CORRELATION OF POSITRON LIFETIME WITH THE ANGLE BETWEEN THE ANNIHILATION GAMMA RAYS*

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Previous investigators have found a "narrow component," attributed to the annihilation of singlet positronium (Ps), in the angular distribution of annihilation radiation from many amorphous materials.[1,2] The lifetime distribution of positrons in these materials contains a long-lived component, attributed to the presence of triplet Ps.[3] It has been suggested that a measurement of positron lifetimes as a function of the angle between the annihilation gamma rays would clarify the picture of positron interactions in these materials.[4,5] One experiment of this type has been reported[6]; the results were unexpected and hard to understand.

In our experiment, positron lifetime distributions in Teflon were obtained for two different selections of angles between the annihilation gammas: "small angles," which should include most of the singlet Ps annihilations, and "large angles," which should include no singlet Ps annihilations. Figure 1 is a block diagram of the apparatus. About 50 microcuries of Na^{22} were deposited within a 3-mm radius in a flat Teflon sandwich, which rests on scintillator 1, a plastic scintillator $1\frac{1}{2}$ in. in diameter by $1\frac{1}{2}$ in. long. Detector 2 also has a plastic scintillant, but detector 3 uses sodium iodide; both detectors are 2 in. in diameter by 6 in. long, and are placed 50 cm from the source. The diagram indicates the small-angle selection; the lead blocks in front of detectors 2 and 3 contain three slits, each 1 mm wide and 6 in. long, spaced 10 mm apart. Each slit lies on a straight line through the source and a corresponding slit on the other side so that a coincidence count between detectors 2 and 3 indicates that the horizontal projection of the angle between the gamma rays was approximately $\pi \pm 0.002$ rad. No "cross talk" between slits occurs, since the entire angular distribution for positrons in Teflon is limited to angles of $\pi \pm 0.010$ rad. When large angles are selected, a 3-mm wide slit is placed in front of detector 2, and a lead block 7 mm wide is placed in front of detector 3 and aligned with the source and slit, so that a coincidence count between these counters indicates an angle which differs from π by more than 0.004 rad.[7]

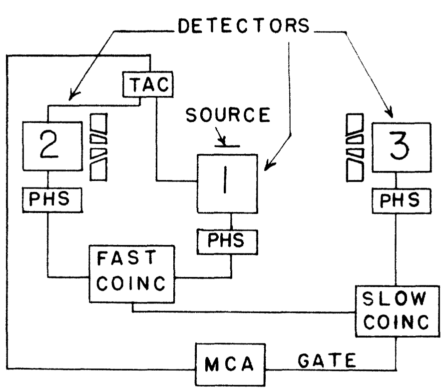

FIG. 1. Block diagram of apparatus with small-angle slits in position.

Detectors 1 and 2 are used to determine the positron lifetime in the usual way, by means of a time-to-amplitude converter (TAC).[8] The output of the TAC is fed to a multichannel analyzer, which is gated by coincidence circuitry fed by single-channel pulse-height selectors (PHS) on all three counters. If all three counters produce coincident pulses of the proper size, the TAC pulse is analyzed and stored in one 100-channel subgroup of the analyzer; if only counters 1 and 2 have coincident pulses of the proper size, the TAC-pulse information is stored in a second 100-channel subgroup. Thus two lifetime distributions are obtained simultaneously, one with and one without angular selection. Since the counting rate in counter 1 is quite high (20 000/sec in the selected energy range), a pile-up rejector[9] is used on the pulses from this counter to reject pulses which are preceded too closely (within 5 μsec) by another pulse. A tunnel-diode discriminator is also used on the output of this counter to prevent pulses from annihilation gamma rays from reaching the TAC. Background is kept to a minimum by the use of jitter-free pulse-height selectors on detectors 1 and 2, feeding a fast coincidence circuit with a resolution time of 50 nanoseconds.

The individual counting rates in each counter and the true and random coincidence rates between pairs of counters were measured in order to obtain a check on the background counting rates. In the worst case, the background rate per channel was about $\frac{1}{2}\%$ of the rate in the peak channel of the curve. Figure 2 shows the results.

