AN34 Experiment 9

Time Coincidence Techniques and Absolute Activity Measurements

EQUIPMENT NEEDED FROM ORTEC

- 4001A/4002D NIM Bin and Power Supply (2 ea.)
- 113 Preamplifier (2 ea.)
- 905-3 NaI(Tl) Detector and PM Tube Assembly
- 142A Preamplifier
- ALPHA-PPS-115 Vacuum Pump Station
- BA-015-025-1500 Surface Barrier Detector
- TRUMP-PCI-2K MCA System including PC operating Windows 98/2000/XP (other ORTEC MCAs may be used.)
- 266 PM Tube Base
- 551 Timing Single Channel Analyzer (2 ea.)
- 425A Nanosecond Delay
- C-36-12 Cable (2 ea.)
- C-24-12 Cable (6 ea.)
- C-24-1 Cable (12 ea.)
- C-25-1 Cable (3 ea.)
- C-29 BNC Tee Connector (6 ea.)
- 428 Detector Bias Supply
- 567 Time-to-Amplitude Converter and SCA
- 556 High Voltage Power Supply
- 480 Pulser
- 974 Quad Counter and Timer
- 418A Universal Coincidence
- 855 Dual Spectroscopy Amplifier

Other Equipment Needed

- Oscilloscope
- Vacuum Chamber with thin plastic window, 4-in. diameter x 6-in high. Most α and β experiments can be done in this chamber and also α,γ, or β,γ coincidence experiments.
- Stand for 2- x 2-in. phototube. Supports the phototube over the vacuum chamber.
- ^{60}Co Radioactive Source, 1–5 µCi (beta source)
- Sealed Solid Disk Gamma-Ray Sources ~1 µCi, ^{137}Cs, ^{60}Co, ^{22}Na, ^{65}Zn, ^{54}Mn (substitute alternate sources with similar energies).

Purpose

This experiment will utilize some of the basic instrument configurations for time coincidence studies, including time spectroscopy. It includes a brief discussion of typical decay schemes because these include sources of coincident events on which measurements can be made.

Introduction

Time coincidence counting is defined as a method for detecting and identifying radioactive materials and for calibrating their disintegration rates. The absolute activity measurement can be made by counting two or more characteristic radiation events, such as beta and gamma, that occur either together or within a specified time relationship to each other. In this experiment, ^{60}Co is the isotope that is used.

Many beta and gamma sources used in nuclear training laboratories are produced with nuclear reactors. Typically, a certain stable isotope is placed in the reactor core for a specified time period. The neutron flux in the reactor core could be as much as 10^{14} neutrons per cm^2 per second. This means that 10^{14} thermal neutrons bombard each cm^2 of the sample per second. As a result of this bombardment, the sample becomes radioactive.

At thermal neutron energies the most probable neutron reaction is the so-called (n,γ) reaction. A simplified explanation of this reaction is that a neutron from the reactor collides with one of the stable nuclei in the sample and, in so doing, is absorbed into the nucleus, causing a new nucleus to be formed. The new nucleus is most probably unstable and will rid itself of this excess energy by emitting a radioactive particle. For (n,γ) neutron activation, the excited nucleus is neutron-rich, and the most probable decay mode for a neutron-rich isotope is beta decay. The beta decay is usually followed by gamma emission. In order to see this, consider the simple decay scheme shown in Fig. 9.1.

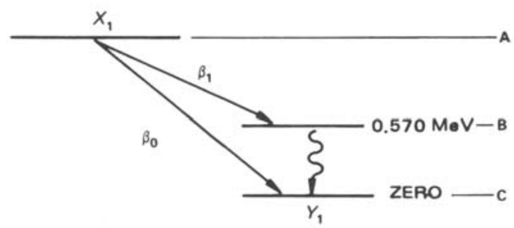

Fig. 9.1.

