Gamma-Ray coincidence and $^{60}$Co angular correlation

With two γ-ray detectors, it is possible to determine that two γ-rays are part of the same cascade by measuring the spectrum in one detector coincident with a given energy measured in the other. For example, if one detector measured a photo-peak count from the $^{60}$Co 1332 keV γ-ray, the other detector can measure a signal from the 1173 keV γ but not another 1332 keV γ-ray. It is also possible to measure a small but real angular correlation between the emitted pairs of γ-rays.

Measurements 1: $^{60}$Co γ-ray cascade

1. The instructions from lab3 (gamma-gamma coincidence for $^{22}$Na) will be helpful.
2. With the two detectors facing one another, place a $^{60}$Co source between them.
3. Record energy spectra from both detectors.
4. Using the setup in figure 1, set SCA1 so that it fires when the signal in detector 1 brackets the 1332 keV photo-peak and record this spectrum.
5. Using the setup in figure 2, record the spectrum from detector 2 gated by the SCA signal from detector 1.
6. Change the detector 1 SCA to bracket the 1173 keV peak and repeat step 4.

Hints: Using tape, label the cables that will be plugged in to the MCA. When setting the SCA (step 3 / figure 1), define a ROI on the desired peak for detector 1 and zero the accumulating spectrum every few seconds until only the red bins are accumulating.

Measurements 2: $^{60}$Co γ-ray angular correlation

The Table of Isotopes\(^8\) gives the spins of most of the nuclear levels that have been measured. Many of these spin assignments were made on the basis of angular correlation measurements. In the case of gamma-gamma angular correlation, an experimental arrangement similar to our goniometer is used. The fixed detector is set to measure only $\gamma_1$, and the movable detector observes $\gamma_2$. The number of coincidences between $\gamma_1$ and $\gamma_2$ is then determined as a function of $\theta$ (the angle between the two detectors). A plot of the number of coincidence events per unit time as a function of the angle $\theta$ is called the measured angular correlation. The measurement of $\gamma_1$ in a fixed direction determines nuclei, which have angular distribution of the resulting radiation $\gamma_2$, which is nonisotropic. This is a result of the nonisotropic distribution of spin orientations in $^{60}$Co. Figure 1 shows that $^{60}$Co beta decays to the 2.507-MeV (4+) state which gamma branches through the 1.3325-MeV (2+) state to the ground state (0+) of $^{60}$Ni.

These angular momenta determine the shape of the correlation function of the isotope. A complete discussion of the theoretical arguments associated with the angular correlation measurements is presented in textbooks. The theoretical correlation function $w(\theta)$ for $^{60}$Co is given by
\[ w(\theta) = a_0 + a_2 \cos^2 \theta = a_4 \cos^4(\theta) , \]

where \( a_0 = 1, a_2 = 1/8, \) and \( a_4 = 1/24. \)

The correlation function \( w(\theta) \) changes by only 17\% from 90 to 180° and is therefore not so easy to measure. You will try to measure this effect.

The anisotropy (A) associated with an angular correlation measurement is defined as

\[ A(X^\circ) = \frac{w(180^\circ) - w(X^\circ)}{w(X^\circ)} \]

Two references that discuss this correlation are


A google search of each reference will point you to a page on aps.org where the papers can be downloaded.

**PROCEDURE**

1. Use the same setup as described above, produce the gate with the 1.33 MeV photo peak of the stationary detector.

2. Set the angle \( \theta \) carefully at 180° and perform a coincidence measurement for a sufficiently long time. You will need to figure out, using the statistical error of \( 1/\sqrt{N} \), what sufficiently long is. Note the number of events in the predominant 1.17 MeV peak and the statistical error in the number. Perform the same measurement at other angles, for example 90, 135, and if time permits, some angles in between.

**Plots to be provided at the end of the lab (these plots should also appear in your final report possibly associated with further analysis):**

1. STEP 2: ungated \(^{60}\text{Co}\) energy spectra from both detectors
2. STEP 3: energy spectrum from detector 1 gated on SCA1.
3. STEP 4: energy spectrum from detector 2 gated on SCA1.
4. MEASUREMENT 2 / EQUIV. STEP 4: energy spectrum from detector 2 gated on SCA1

Calculations in lab report
1. Explanation of how the apparatus including the coincidence gating works.
2. Above spectra including spectra for gating off the 1173 keV peak
3. Statistical analysis to determine whether the 1173 keV and 1332 keV gammas are produced in coincidence or not
4. Plot comparing your measurements at different angles, including error, superimposed on the predicted values based on the equation for A(X).
Figure 1: setting SCA1 around narrow energy band in $\gamma_1$
Figure 2: spectrum $\gamma_2$ gated on SCA1