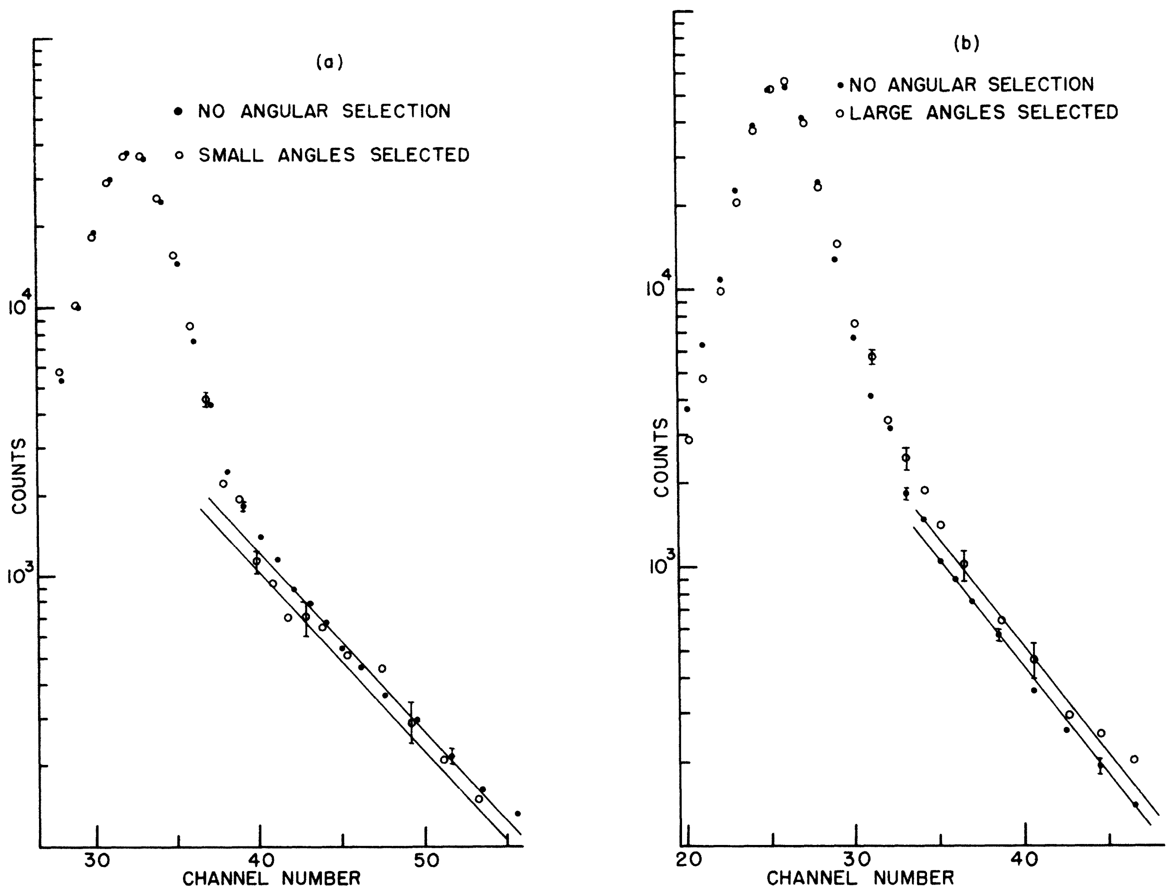

FIG. 2. Positron lifetime distributions for selected angles between annihilating gamma rays. Each selected curve is normalized to equal area with an unselected curve obtained simultaneously; vertical axis shows counts in unselected curve. Background counts have been subtracted. The error bars show the standard deviation in the statistics. (a) "Small angles." –Angle between gammas ranged from $\pi-0.002$ to $\pi+0.002$ rad. 2300 counts in selected peak (90-hour run). 5.7×10^{-10} sec per channel. (b) "Large angles." –Angle between gammas differs from π by more than 0.004 rad. 3400 counts in selected peak (114-hour run). 5.9×10^{-10} sec per channel.

The points on each selected-angle curve were multiplied by a constant factor to make the total number of counts equal to the total in the corresponding unselected curve. In Fig. 2(b) the slight shift between the peaks of the two curves could be caused by drifts in both the gain of the lifetime circuitry and the efficiency for counting triple coincidences. However, this shift is only about 0.1 channel, and does not affect the conclusion.

The most significant part of the curves is the beginning of the long-lived tail where the statistical error is not serious. The total number of counts in the tails is $11\,684\pm440$ (after normalization) for small angles, versus 12 137 for unselected angle in Fig. 2(a); and $20\,411\pm580$ (after normalization) for large angles, versus 16 458 for the corresponding unselected curve in Fig. 2(b). These results show that the long-lived component is less intense in the small-angle case than it is in the large-angle case. This is the expected result; it arises because the annihilations of singlet Ps, which has a short lifetime (1.25×10^{-10} sec), are included in the small-angle curve but not in the large-angle curve. The difference between the curves is quite small, because approximately 70% of each curve arises from annihilation of free positrons, which also have a short lifetime, indistinguishable from that of singlet Ps.

The triple-coincidence curves each contain more counts than the results reported by Fabri, Germagnoli, and Randone,[6] and the time axis extends further, but, in contrast to their results, the long-lived component seems to consist of a single exponential in all cases.

