

Radiation Annihilation, Revised Notes on Procedure

Physics 510 Experiment N-12

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1 Procedure

- I Using the block diagram of the electronic setup, check that all BNC's are in the correct place.
- II Place the ^{22}Na source between the two PMT's with the source closer to PMT A and further from PMT B.
- III For PMT-A adjust the voltage and amplifier gain in order to see the complete range of pulse heights on the oscilloscope.
 - A Send the AMP OUT through the delay line (which should originally have all settings on zero), the DELAY OUT should hook-up to one channel on the oscilloscope.
 - B First look for the characteristic .511 MeV annihilation gamma-ray which will show a distinct photoelectric absorption line. At this voltage and gain, the pulse should not look saturated (it should not be squared off).
 - C The 1.28 MeV gamma-ray may be saturated at this gain, to check this simply lower the gain by a factor of two. By doing this all lines should now be observed clearly.
 - D To check that annihilation radiation is in fact being observed attach ANAL OUT (analyzer out) from PMT-A to the trigger on the oscilloscope.
 - E Now trigger the spectrum via the pulse from ANAL OUT.
 - F Note how only the tail end of the spectrum can be observed. In order to see the full spectrum, increase the delay in the delay line from zero until there is a 0.25-0.5 μsec plateau before the full spectrum. (The fine delay knob might give some problems, if it does, just hit it softly.)
 - G Changing PMT-A's discriminator unit to integral mode, now raise the threshold from zero and note the effect on the spectrum.
 - H Finally, lower the threshold to zero again and raise it until the noise in the spectrum is cut-out.

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- I Now trigger the oscilloscope with the coincidence line used to gate the experiment. It will be necessary to flip the trigger knob from positive to negative to see the spectrum. Again, increase the delay in the delay line from the previous setting until there is a 0.25-0.5 μsec plateau before the full spectrum.
 - J Record all settings.
- IV For PMT-B adjust the voltage and amplifier gain in order to see the complete range of pulse heights on the oscilloscope.
- A Repeat steps A)-G) in part II except now for PMT-B.
 - B Now raise the threshold until all lines below the .511 MeV line are cut-out.
 - C Change PMT-B's discriminator unit from integral to differential mode (operating in this mode allows the window width to have an affect).
 - D Decrease your window width from the maximum setting until the .511 MeV peak is completely isolated.
 - E Record all settings.
- V Observation of coincidence pulses.
- A Attach the BNC from the "channel monitor" (located on the coincidence unit) to the free channel on the oscilloscope.
 - B For each channel adjust the width of the pulse to be approximately 0.5 μsec via the width knob for the corresponding channel on the coincidence unit.
 - C Align the two pulses on the oscilloscope via the delay knob for the corresponding channel on the coincidence unit, this assures that the pulses will in fact indicate a coincidence event.
 - D Record all settings.
- VI Preparation for data collection.
- A Reconnect PMT-A through the delay line, and restore the delay settings for PMT-A.
 - B Make sure that all settings match the previously recorded settings.
 - C Measure, from the center of the source, the distance to each PMT.
 - D Record crystal dimensions for each PMT.
 - E With a BNC split, observe your triggered spectrum (triggered by the gating line) on the oscilloscope while also sending it to the PHA (Pulse Height Analyzer) as indicated in Figure 1.
 - F Check that the PHA is in fact receiving the gated signal from the output of the coincidence counter as in Figure 1, the switch on the coincidence counter must be placed to "coincidence" or else the gating line is ineffective.
 - G Follow instructions on the cheat sheet for operation of the PHA.
- VII Data collection.
- A In order to have all data necessary to calculate the efficiency of the coincidence unit, the scalers (counters) must be utilized. Before data collection begins, zero all counters. (It is possible that the coincidence counter is still malfunctioning, if this is the case have PMT-A's counter count coincidence pulses by adding an extra BNC running from the coincidence unit to the counter.) At the instant data collection begins the counters will need to be turned on and

buttons at once may be necessary. Stop the counters at the instant the run is finished. Record these numbers as they relate the total number of counts received by PMT-B; comparison of this number with the coincidence number will yield the efficiency of the coincidence counter.

B Start data collection as indicated on the cheat sheet. Counts from PMT-A will now only be recorded if they are in fact in coincidence with PMT-B, the gating line from the coincidence unit insures this.

C To save data to the hard-drive once the run is complete, two methods should be utilized.

1 Escape until MOVE is an option on the PHA^{MCF} and type "m" and then enter. Now another manifold has been entered, type "d" and enter to open the DATA manifold. The prompt "from FTT" will appear, hit enter; the prompt "to" will appear, type C:\MCA\filename. Two prompts will appear after this, ignore both by hitting enter. The data will now be saved as a .dat file.

2 Escape until UTIL (utility) is an option on the PHA and type "u" and then enter. Now the utility manifold has been entered, type "p" and enter to open the PRINT manifold. Type "d" and enter to open the DATA manifold, here type filename.txt. Now the data is saved in a format that modern day computers are able to read.

D To save the data to disk escape until SYSTEM is an option, type "s" and hit enter. The terminal of the computer is now shown. Type "dir", now type "copy filename.txt a:\\" making sure that a disk is in fact in the computer. Once this procedure is complete, the data will be stored on the disk as a .txt file.

E To print the screen seen on the PHA, escape until UTIL (utility) is an option on the PHA and type "u" and then enter. Now the utility manifold has been entered, type "p" and enter to open the PRINT manifold. Here type "c" and enter to open the SCREEN manifold, by default the PHA will have filled in the printing option as "PRN" so just hit enter.

