EXPERIMENT 25

Time-of-Flight Spectroscopy

EQUIPMENT NEEDED FROM EG&G ORTEC FOR EXPERIMENT 25.1

Two Bins and Power Supplies
Transmission Detector TD-25-25-15
Surface Barrier Detector A-019-300-100
Two 142B Preamplifiers
480 Pulser
428 Bias Supply
574 Timing Amplifier
Two 473A Constant-Fraction Discriminators
457 Time-to-Amplitude Converter
572 Amplifier
ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
M367 Alpha Time-of-Flight Chamber
DB463 Delay Box
ORC-25 Cable Set
1 μCi ^{241}Am
Source Kit SK-1A
Vacuum Pump
Oscilloscope
459 5-kV Detector Bias Supply
Copper Absorber Kit MCU-5
Aluminum Absorber Kit MAL-25

EQUIPMENT NEEDED FROM EG&G ORTEC FOR EXPERIMENT 25.2

Two Model 905-11-S 8850 PM Tubes with 1-in. x 1-in. Pilot U Plastic Scintillator
Two 265-S PM Bases
Two 556 High Voltage Power Supplies
Two 583 Constant-Fraction Differential Discriminator/SCAs
DB463 Delay Box
414A Fast Coincidence
457 Time-to-Amplitude Converter
ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
Two MT-624 Stands for Photomultiplier Tubes and Source
10 μCi ^{22}Na Source
Source Kit SK-1G
MT050 Splitter
Two Bins and Power Supplies
ORC-25 Cable Set

Purpose

State-of-the-art, fast-timing techniques will be used to do two time-of-flight experiments. In the first experiment, the time-of-flight of alphas from an ^{241}Am source will be measured. This technique will be used to measure the energy loss of alphas after they pass through thin foils (as in Experiment 5). In the second experiment time-of-flight techniques will be used to measure the flight time of a gamma over a known flight path, and the velocity of the gamma, and therefore the velocity of light, can be determined.

EXPERIMENT 25.1

Alpha Particle Time-of-Flight and Energy Loss Measurements

A block diagram of the electronics used for this experiment is shown in Fig. 25.1. Alphas from the ^{241}Am source are allowed to pass through the ΔE detector and are completely stopped in the E detector. The experiment is done in a chamber that is evacuated with a fore pump. The ΔE detector is a thin, transmission detector $\sim$15 μm thick. Alphas from ^{241}Am will deposit on the order of 2 MeV in the ΔE detector. Since alphas from the source have an energy of 5.48 MeV, those passing through the ΔE detector will have an energy of $\sim$3.48 MeV. The energy of this group of alphas can easily be measured by calibrating the 572 amplifier and the MCA as outlined in Experiment 4.

The chamber is designed so that the source and the ΔE detector can be moved together towards the E detector. The start pulse for the time-to-amplitude converter, (TAC), is derived from the ΔE detector. The stop pulse comes from the E detector. When properly set up and calibrated (see Procedure), the TAC output into the MCA shows a single isolated peak in a specified channel. Next the source and the ΔE detector are moved a few centimeters closer to the E detector. The peak moves a number of channels, ΔC, in the MCA.

From the calibration of the TAC, the time difference, Δt, for this flight path difference, Δx, is measured. The velocity of the alpha particle group is determined by taking the ratio $\Delta x/\Delta t$.

This same procedure is used to measure the velocity of the alpha group after it has passed through a thin copper foil that is placed just in front of the ΔE detector. The energy loss of the alpha group is determined by this time-of-flight technique. This procedure will be repeated for various foils of different thicknesses as in Experiment 5. The results will be compared to the theoretical semiempirical calculations from the literature.

Before attempting this experiment, the student should have completed Experiments 4, 5, and 13. Experiments 4 and 5 deal with surface barrier detectors and energy loss, and Experiment 13 is an introduction to fast timing and the TAC.

