COMPTON SCATTERING

EXPERIMENTAL OBJECTIVES:

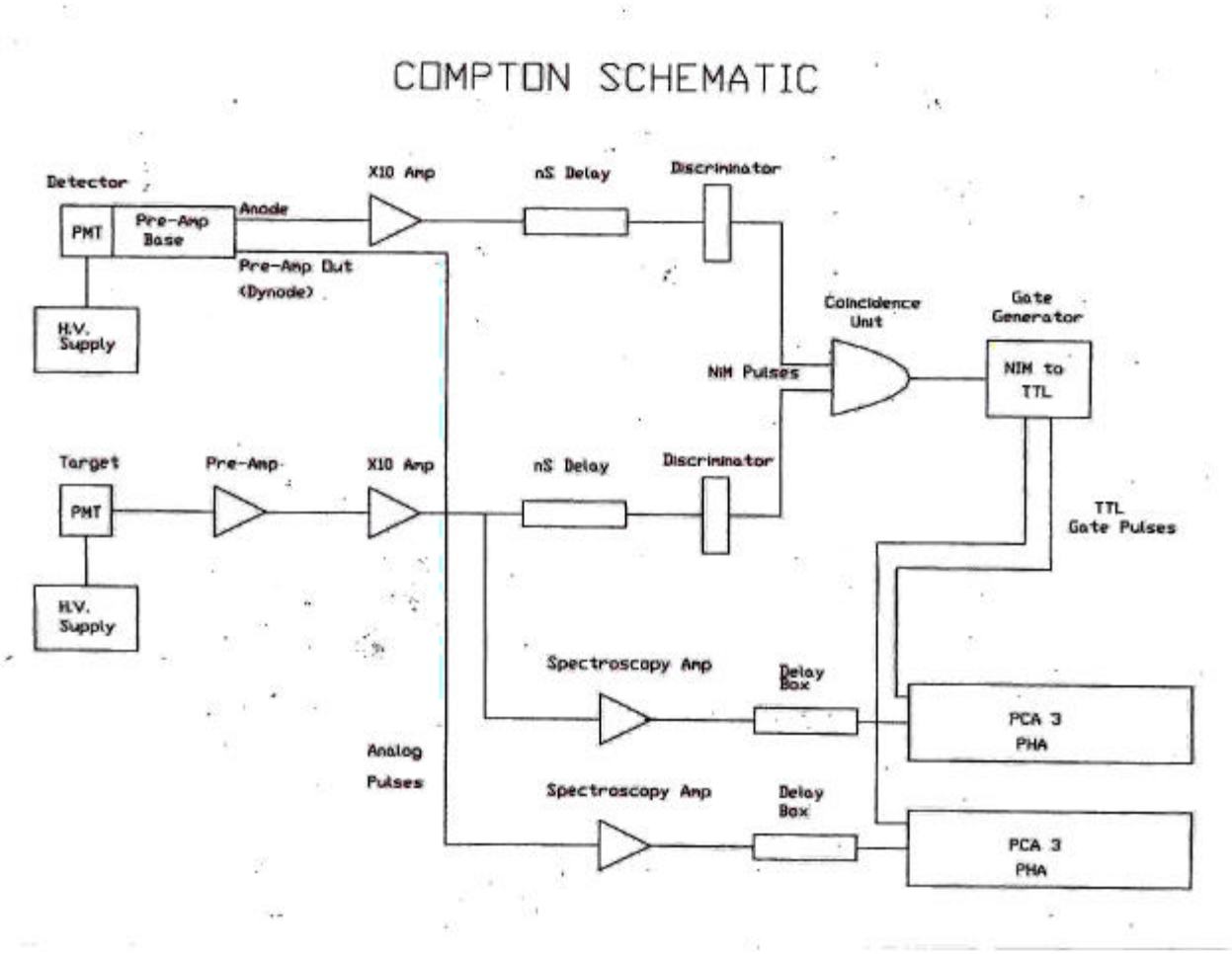
To verify the kinematics of Compton scattering. In addition one should verify that the relative probability of scattering into a given solid angle is given by the Klein-Nishina formula. Note that you will have to make energy dependent corrections to your data, make measurements of the solid angles of the source and both detectors, and measure count rates, taking into account detector efficiencies. Please realize that you have a finite amount of time to complete this experiment. The most time consuming part of the experiment is the setup. Plan to spend a lot of time in the lab the first couple of weeks, so that by the end of the second week you have already taken at least a sample data run.

REFERENCES:

Read Mellissinos 6.3 or any Modern Physics text such as Tipler for the Physics background. Read Mellissinos 5.4 and any of the many detector catalogs for a description of scintillation detectors, and the Lecroy catalog on time coincidence techniques. Use Mellissinos and/or the MIT experimental procedures as guidelines for general procedures and data analysis.

