Measurement of the electrical resistivity of the lithium isotopes at low temperatures

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(Submitted 17 July 1981)
Zh. Eksp. Teor. Fiz. **82**, 793–801 (March 1982)

The electrical resistivity at low temperatures ($T = 10$ to 90 K) of the lithium isotopes ^{6}Li and ^{7}Li and of an isotopic mixture $^{7+6}$Li has been studied. The specimens contained a small amount of chemical impurities. An appreciable difference was observed in the temperature dependence of the resistivity produced both by deformation of the phonon spectrum, related to the change in isotopic composition, and by the presence of chemical impurities making the nonequilibrium part of the electron distribution function more isotropic.

PACS numbers: 72.15.Eb

INTRODUCTION

We have carried out the first investigation at low temperatures ($T = 10$ to 90 K) of the electrical resistivity of the lithium isotopes ^{6}Li and ^{7}Li and of an isotopic mixture $^{7+6}$Li with small amounts of chemical impurities. As is well known, the presence of isotopic disorder leads to deformation of the phonon spectrum. At low temperatures, when electron-phonon scattering processes are appreciably inelastic, the phonon deformation changes the temperature dependence of the resistivity, i.e., $\rho(T)$ (see, for example, Refs. 1,2). The effect of chemical impurities amounts to static disorder of the system. The presence of this disorder produces at $T \ll \Theta$ (Θ is the Debye temperature) a suppression, typical of an ideal crystal, of the fine structure of the non-equilibrium part of the electron distribution function δf (Refs. 3–5), and consequently changes the $\rho(T)$ relation. We may note that both these effects have been studied experimentally earlier, but only separately. The effect linear in the mass difference of the isotopes was examined at $T < \Theta$ in detail by Panov and Samoĭlov[6] using 'dirty' Cd specimens as an example. The effect of isotropization of δf was the subject of many investigations (see the review by Bass[1]).

It is usual to consider lithium as a simple metal with an almost spherical Fermi surface. For such a metal the order of magnitude of the change in ρ due to the effect of impurities making δf isotropic is normally taken to be a few dozen percent (compared with the case of polyvalent metals when ρ can change several fold due to chemical impurities). Since the relative mass difference of the Li isotopes is appreciable, the change in ρ on varying the isotopic composition amounts to 10 to 30%. It was, therefore, possible to hope that in the case of isotopic mixtures of lithium containing chemical impurities, a situation would be realized in which at low temperatures both effects would influence the $\rho(T)$ dependence in equal measure.

The effect of isotopic composition on the electrical resistivity of lithium has been studied earlier.[7-9] However, there are no results for the low-temperature region where the electron-phonon interaction is inelastic and appreciably anisotropic.

It is essential to take into account the fact that on cooling lithium, a martensitic transformation is observed starting at $T \approx 80$ K: lithium transforms from the b.c.c. phase to the h.c.p. phase. It is generally considered that on cooling to $T = 4$ K the amount of h.c.p. phase reaches 80 to 90% in sufficiently pure lithium specimens.[10,11] On heating, the phase composition remains constant up to a temperature ~90 K. It can be considered that static disorder is produced by chemical impurities and not by phase disorder for the specimens we used with $\rho_{300}/\rho_0 \approx 1000$.

THE EXPERIMENTS

Electrical resistivity measurements were carried out on eleven lithium specimens with various chemical purity and isotopic composition. We used four groups of lithium specimens1): natural lithium, lithium-6, lithium-7 and a mixture of the isotopes.

The main characteristics of the groups of specimens studied are given in Table I. It can be seen from the table that the atomic masses and isotopic composition of the specimens of natural lithium and of specimens enriched in the lithium-7 isotope are practically the same. Neglecting the small difference in isotopic composition, we will everywhere in what follows denote both these materials as the lithium-7 isotope. The material with the ratio $\rho_{300}/\rho_0 = 1000$ will be referred to as ^{7}Li and the material with $\rho_{300}/\rho_0 = 370$ as $^7\mathrm{Li}_{im}$.

