expression for H_n should take the form $g'H_n = \gamma - n\alpha$. Everywhere in Secs. 3 and 4, and particularly in Figs. 3–5, α should be replaced by $\alpha/2$.

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Effect of impurities on the thermoelectric properties of tin

N. V. Zavaritskiĭ and A. A. Altukhov

Institute of Physics Problems, USSR Academy of Sciences

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The thermal conductivity and thermoelectric power of pure tin ($\rho_{273K}/\rho_{4.2K} \sim 6 \cdot 10^4$) and of tin containing up to 0.2% of Cd, In, Sb, Te or Pb are measured in the 3.7–7.2°K range. The electronic part of α_e of the thermoelectric power is separated from the component α_{ph} due to electron dragging by the phonons. It is found that α_e, α_{ph} and W_{ph} (the thermal resistance due to electron scattering by phonons) depend on the impurity concentration and increase by several times when ρ_0 is increased up to about 10^{-8} Ω·cm. The changes in α_{ph} and W_{ph} are ascribed to suppression of the anisotropy in the distribution of the nonequilibrium electrons. The variation of α_e is ascribed to the dependence of $\partial \ln \tau_{imp}/\partial \ln E$ on the scattering-center charge (τ_{imp} is the relaxation time for electron scattering by impurities). The values of $\partial \ln \tau/\partial \ln E$ for Cd, In, Sb, Te and Pb impurities in tin and for pure tin are 3.3, 3.1, −1.5, −3.7, 0.3 and −2.4 respectively, on the assumption that $\partial \ln S/\partial \ln E = 1$.

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The thermoelectric power is one of the most sensitive kinetic electronic properties of a metal. Its value depends on the type of impurities introduced into the metal, on the electron structure of the metal in an external magnetic field, etc. All these features of thermoelectric power were observed in various experimental studies devoted to its properties (for a review see[1]), but until recently there were practically no systematic investigations of the thermoelectric power of extremely pure metals or of metals with small amounts of impurities at low temperatures.

The present study was undertaken mainly for the purpose of determining the dependence of the thermoelectric power on a small number of impurities. The investigated object was tin, since we had at our disposal material with an initial impurity concentration less than 10^{-40}% ($\rho_{273\,K}/\rho_{4.2\,K} = 6 \cdot 10^4$). The impurities employed were In, Sb, Cd, Te and Pb. It is obvious that In, Cd, Sb, and Te differ from tin primarily in charge, whereas lead differs in atomic weight. The known published data on the thermoelectric power of tin at low temperatures[2,3] are insufficient and contradictory.

MEASUREMENT PROCEDURE, SAMPLES

The differential thermoelectric power

$$\alpha = \Delta U/\Delta T\,[\mathrm{V}/^{\circ}\mathrm{K}]. \tag{1}$$

where ΔU is the voltage on the sample along which the temperature difference ΔT is produced, is small and amounts to approximately 10^{-8} V/°K at 4.2 °K. Since in the course of the measurements usually $\Delta T \sim 10^{-2}$ °K, to determine α it becomes necessary to measure voltage differences down to $\sim 10^{-12}$ V.

We determined ΔU by a known method with the SKIMP installation[4] as the null indicator (Fig. 1). The sensitivity of the setup was limited by thermal noise in the resistor R_N and amounted to $\sim 10^{-13}$ V. The low-resistance resistor was a plate 1×1 cm of brass foil 0.25 mm thick. Leads of superconducting wire BT-60 were welded to the plate on both sides, one on top of the other, over the entire length. The resistance between these wires perpendicular to the plane of the plate was 1.28×10^{-5} Ω at 4.2 °K. The resistance was constant during the entire measurement cycle. Random changes of the resistance R_N when installed in the cryostat were possible. These changes of resistance took place in our case during the initial stage of the work. As a result, all the thermoelectric-power values cited by us earlier[5] must be multiplied by 1.177.

