

Proceedings of the 24th Polish Seminar on Positron Annihilation, Sobótka-Górka 1992

## DISTORTION OF THE POSITRON LIFETIME SPECTRA IN BaF<sub>2</sub> SPECTROMETERS

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High efficiency of BaF<sub>2</sub> scintillators creates the risk of distortion of the positron lifetime distributions due to summing and backscattering. In the 180° geometry it leads to the appearance of a spurious shortlived component.

PACS numbers: 06.50.Dc, 07.85.+n

An essential improvement of nuclear lifetime spectrometry in the subnanosecond range was achieved in 1983, when the new scintillators, BaF<sub>2</sub> single crystals, were proposed by Laval and Moszynski [1]. The main advantage of BaF<sub>2</sub> comparing to the traditional plastic scintillators, consists in:

- very short fluorescence time enabling to reduce the instrumental time resolution further,
- high efficiency of the gamma ray registration owing to the high  $Z$  of barium; the energy spectra contain well-defined full energy peaks, no need to set the windows on the continuous Compton spectrum.

High efficiency greatly increased the coincidence counting rate and shortened the time of measurement. The high efficiency, being an essential advantage of the new scintillator, can be the source of spectrum distortions in one particular case: the positron lifetime measurements. That is due to the summing effects.

In the positron lifetime measurements the START pulse is produced by 1274 keV <sup>22</sup>Na gamma ray, STOP pulse — by one of two annihilation quanta. Traditional geometry in these measurements is face-to-face; two scintillators are usually as close to each other as possible, and the source-sample sandwich is placed between them. When the solid angle subtended by the "start" scintillator is close to  $2\pi$ , one of annihilation quanta must enter that scintillator. The majority of positrons in a solid does not survive 1 ns, i.e. they live shorter than the risetime of PM output pulse, thus 1274 keV and annihilation quanta sum perfectly. Total intensity of sum events relative to the "normal" ones is roughly close to the 511 keV registration efficiency.

In the coincidence spectra and "linear geometry" the summing effect remains unchanged, independent on counter spacing: if the STOP counter is actuated by 511 keV quantum, the other constituent of annihilation pair certainly enters the START counter.

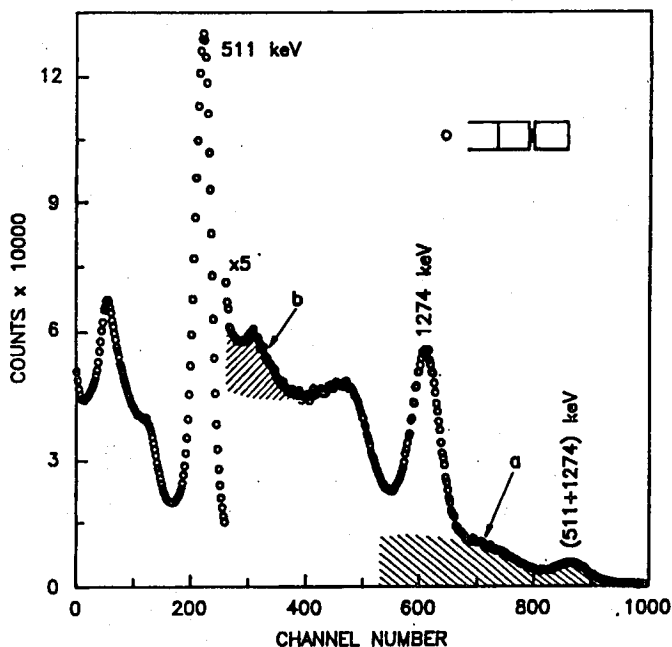


Fig. 1. A single spectrum of the radiation from the sample-source sandwich registered by  $\text{BaF}_2$  counter. Hatched areas denote the high energy parts of sum spectra: (a)  $(1274+511)$  keV, (b)  $511$  keV + backscattering.

The energy spectrum registered in  $\text{BaF}_2$  spectrometer is shown in Fig. 1; the sum part over  $1274$  keV is well visible. In the lifetime measurements the energy windows are set at the  $1274$  keV and  $511$  keV full energy (FE) peaks. In the linear geometry the spectrometer registers several kinds of time intervals:

- (1)  $1274$  keV FE– $511$  keV FE, the undistorted time intervals, “good events”;
- (2) (Compton electron from  $1274$  keV +  $511$  keV)– $511$  keV FE. Scattering of the  $1274$  keV gamma ray in the scintillator at the angle exceeding  $66^\circ$  gives the recoil electron with the energy sufficient, when combined with the energy deposited by the annihilation photon, to trigger the START;
- (3) (Compton electron from  $1274$  keV +  $511$  keV)–( $511$  keV + backscattered gamma ray). If the Compton effect in the START counter scatters the gamma ray backwards, this last enters the STOP counter bringing here the energy of about  $210$  keV.

Other combinations are also possible, e.g. with backscattering the  $511$  keV quanta in the start counter or outside it (in the surrounding material).

Summing distorts the measured time intervals (the effect was observed by Dannefaer [2] in plastic scintillators and broad windows still in 1981). It follows from the operation principle of constant fraction discriminators (CFD), producing

the timing signal at the moment when the bipolar pulse crosses zero. When the pulse is a sum of two signals, the delayed component of the sum delays the moment of zero crossing. It can be seen in Fig. 2.

