EXPERIMENT 12

Annihilation Radiation Coincidence Studies with ^{22}Na

Scope

The annihilation radiation from a ^{22}Na source will be studied with an angular correlation apparatus. The β^+ particles from the source will be converted in a foil and the resultant .511 MeV annihilation quanta will be measured with two NaI(Tℓ) detectors. The angular correlation table that will be used for this experiment has provisions to fix one of the NaI(Tℓ) detectors and rotate the other one. With this system, we will verify the angular correlation of the annihilation radiation. These quanta will be shown to be emitted with an angular separation of 180 degrees, which is the only correlation that can conserve linear momentum for the two photons. This angular correlation will be verified by using three different coincidence arrangements.

Discussion

Figure 12.1 shows the decay scheme of ^{22}Na and the resultant NaI(Tℓ) spectrum. **Note:** The positrons are in coincidence with γ's from the 1.274 MeV (2+) state. The mean life of the 1.274 MeV state is 3×10^{-12} sec and therefore, from our timing situation, decay is immediate. A small fraction of the positrons (0.05%) decay directly to the ground state of ^{22}Na. The Q_{EC} = 2.843 MeV shown in the figure is the excess energy that would be available if Electron Capture (EC) occurred to the ground state of ^{22}Na.

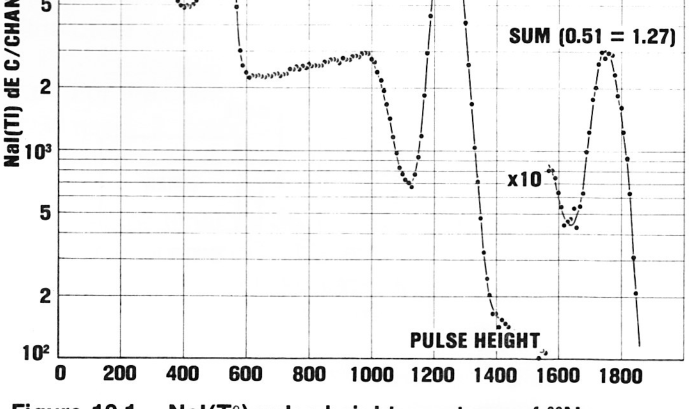

Figure 12.1. NaI(Tℓ) pulse height spectrum of ^{22}Na.

The β^+ end point energy to the ground state is 1.74 MeV. Most of the β^+ particles (90%) go to the (2^+) level at 1.274 MeV. The positron continuum to this level would have an end point energy of 0.466 MeV. Figure 12.2 shows what the distribution of β^+ particles would look like if we counted them with a β^+ pulse height analyzer.

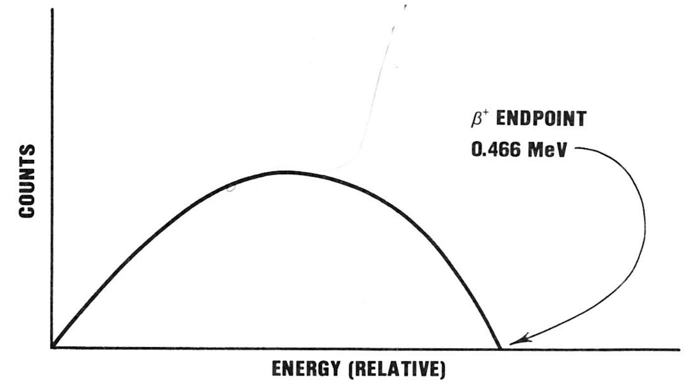

Figure 12.2. β^+ distribution from a ^{22}Na source.

In our experiment, we will encapsulate the ^{22}Na source with two converter foils to insure that most of the β^+ particles annihilate at the source. Basically the β^+ particles leave the source in an isotropic manner. When they enter the converter foil, they quickly (1×10^{-9} sec) lose energy by dE/dx in the foil. When a β^+ has essentially lost all of its energy, it finds an electron and captures that electron to form positronium which decays by the annihilation of the e^+ and e^- into two gammas. Conservation of momentum tells us that these gammas have to go off in opposite directions. This gives an angular separation of the gammas of 180 degrees. In this experiment, we will verify these conservation principles.