The temperature gradient was produced in the apparatus shown in Fig. 1. The sample was thermally insulated from the surrounding helium by means of a dewar turned upside down. The copper rod 4 soldered

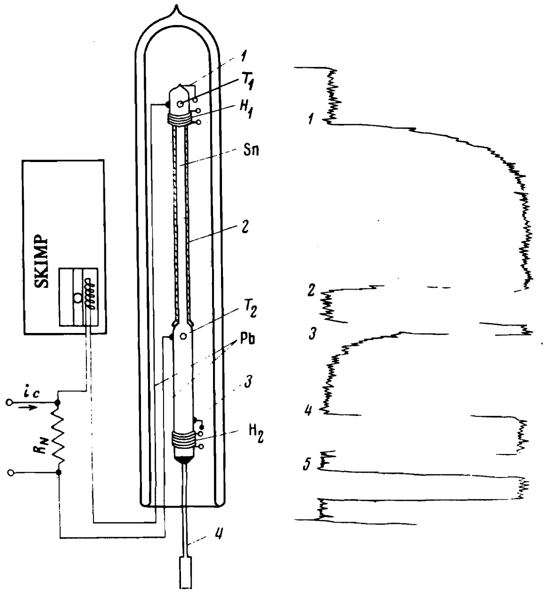

FIG. 1. Schematic diagram of installation for the measurement of thermoelectric power: 1, 3—current leads for the measurement of the Sn sample resistance; Pb—lead leads for the measurement of the voltage drop on the sample; T_1, T_2—thermometers, H_1, H_2—heaters, 2—glass capillary, 4—copper rod. On the right is shown a typical reading of the SKIMP installation as a function of time: 1, 3—turning the heaters on and off, 2—turning on and then off the compensating voltage, 4—the same for the control signal, 5—the same for the current through the sample.

to the sample was used for measurements at temperatures higher than 4.2 °K. The thermal conductivity of the helium gas was negligibly small in comparison with the thermal conductivity of the sample. The sample temperature was varied with the aid of heaters H_1 and H_2 wound on the sample and wrapped in several layers of paper. The sample temperature was measured with carbon resistors T_1 and T_2 placed in holes bored into the metal electrolytically. The measurement of ΔT was the most complicated task and introduced the largest error, reaching ~10% for the pure samples in the value of α.

A typical plot of the measurements of ΔU is shown in Fig. 1 on the right. Control experiments have shown that at given ΔT and T the value of ΔU does not depend on whether the lead leads are connected to the sample mechanically, soldered with Wood's alloy, or fused directly into the tin.

The measurements were made on single-crystal tin samples grown in glass molds. The sample orientation was determined by x-ray diffraction. Molds with irregular shapes were used. The central cylindrical part had a diameter 2 mm. The thicker sections on both sides of the central part were ~5 mm in diameter and were used to install the thermometers, the contacts, and the heaters. The glass was etched off from these parts of the sample. For the most part we investigated single crystals grown along the [110] direction. The growth rate was ~1 mm/min.

To introduce the impurities into the tin we used spectrally pure Cd, In, Sb, Te, and Pb. The concentration of the introduced impurity C was determined by weighing or by further dilution. It was assumed that the impurity is uniformly distributed over the sample in the region where ρ_0 is directly proportional to C. At concentrations larger than 0.03 and 0.2%, respectively, for the systems Sn–Te and Sn–Pb, there was no direct proportionality of C and ρ_0. The values of C and ρ_0 for the samples investigated by us are given in the table. The ratio $\Delta\rho_0/C$ obtained by us for all impurities was close to that given in[6].

The thermoelectric power was measured in the range from 3.72 to 7.2 °K. In this interval, lead was superconducting and its thermoelectric power equal to 0.

RESULTS AND DISCUSSION

1. By measuring the power consumed by the heater H_1 it is possible to calculate, from the value ΔT and the geometrical dimensions of the sample, the thermal conductivity K. The results are plotted in coordinates T/K and T^3 in Fig. 2.

It is known that in the region $T \ll T_D$ we have

$$T/K=\rho_0/L+BT^3, \tag{2}$$

where $L=2.45\times10^{-8}$ W·Ω/cm-°K. The arrows in Fig.

