Gamma Angular Correlation in Positronium

Carly Hall
Dept. of Physics
University of Hawai'i at Manoa
carlyh6@hawaii.edu
September 27, 2016

Abstract

In this lab, we used three data sets of the angular correlation of ^{22}Na from three different distances from the source to calibrate the apparatus shown in Figure 4 in order to find the angular correlation of ^{60}Co and find the area of overlap of the two photomultipliers.

I. Introduction

In order to find the correlating angle in gamma rays emitted from any active sample (^{22}Na and ^{60}Co in this study) it must first be understood where the gamma rays come from. The decay scheme of both samples are shown in Figure 1 and Figure 2 respectively bellow.

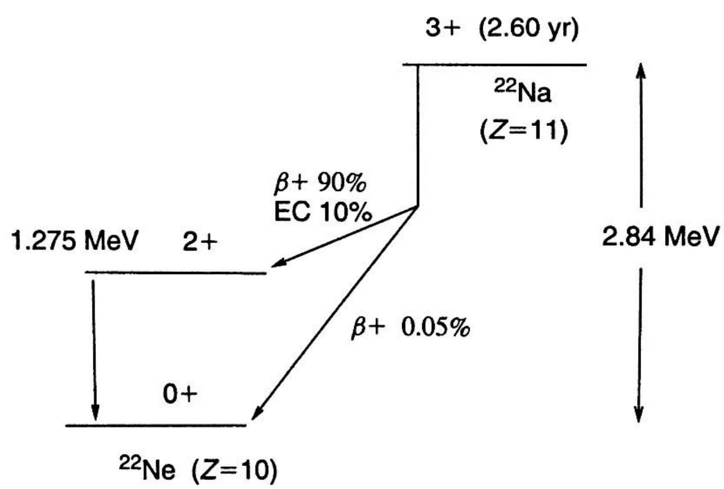

Figure 1. The decay scheme of Sodium 22 into Neon 22 by emitting two gamma rays and with a low probability of a third photon being emitted. [1]

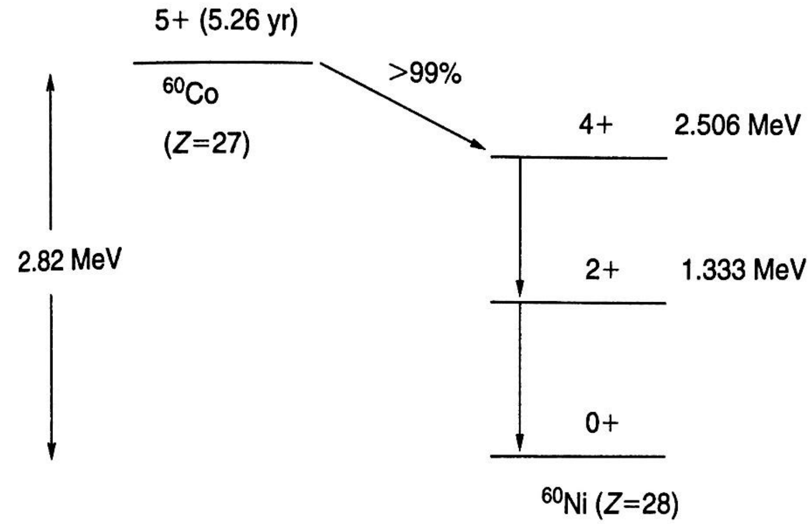

Figure 2. The decay of Cobalt 60 into Nickle 60 by emitting three gamma rays. [1]

When observing the Sodium 22 sample, it is known that because of conservation of energy, the two gamma rays are emitted at 180˚ degrees from each other as shown in Figure 3 bellow

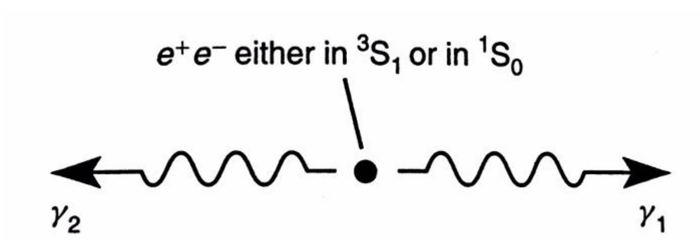

Figure 3: Capture of a positron by an electron to form Positronium and the subsequent annihilation of the positron-electron pair into two gamma rays. [1]

The Cobalt 60 sample goes through the same process though the annihilation is not as simple because it releases three gamma rays. They both follow Equation 1 bellow with their individual correlation results.

$$C(\theta) = \delta(\pi - \theta) \quad [1]$$

We are able to detect the correlating angles using the apparatus shown in Figure 4 bellow connected in a circuit with an oscilloscope, discriminator, delay box, and coincidence unit in that order.

