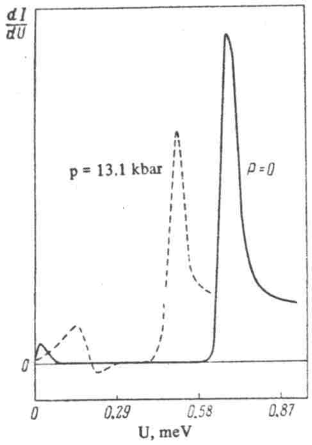

FIG. 6. Influence of high pressures on the differential conductance of an Al-I-Tl sample; T = 1.17°K.

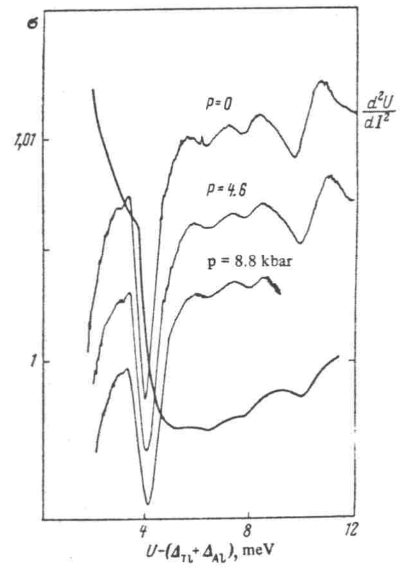

FIG. 7. Normalized conductance of an Al-I-Tl sample at P = 0 and the $(d^2U/dI^2) = f(U)$ characteristics at various pressures; T = 1.17°K.

± 0.03 meV, in good agreement with the results of Rowell and Kopf[2] and those of Clark.[36] The shift of the longitudinal vibrations ω_l was determined up to 5 kbar and the shift of the transverse vibrations ω_t was determined up to 9 kbar (Fig. 7). The values given in Table II are the averages of measurements of four samples. In contrast to lead, the shift was very weak for the transverse phonons ω_t. The values of $d(\ln \omega_\nu)/dP$ could be used to estimate the lattice Grüneisen constant γ_{ω_ν}. Using the tabulated compressibility of thallium, $\kappa = 2.77 \times 10^{-6}$, given in the review by Brandt and Ginzburg,[37] we found that $\gamma_{\omega_t} = 1.35$ and $\gamma_{\omega_l} = 2.1$. Obviously, these estimates were very rough since, to our knowledge, the experimental data on the compressibility of thallium (particularly thallium films) at low temperatures were not reliable.

5. CONCLUSIONS

By using the tunnel effect in investigations of superconductors under pressure, we were able to supplement the traditional measurements of $T_c(P)$ and $H_c(P)$ with the data on the shift of the energy gap and of the phonon spectrum under pressure. A theory of superconductors

Table II. Pressure-induced changes in the phonon frequencies and critical temperature of thallium films

	Investigated quantity X		
	ω_t	ω_l	T_c
X, meV	3.99	9.50	2.38° K
dX/dP, 10^{-5} meV/bar	1.48±0.7	5.45±1	$-(0.6\pm0.1)\cdot 10^{-5}$ deg/bar
$d\ln X/dP$, 10^{-6} bar^{-1}	3.7	5.75	$-2.52\cdot 10^{-6}$ deg/bar

with a strong electron-phonon coupling could explain satisfactorily the observed change in $2\Delta/kT_c$ for Pb as being due to a change in the phonon spectrum. It was found that the energy gap anisotropy of lead was basically unaffected in the investigated range of pressures. In principle, the tunnel effect could be used to determine directly the frequency dependence of the lattice Grüneisen constant:[38]

$$\gamma_{\omega_\nu} = \frac{1}{\varkappa}\frac{d\ln\omega_\nu}{dP}.$$

However, the experimental error in the determination of $d\omega_\nu/dP$ (Tables I and II) for lead and thallium was too large to allow us to separate the contributions of the long-wavelength (ω_t) and short-wavelength (ω_l) vibrations to the Grüneisen constant γ.

The results could be improved by the use of symmetrical superconducting tunnel junctions and very low temperatures. It would also be interesting to investigate the tunnel effect in bulk materials under pressure.

The use of high pressures meant that the tunnel contacts had to satisfy more than usually stringent requirements. Our investigation demonstrated the full "compatibility" of the electron tunneling method with the high-pressure technique. Difficulties were encountered, particularly in the changes and irreversibility of the contact conductance at pressures above 15 kbar; these effects were due to the deformation of the potential barrier and the participation of other (in addition to the tunnel effect) conduction mechanisms. However, these technical difficulties should not be insuperable. The search for new barrier materials and further improvements in the technology of the fabrication of aluminum oxide barrier diodes should stimulate investigations of the tunnel effect in superconductors under pressure.

The authors are grateful to V. G Bar'yakhtar and B. T. Geĭlikman for their stimulating discussions of the problem of the energy gap anisotropy; to I. O. Kulik and A. E. Gorbonosov for discussing some problems related to the tunneling in anisotropic superconductors; and to A. G. Shepelev for valuable discussions of the results.

[1] J. Bardeen, L. N. Cooper, and J. R. Schrieffer, Phys. Rev., 108, 1175 (1957).

[2] J. M. Rowell and L. Kopf, Phys. Rev. 137, A907 (1965).

[3] A. G. Shepelev, Usp. Fiz. Nauk 96, 217 (1968); [Sov. Phys.-Usp. 11, 690 (1969)].

[4] A. A. Galkin and V. M. Svistunov, Phys. Status Solidi 26, K55 (1968).

[5] J. P. Franck and W. J. Keeler, Phys. Rev. Lett. 20, 379 (1968).