F To identify a region of interest (ROI) or do more complicated things, see the PHA user manual. It is recommended that the beginning and ending bin numbers for both structures on the spectrum are recorded for ease in analysis later on.

VIII Data collection of the accidental coincidence rate.

A Maintaining the same settings as above, simply move PMT-B out of the direct line of sight (approximately 25 degrees or more) while maintaining the distance from the source to PMT-B. Read some literature to understand why this is done.

B Collect data with this new configuration for the same duration as above. This data is effectively the background noise in the system, it will need to be taken out of the data collected in VI B to insure more accurate cross-sections.

C Save the data as indicated above.

IX Data analysis.

A The .txt files can be read by excel and other analysis programs, thus these files should be saved to disk to be analyzed. The number of counts under each structure in the spectra should ideally be the same.

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- B Talk to an instructor about the effect of the size of the crystal when analyzing the cross-sections.
- C Another good reference is: *Radiation Detection and Measurement* by Knoll.

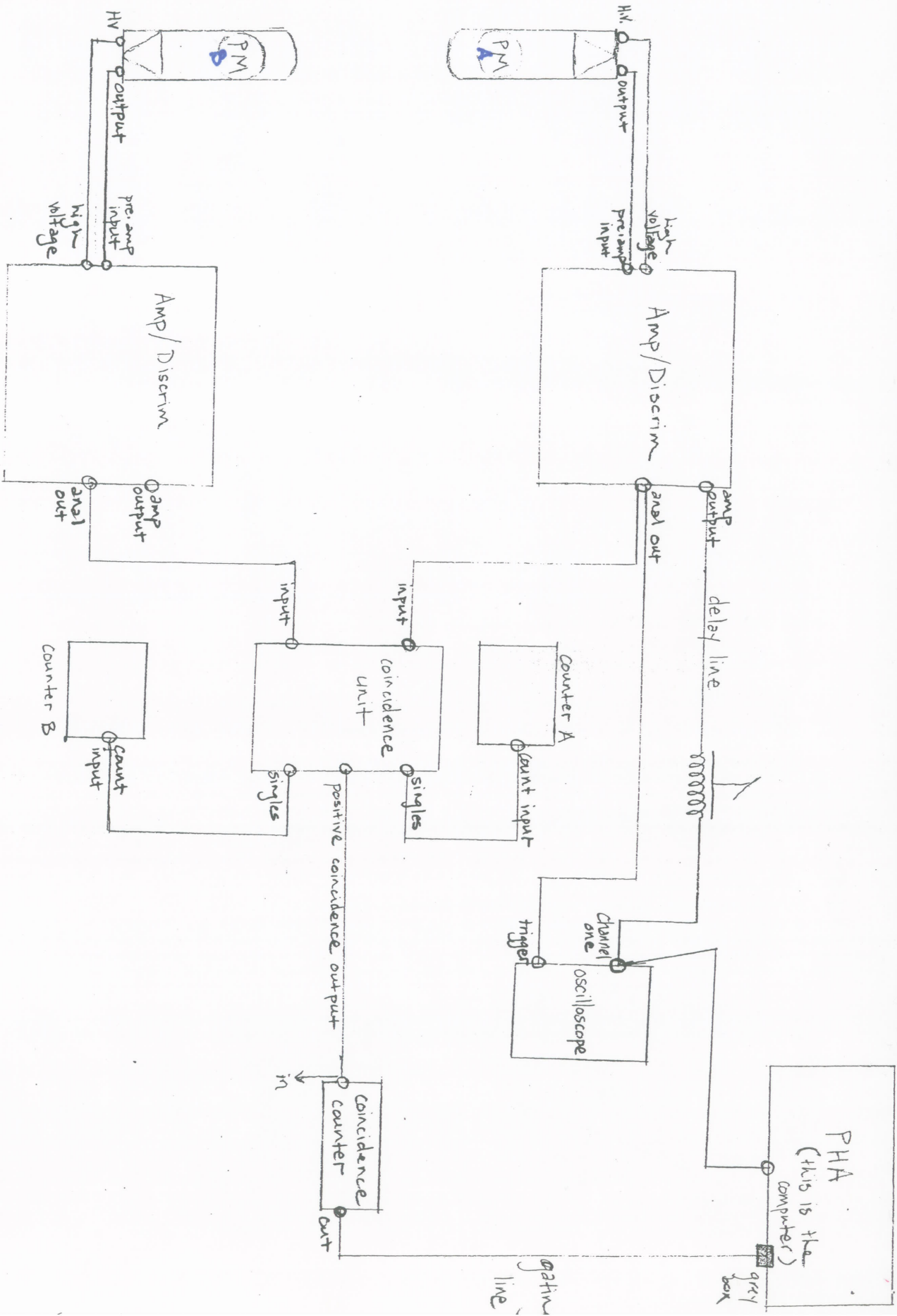


Figure 1: Block Diagram of Experimental Setup.

PHYSICS 410/510
EXPERIMENT N-12
GAMMA-RAY DETECTION WITH SCINTILLATOR AND PHOTOMULTIPLIER,
APPLIED TO RADIATION FROM POSITRON-ELECTRON ANNIHILATION.

OBJECTIVE:

To become familiar with equipment and techniques employed in the study of gamma-ray spectra with scintillators, and to become familiar with the absorption processes of gamma rays; specifically to make an approximate measurement of the cross sections for Compton scattering and photoelectric absorption of 0.51 MeV gamma-rays in NaI or KI crystals.