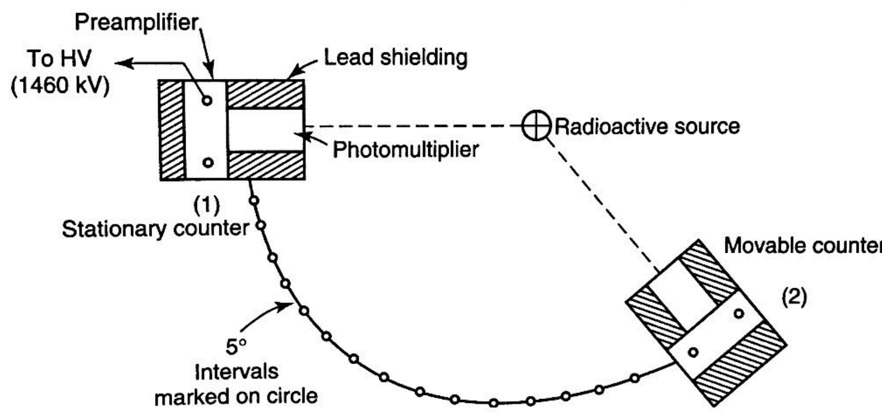

Figure 4: Apparatus that can be used for angular correlation measurements. Two scintillation crystals mounted on photomultipliers are protected by appropriate lead shielding. One counter assembly is fixed, whereas the other can be rotated about the position of the source. [1]

The first data taken was a delay curve of the Sodium 22 sample to find the resolving time of the circuit. Then the angular correlation was measured at three different distances from the Sodium 22 sample and one distance from the Cobalt 60 sample with ground noise accounted for. The area of overlap was then calculated and plotted as a continuous function.

II. Calculations

After taking data on the three angular correlations at different distance from the Sodium 22 sample, the curves were fitted to the Gaussian function [2] bellow

$$f(x) = \frac{c}{\sigma\sqrt{2*\pi}} * e^{\frac{-(x-x_0)^2}{2*\sigma^2}} + d \qquad [2]$$

The data for the Cobalt 60 sample was fit to a simplified cosine function [1]

$$\alpha(\theta) = 1 + \mathrm{a} * \cos^2(\theta) \quad [3]$$

The area function of the area of overlap of the two photomultipliers was calculated from the geometry of the apparatus and found to be [3]

$$area = 2R^2[\mathrm{acos}(|x|) - |x| * \sqrt{1 - x^2}] \quad [4]$$

Where

$$x = L * \sin(\theta)/4R$$

L and R being dimensions of the apparatus defined in the Data section.

From the angular correlation curves, we found the full-width half-maximum by taking have of f(x)=0, and finding the points of intersection.

III. Data

Table 1: Specifications of the discriminator

Discrimina	50 mV
width	25 nsec

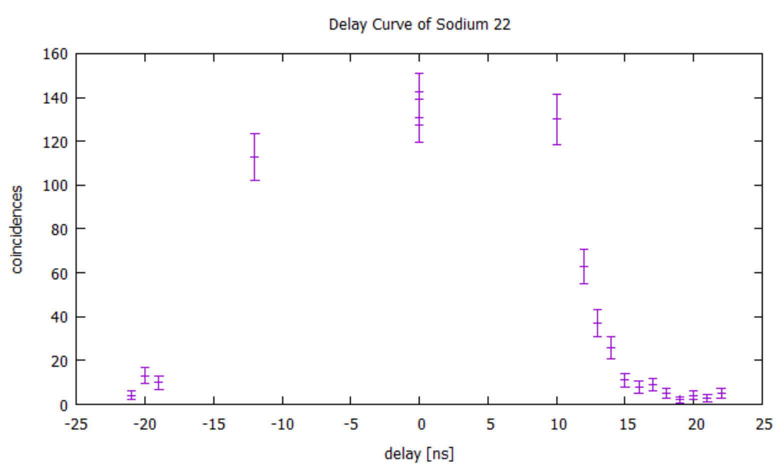

Figure 5: The delay curve of the Sodium 22 sample.

