EXPERIMENT 14

Nuclear Lifetimes and the Coincidence Method

EQUIPMENT NEEDED FROM EG&G ORTEC

Two 113 Scintillation Preamplifiers
Two 266 Photomultiplier Tube Bases
Two Bins and Power Supplies
418A Universal Coincidence
Two 551 Timing Single-Channel Analyzers
567 Time-to-Amplitude Converter and SCA
Two 556 High Voltage Power Supplies
480 Pulser
875 Counter
Two 575A Amplifiers
719 Timer
905-3 NaI(Tl) 2- by 2-in. Detector and PM tube
ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
Oscilloscope
20-μCi ^{57}Co source
Source Kit SK-1G
905-1B Thin Window NaI(Tl) Detector with PM Tube
ORC-14 Cable Set

OPTIONAL EQUIPMENT FOR EXPERIMENT 14.3

GEM-10195 Coaxial Detector System
SLP-06175 Si(Li) X-Ray Detector System

Purpose

This experiment will use the coincidence method of timing identification to measure the mean lifetime in the decay scheme of ^{57}Co.

Introduction

The measurement of the lifetimes of excited nuclear states constitutes an important experimental technique in nuclear physics. Many nuclear states remain excited for mean lifetimes that are measured easily with the techniques outlined in Experiment 9. The lifetime of a nuclear state is related to its width, (energy), by the uncertainty principle:

$$\Delta E \Delta t = \hbar , \qquad (1)$$

where

ΔE = uncertainty in energy associated with a state,
Δt = uncertainty in time associated with the state,
$\hbar$ = 1.054 x 10^{-34} joules-s.

In general, for nuclear lifetimes, Eq. (1) becomes

$$\tau = \frac{\hbar}{\Gamma} , \qquad (2)$$

where τ = mean life of a level of width Γ.

In this experiment several techniques are outlined for measuring the lifetime of the first excited state of ^{57}Fe. The accepted value for this lifetime is 98 ns, which is well within the measuring capabilities of the coincidence techniques discussed in Experiment 9.

The decay scheme for ^{57}Co is shown in Fig. 14.1. The decay of this isotope is essentially all by electron capture, (EC), to the 136-keV level of ^{57}Fe. Figure 14.2 shows a high-resolution x-ray spectrum of ^{57}Co, in which the K_{α_1} and K_{β_1} x rays resulting from the electron capture are shown. The decay of the 136-keV level of ^{57}Fe can occur by one of two principal modes: by a 136-keV gamma directly to the ground state or

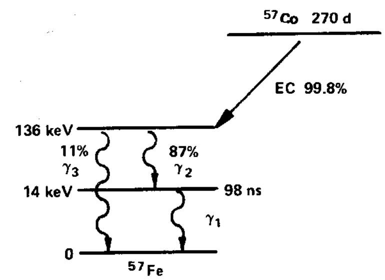

Fig. 14.1. Decay Scheme of ^{57}Co.

by branching through the 14-keV level to ground state. The 136-keV gamma, (γ_3), branch occurs 11% of the time. The 122-keV gamma, (γ_2), is 87% abundant. The 14-keV level, (γ_1), de-excites most of the time by internal conversion. The ratio of internal conversion to gamma decay, (e/γ), for this level is ~9.0. The 14-keV gamma is also shown in Fig. 14.2. Figure 14.3 shows a high-resolution gamma spectrum of a ^{57}Co source. The lifetime of the 14-keV state can be measured by determining the time distribution of coincidence events between γ_2 and γ_1.

