PRESSURE DEPENDENCE OF THE ELECTRICAL PROPERTIES OF PbTe AND PbS

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We have measured the variation of the thermoelectric power α and the electrical conductivity σ with uniform (omnidirectional) pressure up to 9000 kg/cm^2 applied at room temperature to single-crystal n- and p-type samples of PbTe and PbS. Oil was used as the pressure-transmitting medium. The apparatus was the same as that used in earlier work [1].

The thermoelectric power α, the electrical conductivity σ, and the carrier density $\underline{n}$ are listed in the adjoining table. This table also gives the percentage change in α and σ at a pressure P = 1000 kg/cm^2 ($d\alpha/\alpha dP$ and $d\sigma/\sigma dP$). One of the experimental curves is shown in the figure; the other curves were similar.

From the variation of the thermoelectric power and the electrical conductivity we can calculate the variation of the effective mass m* and the mobility $\underline{u}$. The method of calculation of m* and $\underline{u}$ was the same as that used earlier in analyzing the results of similar measurements carried out on samples of PbSe [1].

The variation of m* was calculated from the variation of the thermoelectric power

$$\alpha = \frac{k}{q}\left[\frac{r+2}{r+1}\frac{F_{r+1}(\mu^*)}{F_r(\mu^*)} - \mu^*\right];$$

$$\frac{1}{\alpha}\frac{d\alpha}{dP} = \frac{k}{\alpha q}\left[\frac{r+2}{r+1}\frac{d}{d\mu^*}\left(\frac{F_{r+1}}{F_r}\right) - 1\right]\frac{d\mu^*}{dP} \qquad (1)$$

$$n = \frac{4\pi(2m^*kT)^{3/2}}{h^3}F_{1/2}(\mu^*);$$

$$\frac{d\ln m^*}{dP} = -\frac{1}{3}\frac{F_{-1/2}(\mu^*)}{F_{1/2}(\mu^*)}\frac{d\mu^*}{dP},$$

where F_r are Fermi integrals, μ^* is the chemical potential level in units of kT, $\underline{r}$ is the power exponent in the dependence of the mean free path (l) of an electron on its energy $[l(\varepsilon) \sim \varepsilon^r]$. The table lists the values of d ln m*/dP calculated using Eqs. (1) and (2) for r = 0 [2, 3].*

The linear variation of the electrical conductivity with pressure is related to the variation of the mobility. This was confirmed by measurements of the Hall coefficient R_H, at pressures up to 9000 kg/cm^2, on the purest n- and p-type samples.

To determine that part in the mobility variation which is related to the variation of the chemical potential μ^*, the equivalent variation of the mobility was calculated for a nondegenerate sample (denoted by the subscript "nd"):

$$\sigma = nqu_{nd}\frac{\Gamma\left(\frac{3}{2}\right)}{\Gamma(r+1)}\frac{F_r(\mu^*)}{F_{1/2}(\mu^*)};$$

$$\frac{d\ln\sigma}{dP} = \frac{d\ln u_{nd}}{dP} + \frac{d}{d\mu^*}\left(\frac{F_r}{F_{1/2}}\right)\frac{d\mu^*}{dP}, \qquad (3)$$

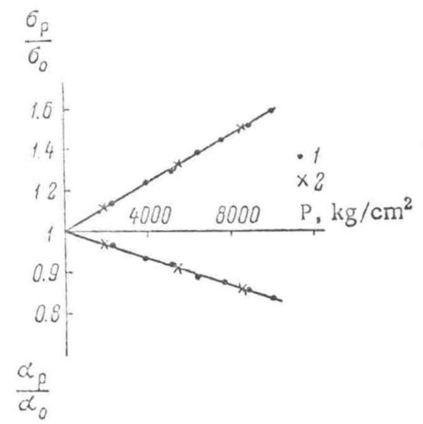
where Γ is the gamma function.

The calculated values of $d(\ln u_{nd})/dt$ are also given in the table.

Calculations carried out for r = 1/2 and r = 1 (not listed in the table) give practically the same values of d(ln m)/dp.

