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

EQUIPMENT NEEDED FROM EG&G ORTEC	
Two 113 Scintillation Preamplifiers	Two 551 Timing Single-Channel Analyzers
Two 266 Photomultiplier Tube Bases	719 Timer
Two Bins and Power Supplies	Two 905-3 NaI(Tl) 2- x 2-in. Detectors with Phototubes
418A Universal Coincidence	ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
426 Linear Gate	Oscilloscope
427A Delay Amplifier	10-μCi ^{60}Co gamma source
Two 556 High Voltage Power Supplies	Source Kit SK-1G
480 Pulser	306 Gamma-Gamma Angular Correlation Table with fixed and rotating shield for the detectors
Three 875 Counters	ORC-19 Cable Set
Two 575A Amplifiers	

Purpose

In this experiment the coincidence technique outlined in Experiments 9 and 13 will be used to study the gamma decay of ^{60}Co. Angular correlation concepts will also be introduced.

Introduction

There are two parts to Experiment 19: (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 and the coefficients of the correlation function. The decay scheme for ^{60}Co is shown in Fig. 19.1.

Note in Fig. 19.1 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 19.2 shows an NaI(Tl) spectrum of ^{60}Co.

In order to verify that γ_1 and γ_2 are in coincidence, it is necessary to use the experimental techniques that were outlined in Experiment 13. Figure 19.3 shows the geometrical setup that will be used for both the γ_1-γ_2 coincidence verification and the angular correlation measurement in this experiment.

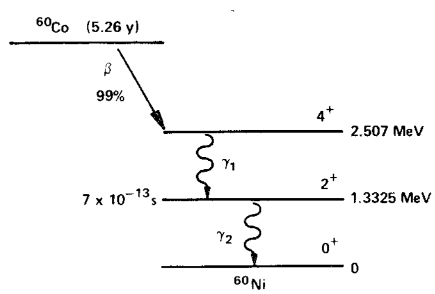

Fig. 19.1. Decay Scheme for ^{60}Co.

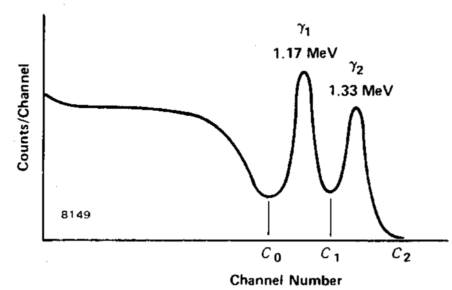

Fig. 19.2. NaI(Tl) Spectrum of ^{60}Co.

Since the angular correlation of γ_1 and γ_2 is nearly isotropic, the angle θ in Fig. 19.3 can be set at any value for the coincidence verification. Usually the most convenient angle is 180°. A typical electronics setup for the measurement is shown in Fig. 19.4.

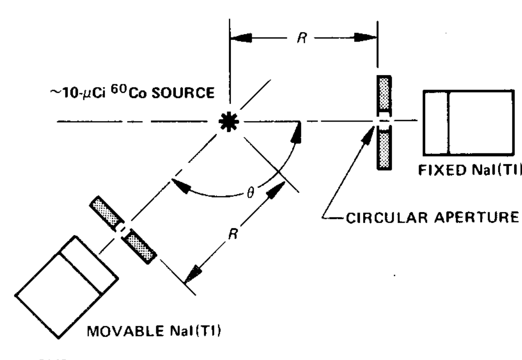

Fig. 19.3. Experimental Arrangement for Coincidence and Angular Correlation Measurements Using an EG&G ORTEC 306 Table.

