

### 27.1. Purpose

Measuring how long it takes for a positron to find an electron and annihilate can be a useful tool for studying free electron densities, vacancies, voids and defects in metals, semiconductors and insulators (Ref. 1 and 2). This experiment is an introduction to the methodology. After setting up the timing electronics, positron lifetimes will be measured in cadmium (a metal) and TEFLON® (an insulator). The lifetimes will be compared to typical values for those materials, and reasons for the large difference in lifetimes will be explored.

The experiment requires 3 to 4 hours for set up, followed by an overnight data acquisition of the instrument response function with a 10  $\mu\text{Ci}$   $^{60}\text{Co}$  source. A subsequent 4-hour data acquisition is required with the Cd/ $^{22}\text{Na}$ /Cd sandwich employing a thin-window, 10  $\mu\text{Ci}$   $^{22}\text{Na}$  source. This second run can be started immediately after the prior overnight data acquisition, or it can be implemented during the next laboratory period. Finally, another overnight run of at least 10 hours with the TEFLON/ $^{22}\text{Na}$ /TEFLON sandwich is required. Unsupervised access to the laboratory will need to be prevented during the overnight runs to avoid unintended exposure to the radioactive sources.

#### Equipment Required from ORTEC

- Two each 905-21 Fast Plastic Scintillator, PMT and 265A PMT Base; (Bicron BC418 12.9 cm<sup>3</sup> truncated-cone scintillator).
- Two 556 High-Voltage Power Supplies.
- Two 583B Constant-Fraction Differential Discriminator/SCAs.
- One DB463 Delay Box.
- One 414A Fast Coincidence.
- One 480 Pulser.
- One 567 Time-to-Amplitude Converter/SCA.
- One 4001A/4002D NIM Bin and Power Supply.
- EASY-MCA 8k System including a USB cable, a suitable PC and MAESTRO-32 software.
- Coaxial Cables and Adaptors:
  - Two C-25-15INCH-S Special RG-58A/U 50- $\Omega$  coaxial cables with BNC plugs, 38-cm (15-inch) length (for the constant-fraction shaping delays on the 583B timing discriminators).
  - Three C-25-1 RG-58A/U 50- $\Omega$  coaxial cables with BNC plugs, 30-cm (1-ft) length.
  - Six C-25-2 RG-58A/U 50- $\Omega$  coaxial cables with BNC plugs, 0.61-m (2-ft) length.
  - Three C-25-4 RG-58A/U 50- $\Omega$  coaxial cables with BNC plugs, 1.2-m (4-ft) length.
  - Two C-25-12 RG-58A/U 50- $\Omega$  coaxial cables with BNC plugs, 3.7-m (12-ft) length.
  - Three C-24-2 RG-62A/U 93- $\Omega$  coaxial cables with BNC plugs, 0.61-m (2-ft) length.
  - Two C-24-4 RG-62A/U 93- $\Omega$  coaxial cables with BNC plugs, 1.2-m (4-ft) length.
  - Two C-36-12 RG-59A/U 75- $\Omega$  coaxial cables with SHV Female Plugs, 3.7-m (12-ft) length.

- MT050 50- $\Omega$  Matched Tee Signal Splitter.
- Two C-28 Terminators, 50- $\Omega$  (male BNC plug).
- POSK-22-10  $^{22}\text{Na}$  radioactive source, 10- $\mu\text{Ci}$  activity, with 3.6-mg/cm<sup>2</sup> thin polyimide windows for positron emission.
- GF-060-M-10  $^{60}\text{Co}$  source with 10  $\mu\text{Ci}$  activity.
- FOIL-CD-40 box of 10 Cadmium foils, 0.5-inch diameter  $\times$  0.040 inches thick (12.7 mm  $\times$  1.020 mm).
- PLS-SLIDER Mounts 2 each of the 905-21 scintillation detector with adjustable spacing.
- Retort Stand with Clamp, consisting of:
  - One SA04544M Ring Stand with Triangular Support.
  - One SB10760M Right-Angle Clamp Holder.
  - One SB28602M Extension Clamp (3-fingered).
- POLYCARB-SHEET Interstate Plastics LEXAN® polycarbonate sheet 0.060 inch  $\times$  12 inch  $\times$  12 inch (0.15 cm  $\times$  30.5 cm  $\times$  30.5 cm).
- PTFE-SHEET Professional Plastics virgin PTFE (TEFLON®) sheet 12 inches  $\times$  12 inches  $\times$  0.093 inches thick for making 12.7 mm diameter  $\times$  2.36 mm thick TEFLON® sample disks.
- TDS3032C 300 MHz, 2-Channel Digital Oscilloscope.

#### Equipment Required from Other Suppliers

- Long forceps or tweezers to manipulate the radioactive sources, while maintaining a distance of at least 10 cm between the source and the fingers.
- Small, flat-blade screwdriver for tuning screwdriver-adjustable controls, or an equivalent potentiometer adjustment tool.
- Volt-Amp-Ohm meter capable of measuring 0.5  $\pm$  0.1 mV.
- Box of 12 each  $\frac{3}{4}$ -inch Binder Clips.

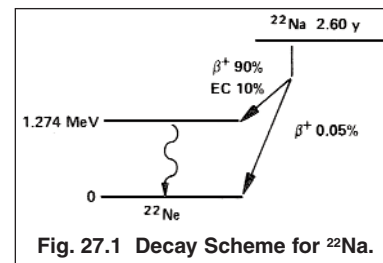
# Experiment 27

## Positron Annihilation Lifetime Spectrometry

### 27.2. The Basics of Positron Lifetime Spectrometry

#### 27.2.1. Positron Emission and Annihilation

The positrons for this experiment are generated by a  $^{22}\text{Na}$  radioactive source. As shown in Fig. 27.1,  $^{22}\text{Na}$  has a half-life of 2.6 years, and decays into  $^{22}\text{Ne}$  by either positron ( $\beta^+$ ) emission or by electron capture (Ref. 3). In 90% of the decays, positrons are emitted with an end-point energy of 545 keV, leaving  $^{22}\text{Ne}$  in the 1.274-MeV excited state. The half-life of this excited state is 3 picoseconds, resulting in prompt emission of a 1274-keV gamma-ray, as the isotope transitions to the ground state. Because of the extremely brief lifetime of the excited state, emission of the 1274-keV gamma ray can be used to mark the time at which the positron was emitted.



The Eckert & Ziegler  $^{22}\text{Na}$  source is deposited on a thin ( $3.6 \text{ mg/cm}^2$ ) polyimide (Kapton®) film, and covered with another polyimide film of equal thickness. The film is thin enough to cause negligible energy loss of the positrons as they exit the source at  $90^\circ$  to the film surface. Two disks of the sample material to be analyzed are placed in close contact with the source encapsulation, with a disk on either side of the source. The intent is to have the positrons enter the sample material with negligible interactions in the air gap between the source and the sample material. The sample material must be thick enough to completely stop the positrons, but not so thick that it severely attenuates the intensity of the 511-keV annihilation gamma rays that are created within the sample.

When the energetic positron enters the sample, it loses energy by interacting with electrons bound to the atoms, and causing ionization. This slowing down to thermal energies consumes only a few picoseconds. Once the positron is reduced to thermal energies, it has a much higher probability of being captured by an electron, as the positron diffuses through the material.

For metals, there is a high density of free electrons in the conduction band. When the positron encounters an attractive free electron, the two combine in mutual annihilation. The total mass of the pair is converted to energy, which is emitted as two gamma rays of equal energy travelling in opposite directions. The energy of each annihilation gamma ray is

$$E_\gamma = m_e c^2 = 511 \text{ keV} \quad (1)$$

Where  $m_e$  is the rest mass of the electron (or the positron) and  $c$  is the speed of light. At least two photons must be produced in order to satisfy conservation of momentum. For metals, the positron mean lifetime is typically in the range of 100 to 450 picoseconds (Ref. 2).

