served widths of 10^{10} and 1.4×10^{10} sec^{-1} for the $P_{\frac{3}{2}}$ and $P_{\frac{1}{2}}$ components. This intensity ratio indicates some self-reversal. However, the line contours showed no real dip in the peak but a peak somewhat flattened by self-reversal. These peak intensities predict a total absorption of 0.16 photon per atom in the illuminated part of the beam.

With zero magnetic field along the axis (applied $H=0.12$ gauss), the measured polarization ratio agrees with that calculated, assuming no atomic polarization. Also, this is in agreement with the results of Ellett and Heydenburg[5] and with our measurements on unpolarized incident light.

The polarization ratio intensity dependence (Fig. 3) is in good agreement with that computed from the known light intensity. The measured shift in polarization ratio for curve A ($R=0.9$ percent) agrees with the computed value of 0.8 percent. The polarization ratio is found to be independent of sodium beam intensity indicating negligible light trapping.

The computed effect of one-, two- and three-photon scattering on the occupation numbers of the states and the mean values of m_F and m_I are given in Table I. The polarization ratio of the salt scattered photon is also given. Equal peak intensities of the sodium D lines were assumed in the computation.

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Hall Effect and Conductivity of InSb Single Crystals

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WELKER[1] has described the conductivity and room temperature Hall effect of polycrystalline samples of the semiconducting compound indium antimonide, InSb. More recently Breckenridge, Hosler, and Oshinsky[2] have reported similar measurements as a function of temperature on polycrystalline samples.

We have recently grown large single crystals of InSb. The preparation of the compound has been described earlier,[3] and the material used in these measurements was extensively purified by zone refining.[4] The single crystals were grown from this material by the pulling technique developed by Teal and Little for germanium.[5] The resulting crystals were quite similar in appearance to single crystals of germanium.

The Hall effect and conductivity of these single crystals have been measured and the results are shown in Figs. 1 and 2. In these figures, the points are experimental values and the solid lines are calculated as described below.

Samples A and B show a reversal in the sign of the Hall coefficient R at 155°K and 182°K, respectively. These samples are p type below these temperatures and n type above. Sample C is n type down to the lowest temperature attained. The densities of extrinsic carriers in A, B, and C obtained from the expression

$$R=7.4\times10^{18}/n, \tag{1}$$

are 2.1×10^{15}, 1.2×10^{16}, and 1.7×10^{16} per cubic centimeter, respectively.

In a nondegenerate semiconductor, the Hall coefficient R and conductivity σ are given by the expressions,[6]

$$\sigma=e(n\mu_n+p\mu_p), \tag{2}$$

$$R=\frac{3\pi}{8e}\frac{nb^2+p}{(nb+p)^2}, \tag{3}$$

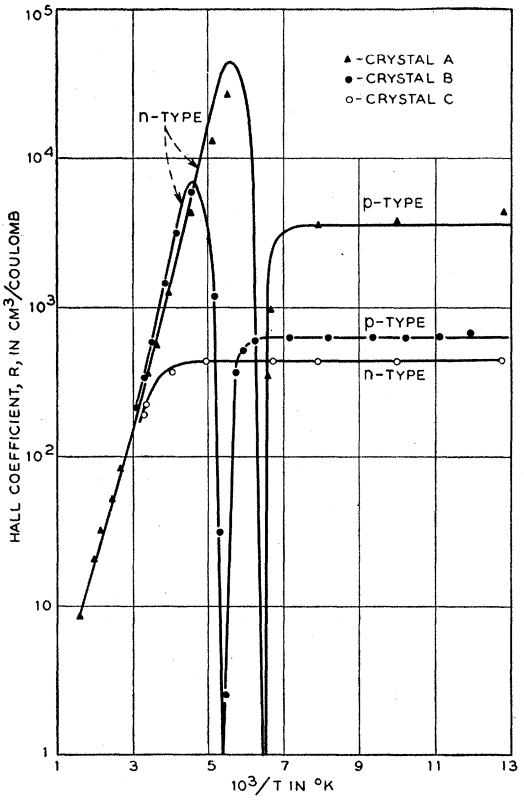

FIG. 1. Hall coefficient of indium antimonide as a function of temperature.