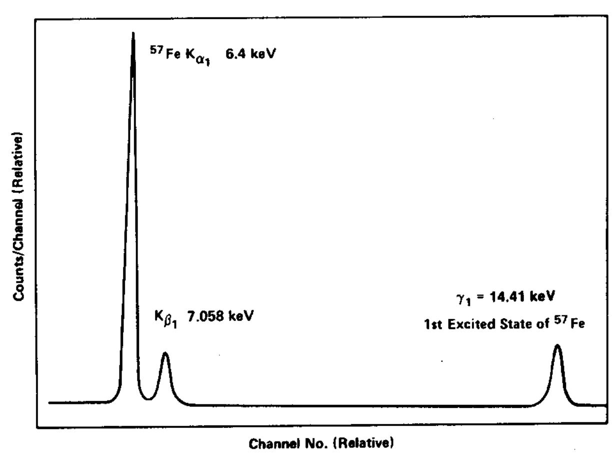

Fig. 14.2. Low-Energy Photon Spectrum from ^{57}Co.

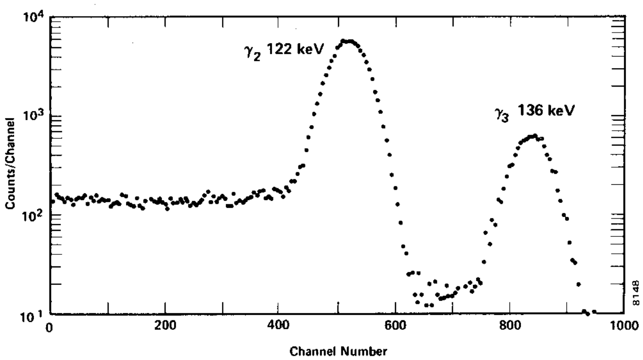

Fig. 14.3. High-Resolution Gamma Spectrum for ^{57}Co.

Experimentally the best way to do this delayed coincidence experiment is with a time-to-amplitude converter (TAC). In Experiment 9 the TAC was used to indicate pairs of coincident pulses and to measure the variation in their relative times of occurrence. In Experiment 14.1, γ_2 will be used to start a time measurement, and γ_1 will be used to stop the measurement. The output of the TAC will then provide a time distribution of the lifetime of the first excited state of ^{57}Fe, calibrated with known delays as in Experiment 9. In Experiment 14.2 the same information is obtained by measuring the γ_1 and γ_2 coincidence event rate with a fast coincidence circuit as a function of the delay in the γ_1 side of the circuit. These techniques are repeated in Experiment 14.3 using detectors with different spectral response characteristics.

EXPERIMENT 14.1

Lifetime Measurement of the 14-keV State in ^{57}Fe Using the Time-to-Amplitude Converter Method

Procedure

1. Set up the electronics as shown in Fig. 14.4. The 905-3 NaI(Tl) detector will be used to detect the γ_2 events at 122 keV and to start a time measurement for each sensed event. The other NaL(Tl) detector, the one with the thin window, will be used to detect the γ_1 events at 14.41 keV and to stop the time measurements. Adjust each 556 High Voltage Power Supply to the voltage that is recommended for its detector.

2. Adjust the gain of the 575A Amplifier in the Start circuit in Fig. 14.4 so that the output pulses for the 122-keV gammas from ^{57}Co are ~5 V in amplitude. Use the bipolar output of the 575A to connect to the 551 Timing SCA in the Start circuit. For reference, Fig. 14.5 shows a typical spectrum of ^{57}Co as it will appear at the output of this amplifier. Note that the 122-keV and 136-keV lines are not resolved in the spectrum