Insulators represent the opposite extreme compared to metals, because insulators have virtually no electrons in the conduction band. For insulators, the positron has to find a loosely bound valence electron. This favors the formation of Positronium, which is an atom like Hydrogen, but with the proton replaced by a positron. Positronium can exist in two different states (Ref. 4). For para-Positronium, the spins of the electron and the positron are in opposite directions. This state has a mean lifetime of 125 ps. In ortho-Positronium both spins are in the same direction. Ortho-Positronium has a much longer mean lifetime, 142 ns.

Para-Positronium decays primarily by emitting two 511-keV gamma rays at essentially  $180^\circ$  to each other. It can also decay by the emission of four gamma rays, but a branching ratio of  $1.4 \times 10^{-6}$  renders that decay mode rather insignificant. Ortho-Positronium decays primarily by the emission of three gamma rays, whose energies sum to 1022 keV. It can also decay by the emission of five gamma rays, but a branching ratio of  $\sim 1.0 \times 10^{-6}$  makes that mode a negligible alternative.

Taking all of these effects into account, the lifetime of positrons is much longer in insulators than in metals, because of the scarcity of free electrons in an insulator.

#### 27.2.2. The Effect of Vacancies, Voids and Defects

The positron lifetime is affected by vacancies, voids and defects in the material being studied (Ref. 1 and 2). All of these imperfections alter the density of electrons at the location of the flaw. Thus, the positron has greater difficulty in finding an electron, and the positron lifetime is increased accordingly. For example, pure Molybdenum metal exhibits a typical

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positron annihilation mean lifetime of 121 ps. But, the existence of vacancies in the metal can increase that lifetime by 60 ps, and voids can increase the lifetime by 340 ps (Ref. 2). Thus, positron lifetime spectrometry can be used to study the concentration of defects in materials. Work-hardening of metals, by hammering or flexing, can increase the defect concentration and extend the positron lifetime in the metal. Annealing the metal at an elevated temperature can eliminate the defects and decrease the positron lifetime to the value measured before work-hardening occurred.

In this experiment, the positron lifetime in Cadmium will be measured as an example of the lifetime obtained in metals. Pure Cadmium typically yields a positron mean lifetime of 187 ps. This lifetime can be extended by 80 ps as a result of vacancies in the metal (Ref. 2). TEFLON® (polytetrafluoroethylene) will be studied as an example of an insulator. TEFLON® normally exhibits three lifetime components (Ref. 5). The most intense component has a mean lifetime ( $\tau_1$ ) of approximately 0.3 ns, the second most intense component has a mean lifetime ( $\tau_2$ ) in the range of 0.6 to 1.1 ns, and the least intense component has a mean lifetime ( $\tau_3$ ) in the range of 1.7 to 4.1 ns.

### 27.2.3. The Mathematical Models

For the development of the expected shape of the positron lifetime spectrum, start by ignoring the finite width of the prompt response of the time spectrometer and the flat random background under the spectrum. Generally, the shape of the spectrum can involve  $k + 1$  exponential decay components, each with a different lifetime. Thus the shape of the ideal spectrum can be described by Equation (2).

$$y(t) = \sum_{i=1}^{k+1} \frac{I_i}{\tau_i} \exp\left(-\frac{t}{\tau_i}\right) \quad (2)$$

Where  $y(t)$  is the counting rate (vertical axis) as a function of the time  $t$  (horizontal axis),  $\tau_i$  is the mean lifetime of the  $i^{\text{th}}$  component, and  $I_i$  is the intensity of the  $i^{\text{th}}$  component<sup>1</sup>. Usually,  $\tau_1 = \tau_b$ , where  $\tau_b$  is the mean lifetime for the bulk material without defects. Positron trapping in open-volume defects leads to long-lived decay components. The trapping rate in a particular type of defect,  $K_d$  can be related to the defect concentration  $C_d$ , and the mean lifetimes by

$$K_d = \mu_d C_d = \frac{I_d}{I_b} \left( \frac{1}{\tau_b} - \frac{1}{\tau_d} \right) \quad (3)$$

Where  $\mu_d$  is the trapping coefficient,  $I_b$  and  $\tau_b$  are the intensity and the mean lifetime, respectively, for the bulk material component in Equation (2), and  $I_d$  and  $\tau_d$  are the intensity and mean lifetime, respectively, for the trapping defect component in Equation (2). Obviously, the bulk component will have the highest intensity and the shortest mean lifetime. The components caused by trapping will have lower intensities and longer mean lifetimes. Via Equation (3), the prevalence of the various types of positron traps can be calculated from the measured lifetime spectrum (Ref. 6).

The lifetime spectrum is somewhat complicated by the fact that the detectors and electronics in the time spectrometer have a finite time resolution, and because there is a flat random background that accumulates under the spectrum. The flat background,  $B$ , modifies equation (2) to

$$y(t) = B + \sum_{i=1}^{k+1} \frac{I_i}{\tau_i} \exp\left(-\frac{t}{\tau_i}\right) \quad (4)$$

When the lifetime is zero and the instrumentation is properly adjusted, the time spectrometer generates a prompt peak in the time spectrum that has approximately the shape of a Gaussian function.

$$G(t) = \frac{1}{\sigma \sqrt{\pi}} \exp\left[-\left(\frac{t-t_0}{\sigma}\right)^2\right] \quad (5)$$

<sup>1</sup>As stated in equation (2), the intensity  $I_i$  is the total area under the exponential from  $t = 0$  to  $\infty$ .

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The full width of this peak at half its maximum height (FWHM) is calculated from

$$\text{FWHM} = 2 \sigma \sqrt{\ln 2} \tag{6}$$

Typical values for the FWHM range from 180 to 250 ps depending on the quality and tuning of the time spectrometer (Ref. 7 and 8).

The prompt response in Equation (5) is usually measured using the 1.17-MeV and 1.33-MeV gamma rays from a  $^{60}\text{Co}$  source, with the energy windows set for the 1.274-MeV and 511-keV energies from the  $^{22}\text{Na}$  source. The 1.33-MeV gamma ray follows the 1.17-MeV gamma ray with a 0.7-ps lifetime (Ref. 3). Thus, the two gamma rays from  $^{60}\text{Co}$  are virtually in prompt coincidence. Figures 27.2 and 27.3 show a prompt response spectrum for a typical time spectrometer. The vertical (counts) scale is linear in Fig. 27.2, making it easy to identify the FWHM and the Gaussian shape. Fig. 27.3 is the same spectrum, but with a logarithmic vertical scale. This makes it easier to judge the symmetry of the response function in the wings of the Gaussian peak. The calibration of the horizontal time scale is 6.345 ps/channel, and the FWHM is 222 ps. Note that the Gaussian peak is slightly skewed in the tail on the left side of the peak. Usually, this asymmetry can be minimized by tweaking the WALK adjustments of the 583B Constant-Fraction Differential Discriminators.

The lifetime spectrum measured by the time spectrometer is a convolution of Equations (4) and (5), viz.,

$$N(t) = G(t) \otimes Y(t) = \int_{-\infty}^{\infty} G(t - t') Y(t') dt' \tag{7}$$

As shown in Fig. 27.4, the prompt response function for the time spectrometer blurs the beginning of the lifetime spectrum near  $t = 0$ , but has little effect on the shape of the spectrum at much later times. For a spectrometer with infinitesimal time resolution, the beginning of the spectrum should rise abruptly from zero to the maximum value at the start of the exponential decay. The gradual rise of the function from 0 to 1 ns in Fig. 27.4, represents the integration of the finite prompt response function as described in Equation (7). If the dominant lifetime is large compared to the width of the prompt instrument response function, the time taken to rise from 12% of the maximum to 76% of the maximum at the beginning of the lifetime spectrum corresponds to the FWHM of the instrument response function,  $G(t)$ .

Note that the positron lifetime recorded in Fig. 27.4 reveals three components,  $\tau_1$ ,  $\tau_2$ , and  $\tau_3$ . For accurate measurement of the positron lifetime components, sophisticated software is usually employed to implement a least-squares fit of Equation (7) to the recorded spectrum. From that software analysis the intensities and lifetimes of the various components can be extracted, together with the estimated uncertainty of those parameters. In this experiment, simpler methods will be employed to estimate the mean lifetimes.

