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Parapositronium lifetime

A. P. PATRO and P. SEN

Saha Institute of Nuclear Physics, Calcutta-9, India

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Abstract. Parapositronium lifetime has been measured in toluene and fused quartz samples in a time distribution measurement experiment. The lifetime and intensity of the parapositronium components are τ_0 $(0{\cdot}115 \pm 0{\cdot}015)$ ns with I_0 $(15 \pm 6)\%$ for toluene and τ_0 $(0{\cdot}126 \pm 0{\cdot}010)$ ns with I_0 $(14 \pm 6)\%$ for fused quartz.

1. Introduction

The positron lifetime distribution in condensed matter is a complex one. Generally it consists of a long component of the order of a few nanoseconds due to the decay of orthopositronium by a pick-off process and a short component, a few times one tenth of a nanosecond due to an admixture of parapositronium and free annihilation. Because of the limited resolution of the time measuring systems, the lifetime of parapositronium has not been obtained previously from time distribution measurements.

Bisi *et al.* (1962) have measured the lifetime of parapositronium $0{\cdot}123 \pm 0{\cdot}008$ ns and $0{\cdot}121 \pm 0{\cdot}011$ ns respectively, for teflon and lucite, by measuring the magnetic quenching of the positronium decay and using the theoretical value $(8{\cdot}3462 \times 10^{-4}$ eV) of the ground state splitting. Recently Theriot *et al.* (1970) have redetermined, more accurately, the fine structure interval of the ground state of positronium. Their experiments yielded the parapositronium annihilation rate $0{\cdot}799 \pm 0{\cdot}011 \times 10^{10}$ s^{-1} or parapositronium lifetime $0{\cdot}125 \pm 0{\cdot}002$ ns.

With considerable improvement in the lifetime measuring system it was felt that a direct determination of the parapositronium lifetime was possible and in what follows we present the results of measurements of the parapositronium lifetime.

2. Experimental technique

A conventional two detector set up with a time-to-amplitude converter and a multichannel analyser has been used in the measurements of positron lifetimes. Pilot B phosphors and XP 1021 photomultipliers along with an energy compensator (Sen and Patro 1968a) and a differential time-to-amplitude converter (Sen and Patro 1968b) have been employed to get the improved time resolution spectrum. For positronium lifetime studies a prompt resolution of approximately 180 ps (fwhm) with slopes of approximately 35 ps was achieved (see figure 1). This prompt resolution curve was obtained with a ^{60}Co source using the same settings of the energy windows as with a ^{22}Na source. This figure of 180 ps is quite close to the theoretical value of 170 ps (fwhm) for positron lifetime experiments given by Ogata and Tao (1969). Details of the performance of the complete timing system have been published elsewhere (Sen and Patro 1970).

The positron source used was ^{22}Na deposited and sandwiched between two 0·2 mm thick nickel foils. The analysis of the time distribution curve was done by a least square fitting of each component and using the peeling off method by subtracting the longer components one by one as done by Bertolaccini *et al.* (1966). The intensities

were determined by using the method of Green and Bell (1957) taking into account the correction factor due to the finite width of the prompt resolution curve for the shorter components.

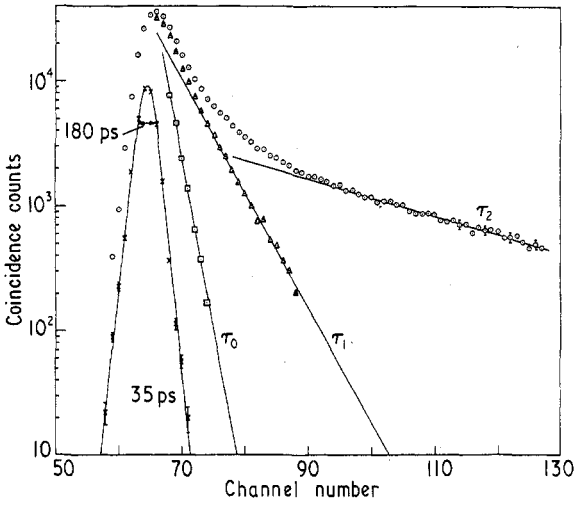

Figure 1. Time distribution spectrum obtained with toluene sample. 1 channel = $0{\cdot}69 \times 10^{-10}$ s. × prompt curve taken with a ^{60}Co source.