This decay scheme is quite simple to understand. As was pointed out earlier, in a decay scheme the energy of excitation of a nucleus is plotted in the vertical direction. The possible energy levels available in the decay are shown as horizontal lines in the figure. The lines in Fig. 9.1 have been drawn to the right to point out the significance of these levels. X_1 decays by beta emission to Y_1. There are two possible modes to this decay, which in the figure are lableled β_0 and β_1. In other words, the excited X_1 nucleus has two possible routes to become de-excited.

In the diagram, C is the zero energy of Y_1, which is called the ground state of Y_1. Another possible state of Y_1 is the 0.570 MeV state, labeled B in the diagram. The second decay mode for X_1 consists of the emission of a beta particle, β_1, followed promptly by a gamma. Prompt means that the lifetime of the state is very short. These lifetimes usually range from 10^{-8} to 10^{-21} seconds. The gamma energy is exactly the same as the first excited state of Y_1. In the diagram, it is seen that this energy is 0.570 MeV. In other words, for this decay mode, β_1 is emitted to the first excited state of Y_1, which immediately decays to the ground state of Y_1. If the beta spectrum from X_1 is studied as in Experiment 6, the two betas will be observed. However, a (β,γ) coincidence experiment will quickly show that only β_1 is in coincidence with the 0.570 MeV gamma. This technique will be used later in the experiment to determine the absolute activity of a sample.

(α,γ) Coincidence

In order to understand (α,γ) coincidence, a simple example will be used. Let us assume that we have an alpha source (A) that decays by alpha emission to a stable isotope (B) with the scheme shown in Fig. 9.2.

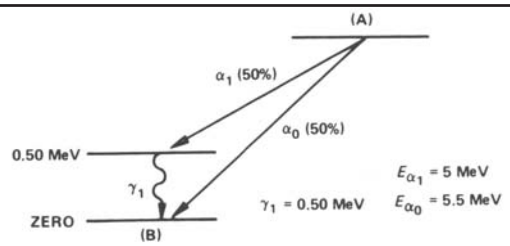

Fig. 9.2.

From the decay scheme, it can be seen that 50% of the time (A) goes directly to the ground state of (B). The other 50% of the time, decay is by an (α,γ) branch, which is similar to the (β,γ) branch in the previous example. The decay is by a 5 MeV alpha (α_1) followed immediately by a 0.50 MeV gamma. Thus the α_1 and γ_1 are in coincidence. For this example, every α_1 is followed by a γ_1. Fig. 9.3 shows the alpha and gamma spectra for the source as they would have been measured in the previous experiments.

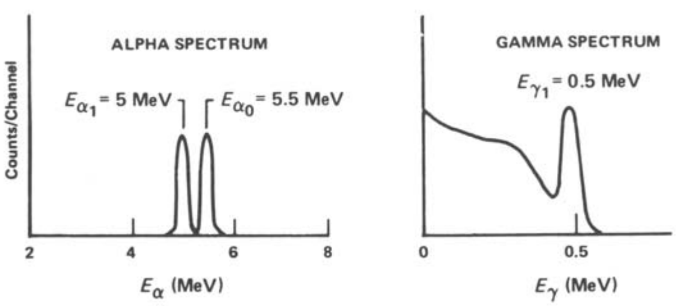

Fig. 9.3.

If the electronics are set up with a surface barrier detector to look at the alphas and with a NaI(Tl) detector to look at the gammas, it will be observed that there are no gammas in coincidence with α_0.

(γ,γ) Coincidence

In all the examples shown thus far in this experiment, gamma decay occurs directly to the ground state of the final stable nucleus. It is possible for a nucleus to de-excite with the emission of several gammas. In order to understand this, let us consider the simple decay scheme shown in Fig. 9.4.

