# Compton Scattering Experiment

## *Introduction*

The collision of a gamma ray with a free electron is explained by the Compton interaction. The gamma ray is scattered by the electron, transferring some of its energy to the electron in the process. In the first part of this experiment the energy of the scattered gamma ray is measured as a function of the scattering angle. In part two the differential cross-section for Compton scattering is measured as a function of the scattering angle and the results are compared with theoretical predictions.

## *Equipment*

$^{137}Cs$ gamma ray source
2" × 2" NaI(Tl) scintillation detector
Photomultiplier tube and amplifier
Software – Maestro-32

# Part 1: Energy Determination

## *Theory*

The kinematic equations that describe the Compton interaction are exactly the same equations governing the collision of two billiard balls. Figure 1 shows the interaction schematically.

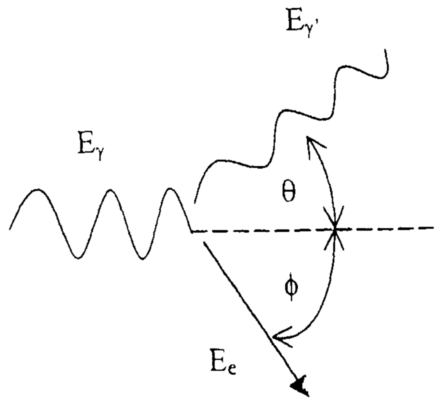



**Figure 1:** Scattering caused by Compton interaction.

In this figure, a gamma ray of energy $E_\gamma$ scatters from an electron with an energy $E_{\gamma'}$ and a scattering angle $\theta$. The energy that the electron gains in the collision is $E_e$ and its scattering angle is $\phi$. During the interaction both energy and momentum are conserved.

Conservation of energy: $$E_\gamma = E_{\gamma'} + E_e \tag{1}$$

Conservation of momentum: x direction $$\frac{hf}{c} = \frac{hf'}{c}\cos(\theta) + mv\cos(\phi) \tag{2}$$

y direction $$0 = \frac{hf'}{c}\sin(\theta) - mv\sin(\phi) \tag{3}$$

In the above equations: $E_\gamma = hf$ and $E_{\gamma'} = hf'$

$E_e = mc^2 - m_0c^2$

$m = m_0/(1 - v^2/c^2)^{-1/2}$

where $m_0$ is the rest mass of the electron and v is the velocity of the recoil electron.

Solving these equations for $E_{\gamma'}$ gives:

$$E_{\gamma'} = \frac{E_\gamma}{1 + \frac{E\gamma}{m_0c^2}(1 - \cos(\theta))} \tag{4}$$

Using MeV for the units of energy $m_0c^2$ is equal to 0.511 MeV and $E_\gamma$ is equal to 0.662 MeV for the $^{137}Cs$ source used in this experiment. Substituting these values into Equation 4 gives:

$$E_{\gamma'} = \frac{0.662}{1 + 1.295(1 - \cos(\theta))} \tag{5}$$

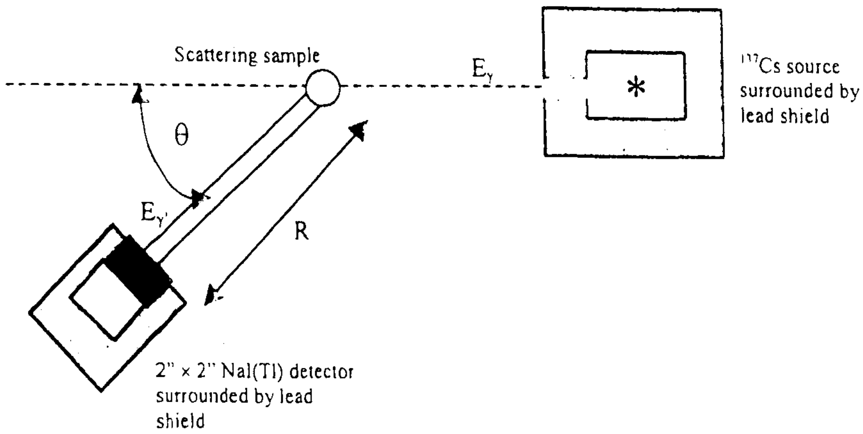
or written in terms of $1/E_{\gamma'}$ we get:

$$\frac{1}{E_{\gamma'}} = 1.51 + 1.956(1 - \cos(\theta)) \tag{6}$$

Therefore a plot of $1/E_{\gamma'}$ against $(1-\cos(\theta))$ should yield a straight line with a y-intercept of 1.51 and a slope of 1.956.