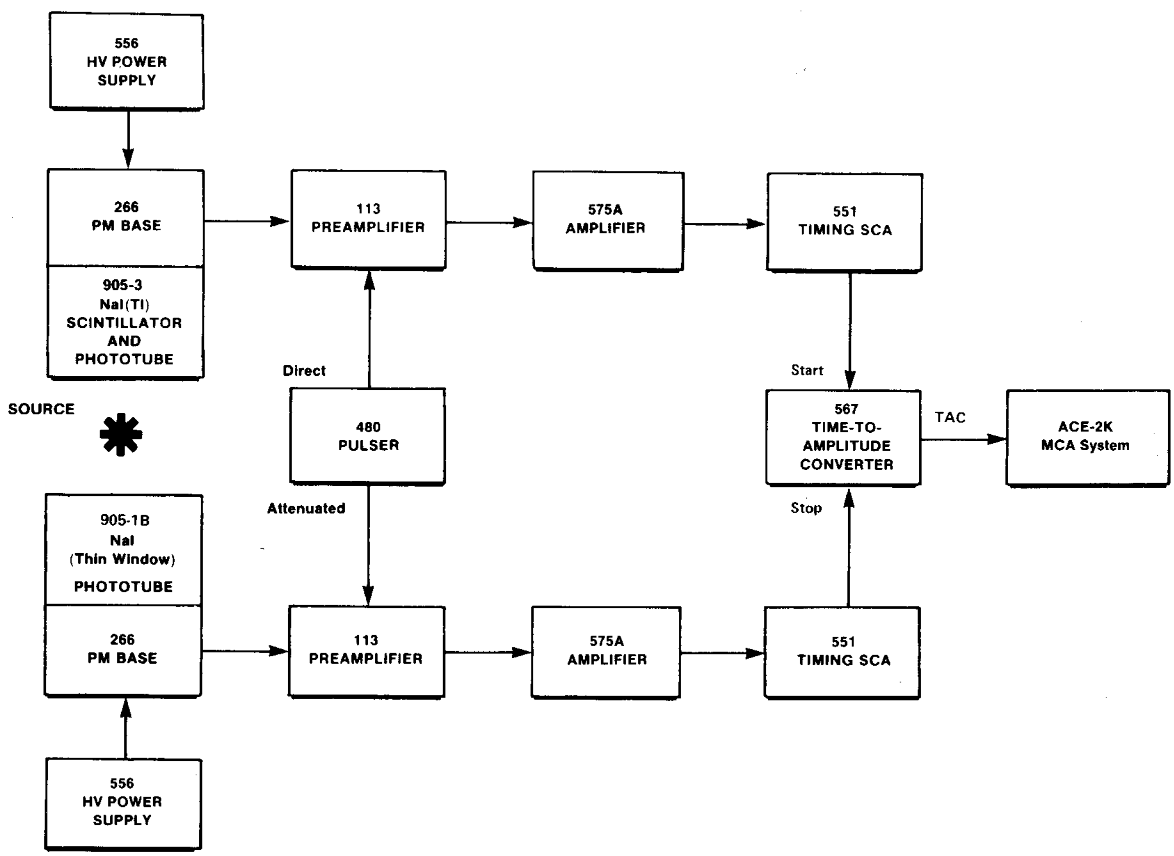

Fig. 14.4. Electronics for Lifetime Measurement with TAC.

taken with the NaL(Tl) detector as they were when taken with an HPGe detector (Fig. 14.3).

3. Set the 551 in the 2- x 2-in. NaI channel for a 400-ns delay (0.4 μs). Adjust the Lower-Level control so that the lower-level threshold lies somewhere in the valley between the photopeaks and the Compton edge (in Fig. 14.5, this is about channel 50). Set the Upper-Level control fully clockwise and select the Normal mode. Connect the fast negative output to the Start input of the 567.

4. Adjust the gain of the 575A Amplifier in the Stop circuit in Fig. 14.4 so that the output pulses for the 14.41-keV gammas from ^{57}Co are ~5 V in amplitude. Use the bipolar output of the amplifier to connect to the 551 Timing SCA in the Stop circuit. For reference, Fig. 14.6 shows a typical spectrum of the 14.41-keV gammas from a thin-window NaL(Tl) detector. The ^{57}Fe Kα_1 and Kβ_1 x rays that are shown in Fig. 14.2 do not appear in Fig. 14.6. It is also interesting to note that the resolution of the spectrum obtained with the Si(Li) system is 16 times better than that of the same spectrum taken with the thin-window NaL(Tl).