There are a number of experimental difficulties which arise when working with lithium. Bearing in mind its high chemical activity, all operations involved in preparing specimens and mounting them in the holder were carried out in a sealed box under an argon atmosphere. We did not notice any traces of chemical

TABLE I.

Material	Specimen symbol	$\frac{\rho_{300}}{\rho_0}$	Chemical purity	^{7}Li, %	^{6}Li, %	m a.m.u.	Number of specimens measured
Natural lithium	^{7}Li	1000	99.93	92.58	7.48	6.942	3
Lithium enriched in the lithium-7 isotope	$^7\mathrm{Li}_{im}$	370	99.88	93.8	6.2	6.942	2
Lithium enriched in the lithium-6 isotope	^{6}Li	800	99.90	8.9	91.1	6.104	4
Mixture of the lithium-7 and lithium-6 isotopes	$^{7+6}$Li	650	99.90	55.6	44.4	6.572	2

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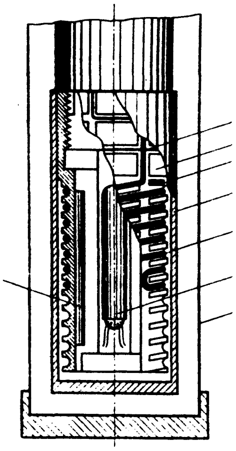

FIG. 1. Cryogenic insert with the specimen: 1—specimen, 2—press contacts, 3—copper specimen holder, 4—sensor of temperature controller, 5—cap, 6—TSU thermometer, 7—vacuum jacket, 8—temperature-regulator heater.

attack on the specimens after the measurements had been made.

The specimens were prepared in the form of a wire by extrusion through a 0.5 mm diameter die, using a mechanical press. The specimens were ~30 cm long so that their room-temperature resistance was ~0.1 Ω.

The lithium wire 1 was wound in a bifilar manner on the copper holder 3 (see Fig. 1), at the end of which were mounted copper pressed contacts 2; the cap 5 laid over the top pressed the ends of the specimen to the contacts. The leads of thermometer 6 (30 cm long) and the heater element of the temperature regulator 8 were stuck with BF-2 adhesive to the inner surface of the holder. The sensor[2)] of the temperature regulator 4 was attached to the outer surface of the holder. The whole system was housed inside vacuum jacket 7. The cryogenic insert was put together inside the box. During the measurements the air pressure in the vacuum jacket was less than 10^{-5} mm Hg. On the whole the cryogenic system was similar to that described by Richardson and McClintock.[12]

The temperature of the specimens was maintained constant to within ±5 mK during the measurements. The temperature was varied from 1.3 to 100 K and was measured by a TSU carbon thermometer from VNIIFTRI to an accuracy not worse than ±50 mK. The electrical resistance was measured by a four-lead system using a R363-1 potentiometer (sensitivity 2 $\times 10^{-8}$ V). The specimen was supplied with a current of 0.1 A from a dc source of stability better than 10^{-5}.

Measurement of the geometrical dimensions of specimens generally introduces an additional error into the determination of the specific resistivity of a metal and, besides, this measurement of the dimensions of lithium specimens is in itself very complicated. We therefore did not use the resistivities proper for comparing the various specimens, but normalized resistivities $\rho(T)$ determined from the expression

$$\rho(T)=[R(T)-R_0]/R_{300},$$

where $R(T)$ is the specimens resistance at temperature T; R_0 is the residual resistivity of a specimen determined by extrapolation of the low-temperature part of the resistance to 0 K; R_{300} is the specimen resistance at $T = 300$ K.

It is clear from the definition of the normalized resistivity that $\rho(300)=1$ for any isotopic composition. In actual fact the proper resistivity of the lithium isotopes differ by about 2% at 300 K. We confirmed this established fact[9] by measurement of the resistivity of the lithium-6 and lithium-7 isotopes at room temperature. Bearing this in mind we introduced the corresponding corrections everywhere to the observed isotope effects.