Procedure

1. Set up the electronics as shown in Fig. 25.1. The interconnecting cables for all of the fast timing portions of Fig. 25.1 should be 50-Ω cable. These cables are provided in the

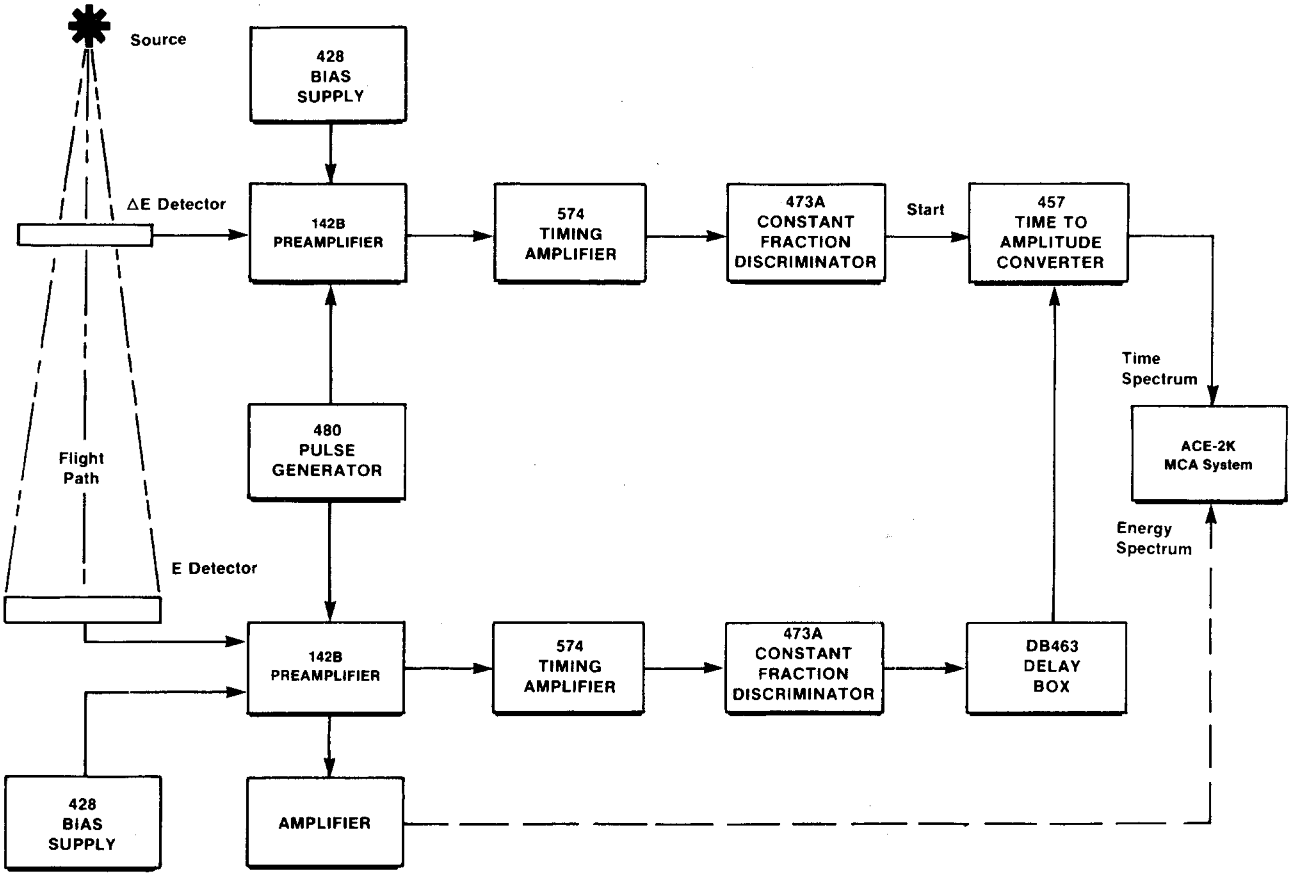

Fig. 25.1. Block Diagram of Electronics for the Alpha Particle Time-of-Flight Experiment.

ORC-25 Cable Set. The timing output of the 142B Preamplifier is connected to the input of the 574 Timing Amplifier for both the ΔE and E detectors. For the E detector the energy output, (E), of the 142B Preamplifier is fed into the 572 Amplifier for pulse-height analysis processing as in all of the previous experiments.

2. In this experiment the transmitted energy of the alphas from the source are measured in two ways: (1) directly, by calibrating the E detector, and (2) by measuring the velocity of the alphas by time-of-flight techniques. In order to measure the transmitted energy directly, it is necessary to calibrate the E detector with the ^{241}Am source. This is done by removing the ΔE detector and calibrating the E detector by normalizing the 480 pulse generator as in Experiment 4.