5. Set the 551 in the thin-window NaI channel for minimum delay (100 ns). Adjust the Lower-Level dial so that the lower-level threshold corresponds to the valley in the pulse height spectrum (about channel 20 in Fig. 14.6). Set the Upper-Level control fully clockwise and select the Normal mode of operation. Connect the fast negative output to the Stop input of the 567 TAC.

6. Set the 567 for its 400-ns range and Anticoincidence mode. Connect its output to the MCA.

7. Remove the ^{57}Co source and turn on the 480 Pulser. Set one X10 attenuator switch On and the other attenuator switches Off. Adjust the Pulse-Height dial and the Cal control as necessary to obtain an approximate 7-V amplitude out of the amplifiers (both amplifiers should have similar output levels ±1 V). Both of the 551 Timing SCAs should now be counting the pulses from the 480, and thus should generate a time measurement with the 567. These time measurements should be ~200 ns, the difference in delays in the two circuits.

8. Feed the 567 TAC output to the MCA and accumulate for a period of time long enough to determine the position of the peak. Increase the delay on the 551 in the Stop channel to 600 ns and determine the new peak location on the MCA. Repeat for delays of 700, 800, 850, and 875 ns.

EXERCISE

Plot a curve of delay vs channel number for your data and determine the calibration in nanoseconds per channel. This technique was outlined in Experiment 9 (Fig. 9.9).

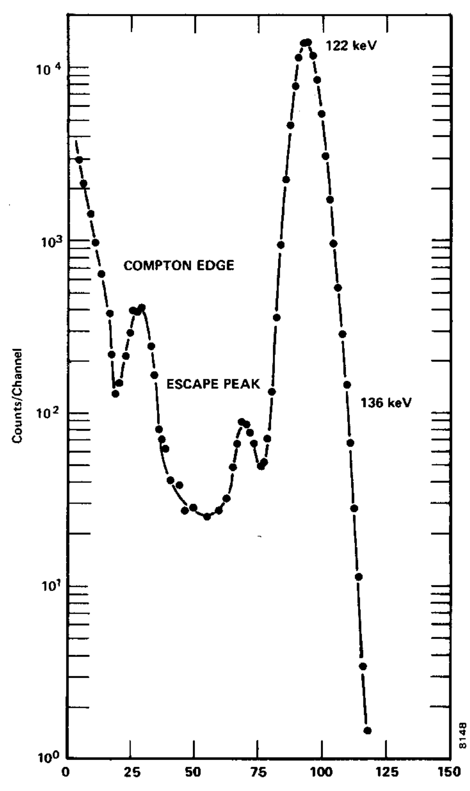

Fig. 14.5. Spectrum of ^{57}Co Taken with 2- by 2-in. NaI(Tl) Detector.

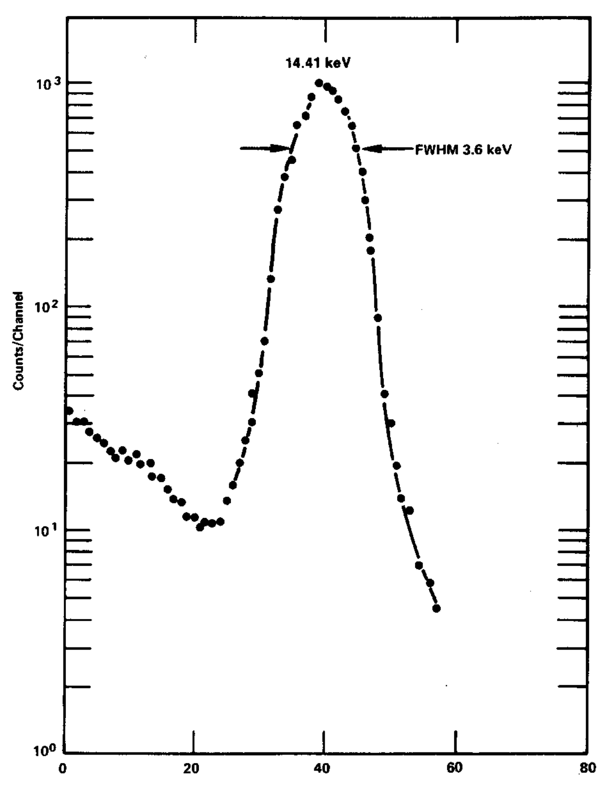

Fig. 14.6. Spectrum of 14.41-keV Gamma from ^{57}Co Taken with Thin-Window NaI(Tl) Detector.