In order to avoid the complications related to a change in phase composition which occurs at the martensitic transition, the electrical resistance was only measured on heating specimens from 1.3 to 90 K, which is the region where the phase composition does not vary with temperature. The identical method of sample preparation, the closeness of chemical composition, and the reproducibility of the experimental conditions make it possible to assume that the phase composition of different specimens was the same to within 10%. In addition, a special experiment was carried out confirming the already established experimental fact that the resistivity is weakly dependent on a change in phase composition. The small specimen phase-composition difference which could nevertheless exist (≈10%) should therefore not influence appreciably the study of the temperature dependence of the resistivity of different lithium specimens (see Dugdale and Gugan[11], who studied in detail the effect of the martensitic transition on the resistivity of lithium).

About 45 points were measured for each specimen in the determination of the temperature dependence of the resistivity. These experimental results were processed by a computer and values of $\rho(T)$ were calculated for a temperature set standard for all specimens. Mean values for different specimens of a given group (see Table I) were used when considering the temperature dependence. Results obtained for lithium specimens of all four groups are presented in Table II.

It was convenient to analyze the isotope effect in terms of the temperature dependence of the coefficients

TABLE II. Values of the normalized electrical resistivities $\rho = 10^3\,[R(T)-R_0]/R_{300}$ of the lithium specimens studied, tabulated at certain standard temperatures.

T, K	$^7\rho$	$^6\rho$	$^{7+6}\rho$	$^7\rho_{im}$
6	0.013	0.011	0.011	0.010
8	0.026	0.023	0.025	0.026
10	0.054	0.047	0.056	0.062
11	0.076	0.070	0.081	0.094
12	0.102	0.102	0.114	0.135
13	0.140	0.141	0.161	0.188
14	0.200	0.189	0.222	0.257
16	0.373	0.321	0.393	0.447
18	0.602	0.512	0.630	0.706
20	0.890	0.773	0.938	1.047
22	1.257	1.110	1.322	1.477
24	1.724	1.525	1.797	2.100
26	2.302	2.024	2.381	2.657
28	3.004	2.657	3.090	3.437
30	3.845	3.409	4.088	4.363
32	4.865	4.316	4.955	5.465
34	6.123	5.410	6.167	6.770
36	7.556	6.655	7.558	8.233
38	9.265	8.128	9.200	10.009
40	11.173	9.785	11.064	11.988
45	17.109	14.980	16.878	18,072
50	24.726	21.734	24.205	25.827
55	34.096	30.156	33.393	35.334
60	45.150	40.269	44.249	46.554
65	57.645	52.015	56.413	59.325
70	71.650	65.246	69.825	73.622
75	86.961	79.696	84.641	89.285
80	103.365	94.593	100.812	105.996
85	120.511	110.399	118.506	123.773
90	137.373	126.387	137.487	142.110

$$\eta_{\Delta M} = ({}^{M_1}\rho - {}^{M_2}\rho)/{}^{M_2}\rho$$

($M_{1,2}$ are the isotopic masses). Although the electrical resistance R of a specimen was measured quite accurately ($< 0.2\%$ at $T > 10$ K), the error in determining η was then appreciably greater, especially for $T < 20$ K, when $R(T) \leq R_0$. This is explained by the fact that in obtaining the values of $\eta_{\Delta M}$, two nearly equal quantities have to be subtracted twice: $\rho = [R(T) - R_0]/R_{300}$ and $\rho_{\Delta M} = ({}^7\rho - {}^6\rho)/{}^6\rho$. As a result, the error in determining $\rho_{\Delta M}$ for $T > 20$ K is about 1%, while the error is so great for $T < 10$ K that it was impossible to analyze the isotope effects.

RESULTS AND DISCUSSION

The experimental results for the four groups of specimens allow us to consider the manifestations in the temperature dependence $\rho(T)$, of effects connected with isotopic deformation of the phonon spectrum and the isotropy of the fine structure of δf.

We start with the isotope effect. As is well known, the effective atomic pseudopotential is the same for different isotopes. As a result, the electronic spectrum and the force parameters describing the dynamic atomic interactions do not change on varying the isotopic composition. However, the effective masses differ for different isotopic compositions, leading to a readjustment of the phonon spectrum. This isotopic deformation of the phonon spectrum should change the low-temperature dependence of the electrical resistivity $\rho(T)$, when the phonon-electron scattering processes are essentially inelastic. The resistivity is the same for different isotopes in the classical temperature region where electronic transitions can be considered quasielastic.