Sample number*	Impurity concentration, wt.%	$\rho_{4,2\mathrm{K}}\cdot10^{6}$, Ω·cm	$(B\pm2)\cdot10^{4}$, cm/W·°K	$(-a\pm0.05)\cdot10^{8}$, V/°K^2	$(-b\pm0.015)\cdot10^{9}$, V/°K^2	Note
Sn 1 **	–	0.42		−0.04	0.19	
Sn 2 ****	–	0.5		−0.12	0.18	
Sn 3	–	0.35		−0.17	0.14	
Sn 4	–	0.22		−0.15	0.11	
»	–	0.22	4.3	−0.24	0.17	After one year
Sn 5	–	0.28		−0.15	0.11	
»	–	0.28	4.0	−0.26	0.20	After one year
»	—	0.28	4.0	−0.22	0.20	After annealing
Sn 6 ***	–	0.28		−0.12	0.17	After deformation
	–	0.39		−0.084	0.15	
In 1	0.13	80		1.04	0.33	
»	0.13	80		1.07	0.25	After one year
»	0.13	80		1.04	0.25	After annealing
In 2	0.06	38		0.99	0.33	
In 3	0.028	17	14.5	0.84	0.30	
In 4	0.016	9.7	11.4	0.67	0.28	
»	0.016	9.7	11.4	1.43	−0.14	After deformation in the course of annealing
In 5	0.0022	1.8		0.23	0.17	
Sb 1	0.105	66		−0.03	0.39	
Sb 2	0.059	43		−0.003	0.38	
»	0.059	43	17.4	0.05	0.32	After one year
Sb 3	0.012	9.3		0.006	0.31	
Sb 4	0.0033	2.8		0.02	0.19	
Cd 1	0.086	133		1.120	0.22	
Cd 2	0.033	36	16.1	1.24	0.117	
»	0.033	36	16.1	1.12	0.21	After annealing
(Cd 3)	0.011	18	15.5	1.215	0.128	Deformed
(Cd 4)	0.016	17	15.2	1.149	0.132	Sample with striking capillary
Cd 5	0.0068	9.3	12.3	1.15	0.125	
»	0.0068	9.3	12.3	1.15	0.125	Prior to annealing
Cd 6	0.0025	3.5		0.83	0.085	After annealing
»	0.0025	3.5		0.83	0.085	After annealing
(Te 1)	0.78	27		−0.35	0.28	
»	0.78	22		−0.42	0.36	After annealing
(Te 2)	0.14	30		−0.34	0.28	
(Te 3)	0.07	29		−0.35	0.28	
Te 4	0.023	24	18	−0.50	0.37	
Te 5	0.0056	7.1	9	−0.46	0.36	
(Pb 1)	0.213	35	22	0.77	0.07	
(Pb 2)	0.532	33		0.3	0.04	
Pb 3	0.198	25	21	0.4	0.17	
(Pb 4)	0.055	12	14.8	0.74	0.06	Sample with striking capillary
Pb 5	0.016	3.9	6	0.26	0.14	

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*The numbers in the parentheses are those of samples not taken into account in the work

**Samples with diameter 1–1.5 mm

***Sample oriented along [001]

****Sample diameter 1 mm, orientation [001]

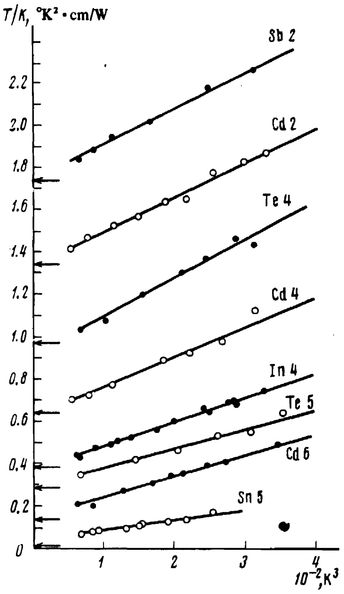

FIG. 2. Temperature dependence of the thermal resistance of tin in the normal state (for the characteristics of the samples see the table). The arrows indicate the values of ρ_0/L obtained by measuring the residual resistivity.

