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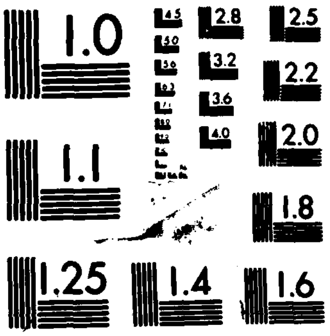

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FOREIGN TECHNOLOGY DIVISION

QUESTION OF THE CHANGE IN THERMAL CONDUCTIVITY OF SEMICONDUCTORS IN A MAGNETIC FIELD

by

Kh. I Amirkhanov, A.Z. Daibov, V.P. Zhuze

HUMAN TRANSLATION

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

QUESTION OF THE CHANGE IN THERMAL CONDUCTIVITY OF SEMICONDUCTORS IN A MAGNETIC FIELD

Full member of the Academy of Sciences Kh. I. Amirkhanov, A. Z. Daibov and V. P. Zhuze

The Maggi-Righi-Leduc[1] effect consists, ~~as is well-known,~~ in the appearance of an additional longitudinal difference in temperatures ΔT in the plate of a conductor placed in a transverse magnetic field $H_\perp$ if there is a temperature gradient along the plate. [*FOOTNOTE*[1]: Hereafter just MRL effect will be used.] The appearance of this difference in temperatures leads to a decrease in the effective part of thermal conductivity.

A rather large number of works is devoted to the experimental study of the MRL effect in metals [1-4]. As should be expected, on the basis of the existing theories [5, 6], the change in thermal conductivity of metals λ in a transverse magnetic field $H_\perp$ is very small and in the majority of the metals investigated could not be detected in the experiment at the standard temperatures and very powerful fields. A considerable effect of the MRL was observed only in Bi [1, 7-9], which is completely explainable if we take into consideration the comparative low concentration of carriers of the charge in it and their high mobility.

It was a completely different matter thus far in the case of semiconductors.[2] [FOOTNOTE[2]: Hereafter PP]. The heat transfer in them is accomplished mainly by phonons. That part of the thermal conductivity which is determined by the diffusion of electrons in the standard PP is small and becomes noticeable only when the PP are good conductors. This part of the thermal conductivity is connected with electrical conductivity by the Wiedemann-Franz relation [10-13]. In the first approximation it is possible to assume that for each 1000 Ω^{-1} cm^{-1}, the magnitude of the electron part of thermal conductivity λ_3 consists of 0.001 cal/deg·cm·s for degenerated PP and 0.0016 cal/deg·cm·s in the generation region.

Calculation of the thermomagnetic MRL effect for PP with a different nature of the chemical bond has been made by K. B. Tolpygo [14]. In the case of the isothermal effect:

$$\frac{\lambda_0 - \lambda_{\text{н}}}{\lambda_0} = \frac{\lambda_{\text{э}}}{\lambda_{\text{э}} - \lambda_{\text{ф}}} (R_{\text{из}} \sigma B)^2 \frac{n^2 - n - 2}{\frac{n}{2} - 2} \frac{b_n}{a_n^2}. \qquad (1)$$

For the adiabatic case:

$$\frac{\lambda_0 - \lambda_H}{\lambda_0} = \frac{\lambda_э}{\lambda_э + \lambda_\Phi} \frac{(R_{Hз}\sigma B)^2}{\frac{n}{2}+2} \left\{(n^2 - n + 2)\frac{b_n}{a_n^2} - \left(\frac{n-1}{2}\right)^2 - \frac{\left[\left(\frac{n+1}{2}\right)^2 + \frac{3}{2}\right]\lambda_э}{\left(\frac{n}{2}+2\right)(\lambda_э + \lambda_\Phi)}\right\}. \quad (2)$$

Here $\lambda_э$ and λ_Φ are the conducitivities caused by electrons and phonons, respectively, $R_{Hз}$ - Hall constant, σ - electrical conductivity, and B - magnetic induction. In the derivation of (1) and (2) it is assumed that the mean free path of electrons $l = l_0(T)v^n$, where v is the velocity of the electron. In PP with atomic lattice l does not depend on v(n=0). For ion PP at "low" temperatures, when $kT<<h\omega_0$ (where ω_0 is the maximum frequency of the longitudinal optical oscillations), n=1. When $kT>>h\omega_0$ n=2. Values of coefficient l_n/a_n^2 are tabulated in work [14]; for atomic lattices it is equal to 1.2732. For ion crystals at "low" temperature b_n/a_n^2 =1.0000and at hight temperature, 1.0868.