## *Procedure*

A schematic diagram of the apparatus used in this experiment is shown in Figure 2. As mentioned previously, the source used in this experiment is a high activity $^{137}Cs$ source, which is surrounded by a lead shield. **The source aperture should only be open when the source is in use.** The scattering sample is placed directly in front of the source aperture and the NaI(Tl) detector is on a movable arm pivoted about the centre of the scattering sample. The detector, scattering sample and source aperture must be aligned in the same horizontal plane.




CALIBRATION?

For scattering angles (θ) between 20° and 100°, in steps of 5°, measure the gamma spectra. The spectra should be counted until at least 10 000 net counts have amassed under the photopeak. Record the energy of the scattered gamma ray corresponding to each angle.

## *Analysis*

Plot $1/E_{\gamma'}$ against $(1-\cos(\theta))$ and determine the slope and intercept. Plot the calculated results (from Equation 6) on the same graph and compare.

## Calibration

| Calibration Source | Energy of Photopeak (keV) | Channel number |
|---|---|---|
| Am-241 | 59.5 | |
| Ba-133 | 303<br>356 | |
| Cs-137 | 662 | |

## Calibration:

| Calibration Source | Energy of Photopeak (keV) | Channel number |
| --- | --- | --- |
| Ba-133 | 276.4<br>302.9<br>356.0<br>383.9 | |
| Cs-137 | 661.7 | |
| Co-60 | 1173<br>1332 | |

## Part 2: Cross-Section Determination

### *Theory*

The differential cross-section for Compton scattering (i.e. the probability that an incident photon is Compton scattered at an angle θ) can be calculated using the *Klein-Nishina formula*:

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{theory}} = \frac{r_0^2}{2}\left\{\frac{1+\cos^2\theta}{[1+\alpha(1-\cos\theta)]^2}\right\}\times\left\{1+\frac{\alpha^2(1-\cos\theta)^2}{(1+\cos^2\theta)(1+\alpha[1-\cos\theta])}\right\},\ \left(\frac{cm^2}{sr}\right) \qquad (7)$$

where

$r_0 = 2.82 \times 10^{-13}$ cm (classical electron radius),

$\alpha = \frac{E_\gamma}{m_0c^2} = \frac{0.662\,\text{MeV}}{0.511\text{MeV}} = 1.29$ for $^{137}Cs$,

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

### ***Procedure***

For the spectra counted in part 1 determine the **NET** counts under the photopeak (and the associated error) for each angle measured and record the time each angle was counted for.

### ***Analysis***

The measured differential cross-section can be calculated using the following equation:

$$\left(\frac{\partial\sigma}{\partial\Omega}\right)_{measured} = \frac{\Sigma_{\gamma'}}{N\,\Delta\Omega\,I} \qquad (8)$$

where

$\Sigma_{\gamma'}$ = sum under the photopeak divided by the counting time and divided by the intrinsic peak efficiency (see Appendix A)

N = number of electrons in the scattering sample

$$= \frac{(\text{mass of scattering rod})\,(\text{atomic no.})\,(\text{Avogadro's no.})}{(\text{atomic mass})}$$

$\Delta\Omega$ = solid angle of the detector in steradians

$$= \frac{\text{area of detector (cm}^2\text{)}}{\left(R_2\ \text{(cm)}\right)^2}$$

I = the number of incident gamma rays per $cm^2$ per s at the scattering sample

$= 1.013 \times 10^6\ e^{-(t/43.48)}$ Bq $cm^{-2}$ (where t is the time in years since August 1977)

Plot the theoretical and measured differential cross-section against scattering angle and compare.

