up by the specimen. This is about twice that actually observed.

The results clearly show that thin specimens must be mounted in a strain-free fashion for this type of measurement if data characteristic of the unstrained material are desired. It follows that cooling the specimen by conduction through a solid backing is unsatisfactory since it is practically impossible to arrange for the relative expansion to be zero. Recourse must be had to direct immersion in the cooling liquid, which brings its own difficulties,[10] or immersion in thermal exchange gas.[11,12] The latter method is used in this laboratory. These considerations will apply, of course, to other materials than Ge.

Strain in the specimens will also affect magneto-absorption measurements. Clearly, a uniform strain will shift the band edges and the adjacent Landau levels to roughly the same extent. The magneto-absorption bands will thus experience an appreciable shift (of the same order as that of the exciton absorption), but it is unlikely that changes in their relative positions will be detectable by the spectroscopic means currently in use. The practical situation with a backed specimen is almost certainly one of nonuniform strain and will be more complicated.

Finally it is emphasized that the condition of the specimens should be kept very much in mind when correlating data obtained from different experiments.

We are indebted to the Lincoln group for lending us two of their specimens and for communicating their results to us before publication. Our thin specimens were skillfully prepared by S. C. J. Brooke. This Letter is published by permission of H. B. M. Stationery Office.

[1]Macfarlane, McLean, Quarrington, and Roberts, Proc. Phys. Soc. (London) 71, 863 (1958).

[2]Zwerdling, Lax, Roth, and Button, Phys. Rev. (to be published). In this paper the transmission ratio of a sample at 77°K is given and can be directly compared with out results.

[3]Zwerdling, Lax, and Roth, Phys. Rev. 108, 1402 (1957).

[4]In reference 1 we state that our value for $E_0$ at 291°K should be regarded as less reliable than those at the lower temperatures. This is so, but should not be taken to imply that it is unreliable in the present context. The discrepancies which we are now discussing (~0.006 ev) are more than ten times as great as the error in $E_0$.

[5]Macfarlane, McLean, Quarrington, and Roberts, Phys. Rev. 108, 1377 (1957).

[6]A thermosetting adhesive similar to Allymer cement. We understand Allymer cement is used by the Lincoln group.

[7]R. J. Elliott, Phys. Rev. 108, 1384 (1957).

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## MAGNETIC FORM FACTOR OF COBALT*

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We wish to report preliminary results on the magnetic form factor of the face-centered cubic phase of metallic cobalt, which indicate a deviation from spherical symmetry for its $3d$ electrons. These measurements represent a continuation of studies on the angular dependence of the magnetic scattering in the transition elements using a polarized neutron beam spectrometer[1]; the results on iron and nickel have been already reported in reference 1. These studies were undertaken because of the current interest in the $3d$ electron configurations in the transition elements and the pertinence of magnetic form factor data to such discussions.

The sensitivity of the polarized beam technique in establishing the absolute magnitude of the magnetic scattering depends on the ratio of the nuclear scattering amplitude to the magnetic scattering amplitude at the different scattering angles. For cobalt, this ratio is very favorable and it is possible to obtain sizable differences in the reflectivities for beams of different polarization even for large scattering angles, where the magnetic scattering is greatly reduced. For this reason every effort was made to reduce the in-

trinsic experimental uncertainties present in this type of measurement to a minimum so as to ascertain whether in cobalt the angular dependence of the magnetic scattering gives any definite indication of structure in the distribution of unpaired electrons.

The method used to obtain the absolute magnetic scattering amplitude has been described in detail in reference 1. Briefly, the ratio of reflected intensities from a magnetized single crystal is measured for incoming neutrons polarized first parallel to the field on the crystal, and then antiparallel. This polarization ratio for a particular Bragg reflection depends on the ratio $p_{hkl}/b_{hkl}$, where $p_{hkl}$ and $b_{hkl}$ are the magnetic and nuclear structure factors for the $(hkl)$ reflection. Since $b_{hkl}$ is known, the measurement yields $p_{hkl}$. It is necessary to correct the observed values of the polarization ratio for the presence of extinction in the test crystal and for the depolarization of the neutron beam as it traverses the crystal. The latter was measured by a method given in reference 1, and was shown to be less than 1%. Extinction, although small, was estimated by performing the measurements for crystals of different thicknesses and at two different neutron wavelengths (0.89A and 1.04A).

