cal value d_{011} = 2.794 (which follows from the order of the interplanar distance of the monoclinic lattice) is in splendid agreement with the observed value. In our case such a criterion is fully justified since the (011) reflection is the most intense one of the neutron pattern.

Having the set of data listed in the table, it is not difficult to find the unit-cell parameters of the α modification of oxygen: a = 4.284 ± 0.009, b = 3.448 ± 0.007, c = 3.081± 0.011, β = 110°4' ± 11'.

The indices of all the succeeding reflections followed the sequence indicated over the reflections of Fig. 1.

The cells contain two oxygen molecules, and the density at 20.4°K is 1.489 g/cm^3. Consequently, practically no change in density takes place in the β → α transition, unlike the γ → β transition, where the density increases 13%.

Preliminary calculations of the coordinates of the oxygen atoms have confirmed the assumed model of the β → α transition, in which the axis of the O_2 molecule is fixed along the rhombohedral axis of β-O_2.

A universal determination of the coordinates of the atoms was carried out jointly with E. B. Vul and Yu. G. Fedorov [6] by the nonlocal-search method used earlier for x-ray structure analysis [7].

During the course of the search, which was made in the entire region of possible values of the atom coordinates, we established uniqueness of the obtained solution, namely, we obtained the following values of the oxygen-atom coordinates: ±(x, 0, z) and ±(1/2 + x, 1/2, 1/2 + z), where x = 0.104, z = 0.044, and R = 5.9%.

The magnetic structure of the α modification of oxygen, as follows from the neutron pattern that contains reflections with an odd sum of indices, is antiferromagnetic with magnetic moments oriented along the crystal axis and perpendicular to the molecule axis.

[1] R.A.Alikhanov, Proc. 3rd Reg. Conf. Prague, 127, 1963; JETP **45**, 812 (1963), Soviet Phys. JETP **18**, 556 (1964); J. de Phys. **25**, 449 (1964); ITEPh Preprint No. 460, 1966.

[2] I.L.Mc Lennan, I.O.Wilhelm. Phil. Mag., 7/3, 383, 1927.

[3] M.Ruhemann. Zs. Phys. **76**, 368, 1932.

[4] H.H.Mooy. Leiden Comm.,N 233 a, 1932.

[5] M.Hörl. Acta Cryst., **15**, 845, 1962.

[6] R.A.Alikhanov, E.B.Vul, Yu.G.Fedorov, Abstracts VII Intern. Congress Crystallogr. p. 88, 1966.

[7] I.M.Gel'fand, I.I.Pyatetskii-Shapiro, Yu.G.Fedorov, DAN SSSR **152**, 191 (1963).

PHONON SPECTRUM OF THE SUPERCONDUCTING MODIFICATION OF BISMUTH

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It is known [1,2] that bismuth condensed on a surface cooled to 2 - 4°K froms a new crystallographic modification, in which the metal is a superconductor with a critical temperature 6°K. We have investigated bismuth by the tunnel-effect method to be able (i) to measure the gap Δ_0 in the electron spectrum of this superconductor and (ii) to obtain information on the phonon spectrum distribution density.

According to Eliashberg [3], the phonon spectrum distribution density $F(\omega) = \int dq^3 \delta(\omega-\omega_q)$ determines $\Delta(\omega)$, namely in integral form [4]:

$$\Delta(\omega) = \frac{1}{Z(\omega)} \int_{\Delta_0}^{\omega_c} d\nu \, Re \frac{\Delta(\nu)}{(\nu^2 - \Delta^2(\nu))^{1/2}} \{K^+(\nu, \omega) - N_0 U_c\},$$

$$1 - Z(\omega) = \int_{\Delta_0}^{\infty} d\nu \, Re \frac{\nu}{(\nu^2 - \Delta^2(\nu))^{1/2}} K^-(\nu, \omega), \tag{1}$$

$$K^{+}_{-}(\nu\omega) = \int d\omega' a^2(\omega') F(\omega') \left(\frac{1}{\nu + \omega' + \omega + i\delta} \pm \frac{1}{\nu + \omega' - \omega - i\delta} \right),$$

where $d^2(\omega)$ is the electron-phonon interaction constant. The real part of $\Delta^2(\omega)$, as is well known, is connected with the dependence of the current I_s through the tunnel junction on the voltage V. Thus, since the effective electron density of the superconductor is

$$N_s(\omega) = N_0 \, Re \frac{(\omega)}{(\omega^2 - \Delta^2(\omega))^{1/2}},$$

we get

$$\left. \frac{dI_s}{dv} \middle/ \frac{dI_n}{dv} \right|_{T \to 0} = \frac{N_s(o)}{N_0} \simeq 1 + \frac{1}{2\omega^2} Re \, \Delta^2(\omega).$$

This makes it possible, as shown in [4-6], to reconstruct the phonon spectrum, or more accurately, the function $\alpha^2(\omega)F(\omega)$ of the investigated metal from the tunnel characteristics of the superconductor.