EXPERIMENT 12.1

Annihilation Measurements with a Multipurpose Coincidence Circuit

Discussion

From an electronic point of view, this experiment is quite similar to experiment 11. The student is urged to do experiment 11 before attempting this experiment. In the experimental procedure, we will assume that you are familiar with all of the techniques discussed in experiment 11. The only real difference is that we will use two NaI(Tℓ) detectors for the two input channels instead of the pulse generator used in experiment 11.

Figure 12.3 shows a plan view of the angular correlation table that will be used for this experiment. After the timing has been set for the electronics that will be used (fig. 12.4), it is a simple matter to fix one of the detectors and then record coincidence events as a functio[n]... Since the annihilation radiation $\gamma_1 + \gamma_2$ leave th[e]... with an angular separation of 180 degrees, our m[ax]... counting rate will be observed at $\theta = 0$ in fig. 12.3... experiment, we will record coincidence events... angles listed in Table 12.1. We will also make a... table for angles on the other side of zero ($-\theta$). W[hen we] have finished with the experimental data, a pl[ot of] data similar to fig. 12.5 will be made for the da[ta]...

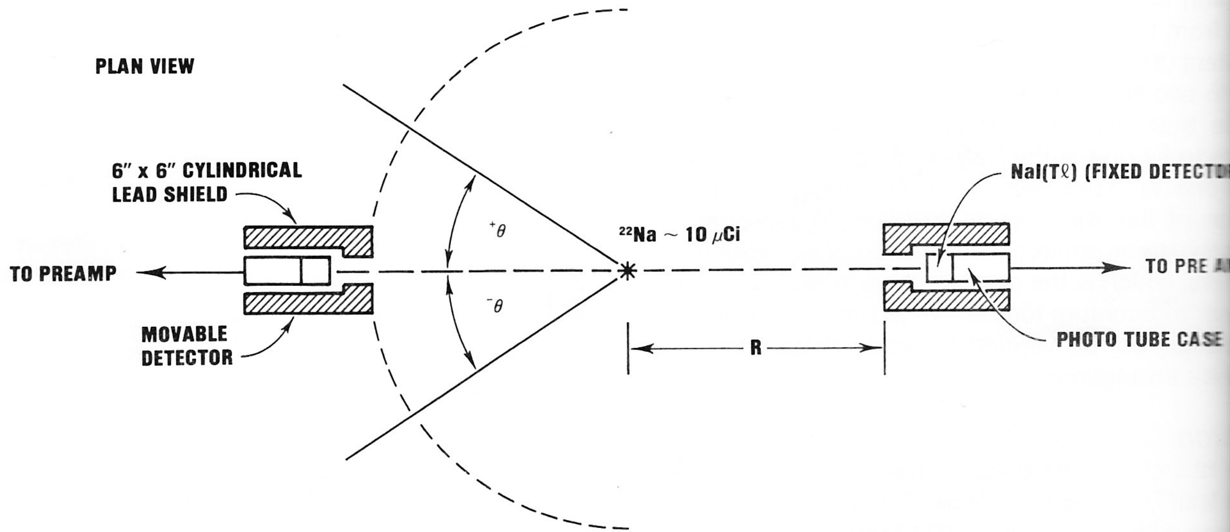

Figure 12.3. Angular correlation table with heavy rotating lead shields for the NaI(Tℓ) detectors.

