force of the magnetic field, and therefore the energy of the field undergoing compression will increase. Since in a uniform field the full energy is $\epsilon = H^2 v/8\pi$, where v is the volume of the cavity; therefore, according to (3),

$$\mathcal{E}/\mathcal{E}_0 = R_0/R = n. \quad . \qquad (5)$$

Thus as a result of an n–fold compression of a hollow sphere, the magnetic field inside the cavity increases by a factor n^2.

The same reasoning holds not only for a spherical shell but for any solid loop; for example, for a torus. In all cases the magnetic field will increase in proportion to the square of the diminution of linear dimensions.

A uniform and intense hydrostatic compression of a sphere, or an inward compression of a solid loop, is quite realizable by means of cumulative explosion of an explosive material. Thus if, by means of implosion, over a period of a second, one compresses a hollow copper sphere so that its internal diameter contracts, say, by a factor 10, the magnetic field inside the sphere will increase by a factor 100. Consequently, an initial magnetic field of 10^5 oe will increase in the example considered to 10^7 oe.

Obviously an accelerator based on the application of very strong magnetic fields obtained by the method under consideration will not be a device with periodic action. Such an accelerator can be designed only for obtaining single pulses of accelerated particles. This circumstance, however, does not constitute a serious disadvantage; for with the known cyclic methods of acceleration, the frequency of the pulses of accelerated particles decreases rapidly with increase of energy, and this is equivalent to operation of the apparatus under single–pulse conditions.

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The Influence of the Entrainment of Electrons by Phonons on Thermomagnetic Effects in Semiconductors

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THE effect of a nonequilibrium distribution of phonons (entrainment of electrons by phonons) on thermoelectric and thermomagnetic effects was first calculated for metals by L. E. Gurevich.[1,2] In semiconductors at temperatures of the order of room temperature, this entrainment has practically no effect on the thermoelectric power. But it is important at low temperatures [3–5]. The purpose of the present note is the calculation of the effect of electron entrainment by phonons on the transverse and longitudinal Nernst–Ettinghausen (N–E) effects in semiconductors.

We shall assume that the electron distribution function in the conduction band is $n = n^0 + n'$, where n' is the small deviation from the equilibrium value n^0. Similarly for phonons $N = N^0 + N'$. At low temperatures, electrons are entrained principally by the acoustic phonons with the highest velocity ω_1; these have considerably longer mean free time τ_{ph} than the phonons which belong to the other two acoustic branches,[6] and the optical vibrations are not excited. A solution of the transport equation on the assumption that the electrons have relaxation time $\tau_e(\epsilon)$, and that their effective mass m is isotropic, gives

$$n' = \frac{\tau_e}{m}\frac{1}{1+(e\tau_e H/mc)^2}\left\{\left(\frac{\varepsilon-\mu_0+g}{T}\nabla T+\nabla\mu,\mathrm{p}\right)+\frac{e\tau_e}{mc}\left(\frac{\varepsilon-\mu_0+g}{T}[\mathrm{H}\nabla T]+[\mathrm{H}\nabla\mu],\mathrm{p}\right)\right\}\int\frac{\partial n^0}{\partial\varepsilon}. \qquad (1)$$

Here $\mu = \mu_0 - e\varphi$ is the electrochemical potential, ϵ is the electron energy and p is their quasi-momentum; the magnetic field H is perpendicular to ∇T and $\nabla\mu$. The term which results from the entrainment is of the order

$$g \approx m w_1^2 \tau_{ph}/\tau_e', \qquad (2),$$

where τ_e' is the relaxation time of electrons which are only scattered by phonons.