In Fig. 9.4 the nucleus (C) decays to the nucleus (D) by beta emission followed by gamma decay. A simple way to look at the decay is as follows: the beta emission of (C) results in the nucleus (D), which is left with an excess energy of excitation of 1.0 MeV. The excited (D) nucleus gives off its energy of

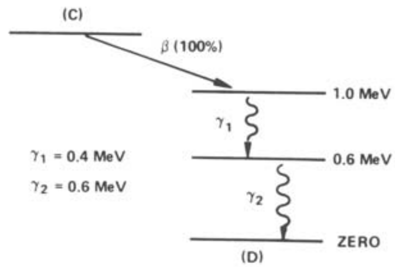

Fig. 9.4.

excitation by the emission of, first γ_1, which has an energy of 0.4 MeV, and then promptly by the emission of γ_2, which has an energy of 0.6 MeV. Simply stated, for every γ_1 we also have a γ_2. For this simple example the gamma spectrum of isotope (C) is shown in Fig. 9.5. As was pointed out earlier, there would also be a coincidence between the beta particle and either of the gammas. Occasionally, an isotope will branch directly to the ground state without going through the intermediate states. If this happened in the above example, a gamma of 1 MeV energy would also be seen in the spectrum. These probabilities of gamma decay from a given state to the ground state (stable state) through intermediate states are called gamma-ray branching ratios. In later experiments (γ,γ) and (α,γ) coincidence measurements will be made. In this experiment, several possible electronic configurations for coincidence measurements will be considered, and a (β,γ) coincidence setup will be used to determine the absolute activity of a sample.

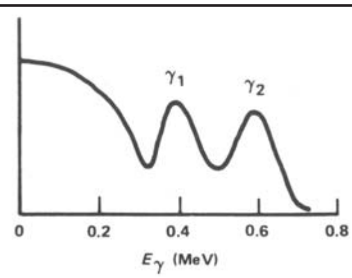

Fig. 9.5.

EXPERIMENT 9.1
Simple Fast Coincidence

In the equipment setup shown in Fig. 9.6, make the following instrument settings:

113 Preamplifiers: 0 pF Input Capacitance.

855 Amplifiers: Negative input; Bipolar output.

551 Timing SCAs: Integral Mode; Lower Level = 50/1000; Delay 0.5 µs; adjust walk (see manual).

418A Universal Coincidence: Inputs A and B Coinc.; C, D, and E Off; Coincidence Requirements 2; Resolving Time maximum, 2 µs.

480 Pulser: Negative Output; Power On; Attenuated Output ~0.5 V (measured with an oscilloscope).

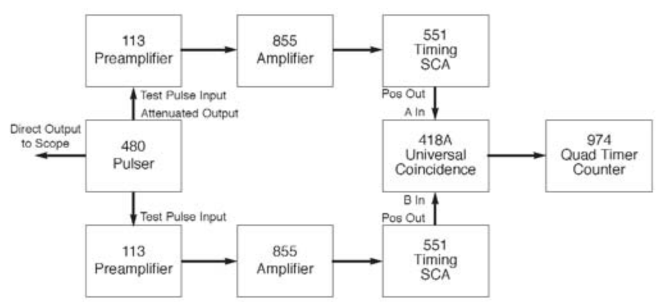

Fig. 9.6. Electronics Interconnections for Experiment 9.1.

Procedure

1. Adjust the gain of each 855 Amplifier so that the output pulse is ~5 V.

2. Set the timer on the 974 for ~100 seconds. Vary the delay on either 551 until the maximum counting rate is observed on Counter 1 of the 974 Timer and Counter. The two branches are now approximately coincident.

3. Clear the counter, set the timer for 10 seconds, and count. If the maximum counting rate was set properly in step 2, the counter should read ~600 (60 Hz for 10 seconds). Change the delay in either 551 by 10 ns (10 dial divisions) and repeat the 10-second count.

EXERCISES

a. Continue changing the delay for enough readings to plot a time coincidence curve similar to that shown in Fig. 9.7.

b. Narrow the resolving time of the 418A to 1 µs and plot the coincidence curve which is similar to Fig. 9.7. (Note: Take readings every 10 ns.)

c. Narrow the resolving time of the 418A to 100 ns and measure the coincidence curve. (Take readings every 10 ns.)

The student should now begin to understand the concept of simple fast time coincidence spectroscopy.