The main experimental difficulties occurred in the course of development of the procedure for preparing the tunnel junctions. We investigated tunnel junction between an oxidized film of aluminum and bismuth condensed at 2°K. The junctions were prepared in sealed glass vessels completely immersed in liquid helium. The aluminum was oxidized for approximately three hours at 200°C in an atmosphere of well-dehydrated air at a pressure 0.5 atm. Particular efforts were made to prevent overheating of the investigated bismuth film both during the course of evaporation of the metal and during the measurement. The point is that the superconducting modification of bismuth is unstable and when heated to 10°K it begins to go over into the usual nonsuperconducting modification [2], and this is accompanied by a considerable change of the tunnel characteristics in the normal phase of the metal, at temperatures above 6°K. The experiment consisted of plotting the I - V, (dV/dI) - V, and (d^2V/dI^2) - V characteristics of the junctions.

The width Δ_0 in the energy spectrum of the bismuth electrons was calculated from I - V and (dV/dI) - V curves similar to those shown in Fig. 1a, on which singularities were clearly pronounced at $\Delta_{0Bi} \pm \Delta_{0Al}$. The width of the bismuth gap is Δ_{0Bi} = 1.185 MeV. The anomalously large ratio $(2\Delta_0/KT_c)$ = 4.6 shows that bismuth, like lead and mercury, is a metal with strong electron-phonon interaction.

To determine the Re $\Delta^2(\omega)$ dependence we used essentially the plots of $-(1/R^2)(d^2V/dI_6^2) \equiv Rn(d^2I_8{}^2/dV^2)$, which show in the 5 - 20 MeV interval clearly pronounced singularities whose character does not change when the junction temperature varies from 1 to 5°K (Fig. 1c, curves 3 - 5). These singularities vanish only in the immediate vicinity of the critical temperature of bismuth. The resistance of all the investigated junctions in the normal state depended on the applied voltage (Fig. 1c, curves 1 - 2). This change is due primarily to the logarithmic maximum of dV/dI as $V \to 0$. Inasmuch as the investigated phenomenon is manifested in a change of the tunnel characteristics as the metal changes from the normal to the superconducting state, we determined Re $\Delta^2(\omega)$ by using the corrected values of $Rn(d^2I_s/dV^2) = Rn(d^2I_s/dV^2 - d^2I_n/dV^2)$. A comparison of the characteristics of various junctions has shown that the value

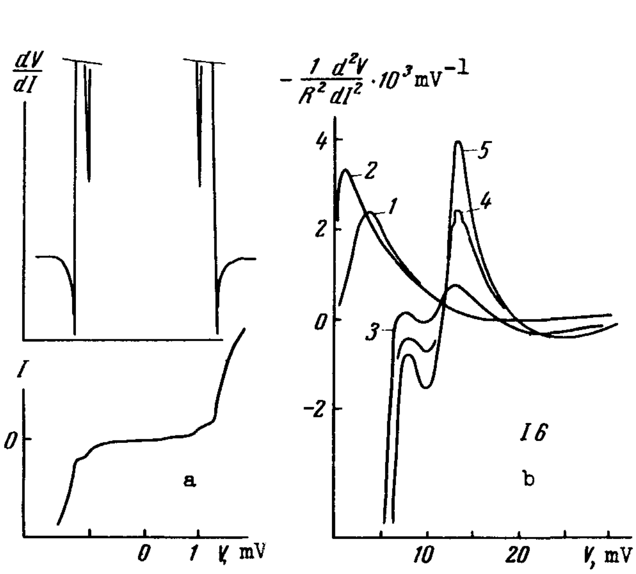

Fig. 1. a - I and dV/dI vs. V for $Bi\text{-}Al_2O_3\text{-}Al$ tunnel junction at 1°K; b - $R(d^2I/dV^2)$ vs. V at 8°K (1), 6.5°K (2), 4.7°K (3), 4.2°K (4) and 1°K (5); 6 - possible error in the plots of $R(d^2I/dV^2)$.

