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.

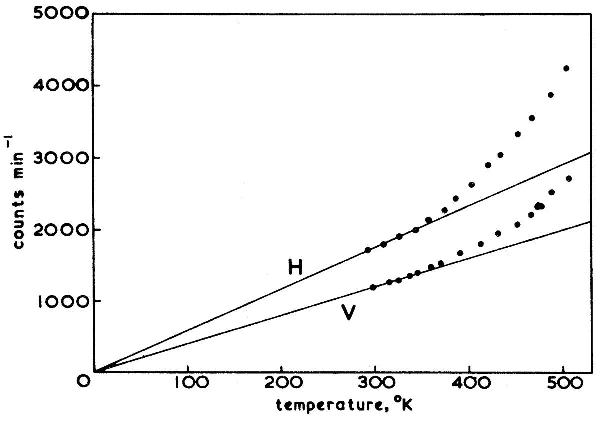

FIG. 3. Temperature dependence of the intensity at a scattering angle of 25′.

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[*] 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

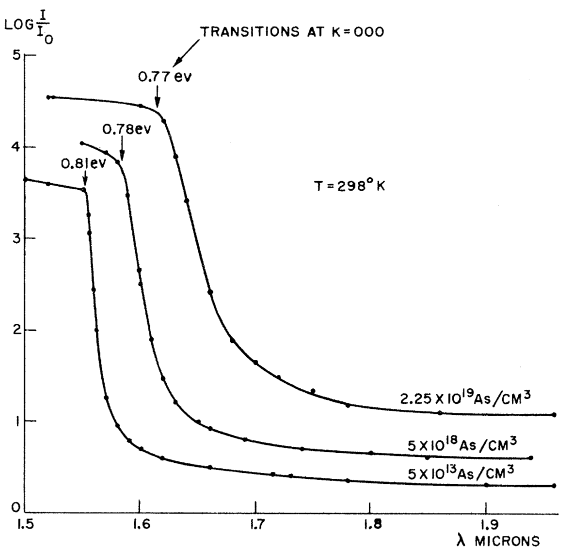

FIG. 1. Optical density of arsenic-doped germanium.

band edge at $\vec{k} = (1, 1, 1)$. However, the data clearly show how doping moves the (0, 0, 0) valley of the conduction band to a lower energy.

A judicious plot of the transmission data can separate the effect of free carrier absorption. Let $I_0(\lambda)$ be the radiation incident on the specimen and assume that the reflection coefficient R is the same for all specimens; then $I_p(\lambda)$, the radiation transmitted by the pure specimen, is

$$I_p(\lambda) = I_0(\lambda)(1 - R)^2 e^{-\alpha(\lambda)x},$$

where $\alpha(\lambda)$ is the absorption coefficient and x is the thickness of the wafer. Note that, since there are very few free carriers, $\alpha(\lambda)$ is purely due to edge absorption. The radiation transmitted by a doped specimen is

$$I_d(\lambda) = I_0(\lambda)(1 - R)^2 e^{-[\alpha'(\lambda) + \alpha_f(\lambda)]x},$$

where $\alpha'(\lambda) \neq \alpha(\lambda)$, and $\alpha_f(\lambda)$ is the free carrier absorption. Then

$$\ln[I_p(\lambda)/I_d(\lambda)] = [\alpha'(\lambda) - \alpha(\lambda) + \alpha_f(\lambda)]x.$$

$\alpha_f(\lambda) = a\lambda^n$ is dominant at long wavelength whereas α and α' are effective in the vicinity of 2 μ. For free carriers in metals $n = 2$, but for germanium values of n up to 3.5 have been reported.[2,3]

In Fig. 2 we have plotted $\log\{\log[I_p(\lambda)/I_d(\lambda)]\}$ vs $\log\lambda$. The data show that free electron absorption in the range studied follows the λ^2 law.

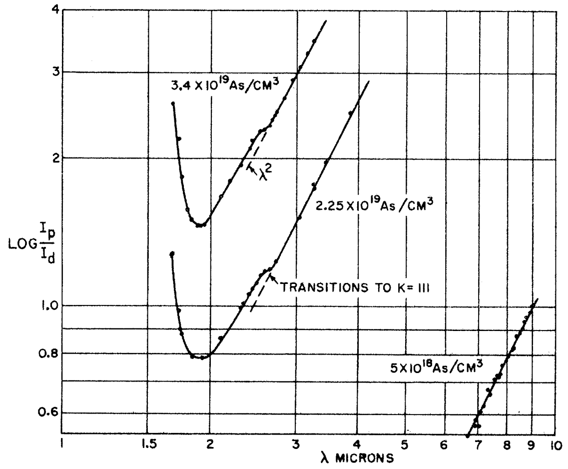

FIG. 2. Increase in absorbance due to high concentrations of donors in germanium.

If the departure from this law at short wavelengths is attributed to the onset of edge absorption, we are led to conclude that the edge of the degenerate conduction band is less than 0.48 ev above the valence band (allowing for the fact that no edge absorption can take place to those states of the conduction band which are already occupied[4]).

The data of Fig. 1 were obtained with a Cary double-beam spectrometer using quartz optics. The sensitivity beyond 2 μ was too poor to reveal the onset of edge absorption. Therefore, another instrument (Perkin Elmer Model 112) with NaCl prism was used to explore the spectral range of Fig. 2 not covered by the first instrument.

The evidence then indicates that for germanium, unlike the case for InSb,[4,5] the shrinkage of the energy gap is greater than the rise of the Fermi level.

A series of measurements of absorption as a function of doping and at low temperature is under way.

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