

the entire interval of temperatures from 50 to 175°C and depended little on the spectral composition of the primary light exciting the PPE.

Observation of the IR quenching confirms the center mechanism of the PPE, which consists of the following. The light corresponding to the edge of the intrinsic absorption produces electron-hole pairs with different lifetimes of the electrons and holes in the free state [3]. The holes become localized on the trapping levels [4] and form in the crystal a system of local charged centers, the interaction of which with the dislocations determines the strengthening of the crystal upon illumination (the photoplastic effect). Additional IR illumination causes the holes to become detached from the trapping levels and increases the recombination efficiency. This process, on the one hand, quenches the photoconductivity (owing to the lowering of the electron concentration in the conduction band) and, on the other hand, leads also to quenching of the PPE, since the concentration of the local charged centers connected with the location of the holes on the trapping levels is decreased.

It should be noted that from the point of view of this model one can understand the previously known fact that the magnitude of the PPE decreases with rising temperature [1].

The purpose of the present article was to report the fact of IR quenching of PPE and to propose in the most general form a possible model of the processes on which it is based. We hope to report in the future the results pertaining to investigations of the detailed mechanism and the kinetics of the indicated processes.

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#### TEMPERATURE DEPENDENCE OF THE LIFETIME OF TRIPLET POSITRONIUM IN ALIPHATIC HYDROCARBONS AND THEIR DERIVATIVES

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The authors have shown previously [1] that the pickoff annihilation of a positronium atom is well described by the "bubble" model first proposed by Ferrell [2] and subsequently developed by Roellig [3]. In the present paper we show the applicability of this model to the description of the pickoff annihilation of the positronium atom in organic liquids. We investigated the temporal distribution of positron annihilation in n-hexadecane, n-octane, n-propanol, and ethanol at temperatures from -20 to 100°C.

The measurements were performed with a setup similar to that described in [4]. The resolution of the apparatus was not worse than 1 nsec, and one analyzer channel corresponded to a time of 0.1 nsec. All the investigated substances were subjected to the necessary treatment so as to eliminate the dissolved oxygen.

According to the "bubble" model in Roellig's interpretation [3] we have

$$1/r_2 N = \pi r_0^2 c z_{\psi\psi} P(kR_0), \quad (1)$$

$$P(kR_0) = \frac{\sin^2 kR_0}{1 - kR_0 \operatorname{ctg} kR_0}, \quad (2)$$

$$k = \sqrt{\frac{4m_e E}{\hbar^2}},$$

where  $P(kR_0)$  is the quantum-mechanical probability that the positronium atom will leave the bubble-well,  $E$  the energy of the positronium atom in the well (reckoned from the bottom of the well), and  $R_0$  the radius of the bubble. As an estimate of  $Z_{\text{eff}}$ , i.e., of the number of electrons on which the positronium is annihilated, we can take the number of valence electrons of the atoms of the molecule [1]. From the condition that the energy of the system consisting of the positronium atom and the liquid be minimal and from the condition that the logarithmic derivative of the wave function of the positronium atom in the well be continuous we obtain

$$\frac{\sin^4 kR_0}{kR_0(\operatorname{tg} kR_0 - kR_0)} = - \frac{\pi \hbar^2 \sigma}{m_e U_0^2}. \quad (4)$$

Relations (1), (2), and (4) yield the dependence of the lifetime of orthopositronium on the temperature ( $\tau_2(t^0)$ ) in a given organic liquid, if we know its temperature dependences of the surface tension ( $\sigma(t^0)$ ), of the number of molecules per unit volume ( $N(t^0)$ ), and of the depth of the well ( $U_0(t)$ ). The functions  $\sigma(t^0)$  and  $N(t^0) = \mu(t^0)A/M$  ( $\mu(t^0)$  is the dependence of the liquid density on the temperature,  $M$  is the molecular weight, and  $A$  is Avogadro's number) are well known for the investigated liquids [5].

