

Physics 122
Winter 2012

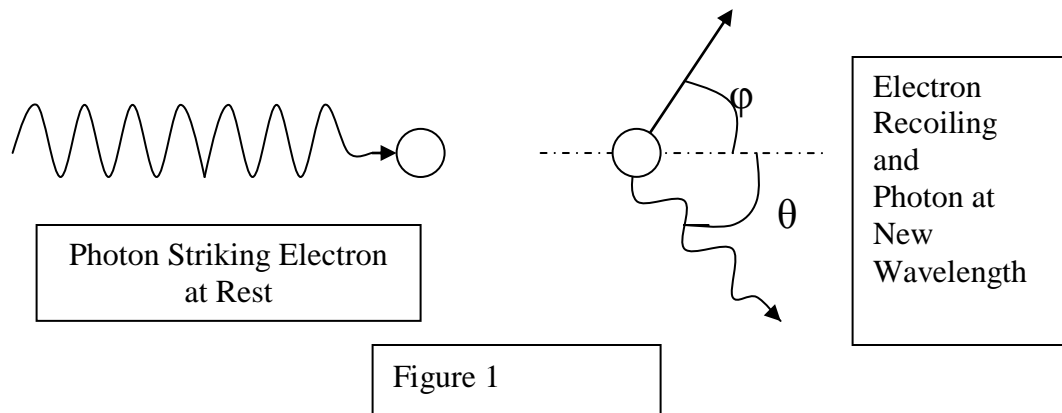
Compton Scattering and Coincidence Counting

Introduction

Through the process of coincidence counting this lab investigates the Compton Effect by measuring the energy of scattered photons. A gamma ray source, ^{137}Cs , emits high energy photons that are scattered from a detector placed in their path. These scattered photons have an energy that is related to their scattering angle; their energy can be measured using scintillation detectors. Through Compton's equation you can calculate the wavelength of the scattered photon. This result will reinforce Planck's findings that as the wavelength of a photon increases its energy decreases.

Background

Arthur Compton devised his experiment in 1923 assuming that light consisted of particles. This theory was first suggested to explain the photoelectric effect, which ran contrary to the classical physics belief that light behaved as a wave. The photoelectric effect deemed that light must have some particle properties since it was able to eject electrons from a piece of metal, and thereby induce a current. Compton's findings were consistent with both Planck's and Einstein's relationships between the energy of photons and their wavelengths. When a photon strikes an electron at rest, the electron recoils off in some direction and the photon continues on new path with a different wavelength, as shown in Figure 1. By using both conservation of momentum and energy, Compton was able to show how this happens; his efforts helped to prove that light behaves as a stream of photons.

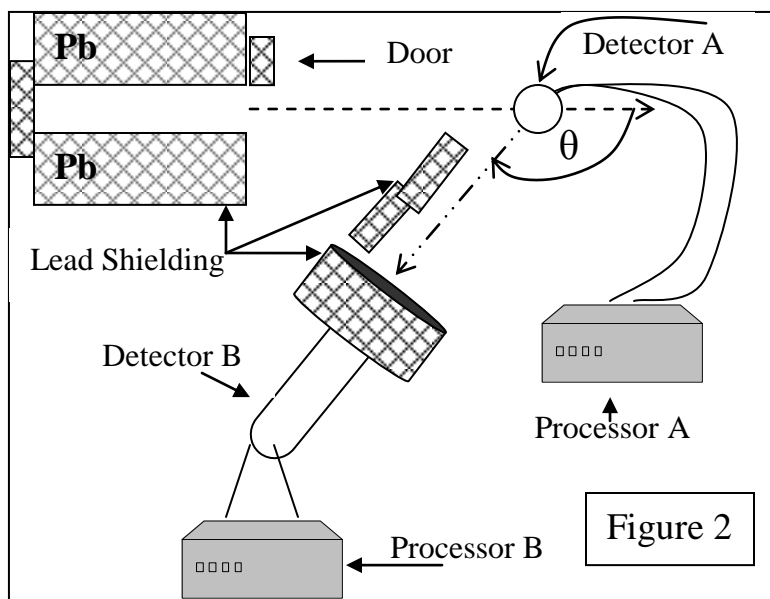


The Apparatus

While the original experiment was done by Compton with x-rays, we will use higher energy gamma rays. The gamma rays, with energy hf , are produced by a ^{137}Cs source and are aimed towards one detector (A). These rays collide with a block of sodium iodide inside the head of the detector, ejecting an electron. The result is the electron traveling off at an angle (ϕ) and the incident photon with a new energy of hf' moving in the θ direction. The second detector (B) is mounted on a rotatable arm and positioned at an angle θ ; it measures the energy of the scattered photon. (See Figure 2)

The gamma ray source and detector B are both shielded by heavy lead shielding to protect you (and the detector) from any unnecessary (or unwanted)

exposure to the radiation. ^{137}Cs is considered a hot source; it is dangerous to handle directly and to be exposed to for extended periods of time. **ALWAYS MAKE SURE THE DOOR IN FRONT OF THE SOURCE IS CLOSED WHEN CHANGING THE ANGLE OF THE DETECTOR.** In addition, do not cross in front of the door when it is open. The lead shielding itself is extremely heavy and should never be lifted more than a foot off the ground to prevent it from being dropped on a foot.



Detector

The detector contains a block of sodium-iodide and a photomultiplier tube within it. When a high energy photon strikes the sodium-iodide block an electron is knocked loose, this electron travels off with an increased energy, creating photons in the scintillator. The photomultiplier tube detects the photons, whose number (and thereby, photocurrent) corresponds to the energy of the photon.

Scintillation Processor

The processor controls both the high voltage going out to the detector and the gain of the signal coming from the detector. A higher voltage sent to the detector will result in the detection of photons with lower energies, whereas, the gain determines pulse height. Once an appropriate set of values has been found these settings should not be changed throughout the lab exercise.