2 mark the values of ρ_0/L with which, as seen from the figure, coincides with $(T/K)_{T\to 0}$, which could be determined sufficiently reliably by extrapolation only for samples with $\rho_0 \gtrsim 5\times 10^{-9}$ Ω-cm. The values of B determined from (2) are shown in the Table and in Fig. 3 as functions of ρ_0 together with data obtained by others.[3,7–9]

The fact that the obtained values of K agree with relation (2), that ρ_0/L agrees with $(T/K)_{T\to 0}$, and that B agrees with the values obtained by others attests to the reliability of our measurements of ΔT.

2. Figure 4 shows the measured values of the thermoelectric power of a number of samples. The transition of the samples to the superconducting state at 3.72 °K is accompanied by an abrupt vanishing of the thermoelectric power. The transition region does not exceed 0.02 °K. This result confirms the conclusion of[2] that there are no precursors of superconductivity in the thermoelectric power of metals above T_c. Below T_c we were unable to observe any ΔU whatever accurate to 10^{-13} V.

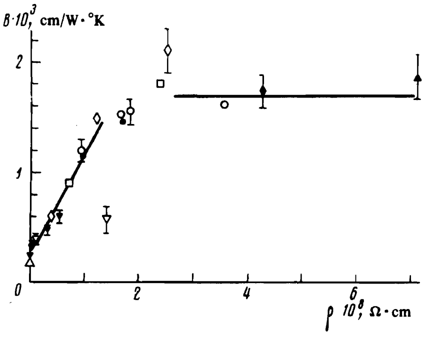

FIG. 3. Dependence of the coefficient B (formula (2)) on the residual resistivity ρ_0. Our data for tin with impurity: ○—Cd, ●—In, ◇—Pb, ◆—Sb, □—Te. Data by others: ▲—[3], △—[7], ▼—[8], ▽—[9].

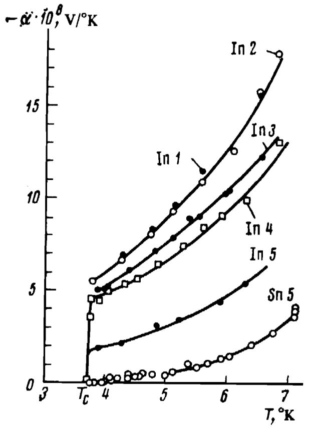

FIG. 4. Temperature dependence of the differential thermoelectric power for a pure sample and for tin samples with In impurity.

In the low temperature region, as shown by Gurevich,[10]

$$\alpha=\alpha_e+\alpha_{ph}, \tag{3}$$

where the term $\alpha_e = aT$ is connected with the direct action of the temperature gradient on the electron system, $\alpha_{ph} = bT^3$ is connected with the dragging of the electrons by the phonon flux produced by the temperature gradient. A numerical analysis has shown that relation (3) describes satisfactorily the function $\alpha(T)$ for most investigated samples. Exceptions were samples made of the original tin. In this case a distinct deviation from (3) is observed. It follows from (3) that

$$\alpha/T=a+bT^2. \tag{4}$$

It is with this relation that the results of our measurements are comparable (see Fig. 5). The values of a and b obtained by numerical analysis are listed in the table.