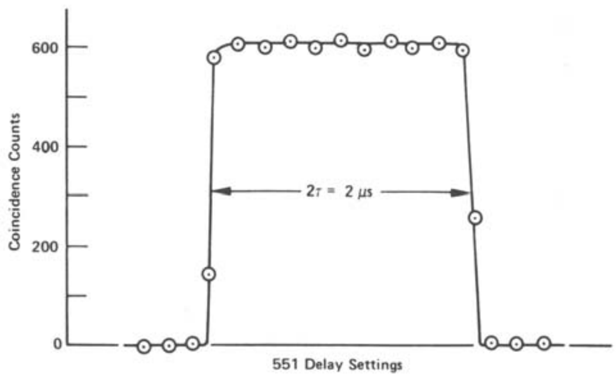

Fig. 9.7. Typical Time Coincidence Curve.

EXPERIMENT 9.2
Fast Coincidence and the Time-to-Amplitude Converter

The Time-to-Ampitude Converter (TAC) can also be used when fast coincidence is required in an experiment. The TAC is basically an instrument that provides an output pulse whose amplitude is proportional to the time difference (Δt) between the start and stop input pulses to the converter. It is, therefore, an electronic clock that can be used to measure very short time differences (~10 x 10^{-12}s). The TAC will not only indicate that two events are in coincidence, but will also tell how the coincident events are distributed with respect to time. The purpose of this experiment is to study some of the properties of the TAC.

In the equipment setup shown in Fig. 9.8, set the instruments as follows:

113 Preamplifiers: 0 pF Input Capacitance.

855 Ampifiers: Negative Input; Bipolar Output.

551 Timing SCA on Start Side: Integral mode; Lower Level = 50/1000, Delay 100 ns; adjust walk (see manual).

551 Timing SCA on Stop Side: Integral mode; Lower Level = 50/1000; Delay 100 ns; adjust walk (see manual).

480 Pulser: Negative Output; Power On; Attenuated.

Output ~0.5 V (measured with an oscilloscope).

567 TAC: 0.2 µs; single-channel controls not used.

425A Delay: 32 ns In; all others Out.

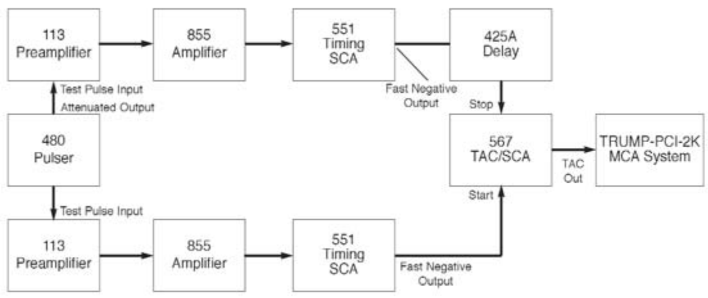

Fig. 9.8. Electronics Interconnections for Experiment 9.2.

Procedure

1. Adjust the gain of each of the 855 Amplifiers so that each Bipolar Output has an amplitude of ~5 V.

2. Accumulate a spectrum in the MCA. A single isolated group of signals should be observed above mid-scale on the display.

3. Set the 1, 2, 4, 8, and 16 ns switches on the 425A Delay to the IN position. This should move the position on the MCA display where the signals are being accumulated to the upper quarter of the display. Record the channel number of the peak.

4. Switch the 16 ns switch to OUT and observe the movement of the analyzer peak. Record the new peak position.

5. Set all the switches on the 425A Delay to OUT, for 0 delay. Record the channel number of the peak in Table 9.1.

Table 9.1

Stop Signal Delay (ns)	Peak Location (Channel No.)	Stop Signal Delay (ns)	Peak Location (Channel No.)
0		35	
5		40	
10		45	
15		50	
20		55	
25		60	
30		65	

EXERCISES

a. Using the 425A Delay, increase the Stop signal delay in 5 ns steps and fill in the peak location channel numbers in Table 9.1.

b. Plot the data from Table 9.1 on linear graph paper. The plot should be similar to that in Fig. 9.9.