From the theory it follows that a noticeable change in λ in the magnetic field should be expected only for the well-conducting PP, with a large value of $\lambda_э$ and, which is especially important, great mobility of the carriers of current u. For the atomic PP, in which $\lambda_э/(\lambda_э\lambda_\Phi)=0.3$, $\sigma=1.6\cdot10^3\Omega^{-1}$ cm $^{-1}=1.6\cdot10^{-6}$ CGSM and R=62.5 CGSM, which corresponds to the concentration of current carriers $N=10^{-8}$ $\Omega^{-3}$and $u=10^4$ cm^2/V·s, the change in λ when $B=10^4$ G consists of about 30% according to (3). In the case of the "classical" PP, in which

$\lambda_{\text{э}}/(\lambda_{\text{э}}+\lambda_{\text{ф}}) \leqslant 0.05$, $\sigma \leqslant 10^{-3}$ Ω^{-1} $cm^{-1} \leq 10^{-12}$ CGSM and $u \leq 10^{2}-10^{3}$ $cm^{2}/V \cdot s$, the value of $\frac{\lambda_0-\lambda_H}{\lambda_0}$ does not exceed 10^{-4}, which, of course, lies within limits of accuracy of the experiment.

There are few works devoted to the experimental study of the MRL effect in PP. Little [15] discovered no change in λ for As in the field $H_{\perp}$=11000 Oe. According to data of Wold [16] and Lloyd [17], the increase in thermal resistance of Te when $H_{\perp}$=6500 Oe consisted of 19%. A. A. Babayev [18, 19] studied the MoS_2. When $H_{\perp}$=7800 Oe and at +145° the thermal resistance grew by 15.8%. At -120° the MRL effect was not observed. As far as we know, information on the MRL effect in PP is limited by these data.

If the negative result of the experiments on As can be considered as corresponding to the theory, then results of studies of Te and MoS_2 sharply contradict it and were presented to us as being very doubtful in connection with the small values of σ and mobility of current carriers in these substances.

For the purpose of clarification of the causes of this nonconformity, we undertook systematic studies of the MRL effect on PP with different σ and u: Te, MoS_2, Bi_2Se_3, Bi_2Te_3, PbTe, and HgSe. Monitoring experiments are conducted on the Bi. Specimens for measurements of λ and electrical characteristics were prepared by the method of hot extrusion and possessed a fine crystalline structure. Specimens of Te and Bi were cast. Table 1 gives parameters of PP at +25° investigated by us. For the HgSe, data for -180° are given.

For the determination of λ of PP and its change in $H_\perp$, both the absolute method [20] and relative (basic measurements) were used. The diameter of the specimens is 15 mm and the thickness, 1-3 mm. Special measures for improving the thermal contact between the separate elements of the scheme were used. The experiments were conducted in conditions close to adiabatic. The accuracy of determinatio of λ by the absolute method was 2-3%; the relative method provided a considerably higher accuracy, reaching 0.2-1.0%.

Results of the work consist in the following. We detected no change in the thermal conductivity of Te, MoS_2, Bi_2Se_3, Bi_2Te_3, and PbTe in $H_\perp$ with a strength to 11,000 Oe. We can confirm with complete certainty that in our specimens the MRL effect consisted clearly of less than 0.2%. The published data on the large value of $\frac{\lambda_0 - \lambda_H}{\lambda_0}$ for Te[16, 17] and MoS_2[18, 19] have not been confirmed by our experiments. Results of our experiments are found in complete agreement with the theory of the MRL effect. The change in λ in such PP as the Te or MoS_2 in $H_\perp \leq 10^4$ Oe, as the calculation shows, must be less than hundreths of a percent, which by far lies beyond limits of the accuracy of the experiment. Obviously, results of works [16-18] are connected with any experimental errors not taken into account.

A considerable increase in the thermal resistance in $H_\perp$ was observed by us only for the Bi and HgSe, which also agrees with the theory.

Actually, as follows from (1) and (2), a noticeable effect of the MRL can be expected only in the PP with large $\lambda_{\text{э}}$, which is still more substantial, with high mobility of the current carriers. The HgSe is a representative exactly of such PP. The experimental data for HgSe are given on Fig. 1. Results of our measurements on Bi agree well with the published data [3, 9]. At 50° the magnitude of the relative change in the thermal resistance of $\Delta W{=}W_{H=0}$ for HgSe (and Bi) linearly depend on the square of the strength of the magnetic field $H_\perp$. At low temperatures this dependence for HgSe (and Bi) is not fulfilled: the transition from the quadratic dependence to the linear one already at comparatively small fields $H_\perp \approx 4\cdot 10^3$ Oe. On the basis of our measurements of the MRL effect in HgSe at 50°, the value of $\frac{\lambda_{\text{э}}}{\lambda_{\text{э}}+\lambda_{\text{ф}}}$ for this substance consists of 0.26, which agrees well with the estimate made in the assumption of feasability of the Wiedemann-Franz law for the PP.

