is emitted in a time short compared with the resolving time of the counter (2 microseconds) we would expect that 70 percent of the pulses should correspond to the sum of the energies of the γ-ray and the β-particle, if all the secondary radiations after internal conversion are re-absorbed in the counter gas. This is seen in the region of peak A, which is much broader than that obtained with an external source of RaD providing 46.7 kev γ-rays. In some cases, however, the L x-rays of bismuth (mainly 10.8 kev and 13.0 kev) escape from the counter, giving rise to the peak at B (36.7 kev).

Careful examination using the 46.7 γ-rays from an external source of RaD (0.5 millicurie) indicated that the maximum at A occurs at an energy 2.7±0.5 kev greater than 46.7 kev; this together with the sharpness of the peak probably indicates the existence of a maximum in the β-spectrum. The point at 46.7 kev corresponds to the zero of energy for the β-spectrum. After comparison with the pulse distribution obtained for the 46.7-kev γ-ray (semi-half width 1.7 kev), it is possible to estimate the