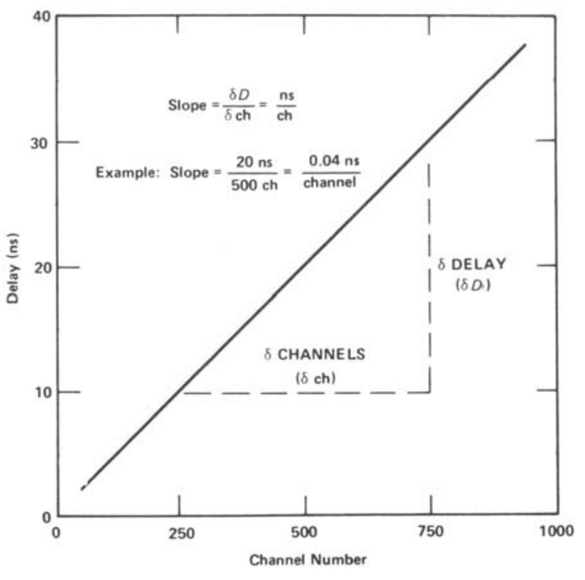

Fig. 9.9. Typical Delay vs. Pulse-Height Curve.

c. Determine the slope of your calibration curve.

d. Determine the time resolution for your system. This is defined as δT in the formula

$$\delta T = (FWHM)\frac{\delta D}{\delta ch} \qquad (1)$$

where the (FWHM) factor is the number of channels across the half-height of the spectrum as defined earlier.

6. Switch the 567 TAC range to 400 ns. The TAC now has a full-scale output range that corresponds to 0–0.4 µs. Change the Delay on the Start 551 to 0.1 µs. Adjust the Delay in the Stop 551 until the TAC output is being stored in the upper quarter of the MCA. Record the peak position.

EXERCISE

e. Continue to change the values of the Delay in the Stop 551 and record the resulting channel locations. Use enough settings to establish a delay vs. pulse height curve for this new range of the TAC and calculate its measured resolution.

EXPERIMENT 9.3
Determination of Absolute Activity by the Coincidence Method

Introduction

Some of the coincidence techniques outlined above will now be used to determine the absolute activity of a ^{60}Co sample. The method consists of counting in the following order:

1. The gamma spectrum for the sample as in Experiment 3,

2. The beta spectrum as in Experiment 6,

3. The (β,γ) coincidence for the sample.

From step 1, the gamma counting rate, Rγ, is determined:

$$R\gamma = A_0\varepsilon\gamma \qquad (2)$$

where A_0 is the true disintegration rate of the sample and εγ is the efficiency of the NaI(Tl) detector.

From step 2 the same information is determined for the betas:

$$R_\beta = A_0\varepsilon_\beta \qquad (3)$$

where ε_β is the efficiency of the beta detector.

The coincidence counting rate measured in step 3 would be:

$$R_c = A_0\varepsilon_\gamma\varepsilon_\beta \qquad (4)$$

From Eqs. (2), (3), and (4), A_0 is given by

$$A_0 = \frac{R_\gamma R_\beta}{R_c} \qquad (5)$$

The purpose of the experiment is to determine A_0 for the ^{60}Co sample.

In the equipment setup shown in Fig. 9.10, set the instruments as follows:

113 Preamplifiers: 0 pF Input.

855 Amplifier (from 113): Negative Input; Bipolar Output.

855 Amplifier (from 142A): Positive Input; Bipolar Output.

551 Timing SCAs: Integral mode; Lower Level 40/1000; Delay Minimum.

418A Universal Coincidence: Coincidence Requirements 2; Resolving Time maximum, 2 µs; Switches A and B Coinc; Switches C, D, and E Off.

Turn on ALPHA-PPS-115 Vacuum Pump Station.

