is the one postulated, some physical property of the new phase would have to be measured. The obvious one under shock conditions might be the conductivity; however, the conductivity might be metallic before the existence of a monatomic lattice if the conduction band overlaps the valence band in the diatomic system. This change might be difficult to detect in the Hugoniot equation of state. Although conductivity measurements have been made at low pressures to show the narrowing down of the energy gap, the present experimental techniques in any case do not allow the determination of very low resistances existing for such short times.

However, an empirical rule for the lengthening of diatomic bonds to metallic bonds can be used to calculate at what volume iodine should have its transition and thus confirm the suggestion made. The empirical evidence can be obtained from the alkali metals which have a diatomic species in the vapor phase and condense into a body-centered cubic metal lattice. From the known interatomic distances[5] it is found that the Li spacing expands by 13.7%, Na by 20.7%, and K and Cs both expand by 15.8%. From the known diatomic distance in iodine and the assumed expansion of 15.8% in interatomic spacing for the heavy elements and also assuming a body-centered structure for the metallic iodine phase, the phase transition for iodine would be predicted to occur at $v/v_0 = 0.53$. This is in agreement with the experimental value. Other elements for which this expansion in spacing is known all fall into the 10 to 20% region.

Earlier theoretical calculations on metallic hydrogen[2] have predicted this expansion of the bond to be about 80%. From quantum mechanical calculations on the metal-like triatomic hydrogen system[6] it can be made plausible that here also the expansion should be near 20%. A 20% expansion over the diatomic distance would mean that, for the monatomic phase of hydrogen to exist, the normal solid phase would have to be compressed by a factor of 30 instead of 10 as previously predicted. The pressure of this transition is then calculated by the Wigner method[1] to be near 20 megabars instead of the 1 megabar estimated earlier.

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NEUTRON SMALL-ANGLE SCATTERING BY SPIN WAVES IN IRON

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Neutron small-angle scattering by spin waves in iron has been observed in virtual isolation at an intensity of several thousand counts per minute, the various other effects that normally complicate such a measurement having been rendered negligible. The theoretical dependence of the scattered intensity on neutron wavelength and scattering angle and on specimen temperature, setting, and magnetization has been confirmed. If iron be regarded as a Heisenberg-Bloch ferromagnet, the cutoff angle of the scattering gives a value of 0.018 ev for the effective exchange integral, in agreement with the value obtained by fitting a $T^{3/2}$ law to the saturation magnetization at low temperatures.

Although it is well known that neutron scattering techniques provide a sensitive means for the detection of spin waves, experiments have been performed on three substances only – magnetite,[1] hematite,[2] and iron.[3] A source of complication is that the spin-wave scattering associated with any planes of nonzero *hkl* in a magnetic crystal is accompanied by phonon scattering whose response to changes in magnetization and temperature must be allowed for. In the present experiment we have avoided this difficulty by studying the scattering at positions close to the main beam, where 1-magnon inelastic scattering is

allowed, but where there is no 1-phonon scattering of neutrons having velocity less than that of sound in the crystal (i.e., in iron, of neutrons with wavelength >1.1 A).

The expected small-angle scattering may be calculated from formula (2.37) of reference 4. For iron it has the distribution shown in Fig. 1. This distribution has two remarkable features: its intensity – the weakest point corresponds at room temperature to a differential cross section of $35\lambda^2$ barns steradian^{-1} atom^{-1} (λ in A); and the fact that to a high degree of approximation it is independent of incident wavelength. Exploiting the latter feature, we allowed a ribbon-shaped beam of Maxwell neutrons from DIDO, 1.60 cm high, 0.125 cm wide, and with cadmium ratio ~1900, to fall upon a cylindrical iron crystal of height 2.14 cm and diameter 0.739 cm. The reactor temperature, specimen thickness, and counter efficiency were such that 92% of the recorded spin-wave-scattered neutrons were, on incidence, slower than the velocity of sound in iron. A vertical counter slit of width 0.190 in. could be tracked across the beam at a distance of 57.3 in., picking up the intensity between parallel lines in Fig. 1; as the incident collimation was better than 6′ of arc the small-angle diffraction pattern could be surveyed down to angles of ~15′. By rotating an applied magnetic field, the expected spin-wave pattern could be turned around the optical axis so as to move the slit effectively from H to V.

