nteraction of positrons with crystals and ınnihilation of positrons on metal surfaces

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(Submitted May 10, 1976)
Pis'ma Zh. Eksp. Teor. Fiz. **23**, No. 12, 691–694 (20 June 1976)

We have observed, for the first time, anomalous passage of positrons through thick silicon single crystals. The suggested channeling mechanism is connected with a specific formation and passage of positronium through the crystal.

PACS numbers: 78.70.Bj

Among the important problems connected with the study of positron annihi- ation, a special place is occupied by the question of motion of positrons prior o their annihilation in crystals. If the crystal is thick enough, ensuring prac- ically complete absorption of the positrons, the latter become thermalized ›rior to annihilation. At low thickness and at a sufficient energy of the charged ›articles, channeling of a collimated positron beam is observed.

We report here the results of a study of the passage of positrons through thick ;ilicon single crystals; these results indicate deviation from the currently ac- :epted regularities.

We investigated two-photon annihilation spectra of annealed polycrystalline ›d and Ta. Positrons from ^{22}Na with activity ~10 μCi passed through a con- 'erter (Si single crystal with (111) face several hundred microns thick), and /ere then incident on the investigated object.

The relative flux of the positrons of energy $E_{max} = 0.54$ MeV passing through he converter was estimated [1] at ~5%. In fact, this value is too high, since he estimate did not take into account the distribution of the positrons in energy. 'he fraction of the transmitted positrons measured by us was lower by almost ne order of magnitude.

It was natural to assume that the positrons channel through the Si crystal. 'here are known experiments [2] that demonstrate the possibility of channeling f protons in gold, under conditions that certainly do not ensure channeling. 1 the cited study, approximately 1% of the protons were trapped in the lattice hannels.

Under our conditions, at a beam diameter ~20 mm and at a crystal thick- ess of several hundred microns, positron channeling presupposes some spe- ial mechanism for their passage. It was assumed that their motion in the onverter crystal is via positronium (Ps) production.

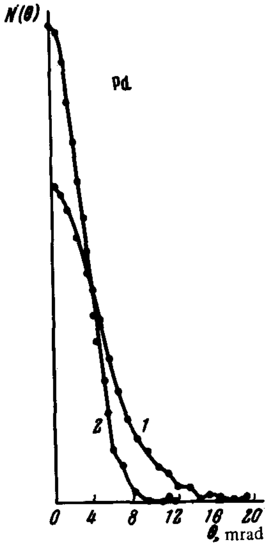

Fig. 1. Dependence of the counting rate $N(\theta)$ (in arbitrary units) on the angle θ between the annihilation photons for polycrystalline palladium: curve 1—without converter, curve 2—with converter.

Figure 1 shows plots, normalized in area, of the angular correlation of the annihilation photons (ADAP) for palladium without a converter (curve 1) and with a converter (curve 2). Curve 1 shows no singularities whatever (the ADAP half-width is 5.2 mrad) and characterizes the annihilation of the positrons in the interior of the metal. [3] Curve 2 indicates the presence of a narrow component connected with Ps annihilation from the singlet state. The half-

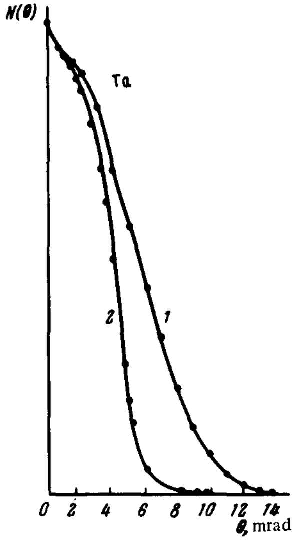

Fig. 2. Dependence of the counting rate $N(\theta)$ (in arbitrary units) on the angle θ between the annihilation photons for polycrystalline tantalum: curve 1—without converter, curve 2—with converter.

width of the curve is 3.6 mrad and corresponds to the interaction of Ps with the surface.

Similar results were obtained for polycrystalline tantalum measuring 25×20 ×0.5 mm. In Fig. 2, the ADAP curves $N(\theta)$ are normalized to the height. On curve 2 (Fig. 2) one can see a narrow maximum with total width ~0.8 mrad, which can be due to annihilation from the ground state [4] on the surface of the oxide layer of Ta. At angles $\theta > 4.5$ mrad, $N(\theta)$ decreases abruptly on this curve.

When comparing the $N(\theta)$ curves from the surfaces of the investigated metals with the $N(\theta)$ curves from the volume, a common feature is the relatively small fraction of the annihilations of the ion cores with electrons on the surface in comparison with the annihilations for the volume.

From the theoretical and experimental investigations it follows that positronium cannot be produced in a metal without the appropriate defects. Therefore the observed narrow component on the ADAP curve from polycrystalline Pd can be interpreted as a result of the interaction of the Ps produced after the passage through the converter with its surface. [1,5] Application of an electric field up to 10^4 V/cm and the change of its direction between the source and the indicated sample did not influence the ADAP curves obtained with the converter. This indicates that the results are not connected with the interaction of the slow positrons with the surface.

We note that formation of positrons in silicon is also forbidden from the point of view of the theory. [5,6] One must therefore assume that the quasipositronium states can be produced in silicon by a specific positron-passage mechanism.

We have demonstrated by special experiments that the indicated irradiation leads to the formation of electron-hole pairs in Si, a fact revealed by observation of radiated recombination after positron irradiation of the Si crystal. This gives grounds for considering the possibility of formation of positronium-like states when positrons interact with electrons from the valence band and the conduction band. The positron of appropriate energy then forms a bound state with an electron from the valence band ($e^+ + e_v^- \rightarrow Ps$), and as it moves farther the positronium dissociates with transfer of an electron to the conduction band ($Ps \rightarrow e^+ + e_c^-$). A consecutive chain of such rapid reactions (even in the absence of a free volume) [4] can accompany the positron until it is converted on the surface of the Si crystal into Ps, which further interacts with the surface of the investigated object.

If the surface of the investigated object is absolutely clean, that is contains no adsorbed films of other substances, it becomes possible to obtain in this manner the ADAP curve for the crystal surface. [3] For an ideally clean metal surface, the half-width of ADAP curve 2 indicated above (Fig. 1) should be even smaller for polycrystalline palladium.

We note in conclusion that the anomalous passage of positrons should be observed also in many other crystals.

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