(6)

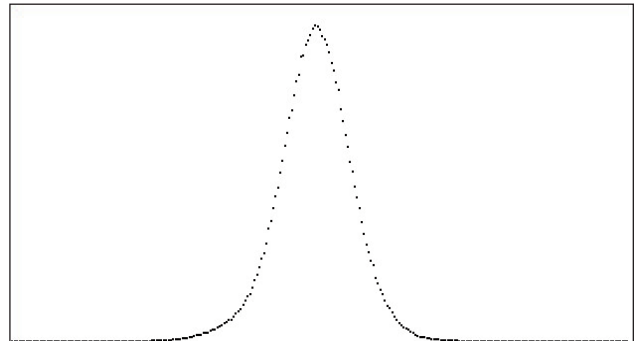


Fig. 27.2. The Prompt Instrument Response Function,  $G(t)$ , for a Lifetime Spectrometer Acquired using a  $^{60}\text{Co}$  Source with the Energy Windows Set from 500 to 1000 keV on the Start Detector and from 200 to 380 keV on the Stop Detector.

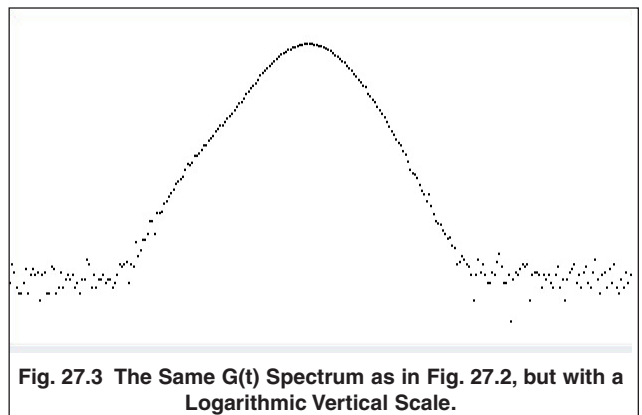


Fig. 27.3 The Same  $G(t)$  Spectrum as in Fig. 27.2, but with a Logarithmic Vertical Scale.

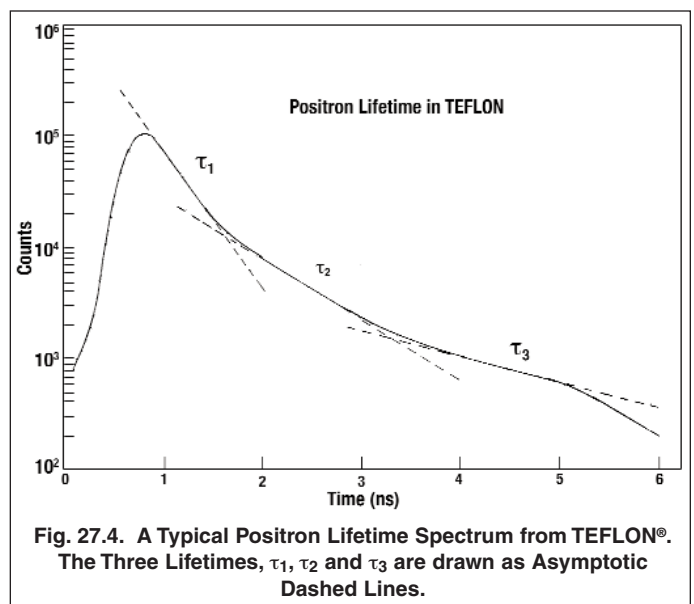


Fig. 27.4. A Typical Positron Lifetime Spectrum from TEFLON®. The Three Lifetimes,  $\tau_1$ ,  $\tau_2$  and  $\tau_3$  are drawn as Asymptotic Dashed Lines.

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For metals, the positron mean lifetime is typically in the range of 100 to 450 picoseconds. This is not large compared to the width of the prompt instrument response function (FWHM = 222 ps). Consequently the positron lifetime shows up as a more gradual linear slope on the right side of the time peak, when the peak is displayed with a logarithmic vertical scale.

It is important to note that exponential decays become straight lines when plotted with a logarithmic vertical scale (counts or intensity) versus a linear horizontal scale for the time axis. Consider Equation (2), when there is only one lifetime component,  $(I_1, \tau_1)$ .

$$y_1(t) = \frac{I_1}{\tau_1} \exp\left(-\frac{t}{\tau_1}\right) \quad (8)$$

Taking the logarithm of both sides of Equation (8), yields:

$$\ln[y_1(t)] = \ln\left[\frac{I_1}{\tau_1}\right] - \left(\frac{t}{\tau_1}\right) \quad (9)$$

This is the equation of a straight line, with a slope of  $-1/\tau_1$ . Consequently, plotting the lifetime spectrum with a logarithmic vertical scale (counts) versus a linear horizontal scale (time) allows one to identify the straight-line region of the decay. The slope of that straight-line segment can be used to measure the mean lifetime,  $\tau_1$ . It can also be deduced from Equation (8) that  $y_1(t)$  decreases by a factor of  $e = 2.718$  over any interval of time equal to the mean lifetime,  $\tau_1$ .

When the logarithm of the prompt instrument response function is calculated from Equation (5), it can be observed that  $\ln[G(t)]$  falls off in proportion to  $-(t - t_0)^2/\sigma^2$ . This is a much more rapid decline with time than experienced in Equation (9). Thus, when  $(t - t_0) \gg \sigma$ , the lifetime in Equation (9) dominates the data, if  $\tau_1 \gg \sigma$ . In this case, the slope of the logarithm of the lifetime curve can be measured at large values of  $t$  to determine  $\tau_1$ . Be aware that it is the natural logarithm ( $\ln(x)$ ; base  $e$ ) that is used in equation (9), not the common logarithm ( $\log(x)$ ; base 10), and  $\ln(x) = 2.3 \log(x)$ .

### 27.2.4. The Sample/Source/Sample Sandwich

The positrons leave the  $^{22}\text{Na}$  source in all directions, and will annihilate in any material they encounter in their path. Therefore, it is important to ensure that the material to be studied completely encapsulates the  $^{22}\text{Na}$  source. Otherwise, lifetime spectra from unintended adjacent materials will contaminate the spectrum. The  $^{22}\text{Na}$  source has an active diameter of 5.08 mm in the center of the 12.7 mm diameter source disk. The material to be studied must be in the form of two sample disks, each with a least a 12.7 mm diameter. A sample disk is placed on either side of the source disk to form a sandwich. The thickness of each sample disk must be greater than the range of 545-keV positrons in the material. Table 27.1 lists the typical positron lifetimes for a variety of materials (free of defects) (Ref. 2), and includes the range for 550-keV positrons in the material (Ref. 9). A thickness of 1.5 to 2 times the range is usually acceptable. The

Atomic Number	Element	Mean Lifetime (ps)	Range for 550-keV Positrons (g/cm <sup>2</sup> )	Density (g/cm <sup>3</sup> )	Range for 550-keV Positrons (cm)	Photon Mass Absorption Coefficient at 500 keV (cm <sup>2</sup> /g)	% Transmission of 500-keV photon at Range Thickness
13	Al	166	0.258	2.70	0.0954	8.45E-02	97.8
26	Fe	107	0.288	7.87	0.0366	8.41E-02	97.6
28	Ni	110	0.285	8.90	0.0320	8.70E-02	97.6
29	Cu	122	0.298	8.96	0.0332	8.36E-02	97.5
30	Zn	160	0.297	7.13	0.0416	8.45E-02	97.5
40	Zr	165	0.315	6.51	0.0484	8.69E-02	97.3
42	Mo	121	0.319	10.22	0.0312	8.85E-02	97.2
47	Ag	138	0.327	10.50	0.0311	9.32E-02	97.0
48	Cd	187	0.332	8.65	0.0384	9.25E-02	97.0
50	Sn	201	0.337	7.31	0.0461	9.37E-02	96.9
73	Ta	113	0.369	16.65	0.0221	1.35E-01	95.1
79	Au	118	0.375	19.32	0.0194	1.53E-01	94.4
Kapton Polyimide Film		382	0.220	1.42	0.1548		
Polytetrafluoroethylene (TEFLON)			0.241	2.20	0.1095	8.38E-02	98.0

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transmission of the thickness of sample for 500-keV gamma rays is also listed in table 27.1 (Ref. 10). For reasonable thicknesses of the sample (1 to 2 times the positron range), the transmission of the 511-keV gamma rays is acceptable.

