method, susceptibilities of the magnitude measured in this experiment may be measured to an accuracy of 1 percent.

Two samples of α Mn were employed in this investigation. One was from a cast ingot[8] and was pickled prior to measurement; the other was a packed capsule of electrolytic flakes and was from the same sample used by Shull in his neutron diffraction investigation. The results are tabulated in Table I. The room temperature susceptibility for both samples was of the order of 10^{-5} emu/g and in good agreement with previously measured values. Both samples also show the maximum below 200°K that is found by the earlier investigators.

TABLE I. Mass susceptibility of α Mn, $\chi \times 10^6$.

T°K	Electrolytic	Cast ingot	Cast ingot degassed
300	10.6	8.8	8.9
120–170	10.9	9.6	⋯
90	10.7	9.4	⋯
77	10.5	9.9	⋯
4.2	11.5[a]	15.0[a]	9.0[a]

[a] Magnetization in a field of 10 kilogauss on a virgin magnetization curve ($\times 10^2$).

The cast sample shows an increasing susceptibility below 100°K. At helium temperatures the sample is definitely ferromagnetic with a remanence of some 0.07 emu/g. The magnetization at each field is increased over the room temperature values by approximately the remanence. The magnetization at 10 kg is approximately 70 percent greater at 4.2°K than at 77°K. The remanence decreases rapidly between helium and hydrogen temperatures but persists to approximately 60°K. This behavior appears to be consistent with the susceptibility curve of Kriessman and McGuire. However, for the electrolytic sample, which is similar to that of Kriessman and McGuire, the increase in susceptibility at helium temperatures is nowhere near so marked, being less than 10 percent. A remanence is still observed but amounts to but 0.005 emu/g. It is well known[9] that many alloys and compounds of manganese, including the hydride and nitride, are ferromagnetic. Chemical analysis of the case sample did indeed show the sample to contain 0.4 percent (atomic) hydrogen, 0.11 percent oxygen, and 0.09 percent nitrogen. Analysis of the electrolytic sample from the diffuse background in the neutron diffraction pattern shows the hydrogen content to be no greater than 0.02 percent. On the supposition that the observed ferromagnetism may have been caused by the presence of interstitial impurities, the "ferromagnetic" sample was given a vacuum anneal treatment of 500°C which presumably removes most of the common interstitial impurities. Following the anneal this sample showed a 2 percent increase in susceptibility at room temperature. At helium temperatures, however, its susceptibility was within 2 percent of its room temperature value and the remanence was down to 0.003 emu/g. One may thus conclude that the onset of ferromagnetism in manganese is associated with the presence of interstitial impurities and the increase observed by Kriessman and McGuire at low temperatures is probably due to the presence of impurities in their sample and is not an intrinsic property of the manganese. Further investigation of the quantitative aspects of this effect and its interpretation is being undertaken in this Laboratory.

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† FOA Fellow on leave from Imperial College, London, England.

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Infrared Absorption of Silicon Near the Lattice Edge

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WE have measured the absorption of a polycrystalline specimen of 100 ohm-cm silicon in the neighborhood of the lattice edge at temperatures from 20°K to 3330°K. High resolution was obtained by the use of glass prisms, the method being to measure the transmitted radiation intensity with and without the specimen present, to deduce the reflection coefficient from the constant value of the transmission coefficient at wavelengths well beyond the absorption edge, and to calculate the absorption from these data.

The results, shown in Fig. 1, indicate that, as with germanium,[1] the absorption constant, K, is well represented at low levels by a law of the form

$$K=A\left[\frac{(h\nu-E_G-k\theta)^2}{1-e^{-\theta/T}}+\frac{(h\nu-E_G+k\theta)^2}{e^{\theta/T}-1}\right].$$

The best fit is obtained with $\theta=600$°K, for which value the full lines in Fig. 1 are drawn. E_G, which in the theory