Results of Measurements and Calculations for PbTe and PbS Samples

Compound	Sample No.	Type	Carrier density, cm^{-3}	α, μV/deg, at 300°K	σ, Ω^{-1}-cm^{-1}	$d\alpha/\alpha dP$, in % per tone	$d\sigma/\sigma dP$, in % per tone	dm^*/m^*dP, in % per tone	$du_{nd}/u_{nd}dP$, in % per tone	s
PbTe	3/1	n	9.4×10^{17}	280	230	− 1.1	6.9	− 2.49	7.0	− 2.8
	26/2	n	4.1×10^{19}	57	4500	− 1.92	5.4	− 1.95	6.25	− 3.2
	14/5	p	2.3×10^{18}	263	280	− 1.2	7.0	− 2.47	7.1	− 2.88
	12/1	p	6.9×10^{18}	191	820	− 1.4	6.7	− 2.24	7.0	− 3.12
	20/1	p	2.0×10^{19}	117	1640	− 1.64	6.2	− 2.12	6.65	− 3.14
	19/1	p	5.0×10^{19}	64	2950	− 1.8	5.8	− 1.82	6.4	− 3.5
PbS	14	n	4.9×10^{18}	236	360	− 0.93	3.7	− 1.8	3.8	− 2.1
	27	n	2.2×10^{19}	94	1860	− 1.35	3.2	− 1.7	3.78	− 2.22
	25	n	7.4×10^{19}	51	3660	− 1.6	3.0	− 1.4	3.7	− 2.64
	43	p	2.1×10^{18}	290	170	− 1.06	6.4	− 2.26	6.56	− 2.9
	42	p	1.1×10^{19}	191	800	− 1.3	4.7	− 2.05	5.0	− 2.44



Dependence of the thermoelectric power and the electrical conductivity on pressure for sample No. 19/1. 1) Pressure increasing; 2) pressure decreasing.

Let us now consider the result obtained.

1. Similar values of the change in the effective mass for n- and p-type samples confirm the earlier suggestion [4] that the effective carrier masses are determined primarily by the "interaction" of the valence and conduction bands. Some difference in the changes of the effective mass between n- and p-type samples of PbS is obviously related to the effect of other bands, which is in qualitative agreement with the work of Walton, Moss and Ellis [5],who found that the effective electron mass determined from the Faraday effect for PbS (0.176) was larger than for PbSe (0.114) and consequently the contribution of other bands in PbS is greater than in PbSe. For the same reason the values of the changes of the effective masses differ more strongly in the case of PbS than for PbSe [1].

2. From the deformation potential theory it is known [6] that

$$u_{\text{nd}} = \frac{2\sqrt{2\pi}}{3}\,\frac{qh^4 c_{11} T^{3/2}}{C^2 k^{3/2}}\, m^{*-5/2}.$$

The experimental values of $s = d(\ln u_{\text{nd}})/d(\ln m^*)$ are close to -2.5 (the average values are -3.10 for PbTe and -2.46 for PbS), obviously indicating that on deformation the effective mass changes to a greater extent than the deformation potential constant C (for details see [1]).

3. Using the results obtained in the present work we may attempt to separate out the thermal expansion and the lattice vibration contributions in the temperature dependence of the effective mass obtained for PbTe by Devyatkova and Smirnov [7]: $m^* \approx T^{0.50}$.

From the known values of the compressibility [8] $(1/V)(dV/dP) = 2.56 \times 10^{-6}$ cm^2/kg and the linear expansion coefficient [9] $(1/l)(dl/dP) = 2.5 \times 10^{-6}$ deg^{-1} we easily find that a pressure of 1000 kg/cm^2 is equivalent (in the sense of changing the separation between atoms) to a temperature change of 34 deg. According to Devyatkova and Smirnov [7] we should have $\delta m^*/m^* = 6.3\%$ for this change, but we found that 1000 kg/cm^2 produced $\delta m^*/m^* = 2.2\%$. It follows that approximately 65% of the change in the effective mass is related to atom vibrations and the other 35% is due to thermal expansion.

4. The relative change of the effective mass under pressure decreases somewhat with increase of the degree of degeneracy of the electron gas (see the adjoining table). This indicates a departure of $\varepsilon(k)$ from a parabola.

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