# Pressure Dependence of the Resistivity, Hall Coefficient, and Energy Gap for InAs†

JULIUS H. TAYLOR
*Morgan State College, Baltimore, Maryland*
(Received August 31, 1955)

The effect of hydrostatic pressure on the resistivity of intrinsic $n$-type InAs has been measured in the range from 1 to 2000 atmospheres. The resistivity and Hall constant were found to increase exponentially with increasing pressure. Measurements of the resistivity and Hall effect yield an increase of 19 and 12 percent respectively for a change in pressure of 2000 atmospheres. If it is assumed the increase in resistivity is produced by an increase in the energy gap our measurements indicate a shift of $8.8\times10^{-6}$ ev/atmosphere. The increase in Hall constant represents a shift of $5.5\times10^{-6}$ ev/atmosphere.

THIS paper presents the experimental results of hydrostatic pressure on the resistivity, Hall coefficient, and energy gap for $n$-type polycrystalline indium arsenide. Unfortunately, the purity of sample used in this investigation was such that measurements had to be taken at temperatures of the order of 200 degrees centigrade in order to work in the intrinsic range. This presents experimental difficulties because of the temperature dependence of the constants being measured. Our results show the resistivity and Hall coefficient increase exponentially with increasing hydrostatic pressure.

Indium arsenide is a semiconducting compound by uniting elements of the III and V columns of the periodic table. It has a zincblende structure thereby exhibiting cubic symmetry. The forbidden band width is about 0.47 electron volt[1] at absolute zero and becomes smaller with increasing temperature at a rate of $4\times10^{-4}$ ev/°K.

A commercial high-pressure bomb was used to make measurements of changes of resistivity with pressure. An adaptor unit of nonmagnetic stainless steel was provided for Hall coefficient measurements. The bomb was immersed in a Prestone motor oil bath which was electronically thermostated at constant temperatures to the order of 1/100 of a degree centigrade. Samples were cut into rectangular parallelepipeds, copper spots were electroplated on the sample, and pressure contacts were made by using phosphorus bronze spring clips. In all measurements, the current and magnetic field were reversed and an average effect was computed. It is assumed in all measurements that changes in sample dimensions accompanying changes in pressure produce a negligible effect. The magnetic field used was 2000 gauss.

Figure 1 shows curves of the resistivity and Hall coefficient as a function of inverse absolute temperature. These curves are typical of these quantities for the intermetallic group.

In Fig. 2 the experimental data for log resistivity and log Hall coefficient are plotted against pressure at different temperatures. Both increase exponentially with pressure, the resistivity at a rate larger than the Hall coefficient at each temperature. Measurements on other samples of different purity show these curves to be typical of the behavior of $n$-type InAs. These curves represent data taken on a sample of highest purity available at the time the experiment was performed. The curves taken at 201 degrees centigrade represent data taken at points on the curves of resistivity and Hall coefficient *vs* reciprocal absolute temperature that are well into the intrinsic range. These curves show a change of 19 and 12 percent, respectively, for the two constants for a change of 2000 atmospheres pressure. This 7 percent difference is explained below.

For an effective mass of 0.06, the largest value of conduction electrons consistent with the accurate use of classical statistics is $0.97\times10^{17}$ per cubic centimeter at 201 degrees centigrade.[2] This criterion is satisfied in the samples used in this investigation.