In order to reveal the isotope effect in ρ we shall analyze the results in Table II for ^{7}Li and ^{6}Li specimens, i.e. $^7\rho$ and $^6\rho$. We note that the difference between $^7\rho$ and $^6\rho$ does not exceed 20% over the whole temperature range studied. It is larger at low temperatures and smaller at relatively high temperatures. The corresponding plot of $\eta_{\Delta M}(T) = ({}^7\rho - {}^6\rho)/{}^6\rho$ is shown in Fig. 2 (curve 1).

The theoretical curve for $\eta_{\Delta M}(T)$, if only the difference in the phonon spectra for ^{7}Li and ^{6}Li is taken into account, can be obtained by using the known universal relationship (see, for example, Refs. 1 and 2)

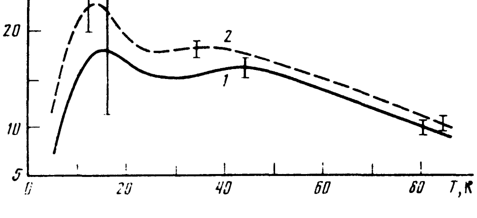

FIG. 2. Temperature dependence of the isotope effect in the electrical resistivity for pure lithium isotopes: $\eta(T) = ({}^7\rho - {}^6\rho)/{}^6\rho$ [1—experimental curve for $\eta_{\Delta M}(T)$, 2—theoretical curve $\eta_{\Delta M \mathrm{calc}}(T)$].

$$ {}^7\rho(T) = {}^6\rho(T')(M_6/M_7)^{1/2}, \quad T' = T(M_7/M_6)^{1/2}. \tag{1}$$

In fact, as can be seen from Eq. (1), if the temperature dependence $\rho(T)$ is known for one isotope, $\rho(T)$ can be calculated for the other isotope. Taking the experimental $^6\rho(T)$ dependence as a basis, we calculated the $^7\rho_{\mathrm{calc}}(T)$ dependence from Eq. (1) and then plotted from them the function $\eta_{\Delta M\,\mathrm{calc}}(T)$, which is designated the theoretical dependence. It is shown in Fig. 2 (curve 2). It can be seen that for the case considered, taking only the isotope effect into account, the theory describes the experimental values for $\eta_{\Delta M}$ quite satisfactorily both qualitatively and quantitatively.

We shall now discuss the nature and scale of the change in resistivity due to the isotropization of the non-equilibrium part of the electron distribution function. We note at the onset how the features of the isotropization of lithium compare with those of other alkali metals (see also Kaveh and Wiser[13]). Firstly, at low temperatures the lithium crystal lattice has preferentially the h.c.p. structure. The gap between the Fermi surface and the Brillouin zone boundary should be small for a monovalent metal if the electrons are considered to be free. It has therefore been predicted more than once that the Fermi surface of lithium intersects the boundary of the first Brillouin zone. Results on, for example, optical absorption[14] and the anomalous temperature dependences of the Hall and Righi-Leduc coefficients[15] indicate this. Secondly, theoretical calculations showed that attempts to describe a large range of experimental results with the help of a single simple model of the pseudopotential were less successful for lithium than for other alkali metals.[16,17] This concerns especially microscopic calculations of the kinetic coefficients. However, the disagreement between the experimental and theoretical results is decreased if it is assumed that the effective pseudopotential at $q \sim 2k_F$ is greater than is predicted by the model proposed by Brovman *et al.*[18] There is, thus, reason to expect that for lithium the anisotropy of electron-phonon scattering processes should be sufficiently pronounced. In other words, the suppression of the fine structure of δf should change ρ in lithium more strongly than in sodium and, probably, in potassium.