3. As seen from Fig. 5, the quantities a and b depend essentially on the amount and type of impurity introduced into the sample. Figure 6 shows a plot of a against the residual resistivity of the sample. In the region where $\rho_0 < 10^{-8}$ Ω-cm the value of a varies approximately in direct proportion to the amount of the

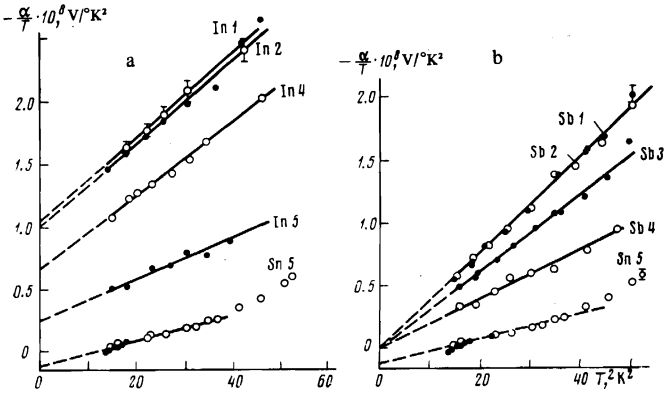

FIG. 5. Dependence of α/T on T^2 for tin samples: a—with In impurity, b—with Sb impurity. Dashed—linear extrapolation to $T = 0$ °K.

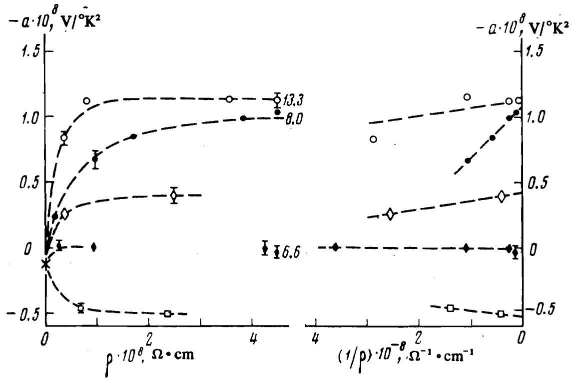

FIG. 6. Dependence of the coefficient a (formula (3)) on the residual resistivity ρ_0. The value of ρ_0 for a number of samples is marked at the points. The asterisk gives the value for pure tin, and the remaining notation is the same as in Fig. 3.

introduced impurity. In the region $\rho_0 > 10^{-8}$ Ω-cm this value tends to a certain limit determined by the type of impurity. The right-hand side of Fig. 6, which shows the character of variation of a at $\rho_0 > 2\times 10^{-8}$ Ω-cm, shows clearly the manner in which a approaches the limiting value a_{lim}.

Figure 7 shows a plot of b against ρ_0. A striking result of a comparison of Figs. 6 and 7 is the similar character of the plots of $a(\rho_0)$ and $b(\rho_0)$, although if a_{lim} is determined by the type of impurity, the limiting values b_{lim}, at least for the systems Sn–In, Sn–Sb, and Sn–Te, do not differ noticeably. An exception to the common $b(\rho_0)$ dependence for impurities with identical atomic weight is the system Sn–Cd, for which $|b(\rho_0)|$ is smaller by an approximate factor 1.5. It is quite probable that this is due to the poor disolution of the Cd in the tin, and consequently to the presence of additional defects or distortions of the crystal lattice of tin. Thus, a 12-h annealing at 200 °C of the Sn–Cd system almost doubles the value of $|b|$. For other systems, annealing increases $|b|$ by only several percent. At the same time, as a result of additional deformation of the samples, $|b|$ usually decreased noticeably.

We propose that the significantly smaller value of $|b|$ obtained in[3] for the Sn–In system may be due to the presence of internal stresses. The point is that they investigated samples with much larger impurity concentration, and this could lead to the appearance of distortions of the crystal lattice of the tin.

4. As seen from Figs. 3, 6, and 7, the plots of $B(\rho_0)$, $a(\rho_0)$, and $b(\rho_0)$ are similar. In all cases, a change of the dependence on ρ_0 and saturation are observed at $\rho_0 \gtrsim 10^{-8}$ Ω-cm. From the data on the temperature dependence of the electric conductivity and the thermal conductivity of tin we have estimated the relaxation times for the scattering of electrons by impurities (τ_{imp}) and by phonons with change of energy ($\tau_{\mathrm{ph}\,E}$) and with change of momentum ($\tau_{\mathrm{ph}\,p}$). It turned out that at 8 °K we have $\tau_{\mathrm{imp}} \sim \tau_{\mathrm{ph}\,E}$ at $\rho_0 \sim 10^{-8}$ Ω-cm and $\tau_{\mathrm{imp}} \sim \tau_{\mathrm{ph}\,p}$ at $\rho_0 \sim 10^{-9}$ Ω-cm.