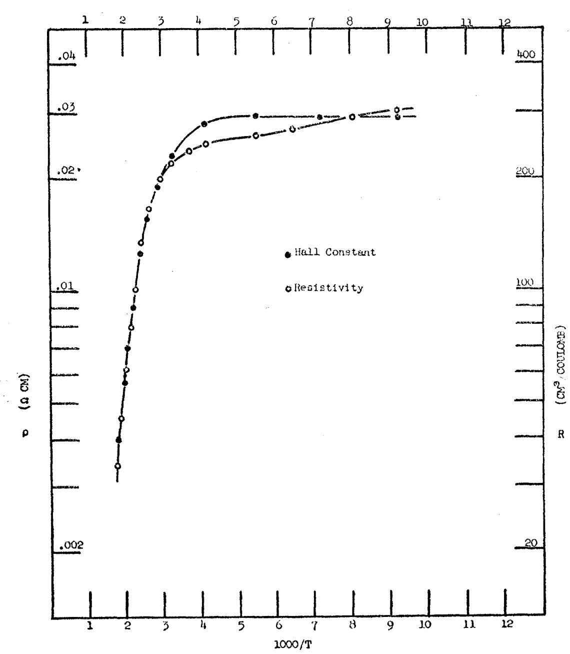


FIG. 1. The resistivity and Hall constant of InAs plotted as a function of the reciprocal absolute temperature.

† This work was supported by a grant from the Office of Ordnance Research, U. S. Army.

[1] Folberth, Madelung, and Weiss, Z. Naturforsch. 99, 954 (1954).

[2] J. S. Blakemore, Elec. Commun. 29, 131–153 (1952).

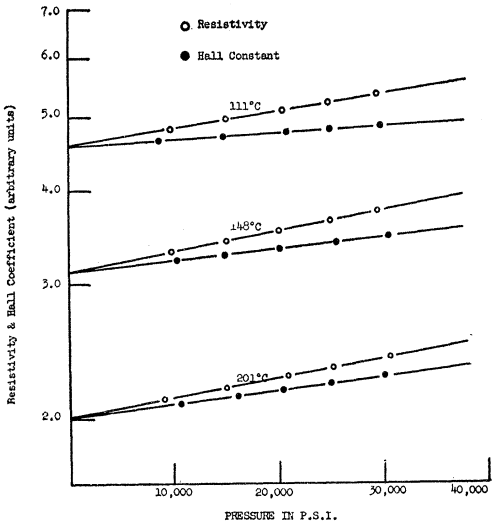


FIG. 2. Relative values of the pressure dependence of the resistivity and Hall constant plotted as a function of pressure in psi at three temperatures.

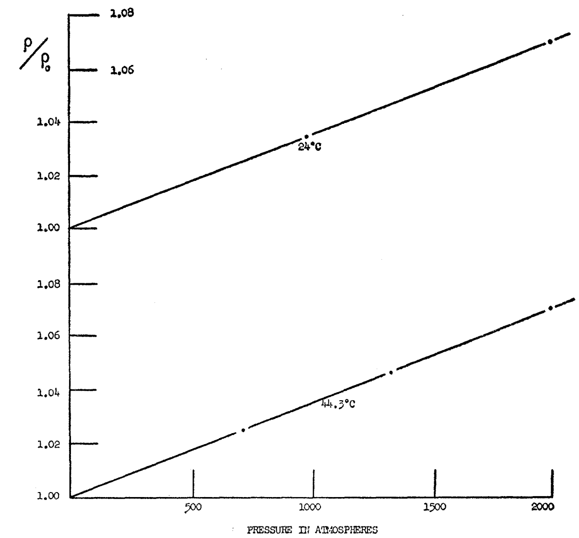


FIG. 4. The pressure dependence of the resistivity of $n$-type InAs for two temperatures in the extrinsic range.

It can be shown that Eq. (1) represents the relationship between the shift in energy gap and the change in $\ln\rho$ with pressure at constant temperature.[3]

$$\left.\frac{dE_g}{dp}\right)_T=-\frac{kT(x^2+C)(x^2+1)}{x^2(C+1)}\frac{d(\ln\rho)}{dp},\qquad(1)$$

where $x^2=p/n$, $C=u_e/u_h=70$(InAs). The values of $x^2$ plotted as a function of absolute temperature calculated from Hall constant and resistivity measurements are shown in Fig. 3. At 201 degrees centigrade, where $x$ has the value 0.7, the correction term $(x^2+C)(x^2+1)/x^2(C+1)$ is equal to 2.43. It should be pointed out that Eq. (1) represents the shift in energy gap with pressure in the absence of any change in mobility.

