Experiment 5 Compton Scattering

See W. R. Leo, pg. 55-57; also Knoll, Ch. 10

In this experiment we will scatter a gamma ray in a plastic scintillator detector (target) and detect the outgoing scattered gamma ray in a Sodium Iodide detector. The apparatus allows you to rotate the NaI detector around the target position and measure energy of the scattered gamma ray as a function of the scattering angle. You will compare your measured $E_\gamma(\theta)$ with the distribution expected from Compton scattering theory.

This is a double scattering arrangement similar to what is shown in Knoll Fig. 10-9.

![Diagram showing Compton scattering process with gamma rays $h\nu_1$, $h\nu_2$ and NaI detector labeled NaI]

Compton scattering occurs when the photon interacts with an electron and scatters through an angle $\theta$ defined by the position of the NaI detector. The recoil electron will deposit its energy in the plastic scintillator (target) and the recoil photon in the NaI detector.

The pulse heights from the Sodium Iodide are recorded in the Multichannel Analyzer (MCA) for each detected scatter. Triggers for this experiment will be coincident signals from the plastic and NaI detectors.

Preliminaries

It is very important, before beginning to work on this experiment, to calculate a table of energies and scattering angles so that you can predict the energies deposited in each detector as a function of the scattering angle. Before beginning to set up the experiment in the laboratory you must make a sketch of the geometry of the set-up and of the electronic logic that will be needed.

Apparatus

In this experiment you will use a plastic scintillating counter as a target and a NaI counter as a detector of the scattered gamma ray. The source will be placed in a lead tube that collimates the gamma rays that strike the target. You will also use the following: discriminators, coincidence units and a gate generator to generate a delay between the
pulse that defines a scatter in the plastic scintillator and the pulse from the NaI detector. The delay is necessary because of the much slower response time of NaI. The procedure for setting up the delay is described below and shown schematically in Figure 1. The output of the NaI is sent to an amplifier that provides the variable pulse required by the Multichannel analyzer. For this experiment we use the Norland MCA for which instructions available on the physic 433 web page. The calibration procedure for the MCA is discussed below. The apparatus is mounted on a table that allows one too set different scattering angles between the incident and scattered gamma ray. A photograph of one of the two set-ups is shown below. The source is behind the lead bricks which form a collimating channel to define a $\gamma$-ray beam. The NaI detector is mounted on the arm which rotates while the plastic target is mounted at the pivot point of the NaI detector that is near the exit of the collimator and is stationary.

![Source, Target and Detector](image1)

Data Taking and Calibration

A good gamma ray source to use for this experiment is $^{137}$Cs. What are the advantages and disadvantages of a $^{60}$Co source? Can you make a rough estimate of the counting
rate to expect? Since the rates are low, backgrounds may be a problem. What are sources of background and how can the background be reduced?

**Calibrating the MCA** so that you can measure the energy of the scattered $\gamma$-ray is critical in this experiment. This needs to be done before you implement the coincidence logic. The NaI output pulse needs to be amplified before being sent to the MCA; the same procedure used in lab 2 last week. Photo-peaks from $^{22}$Na, $^{137}$Cs and $^{133}$Ba sources give well defined energies for your calibration curve. As you acquire the data in the MCA you should make a quick plot of the channel number vs. energy of the photo-peaks to be sure you cover the expected energy range of Compton scattered $\gamma$-rays you expect. Please take care to set the amplifier gain so that all of the above photo-peaks fall within the range of the MCA. **NOTE: once you have acquired your calibration curve you must not change the amplifier gain for the remainder of the experiment.**

**Establishing a coincidence** between plastic scintillators and NaI requires care because the time response of the two detectors is very different. Do you remember which gives the fastest response? Yes, it is the plastic scintillator.

You will need set-up a coincidence gate for the MCA by placing the $^{22}$Na source between the plastic and NaI detectors. The logic units that are needed to set up the delay are a discriminator and two gate generators. The pulse from the plastic scintillator is first sent to a discriminator; the out put of the discriminator becomes the input to the first gate generator. The pulse width of the NIM output of the gate generator should be adjusted to the expected delay between the scintillator and NaI pulse, which is typically 700-800 ns. The compliment NIM from the first gate generator is the input to the second gate generator. The second gate generator will be triggered by the falling edge of the NIM pulse and the TTL (+5 V) output is adjusted to encompass the NaI amplified pulse as shown below. Before proceeding, look at the NIM pulse on the oscilloscope. **How does it differ from the NIM output and what is its function in this experiment?**

After the basic checks with other sources set up the correct geometry, start out by taking $^{137}$Cs data at some favorable scattering angle to observe the rates and to check that the coincidence logic is behaving properly. Then plan a series of measurements at selected angles.
Results

Once you have done the calibrations and taken the data for a few angles the analysis is easy. Compare your data with the theoretical predictions on a suitable graph. You should, however, be aware of both statistical and systematic uncertainties. *What are some of the sources of systematic error? Are your results dominated by statistical or systematic errors? What is the effect of the acceptance angle of each detector and the energy resolution?*

Scattering Cross Section

The second part of the experiment is a measurement of the $\gamma e$ interaction cross section in the plastic slabs provided for this purpose. For this measurement you remove the plastic scintillator and use only the NaI detector. Set-up the NaI detector at $0^\circ$ and measuring the counting rates of the $^{137}\text{Cs}$ photopeak, record this value. Now repeat for several thicknesses of plastic placed at the exit of the lead collimator. You need to measure and record each thickness of absorber.

Analysis

*Compton Scattering* Plot the measured energy of the $\gamma$ versus the angle of scattering and compare with the predictions of the Compton formula. That is, make a graph on which
you display your data points and plot the predicted energy versus scattering angle. 
**Discuss how well your data agrees with the expected Compton scattering distributions.**
Be sure to include your estimate of the errors of your measured data points.

**Scattering Cross section** The transmission of $\gamma$ rays through a slab of material of thickness $x$ is given by $I(x) = I_0 e^{-\mu x}$ where $I(x)$ is the transmitted rate, $I_0$ the incident rate, $1/\mu$ the mean free path and $x$ the thickness of the material. If $n_e$ is the number of free electrons per cm$^3$ in the target, then the total Compton scattering cross section will be given by $\sigma_{\text{tot}} = \mu/n_e$

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