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# PHYSICS

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Fig. 1

Figure 1: Fig. 1

## Abstract

## Full Text

PHYSICS

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# ON THE CHANGE IN THE TOPOLOGY OF THE FERMI SURFACE OF THALLIUM UNDER THE INFLUENCE OF IMPURITIES

As is known, in most superconductors (Sn, In, Pb, etc.) pressure produces a decrease in the superconducting transition temperature  $T_k$ , i.e.  $dT_k/dP < 0$  <sup>(1)</sup>. In zirconium <sup>(2)</sup> and titanium <sup>(3)</sup>,  $T_k$  increases under the influence of pressure,  $dT_k/dP > 0$ .

Thallium exhibits quite different behavior under pressure: in the pressure region up to 2000 kg/cm<sup>2</sup>,  $dT_k/dP > 0$  <sup>(4)</sup>; with a further increase of pressure  $dT_k/dP$  changes sign <sup>(5)</sup>. In addition, in thallium, unlike other superconductors, a sharper influence of the valence of the impurity on  $T_k$  is observed.

Fig. 1. Dependence of  $dT_k/dP$  of thallium on  $\Delta n$ ,  $\Delta n = \Delta Z \cdot C$ . *a*—pure thallium; *b*—thallium with a mercury impurity; *v*—thallium with a bismuth impurity.

The temperature of the superconducting transition depends on the Debye temperature  $\Theta$  and on the density of states at the Fermi surface  $\partial N/\partial \varepsilon$  <sup>(6)</sup>

$$T_k \sim \Theta e^{-1/\rho}, \quad (1)$$

where  $\rho = (\partial N/\partial \varepsilon)V$ ;  $V$  is the electron-phonon interaction constant. The behavior of  $T_k$  in thallium could be related to peculiarities of the energy spectrum of the conduction electrons <sup>(7)</sup>. Such a peculiarity (a change in the number of cavities of the Fermi surface) was experimentally found in studies of the influence of impurities on  $dT_k/dP$  in thallium; the results are presented in this communication.

Indeed, both pressure and an impurity change the number of electrons  $n$  per unit volume and, consequently, change the Fermi energy  $E_F$ . Therefore it seemed

important to carry out studies of the combined effect of impurities of different valence and pressure on  $T_k$  of thallium.

To prepare solid solutions, thallium of purity 99.9998% ( $R_{4.2\text{K}}/R_{300\text{K}} = 1 \div 2 \cdot 10^{-4}$ ) and high-purity bismuth and mercury impurities were used. After homogenization, samples with a uniform distribution of impurity were obtained, as characterized by a narrow interval of the superconducting transition ( $2 \div 3 \cdot 10^{-3}$  K). To create pressure, the ice method using water <sup>(8)</sup> and water-alcohol solutions <sup>(9)</sup> was employed.

The results of measurements of the influence of impurity on  $dT_k/dP$  of thallium, i.e. the influence of the change in electron concentration  $\Delta n \sim \Delta Z \cdot C$ , where  $C$  is the impurity concentration and  $\Delta Z$  is the difference between the valence of thallium and that of the impurity element, are given in Fig. 1.

As is seen from the figure, impurities whose valence is greater than that of thallium (Bi), with increasing impurity concentration, decrease the positive pressure effect  $dT_k/dP|_{P=0}$ , and, beginning from a certain concentration value (0.2 at.%), the pressure effect becomes negative.

Mercury impurity (whose valence is less than that of gallium) has a different effect. In the region of small impurity concentrations (up to 0.5 at.% Hg) the positive pressure effect increases. With a further increase in the impurity concentration the positive effect decreases and becomes negative at  $\sim 0.9$  at.% Hg.

Owing to the one-to-one relation between  $n$  and  $E_F$ , the curve in Fig. 1 essentially represents the dependence of  $dT_k/dP$  on  $E_F$ , and with a sharply pronounced nonlinearity.

From the expression for  $T_k$  the pressure effect  $dT_k/dP$  has the form

$$\frac{dT_k}{dP} = \frac{T_k}{\Theta} \frac{\partial \Theta}{\partial P} + \frac{T_k}{(\partial N / \partial E)_\rho} \frac{\partial(\partial N / \partial E)}{\partial P} + \frac{T_k}{V\rho} \frac{\partial V}{\partial P}. \quad (2)$$

Here the first and third terms vary slowly with changes in  $E_F$ . Essential for consideration of the curve in Fig. 1 is the term

$$\frac{T_k}{(\partial N / \partial E)_\rho} \frac{\partial(\partial N / \partial E)}{\partial P},$$

which can have a singularity. The nonlinearity of the dependence of  $dT_k/dP$  on  $E_F$  is connected with the nonlinearity of

$$\frac{\partial(\partial N / \partial E)}{\partial P}.$$

For a normal metal, the singularity in  $\partial N/\partial E$  was considered in the work of I. M. Lifshitz <sup>(10)</sup>. It is associated with a change in the number of cavities of the Fermi surface and appears sharply at  $E_F = E_k$ , where  $E_k$  is the critical energy of the phenomenon. In contrast, in a superconductor such a singularity will appear in an energy interval  $\Delta E \sim 2\Theta$  because of the electron-phonon interaction.

The phenomenon under consideration is observed in thallium. From the data in Fig. 1, one can estimate the value of  $\Delta E$  under the assumption of a quadratic dispersion law ( $n \sim E_F^{3/2}$ ). Taking  $n = ZN_a/v$ , where  $N_a$  is the number of atoms in the unit cell and  $v$  is the volume of the unit cell, we obtain

$$\frac{\Delta E}{E_F} = \frac{2}{3} \frac{\Delta Z}{Z} C.$$

In our case,  $\Delta E/E_F \simeq 3 \cdot 10^{-3}$ . For  $E_F \simeq 5 \cdot 6 \cdot 10^4 \text{ }^\circ\text{K}$  (i.e.,  $\simeq 1$  electron per atom <sup>(11)</sup>),  $\Delta E \simeq 150\text{--}180 \text{ }^\circ\text{K}$ , which is indeed very close to the value  $2\Theta$  for thallium.

Thus, in thallium it has been experimentally found that, under the influence of an impurity, one of the cavities of the Fermi surface disappears, with  $E_F - E_k \sim \Theta$ . The existence of such a cavity is consistent with other experimental facts about the Fermi surface of thallium (from the de Haas-van Alphen effect <sup>(12)</sup> and from ultrasound absorption in a magnetic field <sup>(11)</sup>).

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*Note: Figure translations are in progress. See original paper for figures.*

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