#### 27.2.5. The Positron Lifetime Spectrometer

Figure 27.5 illustrates the block diagram for the electronic modules in the Positron Lifetime Spectrometer. The gamma-rays from the radioactive source are detected in BC418 plastic scintillators. The BC418 scintillator responds to each detected gamma-ray photon with a flash of light having a rise time of 0.5 ns and a 1.4-ns decay time. The photomultiplier converts the light flash into an amplified signal of electrons to produce an analog, electronic pulse at the anode output on the PMT base. The pulse rise time is about 2 ns and the width is approximately 8 ns. The amplitude of this negative pulse is proportional to the energy deposited in the scintillator by the gamma ray.

The 583B Constant-Fraction Differential Discriminators are responsible for marking the exact

arrival time of the pulses from the Scintillator/PMT assembly. By generating a timing logic pulse when the analog anode pulse reaches 20% of its maximum amplitude, the 583B ensures that all pulses are timed from the same phase point, independent of the pulse amplitude (Ref. 11). In addition to the timing function, the 583B has upper- and lower-level discriminators that are used to select the range of pulse heights (energies) that will be accepted to generate the timing logic pulses. The 583B connected to the Start Input of the TAC will have its discriminators adjusted to accept only the 1274-keV gamma rays from the  $^{22}\text{Na}$  source, while rejecting all of the 511-keV gamma rays. The discriminators on the 583B producing the Stop signal will be adjusted to accept about 90% of the 511-keV gamma-rays, while rejecting 65% of the 1274-keV gamma rays. These constant-fraction and discriminator features will enable narrow peaks to be accumulated in the time spectrum, with symmetric, Gaussian profiles for gamma rays in prompt coincidence.

The timing logic pulses from the 583B timing discriminators are passed through a DB463 Delay Box with selectable coaxial cable delays to compensate for the transmission delay of the 414A Fast Coincidence. The Delay Box also serves to retard the Stop signal so that it arrives a convenient time after the Start pulse at the inputs to the 567 Time-to-Amplitude Converter. The Time-to-Amplitude Converter (TAC) transforms the difference in arrival times between the Start and Stop pulses into an analog pulse height. Subsequently, the EASY-MCA 8k digitizes the analog pulse amplitude, and stores the event as one count in the channel corresponding to the pulse height. As multiple Start-Stop pairs are processed during a data acquisition period, the EASY-MCA builds up a histogram that represents the number of pairs versus their difference in arrival times. The result is a positron annihilation time spectrum.

In coincidence experiments, the TAC can be flooded with a lot of Start pulses for which there are no corresponding Stop events. This causes a lot of useless dead time in the TAC. The addition of the 414A Fast Coincidence overcomes this situation by opening the Start Gate on the TAC only when it detects a pair of Start and Stop events within 110 ns of each other.

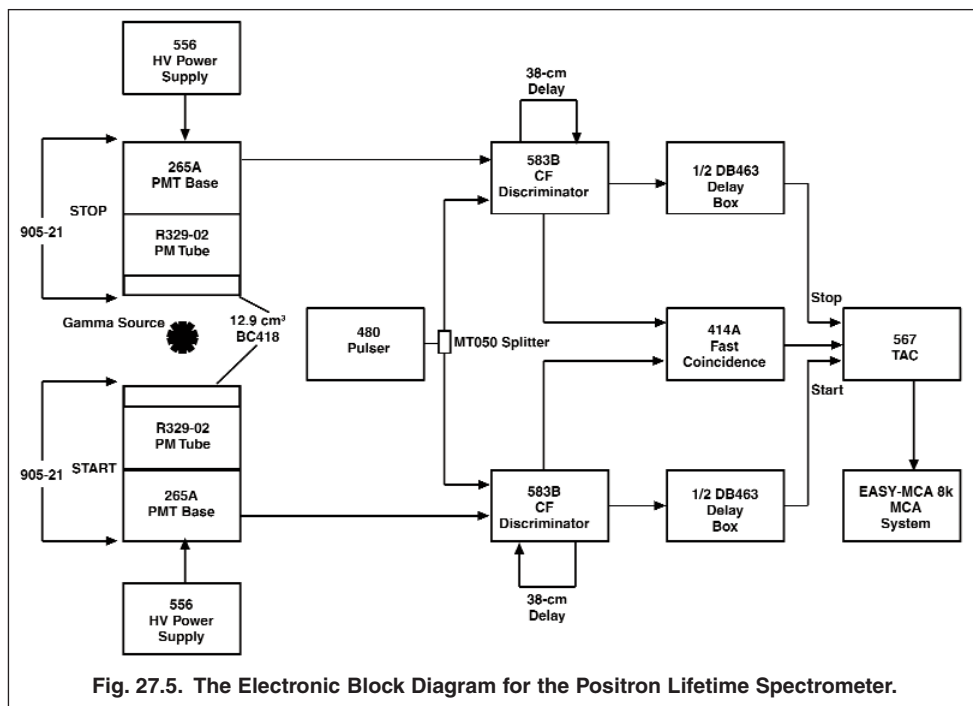


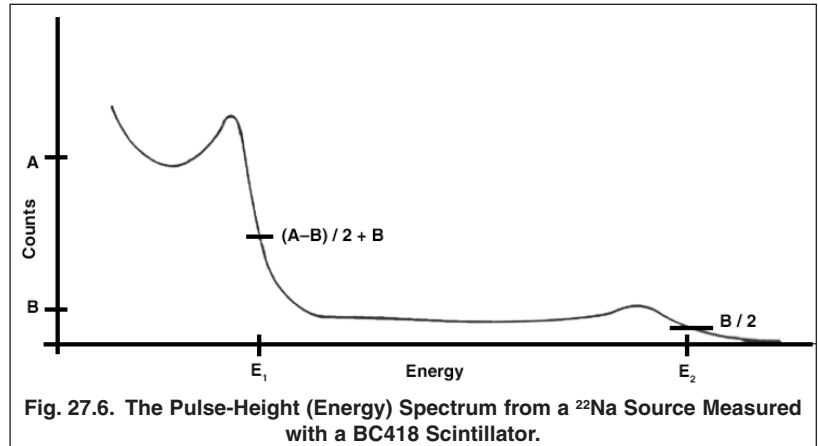
Fig. 27.5. The Electronic Block Diagram for the Positron Lifetime Spectrometer.

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### 27.2.6. The Detector Pulse-Height Spectrum for $^{22}\text{Na}$

Figure 27.6 shows the typical pulse-height (energy) spectrum delivered by a BC418 scintillator on a photomultiplier tube (Ref. 12). Because BC418 is composed entirely of hydrocarbon compounds, gamma-ray detection in the scintillator is dominated by the Compton scattering interaction. The photopeak is absent, because the cross section for the photoelectric interaction is proportional to  $Z^5$ , and the average atomic number is low, i.e., about half way between  $Z = 1$  and  $Z = 12$ . High-atomic-number scintillators, such as  $\text{NaI(Tl)}$ , generate photopeaks with excellent energy resolution, but lack the sub-nanosecond timing properties offered by fast plastic scintillators.



The 1.274-MeV gamma ray causes a rather flat Compton distribution in the energy spectrum, with a Compton edge at 1.06 MeV, ( $E_2$  in Fig. 27.6). Offering noticeably greater intensity, the 511-keV annihilation gamma rays produce a Compton edge at 341 keV ( $E_1$  in Fig. 27.6), with a broad Compton distribution extending towards zero energy. (For details on the Compton edge and Compton distribution, see Experiment 3.) This pulse-height (energy) spectrum will be referenced when setting up the discriminators on the 583B timing discriminators.

