ORTEC®

AN34 Experiments in Nuclear Science Laboratory Manual Fourth Edition

Experiment IV-10
Compton Scattering

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ADVANCED MEASUREMENT TECHNOLOGY

Introduction

Compton scattering is the inelastic scattering of a photon by a quasi-free charged particle, usually an electron. It results in a decrease in energy (increase in wavelength) of the photon (which may be an X-ray or gamma ray photon), called the Compton effect. Part of the energy of the photon is transferred to the recoiling electron. The Compton effect was observed by Arthur Holly Compton in 1923 at Washington University in St. Louis and further verified by his graduate student Y. H. Woo in the years following. Compton earned the 1927 Nobel Prize in Physics for the discovery.

This experiment explores Compton Scattering using the 662-keV gamma-ray from a 5 mCi ^{137}Cs radioactive source. The dependence of the scattered gamma-ray energy on the scattering angle will be measured and compared to the theoretical equation. Additionally, the differential scattering cross section will be measured and compared to the theoretical Klein-Nishina expression. The measurements will use an aluminum rod as the scatterer.[1]

Relevant Information

The collision of a gamma ray with a free electron is explained by the Compton-scattering theory. The kinematic equations describing this interaction are exactly the same as the equations for two billiard balls colliding with each other, except that the balls are of two different sizes. Fig. IV-10.1 shows the interaction.

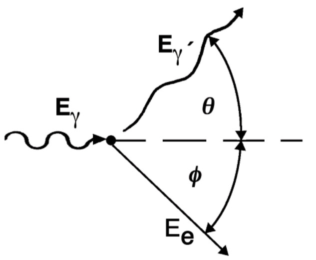

Fig. IV-10.1. Angles and Energies Defined for the Compton Scattering Process.

In Fig. IV-10.1 a gamma of energy $E\gamma$ scatters from a free electron. After scattering, the gamma-ray departs at an angle θ with respect to its original direction. The energy of the scattered gamma-ray is lowered to $E_{\gamma'}$. That difference in gamma-ray energies is transferred to the electron, which recoils at an angle ϕ with respect to the original gamma-ray direction, and carries off an energy E_e. The laws of conservation of energy and momentum for the interaction are as follows:

Conservation of energy:

$$E_\gamma = E_{\gamma'} + E_e \quad (1)$$

Conservation of momentum:

X direction:

$$\frac{h\nu}{c} = \frac{h\nu'}{c}\cos\theta + mv_e\cos\phi \quad (2a)$$

Y direction:

$$0 = \frac{h\nu'}{c}\sin\theta - mv_e\sin\phi \quad (2b)$$

In equations (1), (2) and (3), ν and ν' are the frequencies of the incident and scattered gamma rays, respectively, and h is Plank's Constant (6.63×10^{-27} erg sec.). Consequently,

$$E_\gamma = h\nu \quad (3a)$$

$$E_{\gamma'} = h\nu' \quad (3b)$$

Also

$$E_e = mc^2 - m_0c^2 \quad (3c)$$

$$m = \frac{m_0}{\sqrt{1-\frac{v_e^2}{c^2}}} \quad (3d)$$

For the electron, the rest mass is m_0, and the recoil velocity is v_e.

[1] In the corresponding third edition experiment, based largely on NIM modules, two additional investigations are available: The aluminum rod is replaced with a plastic scintillator. This substitution allows coincidence techniques to be employed to reduce the interfering background, and permits measurement of the electron recoil energy.

Compton Scattering

Solving equations (1), (2) and (3) results in the well-known equation expressing the energy of the Compton-scattered gamma ray as a function of the scattering angle, θ.

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

Note that Eq. (4) is easy to use if all energies are expressed in MeV. From Experiments 3 and 7, the rest-mass equivalent energy of the electron, m_0c^2, is equal to 0.511 MeV. In this experiment, E_γ is the energy of the source (0.662 MeV for ^{137}Cs), and θ is the measured laboratory scattering angle.