Thus, the changes in the values of a, b, and B and in the character of the $a(\rho_0)$, $b(\rho_0)$ and $B(\rho_0)$ dependences is probably connected with a transition from the region of electron scattering by phonons to the region of scattering by defects and impurities. The character of the $a(\rho_0)$, $b(\rho_0)$ and $B(\rho_0)$ dependences can be described, in first-order approximation, by the generalized Gorter formula[1]

$$\lambda = \frac{\lambda_{ph} W_{ph} + \lambda_{imp} W_{imp}}{W_{ph} + W_{imp}}, \tag{5}$$

where λ_{ph} and λ_{imp} are the values of the kinetic coefficients in the scattering of electrons by phonons and impurities, for example B, b, or a; W_{ph} and W_{imp} is the thermal resistance for the same independent scattering processes. The ratio $W_{\mathrm{ph}}/W_{\mathrm{imp}}$ can depend on the temperature. Consequently, the quantities B, b, and a can also vary with temperature, as is indeed observed in experiment for sufficiently pure samples. This circumstance is probably the cause of the term proportional to T^4 observed in the thermoelectric power of high-purity gallium.[11]

5. Let us see what can cause B_{imp} to differ from B_{ph} (or b_{imp} from b_{ph}). The quantities B and b are determined by the interaction of the electron and phonon systems. If the electrons are scattered only at phonons, at low temperature, the non-equilibrium electrons have an anisotropy distribution even if the Fermi surface is spherical. As a result, the resistivity is decreased by several times in comparison with the case of isotropic electron scattering. In the presence of electron scattering by the impurities, the anisotropy of the electron distribution decreases. As a result, all the kinetic coefficients are altered. This is one of the mechanisms that lead to non-additivity of the scattering of the electrons by the impurities and phonons.

It appears that this effect was first examined in detail by Ziman,[12] later in[13], and finally recently in[14,15]. If it is assumed that the terms cubic in temperature in the expression for the thermoelectric power (3) and the thermal resistivity (2) are determined respectively only by the dragging of the electrons by the phonon flux and by the scattering of the electrons by the phonons, then the role of the anisotropy can be assessed from the variation of the coefficients b and B with the impurity concentration. Assuming that in pure samples the distribution of the nonequilibrium carrier is anisotropic, and in the case of samples with $\rho_0 > 10^{-8}$ Ω-cm is fully isotropic, we obtain from the

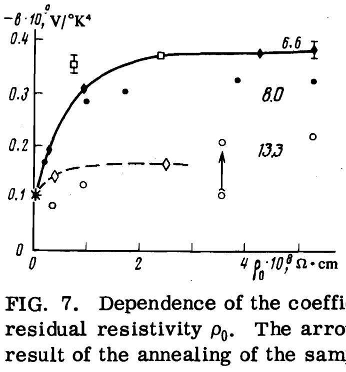

FIG. 7. Dependence of the coefficient b (formula (3)) on the residual resistivity ρ_0. The arrow shows the change of b as a result of the annealing of the sample. The notation is the same as in Fig. 6.

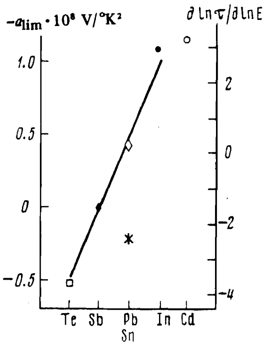

FIG. 8. Values of $a_{\lim}$ and $\partial \ln \tau/\partial \ln E$ for different impurities The value of $\partial \ln\tau/\partial \ln E$ was calculated in the free-electron model. The symbols are the same as in Fig. 7. The values of $a_{\lim}$ and $\partial \ln\tau/\partial \ln E$ for pure Sn characterize the scattering of electrons by phonons, in contrast to other systems.

data of Figs. 3 and 7 that the presence of anisotropy leads to a suppression of the phonon dragging by at least a factor of 3 and of the phonon scattering of the electrons by up to a factor of 9.

