PHGN 326
Experiment 6:

A Study of the Decay Scheme and Angular Correlation of ^{60}Co

PURPOSE

In this experiment coincidence techniques will be used to study the gamma decay of ^{60}Co. Angular correlation concepts will also be briefly introduced.

INTRODUCTION

There are two parts to Experiment 6: (1) a gamma-gamma coincidence experiment that will be performed to show that the two gammas from ^{60}Co are in coincidence and (2) measurement of the angular correlation of these two gammas and determination of the anisotropy. The decay scheme for ^{60}Co is shown in Fig. 1.

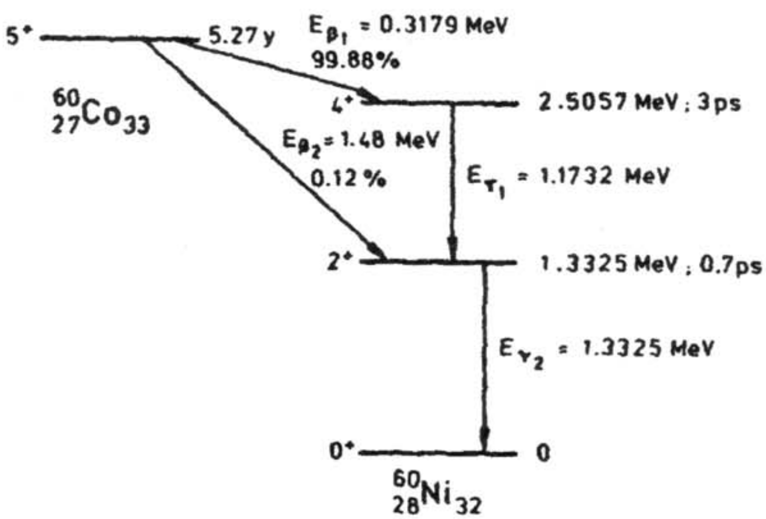

Fig. 1. Decay Scheme for ^{60}Co.

Note in Fig. 1 that the ^{60}Co beta decays to the 2.507-MeV level of ^{60}Ni and this de-excites by a gamma cascade through the 1.3325-MeV state. Since the lifetime of the 1.3325-MeV state is only 0.7 ps, the two gammas will appear to be in coincidence experimentally. Figure 2 shows a NaI(TI) spectrum of ^{60}Co.

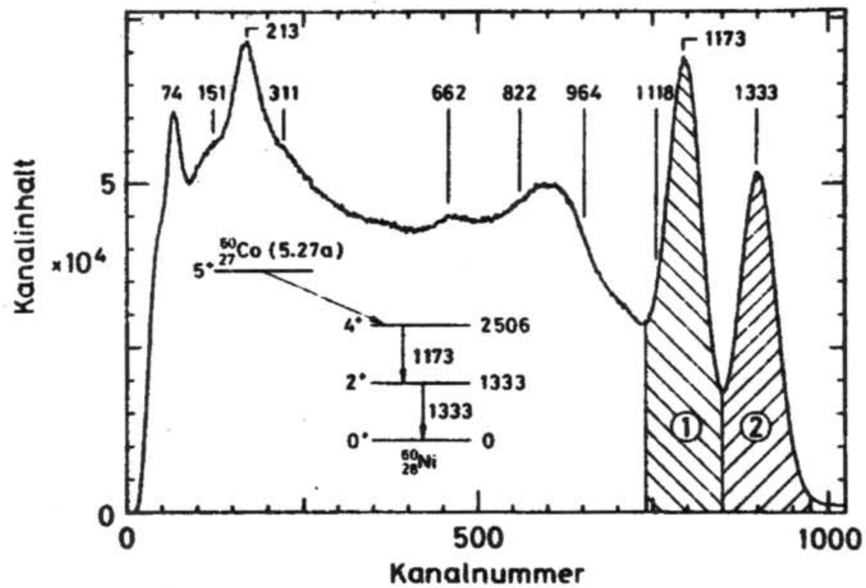

Fig. 2. NaI(TI) Spectrum of ^{60}Co.

In order to verify that γ_1 and γ_2 are in coincidence, it is necessary to use experimental techniques that are new to you. You will mount two NaJ Scintillation detectors, each at around the same distance from the ^{60}Co radioactive source, on a goniometer. Since the angular correlation of γ_1 and γ_2 is nearly isotropic, the angle θ between the two detectors in this experiment can be set at any value for the coincidence verification. Usually the most convenient angle is 180.

(1) Verification of the Gamma-Gamma Coincidence of ^{60}Co

PROCEDURE

1. Mount the NaI(Tl) detectors under 0 and 180 degrees in their stand. Mount the radioactive source. The center of the source should be on the same height as the center of the detector crystal. Connect the photomultiplier bases (base) to the photomultiplier (PM) connectors.
2. Connect the high voltage (HV) input of the PM bases to the HV outputs of the HV power supplies. One base has a preamplifier, which you have to connect to the power outlet at the back of one of the main amplifiers.
3. Connect the preamp outputs of the PM base to the oscilloscope. Signals visible?
4. Turn on the HV power supply (screw/switch on the back side should be on positive). Try if you see signals turning up the voltage in +100 V steps. Maximum + 800 Volts!!!