## 27.3. Set-Up and Calibration Procedures

### 27.3.1. Basic Connections

**NOTE:** 50- $\Omega$  RG-58A/U coaxial cables must be used for all the fast, negative timing signals. For the slow, positive logic pulses, 93- $\Omega$  RG-62A/U cables can be used.

1. If not already accomplished, mount the two 905-21 Scintillator/PMT/PMT-Base assemblies on the Bertelkamp PLS-SLIDER as shown in Fig. 27.7. Initially, the distance between the front surfaces of the scintillators can be set to 5.6 cm. Take advantage of the 3.7-m cables to locate the detectors as far away from the supporting electronics and personnel as possible. Position the retort stand and clamp for mounting the source half-way between the two detectors. But, do not install the 10- $\mu\text{Ci}$   $^{22}\text{Na}$  source until needed, in order to minimize radiation exposure.
2. Place a C-28 50- $\Omega$  terminator on the DYNODE output of each 265A PMT Base.
3. Insert the modules in the NIM Bin, but leave the Bin power and HV power turned off. To avoid confusion, it may be advantageous to install a 556 HV Power Supply at each end of the bin, and locate a 583B timing discriminator next to each HV supply. This organizes the controls specific to each detector at opposite ends of the bin. The rest of the modules can be located anywhere in the remaining bin space. Note that the DB463 Delay Box and the EASY-MCA 8k do not go in the bin.
4. Using a 3.7-m C-36-12 cable, connect the HV OUTPUT on the rear of the 556 at the right end of the bin to the HIGH VOLTAGE input on the STOP 265A PMT Base. Make sure that the POLARITY switch on the rear panel of the 556 is turned to NEGative. Using a 3.7-m C-25-12 cable connect the ANODE output on that same PMT Base to the INPUT of the 583B located at the right end of the bin. Connect one of the 38-cm-long C-25-15INCH-S Special RG-58A/U 50- $\Omega$  coaxial cables between the two DELAY connectors on this 583B front panel.



Fig. 27.7. The Two Scintillation Detectors Mounted on the Bertelkamp PLS-SLIDER.

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5. Repeat the connections in step 4, but with the START detector and the 556 and 583B modules at the left end of the bin.
6. Using 0.61-m C-25-2 RG-58A/U 50- $\Omega$  coaxial cables, connect the TIMING OUTPUT of the left-end 583B to the top left INPUT on the DB463 Delay Box. Connect the OUTPUT of this delay section to the INPUT of the top right delay section of the DB463. Connect the OUTPUT of this latter delay section to the START INPUT of the 567 TAC.
7. Repeat the connections in step 6 for the right-end 583B, the lower delay sections on the DB463, and the STOP INPUT of the 567 TAC.
8. Using a 0.61-m C-24-2 RG-62A/U 93- $\Omega$  coaxial cable, connect the BK OUT (blocking output) of the left-end 583B to the A COINCidence input on the 414A.
9. Repeat step 8 for the right-end 583B and the B COINCidence input of the 414A.
10. On the 414A set the INPUT CONTROL switches to IN for inputs A and B, and OUT for inputs C and D. Set the RESOLVING TIME dial to its maximum (clockwise) value (110 ns) and lock the dial.
11. Using a 0.61-m C-24-2 RG-62A/U 93- $\Omega$  coaxial cable, connect the 414A OUTPUT to the START GATE input on the 567 TAC.
12. Using a 1.2-m C-24-4 RG-62A/U 93- $\Omega$  coaxial cable, connect the TAC OUTPUT on the 567 to the analog INPUT on the EASY-MCA 8k analyzer.
13. Make sure the EASY-MCA is connected to the supporting computer via a USB cable and that the MAESTRO-32 software is running on the computer.

#### 27.3.1. Initial Settings

1. On both 583B timing modules, set the UPPER LEVEL dial to its maximum clockwise value. Set the LOWER LEVEL dial to 50 mV. Set the DIFF/INT switch to DIFFerential, and place the CF/SRT switch in the CF position. Turn the BK OUT WIDTH to its maximum value (1  $\mu$ s). Using a voltmeter on the front-panel test point, turn the WALK screwdriver adjustment to achieve a reading of  $-0.5$  mV on the voltmeter.
2. For the sections of the DB463 supporting the Start signal, select a total delay of 100 ns. On the sections supporting the Stop signal, set the total delay to 120 ns.
3. On the 567 TAC set the STROBE switch to INTernal, the START GATE switch to COINCidence, the STOP GATE switch to ANTicoincidence, and the TAC INHIBIT switch to the OUT position. Select the 50-ns RANGE and the X1 MULTIPLIER.
4. With the MAESTRO-32 software operating the EASY-MCA, select a conversion gain of approximately 4000 channels full scale. Set the ADC ULD to 100% of full scale and the ADC LLD to 2% of full scale. Turn the ADC Gate OFF. Set all preset counting and time limits to OFF.
5. Turn on the 4001A/4002D NIM Bin power.
6. Choose an initial High Voltage setting of  $-2000$  V on both 556 High Voltage Power Supplies, and turn the two power supplies on.
7. Consult the Appendix on how to assemble the Cd/<sup>22</sup>Na/Cd sample/source/sample sandwich, and how to support it between the two detectors with the retort stand and clamp. Mount the sandwich half way between the two detectors, ensuring that the Cd disks are concentric with the common, axial centerlines of the two detectors. To avoid unnecessary exposure to the radiation from this source, maximize your distance from the source, and minimize the time spent in close proximity to the source.
8. For the detector providing the Start signals, disconnect the ANODE output from the 583B, and connect it instead to the oscilloscope signal input. Set the input impedance of the oscilloscope to 50  $\Omega$  to properly terminate the 50- $\Omega$ , C-25-12 coaxial cable. With a horizontal scale of 5 ns/cm, and a vertical scale of 1 Volt/cm, trigger the oscilloscope on the negative anode signals to display the pulses. The pulse-height distribution observed on the oscilloscope should correspond to the distribution illustrated in Fig. 27.6.

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9. Check with the Laboratory Manager regarding whether or not the photomultiplier tube base has been adjusted for optimum performance. If not, then iteratively adjust the 2nd dynode voltage and the focus control to achieve the maximum signal amplitude at the anode output. Next, raise the high voltage applied to the PMT enough to cause at least 30% of the output pulses to saturate, i.e., exhibit a flattening of their maximum amplitude. Adjust the 12th dynode voltage control to maximize the pulse-height voltage at which flattened tops occur.
10. Adjust the High Voltage applied to this detector until the maximum pulse height observed on the oscilloscope is approximately 2 Volts. To avoid distorting the pulse amplitude, the oscilloscope must add a rise time that is less than 1.5 ns. A 300-MHz oscilloscope bandwidth (corresponding to a 1.2-ns rise time) should be adequate.
11. Record the amplitude of the pulses corresponding to the 1.06-MeV Compton edge from the 1.274-MeV gamma ray ( $E_2$  in Fig. 27.6). Label this recorded voltage  $V_{1060}$ . Observe and record the amplitude where the intensity increases for pulses at and below the 341-keV Compton edge from the 511-keV gamma rays. Denote this voltage as  $V_{341}$ .