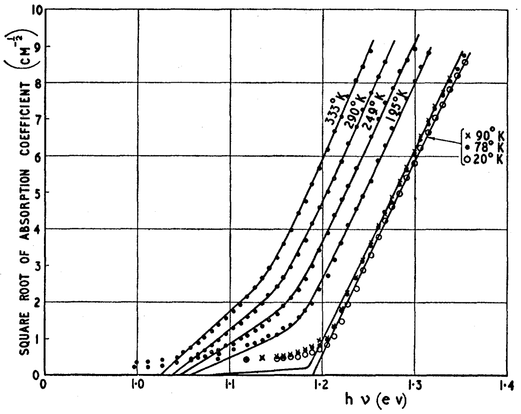

FIG. 1. Dependence of absorption constant on photon energy for silicon.

of indirect transitions[1,2] is the energy gap, varies with temperature as shown in Fig. 2. It behaves quadratically at low temperatures just as for germanium. We observe that our values for K agree substantially with those of Fan, Shepherd, and Spitzer[3] at room temperature.

From cyclotron resonance experiments[4,5] we know that the energy maximum of the valence band is at the origin and equal energy minima occur along the six [1,0,0] axes of momentum in the conduction band. According to the theory that the absorption tail beyond the lattice edge is due to indirect transitions, $k\theta$ is then the energy of the longitudinal acoustic wave with momentum equal to the momentum of the electrons at the minimum of the conduction band. From the known values of the elastic constants of silicon[6] and the theory of vibrations of the diamond lattice,[7] we estimate that the conduction band minima occur at a momentum of 9.0×10^7 cm^{-1}, which is about 7/9 of the distance from the center to the edge of the Brillouin zone in the [1,0,0] direction.

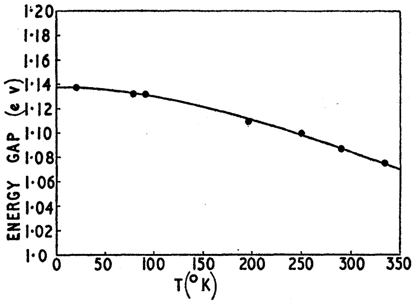

FIG. 2. Dependence of energy gap on temperature for silicon.

We have attempted to correlate the intrinsic carrier concentration n_i of Morin and Maita[8] with our values of E_G. We find

$$n_i=4.82\times10^{15}T^{\frac{3}{2}}(\bar{m}/m_0)^{\frac{3}{2}}N_c^{\frac{1}{2}}\exp(-E_G/2kT),$$

where $\bar{m}=0.44m_0$ is calculated from the effective masses of holes and electrons[4,5] and $N_c=6$ is the number of energy minima in the conduction band. At $T=333$°K this gives $n_i=1.50\times10^{11}$ cm^{-3}. Morin and Maita give data for n_i only above 450°K but if these data are extrapolated to 333°K, using their empirical formula, one gets $n_i=1.65\times10^{11}$ cm^{-3}. The discrepancy is about 10 percent.

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New Radiation Resulting from Recombination of Holes and Electrons in Germanium

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INTRINSIC radiation from germanium due to recombination of injected holes and electrons has been reported by Haynes and Briggs[1] and by Newman.[2] The results of these investigations show that the maximum of the energy radiated from the specimens used occurs at a wavelength of about 1.8μ. This result is in good agreement with that calculated by van Roosbroeck and Shockley[3] and by Newman[2] using the principle of detailed balancing and the optical absorption data of Briggs.[4] Recently, however, evidence has been found which shows that additional radiation is produced by a different recombination mechanism resulting in a second maximum at a wavelength of 1.5μ.

Evidence for this radiation was first found in the examination of radiation produced in germanium by a technique which is shown schematically in Fig. 1. The light from a ribbon filament tungsten lamp was passed through a water absorption cell 10 cm long and focused on a thin slice of germanium (1.2×10^{-2} cm thick).

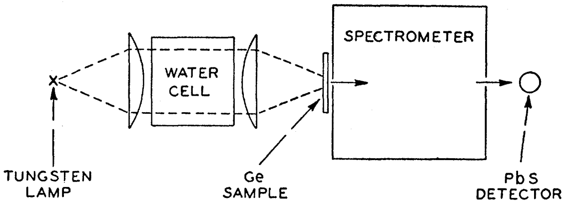

FIG. 1. Schematic arrangement used to measure recombination radiation as a function of wavelength.