The distortion of the crystal lattice causes additional phonon scattering. As a result, the momentum transferred to the electron system from the phonons is decreased, and consequently the value of $|b|$ is small. Lattice distortion can either be the result of mechanical deformation of the lattice or occur near impurity centers. The effect of additional phonon scattering by impurity centers cannot be eliminated in measurements of phonon dragging. Consequently, the value of $|b_{\text{imp}}|$ of the impurities can actually be lower than the value obtained in the absence of phonon scattering by lattice distortions. By the same token, the foregoing estimates of the influence of the anisotropy on the phonon dragging should be regarded as a lower bound of the possible magnitude of the effect.

We assume that the small value of $|b_{\text{imp}}|$ for the Sn–Pb system is due to phonon scattering by lattice distortions caused by impurities of greatly differing mass. We note that the effect of the additional scattering of the phonons by the distortions influences not so strongly the scattering of the electrons by phonons, since B is not very sensitive to the lattice deformation or to the type of impurity.

6. Consider now the change of the electronic part of the thermoelectric power. It is known that

$$a=-\frac{\pi k^2}{3|e|}\left(\frac{\partial \ln \sigma}{\partial E}\right)_{E_F}=-\frac{\pi k^2}{3|e|E_F}\left(\frac{1}{2}+\frac{\partial \ln \tau}{\partial \ln E}+\frac{\partial \ln S_F}{\partial \ln E}\right), \qquad (6)$$

where σ is the conductivity of the metal and S_F is the section of the Fermi surface. Introduction of impurity atoms can alter both $\partial \ln S_F/\partial \ln E$, and $\partial \ln\tau/\partial \ln E$. We recall that a_{imp} depends on the type of impurity (Fig. 8). In the case when $\partial \ln S_F/\partial \ln E$ changes, it is natural to expect the change of a to be directly proportional to the concentration of the introduced impurity. The presence of a constant value of a_{imp} at $C \gtrsim 0.1\%$ could not be explained in this model.

It appears that in the investigated systems the principal role was played by the change of $\partial \ln\tau/\partial \ln E$. Introduction of an impurity atom into the solvent matrix causes a distortion of the internal field. As a result, electrons are scattered by the impurity atom. One of the methods of calculating this effect is based on Friedel's known sum rule.[15] In this method, the impurity center is approximated by a field such that

$$Z=\frac{2}{\pi}\sum(2L+1)\eta_L(k_F), \qquad (7)$$

where Z is the charge of the impurity relative to the charge of the solvent atom and η_L are the phase shifts for the central wave function with angular momentum L. Relation (7) is satisfied by the proper choice of the parameters of the approximating field.

The quantities η_L can be used to express the scattering of the electrons by the impurity center, namely

$$\frac{1}{\tau_{imp}}\sim\frac{C}{me^2}\sum(L+1)\sin^2(\eta_L-\eta_{L+1}). \qquad (8)$$

Using (8), we obtain estimates for the variation of a in electron scattering by impurities:

$$\Delta a\sim\frac{\partial \ln \tau_{imp}}{\partial \ln E}\sim\frac{\Sigma(L+1)\sin 2(\eta_L-\eta_{L+1})}{\Sigma(L+1)\sin^2(\eta_L-\eta_{L+1})}\left(\frac{d\eta_L}{dE}-\frac{d\eta_{L+1}}{dE}\right). \qquad (9)$$

Thus, $a_{\lim}$ is determined in this model by the type of impurity and does not depend on the impurity concentration.