Equation (4) is convenient for calculating the energy of the Compton-scattered gamma ray if the original energy and scattering angle are known. For comparing the predicted $E_{\gamma'}$ to the measured $E_{\gamma'}$ in this experiment, it is useful to rearrange equation (4) to the form:

$$\frac{1}{E_{\gamma'}} = \frac{1}{E_\gamma} + \left[\frac{1}{m_0c^2}\right](1 - \cos\theta) \qquad (5a)$$

For E_γ = 0.662 MeV and m_0c^2 = 0.511 MeV, equation (5a) becomes

$$\frac{1}{E_{\gamma'}} = 1.51 + 1.957\,(1 - \cos\theta) \qquad (5b)$$

Hence, if $(1/E_{\gamma'})$ is plotted against (1 – cosθ) on a linear graph equation (5b) will form a straight line with a slope of 1.957 MeV^{-1} and an intercept of 1.51 MeV^{-1}.

Calculating the Peak Position Uncertainty

If the background under the photopeak is negligible, as it should be in this experiment, and the position of the photopeak is calculated as the centroid of the area under the peak, counting statistics will contribute a predicted standard deviation in the centroid energy given by

$$\sigma_{E\gamma'} = \frac{FWHM}{2.35\sqrt{\Sigma_{\gamma'}}} \qquad (6)$$

Where FWHM is the full width of the photopeak in MeV at half the height of the peak, and Σγ' is the total counts in the region of interest set across the entire width of the peak at the baseline (ref. 9). Equation (6) can be used to estimate the measurement error in the photopeak position for plotting on the graphs below.

Equipment Required

• **905-3** 2-inch x 2-inch (5.08-cm x 5.08-cm) NaI(Tl) Detector/Photomultiplier Assembly. • **digiBASE** 14-Pin PMT Base, Digital MCA, Preamplifier, High Voltage Supply, MAESTRO software and USB cable. (digiBASE-E may be substituted.) • **306-AX** Angular Correlation Table (with two detector shields, two rotating detector arms, and one shielded source collimator/enclosure). Includes AL-ROD-AX Aluminum Scattering Rod, 0.5-in diameter x 4-in. long (1.27 cm x 10.2 cm), ASTM 6061-T651 alloy.	• **CS173-5M*** 5-mCi ^{137}Cs Source. A license is required for this source. • **RSS8** Gamma-Ray Source Kit including: ^{133}Ba, ^{109}Cd, ^{57}Co, ^{60}Co, ^{137}Cs, ^{54}Mn and ^{22}Na, each with a 1 µCi source activity, and a Cs/Zn mixed source incorporating 0.5 µCi of ^{137}Cs and 1 µCi of ^{65}Zn. The source kit enables energy calibration from 32 to 1333 keV. • Personal Computer with a USB port and a recent, supportable version of the Windows operating system.
*Sources are available direct from supplier. See the ORTEC website at www.ortec-online.com/Service-Support/Library/Experiments-Radioactive-Source-Suppliers.aspx	

Apparatus and Geometry

Fig. IV-10.2 shows the geometry used for the experiments described below for Compton scattering. Experiments IV-10.1 and IV-10.2 are simple scattering experiments using an aluminum scattering sample.

The Compton scattering experiments are set up by employing the 306-AX Angular Correlation Table. As indicated in Figure IV-10.2, the source to scatterer distance, R_1 = 12 inches (30.5 cm), and the distance from the center of the scatterer to the front surface of the NaI(Tl) detector is R_2 = 12 inches (30.5 cm). The shielded source container incorporates a square collimator on its front surface that limits the area illuminated by the gamma rays at the center of the scatterer to a 2-inch wide by 2-inch tall square (5.08 cm x 5.08 cm). As instructed in the appendix, this illuminated square should be centered on the scatterer. Thus the illuminated volume of the scatterer will be confined to 5.08 cm along its axial length and the 1.27 cm width determined by the 0.5-inch diameter of the rod or scintillator.