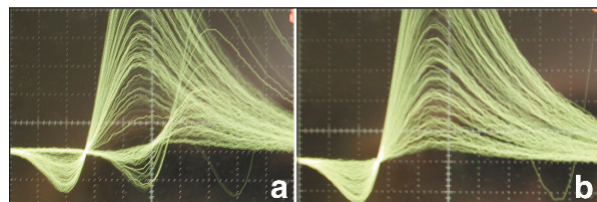
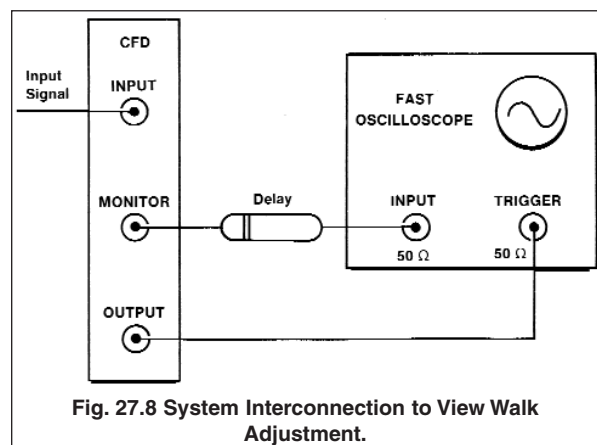
### LINEAR RESPONSE VALIDATION:

- a. Calculate the ratio,  $V_{341}/V_{1060}$ .
  - b. How closely does the voltage ratio match 0.341/1.06?
  - c. If there is a significant discrepancy, what is causing that deviation?
12. Repeat steps 8 through 11 for the detector and 583B that deliver the Stop pulses to the TAC.
  13. Return the cable connections to those specified in Fig. 27.5 and section 27.3.1.

### 27.3.2. Adjusting the WALK Control on the 583B Timing Discriminators

The CF MONitor output provides an attenuated version of the Constant-Fraction zero-crossing signal that is formed inside the 583B Timing module. This signal is produced by attenuating the INPUT signal to 20% of its original value and adding that pulse to a delayed and inverted copy of the original INPUT pulse (Ref. 11 and 13). In this experiment that delay is set to 2.5 ns by the C-25-15INCH-S external DELAY cable. The result, illustrated in Fig. 27.9b, is a bipolar signal starting with a small negative lobe, followed by a zero crossing to form a much larger and longer-lasting positive lobe. The zero crossing occurs at 20% of the original pulse height. Thus, all pulses cross through zero at the same fraction of their original pulse height, making the zero-crossing time independent of pulse amplitude. An internal discriminator detects the zero-crossing point to generate the timing output pulse. The positive lobe of the CF MONitor signal has about 42% of the amplitude of the negative pulse at the 583B INPUT. See references 11 and 13 or the 583B Instruction Manual for more details.

1. Connect the START 583B to the oscilloscope as shown in Fig. 27.8 using 50- $\Omega$  coaxial cables. For the Delay, use a section of the DB463. Make sure both the Trigger Input and the Signal Input of the oscilloscope are terminated in 50- $\Omega$ .
2. Adjust the oscilloscope display and triggering, as well as the DB463 delay until the picture shown in Fig. 27.9 is observed on the oscilloscope.
3. Adjust the WALK potentiometer on the 583B front panel until all the bipolar pulses cross through the zero-volt baseline at the same time as illustrated in Fig. 27.9b.
4. Repeat steps 1 through 3 for the STOP 583B.
5. Return the cable connections to those specified in Fig. 27.5 and section 27.3.1.



**Fig 27.9 CF MONitor Signal Triggered by the 583B Timing Output with a) Improper WALK Adjustment, and b) Ideal Walk Adjustment.**

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### 27.3.4. Optimizing the Source-to-Detector Distance

1. Continuing with the set-up from step 5 of the previous section, connect the BK OUT (blocking output) of the START 583B to the analog INPUT of the EASY-MCA. Acquire a spectrum for a few seconds. There should be a single narrow peak in the spectrum at about 50% of full scale. Calculate the counting rate by summing all the counts in the spectrum and dividing by the elapsed live time.
2. If the counting rate does not lie between 9,000 and 11,000 counts per second. Move the detector closer to, or further away from, the  $^{22}\text{Na}$  source to achieve a counting rate within those limits.
3. Repeat this counting rate measurement and adjustment with the STOP path.
4. Determine the source-to-detector distance that makes that distance the same for both detectors, yet keeps the counting rate within the 9,000 to 11,000 counts/s limits for each detector. Set both detectors to that same distance and record the spacing.
5. Return the cable connections to those specified in Fig. 27.5 and section 27.3.1.

### 27.3.5. Calibrating the TAC/MCA Time Scale with a Pulser

1. Using a 30-cm C-25-1 RG-58A/U 50- $\Omega$  coaxial cable, connect the middle connector on the MT050 50- $\Omega$  Matched Tee Signal Splitter to the ATTENUATED OUTPUT on the 480 Pulser. Set the Pulser polarity to NEGATIVE.
2. Disconnect the coaxial cables from the two detector ANODE outputs and connect them instead to the remaining two connectors on the MT050 Signal Splitter. Turn the Pulser ON. This arrangement will supply synchronized electronic pulses to both 583B INPUTS.
3. With the oscilloscope set for a 1-M $\Omega$  input impedance, observe the BK (blocking) OUTPUT of one of the 583B modules. Adjust the ATTENUATOR switches and the PULSE HEIGHT dial to find the lowest and highest pulse heights that generate a BK OUTPUT. Record these two limits.
4. Repeat step 3 with the other 583B.
5. Set the 480 Pulser to a pulse height that is approximately in the middle of the lowest to highest acceptable range for both 583B timing modules. Lock the dial.
6. With the BK OUTPUTS reconnected to the 414A, acquire a spectrum on the EASY-MCA. A narrow peak should be observed growing at approximately 60 counts/second (or your local ac power line frequency) near mid-scale in the spectrum. Stop the acquisition when enough counts have been accumulated to form a well-defined peak.
7. To calibrate the time scale for the spectrum on the EASY-MCA change the DB463 Stop delay by 4 ns and continue the spectrum acquisition to obtain a second, well-defined peak. Repeat this process enough times to produce time calibration peaks distributed over the entire time spectrum spanned by the EASY-MCA. For more details, see AN34 Experiment 25. You may wish to save a copy of your time calibration spectrum for future reference.
8. Plot the peak positions (x-axis) versus time delay (y-axis) to establish a time calibration for the spectrometer. Calculate the slope of the calibration curve (ns per channel). Note that the response of the TAC is somewhat non-linear from 0 to 10 ns. Consequently, only the 10- to 50 ns range offers good linearity for the measurements in this experiment.
9. Select a final STOP delay on the DB463 that places the pulser time peak at about 40% of full scale on the MCA. This will be the approximate time = 0 position for the experiment.
10. Disconnect the 583B INPUTS from the Pulser and Signal Splitter. Reconnect the 583B INPUTS to their appropriate detector ANODE outputs.

### 27.3.6. Finalizing the Discriminator Thresholds

1. Select the 583B associated with the START path. Connect the CF MONITOR output and one of the TIMING OUTPUTS to the oscilloscope as instructed in Section 27.3.3. Trigger the oscilloscope on the negative TIMING OUTPUT to yield the display shown in Fig. 27.9b.