Bearing this in mind, we compare the results of Table II for ^{7}Li and ^{7}Li$_{\mathrm{im}}$, which only differ in their chemical impurity content. We introduce the factor $\eta_{\mathrm{im}} = ({}^7\rho_{\mathrm{im}} - {}^7\rho)/{}^7\rho$, which directly describes the effect of isotropization of δf, into the discussion. ${}^7\rho_{\mathrm{im}} - {}^7\rho$ is here the difference between the resistivities of 'dirty' and 'clean' specimens of the lithium-7 isotopes, i.e. the so-called departure from Matthiessen's rule. Curve 1 of $\eta_{\mathrm{im}}(T)$ shown in Fig. 3 is of the standard form. Namely, at low temperatures, when electron-phonon umklapp processes are frozen out, an asymmetrical peak is observed on the $\rho_{\mathrm{im}}(T)$ curve. At the maximum, when $T_{\max} = 15$ K, the value of η_{im} is about 0.3. Unfortunately, the residual resistivities of the lithium specimens studied differed little from one another, so that the real factor η_{im} for Li could be larger. The nature of the structure of the peak in the $\eta_{\mathrm{im}}(T)$ curve remains unclear. The splitting could be

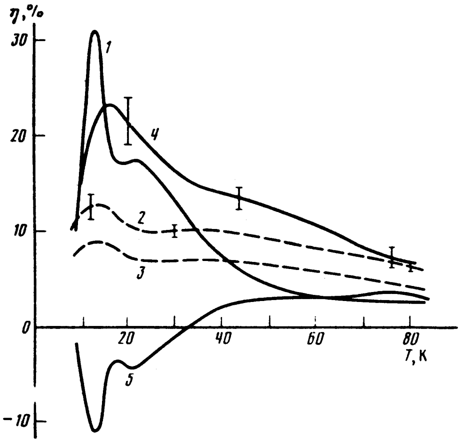

FIG. 3. Temperature dependence of the change in electrical resistivity of lithium, $\eta(T)$, produced by the isotope effect and the isotropization phenomenon. The solid curves were obtained from the experimental results, the dashed curves by using the theoretical expression, Eq. (1): 1) $\eta_{im} = ({}^7\rho_{im} - {}^7\rho)/{}^7\rho$, 2) $\eta'_{\Delta M calc} = ({}^{7+6}\rho_{calc} - {}^6\rho)/{}^6\rho$, 3) $\eta''_{\Delta M calc} = ({}^7\rho - {}^{7+6}\rho_{calc})/{}^7\rho$, 4) $\eta' = ({}^{7+6}\rho - {}^6\rho)/{}^6\rho = \eta'_{\Delta M} + \eta'_{im}$, 5) $\eta'' = ({}^7\rho - {}^{7+6}\rho)/{}^7\rho = \eta''_{\Delta M} - \eta''_{im}$.

produced by the non-coincidence of the temperature intervals, in the first of which the fine angular structure of δf is important for scattering processes, while in the second, consideration of the energy dependence of δf is more important. However, it cannot be ruled out that the splitting is produced by specific properties of the geometry of electron-phonon interaction in a h.c.p. metal.

Finally, we analyze the temperature dependence of the electrical resisitivity of mixtures of the lithium 6 and 7 isotopes. We use the results in Table II for this group of ${}^{7+6}$Li specimens and compare them with the results for ^{7}Li and ^{6}Li specimens. Figure 3 shows curves for the factors

$$\eta' = ({}^{7+6}\rho - {}^6\rho)/{}^6\rho, \quad \eta'' = ({}^7\rho - {}^{7+6}\rho)/{}^7\rho. \tag{2}$$

If the temperature variation of ρ for the three isotopic mixtures ^{7}Li, ^{6}Li and ${}^{7+6}$Li were only determined by electron-phonon scattering processes, the temperature dependences of η' and η'' would be given by curves 2 and 3 shown in Fig. 3, which are very close. [These theoretical curves are constructed by using Eq. (1), as is the curve $\eta_{\Delta M\,calc}(T)$ in Fig. 2.] The experimental curves for η' and η'' turn out to be quite different (see curves 4 and 5 in Fig. 3). There is a sharp maximum on the η' curve at $T = T_{max}$, while a minimum is observed for η''. While η' is positive throughout, η'' is negative at $T = T_{max}$.