REFERENCES:

*Hofstadter and McIntyre, Phys. Rev. 80, 631, 1950.

*Mimeographed Notes on Experiments N-12 and N-13.

Hofstadter and McIntyre, Phys. Rev. 78, 617, 1950;
78, 619, 1950.

Corson and Wilson, Rev. Sci. Inst. 19, 207, 1948: the section on photomultipliers and scintillators.

Heitler, QUANTUM THEORY OF RADIATION, Oxford University Press, Second Ed., 1944; pp.119-127 (photoelectric effect), 146-160 (Compton effect), 186-204 (pair production), and 204-209 (positron-electron annihilation).

Circuit diagrams (in laboratory near apparatus: please do not remove them from the laboratory).

REVISED NOTES ON OPERATION OF CIRCUITRY

These notes replace the paragraphs in the old notes referring to the Electronic Circuits and Adjustments. It is helpful, however, to read the old notes to understand the working of a Differential Discriminator, Calibration, etc.

1. Read the manuals for all the RIDL module type circuits, i.e., single channel analyzer, coincidence unit, H.V. supply, etc. Also read the manual for the gammascopes (Pulse Height Analyzer).
2. Refer to the Block diagram (Fig. 1) for the interconnection of the various modules.
3. The use of an oscilloscope is essential in this experiment. Use a pulser to become familiar with the operation of the oscilloscope.
4. Observe the output of each amplifier on the oscilloscope.

Adjust the counter-H.V. and the Amplifier gain to get a complete range of pulse heights with a Na^{22} source. The 0.51 MeV annihilation gamma-ray should show a distinct photoelectric "line", and the amplifier output should not be saturated, i.e., "squared off" for this pulse size. Bigger pulses from the 1.28 MeV gamma-ray may be saturated at this gain. To observe these clearly, lower the amplifier gain by a factor of 2. Check that you are looking at annihilation radiation by triggering the oscilloscope trace by the output of the coincidence circuit.

Check the effect of the discriminator "threshold" setting by varying this threshold and observing the minimum pulse visible when the trace is triggered by the coincidence. (The discriminators should be operated in the "integral" mode.) Notice that if the threshold is set too low, it may cut off the smallest pulses. This may depend on the behavior of the particular discriminator at a very low threshold. Also notice that a particular Amplifier-Discriminator may "self-trigger" (i.e., with no input) if the discriminator level is set too low and the amplifier gain too high. There is thus a minimum safe operating threshold for each discriminator.

5. Observe the pulse shapes that actually make the coincidence--these are available at the "channel monitor" points on the front of the COINCIDENCE circuit. (Use an oscilloscope probe.) Adjust the width of each pulse to a reasonable value (~ 0.5 $\mu\text{sec.}$)
6. Adjust the "coincidence level" so that the scaler counts coincidences. Check that the counting rate is independent of this setting until the coincidence level is set high enough to cut out all counts completely. If this is not so, or the scaler does not

- count at all, adjust the "Delay" of one input channel with respect to the other until you find the setting where a maximum counting-rate is obtained. Set the coincidence level in the middle of the counting range.
7. Now take a "Delay Curve" of the counting-rate vs. relative delay between the two input channels. Set the relative delays to correspond to the middle of the flat top of the curve.
 8. THIS PROCEDURE SHOULD BE CARRIED OUT MOST ACCURATELY! Now check that the coincidence pulse for gating the Pulse-Height-Analyzer (PHA) arrives at the GATING input of the PHA between 0.25 μ sec and 0.5 μ sec before the arrival of the pulse to be analyzed at the INPUT of the PHA. Do this by looking at these signals simultaneously on the oscilloscope, triggering the oscilloscope trace by the coincidence pulse. It will be necessary to use a delay ($\sim 3 \mu$ sec - 3.5 μ sec) in the pulse input line to obtain the proper time relationship. (Figure out why this is so.) For fine adjustment, adjust the delays on the coincidence, leaving the relative delay between the two channels fixed.
 9. Learn to use the PHA with an ungated input, i.e., turn the PHA "GATING" switch to "Anti-coincidence", with no input to the COINCIDENCE INPUT of the PHA. If everything is working satisfactorily, the spectrum obtained with a COINCIDENCE gated input should look very similar to the "singles" spectrum.

To clean up the coincidence spectrum, you should adjust the discriminator for the geometry-defining counter so that only the photo-electric peak of the annihilation gamma-ray gives an output (Analyzer Output) to the coincidence circuit. The discriminator can be used in its "Differential Mode". The threshold and window settings are to be adjusted by analyzing the output of this channel on the PHA and observing that only the photo-electric peak appears in a gated spectrum, and in the proper channels!