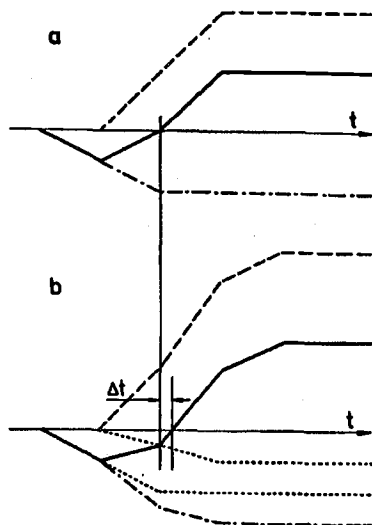


Fig. 2. Formation of bipolar pulse in CF discriminator; (a) normal pulse, (b) sum pulse. Dots — two summing pulses shifted in time, dash-dot — sum pulse, broken line — inverted and delayed pulse; continuous line — resultant bipolar pulse. Note the delay  $\Delta t$  of zero crossing in case (b).

In the case (2) the stop signal is produced at proper time, while the start signal is delayed roughly proportionally to the lifetime of a positron. The lifetime spectrum contains an excess of short intervals; “good events” (case 1) produce one exponential component, the “simple summing events” (case 2) form an additional spurious component of smaller lifetime.

In the case (3) (“summing-backscattering events”) both start and stop signals are shifted in time. Although the distortion of time spectrum in that case is more complex, generally one observes also the appearance of shortlived distribution.

The distortion of time spectrum can be demonstrated using the samples in which a single, relatively longlived, component exists (no positronium formation). The measurements described below were performed with solid polycrystalline azulene [3]. The spectra recorded in a summing-safe geometry, i.e. with the sample-source sandwich placed out of the volume between the scintillators (Fig. 3), show that one exponential component is present, its lifetime is 326 ps (possible other component does not exceed 0.35% of total intensity).

The spectrometer used in the measurements reported in this paper was a standard one, with  $BaF_2$  crystals  $\phi = 25$  mm,  $h = 12$  mm. Typical fraction in CFD was 0.1. The spectra were analysed using the RESOLUTION program [4],

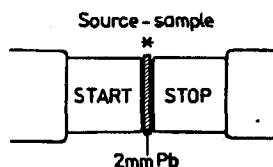


Fig. 3. "Summing-safe" geometry in positron lifetime measurements.

assuming the prompt curve as a sum of two or, if necessary, three gaussians. To avoid the problems with the source envelope correction, the  $^{22}\text{NaCl}$  active solution was deposited directly at one sample and evaporated.

TABLE  
Fitted parameters of the positron lifetime spectra in azulene, registered in the linear geometry.

Filters	$\tau_1$ [ps]	$I_1$ [%]	$\tau_2$ [ps]	$I_2$ [%]	Variance
No filters	$230 \pm 10$	$31.0 \pm 4.3$	$346 \pm 4$	$69.0 \pm 4.3$	1.56
6 mm Pb in front of START	$194 \pm 42$	$8.3 \pm 3.2$	$334 \pm 3$	$91.7 \pm 3.2$	1.14

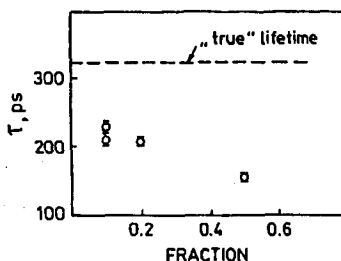


Fig. 4. The dependence of lifetimes of the spurious component registered in the linear geometry on the fraction in CF discriminator in the start channel. Two values of  $\tau$  for  $f = 0.1$  were obtained at various settings of voltages in CFD.

The result of analysis of the azulene spectrum registered in the "linear" face-to-face geometry is shown in Table. The intensity of the spurious component measured in various runs is 25% or more. The delay of zero crossing caused by summing should depend on the fraction  $f$ . The smaller is the fraction, the smaller is the deviation of the "lifetime" of the false component from that of the real one. This effect is illustrated in Fig. 4.

In the case of azulene or other organic media, where the free annihilation lifetime is of the order of 300 ps, the false component is easily separable from the

proper one. With shortening the lifetimes, splitting the spectrum into these two components becomes much more difficult. The measurements with the samples in the form of nickel or palladium bars have shown that at the statistics of  $2.5 \times 10^6$  coincidences per spectrum still one component is seen. The only effect observed consists in shortening of the fitted lifetime by several picoseconds comparing to the measurements in summing-safe, triangular geometry.

Certain reduction of the spurious component can be achieved by placing about 6 mm of Pb in front of START counter. Such a filter absorbs practically all backscattered quanta, and also reduces the relative intensity of unwanted 511 keV line in the start counter. However, this procedure strongly diminishes the total coincidence counting rate and, moreover, it reduces only, does not eliminate the spurious component. Another "partial solution" can be the application of conical scintillators.

In conclusion one can state that the linear, 180° geometry is not acceptable in the positron lifetime measurements with BaF<sub>2</sub> scintillators. The source must be placed in such a fashion that only one of the pair of annihilation quanta is able to enter the scintillators.

The authors wish to thank Dr Ewa Dębowska who supplied us with pure defectless metal samples.

### References

- [1] M. Laval, M. Moszynski, R. Allemand, E. Cormoreche, P. Guignot, R. Ordu, J. Vacher, *Nucl. Instrum. Methods Phys. Res.* **206**, 169 (1983).
- [2] S. Dannefaer, *Appl. Phys. A* **26**, 255 (1981).
- [3] T. Goworek, C. Rybka, R. Wasiewicz, J. Wawryszczuk, *Phys. Status. Solidi B* **113**, K9 (1982).
- [4] P. Kirkegaard, N.J. Pedersen, M. Eldrup, *Positron Annihilation*, Eds. L. Dorikens-Vanpraet, M. Dorikens, D. Segers, World Scientific, Singapore 1989, p. 642.