Thus it can be concluded that the high concentration of DFP necessary to inhibit the pseudo cholinesterase in normal rat serum is due, in part at least, to the fact that the DFP combines preferentially with other proteins in the serum—namely, the aliesterase. Although the aliesterases of some other types of serum (e.g., of human serum) are not sensitive to inhibition by low concentrations of DFP (*6, 8*), it is still possible that other enzymes or protein groups might interfere with the reaction between DFP and pseudo cholinesterase in the same way. Inhibitors such as eserine, prostigmine, and analogs, on the other hand, appear to be relatively specific for the cholinesterases. It seems probable that the use of DFP may enable the determination of cholinesterase concentration in highly purified preparations of the cholinesterase (*9*), but the results obtained with crude enzyme preparations cannot always be relied upon, since the presence of other hydrolytic enzymes may protect the cholinesterases against inhibition by DFP.


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## The Hall Effect and Electrical Resistivity of Tellurium[1]


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At low and high temperatures, tellurium is a P-type semiconductor, but in samples of adequate purity there is a range of temperatures within which the sign of the Hall coefficient is negative. This anomalous behavior, which has been noted by several observers (*1, 2*), has been studied in very pure tellurium prepared by multiple fractional distillation in an atmosphere of helium.

Fig. 1 shows the behavior of the Hall coefficient $R$, for samples of varying degrees of purity. Curve $A$ is from a sample of c. p. grade tellurium containing an extrinsic carrier concentration of about $10^{18}$ carriers/cm$^3$. Curve $D$ is for a sample containing about $10^{15}$ carriers/cm$^3$. The remaining curves are for samples of intermediate degrees of purity.

In all samples containing fewer than about $10^{17}$ carriers/cm$^3$, $R$ is negative within a certain range of temperature. At low temperature $R$ is always positive, changing to negative at a temperature which depends upon the extrinsic carrier concentration. $R$ remains negative between this point and the temperature 230° C near which the sign becomes positive again and remains so to the melting point. The upper reversal temperature is fixed at approximately 230° C, but the lower reversal temperature is related to the carrier concentration by the empirical relationship

$$\ln R' = A + b/T_r,$$

where $R'$ is the value of the Hall coefficient in the exhaustion range, $T_r$ is the temperature of reversal, and $a$ and $b$ are constants.

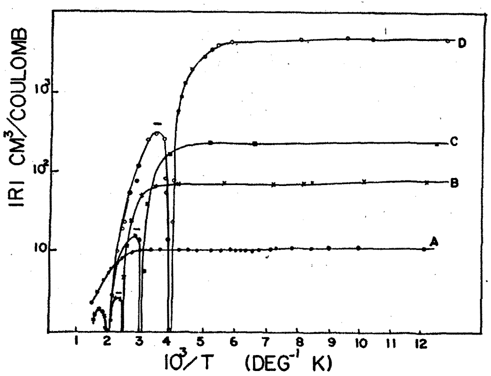


FIG. 1. The Hall effect in tellurium. The logarithm of the Hall constant $R$ is plotted against $1/T$.

In samples cut from single crystals of tellurium, neither the value nor sign of $R$ depends upon the orientation of the sample with respect to the magnetic field or crystallographic axes. Measurements of the Hall effect made with an a-c method show that the anomalous behavior is not due to the Ettingshausen effect. This conclusion has also been verified by direct measurement of the thermoelectric power and Ettingshausen coefficient.

Fig. 2 shows the resistivity as a function of temperature for a number of polycrystalline samples. The intrinsic resistivity at 27° C is approximately 0.5 ohm-cm, but an exact value cannot be given because

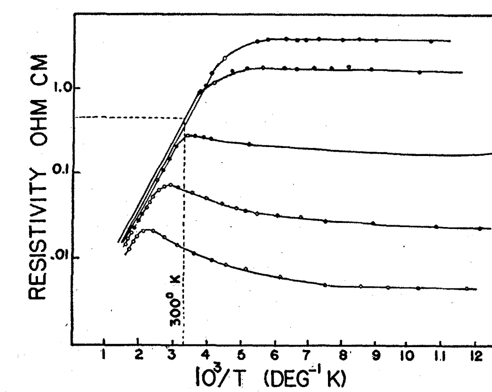


FIG. 2. The resistivity of tellurium measured in polycrystalline samples. Logarithm of the resistivity in ohm-cm plotted against $1/T$.

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[3] Work carried out under contract with the Signal Corps.

of variations depending upon the preferred orientation of the crystallites in the sample. From the slope of the $\rho$ vs. $1/T$ curve in the intrinsic range, the width of the forbidden band is found to be $0.33 \pm .01$ ev.