Table 1

(1) Вещество	(2) Т-ра в °Ц	(3) Теплопроводность λ в кал·см⁻¹·сек⁻¹·град⁻¹	(4) Электропроводность σ в ом⁻¹·см⁻¹	(5) Постоянная эффекта Холла R в CGSM	(6) Подвижность носителей тока u в см/в·сек	(7) Концентрация носителей тока N в см⁻³	(8) Вычисленное значение $\frac{\lambda_э}{\lambda_э - \lambda_ф}$ *
Bi	+25	0,0186	6760	8,40	4820	$8,8\cdot10^{18}$	0,58
HgSe	25	0,0042	1840	45,0	6500	$1,65\cdot10^{18}$	0,23
	−180	—	1870	45,3	7170	$1,63\cdot10^{19}$	
PbTe	+25		535	25,4	1150	$2,9\cdot10^{19}$	
Bi_2Te_3	25	0,0043	1500	40,6	1370	$6,8\cdot10^{18}$	0,28
Bi_2Se_3	25	—	152	3,5	45,2	$2,1\cdot10^{19}$	
MoS_2	25	0,0065	0,155	$4,35\cdot10^{3}$	57,0	$1,7\cdot10^{16}$	1,5·10 [illegible]
Te	25	0,004	4,25	2130	770	$3,46\cdot10^{16}$	0,001

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* Estimate is made on the basis of the Wiedemann-Franz law.

Key: (1) Substance. (2). Temperature, °C. (3). Thermal conductivity λ in cal·cm⁻¹·s⁻¹·deg⁻¹. (4). Electrical conductivity σ in Ω⁻¹·cm⁻¹. (5). Constant Hall effect R in CGSM. (6). Mobility of current carriers u in cm/V·s. (7). Concentration of current carriers N in cm⁻³. (8). Computed value.

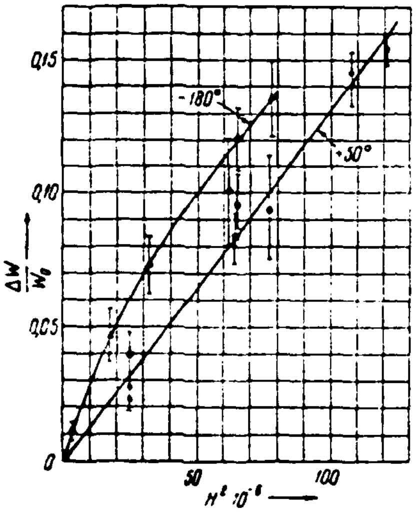

Fig. 1.

References

[1] W. Meissner. Handb. d. Exper. Phys., II. 2, 491 (1935). [2] W. de Haas, J. de Nobel, Physica, 5, 449 (1938). [3] J. de Nobel, Physica, 15, 532 (1949). [4] H. Brown, Phys. Rev., 32, 508 (1928). [5] F. Sauter, M. Kohler, Ann. d. Phys., 42, 110 (1942). [6] M. Kohler, ibid., 6, 18 (1949). [7] W. de Haas, A. Gerristen, W. Capel, Physica, 3, 1143 (1936). [8] R. Reddemann, Ann. d. Phys., 20, 441 (1934). [9] E. Grüneisen, K. Rausch, K. Weiss, ibid., 7, 1 (1950). [10] Ю. А. Дунаев, ЖТФ, 16, 1101 (1946). [11] Е. Д. Девяткова, Ю. П. Маслаковец, Л. С. Стильбанс, ЖТФ, 22, 129 (1952). [12] А. Ф. Иоффе, ДАН, 87, 369 (1952). [13] А. В. Иоффе, А. Ф. Иоффе, ЖТФ, 22, 2005 (1952). [14] К. Б. Толпыго, Тр. Инст. физ. АН УССР, в. 3, 52 (1952). [15] N. Little, Phys. Rev., 28, 418 (1926). [16] P. J. Wold, ibid., 7, 169 (1916). [17] M. G. Lloyd, Am. J. Sci., 12, 57 (1901). [18] А. А. Бабаев, *Диссертация*, Архив Инст. физ. и матем. АН Аз. ССР, 1949. [19] Х. И. Амирханов, ЖТФ, 21, 240 (1951). [20] Х. И. Амирханов, Изв. АН Аз.ССР, 15, 39 (1949).

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