Improvements of the apparatus are underway. It is hoped that an accurate determination of the relative intensities of the long-lived component can be made. If sufficiently precise, this result could be used to deduce some features of the angular distribution of the annihilation radiation from triplet Ps. For example, the curves in Fig. 2(b) suggest that the angular distribution from the triplet Ps is broader than that from free positrons, because the difference between the selected and the unselected curves is greater than would be expected from the mere absence of the singlet Ps annihilation. Better statistics are needed to arrive at any definite conclusions. Such results might then be useful in explaining the interactions of triplet Ps in matter.

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[1]A. T. Stewart, Phys. Rev. 99, 594 (1955).

[2]L. A. Page and M. Heinberg, Phys. Rev. 102, 1545 (1956).

[3]R. E. Bell and R. L. Graham, Phys. Rev. 90, 644 (1953).

[4]S. Berko and F. L. Hereford, Rev. Mod. Phys. 28, 299 (1956).

[5]R. A. Ferrell, Rev. Mod. Phys. 28, 308 (1956).

[6]G. Fabri, E. Germagnoli, and G. Randone, Phys. Letters 3, 6 (1962).

[7]The angular limits are not exact, since they do not allow for the spread in the source of the annihilations, caused by penetration of positrons into the Teflon. This spread causes a smearing of the angular resolution function, but fewer than 10% of the events exceed these limits.

[8]See, for example, R. E. Bell and M. H. Jørgensen, Can. J. Phys. 38, 652 (1960).

[9]J. D. McGervey and V. F. Walters, Nucl. Instr. Methods 25, 219 (1964).

NEUTRON GROUPS FROM $O^{16}(\gamma, n)O^{15}$

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Yergin *et al.*[1] have recently published the spectrum of neutrons from the irradiation of O^{16} with 34-MeV bremsstrahlung. The spectrum was analyzed in terms of neutron groups to low-lying states of O^{15}, including remarkably strong branching to the even-parity states near 5.2-MeV excitation (a close doublet $J^{\Pi} = \frac{1}{2}^+$, $\frac{5}{2}^+$). This has important implications for the shell-model interpretation of O^{16}, and indeed might be regarded as a disaster for the single particle-hole description of the giant dipole resonance.[2] The simple shell model predicts that the giant dipole resonance of O^{16} decays only to the ground state ($J^{\Pi} = \frac{1}{2}^-$, $p_{1/2}$ hole) and the 6.2-MeV excited state ($J^{\Pi} = \frac{3}{2}^-$, $p_{3/2}$ hole) of O^{15} (or N^{15}).

The analysis of Yergin *et al.*[1] depends on a comparison of their bremsstrahlung-induced neutron *spectrum* (corrected for the bremsstrahlung intensity versus gamma-energy variation) with the *yield curve* (all neutron groups) of $O^{16}(\gamma, n)O^{15}$ as a function of gamma-ray energy.[3] Because there are few low excited states of O^{15} the two curves are very similar. See Fig. 1, which compares the *spectrum* of Yergin *et al.* with the $O^{16}(\gamma, n)O^{15}$ *yield curve* of Caldwell *et al.*[4] obtained with monochromatic γ rays. Neutrons to excited states of O^{15} appear in the *spectrum* at the low-energy end, $E_\gamma \lesssim 21$ MeV, since the gamma-ray energy is identified from the neutron energy. However, in this same energy region, the *yield curve* is a direct measurement of ground-state neutrons only, (γ, n_0), since the gamma energy is not sufficient to give neutrons to O^{15} excited states. On the other hand, at the high-energy end ($E_\gamma > 21$ MeV) the *spectrum* is almost pure (γ, n_0) due to the combined effect of small cross section and decreasing bremsstrahlung intensity for gamma rays of 5 or 6 MeV higher energy; while the *yield curve* above 21 MeV contains excited-state as well as ground-state neutrons. Yergin *et al.*[1] ignore the evidence available at the high-energy end and, in fact, their analysis is incompatible with the requirement that the *yield curve* should exceed the *spectrum* in this region.

The problem is illustrated in Fig. 1. It is noted that the resolution in the *yield curve* is somewhat poorer than in the *spectrum* particularly at the low-energy end.[3,5] The two curves have been roughly normalized at the 22.2-MeV peak. This is not entirely arbitrary. At 22.2-MeV excitation in O^{16} there is only 0.3 MeV available for neutron decay to the 6.2-MeV state of O^{15}, so the excited-state neutrons probably do not make a big contribution in this region of the *yield curve*. The assumption that the *spectrum* at 22.2 MeV is purely (γ, n_0), which was justified