Gamma Angular Correlation in Positronium

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The purpose of this study is to measure fast electronics using angular correlations of the radioactive element isotopes Na^{22} and Co^{60}. The annihilation of Na^{22} and the nuclear decay of Co^{60} creates gamma ray emissions, which are detected by two organic scintillators at defined angles between 90°and 270°. Both isotope sources showed the largest rate of coincidences when the two counters were back to back. Counts were far lower at angles further away from 180°and showed a distribution decrease with a peak at 180°.

Background

Positron Emission Tomography (PET) is a method of studying how organs and tissues are working using positronium annihilation [1]. Rather than X-rays or magnetic fields, PET scans rely on use of positron isotope injection into the body. The benefits of PET scans are the ability to pick up very small areas of activity, and differentiating scar tissue [2].

Apparatus

The apparatus includes two detectors equipped with plastic scintillators and NaI(T1) seen in figure 7. The detectors are placed at two ends with a swivel with an adjustable angle. One detector remained stationary (static) while the other detector (dynamic) angle was changed in 5° -10° increments. This angle is manipulated throughout the study to measure the angular correlation of two resultant photons. The radioactive source is placed between the two detectors and remains for the full data collection duration. Instruments used to collect data include a scaler, delay box, discriminator, and coincidence unit. The fast electronic system is shown in figure 6, and portrays the two detectors leading to the scaler that counts photon coincidences.

Procedure

Table I. *Initial Apparatus Parameters*

Radioactive Isotope	Separation Distance (cm)	Static Voltage (V)	Dynamic Voltage (V)	Time Interval (sec.)
Na^{22}	4	1500	1580	400
Na^{22}	10	1500	1580	400
Na^{22}	15	1500	1580	400
Co^{60}	4	1510	1500	400

For the Na^{22} source, the collected angles included a range from 90° to 270°. Conversely, the Co^{60} source required a range from 90° to 180°. The angles around 180°were counted in increments of 5°, but 10°elsewhere. Initial parameters for detection are included in table 1. Gamma ray emissions for the two element isotopes are generated in unique situations. Na^{22} emits a pair of gamma rays by the annihilation of positronium directly opposite directions at 180°. Unlike this mechanism, Co^{60} emits a pair of gamma rays via nuclear decay by beta decay to Ni^{60} [3].

$$Rate_{accidental} = R_1 R_2 \Delta t \tag{1}$$

The rate of accidentals is included in equation 1. The rate of accidentals were not subtracted in this study. Accidentals were muted with setup procedures by limiting the amount of double pulsing, and stacking pulse signatures in time one after the other.

Calculation of Results and Errors

Results show a Gaussian trend from the Na^{22} isotope at all separation distances, portraying a count peak at 180°and diminishing from there. Co^{60} also decreases at angles less than 180°. Moving the detectors further away from the source proved that counts decrease as separation distance increases. Figure 5 represents the theoretical overlapped area of the FWHM values for the three separation distances of the given initial parameters.

Na^{22} Isotope Results

Figures 1, 2, and 3 show the angular correlation of Na^{22} for three varying separation distances of the detector to the source. The 4 cm separation had a mean of 190.17 counts with a σ of 12.88±0.41. The 10 cm separation had 180.14 with a σ of 6.53±0.29. Finally, the 15 cm separation had 176.43 counts, with a σ of 4.30±0.19. Mean values were calculated using a least squares fit on the Gaussian fit. Three full width half maximum (FWHM) values for the corresponding separation distances were derived from the count rates along with the angles. The FWHM calculated using the normalized background as the Gaussian fit flattened were 45.23° (4 cm), 17.03° (10 cm), and 10.11° (15 cm).

Co^{60} Isotope Results

Again using a least squares fit on figure 4, the coefficients consisted of, $a_1 = 0.09° \pm 0.097°$ and $a_2 = -0.04° \pm 0.10°$. Despite slight deviations, the results are consistent with theoretical expectations given the low statistics.

Discussion

Na^{22} Isotope

Comparing to the theoretical value of the FWHM of 47.52°in configuration with $4\,\sigma$ separation, the σ was 17.81±0.52. For 10 cm and 15 cm, the were 7.25±0.26 and 4.30±0.19 respectively. Figures 1, 2, and 3 show the measured element sources, but the location of the peaks are slightly off of 180° most likely from misalignment of the apparatus. In addition, the background counts are above zero. The major cause is due to the additional annihilation photon emitted from the source in coincidence with a 1.275 MeV gamma ray. A minor factor of fluctuation is attributed to Possion fluctuation, as all counting angles were never zero.

Co^{60} Isotope

Fits to the Co^{60} data gave coefficients of $a_1 = 0.09 \pm 0.097$ and $a_2 = -0.04 \pm 0.10$. These two values were within $\pm 1\,\sigma$ of the theoretical expectations $a_1 = 0.125$ and $a_2 = 0.042$ [3]. The study intended to use lead shields to isolate the radioactive source, but seemed to add a significant amount of background. The background was attributed to the Compton Scattering as the detectors were not completely enclosed by the lead shields, and the shields may have added additional reflections due to the separation distance versus the decay time. The separation distance was reduced to 4 cm, providing time for scattered rays to hit the two detectors, ultimately resulting in copious detection rates.

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[3] Melissinos, A., & Napolitano, J. (2003). Experiments in Modern Physics, Second Edition (2nd Edition ed.). New York: Academic Press.