The width of this curve was found to be 25 Nanoseconds.

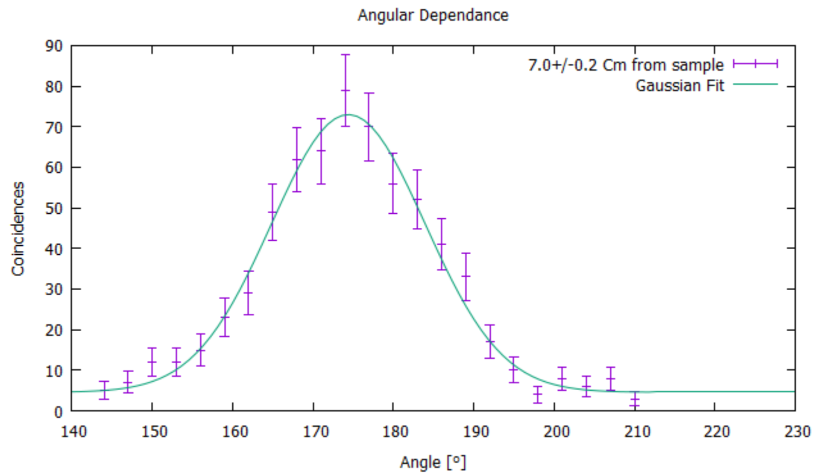

Figure 6: the angular dependence of Sodium 22 with photomultipliers 7 cm from sample with the background noise set at 5 coincidences fit to Equation [2].

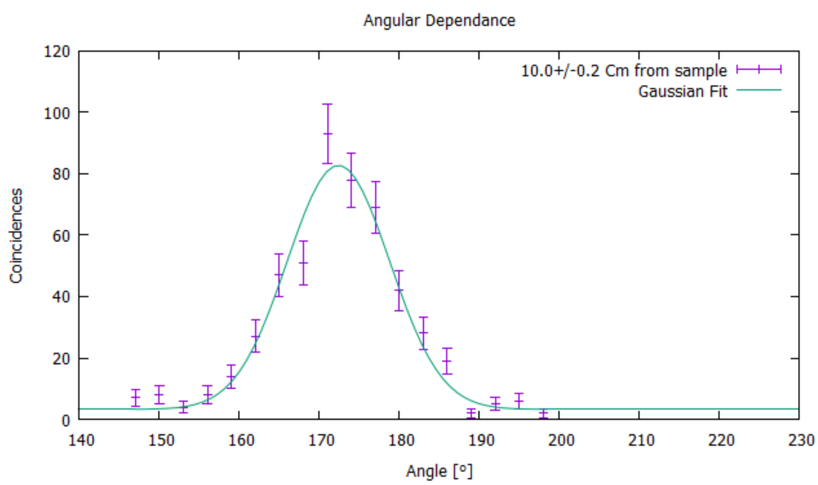

Figure 7: the angular dependence of Sodium 22 with the photomultipliers 10 cm from the sample with the background noise set at 7 coincidences fit to Equation [2].

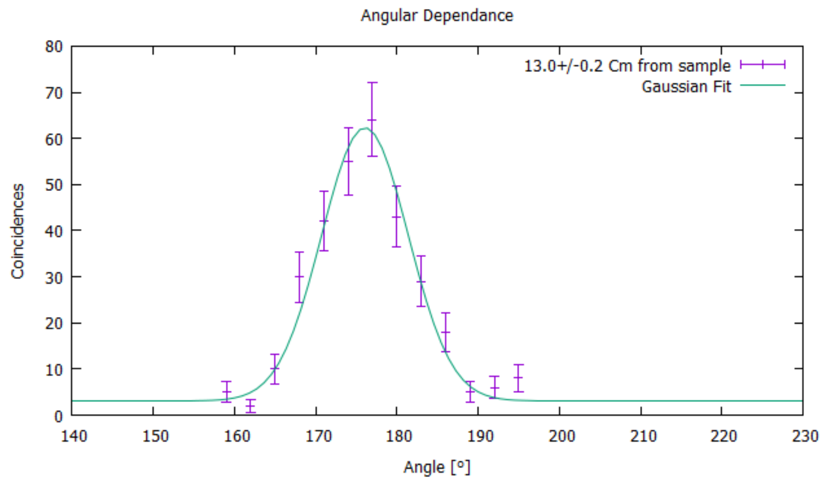

Figure 8: The angular correlation of Sodium 22 with the photomultipliers 13 cm from the sample with the background noise set at 5 coincidences fit to Equation [2].