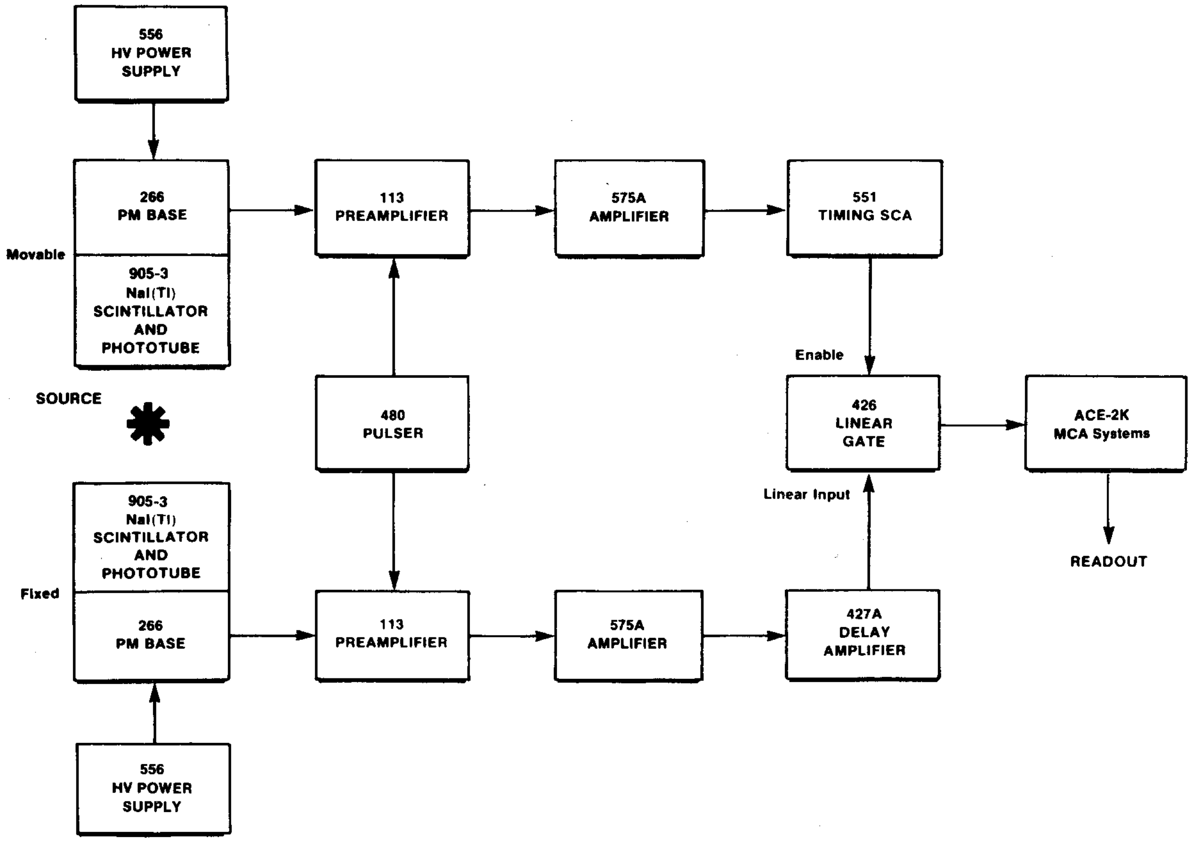

Fig. 19.4. Electronics for ^{60}Co Coincidence Experiment.

EXPERIMENT 19.1

Verification of the Gamma-Gamma Coincidence of ^{60}Co

Procedure

1. Set up the electronics as shown in Fig. 19.4. Adjust the 556 High Voltage Power Supplies to the values recommended for the 905-3 Detectors. Adjust the gain of each 575A Amplifier so that the 1.33-MeV gamma pulses at the output are ~6 V in amplitude. Figure 19.2 shows a typical spectrum that could be obtained from either amplifier output with an MCA.

2. Set the 551 Timing SCA for the Window mode and adjust its Lower- and Upper-Level controls to bracket the 1.17-MeV photopeak pulses. In Fig. 19.2, this is the region between C_0 and C_1. Use a 100-ns delay.

3. On the 426 Linear Gate, set the gate width at maximum (4 μs).

4. Turn on the pulse generator and adjust its pulse height, calibration, and attenuator controls to obtain output from the 551 Timing SCA.

5. Adjust the gate width on the 426 and the delay setting of the 427A so that the pulses out of the linear gate are similar to Fig. 19.5. The combination will open the gate just before the linear input pulse arrives and will close it after ~2 μs. Turn off the pulse generator.

6. Accumulate a spectrum in the MCA. This spectrum should include only the 1.33-MeV peak and its Compton edge. The 1.17-MeV peak of Fig. 19.2 will be virtually eliminated. These results will show that the 1.17- and 1.33-MeV gammas are in coincidence because a 1.17-MeV gamma was required in the SCA in order to pass each 1.33-MeV pulse that was contributed into the spectrum.

7. Repeat the experiment with the 551 Timing SCA set to bracket the 1.33-MeV peak. Under these conditions, only the 1.17-MeV peak and its Compton should appear in the MCA spectrum. These two measurements verify that γ_1 and γ_2 in Fig. 19.1 are prompt cascade gammas. Experiment 19.2

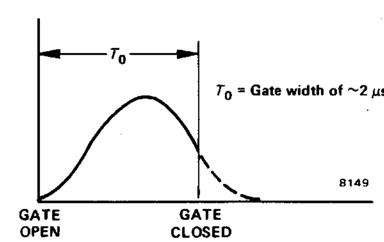

Fig. 19.5. Output of the Linear Gate.

describes the procedure necessary for studying their angular correlation.