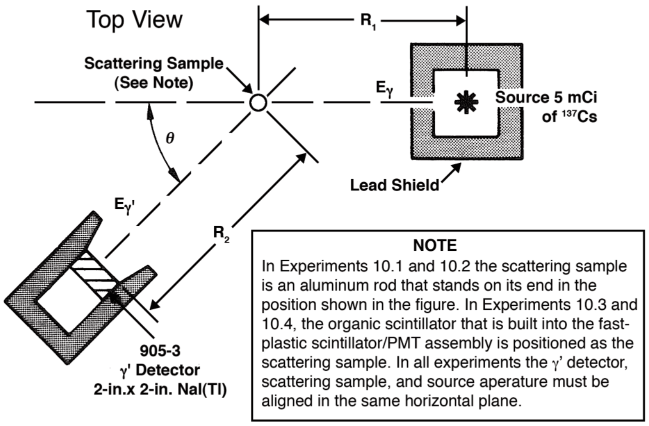

Fig. IV-10.2. The Compton Scattering Geometry Implemented via the 306-AX Angular Correlation Table.

The 5 mCi ^{137}Cs source should already be installed in its shielded collimator by the Laboratory Manager, and the NaI(Tl) detector with its lead shield should already be mounted on the arm that provides for setting the desired scattering angle. See the appendix on this experiment for details on setting up and aligning the apparatus.

CAUTION

The ^{137}Cs source employed in this experiment has a very high activity (5 mCi). To reduce radiation exposure, handling of the small 6.4 mm diameter source capsule should be minimized, and tongs should be employed to increase the distance from the source capsule to the hands. Once the source is properly installed in the shielded collimator and the cover is secured over the collimator opening, the radiation exposure is reduced to less than that caused by a 1 µCi source at a minimum distance of 7.6 cm. This shielding can be used for storing the source when not being used in the measurement.

During the Compton scattering experiment, the cover over the collimator opening must be removed. While the cover is open, minimize the time any body parts are inserted into the direct beam of gamma rays streaming through the collimator, and maximize your distance from the source in that direct beam.

For safety, the shielded cover should be applied over the collimator opening whenever the output from the source is not needed. If the enclosed source is left unattended, that collimator cover should be secured with a lock to dissuade tampering.

EXPERIMENT IV-10.1. Simple Compton Scattering: Energy Determination

Procedure

1. Using E_γ = 0.662 MeV for ^{137}Cs in Eq. (4), calculate the values for $E_{\gamma'}$ and enter them in Table IV-10.1 for the angles listed.
2. Set up the electronics as shown in Fig. IV-10.3. More specifically:
3. Check that the NaI(Tl) detector and PMT assembly is properly inserted in the lead shield on the movable arm. The annular shield should protrude 2 inches (5.08 cm) beyond the front surface of the detector, and the distance from the front surface of the NaI(Tl) crystal to the center of the aluminum rod should be 12 inches (30.5 cm).

Table IV-10.1. Data for the Aluminum Scatterer.

θ (degrees)	Calculated $E_{\gamma'}$ (MeV)	Measured $E_{\gamma'}$ (MeV)	Preset Live Time, t_L (seconds)	Photopeak Sum, $\Sigma_{\gamma'}$	Photopeak FWHM (MeV)
0					
20					
40					
60					
80					
100					
120					
140					
160					
180					

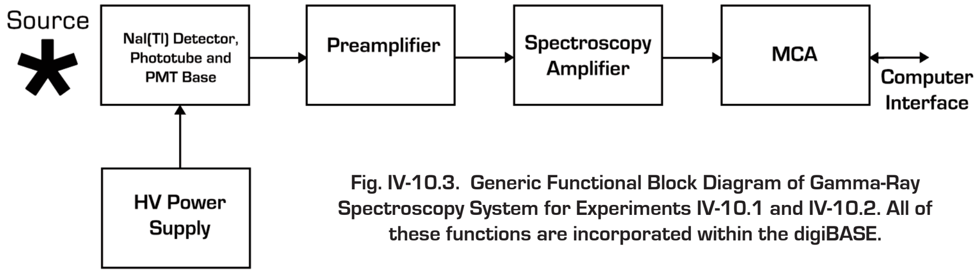

Fig. IV-10.3. Generic Functional Block Diagram of Gamma-Ray Spectroscopy System for Experiments IV-10.1 and IV-10.2. All of these functions are incorporated within the digiBASE.