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Figure Page

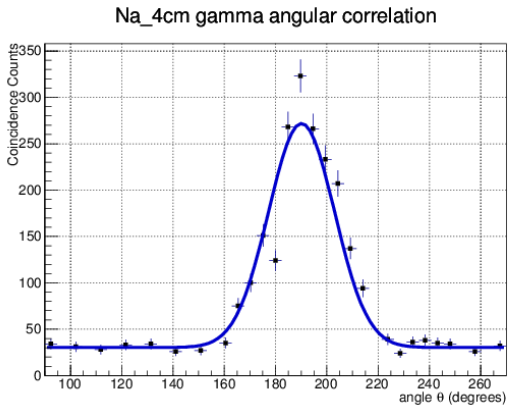

Figure 1. *Angular correlation of two photons from Na^{22} at 4 cm separation.*

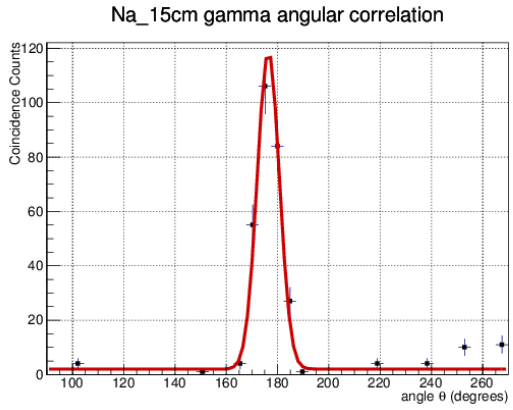

Figure 3. *Angular correlation of Na^{22} at 15 cm separation.*

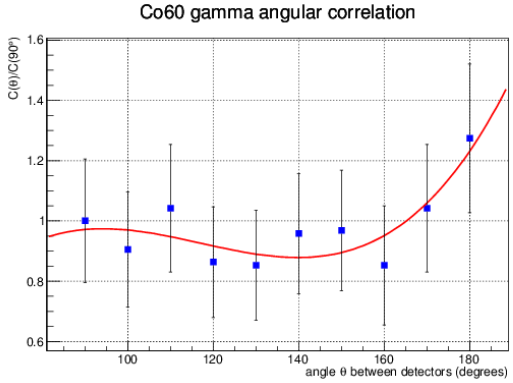

Figure 4. *Angular correlation of the γ-γ pairs from Co^{60}.*

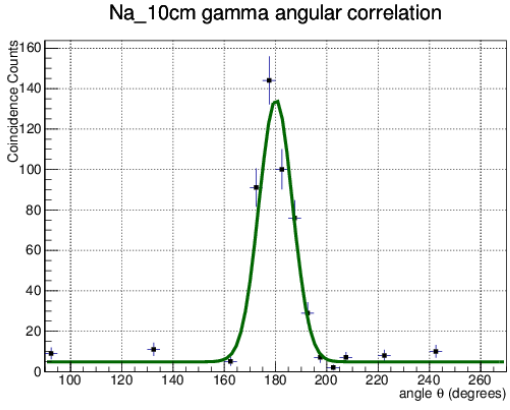

Figure 2. *Angular correlation of Na^{22} at 10 cm separation.*

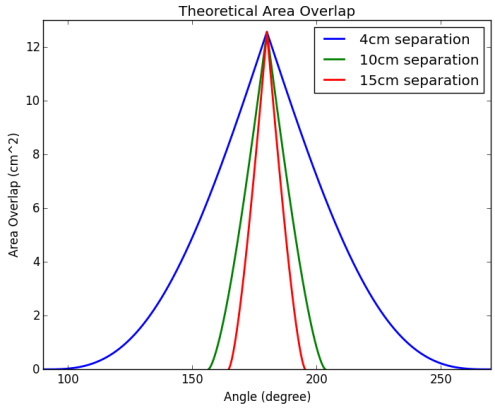

Figure 5. *A theoretical area overlap for the full width half maximum values for all three separation distances.*

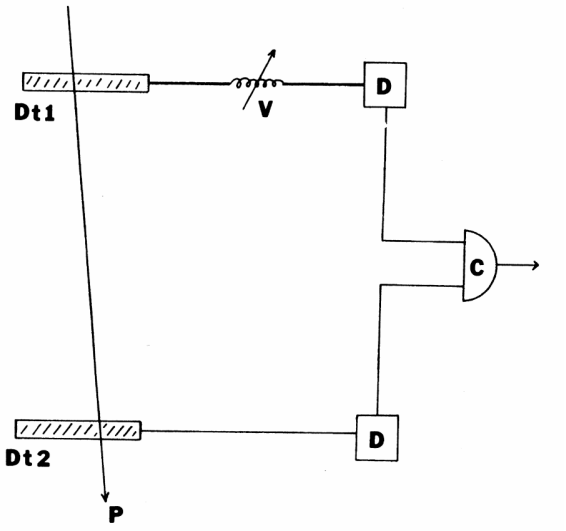

Figure 6. *The logic of the detector system. The photons are detected by the detectors (Dt1,Dt2), the signal is sent to the discriminators (D), and are then counted by the scaler (C) [4].*

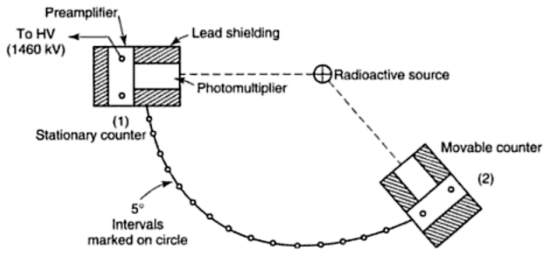

Figure 7. *The detector apparatus including the two organic scintillator detectors. The angle is adjustable and was changed by a set amount of degrees to show angular correlations. [3].*