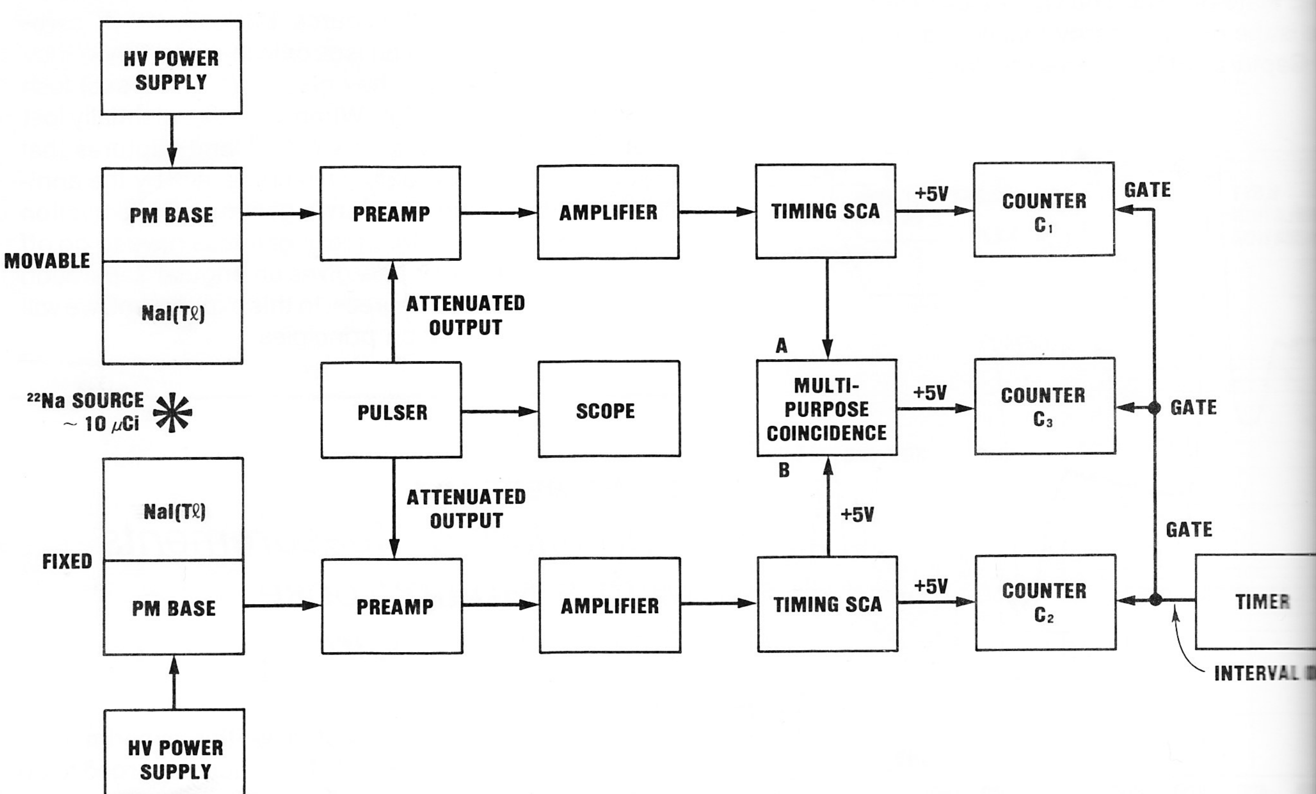

Figure 12.4. Electronics for annihilation measurements with a multipurpose coincidence circuit.

Table 12.1 Coincidence Data for the Annihilation Experiment

Run No.	+ degrees	C_1 counts/s	C_2 counts/sec	C_3 counts/sec
1	0			
2	1			
3	2			
4	3			
5	4			
6	5			
7	6			
8	7			
9	8			
10	9			
11	10			
12	12			
13	15			
14	20			

Experimental Procedure

1. Place the copper converter foils on either side of the 10 μCi ^{22}Na source and secure the foils with tape. Place the source in the center pivot of the angular correlation table. Adjust the high voltage on each NaI(Tℓ) detector to its recommended value. Set each amplifier on 1 μsec peaking time. Use the bipolar output of each amplifier into the SCAs. Adjust the gain of each amplifier so that the 1.274 MeV gammas are about 5 volts in amplitude.

2. Remove the source and turn on the pulse generator. Adjust the pulser so that the output pulses from each amplifier are about 3.5 volts. Set each timing SCA in the integral mode with the lower level set at 50/1000. Set the delays at minimum. Use a BNC Tee on the +5 volt logic pulse from each SCA. For each SCA, one output logic pulse goes into the multipurpose coincidence input and the other goes into the counter as shown in fig. 12.4.