Note:

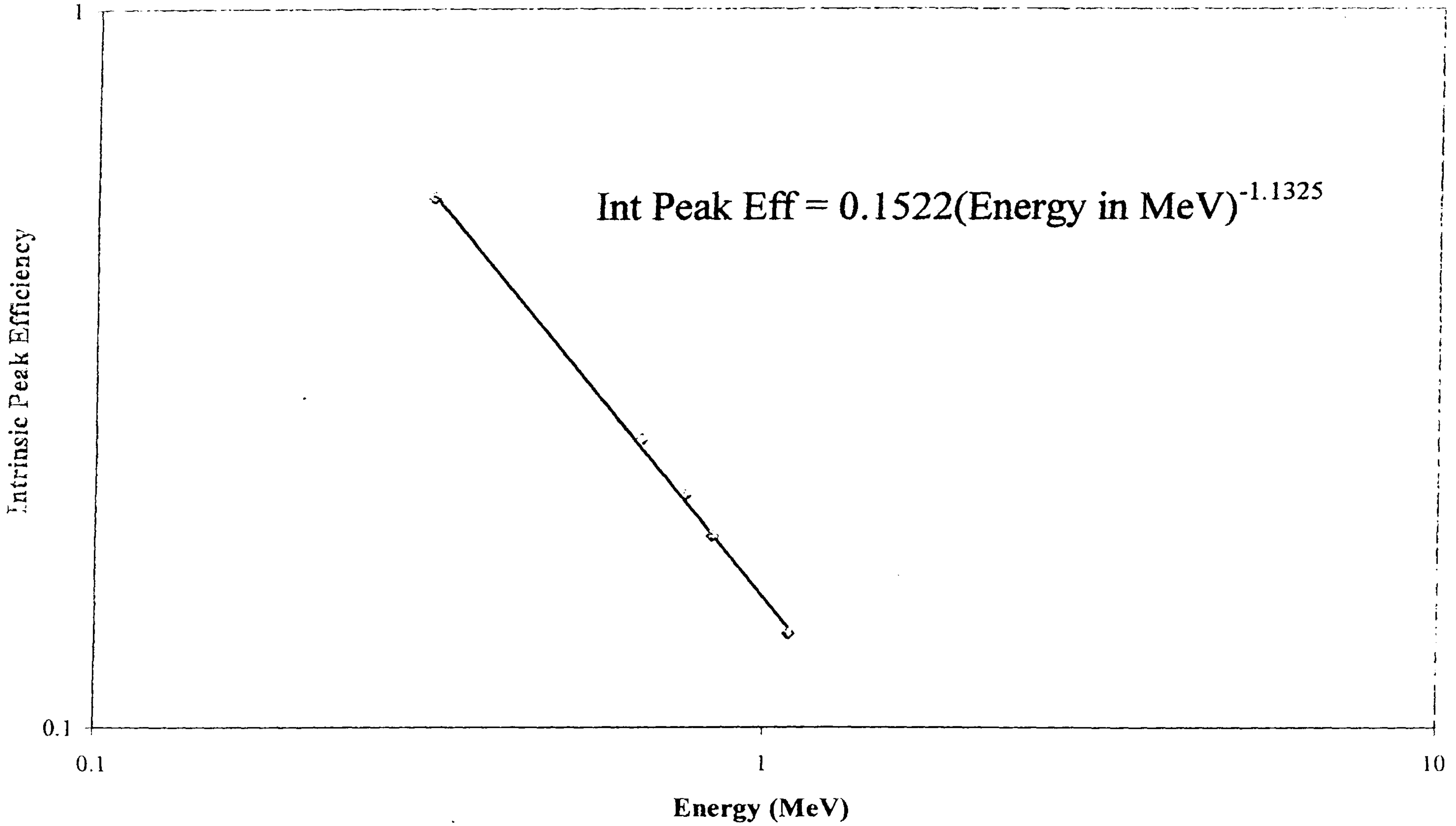
Radius of detector = 2.5 cm

$R_2$ = distance from detector to the scattering sample $\approx$ 26 cm

Mass of scattering rod = 79.3 g

References:

Introduction to Nuclear Physics, K.S. Krane



Int Peak Eff = 0.1522(Energy in MeV)$^{-1.1325}$
Intrinsic Peak Efficiency
Energy (MeV)
1
0.1
0.1
1
10