Angular correlation of double internal bremsstrahlung in electron capture

B. A. Logan
Physics Department, University of Ottawa, Ottawa, Ontario, Canada

A. Ljubičić and K. Pisk
Institute Rudjer Bošković, Zagreb, Yugoslavia

Z. Roller-Ivanović
Institute for Natural Sciences and Mathematics, University of Rijeka, Rijeka, Yugoslavia

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The angular correlation of photons emitted in double internal bremsstrahlung associated with electron capture has been investigated. A ^{37}Ar source was studied and the correlation investigated for relative emission angles which ranged from 60 to 140°. The results are in reasonable agreement with an existing theoretical prediction.

[RADIOACTIVITY ^{37}Ar: measured angular correlation of DIB.]

Although double internal bremsstrahlung (DIB) was observed several years ago in β decay,[1-3] the first observation of DIB in electron capture was made only recently. The electron capture decay of ^{37}Ar was studied and measurements were limited to coincident photons emitted at 90° with respect to each other, with sum energies ranging from 210 to 810 keV, the transition energy of the ^{37}Ar decay. A rough estimate of the total relative probability of DIB, with respect to that of internal bremsstrahlung (IB), was made by assuming isotropic photon emission, even though it was realized that this assumption was not expected to be valid.

More recently we have made some theoretical estimates of DIB in electron capture and we were able to predict the energy distribution and angular correlation of the emitted photons.[5,6] These predictions are in good agreement with the experimental data available for the relative emission angle of 90°. In order to extend the data available for DIB in electron capture and to check the validity of our theoretical predictions more thoroughly we have made an experimental investigation of the angular correlation of coincident photons emitted in the decay of ^{37}Ar.

The experimental arrangement involved a 30 cm $\times$30 cm$\times$10 cm lead block with a central hole for mounting the ^{37}Ar source. Photons from the source were detected in two 5 cm$\times$5 cm diam NaI(Tl) counters placed inside various inserts in the lead blocks. In principle the arrangement allowed measurements for relative emission angles ranging from 50° to 180°. The source to NaI(Tl) crystal face distances varied from 7.5 to 11 cm for the angular range investigated. ^{37}Ar sources were obtained from Oak Ridge National Laboratory with initial activities of 1.3 → 1.5 mCi and were only used when the activity had decayed to 0.8 mCi. Sources were useful for activity levels above about 0.25 mCi. For smaller values of the relative emission angle θ ($\theta \leq 120°$), 5 cm^3 glass ampoules were used, but for θ values greater than this a 1 cm^3 glass ampoule was used. For measurements at $\theta > 120°$, extra lead shielding was placed around the source to prevent Compton scattering between the detectors of the more intense IB radiation.

A conventional time-to-amplitude converter and single-channel-analyzer arrangement defined coincidences between the detectors. The full width at half maximum of the timing system was about 15 nsec but an effective resolving time of 60 nsec was used in the measurements. After the coincidence requirement, pulses from the two detectors were digitized and recorded in a PDP-9 computer operating with a 64$\times$64 channel dual-parameter pulse-height-analysis system. Spectra in each detector were recorded for the energy range of 100 – 840 keV. No corrections were made for Compton events in the two detectors. This is reasonable as the spectra are dominated by the contributions from lower-energy photons, in regions where the response of the NaI(Tl) crystals is dominated by the photoelectric effect. The same approximation was used in the earlier measurement[4] and in the observations of DIB in β decay.[1-3]

At each value of θ three measurements were necessary: $N_c(E,\theta)$, the coincidence counting rate for photon pairs with a sum energy E; $N_R(E,\theta)$, the random counting rate; and $N_B(E,\theta)$, the background counting rate as determined by removing the source. $N_{DIB}(E,\theta)$, the counting rate for

TABLE I. The experimental counting rates and the theoretical predictions.

Relative angle of emission θ (deg)	Experimental counting rate (counts/h)	Theoretical value
60	3.33 ± 0.37	2.89
70	2.83 ± 0.45	2.89
90	2.93 ± 0.21	2.93
120	2.46 ± 0.35	3.82
130	3.66 ± 0.51	4.38
140	3.54 ± 0.69	4.84

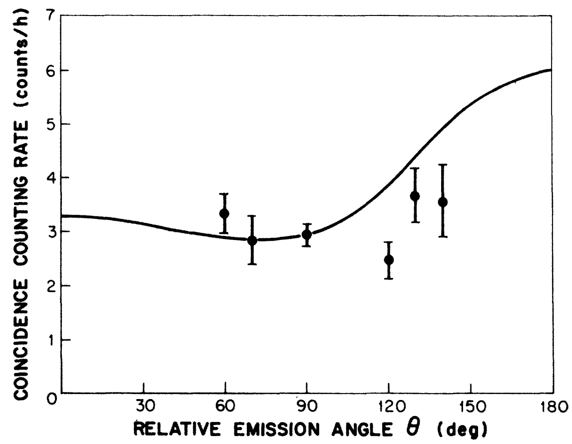

FIG. 1. The theoretical distribution and experimental results.

double internal bremsstrahlung events with a sum energy E and a relative emission angle θ, was obtained from

$$N_{\mathrm{DIB}}(E,\theta) = N_c(E,\theta) - N_R(E,\theta) - N_B(E,\theta).$$

In practice several measurements of $N_{\mathrm{DIB}}(E,\theta)$ were made at each angle.

For $\theta \leq 90°$ it was possible to check the contributions produced by Compton scattering between the detectors by blocking the entrance to one counter with a tungsten plug. In all cases the counting rate observed was, within the statistical accuracy attained, no greater than the corresponding $N_B(E,\theta)$ value. At larger values of θ this procedure was unsuitable as the tungsten plug would absorb photons which may have otherwise Compton scattered between the detectors. However, at large θ values the source to counter distances were increased and supplementary shielding was placed around the source. At least 1 cm of lead path was presented to any possible photon trajectories between the detectors and this was adequate to absorb the low-energy photons associated with large angle scattering of the IB radiation.

Measurements were made with three ^{37}Ar sources, each source being used for 2 → 3 months. Typical $N_{\mathrm{DIB}}(E,\theta)$ values ranged from 0.3 → 3 counts /h for summations over sum energies in the range of 210 – 810 keV. Data were obtained at θ values ranging from 60° to 140°. At all angles the source strength, and any possible changes due to the counters subtending different solid angles at the source, were monitored by frequent measurements of the IB spectra in each detector. Except for the larger angles where the source to counter distances were varied deliberately the geometrical corrections were negligible.

Although the theory is capable of giving very detailed predictions of the energy distribution and angular correlation of the two photons, the statistical accuracy of the experimental data, even after a continual data accumulation for about eight months, is limited and a realistic comparison is only possible if both the theoretical predictions and the experimental data are summed over the energy range of 210 – 810 keV. The summed experimental counting rates given in Table I are normalized to correct for variations in the strengths of the different sources, for radioactive decay, and for variations in the solid angle at different θ values. The uncertainties are statistical standard deviations. The theoretical values obtained by summing over the appropriate energy range are also given in Table I. The theoretical correlation and experimental data are also shown in Fig. 1.

In the angular region studied the experimental data are in reasonable agreement with the theoretical predictions. Our results show that the angular correlation does not vary significantly over the reasonably wide angular region studied. This suggests that the rough estimate of 6×10^{-4} for the relative probability of DIB with respect to that of IB in electron capture, which we made previously assuming isotropic emission, is reasonably accurate.

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