sion of the results, and Yu. G. Mamaladze for useful discussions during the performance and interpretation of the experiment.

[1] J. R. Pellam, Proc. of the 7th Internat. Conf. on Low Temp. Physics, p. 268, Univ. of Toronto, Canada, 1960.

[2] J. R. Pellam, Phys. Rev. Lett. 5, 189 (1960).

[3] J. R. Pellam, 9th Internat. Conf. on Low Temp. Physics, Program and Abstracts, p. 11, Ohio State Univ. - Battelle Memorial Institute, 1964.

THE ROLE OF THE ANISOTROPY OF SCATTERING IN TELLURIUM

L. S. Dubinskaya and I. I. Farbshtein
Institute of Semiconductors, USSR Academy of Sciences
Submitted 26 July 1965

The bulk of the experimental data on annealed tellurium single crystals at low temperatures points to the conclusion that the equal-energy surface of the hole carriers is an ellipsoid of revolution whose axis coincides with the threefold axis and whose center is at $k = 0$ [1,2]. Recently Mendem and Dexter [3] measured the effective masses of the holes in tellurium, confirming such a model, and obtained values $m_1 = m_2 = 0.126m_0$, and $m_3 = 0.24m_0$, i.e., $m_{11}/m_{33} = 0.525$. In such a model we have $\sigma_{33}/\sigma_{11} = m_{11}/m_{33}$ for isotropic scattering. From galvanometric measurements at 4.2°K, they obtained for pure tellurium single crystals $\sigma_{33}/\sigma_{11} = 1.3 \pm 0.1$ which leads to $m_{11}/m_{33} \simeq 1.3$, assuming isotropic scattering. The reason for this apparent contradiction lies in the fact that anisotropy of scattering is expected in tellurium. Then, under the condition that we can introduce the relaxation-time tensor [4], we have

$$\frac{\sigma_{33}}{\sigma_{11}} = \frac{\langle \tau_{33} \rangle}{\langle \tau_{11} \rangle} \cdot \frac{m_{11}}{m_{33}} . \qquad (1)$$

The anisotropy of the scattering of holes by ionized impurities in tellurium is connected both with the anisotropy of the carrier energy spectrum and with the dielectric constant anisotropy which leads to anisotropy of the scattering potential itself. The theory of galvanomagnetic effects for arbitrary scattering anisotropy was developed in [5,6]. It was shown in [5] that for the scattering of carriers by ionized impurities in a uniaxial crystal one can introduce the so-called "current" relaxation-type tensor, the components of which determine the electric-conductivity tensor

$$\sigma_{ii} = \frac{e^2 n \langle \tau_{ii} \rangle}{m_{ii}} .$$

Following [5] we can obtain, given a single-ellipsoid model of the equal-energy surface and an anisotropic dielectric constant, approximate expressions for τ_{33} and $\tau_{11} = \tau_{22}$. In the case when $m'_{33} > m'_{11} = m'_{22}$, where $m'_{ii}\kappa_{ii}$, and κ_{ii} are the components of the dielectric tensor, we have

$$\frac{1}{\tau_{33}} = \frac{3\pi\, Ne^4\sqrt{2m_{33}}}{8m_{11}'^2\,\beta^3\,\epsilon^{3/2}}\left\{2\left(\tan^{-1}\beta - \frac{\beta}{1+\beta^2}\right)\ln(\gamma^{-2}) - 2\tan^{-1}\beta\ln(1+\beta^2)\right.$$

$$\left. + 4L(\tan^{-1}\beta) + (1+\beta^2)\left[\tan^{-1}\beta + \frac{\beta(\beta^2-1)}{(1+\beta^2)^2}\right]\gamma^2\right\}, \qquad (2)$$

$$\frac{1}{\tau_{11}} = \frac{3\pi\, Ne^4\sqrt{2m_{33}}}{8m_{11}'^2\,\beta^3\,\epsilon^{3/2}}\left\{\left[(\beta^2-1)\tan^{-1}\beta + \beta\right]\ln(\gamma^{-2}) - 2\beta^2\tan^{-1}\beta\right.$$

$$- (\beta^2-1)\tan^{-1}\beta\ln(1+\beta^2) + 2(\beta^2-1)\,L\tan^{-1}\beta + \frac{1+\beta^2}{2}\left[(3\beta^2-1)\tan^{-1}\beta\right. \qquad (3)$$

$$\left.\left. + \frac{\beta(3\beta^2+1)}{1+\beta^2}\right]\gamma^2\right\}.$$

$\beta^2 = (m_3' - m_1')/m_1'$, L(t) is the Lobachevskii function, $\gamma^2 = \hbar^2/8\epsilon a^2 m_3'$, ϵ is the electron energy, and a^2 the Debye-Huckel screening radius.