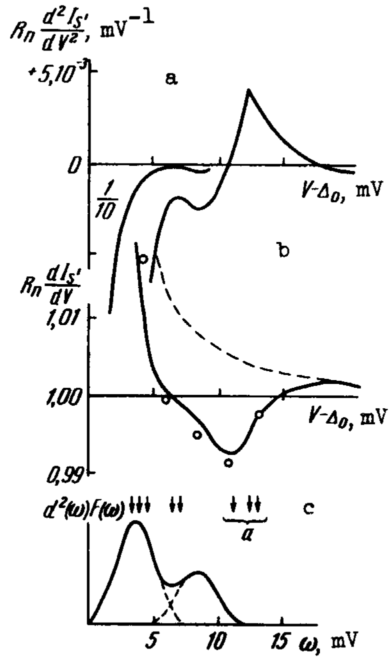

Fig. 2. a - Corrected value of $R(d^2I_s/dV^2)$; b - solid curve, calculated according to curve 2a; dashed - theoretical under the assumption Δ = const, circles - first approximation according to (1) with $\alpha^2(\omega)F(\omega)$ as given in Fig. 2c.

of $R(d^2I_s/dV^2)$ (Fig. 2a) does not change, within the limits of the possible error ($\sim 4\times10^{-4}$ MeV), when $R(d^2I_n/dV^2)$ changes by a factor of several times. Figure 2c shows the value of R(dI/dV) obtained by integrating the curve of Fig. 2a.

Comparing the plot of $R_n(d^2I_s/dV^2)$ with the results of [4-6], we can readily establish that one of the maxima of $\alpha^2(\omega)F(\omega)$ of the superconducting modification of bismuth is located near 8.5 MeV and the upper limit of $\alpha^2(\omega)F(\omega)$ is near 12 MeV. A numerical analysis using Eqs. (1) has shown that the second maximum of $\alpha^2(\omega)F(\omega)$ lies near 3.5 MeV.* Figure 2b shows a possible form of the function $\alpha^2(\omega)F(\omega)$, which an approximate numerical calculation has shown to agree fairly well with the experimental data (Fig. 2c). It must be emphasized that a more accurate calculation may change somewhat the form of the maxima of the function $\alpha^2(\omega)F(\omega)$.

The arrows in Fig. 2c shows the Van-Hove singularities, at $q \neq 0$, of the phonon spectrum of ordinary bismuth, as calculated by E. G. Brovman and Yu. M. Kaganov in accord with neutron-diffraction investigations [1]. The letter a designates singularities due to the split-off optical branch. The maxima of $F(\omega)$ of ordinary bismuth are located near these values of ω. The transition of the bismuth into the superconducting crystalline modification is apparently accompanied by an essential change in the distribution density of the phonon spectrum. This may be connected with the difference between the crystallographic structures of the metal in the ordinary and superconducting modifications [8].

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[1] R.Hilsch. Proc. Intern. Confer. of Low Temperature Physics, Oxford, 1951, p.119.
[2] N.V.Zavaritskii, DAN SSSR **86**, 687 (1952) and **91**, 787 (1953).
[3] G.M.Eliashberg, JETP **38**, 966 (1954), Soviet Phys. JETP **12**, 696 (1954).
[4] D.J.Salapino, J.R.Shrieffer, J.M.Wilkins. Phys. Rev., **148**, 263, 1966.
[5] J.M.Rowell, R.W.Anderson, D.E.Thomas. Phys. Rev. Lett., **10**, 334, 1963.
[6] W.L.McMillan, J.M.Rowell. Phys. Rev. Lett., **14**, 108, 1965.
[7] J.L.Yarnell, J.L.Warren, P.Wenzel, S.H.Koenig. IBM J. of res. and devel., **8**, 234, 1964.
[8] W.Buckel. Zs. Phys., **138**, 136, 1964.

*Inasmuch as superconductivity theory [3] deals with a metal having an ideal crystal lattice, one cannot exclude the possibility that the conclusions of the theory [3-4] are not fully applicable to samples in the form of films, which are usually used in experiments on the tunnel effect, and all the more the films of metal condensed at helium temperature, in which the very concept of regular crystal lattice loses meaning [8]. It is obvious that in using Eq. (1) to reconstruct the function $\alpha(\omega)F(\omega)$ we are performing an operation which is not fully correct from the point of view of the theory [3]. It would be more correct to compare the experimental data with the theory of an amorphous superconducting metal. However, this question has not been fully considered theoretically.

DETERMINATION OF THE DIFFUSION COEFFICIENTS BY HETERODYNING LIGHT SCATTERED BY LIQUID SOLUTIONS

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The kinetics of the thermal fluctuations in pure liquids and of the concentration in solutions becomes manifest in the spectrum of the scattered light in the form of an unshifted line whose width is proportional to the coefficient of temperature conductivity or to the coefficient of diffusion [1]. The line half-widths due to the temperature-conductivity or diffusion coefficients range from several Hz to dozens of MHz. These lines are particularly nar-