3. For the coincidence circuit, set the resolving time at 250 nsec, 2 coincidence requirements, use A and B inputs, and route the F output into counter C_3.

4. Set the timer for 300 sec and start all counters. If the timing is correct, C_1, C_2, and C_3 should all give Σ/t = 60 Hz. If this is not the case, adjust the delays on the SCAs until the timing is correct.

5. Turn off the pulse generator and place the ^{22}Na source in its position on the angular correlation table. Set the angle at 0 degrees and the timer at 300 sec. For each counter, determine Σ/t in counts/sec and fill in the first entry in Table 12.1. Continue for the other angular settings in the table. Repeat this whole data table for negative angles $(-\theta)$ with the same absolute values as the positive angles in Table 12.1. Of course, the counting time will have to be increased for the larger angles to get reasonable statistics. If the system is lined up properly, the counting rates in counters C_1 and C_2 should remain about the same because, without the coincident requirement, we are simply looking at an isotropic source of gammas.

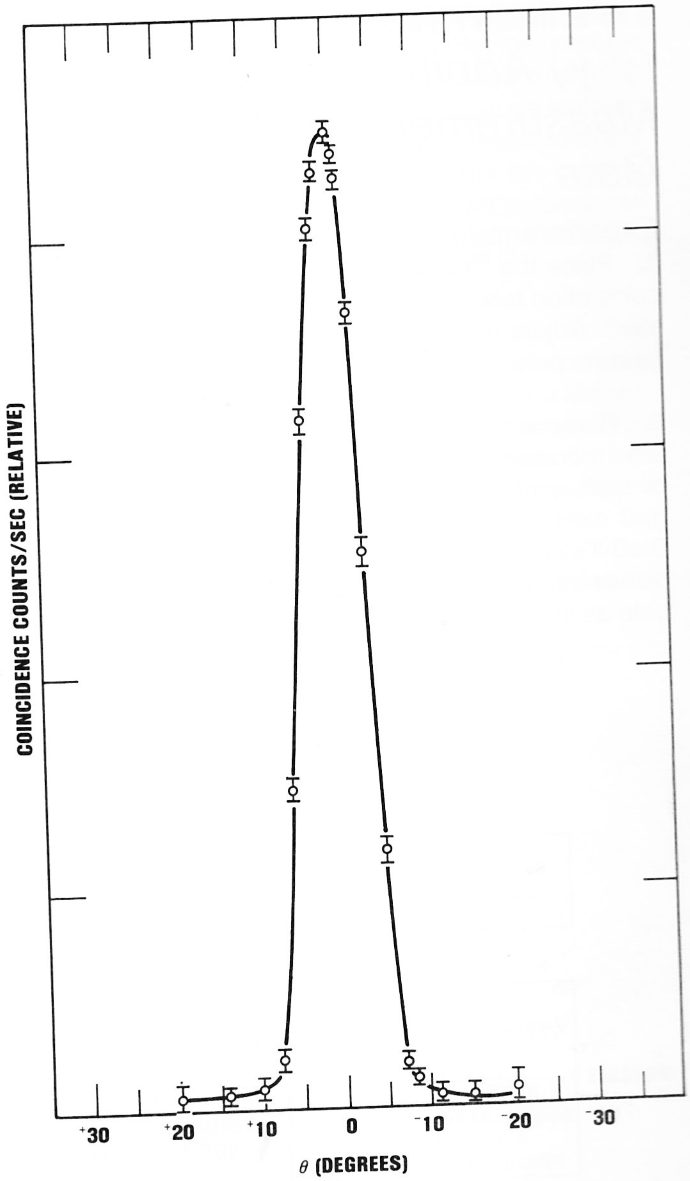

Figure 12.5. Angular correlation data for ^{22}Na.

Exercise Plot the number of coincidence counts/sec vs θ from your data. Your angular distribution should be similar to fig. 12.5.

