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## Abstract

## Full Text

## PHYSICS

I. Ya. DEKHTYAR and V. S. MIKHALENKOV

### THE INFLUENCE OF TEMPERATURE ON THE ANGULAR CORRELATION OF $\gamma$ -QUANTA ARISING IN THE ANNIHILATION OF POSITRONS AND ELECTRONS IN BISMUTH

(Presented by Academician G. V. Kurdyumov, 15 VII 1960)

In a previous paper <sup>(1)</sup>, results were presented on the study of the angular correlation of  $\gamma$ -quanta arising in the annihilation of positrons and electrons in bismuth at room temperature. The study of this phenomenon on a bismuth single crystal, using the proposed method, made it possible to establish the anisotropy of the shape of the cross section of the energy surface perpendicular to the principal axis of the crystal. The maximum anisotropy of the shape of this cross section in two directions perpendicular to the principal axis is about 14%, and, taking into account the vertical resolution function due to the finite thickness of the detectors and the source, it is equal (in terms of the magnitudes of the mean maximum electron momenta) to approximately 12%.

The shape of the angular-correlation curves may be due to a number of causes <sup>(2)</sup> and, apparently, should depend on the nature of the interaction of positrons with lattice vibrations.

It is therefore of interest to determine the influence of both low and high temperatures on the shape of the angular-correlation curves of  $\gamma$ -quanta arising in the annihilation of positrons and electrons, and also to study the nature of the change in anisotropy of the shape of the cross section of the energy surface. Below are given the results of such an investigation, carried out for bismuth at  $90^\circ\text{K}$ , with the results obtained being compared with data obtained for bismuth at  $300^\circ\text{K}$  <sup>(1)</sup>.

**Fig. 1.** Curves of the angular distribution of  $\gamma$ -quanta formed in annihilation for the direction  $\psi = 90^\circ$ . 1  $-300^\circ\text{K}$ , 2  $-90^\circ\text{K}$ .

To carry out the indicated investigation, the same method was used as in paper

Fig. 2. Angular diagram of the effective maximum momenta of electron momenta in bismuth in the basal plane. 1–300°K, 2–90°K.

Figure 2: Fig. 2. Angular diagram of the effective maximum momenta of electron momenta in bismuth in the basal plane. 1–300°K, 2–90°K.

(<sup>1</sup>), with the difference that, in order to make measurements at low temperatures possible, the positron source ( $\text{Na}^{22}$ ), together with the sample (Bi crystal), was placed at the bottom of a glass Dewar, which was mounted vertically on the goniometric table and then adjusted so that the axis of the table coincided with the axis of the crystal.

In this position, the angular-correlation curves of the  $\gamma$ -quanta arising in the annihilation of positrons and electrons in bismuth were recorded both at room temperature and at the temperature of liquid nitrogen. In the case of room temperature, the curves were obtained after each 15° rotation of the crystal about the principal axis, and in the case of low temperature after each 30° (Fig. 2).

Figure 1 presents curves of the dependence of the coincidence counting rate  $I$  on the angle  $\alpha$ , which characterizes the deviation of the direction of the  $\gamma$ -photons from 180°. On the abscissa axis, it is not the angle  $\alpha$  itself that is plotted, but the magnitude of the vertical displacement  $x$  of one of the scintillation counters from the zero position. Knowing the distance  $L$  from the counter to the axis of the goniometer table, this angle is easily determined:  $\alpha = x/L$ .

The shape of the curves obtained can be characterized by the half-width  $b/2$ , which corresponds to the width of the distribution at half the height of its maximum. Table 1 gives the values of  $b/2$  for every 30° of the crystal-orientation angle, obtained from angular-correlation curves similar to those shown in Fig. 1. The error in determining the half-width is  $\pm 0.1 \cdot 10^{-3}$  rad.

**Fig. 2.** Angular diagram of the effective maximum momenta of electron momenta in bismuth in the basal plane. 1–300°K, 2–90°K.

Figure 2 shows a polar diagram for the values of the mean magnitudes of the maximum electron momenta, expressed in units of  $mc$  ( $m$  is the photon mass,  $c$  is the speed of light).

As is seen from the data of Table 1 and Fig. 2, for all crystal orientations the values of the effective quantities characterizing the angular-correlation curve at 90°K are substantially smaller than the corresponding values at 300°K. At the same time, although the anisotropy of the measured quantities is also retained at 90°K, the maximum value of the anisotropy at this temperature is equal to  $\sim 8\%$ , whereas at 300°K it amounts to  $\sim 15\%$ .\* In Ref. (1) the maximum anisotropy is approximately 14%.

**Table 1**

Values of  $b/2$  ( $10^{-3}$  rad.)

$T, ^\circ\text{K}$	$\psi = 0^\circ$	$\psi = 30^\circ$	$\psi = 60^\circ$	$\psi = 90^\circ$	$\psi = 120^\circ$	$\psi = 150^\circ$	$\psi = 180^\circ$
90	5.6	5.35	5.5	5.55	5.45	5.5	5.23
300	6.15	5.62	6.28	7.2	6.82	5.82	5.95

As was already noted in Ref. (1), the coincidence counting rate  $I$  is proportional to the number of electrons  $N$  with momentum component along the  $z$  axis equal to  $p_z$ , i.e., to a first approximation one may write

$$I(\alpha) = \beta N_z(p_z).$$

If one starts from the Sommerfeld model of the metal, we have (1):

$$I(\alpha) = \beta (p_m^2 - p_z^2),$$

where  $p_m$  is the maximum value of the electron momentum (expressed in units of  $mc$ ). Thus,

$$\beta = I_{\max}/p_m^2.$$

It should be noted that in our case we obtain not the true values of the maximum electron momenta, but effective ones.

From the data obtained in the present work, for Bi the value of  $\beta$  at the temperatures studied is

$$\beta_{90^\circ\text{K}} = 3.96 \cdot 10^5, \quad \beta_{300^\circ\text{K}} = 4.3 \cdot 10^5.$$

\* The maximum anisotropy values are determined as the relative changes of the corresponding quantities at  $\psi = 0 \div 180^\circ$  and  $\psi = 90^\circ$ .

The data obtained can be interpreted from the standpoint of a change in the character of positron annihilation with electrons. According to the theoretical estimate given in [3], under certain conditions, alongside two-photon annihilation there exists, with some probability, one-photon annihilation, in which the interaction of a positron with an electron in a metal leads to the appearance of only one  $\gamma$  quantum; this may be regarded as a process in some sense inverse to the ordinary photoelectric effect.

It turns out that at low positron energies one-photon annihilation is considerably less probable than two-photon annihilation. At a positron energy of the order

of  $10m'_0$  ( $m_0$  is the positron mass), the ratio of the probabilities of one-photon annihilation to two-photon annihilation is maximal. For bismuth this ratio is about 0.2.

Thus, if the indicated phenomenon is taken into account and it is assumed that at low temperatures, alongside two-photon annihilation, a certain fraction of one-photon annihilation takes place, then, since angular-correlation curves such as those shown in Fig. 1 correspond to the registration by the counters of only coincident pulses arising in two-photon annihilation, the counting intensity at  $90^\circ$  K should be lower. In this case, the decrease in the total area under the curve at  $90^\circ$  K in comparison with the area at  $300^\circ$  K signifies a decrease in the total number of positrons participating in two-photon annihilation. The relative decrease in the area under the indicated curves on going from  $300$  to  $90^\circ$  K is approximately 30%.

Further investigation is necessary to determine other possible causes responsible for the temperature dependence of the angular-correlation curves of  $\gamma$  quanta in the annihilation of positrons and electrons in metals.

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

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