MCA

The MCA (multi-channel analyzer) is a combination of hardware (a card in the computer) and software. The MCA sorts the electrical pulses according to their voltage, and presents a histogram display representing how many pulses, with heights in a given range, it receives for each channel number (corresponding to energy level). At a low gain setting on the processors one channel may correspond to all energy levels between 1.0 and 1.1 (KeV), while at a higher gain that same channel may have the energy values of 1.0 to 1.01 (KeV). The number of pulses is on the vertical axis of the computer screen, with the corresponding energy along the horizontal axis. This is the spectrum of the detected gamma rays.

Universal Coincidence

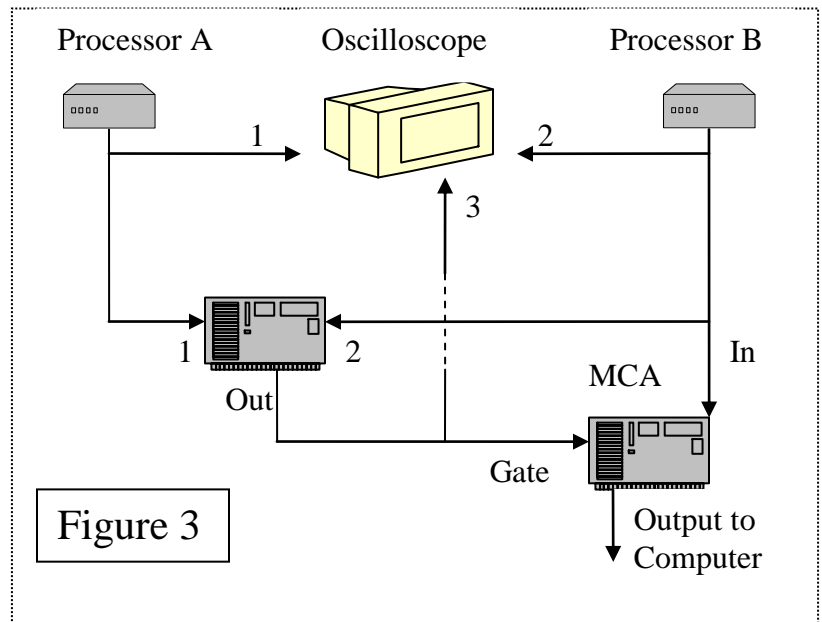
A coincidence generator takes the two energy signals produced by the detectors and generates an output pulse when both are received within the same time window. This time window is set to roughly 0.4 micro-seconds, which is ample time for the signals to be received.

Maestro Computer Program

This program measures the number of counts the detector collects at the different energy levels. Using histogram plotting this program deposits the collected energy levels into specific energy bins, or channels. The vertical axis represents the number of counts or pulses the MCA receives with the corresponding energy along the horizontal axis. It displays how many counts are received in each channel; these form energy peaks which are what we are looking for.

The detectors each have their own processors which send the computer a signal every time a pulse is recorded with a height proportional to the corresponding energy of the scattered gamma. The detectors work by measuring the light producing by a moving electron that, in our case, is scattered by a photon striking it. We only want to measure the energy of the photon scattered from detector A and then detected by B. By using coincidence, we can make sure that the detected photon was in fact scattered from detector A. By connecting both of

the processors to the Universal Coincidence generator it will create a pulse if and only if there is a signal from both detectors within some short time window. (See Figures 2 and Figure 3)



Procedures

1. Calibrate the MCA: Using both the ^{133}Ba and ^{22}Na sources, calculate the keV/Channel factor in the computer. Place one of the samples close to detector 'B,' start the collection on the computer and run until there are defined peaks. You can highlight a peak by using the 'ROI (region of interest)' toolbar, click it and select "mark." Now by clicking on one side of a peak, and moving to the other side with the arrows, you can select the peak area. Under the calculate menu, select "calibration" and destroy the current calibration. Now right click on one peak and chose 'peak info.' Again, under calibration menu selection there is a space for a value to be entered, enter the value that you have found for the corresponding peak, and repeat this process if there is another available peak and again with the other sample source. Do not destroy the calibration between entering the values for each peak. Only have one source near the detector (B) at a time, but have it as close as possible for calibration. Make sure you are collecting data without using the coincidence circuitry.
2. Data Collection: In order to obtain a readable peak data must be collected for a long enough time. Under the 'Acquire' menu select 'properties' and then 'presets;' 900 seconds (15 minutes) is enough time to generate a readable peak. Note: There are two different times; real and live. Live is the actual time the computer is counting - it sometimes will not be able to keep up with the amount of data - whereas real time is the total time the program was running for. Under the same 'properties' option you can change the collection method to coincidence. Now move detector B to a convenient angle, between 20° and 120° degrees, open the door to the ^{137}Cs source and measure the energy of the Compton scattered gamma rays. After collecting data for a preset time CLOSE the door, and change angle of detector B, reopen the door and record the new data from this angle.

Results

After every different data collection at a different angle, be sure to record all peak information by highlighting that peak. A correctly calibrated computer will automatically calculate the peak energy level of a selected peak; it will also provide the error within that calculation, full width half maximum, FWHM. There will also be some inaccuracy within the angular placement of the swing arm; you must determine that error as well. Make sure to save each collected spectrum; they contain the raw data for the number of counts per energy level, which can be opened and using Excel, graphed. From the Compton equation, expressed in terms of energy of the photons,

$$\frac{1}{E'} = \frac{1}{E} + \frac{1 - \cos \theta}{m_0 c^2}$$

use your data to determine the initial energy of the ^{137}Cs gamma ray, and also the mass of the electron.