The function in (1) leads to the following expres-

sion for the current:

$$\mathbf{i} = \sigma_1 \nabla\mu + \sigma_2 \nabla T + \sigma_3 [\mathbf{H} \nabla T] + \sigma_4 [\mathbf{H} \nabla\mu]. \quad (3)$$

Here the coefficients σ_1 and σ_2 are of the same form as in the absence of entrainment and $\sigma_2 = \sigma_2^{(1)} + \sigma_2^{(2)}$, where $\sigma_2^{(1)}$ results from the entrainment, while $\sigma_2^{(2)}$ corresponds to the usual mechanism. The coefficient σ_3 can be divided into two similar components, and thus also the constant of the transverse N–E effect.

$$Q = (\sigma_1\sigma_3 - \sigma_2\sigma_4)/e[\sigma_1^2 + (\sigma_4 H)^2] \quad (4)$$

can be represented as $Q = Q^{(1)} + Q^{(2)}$, where the term $Q^{(1)}$ is associated with entrainment.

We equate the coefficient ratio $Q^{(1)} / Q^{(2)}$ to the differential thermoelectromotive force ratio $\alpha^{(1)} / \alpha^{(2)}$ at the same temperature. The chemical potential μ_0 appears in the expression for $\alpha^{(2)}$ but not in the formula for $Q^{(2)}$. It therefore follows from (1) that in nondegenerate semiconductors, where essentially $\epsilon \approx kT$, the first ratio is greater than the second by a factor of, roughly, μ_0 / kT. Thus the entrainment has a considerably greater effect on the transverse N–E effect than on the thermoelectromotive force. The same considerations can be applied to the longitudinal N–E effect.

In a weak field we have, in order of magnitude,

$$Q^{(1)} \approx (k/c)\ (w_1^2/kT)\ (\tau_e/\tau_e)\ \tau_{ph}. \quad (5)$$

The variation of the thermoelectromotive force in a weak magnetic field is

$$\Delta\alpha^{(1)} = \alpha^{(1)}(H) - \alpha^{(1)}(0) \approx \frac{k}{e}\frac{mw_1^2}{kT}\frac{\tau_{ph}}{\tau_e'}\left(\frac{uH}{c}\right)^2, \quad (6)$$

in order of magnitude, where u is the mobility.

According to Herring,[6] in an unbounded cubic crystal $1/\tau_{ph} = \Lambda q^2$, where q is the wave vector. Far below the Debye temperature

$$\Lambda \approx (kT)^3/\rho\hbar^2\omega^3, \quad (7)$$

where ρ is the density of the crystal and ω is the average speed of sound. When $\tau_e = \tau_e'$ we have from (5) and (7) $Q \sim T^{-5}$.

If the dependence of τ_e on energy ϵ and temperature T is

$$\tau_e = f_1(T)\, f_2(\epsilon/kT) \quad (8)$$

and τ_e' and g have the same functional form, then in an arbitrary magnetic field,

$$Q^{(1)}(H) = Q^{(1)}(0)\, \psi_1(uH/c), \quad (9)$$

$$\Delta\alpha^{(1)}(H) = (c/u)\, Q^{(1)}(0)\, \psi_2(uH/c)\, (uH/c)^2, \quad (10)$$

where ψ_1 and ψ_2 depend on temperature only through the indicated argument, and $\psi_2(0) \approx \psi_1(0) = 1$

In particular, from the usual assumptions regarding the character of the interaction between electrons and phonons, which lead to energy–independence of the mean free path l ($\tau_e = \tau_e' \sim \epsilon^{-1/2}$):

$$Q^{(1)}(H) = \frac{4\hbar^2 w_1^2}{9\pi mc\Lambda kT^2 (uH/c)^2}\,\frac{\rho(H) - \rho(0)}{\rho(0)}, \quad (11)$$

$$\Delta\alpha^{(1)}(H) = -\frac{\hbar^2 w_1^2}{6m_\Lambda ukT^2}\,\frac{R(H) - R(0)}{R(0)}. \quad (12)$$

Here $\rho(H)$ and $R(H)$ are the resistivity and Hall constant in a transverse magnetic field. The ratios $R(H)/R(0)$ and $\rho(H)/\rho(0)$ depend only on the parameter uH/c and were calculated in Refs. [8–10].