EXPERIMENT 19.2

Angular Correlation of ^{60}Co

The Table of Isotopes (ref. 4) 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 Fig. 19.3 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 an 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 19.1 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 refs. 1 and 2. The theoretical correlation function, $w(\theta)$, for ^{60}Co is given by

$$w(\theta) = a_0 + a_2 \cos^2\theta + a_4 \cos^4(\theta) \ , \tag{1}$$

where $a_0 = 1$, $a_2 = 1/8$, and $a_4 = 1/24$.

Table 19.1 shows the calculated values for $w(\theta)$ for angles between 90° and 180° in 10° increments for ^{60}Co.

It can be seen from Table 19.1 that the correlation function, $w(\theta)$, changes by only 17% from 90 to 180°. Therefore counting statistics of ~1% should be obtained when the experiment is performed.

Table 19.1. 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

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

$$A = \frac{w(180^\circ) - w(90^\circ)}{w(90^\circ)} \ . \tag{2}$$

A comparison of the experimental anisotropy with the theoretical value will reveal that angular correlation measurements are capable of rather high precision.

In this experiment the experimental angular correlation, $w(\theta)$, will be compared to Eq. (1) and the values shown in Table 19.1, and the calculated and measured anisotropy will be compared to Eq. (2).

Procedure

1. Set up the electronics as shown in Fig. 19.6. Adjust the gain of each 575A Amplifier for a bipolar output of ~6 V for the 1.33-MeV gamma pulses.

2. Set the resolving time of the 418A at 100 ns. Adjust the delays in the outputs of both 551 Timing SCAs so that the maximum coincidence counting rate is observed for pulses from the pulse generator. This technique is outlined in Experiments 9 and 13.

3. Set both 551 Timing SCAs for the Window mode and adjust the window widths. Set the window for pulses from the fixed detector so that it spans the 1.17-MeV peak. Set the window for the movable detector so that it spans the 1.33-MeV peak.

4. Set the angle, θ, carefully at 180° (Fig. 19.3). Turn off the pulse generator and accumulate a total count, N_T, through a period of time, t_1, that is long enough to obtain 1% statistics in the coincidence counter. Also measure the number of counts in the counters for the side channels. To determine the actual time coincidence rate a correction must be made for the number of accidental coincidence counts. Determine the accidental rate, N_{acc}, from the formula

$$N_{acc} = 2\tau N_1 N_2, \tag{3}$$

where

τ = resolving time of the coincidence unit,
N_1 = counting rate in the counter for the fixed detector,
N_2 = counting rate in the counter for the movable detector.

The angular correlation function, $w(\theta)$, for 180° is then

$$w(\theta) = N_T - N_{acc} \ . \tag{4}$$

5. Repeat the measurements in step **4** and determine $w(\theta)$ for the other angles listed in Table 19.1. It is a good practice to repeat the measurement at 90° several times during the course of the experiment to ensure proper alignment of the system.