The test crystal for the fcc measurements consisted of a pillar crystal of the alloy $Co_{0.92}Fe_{0.08}$, the presence of the iron serving to stabilize the cobalt in the fcc phase. All measurements were made at room temperature. The results of the measurements taken to date are shown in Table I and plotted in Fig. 1. In calculating the magnetic scattering amplitudes we have used the values $b_{Co} = 0.25 \times 10^{-12}$ cm $^2$ and $b_{Fe} = 0.96 \times 10^{-12}$ cm.

Table I. Magnetic form factor of face-centered cubic cobalt.

| Reflection | $\sin\theta/\lambda$ | $p_{hkl}/b_{hkl}$ | $f$ |
|---|---|---|---|
| (111) | 0.244 | 1.21 ±0.06 | 0.781±0.040 |
| (200) | 0.283 | 1.01 ±0.06 | 0.652±0.040 |
| (220) | 0.397 | 0.575±0.005 | 0.371±0.003 |
| (311) | 0.467 | 0.418±0.003 | 0.270±0.002 |
| (222) | 0.487 | 0.350±0.002 | 0.266±0.002 |
| (400) | 0.563 | 0.286±0.006 | 0.184±0.004 |
| (331) | 0.613 | 0.166±0.002 | 0.107±0.002 |
| (422) | 0.689 | 0.091±0.006 | 0.059±0.004 |
| (333) | 0.731 | 0.054±0.006 | 0.035±0.004 |
| (440) | 0.796 | 0.034±0.003 | 0.022±0.002 |

Of particular interest in the data is the failure of the form factor values for some of the higher $(hkl)$ reflections to fall on a smooth curve, in particular the (311) and (400) reflections. In order to emphasize that these "bumps" are real, we have plotted in Fig. 2 the outer portion of the form factor curve on an expanded scale along with the estimated uncertainties in the measurements. These "bumps" have led us to suggest a deviation from spherical symmetry for the $3d$ electrons. As far as we know, these measurements give the first experimental indication of such a departure. A somewhat similar behavior to the above had also been noticed in the fcc nickel form factor. However, because of the low magnetic scattering amplitude of nickel, espe-

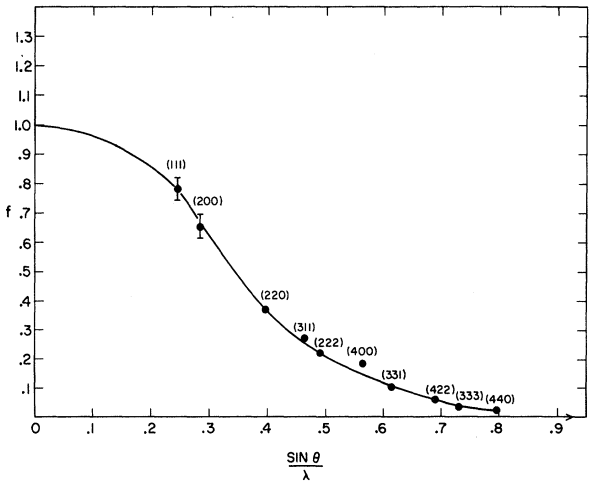


FIG. 1. Magnetic form factor of face-centered cubic cobalt.

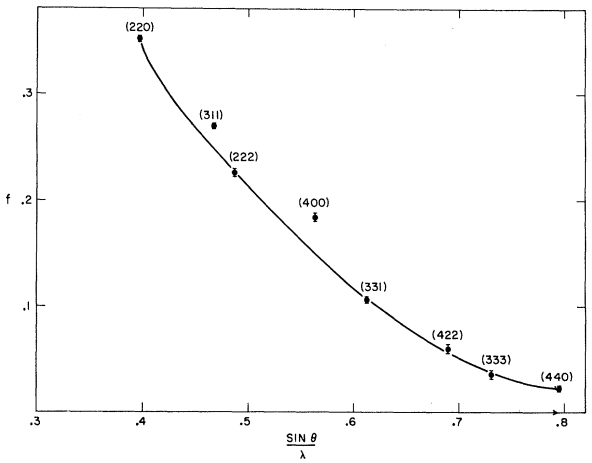


FIG. 2. Outer portion of the magnetic form factor curve of fcc Co.

cially at the higher scattering angles, it was difficult to place these observed "bumps" on a more definite basis.