9. Turn off the pulse generator and return the ^{57}Co source to its position as shown in Fig. 14.4. Return the delay on the 551 to 500 ns and accumulate a spectrum in the MCA. Figure 14.7 shows the results of a typical measurement that was made for this experiment. In order to smooth out the distribution, groups of ten channels were averaged and plotted. The slope of the delay vs channel number for Fig. 14.7 was 0.73 ns/channel. The lifetime of the state is therefore the product of the number of channels for half intensity times the 0.73 ns/channel. For the data in Fig. 14.7 this product is ~95 ns, which is quite close to the accepted value of 98 ns. The data in Fig. 14.7 required a 2-h run. The electronic setup and time calibration also required ~2 h. Therefore the whole experiment should require a 4-h laboratory period.

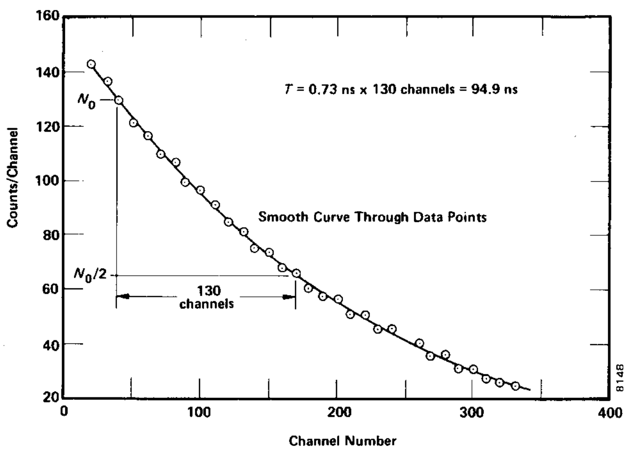

Fig. 14.7. Mean Lifetime Calculation.

EXPERIMENT 14.2

Lifetime Measurement of the 14-keV State in ^{57}Fe Using the Delayed Coincidence Method

This experiment is identical to Experiment 14.1 except for the instrument that is used to measure the lifetime. Where the TAC and MCA were used to make the measurements in the previous experiment, a fast coincidence circuit with controllable resolving time and a counter and a timer will be used in this experiment.

Procedure

1. Set up the electronics as shown in Fig. 14.8. Adjust the amplifier gains the same as in Experiment 14.1. Adjust the Lower-Level dials of both 551 Timing SCAs the same as in Experiment 14.1, with both the Upper-Level dials at 10 V.

2. Set the delay for the 551 in the A channel in Fig. 14.8 at 500 ns. Use its Pos Out for interconnection to the A Input on the 418A.