We found the following results:

1. Intensity having the anticipated angular dependence was present. Figure 2 shows the difference between the counting rates at H and V as a function of scattering angle and temperature. A form of magnetization-dependent, temperature-dependent scattering is there revealed that cuts off sharply at (correcting for instrumental widths) $25 \pm 1'$, in exact agreement with the theoretical 25′.

2. On rotating the magnetic field from H to V, the expected curve of intensity variation was obtained. At 25′ the intensity ratio H/V was 1.46 $\pm$ 0.02, as against a theoretical 1.40.

3. Absolute intensities were below those calculated for a simple Heisenberg-Bloch ferromagnet, as they must be for a real crystal with anisotropic interactions.[4] For instance, at 25′ the H counting rate (above a background and disorder-scattering contribution of 240 ± 3 min^{-1})

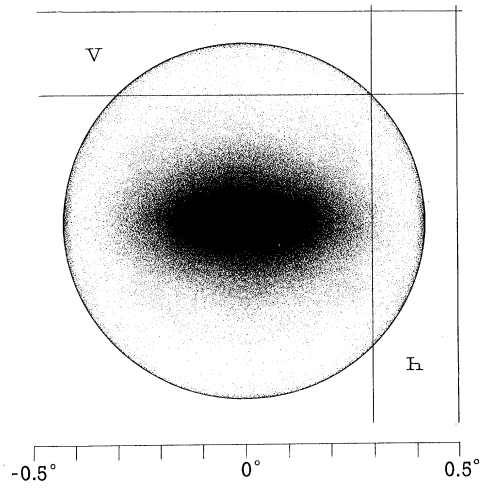

FIG. 1. The theoretical distribution of neutrons scattered near the primary beam by spin waves in iron, assuming perfect collimation. Parallel lines show the effective position in this pattern of the counter slits for horizontal (H) and vertical (V) applied magnetic field.

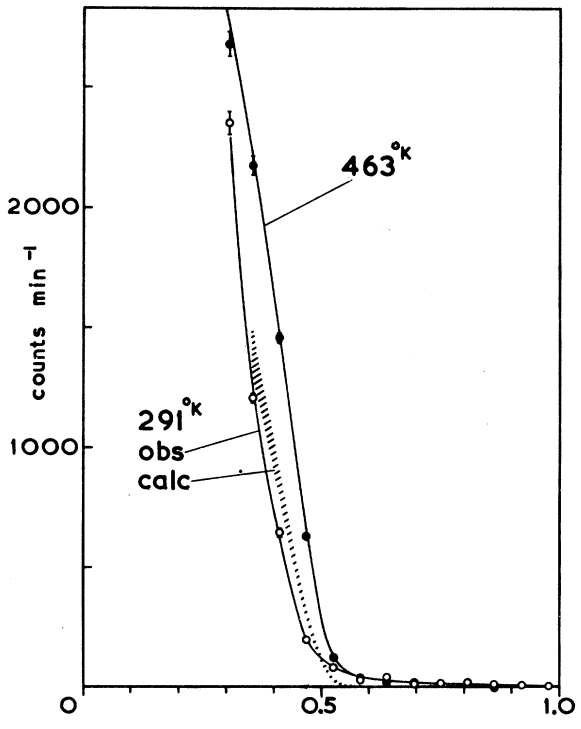

FIG. 2. Difference between the observed counting rates at H and V as a function of angle and temperature, showing a sharp cutoff at the angle predicted. The calculation is for a simple Heisenberg-Bloch ferromagnet without anisotropic interactions.

was 2000 ± 15 min^{-1}, as against a theoretical 3450 ± 240. Crystal-defect scattering was present at some specimen orientations, and was investigated with results that will be described in a more detailed communication.

4. An absorption curve in silver showed that if the differential cross section giving rise to the intensity has the form λ^n, then $n = 2.0 \pm 0.1$. Theory requires λ^2.