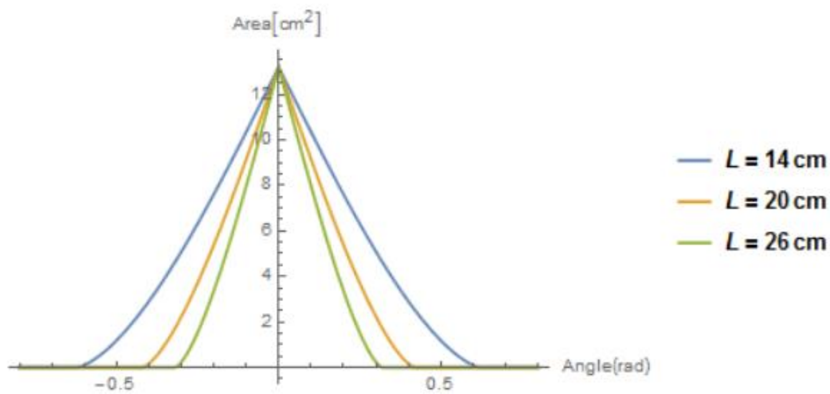

Figure 9: a distribution of the area of overlap as a function of the angle with respect to normal from the stationary photomultiplier and sample for Sodium 22 at all three distances, L is twice the distance from the sample to the photomultiplier.

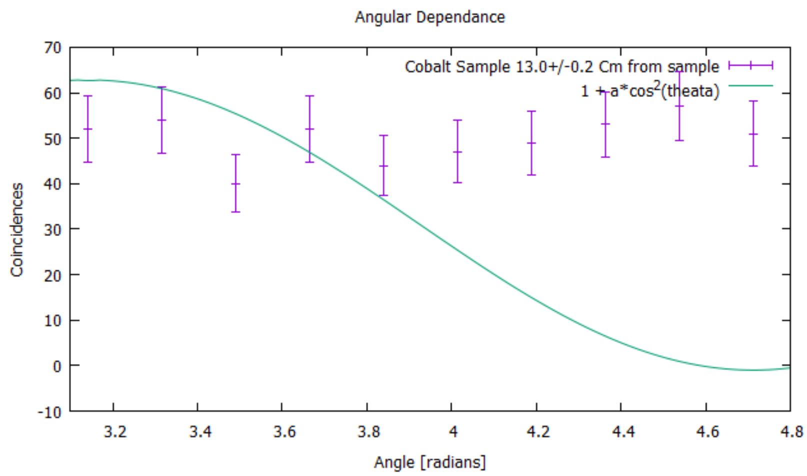

Figure 10: Angular correlation of Cobalt 60 with the photomultiplier 13 cm from the source fit to Equation [3].

Table 2: the full-width half-maximum values of Sodium 22 from figure 9 above calculated from the procedure in the Calculation section.

Distance from source (cm)	Full-Width Half-Maximum (rad)
7.00 +/- 0.02	0.477756
10.00 +/- 0.02	0.332792
13.00 +/- 0.02	0.255508

IV. Error Analysis

The y-error in Figure 5 through Figure 8 and Figure 10 were calculated using

$$\delta y = \sqrt{N} \quad [5]$$

Where *N* is the number of coincidences.

If you take a look at the graphs of the angular correlation, one can see that the peak in coincidences is not at 180˚ as anticipated but at 177˚. This is purely a result of the apparatus used, the alignment is off by about 3˚.

Another possible source of error comes from the disassembly and reassembly of circuit and using different cables in a different order each time the setup was reassembled.

V. Conclusion

From this experiment, we found the angular correlation of the gamma rays emitted from Positronium annihilation of Sodium 22 and Cobalt 60. From the Sodium 22 we were also able to find the full-width half-maximum of the overlapping area of the two scintillators. This is the resolving time of the circuit found in Table 2.

Bibliography

[1] Melissinos, Adrian C. *Experiments in Modern Physics*. New York: Academic, 1966. Print.

[2] http://www.phys.hawaii.edu/~teb/phys480l/gnuplot_example.txt

[3] Noelo Charlotte