Make the calibration so that full scale on the MCA is ~6.0 MeV. Figure 4.9 shows the decay scheme for ^{241}Am and Fig. 4.8 shows a typical pulse height spectrum for the alphas from the source. Now that the E detector is calibrated, the ΔE detector can be replaced in its holder.

3. The timing output of the 142B ΔE Preamplifier should be fed into one of the inputs of the 574 Timing Amplifier. Adjust the 142B for minimum rise time. This procedure is outlined in the Operating and Service Manual. The 574 is a single-width NIM module that contains four independent direct-coupled amplifiers packaged in a single module. The E preamplifier timing output is fed into one of the other amplifiers on the 574. The output of the 574 is connected to the input of the 473A Constant-Fraction Discriminator for both the start and stop channels. The controls of the 473A should be set as follows: Scint 2 shaping mode, constant fraction timing mode. The output pulses from the 473A are fast negative logic pulses. These pulses are fed into the 457 TAC in the start channel and in the stop channel they go into the DB463 Delay Box. The output of the DB463 goes into the stop side of the TAC.

4. The 480 pulse generator was calibrated in step **2**. Set the 480 at 1 MeV and adjust the discriminator level (both start and stop sides) of the 473A so that fast negative output pulses are seen with a scope. The TAC settings should be as follows: 50 ns range, anticoincidence, TAC output. In the stop channel, set all delays out in the DB463 Delay Box except the 22-ns delay. Connect the output of the TAC into the MCA. The MCA should show a single peak in the lower quarter of the analyzer. The TAC can now be calibrated by changing the delay in the DB463 Delay Box and observing the corresponding shift in channel number for the MCA. Figure 25.2 shows a typical MCA spectrum that was taken for

22, 26, 30, and 34 ns delays. Take enough delay settings so that the time per channel can be determined.

5. Determine the time resolution of the system by multiplying the slope of this calibration curve by the FWHM of any of the pulser peaks. In Fig. 25.2 this value is shown to be 0.99 ns.

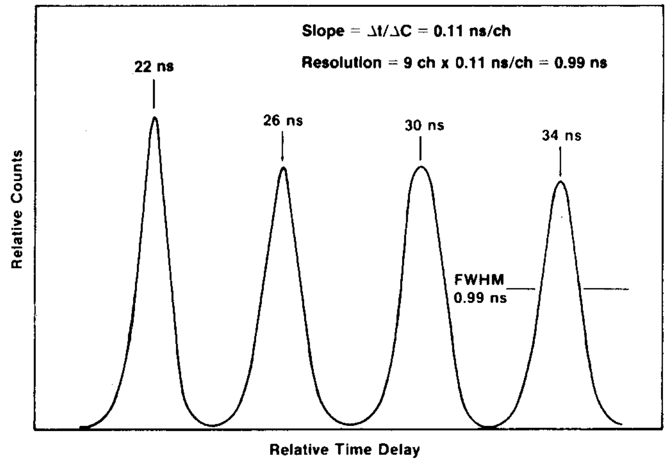

Fig. 25.2. Time-to-Amplitude Converter Calibration with the 480 Pulse Generator.

6. We are now ready to measure the time-of-flight of the alpha group after it has passed through the ΔE detector. Place the ΔE detector back in its original position as shown in Fig. 25.1. Evacuate the system and apply the bias to both detectors. Accumulate a spectrum in the MCA for a period of time long enough to accurately determine the peak position. Adjust the DB463 delay until this group is in the middle range of the MCA. Count for a period of time long enough to accurately determine its position. Record this channel, turn the bias down on both detectors, and move the ΔE detector and source in towards the E detector 3 cm. Evacuate the system with bias on, and count for a period of time long enough to determine the new peak location. From the time calibration, determine Δt. The velocity of the group is simply Δx/Δt. From this velocity calculate the transmitted alpha energy.

7. Measure the energy of the alpha particle directly and compare the results with those of step **6**. Connect the output of the 572 Amplifier into the MCA and accumulate for a period of time long enough to determine the centroid of the peak. From the energy calibration curve of the MCA, determine the energy of this transmitted alpha group. How does it compare with the time-of-flight results? Record both of these values in Table 25.1.

8. Open the vacuum system, move the ΔE detector back to its original position and place the thinnest aluminum foil directly in front of the ΔE detector. Evacuate and determine the channel position of the peak in the time-of-flight spectrum as above. Open the system, move the ΔE detector and foil 3 cm towards the E detector and evacuate. Accumulate a spectrum and determine Δt, ν, and E as in step **6**. Record this value of E under E (time-of-flight) in Table 25.1.