5. Take notes of the results and sketch the signals on the oscilloscope at + 800 V. Rise time, fall time, noise?
6. Connect the preamp outputs to the spectroscopy amplifier inputs. Turn on the power of the NIM bin and check input signal polarity.
7. Connect the oscilloscope to the amplifier output (unipolar). Sketch the signals.
8. Connect the unipolar output of one detector with the ADC/MCA input and start a measurement. Adjust amplification so that you can clearly see the photo peaks in the spectrum.
9. Repeat for the other detector.

We have now coming out of our two amplifiers the detector signals as being useful for taking a normal energy spectrum of the radiation we are looking at. What we want is to verify the coincidence of the two gamma rays emitted from 60-Co. In order to do this, we have to introduce two more types of NIM modules. The first is the Single Channel Analyzer (SCA). It produces a positive standard pulse for each analogue signal received from an amplifier. It is possible to select a pulse height window on the SCA within which signals are accepted and converted. This allows us to reject noise or other unwanted signals. The standard signals from the SCA's provide the ideal input for our next module the Gate and Delay Generator. With this module we produce a gate signal used as input on the gate of the ADC/MCA card in the PC. One of the options of the Multi Channel Analyzer (MCA) is that you can decide if you want to measure the signal you connect to the normal ADC input in coincidence or anti-coincidence with the gate signal. If the ADC input signal falls within the pulse provided as the gate signal it is processed (or not in the case of anti-coincidence). This way we can display signals that are coming in coincidence.

10. Connect the Single-Channel Analyzer (SCA) to the bipolar output of the stationary detector and adjust its Lower- and Upper-Level controls to bracket the 1.33-MeV photo peak pulses. Try this on the oscilloscope putting the unipolar output on channel 1 and trigger with the SCA output on channel 2.
11. Connect the SCA output to the gate and delay generator, set the gate width to about 4 μs, gate height to about 3 Volts. Connect the output signal to channel 2 of the oscilloscope and trigger the unipolar output of the amplifier with your gate signal. Note the time difference between the two signals.
12. In order to move the amplifier signal into the gate signal, we have to run it through a delay unit.
13. Check if they are now overlapping.
14. Connect the gate signal to the gate input at the MCA card and the delayed amplifier signal to the ADC input.
15. Set the ADC/MCA card to coincidence mode.
16. Accumulate a spectrum. You are now seeing signals from one detector, but only the interval selected via the SCA. Vary the interval on the SCA, until you finally have got a good gate only on the 1.33 MeV photo peak.

17. Now connect the second detector through its amplifier and the delay unit to the ADC input.
18. Accumulate a spectrum in the multi channel analyzer. This spectrum should include only the 1.17 MeV peak and its Compton edge. The 1.33-MeV peak of Fig. 2 should be strongly suppressed. These results will show that the 1.17- and 1.33-MeV gammas are in coincidence because a 1.33-MeV gamma was required in the single-channel analyzer in order to pass each 1.17-MeV pulse that was contributed into the spectrum.
19. Repeat the experiment with the SCA set to bracket the 1.17-MeV peak. Under these conditions, only the 1.33-MeV peak and its Compton should appear in the MCA spectrum, but in reality you still see a suppressed 1.17 MeV peak. Why? These two measurements verify that γ_1 and γ_2 in Fig.1 are prompt cascade gammas.

(2) Angular Correlation of ^{60}Co

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 γ_1, and the movable detector observes γ_2. The number of coincidences between γ_1 and γ_2 is then determined as a function of θ (the angle between the two detectors). A plot of the number of coincidence events per unit time as a function of the angle θ is called the measured angular correlation. The measurement of γ_1 in a fixed direction determines nuclei, which have angular distribution of the resulting radiation γ_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 $a_4 = 1/24$.

Table 1 shows the calculated values for $w(\theta)$ for angles between 90° and 180° in 10° increments for ^{60}Co.

Table 1. Angular Correlation Function $w(\theta)$ for ^{60}Co.

θ (deg)	$w(\theta)$
90	1.00000
100	1.00381
110	1.01519
120	1.03385
130	1.05876
140	1.08770
150	1.11719
160	1.14287
170	1.16042
180	1.16667

It can be seen from Table 1 that the correlation function $w(\theta)$ changes by only 17% from 90 to 180° and is therefore not easy to measure. We will nevertheless try to verify the trend.

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

$$A = \frac{w(180°) - w(90°)}{w(90°)}$$

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 θ carefully at 180° and perform a coincidence measurement for 2000 seconds. Note the number of events in the predominant 1.17 MeV peak. Perform the same measurement at 90 and 135 degrees.
3. It is a good practice to repeat the measurement at all angles several times during the course of the experiment to ensure proper alignment of the system.
4. Compare your results to Table 1. They should follow the general trend.