III. SOLID STATE PHYSICS

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A. DYNAMIC REVERSIBILITY IN THE KINETIC THEORY

Boltzmann's integral equation is generally assumed to give a correct account of the kinetic processes in gases when the intermolecular interactions can be described in terms of binary collisions. The purpose of the present investigation is to draw attention to an additional limitation.

The fundamental equations of physics satisfy the principle of dynamic reversibility: the transformation reversing the direction of time $t \to -t$ carries over every solution into another dynamically admissible solution. In contrast, the phenomenological description of such processes as electrical conductivity or viscous flow is irreversible.

It would be desirable to have a statistical theory that contains both the reversible and irreversible aspects and indicates clearly how the latter arises from the former.

It is easily shown that the Boltzmann equation falls short of this requirement. The theory predicts that any inhomogeneity existing at an initial time in an isolated system decays exponentially until the quiescent state is reached. This prediction is in conflict with the principle of dynamic reversibility that requires spontaneous departures from the quiescent state.

From the experimental point of view the implications of the Boltzmann equation are correct for signals above noise level, but the fluctuations (thermal noise) provide us with a clear indication that spontaneous deviations from equilibrium have been too drastically averaged out from the classical theory.

The origin of this shortcoming has been submitted to a detailed analysis, the results of which may be helpful for the formulation of a more general kinetic theory, in which resistivity and noise are accounted for within the same formalism.

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B. MICROWAVE STUDY OF SEMICONDUCTORS

Measurements of the carrier contribution to the dielectric coefficient of germanium have been completed. The carrier contribution is given by $\sigma_i/\omega\epsilon_o$. In order to obtain an effective mass from these measurements, it is necessary to have an expression for σ_i. The general expression for σ in a crystal, from which σ_i may be obtained, is

$$\sigma = \int \frac{(\nabla_k E)_\alpha}{\hbar^2} \frac{e^2}{(\nu_c + j\omega)} \frac{\partial f_o^o}{\partial E} d^3k \tag{1}$$

where f_o^o is the equilibrium distribution function and $(\nabla_k E)_\alpha$ is the gradient of the energy along the direction α in k space. In order to obtain an expression for σ, therefore, something must be known about the energy surfaces. We have obtained an

expression for σ for the conduction band by assuming that the band edge occurs along the 111 axis and that the surfaces of constant energy are ellipsoids of revolution about the minimum. This is the model recently proposed by Lax and his associates (1).

For this model we obtain

$$\sigma_i = \frac{ne^2\omega}{m^*\left(\nu_c^2 + \omega^2\right)} \tag{2}$$

where m^* is given by

$$m^* = \frac{3m_1 m_2}{2m_1 + m_2} \tag{3}$$

where m_1 is the longitudinal mass, and m_2 the transverse mass.

For the same energy surfaces Herring (2) has recently obtained an expression which differs slightly from Eq. 2. His result may be approximated for the present case to

$$\sigma_i = \frac{n\mu^2 m^*\omega}{B}\left[1 - \frac{\omega^2(m^*)^2\mu^2}{Be^2}C\right] \tag{4}$$

where

$$B = \frac{3r(2+r)}{(1+2r)^2}$$

where $r = m_1/m_2$ and

$$C = \frac{\left\langle\dfrac{E}{\nu_c^4}\right\rangle \langle E\rangle}{\left\langle\dfrac{E}{\nu_c^2}\right\rangle^2}$$

the angular brackets indicating Maxwellian averages.

The valence band of germanium, according to recent evidence (3), is two-fold degenerate with the band edge occurring at the origin. In this case, the holes are distributed between the two degenerate bands. Here, integration of Eq. 1 leads to Eq. 2 again, but the effective mass is obtained from the relation

$$\frac{n}{m^*} = \frac{n_1}{m_1} + \frac{n_2}{m_2}$$

where $n = n_1 + n_2$, and m_1 and m_2 are suitable averages of the masses in the two bands.

The measurements were made at two temperatures. For the N material the conductivity followed the law

$$\sigma_T = \sigma_{300} \left(\frac{300}{T}\right)^{1.66}$$

This value of the exponent is in agreement with that obtained by other workers (4). For the P type we obtained

$$\sigma_T = \sigma_{300} \left(\frac{300}{T}\right)^{2.17}$$

whereas the accepted value of the exponent is 2.33 (4).

The measured values of the effective mass are as follows. For electrons we obtain $m^* = 0.10 \pm 0.05\, m_o$ where we have used Eq. 2. If we use Eq. 4 we have $m^* = 0.08 \pm 0.04\, m_o$, where we have used a mass ratio r of 17 as obtained by Lax et al. (1) in calculating B. For holes, the measured value of the mass is $m^* = 0.33 \pm 0.05\, m_o$ when we have used a value of 2.17 for the temperature exponent. If the temperature exponent is taken as 2.33, we get for the mass $m^* = 0.28 \pm 0.05\, m_o$.

These results, for both N and P types are in agreement with results obtained by cyclotron resonance experiments (1, 3) and magnetic susceptibility measurements (5). They are not in agreement, however, with the results of an experiment similar to the present one (6, 7).

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References

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