The anomalous behaviors of η' and η'' are explained by the following reasoning. The isotopic mixture ${}^{7+6}$Li differs from ^{7}Li and ^{6}Li not only in isotopic composition, but also in the chemical impurity content (see Table I). The temperature variation of η is, therefore, determined both by electron-phonon relaxation processes directly ($\eta_{\Delta M}$) and also by relaxation processes which represent interference between elastic impurity and inelastic electron-phonon processes (η_{im}). Since the isotopic contributions to η' and η'' are of the same sign while the impurity contributions are of different signs (the ${}^{7+6}$Li specimens are dirtier than the ^{7}Li and ^{6}Li specimens), it follows that

$$\eta' = \eta_{\Delta M}' + \eta_{im}', \quad \eta'' = \eta_{\Delta M}'' - \eta_{im}''. \tag{3}$$

Thus by taking simultaneous account of the effects considered above, the changes in η' and η'' with temperature, which are unusual for isotopic systems, can be explained. The small systematic discrepancy between curves 1 and 2 in Fig. 3, evidently connected with the difference in chemical purity of ^{7}Li and ^{6}Li, thus becomes understandable.

We have in this way first observed, using the lithium isotopes as an example, an appreciable change in the temperature dependence of electrical resistivity produced both by isotopic deformation of the phonon spectrum and by partial suppression of the fine structure of the nonequilibrium part of the electron distribution function.

We note in conclusion that attempts to reveal the influence of deformation of the phonon spectrum (due to impurities) on electrical resistivity were also undertaken earlier. Metals with relatively small amounts of heavy chemical impurities were chosen for study. The readjustment of the phonon spectrum produced in these systems led to a correction of order cM_1/M_2 in ρ at low T ($c \ll 1$ is the impurity concentration, M_1 and M_2 are the masses of the components of the mixture). However, in the systems initially studied[1] (Mg and noble metals) although there was an appreciable change in the density of long-wavelength phonons, the effect of isotropization of δf played the dominant role in the resistivity. Chernoplekov *et al.*[19] (see also Kus and Taylor[20]) tried to avoid difficulties in the interpretation of the experimental results and from the start studied 'dirty' specimens of V with Ta atoms as impurities. Since the V specimens already contained an appreciable amount of extraneous chemical impurities, the fine structure of δf must have been obscured to a certain extent. By changing the Ta content in such V specimens (the concentration of the atoms of the second component amounted to a few atomic percent), one could count on observing the contribution from quasilocalized phonons. Unfortunately the high concentration of impurity atoms leads not only to a change in the phonon spectrum, but also to an appreciable change in the electron spectrum. The scale of the isotropization of δf is not clear without the corresponding detailed calculations. The question of the influence of the deformation of the phonon spectrum in mixtures with chemical impurities (as distinct from isotopic mixtures!) thus remains, in fact, open.

In conclusion the authors express their thanks to I. K. Kikoin for his interest in the work and to V. I. Ozhogin for discussion of the results. The authors also thank V. I. Tkachev for preparing the pure lithium specimens.

APPENDIX

In order to ascertain the size of the factor η_{im} (characterizing the magnitude of the change in ρ due to masking of the fine structure of δf by impurities) for Li we analyzed theoretically the phonon electrical resistivity for the b.c.c. and f.c.c. phases of the metal. The calculations were carried out within the framework of the microscopic theory developed in Refs. 18, 16 and in Refs. 5, 17 for transition metals. The system of kinetic equations was solved in the same way as by Zhernov and Kagan.[5]

As already mentioned, the static and dynamic characteristics of Li can be well described quantitatively by using the model pseudopotential V_s proposed by Brovman *et al.*[18] (We recall that the psueodpotential is of the Heine-Abarenkov type, while for the dielectric constant of the electron subsystem the representation of Geldart and Taylor[21] was used.) The quantitative description of the resistivity with the pseudopotential V_s is, however, unsatisfactory.