Fig. IV-10.4 digiBASE All-in-One PMT Base, HV, Preamplifier, Amplifier, and Digital MCA.

4. Verify that the 5 mCi ^{137}Cs source in its shield is properly mounted with the source positioned 12 inches (30.5 cm) from the center of the aluminum scatterer. The location of the source in the shield is marked on the outside of the shield (10.2 cm behind the front, outside surface of the collimator). Ensure that the cover shield is in place over the source collimator to shut off the output of 662 keV gamma rays.

IV-10.1.1. Energy Calibration

The system should already be cabled correctly. A single USB cable between the digiBASE and the PC is all that is required.

If the software is installed correctly, then starting the MAESTRO program "MAESTRO for Windows" should result in the main MAESTRO screen appearing (Fig. IV-10.5).

If the screen shows "Buffer" in block 4 (Fig. IV-10.6), then the software has been unable to "find" the digiBASE and assistance should be sought, or the MAESTRO manual referred to.

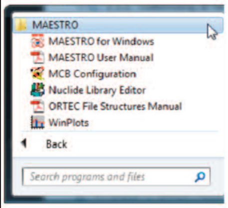

Fig. IV-10.5 Starting MAESTRO.

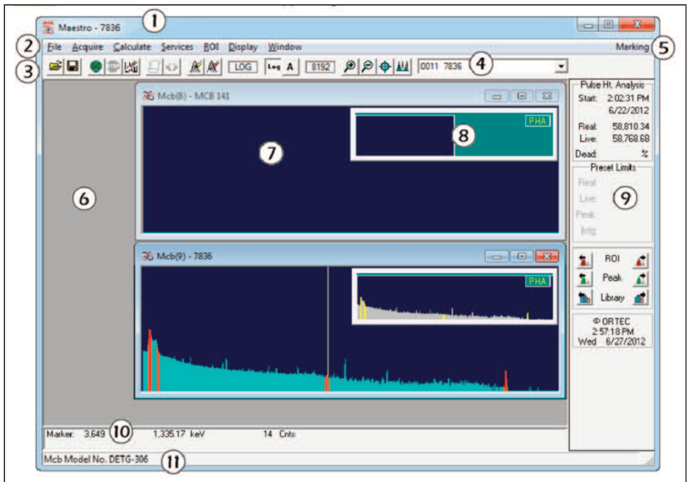

Fig. IV-10.6 Main MAESTRO Screen.

Assuming that the legend in the box reads "digibase", communication is established.

1. Under the MAESTRO menu item "Acquire" select "MCB Properties".

   The MCB properties for the digiBASE will look similar to Fig. IV-10.7 The tabs provide access to the controlling functions of the digiBASE.

2. Ensure that the NaI(Tl) detector assembly is properly mounted in the stand.

3. There are two parameters that ultimately determine the overall gain of the system: the high voltage furnished to the PMT and the gain of the spectroscopy amplifier. The gain of the PMT is quite dependent upon its high voltage. A rule of thumb for most PMTs is that, near the desired operating voltage, a 10% change in the high voltage will change the gain by a factor of 2.

4. The correct high voltage value depends on the PMT being used. Consult your instruction manual for the PMT and select a value in the middle of its normal operating range. Sometimes, the detector will have a stick-on label that lists the percent resolution and the voltage at which that resolution was measured. In that case, use the high voltage value on that label. Lacking those sources to specify the operating voltage, check with the laboratory instructor for the recommended value.