9. Measure the energy of the group directly as in step **7**. Record this value in Table 25.1. Repeat for all of the foils in both foil kits and fill in Table 25.1. Figure 25.3 shows the direct energy measurement for the ^{241}Am source and the various combinations of aluminum absorbers on the same drawing.

EXERCISE

From the dE/dx values in ref. 8 and the procedures in Experiment 5, calculate the theoretical energy loss that would be expected for the tansmitted alpha group. Remember, for our case, E_0 is the energy that the alpha group has when it enters

Table 25.1. Alpha Particle Time-of-Flight and Energy Loss Data.

Foil Thickness* (mg/cm^2)	E (direct) (MeV)	E (time-of-flight) (MeV)	Energy Loss (time-of-flight)	Energy Loss (theory)	% Difference
Aluminum Z = 13 0.250 0.500 0.750					
Copper Z = 29 2.00 4.00 6.00					
Silver Z = 47 0.400 0.600 0.800					

*The foils listed are nominal thicknesses. The actual thicknesses in the kit may be slightly different. The quoted thickness value on the actual foils in the kit will be accurate to ±5%.

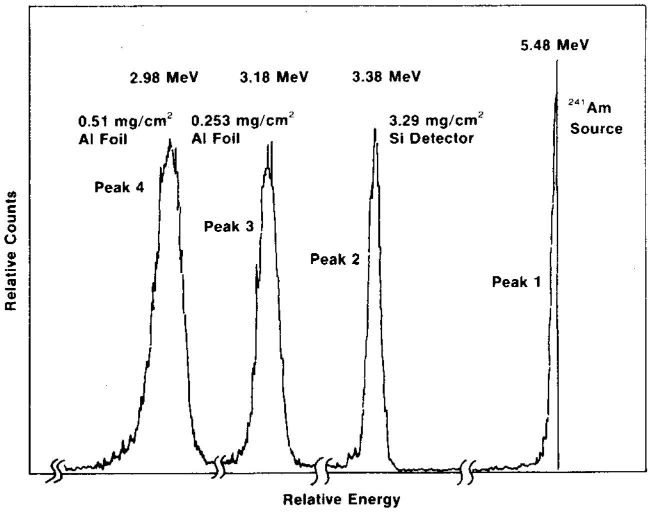

Fig. 25.3. Direct Energy Measurement.

NOTE: Peak 1 is the ^{241}Am source; Peak 2 is the transmitted spectrum through only the ΔE detector; Peak 3 is the transmitted spectrum through the ΔE detector plus 0.253 mg/cm^2 of Al; Peak 4 is the transmitted spectrum through the ΔE detector plus 0.51 mg/cm^2 of Al.

the foil (~3.4 MeV). This is shown in Table 25.1 as E (time-of-flight) with zero foil thickness. Record these values in Table 25.1 as energy loss (theory). From the data recorded in Table 25.1 determine the measured energy loss from the time-of-flight spectra. Calculate the percentage difference and record in Table 25.1.

EXPERIMENT 25.2

Gamma Ray Time-of-Flight and the Speed of Light

Figure 25.4 is a block diagram of the fast-timing coincidence system that will be used in this experiment. Under proper conditions, it will give the best time resolution possible.

The constant-fraction discriminators generate the timing information and determine the energy range of interest simultaneously. If the two gamma flashes fall within the selected energy range and are coincident within the resolving time set on the 414A Fast Coincidence unit, the TAC will