EXPERIMENT 12.2

(γ-γ) Annihilation Measurements with a Linear Gate

Experimental Procedure

1. Place the ^{22}Na source at its position on the angular correlation tables. Set both amplifiers at 1 μsec time constant. Adjust both amplifier gains so that the 1.274 MeV gamma pulses are about 5 volts at the bipolar outputs.

2. Remove the ^{22}Na source and turn on the pulse generator. Increase the amplitude of the pulser until the output of each amplifier is 5 volts. Set SCA #1 as follows: Integral mode, lower level 50/1000, minimum delay. Put a BNC Tee on the positive output of SCA #1 and feed the pulses into counter C_1 and the enable input to the linear gate as shown in fig. 12.6.

2. Set the delay/amplifier on 3 μsec. Put a BNC Tee or its output and feed one cable into the input of the linea gate and the other into timing SCA #2 as shown in fig 12.6. Set SCA's #2 and #3 as follows: Integral mode lower level 50/1000, minimum delay, +5 logic out into the counters.

3. Set the timer for 100 sec and record the counting rates C_1, C_2 and C_3. They should all read 60 Hz.

4. Turn off the pulse generator and place the ^{22}Na source on the angular correlation table.

5. Set the angle at 0 degrees, the timer at 300 sec and run. Fill in the data table as we did for Experiment 12.1

Exercise Plot your data in the manner shown in fig 12.5.