The  $U_0(t^0)$  dependence was calculated in accordance with the Wigner-Seitz scheme [6]. Each molecule of the liquid is represented as a solid cylinder of radius  $a$  equal to the positronium scattering length. Its wave function is then

$$\psi(\rho) = AI_0(q\rho) + BY_0(q\rho). \quad (5)$$

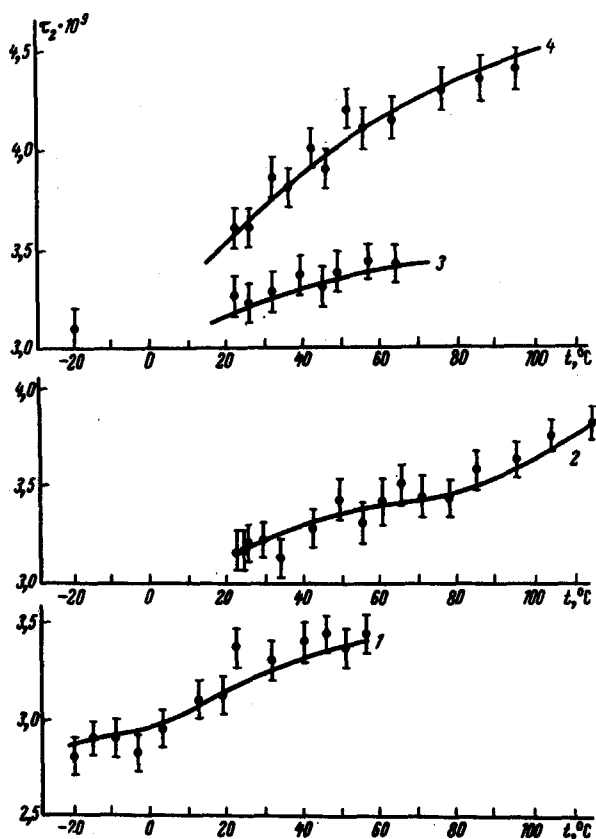
The boundary conditions on the solid (radius  $a$ ) and equivalent (radius  $\rho_s$ ) are respectively

$$\begin{cases} \psi(a) = AI_0(qa) + BY_0(qa) = 0 \\ \left. \frac{\partial \psi}{\partial \rho} \right|_{\rho=\rho_s} = -AI_1(q\rho_s) + (-BY_1(q\rho_s)) = 0 \end{cases}, \quad (6)$$

$$(7)$$

where  $q = (4mU_0/\hbar^2)^{1/2}$ , and  $I_0$ ,  $I_1$ ,  $Y_0$ , and  $Y_1$  are Bessel functions of zeroth and first order of the first and second kind, respectively. The system (7) was solved with respect to  $U_0$  graphically. The values of the equivalent radius  $\rho_s$  at different temperatures were determined from the equation

$$\pi \rho_s^2 [(n_C - 1)r_{C-C} \sin \frac{a}{2} + n_{OH} r_{C-OH} \sin \frac{\beta}{2} + 2\rho_s] = \frac{M}{\mu A}, \quad (8)$$



1 - Temperature dependence of lifetime in ethanol, 2 - n-hexadecane, 3 - n-propanol, 4 - n-octane. Solid curves - theoretical calculation.

approximately equal to the radius of the  $C^{+4}$  ion ( $0.15 - 0.29 \text{ \AA}$ ) [5], and  $r_{Ps}$  is the radius of the positronium atom ( $0.54 \text{ \AA}$ ). Thus,  $0.69 \text{ \AA} \leq a \leq 0.83 \text{ \AA}$ , which is in good agreement with the experimentally obtained values of  $a$ . The agreement between the theoretical calculations and the experimental results leads to two conclusions: (i) the "bubble" model describes correctly the behavior of the positronium atom in aliphatic compounds and their derivatives; (ii) the positronium atom apparently annihilates only on the valence electrons of the molecule atoms, i.e.,  $Z_{eff} = Z_{val}$  (since  $Z_{eff}$  is actually the only parameter of the theory, the agreement between calculation and experiment when the choice  $Z_{eff} = Z_{val}$  is made allows us to draw this conclusion).

where  $n_{OH}$  and  $n_C$  are the numbers of OH groups and carbon atoms in the molecule,  $r_{C-C}$  and  $r_{C-OH}$  are the C-C and C-OH bond lengths,  $\alpha = \beta = 109.5^\circ$  are the CCC and CCO angles.

Equation (8) was obtained under the assumption that the molecules in the liquid are arranged parallel to one another and are closely packed in the plane perpendicular to the molecule axes [7]. The positronium scattering length  $a$  was determined from the best fit of theory and experiment.