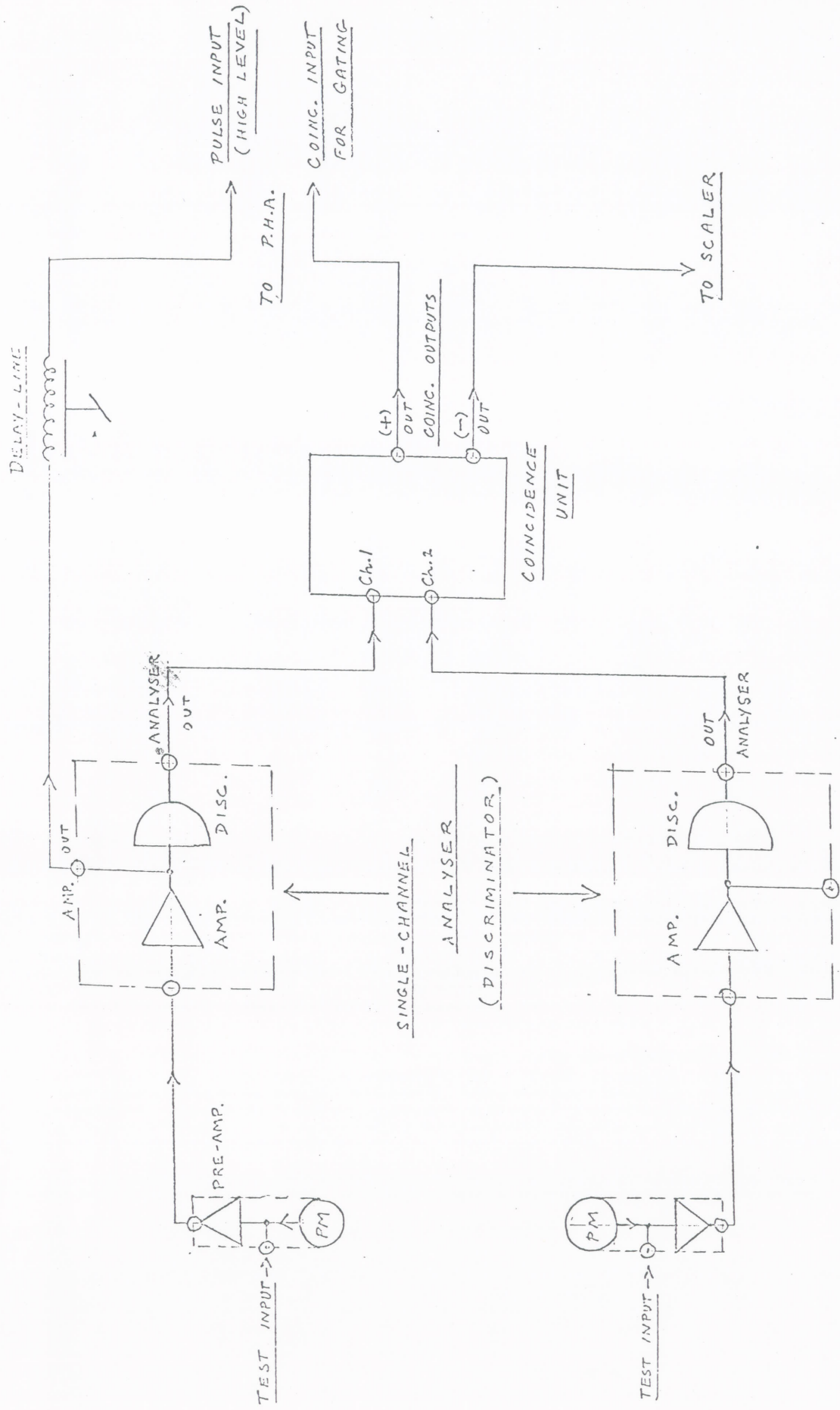


FIG. 1 — BLOCK DIAGRAM OF ELECTRONICS

N-12
 Sept. 1965

I. Introduction to and General Description of the Method of Detection

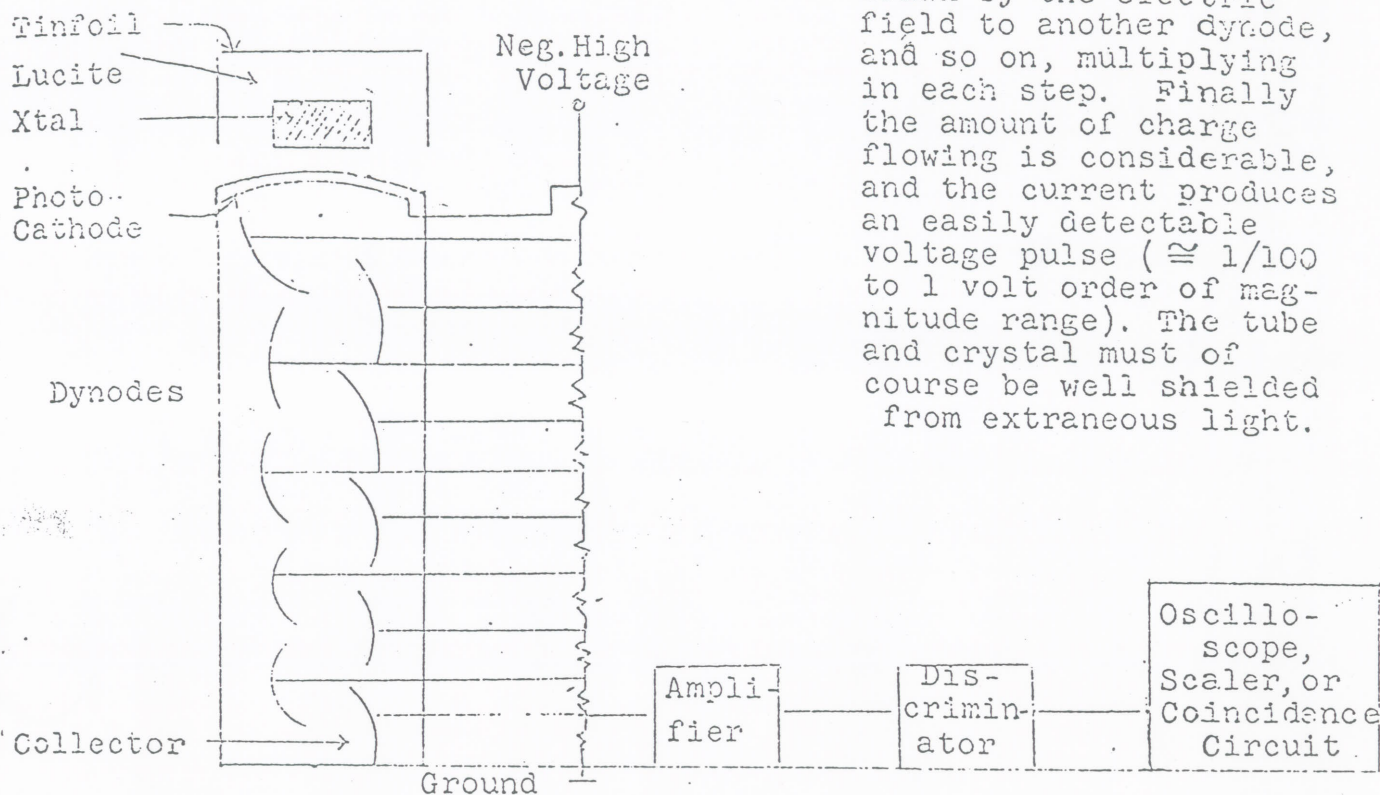
One means of detecting energetic charged particles is by scintillations: i.e., characteristic light emitted from atoms excited by the electric field of a passing particle. This is a rather ancient and historic means of detection, but the early work was done with materials such as zinc sulphide, which, like most other substances, strongly absorb their own characteristic radiation. Therefore, only the light emitted at the surface was detectable and the method was usable only for observing slow alpha particles.