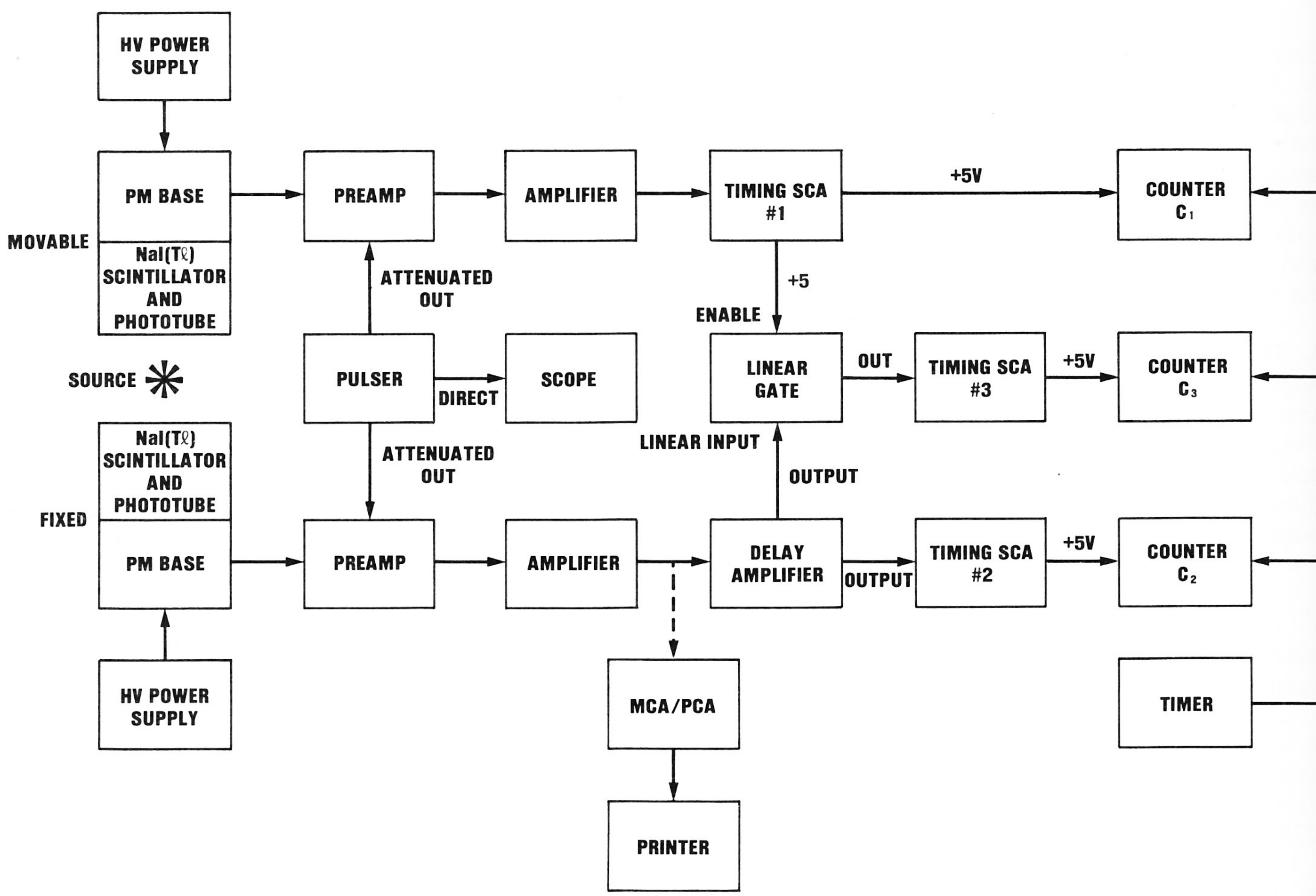

Figure 12.6. Electronics for annihilation measurements using a linear gate.

EXPERIMENT 12.3

(γ-γ) Annihilation Measurements with a Time-to-Amplitude Converter (TAC)

Experimental Procedure

1. Set up the electronics as shown in fig. 12.7. Place the ^{22}Na source in its holder on the angular correlation table. Adjust the gains of both amplifiers so that the output of the 1.274 MeV gammas is approximately 5 volts as in the previous experiment.

2. Remove the ^{22}Na source and turn on the pulse generator. Adjust the pulser pulse height until the output of each amplifier is 5 volts. Set SCA's #1 and #2 as follows: Integral mode, lower level 50/1000. The delay should be minimum on SCA #1 and 50 nsec on SCA #2.

3. Set the TAC on the 200 nsec full scale time range. Feed the output into a 100 ch MCA or PCA.

4. The timer is connected so that it automatically starts and stops counters C_1, C_2 and the MCA. Set the timer for a long time and start counting. C_1 and C_2 should count at a rate of 60 Hz. The MCA should show a single isolated peak if the timing is correct. If no peak is observed in the MCA, increase the delay on SCA #2 until the peak is being recorded about mid-scale on the MCA. Stop the timer; clear everything and count for 100 sec. The MCA, C_1, and C_2 should all show $\Sigma/t = 60$ Hz.

5. Turn off the pulser; place the source on its holder, and set $\theta = 0$ degrees. Set the timer for 300 sec and start counting. The MCA should show a strong group accumulating about mid-scale. If this does not happen, you may have to change the delay on SCA #2 or #1. It is usually pretty easy to find the proper delay setting to put the TAC peak at mid-scale. Clear everything; set the timer at 300 sec and record the first data point. Continue for all of the $\pm\theta$ values in the table and plot a curve similar to fig. 12.5.