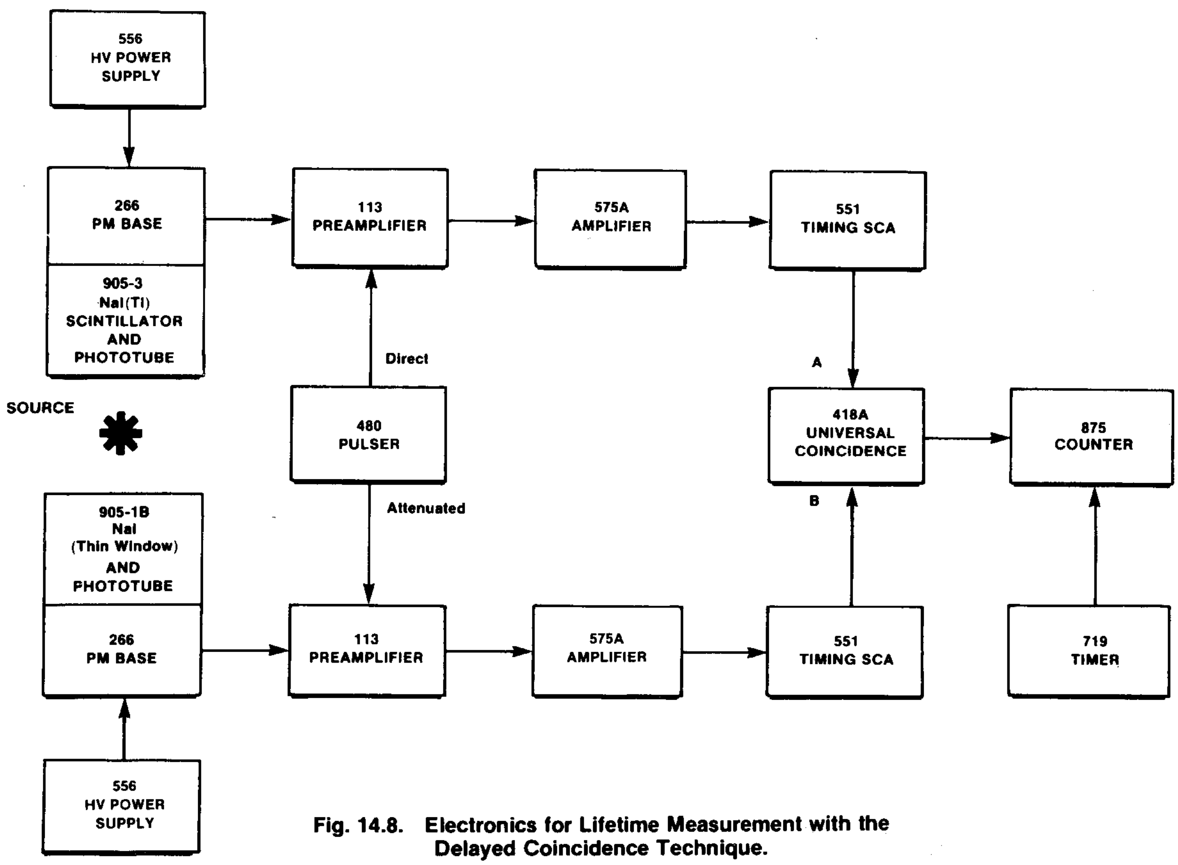

Fig. 14.8. Electronics for Lifetime Measurement with the Delayed Coincidence Technique.

3. Set the delay for the 551 in the B channel in Fig. 14.8 at 500 ns. Use its Pos Out for interconnection to the B Input on the 418A.

4. On the 418A, set the A and B switches at Coinc and the C, D, and E switches at Off. Set the Resolving Time of the 418A at maximum (2 μs). Select 2 for Coincidence Requirements.

5. Remove the ^{57}Co source and turn on the 480 Pulser. Set the attenuation for X10 as in Experiment 14.1. Adjust the Pulse-Height and Cal controls as necessary to obtain an ~7-V amplitude output for both amplifiers. Turn on the 875 Counter and observe the counting rate.

6. Narrow the resolving time of the 418A to 1 μs and adjust the delay of the 551 in the B channel for a maximum counting rate. Since the delay in both circuits is about the same, this should not require much readjustment to obtain a maximum counting rate. Reduce the resolving time of the 418A to 100 ns and again maximize the counting rate with the delay on the same 551. The system is now set for 100-ns coincidence.

7. Turn off the 480 Pulser and replace the ^{57}Co source in its operating position. Count for a time period, controlled by the 719 Timer, long enough to obtain reasonable statistics on the 875 Counter. Record the counting rate.

8. Increase the delay in the 551 in the B channel by 20 ns and repeat the measurement. Continue for delay increases by 40, 60, 80, 100, 120, 140, 160, and 180 ns.