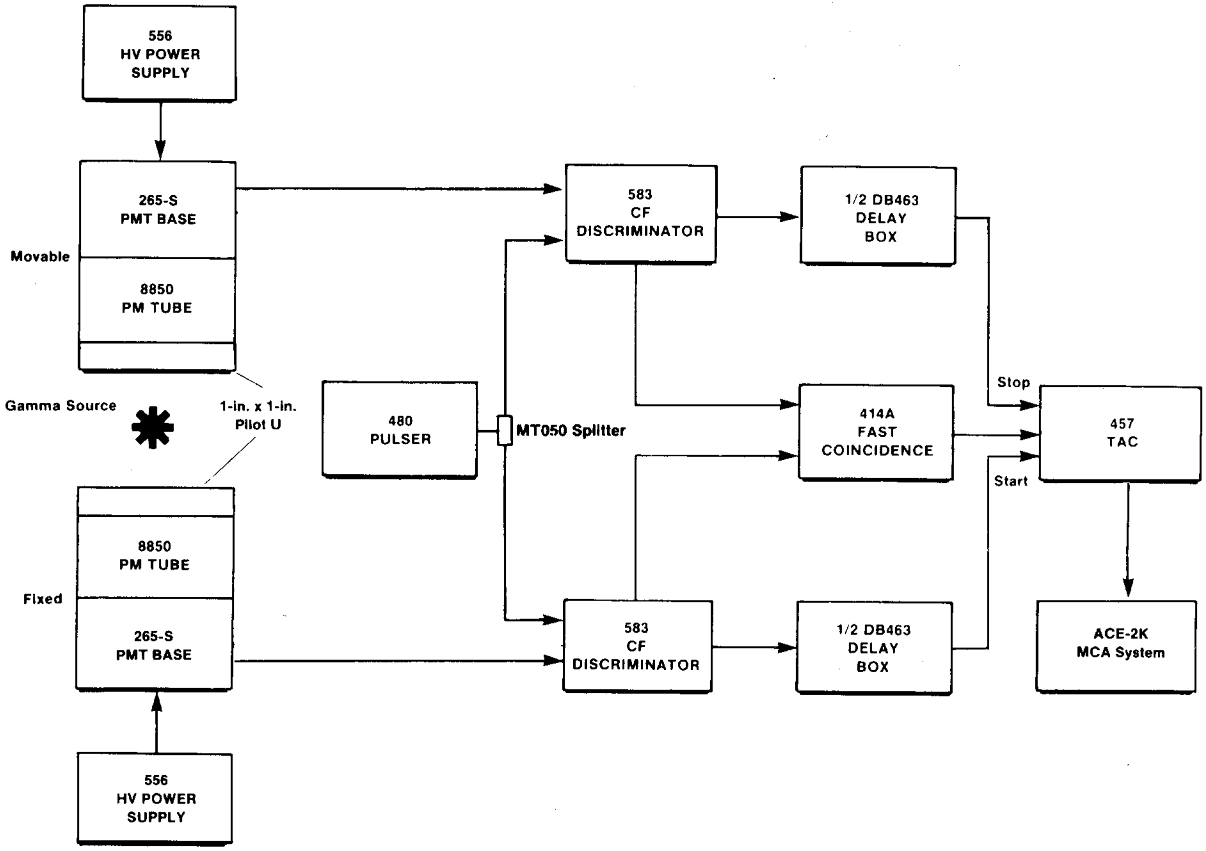

Fig. 25.4. Electronics Setup for the Gamma Ray Time-of-Flight Experiment.

be gated on and record the event. This experiment is similar to Experiment 25.1 in that the TAC will first be calibrated with a pulse generator and then the γ-γ coincidence of the 0.511-MeV γ's from ^{22}Na will be measured. Read Experiment 13 and study Fig. 13.5 before starting this experiment.

The fixed detector will be used to start the TAC and it will be stopped by the movable detector. Next the movable detector will be moved a known flight path and the time difference recorded from the MCA. The velocity of the γ will be calculated from $\gamma = \Delta x/\Delta t$. This measurement will be repeated for several different flight paths.

Figure 3.10 shows the decay scheme of ^{22}Na. Keep in mind that when the β^+ decays, two annihilation γ's of 0.511 MeV are given off with an angular separation of 180°. In this experiment one of these γ's will be used to start the time converter and the other to stop it.

If the pulse-height spectrum from the anode of either of the 265 Photomultiplier Bases is viewed, only the Compton distribution is seen. The reason for this is that the Pilot U scintillator is plastic. Therefore, it is basically a hydrocarbon, a low Z (atomic number) material. Remember that the photoelectric cross section is proportional to Z^5. Since Z is low, the photoelectric effect is essentially nonexistent. The pulse-height distribution will look similar to the neutron distribution shown in Fig. 16.4.

Procedure

1. Set up the electronics as shown in Fig. 25.4. Set the 556 High Voltage Power Supplies to the values recommended in the Operating and Service Manual. Be sure to use the 50-Ω cable which is provided in the cable package for all fast timing connections. The long cable bundle is for the movable detector. These cables are long enough to change the flight path of the movable detector by 6 m. Initially the stands that hold the two phototubes should be placed about 50 cm apart with the source stand midway between the two. Don't put the ^{22}Na source in the stand. This will be done after the system has been calibrated.