The resistivity has also been measured in samples in the form of single crystals. At 27° C the resistivity is 0.56 ohm-cm in the direction perpendicular to the principal axis, and 0.29 ohm-cm in the parallel direction. Since the samples on which the measurements were taken were well into the intrinsic range at room temperature, these values, which are much higher than those previously reported (*3,4*), may be taken as characteristic of pure tellurium.

A complete report, including measurement of the thermoelectric power and Ettingshausen coefficient, is being prepared for publication.


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# Interpretation of the Double Reversal of the Hall Effect in Tellurium


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The double reversal of the Hall effect observed in high purity tellurium samples cannot be explained by conventional semiconductor theory. Bottom (*1*) has shown that the temperature $T_r$ of the reversal at low temperature depends on the concentration of impurities $N_{ex}$[2] and obeys the usual condition for the Hall constant to become zero.

$$\ln \frac{N_{ex}}{T_r^{3/2}} = \ln \left\{ A \frac{c^2-1}{c} \right\} - \frac{\Delta B}{2kT_r} \quad (1)$$

$c$ is the ratio of electron to hole mobility, $\Delta B$ is the width of the energy gap, and $A$ is defined by the relations

$$n' = AT^{3/2}e^{-\Delta B/2kT}, \quad (2)$$

where $n'$ is the concentration of holes or electrons in a pure, intrinsic semiconductor, $k$ is the Boltzmann constant, and $T$ is the absolute temperature.

The higher reversal temperature, as Bottom (*1*) has shown, is independent of impurity content and is the same for all samples. This can be explained if one considers the number of lattice defects[3] $N_D/cm^3$, which in turn depend on the temperature $T$ and on the activation energy of the defect $W$.

$$N_D = \alpha N_L e^{-W/kT} (2). \quad (3)$$

$\alpha$ is determined by the ratio of lattice defects $N_D$ to lattice sites $N_L$ and is of the order of unity. This equation describes the number of lattice defects introduced in germanium by quenching from elevated temperatures (*3*).

$$W = E + \frac{\delta E}{\delta T} T. \quad (4)$$

The temperature coefficient of $W$, suggested by Fan, takes into account a change in the binding energy due to thermal expansion.

The lattice defects are known to give rise to localized states which may act as acceptors (*4–6*). We can set, therefore, approximately

$$N = N_{ex} + N_D, \quad (5)$$

and $N$ is constant in the temperature range where $N_D$ is negligible, but will follow the exponential law (*3*) if $N_{ex}$ becomes very small compared with $N_D$. The conductivity $\sigma$ can now be written as

$$\sigma = eb_2[n'(c+1) + N_{ex} + N_D], \quad (6)$$

where $e$ is the charge of the electron, $b_2$ the hole mobility, and the other letters have the significance indicated above.

Depending on the temperature range, the conductivity will first be determined from Eq. (2), and at higher temperatures, from Eq. (3). Middleton (*7*) found in one sample a second high temperature slope of the log $\rho$ vs. $1/T$ plot. The slope was $8352/T$; and if this is to be attributed to the defects at these high temperatures, one obtains $E = 0.72$ ev.

The condition for zero Hall constant becomes now

$$n' \left( \frac{c^2-1}{c} \right) = N_{ex} + N_D. \quad (7)$$

For a quantitative analysis, the mobility ratio $c$ has to be determined. It was obtained from the ratio of the negative maximum of the Hall constant $R_{max}$, and the Hall constant at exhaustion $R_{ex}$, and an analysis of the scattering mechanism in the exhaustion and transition ranges. In this way one obtains $c = 1.7$.[4]

Using Eq. (1) we obtain $\Delta B = 0.36$ ev, and $A = 1.55 \times 10^{15}$.

If in the high temperature range $N_{ex}$ is small compared with $N_D$, one has for the second reversal at $T = 500°$ K

$$n' \frac{c^2-1}{c} = N_D. \quad (8)$$

For $N_{ex} > 3 \times 10^{17}$ per cc the Hall constant remains positive throughout the whole temperature range. For $N_{ex} \backsim 1.2 \times 10^{17}$ per cc the Hall constant becomes very small and might reach zero at about $T = 480°$ K. Double reversal occurs only if $N_{ex} < 10^{17}$ per cc. The temperature of the lower reversal is then mainly governed by $N_{ex}$; the temperature of the higher reversal occurs at $T = 500°$ K independent of $N_{ex}$.

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[2] We call the number of impurities $N_{ex}$: the number at exhaustion when all impurities are ionized.

[3] The author learned only after completion of his paper that this fact was first realized by W. Schottky (in a letter Feb. 2, 1950, to K. Lark-Horovitz). Schottky has even called this behavior a new type of "intrinsic conductivity," where the temperature dependence in the high temperature range corresponds to the formation and dissociation of a *Te* vacancy plus hole.

[4] We have assumed this mobility ratio as constant up to the temperature of the second Hall reversal.