   The operating voltage will likely fall in the range of +800 to +1300 Volts.

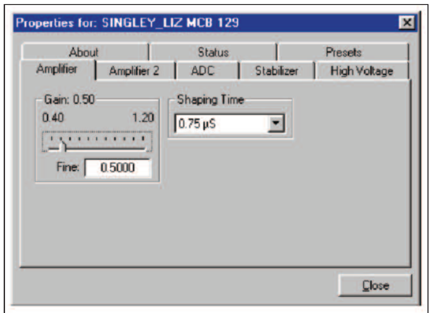

Fig. IV-10.7 MCB Properties.

5. Select the High Voltage tab
6. Enter the detector high voltage in the Target field, click On, and monitor the voltage in the Actual field.
7. On the Amplifier tab, choose a shaping time of 0.75 µS and a starting fine gain setting of 0.5 and 0.5 respectively. (The coarse gain on the digiBASE is set by Jumper, and should not need to be changed).
8. Using the ADC tab select a conversion gain of 1024 channels for the pulse-height range of 0 to +10 Volts. Turn the GATE to Off. For a starting value, the lower level discriminator threshold can be set to about 100 mV (10 channels). Set the upper level discriminator to full scale (1023).
9. On the Presets tab set both real and live presets to Zero ("off").

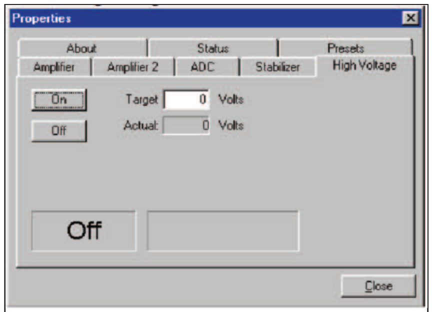

Fig. IV-10.8 High Voltage Tab.

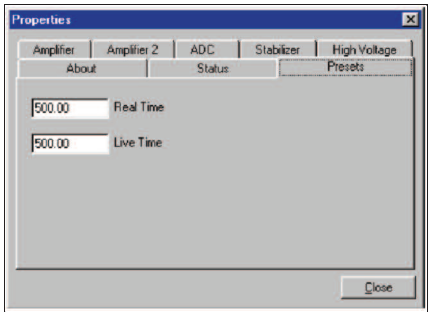

Fig. IV-10.9 Presets Tab.

IV-10.1.2. A Note on Bipolar Filtering

Unlike many "Gaussian" spectroscopy amplifier filters which require so called "Pole-Zero" cancellation, the Bipolar filter in the digiBASE requires no such adjustment. For further discussion on amplifier filters see www.ortec-online.com/download/Amplifier-Introduction.pdf

A representation of the digital bipolar waveform may be displayed through the use of the "InSight" display mode selectable via the "Amplifier 2" tab. Remember to click the "STOP" control on returning to the Amplifier 2 tab or you wll not be able to display the gamma-ray spectrum!

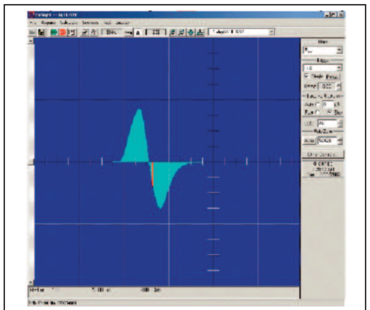

Fig. IV-10.10 Digital Polar Waveform.

IV-10.1.3. Adjusting the Gain for Recording Spectra (refer to Experiment IV-3)

1. From the RSS8 Source Kit, select the 1 µCi ^{137}Cs source and place it directly in front of the NaI(Tl) detector.
2. Set the HV to the designated value. Adjust the amplifier coarse and fine gain until the spectrum looks as in Fig. IV-10.11 Accelerator keys allow this adjustment to be made while observing the spectrum:

ALT+	increases the gain one increment
ALT-	decreases the gain one increment
SHIFT ALT +	increases the gain several increments
SHIFT ALT –	decreases the gain several increments
ALT 1	starts an acquisition
ALT 2	stops an acquisition
ALT 3	clears acquired or acquiring data

3. Acquire a spectrum with the digiBASE for at least 30 seconds, and no more than a couple of minutes. The spectrum should look like Figure IV-10.11
4. Adjust the amplifier gain so that the 662 keV peak is located at circa channel 400 during acquisition by the MCA.