Our setup differs from Mellissinos' by replacement of the inert aluminum scatterer by a Sodium Iodide (NaI) scintillator connected to its own photomultiplier tube. This allows us to define an event as the coincident arrival of pulses from two detectors, thus reducing background noise by orders of magnitude. In addition we get as a bonus the ability to measure the energy spectrum of the recoiling electron. We'll refer to this detector as the electron energy analyzer (EEA). The

scattered gamma ray (the 662 keV photon from a Cesium (Cs) 137 source) is detected by a second NaI(Tl) scintillator connected to another photo-multiplier tube, henceforth referred to as the photon energy analyzer (PEA). NaI is used because it is an efficient gamma ray detector. The sum of the energy in the electron and the photon analyzer/detectors add up to the original 662 keV for all scattering angles. This experiment lends itself to a computerized data acquisition system.



THE APPARATUS:

The apparatus, shown in the figure, is comprised of the two photomultiplier tubes (PMTs) and scintillation detectors, pre-amps, voltage amps, shaping (spectroscopy) amps, NIM (Nuclear Instrument Module) discriminators, a coincidence unit (AND gate), and a TTL Gate Generator (used for gating the pulse height analyzers).

The electron energy analyzer (at the center of the apparatus) uses a 1" dia. by 1" long NaI crystal coupled to a 1.5" PMT. The photon energy analyzer is a 1.75" dia. sodium iodide (NaI) crystal coupled to a 2" PMT. In addition to producing pulses that are proportional in area to energy, the detector/energy analyzers are used to establish an event coincidence between the recoiling electron and the scattered gamma ray photon. When a gamma is scattered from the EEA, it gives up some of it's energy to electrons in the NaI crystal. The balance of the original energy is carried away by the scattered gamma. The student is encouraged to study the mechanism by which light is produced in scintillation materials.

The data acquisition system is comprised of a pair of computer controlled Oxford Instruments PCA-3 pulse height analyzer cards - one for each of the two PMTs used in this experiment. The data acquisition program is called OxfordWin-MCA. For this experiment, each of the PCA-3 cards requires two input signals; one from the spectroscopy amplifier to the PCA input on the card itself, and the other from the Gate Generator to the GATE input on the multi-connector plug assembly at the back of the computer. The PCA-3 pulse height analyzer (PHA) converts the 0-10 volt positive pulse from the spectroscopy amp into a number from 0-2048. Each time an event is recorded, the count is incremented by one in a bin that corresponds to that number. When the PHA receives a gate pulse (a coincidence), both the PEA and EEA channels are digitized simultaneously. Over time, an energy histogram is produced. The display is updated each time an event occurs, provided the size of the pulse does not fall outside the range of the PHA. If a number greater than 2048 occurs, the data point cannot be recorded.

The program displays both the run time and the total number of counts (events) on the screen. In order to determine the number of counts in any particular channel, use the cursor keys or mouse to decrement or increment the channel number.

The program also keeps track of the channel in which the maximum number of counts occurs. This is displayed and updated whenever the display mode is changed, and appears in the upper left of the screen. This can be helpful in locating the photopeak, however it can also be misleading if the channel with the maximum counts does not happen to fall inside the photopeak. (The computer only acquires the data, it is left to you to do the analysis.)
Record a separate data file for each Compton angle measured.

ELECTRONICS SET-UP:

The two most critical aspects of this experiment are timing, and detector calibration. Timing involves the delaying of pulses (using cable length/propagation velocity) in such a way that coincident pulses can arrive simultaneously at a particular point in the system. Pulses generated by the PEA must arrive at the coincidence unit at the same time as the corresponding pulse (generated by the recoiled electron) arrives from the EEA. Use the oscilloscope to examine the relative timing between the two pulses, and adjust the timing using the appropriate length of cable or delay setting. Proper scope triggering is crucial here. Do not use "VERT" mode. Use one of the input channels to trigger the scope, and that will be your timing reference. Take note of the polarity of the pulses, and set the trigger Slope as appropriate. Adjust the trigger threshhold so that it lies on the same side of the baseline (above or below) as the pulses. Na22 is a good source to use for this adjustment because it emits two gammas simultaneously in opposite directions.

There is some probability of an accidental coincidence as a result of both detectors seeing independent gamma rays at the same time. P=Rl*(R2*Timewidth) where Rl and R2 are the count rates of each of the detectors, and Timewidth is the length of the time window in which a coincidence is defined (approximately the width of the discriminator pulses plus timing jitter). Prove this formula before you come into the lab. Obviously the narrower the time window, the lower the background rate. Additionally, one would like to keep Rl*R2 as low as possible, which is why the 1 millicurie (1 curie=$3.7*10^{10}$ disintegrations per second) Cs 137 source should be shielded from a direct view of the PEA detector. Measure the detector rates in order to calculate your accidental background rate. (The actual background can be measured by delaying one of the detectors relative to the other so that only unrelated events are counted.) Note that as the PEA counter is moved out of the direct beam, it will see a different rate R2 and therefore the accidental rate will change. Make sure you have investigated this effect.