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2. Observe the positive lobe of the CF MONitor pulses. The intensity of the pulses in the display should coordinate with the pulse-height distribution shown in Fig. 27.6. The upper 2/3 of the pulse-height range is solely caused by the Compton distribution from the 1274-keV gamma rays. The lower third of the pulse height range is much more intense, because of the superposition of the Compton distribution from the 511-keV gamma rays on top of the lower 1/3 of the Compton distribution from the 1274-keV gamma rays.
3. Adjust the UPPER LEVEL and LOWER LEVEL discriminators on the 583B as follows:
4. Raise the LOWER LEVEL discriminator to the minimum setting that completely cuts off the intense Compton distribution from the 511-keV gamma-rays. Lower the UPPER LEVEL discriminator until it begins to cut off the tallest pulses from the 1274-keV gamma rays. Then, raise the UPPER LEVEL slightly to ensure that none of the 1.274-keV gamma-ray pulses are rejected.
5. Lock the dials and record the dial settings for the UPPER LEVEL and LOWER LEVEL discriminators for the START 583B.
6. Repeat steps 1 through 5 for the 583B associated with the STOP signal, but use the dial settings in step 7.
7. For the STOP 583B, lower the UPPER LEVEL discriminator until it begins to cut off the tallest pulses from the 511-keV gamma rays. Raise the UPPER LEVEL slightly, so that all of the Compton distribution from the 511-keV gamma rays is accepted. Avoid too high a setting, because that will include more 1274-keV gamma-rays without adding 511-keV pulses. Raise the LOWER LEVEL discriminator to 10% of the value on the UPPER LEVEL dial. This should reject pulses that are below 10% of the amplitude of the tallest pulses accepted in the oscilloscope display.
8. Lock the dials and record the dial settings for the UPPER LEVEL and LOWER LEVEL discriminators for the STOP 583B.
9. Steps 1 through 5 should ensure that the START 583B responds to approximately the top 58% of the 1274-keV pulse-height distribution, while rejecting all the 511-keV pulses. Steps 6 through 8 ensure that the STOP 583B will be accepting about 90% of the pulses from the 511-keV gamma rays and rejecting approximately 65% of the pulses from the 1.274-MeV gamma rays.
10. For validation, check that the final dial settings approximately match the values recorded in Section 27.3.2. For the START 583B, the dial readings should be approximately UPPER =  $1.2V_{1060}$  (Volts) and LOWER =  $1.3V_{341}$  (Volts). For the STOP 583B, the dial readings should be approximately UPPER =  $1.1V_{341}$  (Volts) and LOWER =  $0.11V_{341}$  (Volts). (Remember that  $V_{341}$  and  $V_{1060}$  are slightly different for the START and STOP detectors.)
11. Return the cable connections to those specified in Fig. 27.5 and section 27.3.1.

## 27.4. Spectrum Measurements

### 27.4.1. Measurement of the Prompt Instrument Response Function

It will require most of a 4-hour laboratory period to set up the system for the measurement of the prompt instrument response function with  $^{60}\text{Co}$ . At the end of the set-up and calibration, implement the  $^{60}\text{Co}$  measurement as an overnight data acquisition.

To avoid unnecessary exposure to the radiation from the sources, maximize your distance from the sources, and minimize the time spent in close proximity to the sources.

1. Remove the Cd/ $^{22}\text{Na}$ /Cd sandwich from the source/sample holder, and return the 10  $\mu\text{Ci}$   $^{22}\text{Na}$  source to its locked and shielded storage container.
2. Securely suspend the 10  $\mu\text{Ci}$   $^{60}\text{Co}$  source half way between the two detectors on the concentric center lines of the two detectors. Do not handle the source with your fingers. Use long tweezers or forceps to move and position the source.
3. Start an overnight data acquisition on the EASY-MCA. The run needs to last for at least 7 hours. Before leaving the laboratory, check that the low counting rate of pulses is accumulating mostly at about 40% of the full time scale on the horizontal axis of the EASY-MCA spectrum display.

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- At the end of the overnight run, save a copy of the spectrum for printing in your report.
- Measure the FWHM of the peak that represents the prompt instrument response function,  $G(t)$ .  
QUESTION: Is the FWHM within the expected range?
- Using a logarithmic vertical scale in the EASY-MCA display, observe the symmetry of the peak. With a logarithmic vertical scale, the Gaussian peak shape should approximate a parabola.  
QUESTIONS AND ISSUES: Are the skirts of the peak appearing as sloping straight lines on both sides of the peak? Explain any possible reasons for asymmetry or non-linear skirts.
- Return the 10  $\mu\text{Ci}$   $^{60}\text{Co}$  source to its locked and shielded storage container.

#### 27.4.2. Measurement of the Positron Lifetime in Cadmium

This measurement will require data acquisition for at least 4 hours to accumulate more than 300,000 counts in the total spectrum. It can commence immediately after the prior overnight run, or at the beginning of the next laboratory period.

- Mount the Cd/ $^{22}\text{Na}$ /Cd sample/source/sample sandwich half way between the two detectors, with a Cd disk facing each detector. The Cadmium disks should be concentric with the extended centerlines of the two detectors. See the Appendix for details on assembling the Cd/ $^{22}\text{Na}$ /Cd sandwich, and mounting it between the two detectors. To avoid unnecessary exposure to the radiation from the source, maximize your distance from the source, and minimize the time spent in close proximity to the source.
- Initiate a data acquisition on the EASY-MCA. The data acquisition will need to last at least 4 hours for a 10  $\mu\text{Ci}$   $^{22}\text{Na}$  source. The resulting spectrum should have circa 390,000 total counts.
- At the end of the data acquisition, save a copy of the spectrum for analysis and printing in your report.
- Using a logarithmic vertical scale, find the maximum counts in the peak. Call that number  $N_{\text{max}}$ . Find the channel on the right side of the lifetime spectrum that has  $N_{\text{max}}/2$  counts. Call that channel  $C_1$ . Find the channel on the right side of the spectrum that has  $N_{\text{max}}/(2 \times 2.718)$  counts. Call that channel  $C_2$ . You may have to interpolate between channels to achieve sufficient accuracy.
- Calculate  $C_2 - C_1$  and multiply it by the calibrated picoseconds/channel to estimate the mean lifetime for Cadmium.
- As a more accurate method, identify the section towards the right end of the spectrum that closely approximates a straight line (with a logarithmic vertical scale). Draw a straight line through those data points. Measure the slope of the straight line and report that as the mean lifetime for Cadmium (see Equation (9)).

#### QUESTIONS and ISSUES

- How do the estimates in steps 5 and 6 compare to the expected lifetimes for Cadmium?
- What are the limitations on the accuracy of the two methods for estimating the mean lifetime?
- What are the reasons your measured mean lifetime may differ from the expected value?
- How does the prompt instrument response function,  $G(t)$ , as recorded with  $^{60}\text{Co}$ , influence your measurement of the mean lifetime of Cadmium?
- The  $^{22}\text{Na}$  source is deposited on a thin film of Kapton<sup>®</sup>. Can you detect any contamination of the Cadmium lifetime spectrum from the longer mean lifetime of Kapton?
- The transparent plates that hold the sample/source/sample sandwich are made from LEXAN<sup>®</sup> (polycarbonate). LEXAN has three positron mean lifetime components: 125 ps, 0.3 to 0.4 ns, and 2 to 3 ns (Ref. 14). Is there any evidence in your spectrum that the positrons are reaching the LEXAN?
- What steps can be taken to minimize the contamination from Kapton or any other mounting materials near the source?

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- h. This experiment employs a  $180^\circ$  detector-source-detector geometry. When a 1274-keV gamma ray is detected in the START scintillator and a 511-keV annihilation gamma ray is detected in the STOP scintillator, there is approximately a 20% probability that the other 511-keV gamma ray will be detected in the START scintillator. (The intrinsic detector efficiency is approximately 20% at 511 keV.) In that event, linear addition of the 1274- and 511-keV signals will occur in the START detector. What effect will that delayed 511-keV gamma ray have on the START zero crossing in the Constant Fraction signal illustrated in Fig. 27.9b? How will that perturbation impact the positron lifetime spectrum (Ref. 15)? How would you recommend changing the detector-source-detector geometry to eliminate that distortion?
- i. The photons are interacting with the scintillators via Compton scattering. In what way does gamma-ray scattering from the scintillators and surrounding materials interfere with the positron lifetime spectrum?
- j. If a  $90^\circ$  detector-source-detector geometry were used, what could be done to suppress interference from photon scattering (Ref. 1 and 2)?

### 24.4.3. Measurement of the Mean Lifetime in TEFLON®

This measurement requires data acquisition for a minimum of 10 hours to acquire at least 1 million counts in the spectrum. If the measurement in Section 27.4.2 is accomplished during an afternoon laboratory period, it will be convenient to make the TEFLON measurement in an overnight run, starting at the end of the afternoon laboratory period.