5. For some 54°K above room temperature the intensity was proportional to the absolute temperature, and the temperature increase was independent of the crystal setting.

The above points are decisive in identifying single-magnon scattering. An unexpected feature, observed with three different specimens, is that as the temperature of the specimen is raised a markedly nonlinear increase of intensity sets in abruptly at ~346°K (Fig. 3). This apparently sudden failure of the single-spin-wave discussion at a well-defined temperature is strongly reminiscent of the sudden deviation from a $T^{3/2}$ law found by Foner and Thompson[5] in the saturation magnetization of nickel. It is possible to argue from our data that the nonlinear intensity is unconnected with phonons, multiple-quantum scattering, multiple scattering, or crystal defects, nor is it explained by a temperature variation of J_{eff}. Thus it would appear that a moderately excited spin system possesses states that have not hitherto been adequately discussed. The confinement of the nonlinear intensity within 25′ of angle seems to indicate that spin-wave states continue to be involved, and is inconsistent[6] with any application to iron of Wohlfarth's suggestion[7] that collective-electron orbitals may come into play at the temperature where spin-wave theory breaks down for nickel.

We are grateful to Dr. R. J. Elliott for a valuable discussion, to Mr. E. B. Fossey for a computation and to the Monocrystals Company for the iron crystals.

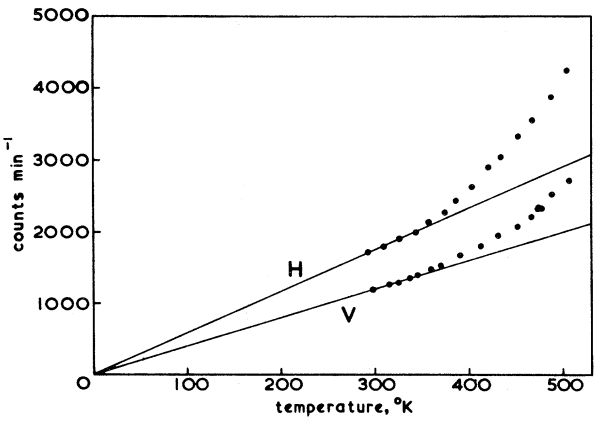

FIG. 3. Temperature dependence of the intensity at a scattering angle of 25′.

*On attachment from the Atomic Energy Establishment, Trombay, India.

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OPTICAL ABSORPTION BY DEGENERATE GERMANIUM

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In a previous note[1] the author has proposed that degeneracy due to impurities in germanium results in an effective shrinkage of the energy gap. This hypothesis had been suggested by the threshold of the emission spectrum which puts the conduction band edge at about 0.5 ev from the valence band. In this case the impurity concentration was estimated as being of the order of 10^{19} cm^{-3}.

Optical transmission measurements were made on wafers of germanium doped with a known concentration of arsenic. Figure 1 shows the optical density of two heavily doped specimens and that of a pure specimen for comparison. Because of free carrier absorption it is difficult to identify the threshold corresponding to the

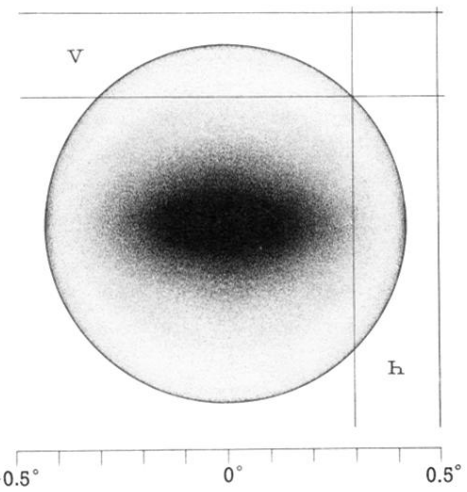

FIG. 1. The theoretical distribution of neutrons scattered near the primary beam by spin waves in iron, assuming perfect collimation. Parallel lines show the effective position in this pattern of the counter slits for horizontal (H) and vertical (V) applied magnetic field.