Determination of the Effective Scattering Mechanism Parameter of Electron Transport Theory*

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For Corbino disk geometry, the variation of thermoelectric power α with magnetic-field strength H is a strong function of the scattering and a weak function of the Fermi level. The zero magnetic-field thermoelectric power is a strong function of the Fermi level and a weak function of the scattering. Thus, measurements of $\Delta\alpha/\alpha(0)$ versus H and $\alpha(0)$ at a particular impurity concentration and temperature should yield a scattering parameter and a Fermi level separately. The transport equation for $\Delta\alpha/\alpha(0)$ has been derived for the case of a simple spherically symmetric energy band, arbitrary scattering, exact statistics, and Corbino disk geometry. The thermoelectric power increased 55% as the magnetic field increased to 22 kgauss for mercuric selenide. Although there is some evidence which indicates that the simple band form does not occur in HgSe, a preliminary comparison of theory and experiment showed satisfactory agreement.

A NEW and sensitive method for determining the effective scattering mechanism parameter, r, of electron transport theory has been found. We assume that the combined effects of all scattering processes acting on the charge carriers can be described by a relaxation time,[1,2] τ,

$$\tau=\tau_0\epsilon^{r-\frac{1}{2}} \tag{1}$$

Lattice scattering by acoustical phonons[2] corresponds to $r=0$ and the extreme case of Conwell-Weisskopf scattering[3] by ionized impurities corresponds to $r=2$. By using Corbino disk geometry,[4,5] we have found that the magneto-Seebeck effect, $\Delta\alpha/\alpha(0)$, is a strong function of r and a weak function of the reduced Fermi level $\xi/kT=\eta$. By contrast, the thermoelectric power or Seebeck coefficient at zero magnetic field, $\alpha(0)$, is a strong function of η and a weak function of r. Measurements of $\Delta\alpha/\alpha(0)$ versus magnetic-field strength and of $\alpha(0)$ should enable one to determine r and η separately.

The electrical resistivity and thermoelectric power for Corbino disk geometry have been formulated below in terms of arbitrary scattering, exact statistics, for all magnetic fields below the quantum region,[6] and for one type of conduction carrier. If the plane of the disk is normal to the magnetic field which is in the z direction, then it can be shown for cylindrical coordinates that

$$\mathbf{P}=\hat{r}P_r \quad \text{and} \quad \psi=\hat{r}P_r\tau/[1+(\omega_c\tau)^2], \tag{2}$$

where the notation of Blatt[7] has been employed except that η here refers to the reduced Fermi level; ω_c is the cyclotron frequency.

Solving for the electrical and thermal current densities in the radial directions, the following simple expressions are obtained:

$$J_r=L_{11}E_r+L_{13}dT/dr, \tag{3}$$

$$Q_r=L_{31}E_r-L_{33}dT/dr, \tag{4}$$

where the coefficients are integrals of the form

$$L_{11}=-\frac{4e^2}{3h^2}\int_0^\infty \frac{\tau(d\epsilon/dk)k^2\partial f_0/\partial\epsilon d\epsilon}{1+(\omega_c\tau)^2}. \tag{5}$$

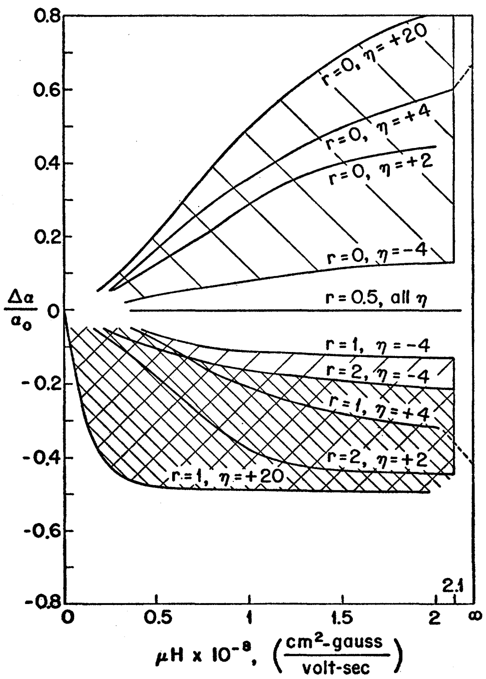

FIG. 1. Theoretical values for the Corbino magneto-Seebeck effect for various values of the scattering mechanism parameter, r, and for various values of the reduced Fermi energy parameter, η, and for a parabolic spherically symmetric electronic energy band.