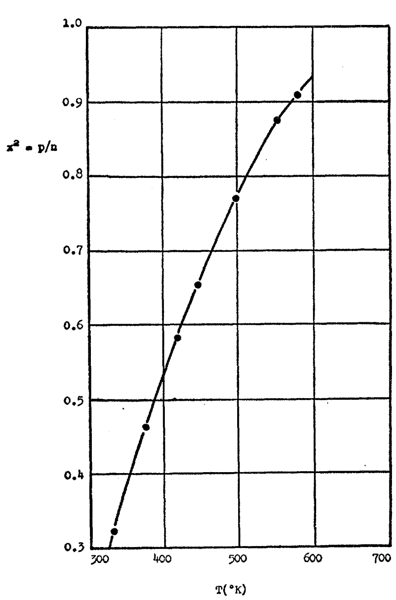


FIG. 3. The value of $x^2=p/n$ as a function of absolute temperature.

For semiconductors of high mobility ratio, the density of the more mobile carriers $n$ is proportional to the reciprocal of the Hall constant, $R$.

$$n=1/Re.\qquad(2)$$

From Eq. (2) an expression similar to Eq. (1) for the shift in energy gap as a result of changes in Hall coefficient with pressure may be derived.

Values for the various constants investigated are shown in Table I. The results for 111°C are calculated from measurements taken in the extrinsic range thereby yielding results much lower than those taken at 148 and 201°C. From room temperature to 100°C the value of the Hall coefficient remained constant for pressure changes of 2000 atmospheres.

Figure 4 shows the results of the pressure dependence of resistivity for low temperatures. These measurements are taken at temperatures where the number of conduction electrons remain relatively constant. In this region, if a change in resistivity is effected by the application of pressure, it must be attributed to a change in the mobility of the carriers. The graph shows a 7 percent increase in resistivity for a pressure change of 2000 atmospheres. Therefore, the value of $5.5\times10^{-6}$

TABLE I. Values of the observed pressure coefficient of resistivity, Hall constant, and shift in energy gap for InAs at three temperatures. Columns four and five are calculated from changes in resistivity and Hall constant respectively.

| °C | $\Delta\rho/\rho$ | $\Delta R/R$ | $dE_g/dp)_T$ (ev/atmos) (resistivity) | $dE_g/dp)_T$ (ev/atmos) (Hall coefficient) |
|---|---|---|---|---|
| 111 | $6.13\times10^{-5}$ | $2.82\times10^{-5}$ | $1.87\times10^{-6}$ | $0.81\times10^{-6}$ |
| 148 | $10.0\times10^{-5}$ | $5.43\times10^{-5}$ | $8.28\times10^{-6}$ | $5.14\times10^{-6}$ |
| 201 | $10.1\times10^{-5}$ | $5.98\times10^{-5}$ | $8.83\times10^{-6}$ | $5.50\times10^{-6}$ |

[3] J. H. Taylor, Phys. Rev. **80**, 919 (1950).

ev/atmosphere calculated from changes in Hall constant is more representative of the true shift in energy gap since it is independent of changes in mobility. Since mobility equals the Hall constant divided by the resistivity, the mobility of InAs decreases with increasing hydrostatic pressure.

I am indebted to Dr. Robert Talley and Mr. Frank Stern of the U. S. Naval Ordnance Laboratory, Silver Spring, Maryland for providing me with samples and many helpful discussions. I should like to thank Donald Long of the University of Pennsylvania, Department of Physics for his informative assistance.

PHYSICAL REVIEW VOLUME 100, NUMBER 6 DECEMBER 15, 1955

# Magnetic Properties of Erbium Metal*

J. F. Elliott,† S. Legvold, and F. H. Spedding
*Institute for Atomic Research, and Department of Physics, Iowa State College, Ames, Iowa*
(Received August 3, 1953; revised manuscript received August 31, 1955)

Measurements of the magnetic moment of erbium metal in the temperature range from 20.4°K to 90°K are reported. The initial susceptibility shows a maximum at 78°K and the metal appears to become ferromagnetic near 20°K.