EXERCISE

Plot the counting rate as a function of delay change. The curve should be similar to that in Fig. 14.7. From these data determine the mean lifetime of the 14-keV state of ^{57}Fe as in Experiment 14.1.

EXPERIMENT 14.3

Alternate Detectors to be Used with the Electronics in Experiments 14.1 and 14.2

Purpose

In Experiments 14.1 and 14.2 the lifetime coincidence requirement was made between two NaI(Tl) detectors. The purpose of this experiment is to point out some other detectors that would be suitable for the measurements. The rest of the electronics can be exactly the same as those indicated in Experiments 14.1 and 14.2.

The Start Side (the 122-keV Gamma)

An HPGe detector could be used for the 122-keV gamma. Figure 14.3 shows a typical output spectrum for a germanium detector. For this measurement an SCA could be set to span the 122-keV peak. Other points with regard to HPGe detectors are covered in Experiment 7. Additional information with regard to time measurements and germanium detectors can be obtained from EG&G ORTEC. Write for EG&G ORTEC's technical publication AN-42, *Principles and Applications of Timing Spectroscopy.*

An organic scintillator such as KL-236, NE-102, or Pilot B could be used to detect the 122-keV gammas. Figure 14.9 shows a spectrum of ^{57}Co obtained with an organic scintillator.

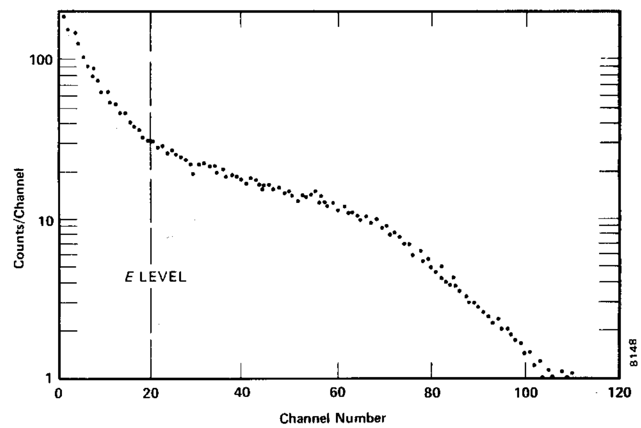

Fig. 14.9. Spectrum of ^{57}Co Obtained with an Organic Scintillator.

The organic scintillator has the advantage of being considerably faster than NaI(Tl) and hence better time resolution can be obtained. Figure 14.10 shows a typical output pulse from an EG&G ORTEC Timing Photomultiplier system and an organic detector.

The Stop Side (the 14-keV Gamma)

A Si(Li) detector could be used for the stop pulse. Figure 14.2 shows an output pulse-height spectrum for ^{57}Co that was taken with one of these high-resolution devices. These detectors also have good timing characteristics. Other features of these detectors are discussed in Experiment 8.

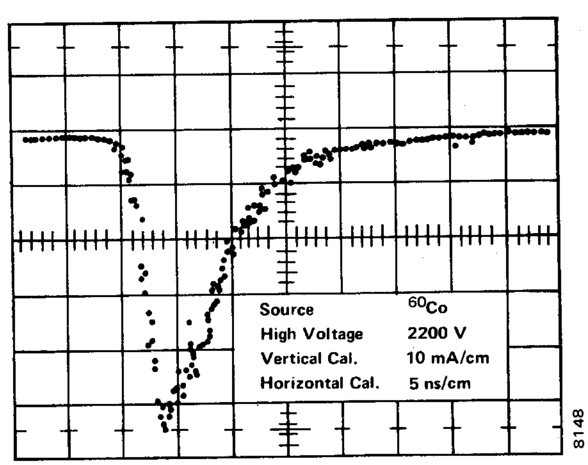

Fig. 14.10. Anode Output Pulse with EG&G ORTEC's 266 Photomultiplier Base and 905-5 Scintillation Detector.

References

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