where n and p are the densities of electrons and holes, respectively, μ_n and μ_p the respective carrier mobilities, e the electronic charge, and $b=\mu_n/\mu_p$. In the temperature range where only one type of

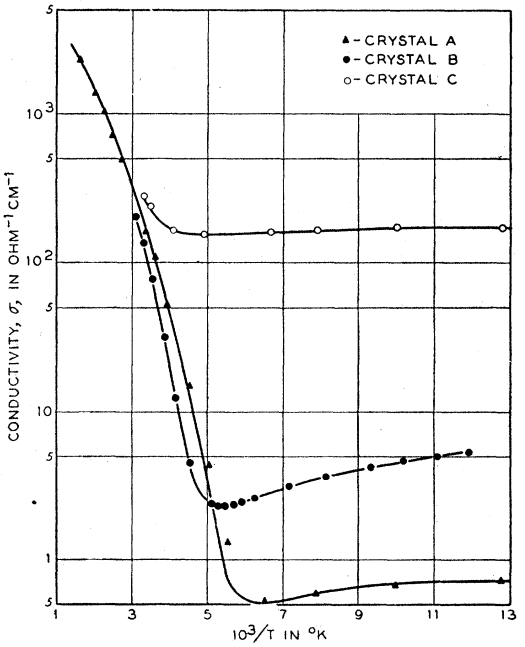

FIG. 2. Conductivity of indium antimonide as a function of temperature.

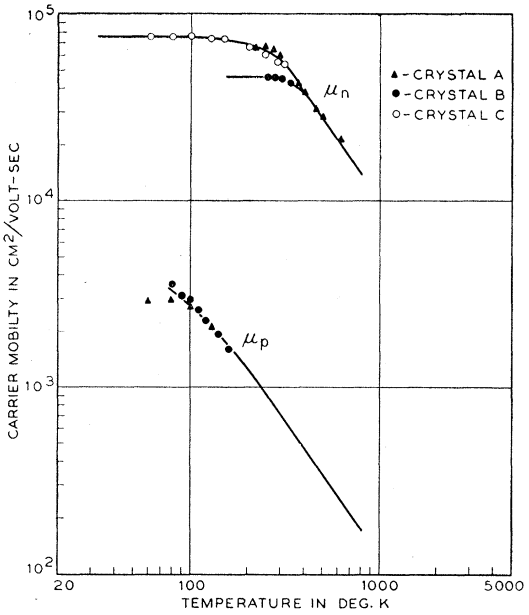

FIG. 3. Mobility of holes and electrons in indium antimonide as a function of temperature.

carrier is important, the carrier mobility is given by the expression

$$\mu = 0.85 R\sigma. \tag{4}$$

Figure 3 is a plot of the carrier mobilities given by Eq. (4) as a function of temperature. The values for holes were taken from the extrinsic range of samples A and B. It is assumed that these follow a $T^{-\frac{3}{2}}$ law at high temperatures since it is not possible to determine the hole mobilities in the intrinsic range. Low temperature electron mobilities are obtained from sample C, and it is assumed that $R\sigma$ closely approximates the electron mobilities in all samples in the intrinsic range. This assumption is felt to be valid because the large value of b (approximately 85) in the intrinsic range predicts a negligible contribution of holes to R and σ at temperatures somewhat above the temperature of Hall reversal. The electron mobility obtained in this manner seems to follow a $T^{-\frac{3}{2}}$ law at high temperatures.

TABLE I. Carrier concentration and energy gap of InSb.