We emphasize that the potential V_s (Ref. 18) is determined uniquely only for $q \to 0$ and $q > 2k_F$. The analytical representation of V_s is approximate[18] for $q \sim 2k_F$. In the present work, therefore, by varying the form of V_s only at $q \sim 2k_F$, a potential V_{eff} was chosen such that on the one hand the static characteristics of the metal could be described as before, while on the other both the phonon spectrum and the electrical resistivity should be described well over a wide temperature range.

The effective pseudopotential V_{eff} found for Li is shown in Fig. 4a (see curve 2). The theoretical curve were obtained by using the pseudopotential V_{eff} for the Li phonon spectrum close to the curves given by Vaks and Trefilov[16] and by Bajpai *et al.*[22] corresponding to b.c.c. and f.c.c. phases. The theoretical values for the resistivity of Li in the b.c.c. phase from 20 to 100 K agree with the experimental results to an accuracy of 10%.

Theoretical curves for η_{im} for the two Li phases were constructed by using the calculated results for ρ. They are shown in Fig. 4b. It appears that the limiting values of η_{im} for both phases differ slightly, in particular $\eta_{im}^{max} \sim 0.3$ to 0.45. This latter agrees with the experimental values for η_{im}^{max} (see Fig. 3, curve 1).

We should point out that in the temperature region where η_{im} is a maximum, the temperature variation of ρ is almost wholly dictated by electron-phonon umklapp processes. The size of η_{im} then depends on the extent of the anisotropy of electron-phonon scattering (see Kagan and Zhernov[3] and Zhernov and Kagan[5] for more detail), which is determined by the gap Δ between the spherical Fermi surface and the nearest Brillouin zone face and the form of the dispersion curves for long-wavelength transverse phonons. By comparing the phonon spectrum for the b.c.c., f.c.c. and h.c.p. phases (see, for example Bajpai *et al.*[22]), and the magnitude of the gap Δ, it can be deduced that $\eta_{im}(T)$ curve for the h.c.p. phase should have a similar temperature dependence and be close in magnitude to the $\eta_{im}(T)$ curve for the b.c.c. phase (curve 2 in Fig. 4b).

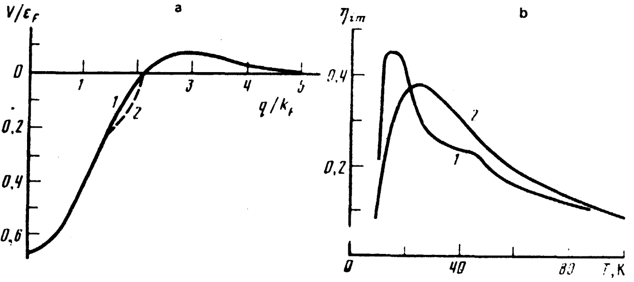

FIG. 4. a) Pseudopotential of lithium: the solid curve corresponds to the model pseudopotential V_s of Refs. 16 and 17; the dashed curve is V_{eff} fitted to the electrical resistivity. b) Temperature dependences of the factors η_{im}, characterizing the scale of the change in electrical resistivity due to impurities: 1 and 2 are curves obtained by using the pseudopotential V_{eff} corresponding to the b.c.c. and f.c.c. phases of Li.

Quantitative calculation has thus shown that the η_{im} curve shown in Fig. 3 (curve 1) really describes the change in ρ due to the isotropization of δf by the impurities.

1) The isotopes of metallic lithium-6 and lithium-7 were obtained from the Government isotope depository (Gosfond) and the lithium of natural isotopic composition from the Institute of Chemistry and Technology of Rare Elements and Mineral Raw Materials of the USSR Academy of Sciences. The isotopic mixture (44.5% ^{6}Li and 55.5% ^{7}Li) was prepared by us by melting the lithium isotopes in vacuum. The isotopic composition was determined with a mass spectrometer.

2) The sensor 4 was a thin-film semiconductor thermometer prepared in the Semiconductors Institute of the Academy of Science and the Institute of Radio and Electronics Academy of Sciences.

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Translated by R. Berman