The figure shows the experimentally obtained results and the theoretically calculated temperature dependences of the lifetime of orthopositronium in n-hexadecane ( $a = 0.846 \pm 0.006 \text{ \AA}$ ), n-octane ( $a = 0.804 \pm 0.006 \text{ \AA}$ ), n-propanol ( $a = 0.638 \pm 0.008 \text{ \AA}$ ), and ethanol ( $a = 0.755 \pm 0.006 \text{ \AA}$ ). The obtained values of  $a$  are in good agreement with the assumption that  $Z_{eff}$  is equal to the number of valence electrons of all the molecule atoms.

Indeed, in this case the minimum possible distance between the molecule axis and the center of the positronium atom (which is equal to  $a$ ) can be estimated at  $a \approx r_{C^{+4}} + r_{Ps}$ , where  $r_{C^{+4}}$  is the radius of the carbon core,

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# NEAR-THRESHOLD SINGULARITIES OF THE YIELD OF DIRECT PHOTONUCLEAR REACTIONS

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The present research was undertaken for the purpose of studying direct photonuclear reactions in the gamma-quantum energy region close to the nucleon-emission threshold. Studies of this kind may yield information on relatively "pure" transition in the nucleus with excitation of a small number of degrees of freedom.

The yield of the reaction  $(\gamma, p)$  was measured for two nuclei: the proton-shell even-even nickel isotope  $Ni^{64}$  and the nucleus  $Cr^{53}$ . The large positive value of the proton and neutron binding energy difference (2.82 MeV for  $Ni^{64}$  and 3.19 MeV for  $Cr^{53}$  [1] leads to suppression of the emission probability of "evaporation" protons, making it possible to regard the indicated reactions as direct. A nickel sample weighing 0.884 g, enriched with  $Ni^{64}$  to 90.3%, and a chromium oxide sample containing 2.0 g of the metal, enriched with  $Cr^{53}$  to 84.3%,<sup>1)</sup> were placed in the beam of gamma quanta from a synchrotron with maximum energy  $E_{\gamma m} = 35$  MeV at a distance 25 cm from the internal target of the accelerator (a vertical platinum wire of 0.3 mm diameter). The effective thickness of the target was governed mainly by the pitch of the electron-beam helix, which amounted to 1  $\mu$ . The activity induced in the samples was recorded with flow-through counters [2]. The half-life of the final  $Co^{63}$  nucleus, 34.8 sec, was determined in preliminary measurements [3]. The stability of the energy  $E_{\gamma m}$  was verified in accord with [4] before and after the irradiation of the samples; the statistical error in the determination of  $E_{\gamma m}$  was on the average 1.3 keV. In the measurement of the yield of the reaction  $Ni^{64}(\gamma, p)Co^{63}$  the background was connected mainly with the contribution of the reaction  $Ni^{64}(n, \gamma)Ni^{65}$  with  $T = 154$  min.

In several measurements, as an added check, we used the reaction  $Cu^{63}(\gamma, n)Cu^{62}$ .

The results of the measurement of the  $(\gamma p)$  yield averaged over  $E_{\gamma m}$  in the interval 10 - 100 keV are shown in Fig. 1. The excess of the observed reaction threshold above the true threshold amounts to  $1.5 \pm 0.1$  MeV for the reaction  $Cr^{53}(\gamma, p)U^{52}$  and  $2.6 \pm 0.2$  MeV for the reaction  $Ni^{64}(\gamma, p)Co^{53}$ . The cross section of the last reaction is  $\sigma = 1 \times 10^{-29}$  cm<sup>2</sup> at  $E_{\gamma m} = 16.2$  MeV. For the reaction  $Ni^{64}(\gamma, p)Co^{63}$  we performed careful measurements of individual sections of the yield curve in narrower intervals of  $E_{\gamma m}$ . Figure 2 shows one of the sections in the region of  $E_{\gamma m} = 16.35$  MeV, investigated in three series of measurements (A, B, C) for one year. Each point combines the results of 15 - 20 measurements in the interval  $E_{\gamma m} = 1.4$  keV. The yield errors are rms. A second section of the same curve in the region of  $E_{\gamma m} = 16.70$  MeV is shown in Fig. 3a. The change in  $E_{\gamma m}$  during one measurement cycle ( $\sim 3$  hrs)

<sup>1)</sup>The samples were obtained from the USSR State Stock of Stable Isotopes.