Because of the change in the symmetry, it would also be of interest to compare the magnetic form factor of hexagonal close-packed Co with that of face-centered cubic Co. Hence we are continuing these measurements in order to refine the fcc data further and to determine the form factor of the hexagonal phase. A detailed report will be submitted upon the completion of this work.

We are indebted to Dr. T. A. Kaplan and Dr. S. J. Pickart for profitable discussions of these results. We also wish to thank Dr. H. J. Williams and Dr. R. M. Bozorth of Bell Telephone Laboratories for supplying us with the crystals.

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## LATTICE VIBRATIONS IN SILICON AND GERMANIUM

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The dispersion curves of lattice waves travelling in the [001] directions of a silicon single crystal have been measured using neutron scattering. The frequency ($\nu$) and wave vector ($\vec{q}$) of each phonon, and the character of each branch, were determined as previously discussed.[1] The complete results for the longitudinal acoustical (LA), longitudinal optical (LO), and the degenerate transverse acoustical (TA) and transverse optical (TO) branches are shown in Fig. 1.

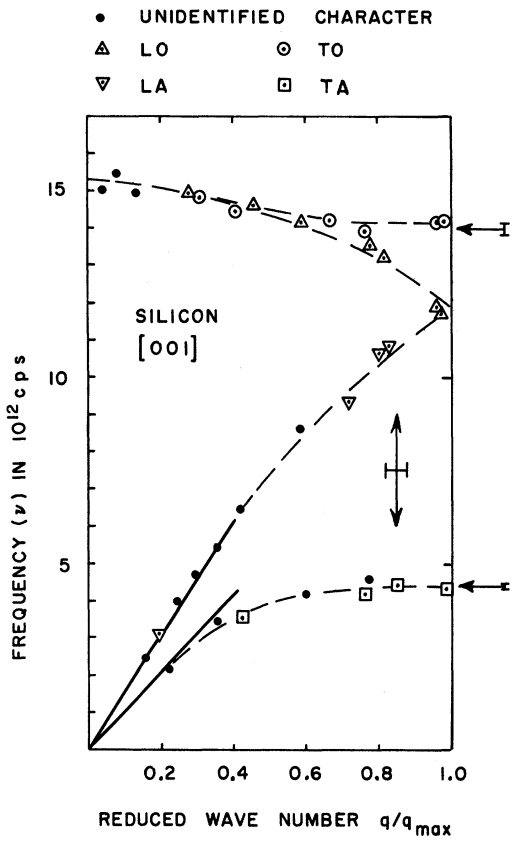


FIG. 1. Frequency vs reduced wave number for lattice vibrations propagating in the [001] direction of the reduced zone in silicon at room temperature. The heavy lines have the slope of the appropriate velocity of sound as found by ultrasonic measurements [H. J. McSkimmin, J. Appl. Phys. 24, 988 (1953)]. The vertical arrow indicates the presumed position ($q_0$) of the minimum of the conduction band (reference 13). The horizontal arrows indicate the frequencies of phonons at $q_0$ found from the indirect transition (references 10-12).

Two series of experiments were performed using a new multiple axis crystal spectrometer at the NRU reactor. In the first, neutrons of 1.900A wavelength were scattered from a single crystal of silicon at angles in the vicinity of 90° with the crystal oriented so that the wave vector of the outgoing neutrons ($\vec{k}'$) lay very nearly along the line ($\bar{2}$, $\bar{2}$, 3) to ($\bar{2}$, $\bar{2}$, 6) of the silicon reciprocal lattice.[2] The wave vectors of all phonons observed in these experiments thus lay in the [001] direction of the reduced zone. In the second series, neutrons of 1.900, 1.350, and 1.693 angstroms were used in the method of successive approximations,[1] in which phonons were measured in regions of reciprocal space in which their polarization, and optical or acoustical character, could be unambiguously determined. All measurements were made at room temperature. The points are believed to define the level of all branches to about 3%. Values of important frequencies (units $10^{12}$ cps) are: Raman ($q=0$) $15.3\pm0.3$, TO[001] $14.2\pm0.3$, L[001] $11.9\pm0.5$, TA[001] $4.35\pm0.15$.