The recent increase in applicability of scintillation detection arose from the investigation of some substances (notably organic crystals such as anthracene, naphthalene and stilbene; or the alkali halides such as sodium or potassium iodide with a small amount of impurity (Tl) for activation; and more recently some organic liquid solutions such as terphenyl in xylene) which are highly transparent to the radiation produced in them. These made possible the detection of high energy protons, mesons, electrons, and quanta. X-rays and gamma rays are detected indirectly, by the excitation produced by electrons resulting from scattering or absorption of the quanta. Neutrons can also be detected indirectly by the excitation caused by the recoil protons or by charged particles resulting from nuclear disintegrations.

There are several outstanding advantages of the scintillation method, including the following:

- (1) The efficiency for gamma ray detection and neutron detection is high because of the density and thickness of the crystal (or solution).
- (2) The amount of light produced can be used as a measure of the energy lost in the crystal and hence of the velocity or energy of the particle or quantum detected.
- (3) The detector can be placed in a vacuum.
- (4) The pulses can be made very sharp in time, allowing fine time resolution and coincidence techniques.
- (5) High counting rates are possible, compared with Geiger counters, because there is no dead time and no quenching problem.

The light is detected with a photomultiplier tube, shown schematically in the diagram. Light falling on a photosensitive surface produces photoelectrons. These are drawn to an electrode called a dynode, being accelerated to about 70-100 ev. on the way. At this energy the efficiency of electron multiplication is high; i.e. more electrons are emitted from the dynode than strike it. The



emitted electrons are drawn by the electric field to another dynode, and so on, multiplying in each step. Finally the amount of charge flowing is considerable, and the current produces an easily detectable voltage pulse ($\cong 1/100$ to 1 volt order of magnitude range). The tube and crystal must of course be well shielded from extraneous light.

II. Factors which Determine the Pulse Height

1. Energy dissipated in the crystal.

The amount of light striking the photo-cathode is in first approximation proportional to the total energy dissipated in the crystal. The main causes of failure of perfect proportionality are (a) variation of light collecting efficiency with position of emission in the crystal, which variation is greatly reduced by the reflections occurring at the surfaces of the lucite mounting, and (b) dependence on specific ionization, or concentration of the dissipated energy. The latter effect is small in the alkali halide crystals.

For incident gamma rays the energy dissipated depends on the interaction process. Photoelectric absorption gives practically all the energy to electrons, Compton effect gives a variable fraction of the energy depending on the angle of scattering, and pair production gives the initial energy minus twice the rest energy of an electron. Of course, in a thick crystal, Compton

effect may be followed by absorption of the scattered quantum, and the positron created in pair production may annihilate with an electron and one or both of the resulting gamma rays may fail to escape. Such double absorption processes may cause as much energy dissipation as the photoelectric process, but they are not very frequent in a crystal that is only about one centimeter thick.

The electrons and positrons that are produced are very likely to be brought fully to rest within the crystal. This is because electrons of around one Mev energy or less are very strongly scattered and do not follow straight paths. Nevertheless, a fraction of those produced near the surface of a crystal will escape, thus reducing the energy dissipation and causing a spread in pulse height even if the produced electrons are monoenergetic. Obviously, this effect grows worse with increasing energy.

2. Variation in photocathode efficiency.

The number of photoelectrons is presumably (except for purely chance fluctuation) proportional to the amount of light incident on the photocathode. The constant of proportionality depends on the wavelength distribution of the light, which is characteristic of the crystal used, but independent of the cause of the excitation. Practical surfaces are not perfectly uniform in their efficiency, so the number of photoelectrons depends slightly on the area which is illuminated and on the age of the tube. A typical efficiency is one photoelectron per 15 to 20 incident quanta of light. Tubes of the same type vary considerably from one to another, both in average efficiency and in uniformity of pulse height produced by constant amounts of light.

3. Statistical Fluctuations.

The number n of photoelectrons is finite (typical value a few hundred) and therefore undergoes chance fluctuations, the root mean square value of which is $n^{1/2}$. The percentage fluctuations are slightly aggravated by chance fluctuations of the average multiplying factor at the first dynode. The "line width" caused by these fluctuations is frequently the chief limitation of the resolving power of the instrument, although the factor (2) is sometimes a strong competitor.