2. Connect the output of the phototubes (anodes) to the inputs of the 583 Constant-Fraction Discriminators. Use one of the timing outputs of the 583 to connect to the input of the DB463 nanosecond Delay Box. On the start side, set the delay on the DB463 at 100 ns. Set the DB463 at delays for a sum of 120 ns on the stop side. Connect a piece of 50-Ω cable (~0.40 m in length) between the two delay outputs of the 583. This sets the required constant-fraction shaping delay for the unit. Repeat for the other 583.

3. The other controls on the 583 should be set as follows: Differential mode, constant-fraction timing mode, lower level (starting) 10%, upper level (starting) 90%. Set the walk adjustment to −0.5 mV.

4. The 480 pulse generator should be on negative, attenuated output. For the 414A Fast Coincidence use the two coincidence inputs on the left. These two toggle switches should be In and the remaining two Out. Use either output of the 414A to gate the TAC. Set the resolving time of the 414A at 40 ns.

5. Set the 457 TAC to the 50-ns range, coincidence mode. Use the TAC output to the MCA.

6. Turn on the 480 Pulser and adjust the pulse height until the TAC output is being stored in the MCA. It should appear in the lower quadrant of the MCA.

7. We will now determine a delay vs pulse height curve for the TAC and the MCA as in Experiment 25.1. Change the DB463 delay on the stop side by 4 ns and record the new peak position. Continue for as many delay values as you wish, to determine the delay vs pulse height curve. Calculate the slope of the curve and determine the resolution of any of the pulser peaks.

8. Figure 25.5 shows two typical pulser peaks for delays of 4 ns and 12 ns. Both peaks in the figure have an FWHM of 8 channels, showing 0.94-ns time resolution for the pulser peaks. Turn off the pulse generator and place the ^{22}Na source in the holder in preparation for the time-of-flight data.

9. Clear the MCA and set the stop delay at 12 ns. Accumulate a spectra in the MCA for the γ-γ coincidence. It should appear in the lower quadrant of the MCA. The resolving time of the 414A can now be lowered and the upper and lower levels of the 583 adjusted for optimum resolution. When both the counting rate and the resolution are satisfactory, lock the dials down. Clear the MCA.

10. Accumulate a spectrum in the MCA for a period of time long enough to accurately determine the peak location. Record the centroid of this peak. Increase the flight path of the movable detector by 1 m and accumulate another spectrum. It should take ~25 times as long to get the same statistics as those obtained for the first measurement.

11. Determine the peak position and the channel shift. Calculate Δt from the slope of the calibration curve. Calculate $C = \Delta x/\Delta t$. How close is your value to the speed of light, 3 x

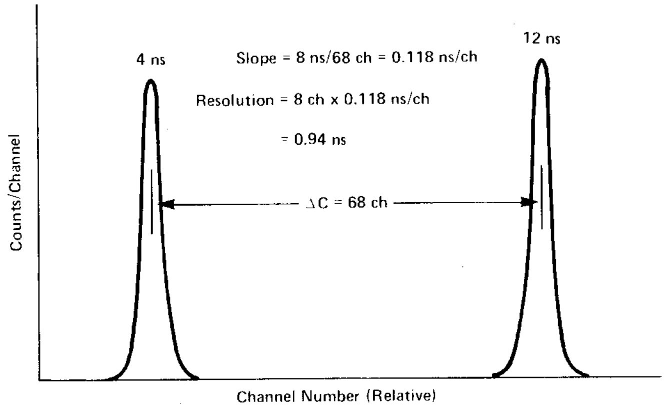

Fig. 25.5. Typical Pulser Peaks Showing the Calculation of Time/Channel for the MCA.

10^8 m/s? For the calibration shown in Fig. 25.5, ΔC should have been about 28 channels. This would give 3.3 ns, which is the correct value.

12. Repeat for flight path changes of 2, 3, and 4 m and calculate the γ velocity for each measurement. The 4-m data might take a few hours, but it should give the most accurate value for C since the major uncertainty in this experiment is in Δx, the flight path difference.

Note of Credit Parts of Experiment 25.1 were developed by Professor Dollard Demarais of the University of Alberta, Canada. A detailed experiment, "Alpha Particle Time-of-Flight" by Professor Demarais and the author, will appear in the *American Journal of Physics* in the summer of 1984.

References

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12. See also the references for Experiments 4 and 5.