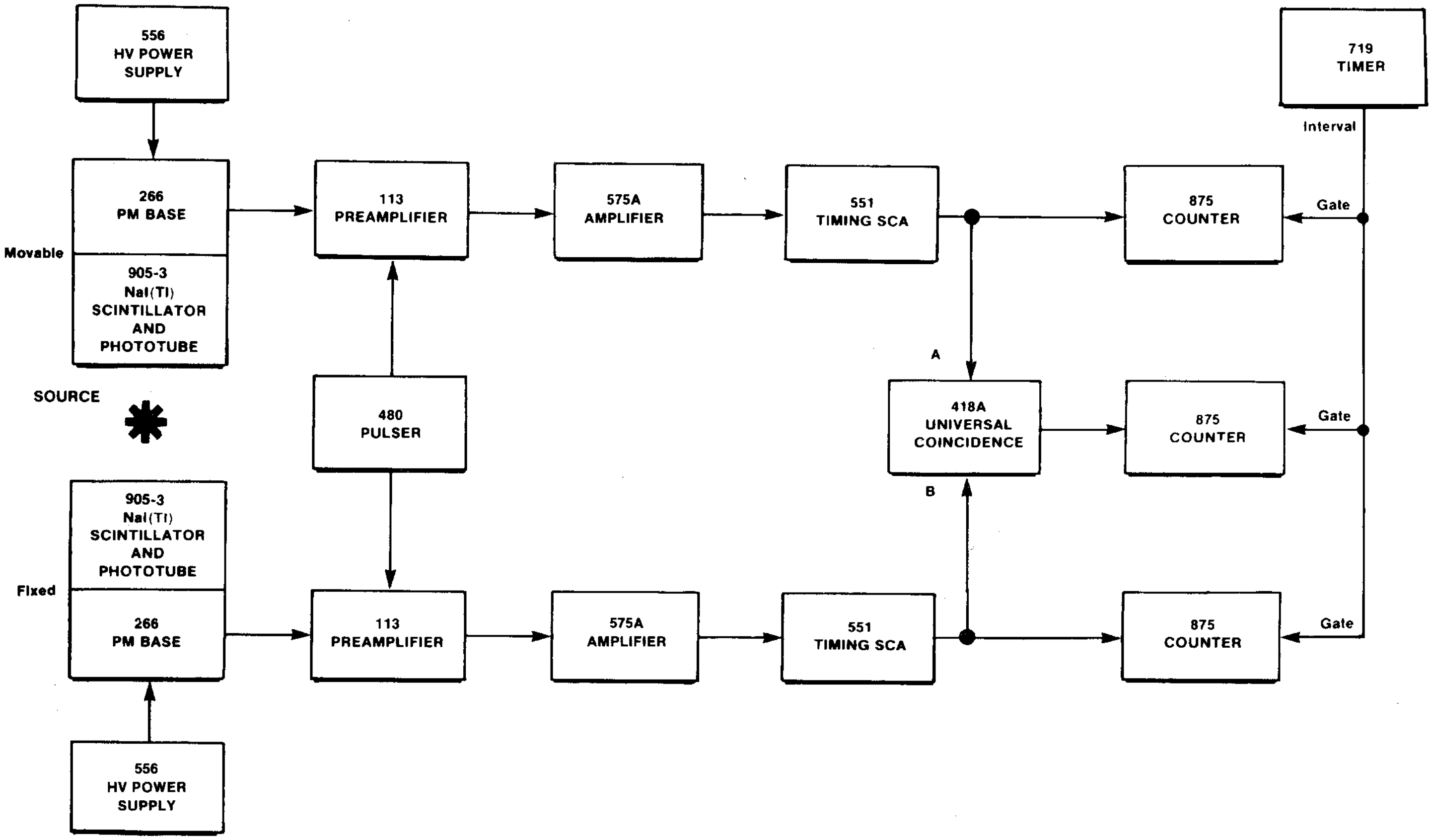

Fig. 19.6. Electronics for γ-γ Angular Correlation Measurements.

EXERCISES

a. In order to easily compare the experimental values with the theoretical values given by Eq. (1), it is more convenient to plot G(θ) vs θ, where G(θ) is calculated by

$$G(\theta) = \frac{w(\theta)}{w(90^\circ)} \tag{5}$$

Plot G(θ) experimental as a function of θ. Do the same for G(θ) theoretical from the data in Table 19.1. Figure 19.7 shows a typical set of experimental and theoretical data for this experiment.

b. Determine the anisotropy from the experimental data. How does this compare to the theoretical value?

c. Make a least-squares-fit to your data points and determine the experimental coefficients to the correlation function. How do your values compare with those in Eq. (1)?

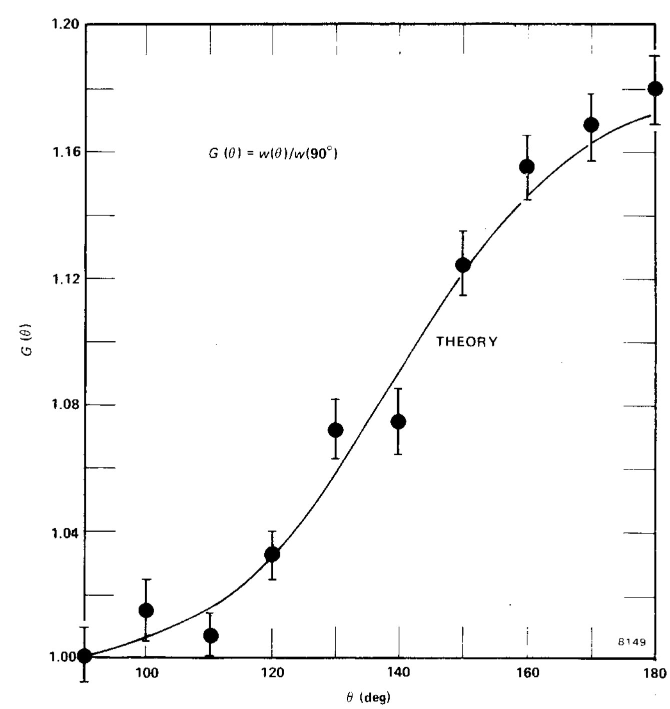

Fig. 19.7. Experimental and Theoretical Angular Correlation w(θ) from ^{60}Co.

References

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