4. Voltage applied to photomultiplier.

The charge multiplying factor at each dynode depends sensitively on the accelerating potential; and this factor enters to the tenth power in determining the final pulse height. Therefore an accurately regulated supply is essential. A change of 70 volts (1/10 of the minimum applied voltage with the 5819 tubes used in the present experiments) changes the gain by a factor of at least two.

At too-high voltages, discharges occur in the tubes and the cathode surfaces can be damaged. Unfortunately, the tubes are expensive. Most of our tubes operate best on one of the three lowest taps of the voltage supply. Do not go higher than the fifth tap with any of the tubes.

III Absorption and Scattering Processes of Gamma Rays

The gamma ray spectra of radioactive substances consist of sets of narrow lines; but in order to identify these lines or to count the number of γ rays which interact in the crystal, one must take into account the different ways in which γ rays may interact, and the fractions of the gamma ray energy given to electrons and positrons (and thus dissipated in the crystal) by the different processes.

It is strongly recommended that the student study these processes by making graphs of relations derivable from the formulas given in the Heitler reference, or in some other, equivalent source. Suggested graphs which are highly instructive are:

- (1) Photoelectric absorption coefficient per cm. vs. gamma ray energy, in NaI or KI (depending on which crystal is used in this experiment), in anthracene and in lucite. A log-log graph is best. Note that the equation derived under the Born approximation is all right for small z , but that the correction is a factor of about 2.5 for Sn ($z=50$) and hence for iodine ($z=53$) also. ← alright
- (2) Total probability per cm for Compton effect vs. gamma ray energy, in the same materials as above.
- (3) Pair production probability per cm vs. gamma ray energy in these materials.
- (4) Energy of scattered quantum in Compton effect vs. angle of scattering for various initial energies; and energy of the recoil electrons plotted on the same graph. A semi-log graph is best.
- (5) Compton scattering probability per unit solid angle vs. angle of scattering, for various initial energies (semi-log graph recommended).
- (6) Energy distribution of the Compton recoil electrons for various initial quantum energies.

For these graphs, the γ ray energies of interest extend from about $1/2 mc^2$ ($1/4$ Mev), which is approximately the average energy of the quanta resulting from scattering of annihilation radiation, up to about 5 or 6 mc^2 , near the energy of the gamma rays from Th C11, and near the maximum energy of gamma rays from natural radioactive sources.

With these curves, the expected pulse height distribution (ignoring temporarily the imperfection of resolution of the photomultiplier and the pulse-height discriminator) can be predicted under various experimental circumstances, of which a few pertinent examples will be given. First, consider a single crystal responding to radiation from a Na^{22} source. Individual atoms in the source emit a positron of 0.53 Mev and then (after a negligible time delay) go to the ground state of Ne^{22} by emitting a gamma ray of 1.30 Mev. The positron comes to rest in a short distance because of ionization and scattering, whereupon it combines with an electron and the pair is annihilated, producing two gamma rays. Since momentum and energy are conserved, these

gamma rays travel in opposite directions, and all have practically a unique energy, mc^2 . The half-life of Na^{22} is about 2.6 years or 8.2×10^7 sec (mean life 1.18×10^8 sec). Therefore, each second about 10^{-8} of the radioactive nuclei disintegrate, the net products in each case being two gamma rays of $E_1/mc^2 = 1$ in opposite directions and one gamma ray of $E_2/mc^2 = 2.55$ in a random direction relative to the others.

Some of the gamma rays will be absorbed in the lucite surrounding the crystal and not reach the latter. Others will undergo Compton scattering in the lucite or other surroundings and the scattered rays may enter the crystal. It is easy to show that the number of Compton-scattered gamma rays which enter the crystal from outside and interact there is about equal to the number of primary gamma rays that undergo Compton scattering in the crystal and produce secondary gamma rays that get out of the crystal. Thus in addition to the gamma rays of $E_1 = mc^2$ and $E_2 = 2.55 mc^2$ entering the crystal, there is a spectrum of secondary scattered gamma rays of lower energy and intermediate energy.

The pulse height distribution will then include:

- (1) a peak at $2.55 mc^2$ due to photoelectric absorption of the 1.3 Mev quanta, plus Compton effect and pair production processes in which the secondaries are also absorbed. The peak is small because the photoelectric cross-section is small at this energy.
- (2) A Compton recoil distribution with a peak at $2.13 mc^2$ and extending from this energy down to zero, due to Compton scattering of the 1.3 Mev quanta.
- (3) A pronounced peak at $1.0 mc^2$ due to photoelectric absorption of the annihilation quanta, which are twice as numerous as the 1.3 Mev gammas and also have much greater absorption cross-sections. The peak contains contributions due to Compton effect in which the secondary fails to get out of the crystal.
- (4) A Compton recoil distribution with a peak at $2/3 mc^2$ due to Compton scattering of annihilation quanta, the spectrum being of roughly constant strength between $2/3 mc^2$ and zero energy.
- (5) A small peak at $0.55 mc^2$ due to pair production by the 1.3 Mev quanta. There is, in addition, a small peak at $1.55 mc^2$ and a distribution between 0.55 and $1.22 mc^2$ due to pairs in which the position annihilates and one of the annihilation quanta is absorbed or scattered.
- (6) A distribution extending from zero to $2.13 mc^2$ due to scattered gamma rays (originally 1.3 Mev) entering the crystal.
- (7) A distribution extending up to $2/3 mc^2$ due to scattered gamma rays (originally $1 mc^2$) entering the crystal. This group is strong in effect, because of the large absorption cross-sections and the fact that the pulses are not spread over a wide range of height.
- (8) Pulses of all sizes due to cosmic rays and other sources of radiation besides the Na^{22} . These pulses can be recognized and subtracted because their frequency remains unchanged when the Na^{22} source is removed.