We note that in any field $Q^{(1)} > 0$, and thus $Q^{(1)}$ and $Q^{(2)}$ have opposite signs.

All of the above conclusions are also valid for holes but with a reversed sign in (12).

The effect of entrainment on thermomagnetic effects has been observed experimentally in p–type germanium [11]. The character of the field and temperature dependences of the transverse N–E effect constant agreed with Eq. (9). However, in comparing the theory and experiment, one must keep in mind the degeneracy of the germanium valence band (the presence of two kinds of holes). The above results can easily be extended if it is assumed that the currents of light and heavy holes can be combined additively. It is then easily shown that if the ratios of the concentrations and mobilities of light and heavy holes are temperature–independent the relations (9) and (10 continue to be valid.

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The Role of Three–Particle Forces in the Three–Body Problem

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THE possible role of the so–called many-particle forces has been discussed recently.[1–6] There are indications that by taking account of three–particle forces, the calculated energies of light nuclei show improved agreement with experiment[7,8] In studying the contribution of three–particle forces, we have confined ourselves to three-body problems: a) the calculation of the binding energies of H^3 and He^3; b) the calculation of the neutron–deuteron scattering cross section. For simplicity, we have neglected the noncentral character and the spin dependence of two-particle nuclear forces. As the total energy operator of tritium we took the sum

$$H = -\sum_{i<j} V_0 \frac{\exp\{-\mu r_{ij}\}}{\mu r_{ij}} + f\frac{K_1(\mu(r_{12}+r_{23}+r_{31}))}{\mu^3 r_{12} r_{23} r_{31}} + \frac{\hbar^2}{2M}(\nabla_1^2+\nabla_2^2+\nabla_3^2),$$

with $i, j = 1,2,3$, where the first term represents the ordinary (two–particle) interaction, the constants $V_0 = 52$ mev and $1/\mu = 1.4 \times 10^{-13}$ cm being chosen to yield the correct deuteron binding energy.[9] 1 The term representing the three–particle interaction was taken in the same form as in Refs.[1–3]. The constant f was not given a fixed value but was chosen to give the correct binding energy of H^3. The choice of the trial function in the variational problem took into account the smallness of the probability, because of strong three–particle repulsion, that the three particles would simultaneously be in very close proximity.

In this way we obtained $f = 153$ mev, which agrees in order of magnitude with the value of 375 mev obobtained by Drell and Huang.[1] For He^3 the calculated value of the Coulomb energy (0.745 mev) was very close to the experimental value, whereas worse results were obtained[7,8] when three–particle forces were neglected. For the potential scattering of neutrons by deuterons, we took into account only the s and p states of the incident particle, with the system able to be in either a doublet or quartet state.[10] The phases of the scattered waves were determined by means of Schwinger's variational method[11,12] with the trial function

$$(a + br)\sin kr + (c + dr)\cos kr,$$

where a, b, c are the variational parameters.

The total cross sections in barns are given in the Table (E is the energy in mev in the laboratory system of coordinates. The letters a and b denote variants of the calculation).

	0.42	2.63	6.71	14.7	26,9	35,0	42.0	60.4	82,2
a	3.76	2.68	1,47	0.485	0,141	0,082	0,049	0.020	0,010
b	3.51	2.48	1,41	0,543	0,211	0,152	0.120	0.074	0,054
c		2.74	1,39	0,784	0,470	0.371	0,315	0.224	0.162

In the Table, a denotes that only two–particle interactions were taken into account; b denotes that both two–particle and three–particle interactions were taken into account with $f = 153$ mev; c denotes the experimental values of the cross sections.[13] The inclusion of three–particle forces somewhat improves the agreement with experiment. But one cannot simultaneously obtain the correct binding energy of H^3, the correct neutron–deuteron scattering cross section and saturation of nuclear forces in heavy nuclei[1] by selecting a single value of the constant f, even when noncentral forces are taken into account. It can therefore be assumed that three–particle interactions play a relatively small part in nuclei, and that these cannot be the principal cause of the saturation of nuclear forces.

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