Using relations (6) and (8) we can determine the dependence of a on Z. We consider the simplest case when only one phase shift $\eta_{L'}=\pi Z/2(2L'+1)$ is large. Then

$$\Delta a\approx\frac{\sin[2\pi Z/(2L'+1)]}{\sin^2[Z\pi/(4L'+2)]}\frac{d\eta_{L'}}{dE}, \qquad (10)$$

i.e., the sign of Δa is determined by the sign of the impurity charge. Obviously, by considering the scattering of electrons by impurity centers we can actually attempt to explain the dependence of $a_{\lim}$ on the type of impurity.

The difficulty in such a quantitative treatment lies, for example, in the fact that at the present time it is still not clear to what extent the Friedel sum rule can be used for tin even in the description of the dependence of the residual resistivity on the type of impurity.[6]

The experimentally obtained values of $a_{\lim}$ make it possible to calculate, by using (5), the value of $\partial \ln\tau_{\text{imp}}/\partial \ln E$. In the calculation we have assumed $E_F = 10.3$ eV, as given in[16], and $\partial \ln S_F/\partial \ln E = 1$, which to a considerable degree is arbitrary. This value of $\partial \ln S_F/\partial \ln E$ holds in the case of free electrons. The results of the calculation are given below:

Impurity :	Cd	In	Pb	Sb	Te	Without impurity
$(a_{\lim}\pm 0.05)\cdot 10^8$, V/°K²:	−1.13	−1.09	−0.43	0	0.52	0.175
$\partial \ln\tau/\partial \ln E \pm 0{,}2$:	3.3	3.1	0.3	−1.5	−3.7	−2.4

Attention is called to the fact that for the initial pure tin the value of $\partial \ln\tau/\partial \ln E$ is close to the value typical of electron scattering by phonons, $\partial \ln\tau_{\text{ph}}/\partial \ln E = -3$, obtained theoretically [17] and experimentally.[18] It is probable that the assumed value $\partial \ln S/\partial \ln E = 1$ is close to the true one.

CONCLUSION

The results of our investigation show that thermoelectric phenomena are a powerful means of investigating kinetic processes in a metal. The magnitude and the temperature dependence of the phonon dragging make it possible to obtain information on phonon scattering by lattice distortions. The electronic part of the thermoelectric power can be connected with the electron scattering by impurities and serve by the same token as a method for investigating distortions of the crystal field by a given impurity. It is obvious that success in this direction will be determined by further experimental and theoretical analysis of these phenomena in metals.

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Phenomenological theory of three-pulse electroacoustic echo in powders

B. D. Laĭkhtman

A. F. Ioffe Physico-technical Institute, USSR Academy of Sciences

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The amplitude and duration of an echo pulse are calculated as functions of the amplitude and frequency of the external field, of the duration of the field pulses, and of the interval between them.

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The recently observed three-pulse electroacoustic echo in powders[1,2] has demonstrated that the investigated substances preserve a prolonged memory of the electric and mechanical actions to which they are subjected. The most interesting in this connection is the question of the mechanism of the memory. Also important is another question of whether the most general properties of the memory, inherent in practically any mechanism, are capable of explaining the main features of the electroacoustic echo, such as the dependence of the amplitude and duration of its pulse on the amplitude and frequency of the fields applied in the three pulses that produce the echo, the duration of these pulses, and the interval between them. The purpose of this paper is to answer the second question.

It should be noted first of all that the memorization takes place apparently in individual grains and not in the powder as a whole. Indeed, the dependence of the echo amplitude on the field frequency in the third pulse has a resonant character with a maximum at the field frequency of the first two pulses and with a width equal to the reciprocal pulse duration.[1] This fact indicates that the memorization is connected with processes occurring in those powder grains whose mechanical-oscillation frequencies are at resonance with the frequency of the external field. Since the experiments were performed under acoustic resonance conditions and the frequency of the external field was much larger than the reciprocal pulse duration, such grains are separated by distances much greater than their dimensions and exert practically no influence on one another.[3] Each resonating grain remembers the phase difference of its own oscillations excited by the first and second pulses of the field. The third field pulse excites, among others, oscillations whose initial phase is equal to the remembered phase difference, and the phase evolution in time goes in a direction opposite to