NEEL,[1] working with the magnetic data of Klemm and Bommer,[2] has predicted a Curie point for erbium at about 40°K. Barson's[3] work on the electrical resistivity of erbium has shown an anomaly at about 80°K. This type of anomaly in the electrical resistivity has been shown to be closely associated with magnetic phenomena in gadolinium[3–5] and dysprosium.[3,6,7] This paper describes the results of investigations of some of the magnetic properties of erbium metal.

The metal used in this study was prepared by methods

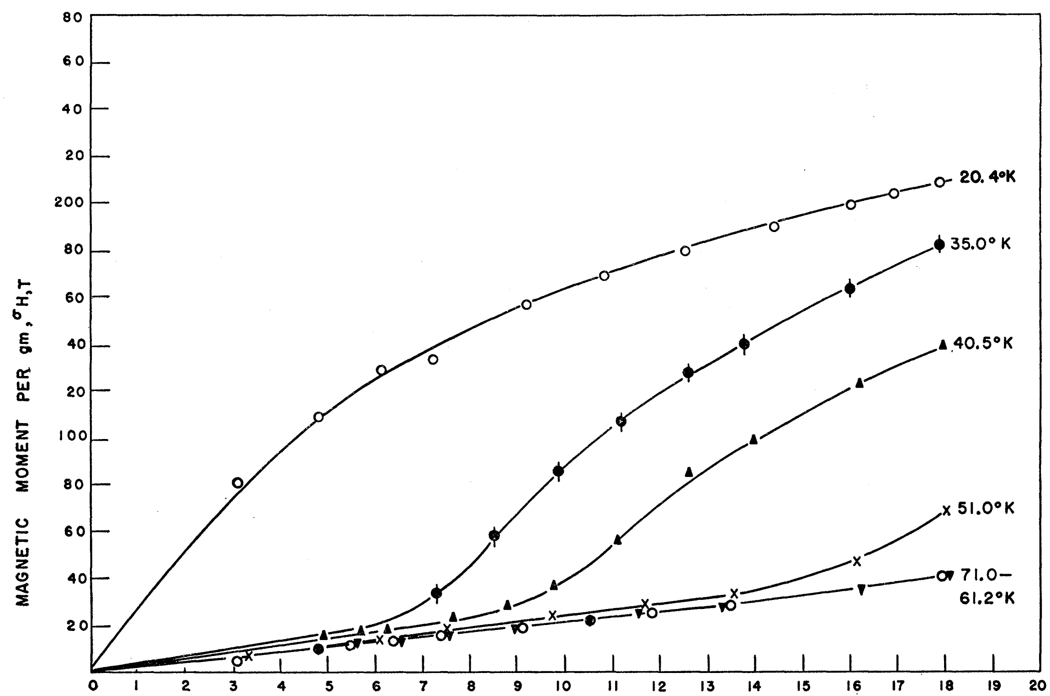


Fig. 1. Magnetization isotherms of erbium metal.

* Contribution No. 242 from the Institute for Atomic Research and Department of Physics, Iowa State College, Ames, Iowa. Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
† Now at General Electric, Syracuse, New York.
1 L. Neel, Z. Electrochem. **45**, 378 (1939).
2 W. Klemm and H. Bommer, Z. anorg. u. allgem. Chem. **231**, 138 (1937).
3 Legvold, Spedding, Barson, and Elliott, Revs. Modern Phys. **25**, 129 (1953).
4 Elliott, Legvold, and Spedding, Phys. Rev. **91**, 28 (1953).
5 Urban, Weiss, and Trombe, Compt. rend. **200**, 2132 (1935).
6 F. Trombe, Compt. rend. **221**, 19 (1945).
7 Elliott, Legvold, and Spedding, Phys. Rev. **94**, 1143 (1954).