In the case of intermediate degeneracy we have

$$a^{-2} = \frac{2e^2\, m^{*3/2}\,(2kT)^{1/2}}{\pi\,\hbar^3}\,F_{-1/2}(\mu^*),$$

where μ^* is the chemical potential and $m^* = (m_{11}^2 m_{33})^{1/3}$. The expressions for τ_{33} and τ_{11} differ only in the factors in the curly brackets. We have calculated $\langle\tau_{33}\rangle/\langle\tau_{11}\rangle$ for tellurium at 4.2°K for a carrier density 10^{14} cm^{-3}, starting from the values $\kappa_{11} = 23.6$ and $\kappa_{33} = 39.7$ obtained by averaging the data of [7], and the values of m_{11} and m_{33} obtained in [3]. In the calculation of $\langle\tau\rangle$ we have carried out the averaging in the usual manner, taking out the expression in the curly brackets outside the integral sign for value of ϵ corresponding to the maximum of the remaining integrand function. In the absence of degeneracy $\bar{\epsilon} = 3kT$.

Calculation yields $\langle\tau_{33}\rangle/\langle\tau_{11}\rangle = 2.29$, and then we get from (1) $\sigma_{33}/\sigma_{11} = 1.21$, which is in good agreement with the experimental value.

Thus, an account of the scattering anisotropy, within the framework of the theory developed in [5,6], allows us to reconcile the data on cyclotron resonance with the galvanomagnetic measurements in the region of scattering by ionized impurities.

A concentration dependence of the anisotropy of electric conductivity at 4.2°K was experimentally observed in [1]. Since γ, which determines the scattering anisotropy, depends on the concentration and on the temperature, we should expect σ_{33}/σ_{11} to depend on these parameters.

The question of the quantitative correspondence between the experimental and theoretical dependence of the scattering anisotropy on the concentration is now under investigation by us.

The authors are grateful to I. Ya. Korenblit and L. L. Korenblit for a discussion of the theoretical questions and to S. S. Shalyt for continuous interest in the work.

[1] Parfen'ev, Pogarskii, Farbshtein, and Shalyt, FTT 4, 3596 (1962), Soviet Phys. Solid State 4, 2630 (1963).
[2] Farbshtein, Pogarskii, and Shalyt, ibid 7, 2383 (1965), Soviet Phys. Solid State, in press.
[3] J. H. Mendem and R. N. Dexter, Bull. Amer. Phys. Soc. 9, 632 (1964).
[4] C. Herring and E. Vogt, Phys. Rev. 101, 944 (1956).
[5] Samoilovich, Korenblit, Dakhovskii, and Iskra, FTT 3, 2939 and 3285 (1961), Soviet Phys. Solid State 3, 2148 and 2385 (1962).
[6] I. Ya. Korenblit, FTT 4, 168 (1962), Soviet Phys. Solid State 4, 120 (1962).
[7] R. S. Caldwell and H. Y. Fan, Phys. Rev. 114, 664 (1959).

CHARGE EXCHANGE OF PROTONS IN ALKALINE METAL VAPOR WITH FORMATION OF HIGHLY EXCITED HYDROGEN ATOMS

R. N. Il'in, V. A. Oparin, E. S. Solov'ev, and N. V. Fedorenko
I. F. Ioffe Physico-technical Institute, USSR Academy of Sciences
Submitted 26 July 1965

Highly excited hydrogen atoms with principal quantum number n close to 10 can be ionized by a strong electric field $\vec{E}$ or by an equivalent field $\vec{E}' = \vec{v} \times \vec{B}$ ($\vec{v}$ - atom velocity, $\vec{B}$ - magnetic induction). This form of ionization is used to accumulate plasma in certain type of traps [1]. One can expect that one of the relatively effective methods of obtaining highly excited hydrogen atoms would be charge exchange of protons with atoms of alkaline and alkali-earth metals [2]. We have therefore investigated the charge exchange of 10 - 180 keV protons in vapor of Li, Na, K, Cs, and Mg.

The atomic beam, obtained by charge exchange of the protons in the vapor of these metals and purified to eliminate the charged particles, was fed into a region with strong electric field, of intensity $E \leq 160$ kV/cm. We measured the ratio of the current of the secondary protons, produced upon ionization of the highly excited atoms in the field E, to the total current of the atoms I(E). This ratio characterizes the relative charge-exchange yield of the highly excited atoms. In individual experiments we measured the total cross section σ_0 for proton charge exchange and the ratio of the total number of atoms produced by charge exchange to the number of protons in the primary beam - Φ_0. It was shown in [3] that from the values of I(E) and Φ_0 it is possible to determine the cross section for charge exchange accompanied by production of highly excited atoms with principal quantum number $n(\sigma_0)$, and that I(E) and Φ yield the number of the same atoms referred to the primary proton beam (Φ_n). It follows from the experimental data that the quantities σ_c^n and Φ_n are proportional to n^{-3}. We therefore present below the values of $n^3\sigma_c^n$ and $n^3\Phi_n$, as results that are independent of n.

Figures 1 and 2 show plots of $\sigma_0(T)$ and $n^3\sigma_c^n(T)$ obtained by us (T is the proton energy). For comparison, Fig. 2 shows besides the data for metallic targets also the plots of $n^3\sigma_c^n(T)$