By considering the values of the cross-sections for the above processes at the various energies concerned, it is possible to predict the appearance of the composite pulse height distribution. This will not be done here. It is apparent, however, that two parts of the curve should be outstanding - the photoelectric peak of the annihilation quanta and the upper edge of the Compton effect distribution of the same quanta. It should be possible to decompose an experimental distribution fairly reliably into the components listed above, and by measuring the areas of the various parts of the curve to estimate the frequencies of occurrence of the various processes.

It is also apparent that if an unknown spectrum is as simple as the one in this illustration, it would be possible to determine the energies accurately, and relative intensities approximately, of the gamma ray lines. However, if the spectrum is complicated by having, say, four or more lines present, the complexity of the experimental pulse height distribution would confuse the results and a determination of the spectrum would not be feasible.

Some improvements are possible. By collimation, one can reduce the number of scattered quanta that enter the crystal. By changing the type of crystal one can change the relative heights of various peaks, since the cross-sections per atom go approximately as Z for Compton effect, Z^2 for pair production and Z^5 for photoelectric effect. Two other experimental situations will be described, however, to illustrate more powerful methods provided by coincidence techniques.

Suppose that coincidences are required between a pulse in one crystal and a pulse in a second one, with the Na^{22} source situated between the crystals on the line joining them. Then, because of the directional correlation and time correlation of the gamma rays produced by positron-electron annihilation, these gamma rays will be recorded with much more efficiency than any other; and the pulse height distribution will be simple to interpret. This technique is exploited in experiment N-12.

Alternatively, suppose that the source is moved slightly out of line so that no straight line can connect the source and both crystals. Let the discriminator bias of one crystal be set below mc^2 and the bias of the other be set between mc^2 and $2.55 mc^2$. Then the annihilation radiation alone cannot be recorded by coincidences between the crystals. Because of the time correlation and the biases set, the coincidences will practically all be due to an annihilation quantum in the crystal with the lower bias and a 1.3 Mev quantum in the crystal with the higher bias. Again, the pulse height distribution in each crystal and its interpretation would be comparatively simple.

Thirdly, imagine one crystal irradiated by the source, and a second crystal well shielded from the source but not shielded from the first crystal. Let the positions be such that the second crystal can receive radiation that has undergone Compton scattering

IV. The Crystals and their Mountings

In this experiment we use NaI crystals activated with traces of Tl. These crystals were grown commercially from highly purified chemicals. They are sealed in thin walled aluminum containers with a front window of Lucite to avoid deterioration due to moisture. The crystal is mounted against the face of the photomultiplier, using a grease for optical seal, and held in place by tape. The whole assembly is covered with black tape to protect it from room light.

V. The Electronic Circuits: Adjustment and Periodic Checking of the Discriminator

1. High voltage supply:

A circuit diagram is in the laboratory. The supply has four outputs, and they should be quite independently variable (in steps provided by the tap switches), since the outputs are through cathode followers. Therefore the outputs are adequate for two simultaneous coincidence experiments.

The voltage range is approximately 700-1400 volts, negative.

The only feature of the four outputs in which they are not independent is that they are all controlled by the same on-off switch. Therefore all four terminals are "hot" if the switch is on. To prevent possible damage to tubes left connected but not in use, turn all outputs to the lowest tap before turning the supply on.

The supply is exceptionally well regulated, but the output will vary slightly until thermal equilibrium of the resistor is reached. Therefore the supply should be on for at least a half hour before taking final sets of measurements.

2. Photomultiplier: Tube type is indicated on base of tube. The cathodes are run at high negative potential and the collectors near ground.

3. Preamplifiers: Each contains a set of resistors to subdivide the high negative voltage for distribution to the dynodes of the photomultiplier, a filter condenser for the high voltage, a one-tube amplifier with cathode degeneration (gain 4-5) and a cathode follower output.

4. Amplifiers:

Each chassis contains two independent amplifiers. Each of these is one loop (3 tubes) of a Model 501 degenerative amplifier

(described in book by Elmore and Sands, also in Laboratory of Nuclear Studies circuit manual), with two cathode follower outputs connected to each amplifier. Normally only one output of each amplifier is used; the second output allows one to look at the pulses on an oscilloscope without disturbing the pulses reaching the discriminator.

The gain control has an "off" position (tap 1), and the other positions attenuate the pulses by factors nominally equal to 16, 8, 4, 2 and 1 (taps 2 to 6 respectively). These factors cannot be depended on accurately. The maximum gain of the amplifier is about 100, and therefore the maximum gain of amplifier plus preamp is about 400.

Standard Pulse Generator, Model 100.

This pulse generator is shared between experiments N-12 and N-13 and is essential for setting and checking the discriminator circuits, and incidentally for testing the preamplifier and amplifier. The maximum pulse output is 1.00 volts; smaller pulses are available in steps provided by a tap switch. The pulse height is given by the product of the scale reading on the meter and the value indicated by the tap switch. The circuit diagram is described by Elmore and Sands.

6. Scaling Circuits:

Scalers are provided to register the counting of the various channels.