The second aspect of the timing to be concerned with is the timing between the gate pulse and the analog pulses from the PEA and the EEA. The gate pulse (the output from the NIM to TTL converter) enables the ADC to begin the conversion of the pulses from each of the detectors into a digital number. The ADC continues its conversion for the duration of the gate. Since the gate pulse is generated by a series of electronic modules, each having a finite propagation delay, the gate signal arrives at the computer 40-60 nsecs after the analog pulses. This delay must be corrected by delaying the arrival of the analog pulses by 40-60 nsecs using the delay modules. Measure delay with the oscilloscope. Please read the equipment catalogs and manuals

for proper techniques and operation of the electronic modules before doing the experiment.

The other critical aspect of the experiment is calibration and gain adjustment of the photomultiplier tubes (PMT's). The height of the pulses from the PMT's and hence the gamma energies (and electron energies) must be adjusted to fall within the display range of the Pulse height Analyzer. The height of the charge pulse (gain) is a function of PMT voltage and the amount of amplification of the pulse signal. Insufficient gain will cause the pulse height spectrum to be shifted too far to the left; excessive gain will cause the spectrum to appear shifted too far to the right.

Refer to the schematic diagram for the system. Because of the particular voltage and impedance requirements at each step in the signal path, three different types of amplifiers must be used - each performing a specific type of function. The pre-amps within the PMT bases are charge sensitive amplifiers that adapt the impedance of the PMT to that of the Spectroscopy amplifiers. The Philips X10 amps boost the signal voltage from the PMT anodes to an appropriate range for the NIM logic modules. You'll note there are two different signal outputs on each of the PMT bases. One output is from the pre-amp, and the other is taken directly from the anode of the PMT. The direct signal has a negative polarity which is suitable (after amplification) for the NIM logic modules. The output from the pre-amps has positive polarity and is suitable for the Spectroscopy amplifiers. The logic circuits are used to generate the GATE, and the Spectroscopy amp signals are sent to the PHA for energy analysis.

Use the oscilloscope at each step of the electronic setup, as you must visually determine that your signals have the correct amplitude and timing. The gain, or amount of amplification is controlled first by the amount of high voltage applied to the PMTs, and secondly by the gain settings of the spectroscopy amplifiers. Excessive PMT voltage will overdrive the pre-amps and amplifiers causing pulse shape distortion and poor energy resolution. This distortions appears on the oscilloscope as a flattening to the peaks of the larger pulses. Make sure the high voltage is set low enough that none of the pulses in the range of interest become distorted. Ultimately, you must adjust the high voltage such that the amplitude of the pulses at the input to the discriminators fall between the -30 mv and –1V discriminator limits. Then set the gain of the spectroscopy amps to the point where both the highest and lowest energies to be measured in the experiment will appear on your PHA spectrum.

It is suggested that you initially place the millicurie Na22 sources directly between the plastic scintillator and the NaI. Na22 is a positron (e+) emitter. The positron stops in the source and annihilates with an electron (e-), it's antiparticle. This releases two 511 keV gamma rays in opposite directions simultaneously (the rest mass of the e+, e- is 511 keV). It is these two coincident gamma rays which allow you to observe a substantial coincidence rate. Check to make sure that the pulses from both of the detectors arrive at the coincidence unit (via the discriminators) within a few nanoseconds of one another. Adjust the propagation delay time using the delay box and/or various lengths of cable.

Once your system timing is properly set, and you are able to produce spectra, you will need to make an energy calibration. It is suggested that you calibrate each detector in the singles mode, which means one detector at a time – rather than in coincidence. This is easily done by disabling one of the inputs on the NIM coincidence module. You should use the microcurie Na22 source as well as a microcurie Cs 137 source (not the millicurie one since the NaI detector will be saturated if it is directly in line with this source). Also calibrate at a lower energy such as 122 keV with Co 57. You should adjust the spectroscopy amp gain so that all energies of interest (for example between 100 KeV and 662 KeV) corresponding to the different scattering angles fall between channels 1 and 2048 of the PHA.

You will need to know the energy of each gamma ray used in the calibration. Use the Chart of the Nuclides to find this information. Record the channel number that corresponds to the photopeak for each gamma energy used. Fit a line to the data to determine the calibration factor in energy per channel. You may prefer to use the calibration utility incorporated into the computer program.

Note that if you have a reasonable coincidence rate but are not acquiring counts on the screen, the pulses from the detector may be either too large or too small to display within the range of the pulse height analyzer. If this is the case and the analyzer is receiving a proper gate pulse, then adjusting the high voltage or the spectroscopy amp gain may bring your spectrum into range. (Hint: if the pulse height spectrum extends all the way to channel 2048, you may be missing something off to the right of the spectrum.) Adjust the gain so that the spectrum fills as much of the screen as possible without going overrange. This will allow you to resolve the lower energies during the experiment. At the bottom (low energy edge) of the spectrum, make sure the discriminator threshold is not set above the pulse height that corresponds to the minimum energy you wish to record in your experiment.