Compton Effect

PURPOSE

In this experiment the techniques for measuring the effects of Compton scattering will be studied. The source will be ^{137}Cs, and the scattering will be caused by its gamma rays striking an aluminum rod.

INTRODUCTION

The collision of a gamma ray with a free electron is explained by the Compton interaction. The kinematic equations that describe this interaction are exactly the same equations as for two billiard balls colliding with each other, except that the balls are of different sizes. Figure 1 shows the interaction.
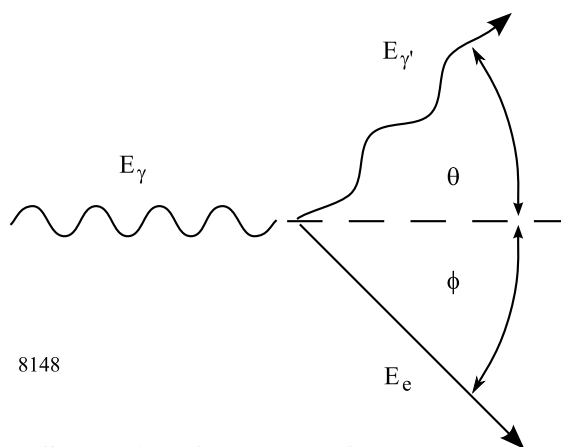

Fig. 1. Scattering Caused by Compton Interaction.

In Fig. 1 a gamma of energy E scatters from an electron with an energy E'. (For convenience, all energies are expressed in MeV.) The energy that the electron gains in the collision is E_e. In Fig. 1, θ and ϕ are the scattering angles for γ' and the electron respectively. The laws of conservation of energy and momentum for the interaction are as follows:

Conservation of energy: $E = E' + E_e$

x direction $\dfrac{hf}{c} = \dfrac{hf'}{c}(\cos\theta) + mv(\cos\theta).$

Conservation of momentum,

y direction $0 = \dfrac{hf'}{c}(\sin\theta) - mv(\sin\varphi)$

Conservation of momentum.

In the above equations, $E = hf'$, $E' = hf'$, $E_e = mc^2 - m_0c^2$, $m = m_0 / (1 - v^2/c^2)^{1/2}$ when $m_0 =$ rest mass of the electron, and $v =$ the velocity of the recoil electron.

Solving the above equations for $E_{\gamma'}$ results in the following:

$$E_{\gamma'} = \dfrac{E_\gamma}{1 + \dfrac{E_\gamma}{m_0 c^2}(1 - \cos\theta)}$$

This equation is easy to use if all energies are expressed in MeV. The electron rest energy $m_0 c^2$ is equal to 0.511 MeV. In this experiment E is the energy of the source (0.662 MeV for ^{137}Cs), and θ is the measured laboratory angle.

The differential cross section for Compton scattering was first proposed by Klein and Nishina. The expression has the following form:

$$\left(\frac{d\sigma}{d\Omega}\right)_{theory} = \frac{r_0^2}{2}\left\{\frac{1+\cos^2\theta}{[1+\alpha(1-\cos\theta)]^2}\right\}$$
$$x\left\{1+\frac{\alpha^2(1-\cos\theta)^2}{[1+\cos^2\theta][1+\alpha(1-\cos\theta)]}\right\}, \left(\frac{cm^2}{sr}\right)$$

where

$r_0 = 2.82\,x10^{-13}\ cm$ (classical electron radius),

$\alpha = \dfrac{E_\gamma}{m_0 c^2} = \dfrac{0.662\ \text{MeV}}{0.511\ \text{MeV}} = 1.29\ \text{for}\ ^{137}Cs$

$d\Omega$ = the measured solid angle in steradians.

In our measurement we will find the corresponding value:

$$\left(\frac{d\sigma}{d\Omega}\right)_{measured} = \frac{\Sigma_{\gamma'}}{N\Delta\Omega I}$$

where

Σ' = sum under the photopeak divided by the intrinsic peak efficiency,

N = number of electrons in the scattering sample
$= \dfrac{(\text{volume})(\text{density})(\text{atomic no.})(\text{Avogadro's no.})}{\text{atomic weight}}$

$\Delta\Omega$ = solid angle in steradims of detector
$= \dfrac{\text{area of detector (cm}^2)}{[R_2\ (\text{cm})]^2}$

I = the number of incident's per cm^2 per s at the scattering sample; this number can be calculated if the activity of the source is known.

In this experiment we will only care for ratios between the measured values at different angles. Thus, it will not be necessary to calculate the above parameters in detail.

PROCEDURE

1. Mount the NaI(T1) detector under 0 degrees in its stand. The collimated 137-Cs source is already mounted. The center of the source should be on the same height as the center of the detector crystal. You can check this with a plastic rod. Connect the photomultiplier base (base) to the photomultiplier (PM) connector.
2. Connect the high voltage (HV) input of the PM base to the HV output of the HV power supply. This base has amplifier, which you have to connect to the power outlet at the back of the main amplifier.
3. Connect the preamp output of the PM base to the oscilloscope. Signals visible?
4. Turn on the HV power supply (screw/switch on the back side should be on positive). Try if you see signals turning up the voltage in +100 V steps. Maximum + 800 Volts!!!
5. Take notes of the results and sketch the signals on the oscilloscope at + 800 V. Rise time, fall time, noise?
6. Connect the preamp output to the spectroscopy amplifier input. Turn on the power of the bin and check input signal polarity.
7. Connect the oscilloscope to the amplifier output (unipolar). Sketch the signal.
8. Connect the unipolar output with the ADC/MCA input and start a measurement. Adjust amplification so that you can clearly see the photo peak in the spectrum. Sketch the spectrum. Check the signal again on the oscilloscope. Voltage of photo peak?
9. Determine the count rate (net) in the photo peak region at 0 degrees and determine the peak position. Use this value for your rough energy calibration. The count rate naturally is very high as the detector is looking into the collimated source.
10. Now take measurements the other angles displayed in the table below. Calculate the peak position you expect first as background peaks will appear in the spectrum.

(deg.)	E' (Calculated)	E' (Measured)
0		
15		
20		
25		
30		
35		
40		
50		

11. Calculate the ratios between the count rates (net) at the different angles and compare them to the ratios of the theoretical prediction. If they do not agree, speculate why!