7. Double Differential Discriminator

It is essential to become familiar with this instrument:

The chassis contains two differential discriminators, each with both an "integral" output and a "differential" output, a coincidence circuit, and a scaler driver. Each differential discriminator is made up of a window amplifier, two discriminators and an anticoincidence circuit. A block diagram of the experiment along with circuit diagrams of the window amplifier, discriminators, a coincidence circuit, coincidence circuit and scaler drivers are available in the laboratory. The input of scaler driver (1) can be connected to the integral, veto, or differential output of the differential discriminator (1) by placing the selector switch (1) in position 1, 2, or 3 respectively. Scaler driver (2) can be similarly connected to the differential discriminator (2) by the scaler (2) switch. The fourth position of both switches connects the corresponding scaler driver to the output of the coincidence circuit.

Basically, the incoming pulse is analyzed in the following way. The window amplifier is essentially a non linear amplifier which amplifies the pulses only if they are greater than a certain amplitude. In this amplifying range, two discriminators are arranged to be triggered by the pulse if the amplitude should be great enough. The discriminator is a trigger circuit which generates a shaped pulse of the order of one microsecond duration whenever the signal on its input exceeds an established voltage. By having two such discriminators with triggering voltages one greater than the other, we have a mechanism for determining when an incoming pulse generates a signal voltage which falls between these two levels. If the amplitude is not sufficient, neither discriminator is triggered. If it exceeds the first discrimination level the first discriminator fires alone. If it exceeds the second discriminator level, then both discriminators are triggered. It is then only necessary to have an anticoincidence circuit to arrange things so that if the first discriminator fires alone, a signal is passed to the scaler, but if both discriminators fire, the second discriminator "vetoes" the pulse from the first one and no signal is transmitted. In order to ensure precise operation, the shaped output pulse of the first discriminator is made to be some what shorter than that of the second, and is delayed by a few tenths of a microsecond to make sure that the veto pulse is overlapping. The veto pulse from the second discriminator is connected internally to the anticoincidence circuit by way of a toggle switch. By opening the toggle switch, the veto signal may be removed, then the output of the discriminator responds to every pulse exceeding the first discrimination level, thus giving an "integral" rate, that is, it counts the integral of all pulses exceeding this level. The 10 turn helipot controls the lower discrimination level while the "window width" controls the increment between the lower and upper discrimination levels. In principle this interval should be independent of the lower discrimination level. This lower level is sometimes called the "lower bias", or "base line setting".

The outputs of the two differential discriminators pass to the coincidence circuit where coincidences are taken with a resolving time of about one microsecond. The output of this coincidence circuit may be registered on a scaler.

Calibration of linearity, zero set and window width.

1. Test Pulses.

Test pulses, approximately 3 usec in length, are desired similar to those produced by the photomultiplier units under actual operation. Connect the output of the Model 100 Pulser to the test pulse pre-amplifier. This unit will differentiate and invert the 150 usec negative pulse from the Model 100 and give a positive output pulse of about 3 usec duration. The power supply for this pre-amp is taken from one of the power supply jacks on the Model 50 Pulse Amplifier. Connect the output of the test pulse pre-amp to the Model 50 Pulse Amplifier. The test pulses for calibration of

the discriminators are then taken from the output of this amplifier.

2. Calibration of the discriminator.

Feed the test pulses to the input of the differential discriminator. Choose a window width, then for a given pulse height input from the pulser, find the discrimination level at which the differential output first begins to fire as the discrimination level is lowered. Then determine the level at which it ceases to fire as it is further lowered, that is, as the pulse is made to exceed the level of the upper discriminator. (In order to locate the approximate level of pulse heights required it may be convenient to count first at the "integral" output.) The measurement of upper and lower discrimination levels should then be repeated for a variety of signal amplitudes to permit the construction of a curve of discrimination level versus pulse height in. A corresponding curve of window width may also be made. The discrimination level curve extrapolated back to zero signal amplitude gives the zero correction which must be made for the helipot setting.

Procedure

In this experiment, we wish to measure the pulse height spectrum of the photon spectrum produced in one crystal of sodium oxide when taken in coincidence with the detection of a photon in a second crystal using photons arising from the annihilation decay of the positrons from Na^{22} .

1. Use the pulser to check calibration of relative gain of the amplifier in various settings.
2. Use the pulser to check linearity, zero and gate widths of the discriminators.
3. Take the pulse height distributions with the differential discriminators for each crystal independently. You should be able to observe both the 0.5 and the 1.28 mev lines. First set the 0.5 mev line at about half scale, (about 25 volt pulses). Then, in order to see the 1.28 mev line, reduce the gain of the amplifier by a factor of 2.
4. Set the counters about 40 cm apart, with the source between them. Observe coincidences using the widest gate widths centered at 0.5 mev. Check that the coincidences are real by moving the source out of line. Now align the source with the source closer to counter A than to counter B in order to make sure that counter B defines the solid angle of the annihilation photon pairs detected by the system. Then set the gate width for counter B in position 2, centered about the annihilation peak, then observe spectrum in

counter A, with gate width in position 1.

5. Under the same geometry as above, measure the rate in counter B alone, (that is without requiring a coincidence with A). This measurement combined with that of the ~~differential~~ differential spectrum in A permits a calculation of the efficiency of counter A for photons of the energy of the annihilation radiation. A measurement of the coincidence rate of counter B with the integral rate in counter A for two different biases suitably chosen will simplify the effort required in this calculation.

6. The accidental coincidence rate may be determined by measurements with the source misaligned.

7. From your data, make an estimate of the relative Compton and Photoelectric cross-sections.