T°K	$(np)^{\frac{1}{2}}$	ΔE (ev) $M^*=1$	ΔE (ev) $M^*=0.083$
150	2.3×10^{13}	0.33	0.24
200	6.8×10^{14}	0.34	0.21
300	2.1×10^{16}	0.37	0.18
400	1.1×10^{17}	0.41	0.15
500	3.0×10^{17}	0.45	0.12

From the carrier mobilities in Fig. 3, the conductivities in Fig. 2, and Eq. (2), it is possible to evaluate n and p as a function of temperature. The procedure is quite similar to that described by Pearson and Bardeen.[6] The solid line curves in Figs. 1 and 2 were obtained using these values of n and p, the mobilities of Fig. 3 and Eqs. (2) and (3). The close fit of the curves and the experimental points demonstrates the mutual consistency of Hall effect and conductivity data with the assumed mobilities. The large maximum in R just above the temperature of Hall reversal is a direct consequence of the large value of b.

From conductivity data, Welker has estimated an energy gap of 0.53 electron volts in InSb.[1] However, it is difficult to obtain a value for the forbidden energy gap ΔE from data of this kind since the effective masses of electrons M_n and holes M_p are unknown. The simple theoretical expression for n and p as a function of T, the absolute temperature, is

$$(np)^{\frac{1}{2}} = 4.9\times10^{15}(M^*)^{\frac{3}{2}}T^{\frac{3}{2}}\exp(-\Delta E/2kT), \tag{5}$$

where k is the Boltzmann constant and $M^*=(M_nM_p)^{\frac{1}{2}}/M$. M is the free electron mass. Table I gives values of $(np)^{\frac{1}{2}}$ as a function of the absolute temperature. These values are the same for all three samples as one would expect. The last two columns of the table give ΔE for two different values of M^*. For $M^*=0.083$, ΔE is 0.18 ev at room temperature, which is the value estimated from infrared absorption measurements performed by Briggs at this laboratory.[7] This effective mass leads to a temperature coefficient of the energy gap of approximately -4×10^{-4} ev per degree at room temperature. This agrees very well with the temperature coefficient of the infrared limit of absorption between room temperature and 77°K.

We wish to thank J. A. Burton and F. J. Morin for their helpful discussion of the results.

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Thermal and Electrical Properties and Crystal Structure of Tungsten Oxide at High Temperatures

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RECENTLY Kehl *et al.*[1] found an anomalous behavior of tungsten oxide near 900°C by a differential thermal analysis. Although we had also independently observed an anomaly of thermal dilatation (an expansion in heating), we happened to know that Foëx[2] had already reported this anomaly. In view of the above situation, the results of our measurements of thermal dilatation of tungsten oxide will be omitted and those on specific heat and dc resistance between 600°C and 1050°C will be reported briefly here.

The specific heat was measured by a conduction calorimeter of the same type as the one used previously,[3] improved to enable us to make reliable measurements at higher temperatures. Figure 1 shows the specific heat measured in heating, in which two anomalies of about 450 cal/M and 280 cal/M are seen near 730°C and 900°C, respectively, the entropy changes being 0.45 cal/M-deg and 0.23 cal/M-deg, respectively. The specific-heat value in our previous letter[3] should be considered as rather preliminary, although the size of the anomaly at 730°C reported there agrees well with the present one.

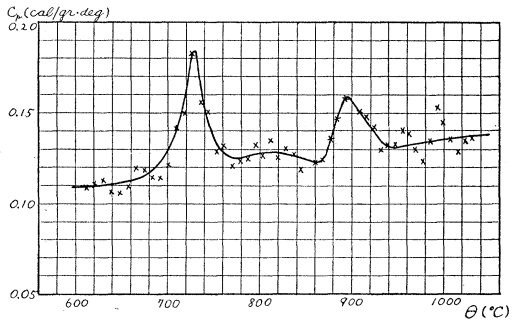

FIG. 1. Specific heat *vs* temperature.