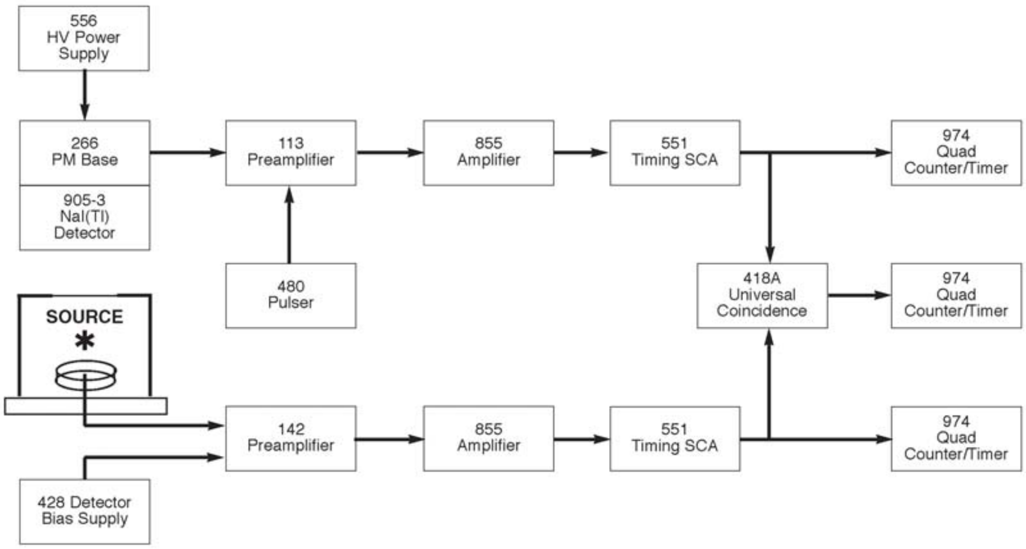

Fig. 9.8. Electronics Interconnections for Experiment 9.2.

Procedure

1. Adjust the 556 high voltage to the polarity and value recommended for the phototube.

2. Adjust the gain of the 855 Amplifier section connected to the 113 preamplifier so that the 1.33 MeV gammas from the ^{60}Co source are ~6 V at the Bipolar output.

3. Gradually increase the 428 Detector Bias Supply voltage to the recommended value for the surface barrier detector.

4. Adjust the gain of the 855 Amplifier section connected to the 142A preamplifier so that the maximum pulse amplitude from the beta continuum is ~7 V.

5. All three counters (1, 2, and 3) of the 974 Timer and Counter should be counting.

6. Stop the timer section of the 974 and clear all three counters to zero.

7. Start counting in Counters 1, 2, and 3 of the 974 by resetting the preset timer section of the instrument and pressing the Count button. Count for a time interval long enough to acquire ~600 counts in Counter 2 (the R_c counter for the coincidence events).

EXERCISE

Calculate A_0 from Eq. (5). How does your value compare with the value indicated for the sample, considering its current rate of decay?

References

1. G. F. Knoll, Radiation Detection and Measurement, John Wiley and Sons, Inc., New York (1979).

2. V. Acosta, C. L. Cowan, and B. J. Graham, Essentials of Modern Physics, Harper and Row, New York (1973).

3. V. Arena, Ionizing Radiation and Life, The C. V. Mosby Co., St. Louis, Missouri (1971).

4. H. L. Andrews, Radiation Biophysics, Prentice-Hall, Englewood Cliffs, New Jersey (1974).

5. P. Quittner, Gamma Ray Spectroscopy, Halsted Press, New York (1972).

6. W. Mann and S. Garfinkel, Radioactivity and Its Measurement, Van Nostrand-Reinhold, New York (1966).

7. Radiological Health Handbook, U.S. Dept. Of Health, Education, and Welfare, PHS Publication 2016. Available from National Technical Information Service, U.S. Dept. Of Commerce, Springfield, Virginia.

8. A. C. Melissinos, Experiments in Modern Physics, Academic Press, New York (1966).

9. K. Siegbahn, Ed., Alpha-, Beta-, and Gamma-Ray Spectroscopy 1 and 2 , North Holland Publishing Co., Amsterdam (1965).

10. A. H. Wapstra, et al., Nuclear Spectroscopy Tables, North Holland Publishing Co., Amsterdam (1959).