1. Remove the  $^{22}\text{Na}$  source from the Cd/ $^{22}\text{Na}$ /Cd sandwich, and assemble it into the TEFLON/ $^{22}\text{Na}$ /TEFLON sandwich. See the Appendix for detailed instructions. Securely mount this TEFLON/ $^{22}\text{Na}$ /TEFLON sandwich half way between the two detectors, with the TEFLON disks concentric with the common centerlines of the two detectors. To avoid unnecessary exposure to the radiation from the source, maximize your distance from the source, and minimize the time spent in close proximity to the source.
2. Initiate a data acquisition on the EASY-MCA. The data acquisition will need to last at least 10 hours for a  $10\ \mu\text{Ci}$   $^{22}\text{Na}$  source. The resulting spectrum should have circa 1 million total counts.
3. At the end of the data acquisition, save a copy of the spectrum for analysis and printing in your report. The lifetime spectrum for TEFLON should have three identifiable lifetime components, as illustrated in Fig. 27.4.
4. To measure the dominant mean lifetime, identify the maximum counts in the spectrum. Call that number  $n_{\text{max}}$ . Find the channel number that has  $0.8n_{\text{max}}$  counts on the decaying side of the spectrum. Call that channel  $c_1$ . Find the channel that has  $(0.8/2.718)n_{\text{max}}$  counts, and label that channel  $c_2$ . Calculate  $c_2 - c_1$  and multiply the result by the picoseconds/channel calibration from Section 27.3.5. Report this answer as your estimate of the dominant mean lifetime for TEFLON.
5. For a more refined estimate of all three lifetime components, plot the spectrum with a logarithmic vertical scale and a linear horizontal scale. As depicted in Fig, 27.4, find the three regions where the logarithm of the spectrum has a linear decay. Draw a straight line through the data points in each of these three regions. Measure the slope of each straight line and calculate the mean lifetime for each component using the model in Equation (9). Report these three mean lifetimes as  $\tau_1$ ,  $\tau_2$  and  $\tau_3$  (shortest to longest).
6. Return the  $10\ \mu\text{Ci}$   $^{22}\text{Na}$  source to its locked and shielded storage container.

### QUESTIONS and ISSUES

- a. Comment on the accuracy limitations of the two methods for measuring  $\tau_1$ .
- b. How do your three lifetimes compare to the expected values for TEFLON?
- c. Explain any reasons why your measured values may deviate from the expected values.
- d. Why is the positron lifetime much longer in TEFLON than in Cadmium?
- e. Why does TEFLON exhibit three lifetime components, whereas Cadmium only shows one lifetime?

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#### 27.5. References

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### 27.A. Appendix

#### Construction and Mounting of the Sample/Source/Sample Sandwiches

This appendix provides the instructions for constructing and assembling the components of the Cd/<sup>22</sup>Na/Cd and the TEFLON/<sup>22</sup>Na/TEFLON sample/source/sample sandwiches. The cutting of the four LEXAN plates and the mounting of the cadmium and TEFLON sample disks on those plates will have to be accomplished by the laboratory manager. Similarly, the cutting of the 12.7-mm diameter disks from the sheet of TEFLON must be implemented by the laboratory manager.

##### 27.A.1. Fabrication of the LEXAN Plates

The LEXAN is supplied as a 0.15 cm × 30.5 cm × 30.5 cm polycarbonate sheet. From this sheet carefully cut 4 squares, each with 0.15 cm × 7.6 cm × 7.6 cm dimensions. Make sure that all four plates match each other's dimension exactly, no matter which sides are selected for the match. The exact match will be helpful in facilitating alignment of the samples disks and the <sup>22</sup>Na source.

##### 27.A.2. Fabrication of the TEFLON Disks

The TEFLON is supplied as a 0.236 cm × 30.5 cm × 30.5 cm sheet of virgin PTFE. From this sheet you will need to cut 2 TEFLON disks that are each 12.7 mm in diameter and 2.36 mm thick.

##### 27.A.3. Mounting the Cadmium Disks on the LEXAN Plates

1. On a piece of paper, draw a 7.6 cm × 7.6 cm square to match the outer dimensions of the LEXAN plates.
2. Find the exact center of that square, and draw a circle with a 12.7 mm diameter around that center.
3. Place one of the LEXAN plates on the paper with its edges exactly aligning with the square on the paper.
4. Clean any grease, oil or dirt off of the center of the LEXAN plate and both sides of the cadmium disks with alcohol.
5. Using either contact cement or a double-sided adhesive tape, mount one of the cadmium disks in the center of the LEXAN plate. Use the circle on the paper to help guide the alignment.
6. If opaque double-sided tape is used, trim away any of the tape that protrudes beyond the circumference of the cadmium disk. Likewise, remove any excess cement. For alignment purposes, it is important to be able to see the outer diameter of the cadmium disk through the LEXAN.
7. Repeat steps 3 through 6 for the second LEXAN plate and another cadmium disk.

##### 27.A.4. Mounting the TEFLON Disks on the LEXAN Plates

Repeat the process in section 27.A.3 for mounting two TEFLON disks on two LEXAN plates. Because TEFLON is a non-stick material, an appropriate cement or double-sided adhesive tape may need to be selected for the application. It may also be helpful to use sandpaper to create a rough surface on the side of the TEFLON to be cemented.

##### 27.A.5. Assembling the Cd/<sup>22</sup>Na/Cd Sandwich

Assembly will be facilitated, and exposure to the radioactive source will be minimized, if a jig is constructed to hold the four corners of two LEXAN plates stacked in exact alignment on posts. If the posts lift the plates a few centimeters above the table surface, the Binder Clips can be applied more easily and more quickly to clamp the two LEXAN plates together along the four edges between the posts.

To avoid unnecessary exposure to the radiation from the source, maximize your distance from the source, and minimize the time spent in close proximity to the source. Do not handle the source with your fingers. Use long tweezers or forceps to move and position the source.

For a 10- $\mu$ Ci <sup>22</sup>Na point source with the positrons converted to 511-keV gamma rays in close proximity to the source, the exposure dose rate is approximately 110 mR/hr at a 1-cm distance, 4.4 mR/hr at 5 cm, 1.1 mR/hr at 10 cm, and 0.01 mR/hr at 100 cm.

## Experiment 27

### Positron Annihilation Lifetime Spectrometry

1. Place the LEXAN plate with the cadmium disk on the four posts, with the cadmium side facing up.
2. During the next step, check that the integrity of the Kapton film encapsulating the  $^{22}\text{Na}$  source has not been violated. If there is any evidence of a rupture of the encapsulation notify the Radiation Safety Officer and do not use the source.
3. Using long tweezers or forceps, place the 10  $\mu\text{Ci}$   $^{22}\text{Na}$  source disk on top of the cadmium disk. Ensure that the outer circumferences of the source and the cadmium disk are exactly aligned.
4. Carefully add the second LEXAN disk with the cadmium side down, so that the cadmium disk presses against, and exactly aligns with, the source and cadmium disk underneath. Make sure the edges of the two LEXAN plates are aligned.
5. Add a  $\frac{3}{4}$ -inch Binder Clip to each of the four edges to clamp the two LEXAN plates together. Check that the source and the two cadmium disks remain in exact alignment, now and throughout the experiment.
6. When transferring the sandwich to the experiment, grasp the assembly by the extreme corner of the LEXAN plates, preferably using a locking forceps.

#### 27.A.6. Assembling the TEFLON/ $^{22}\text{Na}$ /TEFLON Sandwich

1. Use the reverse of the procedure in section 27.A.5 to disassemble the Cd/ $^{22}\text{Na}$ /Cd sandwich.
2. Employ the same procedure outlined in section 27.A.5 to assemble the TEFLON/ $^{22}\text{Na}$ /TEFLON sandwich, except substitute the LEXAN plates with the TEFLON disks for the cadmium disks.

#### 27.A.7. Mounting the Sample/Source/Sample Sandwich between the Detectors

To mount the sandwich between the two detectors, position the three-finger clamp on the retort stand to grasp the LEXAN plates securely at one corner. Adjust the height and horizontal position to place the center of the sample disks on the centerline between the two detectors half way between the detectors. The LEXAN plates should be approximately parallel to the front surfaces of the two scintillators.

It is important to guaranty that the sandwich position is not disturbed during a measurement. To appreciate the sensitivity of the measurement to source position, note that gamma rays travel through 1 cm in 33 ps.

Specifications subject to change  
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