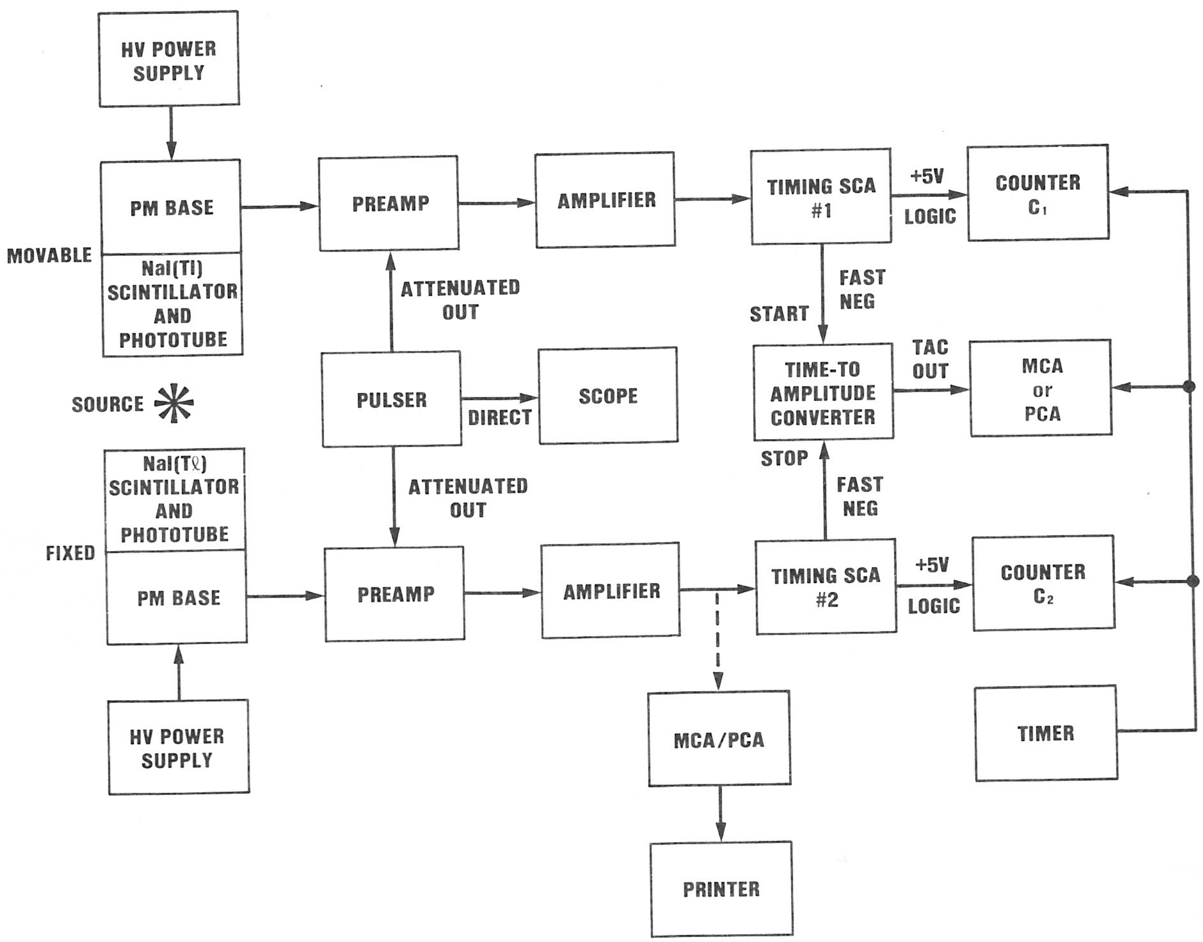

Figure 12.7. Electronics for annihilation measurements with a Time-to-Amplitude Converter (TAC).

REFERENCES FOR *EXPERIMENT 12*

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

2. R. D. Evans, *The Atomic Nucleus*, McGraw-Hill, New York (1955).

3. H. A. Enge, *Introduction to Nuclear Physics,* Addison-Wesley (1966).

4. K. Seigbahn, *Alpha, Beta, and Gamma Spectroscopy*, North Holland Publishing Co., Amsterdam.

5. L. C. Biedenharn and M. E. Rose, *Rev. Mod. Phys.* **25**, 729 (1953).

6. B. L. Cohen, *Concepts of Nuclear Physics*, McGraw-Hill, New York (1971).

7. C. E. Crouthamel, *Applied Gamma-Ray Spectrometry*, Pergammon, New York (1960).

8. C. M. Lederer and V. S. Shirley, Eds., *Table of Isotopes,* 7th Edition, John Wiley and Sons, Inc., New York (1978).

9. F. Adams and R. Dams, *Applied Gamma Ray Spectrometry*, 2nd Edition, Pergammon Press, Ltd. (1970).

10. G. F. Knoll, *Radiation Detection and Measurement*, Wiley, New York (1979).

11. *Nuclear Data Sheets*, Edited by the Nuclear Data Project, Academic Press, New York and London.

12. E. Segre, *Nuclei and Particles*, The Benjamin-Cummings Publishing Co., Reading, Massachusetts (1977).

13. J. B. Marion and F. C. Young, *Nuclear Reaction Analysis*, John Wiley and Sons, New York (1968).