3. Results and discussions

The best sample for observing the parapositronium lifetime is one in which orthopositronium is formed with large intensity. We choose for this purpose toluene and fused quartz as the samples. Figure 1 shows the time distribution spectrum of positrons in toluene. The time spectrum can be resolved into three components as shown in the figure. τ_2 ($2{\cdot}00 \pm 0{\cdot}05$ ns) component with I_2 (33 ± 1)% due to the pick-off process of orthopositronium, τ_1 ($0{\cdot}320 \pm 0{\cdot}020$) ns component with I_1 (52 ± 5)% due to free annihilation and lastly a short lifetime τ_0 ($0{\cdot}115 \pm 0{\cdot}015$) ns component with I_0 (15 ± 6)% due to parapositronium decay. The lifetime and intensity values observed in the fused quartz sample are as follows: τ_2 ($1{\cdot}26 \pm 0{\cdot}02$) ns with I_2 (30 ± 1)%, τ_1 ($0{\cdot}330 \pm 0{\cdot}020$) ns with I_1 (56 ± 5)% and τ_0 ($0{\cdot}126 \pm 0{\cdot}010$) ns with I_0 (14 ± 6)%. The intensity of the parapositronium to orthopositronium should be in the ratio of 1:3 because of the statistical weight factor of the triplet over singlet. At least three to four independent runs were taken with toluene and fused quartz samples and each time the prompt curve was taken with a ^{60}Co source before and after the experimental runs. There was negligible shift in the two prompt curves. The lifetimes and intensities obtained for the parapositronium in all the runs were the same within errors. To be sure that the time measuring system was alright, a run was taken using the same source, with a sample of CCl_4 where no orthopositronium has been observed (Sen and Patro 1969) and hence one should not see any parapositronium also. The CCl_4 data (figure 2) shows clearly a single lifetime of ($0{\cdot}260 \pm 0{\cdot}006$) ns.

The presence of parapositronium was first seen in the work of Bertolaccini *et al.* (1966) in water, though a definite parapositronium lifetime value was not given. Because of the improved time resolution and the fact that we chose toluene and fused quartz as the samples, in which a large amount of positronium is formed, we could

determine the lifetime and intensity of the parapositronium. The lifetime is in agreement within experimental errors with that measured by Bisi *et al.* (1962) and Theriot *et al.* (1970) and the predicted value of 0·125 ns. The intensity ratios of parapositronium to orthopositronium are also in the ratio of 1:3 within errors.

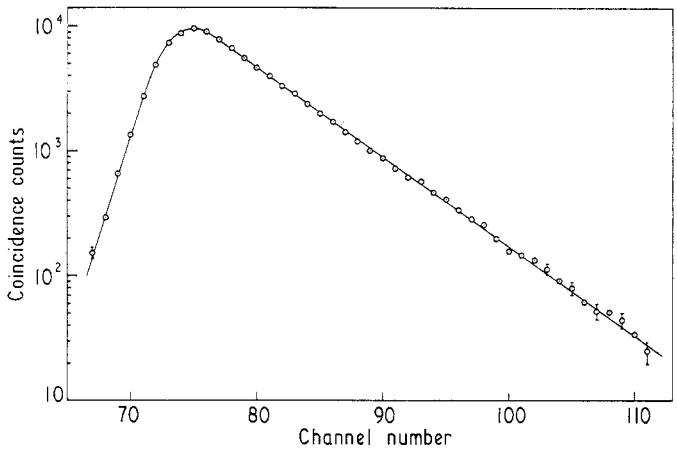

Figure 2. Time distribution spectrum obtained with CCl_4 sample.
1 channel = $0{\cdot}43 \times 10^{-10}$ s.

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