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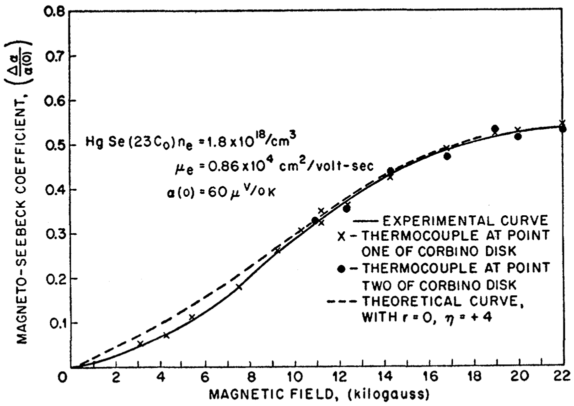

FIG. 2. Experimental and theoretical values for the magneto-Seebeck effect versus magnetic field at room temperature.

The equation for the thermoelectric power in a magnetic field, $\alpha(H)$, and the electrical magnetoresistance, $\Delta\rho/\rho_0$, are obtained as

$$\alpha(H)=-(k/e)[I_2(H)/I_1(H)-\eta], \tag{6}$$

and

$$\Delta\rho/\rho_0=I_1(0)/I_1(H)-1, \tag{7}$$

where

$$I_i(H)=\int_0^\infty \frac{x^{i+r}e^{x-\eta}}{(1+\beta x^{2r-1})(1+e^{x-\eta})^2}dx, \tag{8}$$

$$\beta=\frac{4\mu^2H^2F_{\frac{1}{2}}{}^2(\eta)}{9(r+1)^2F_r{}^2(\eta)}.$$

For $\beta=0$,

$$I_i(H)=I_i(0).$$

The magneto-Seebeck effect for Corbino disk geometry is

$$\frac{\Delta\alpha}{\alpha(0)}=\frac{\alpha(H)-\alpha(0)}{\alpha(0)}=\frac{[I_2(H)/I_1(H)-\eta]}{[I_2(0)/I_1(0)-\eta]}-1. \tag{9}$$

The integral, I_i, has been evaluated numerically by the IBM 709 computer for various values of r, η, β, and i. $\Delta\alpha/\alpha(0)$, when expressed as a function of μH, depends only on r and η. In Fig. 1, theoretical values of $\Delta\alpha/\alpha(0)$ are plotted versus μH for various values of r, η. It is seen that for $r<0.5$, the magneto-Seebeck effect is positive and for $r>0.5$ the effect is negative. The strong dependence of the curves in Fig. 1 on r is noteworthy.

The theory was developed for a band structure in which $\epsilon=\hbar^2k^2/2m^*$. The angular dependence of the magnetoresistance of HgSe shows that the conduction band energy surfaces are nearly spherically symmetric. However, there is evidence[8] that the dependence of energy on wave vector is not quadratic. Nevertheless, as a preliminary check on the theory, the simple band form was assumed, and theory and experiment were compared.

Figure 2 shows the experimental results for the magneto-Seebeck effect obtained at room temperature from measurements on a 2.5-cm diameter single-crystal Corbino disk of HgSe. Also, the theoretical curve is shown for $r=0$ and $\eta=+4$. It is seen that the agreement between theory and experiment is very satisfactory. In Fig. 3, the results of theory and experiment for the Corbino electrical magnetoresistance at room temperature are shown. The magnetoresistance, $\Delta\rho/\rho_0$, is not sensitive to r and η but the results do show that the Hall mobility obtained from $\mu=R\sigma$ is in good agreement with the mobility obtained from the Corbino electrical magnetoresistance.

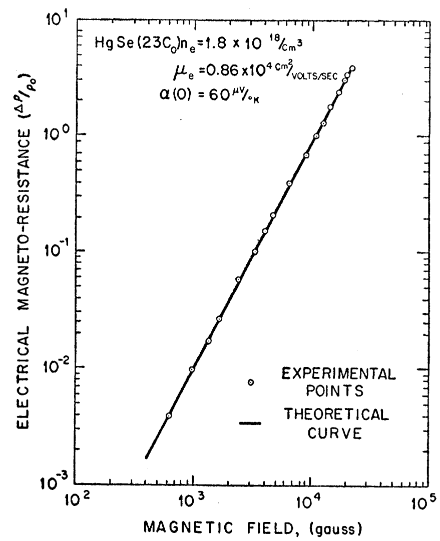

FIG. 3. Experimental and theoretical values for the electrical magnetoresistance for Corbino disk geometry versus magnetic field strength at room temperature.

The effective mass was obtained from the well-known relationship

$$n=4\pi(2m^*kT/h^2)^{\frac{3}{2}}F_{\frac{1}{2}}(\eta). \tag{10}$$

The calculated value of $m^*=0.040$ is in good agreement with that obtained by Lax and Wright[8] from magneto-plasma measurements. A value of 1.9×10^{-13} sec was calculated for the relaxation time.

From the above analysis, it is concluded that information concerning the atomistic parameters: Fermi-level energy, effective scattering mechanism parameter, effective mass, and relaxation time can be obtained from the magneto-Seebeck effect for Corbino disk geometry, when combined with other transport measurements.

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