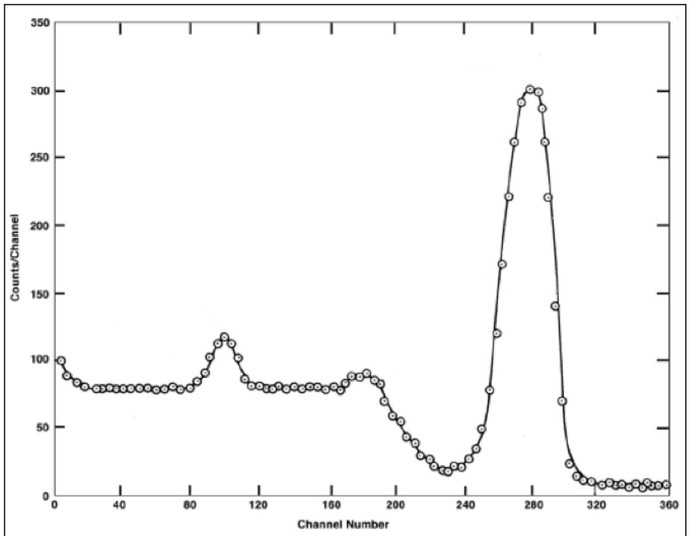

Fig. IV-10.11 NaI(Tl) Spectrum for ^{137}Cs.

IV-3.1.4. Lower-Level Discriminator Adjustment

The optimum setting of the Lower-Level Discriminator threshold is slightly above the maximum noise amplitude. This prevents the MCA from wasting time analyzing the useless information in the noise surrounding the baseline between valid pulses. Setting the Lower-Level Discriminator threshold reasonably close to the noise improves the quality of the automatic dead time correction by measuring the full duration of the pulses at the noise threshold. To adjust the Lower-Level Discriminator use the following procedure.

1. Remove any radioactive sources from the vicinity of the NaI(TI) detector, so that no gamma rays are being detected.
2. Start a data acquisition and observe the Percent Dead Time displayed for the MCA. It should be less than 1%. If the dead time is larger than 1% jump to step 5.
3. Using the MCB Properties menu, reduce the Lower-Level Discriminator threshold, start another acquisition and observe the percent dead time.
4. Keep repeating step 3 until the percent dead time abruptly increases.
5. Once the dead time increases significantly above 1%, gradually increase the Lower-Level Discriminator threshold until the percent dead time is less than 1%.
6. Repeat steps 3 through 5 until you are confident the threshold has been set reasonably close to the noise, with little risk of counting random noise excursions.

The absolute amplitude of the noise at the MCA input is dependent on the preamplifier characteristics and the gain setting on the amplifier. Consequently, the MCA Lower-Level Discriminator threshold should be adjusted any time the amplifier gain is changed, or the preamplifier is replaced with a different unit. Adjustment of this threshold is important whenever a detector system is assembled for initial set-up.

7. Remove the 1 µCi ^{137}Cs source and acquire a spectrum. Ensure that the MCA is not acquiring significant noise events near channel 10. If the noise is accumulating at a noticeable counting rate and the MCA dead time is >1%, raise the lower level discriminator setting until the noise is no longer observed.
8. Select the appropriate sources from the RSS8 source kit and calibrate the digiBASE so that its cursor reads the correct energy of the photopeaks. Table IV-10.2 lists the gamma-ray energies for the isotopes in the source kit.
9. Remove the energy-calibration sources. Install the aluminum rod vertically in the scattering position at the center of the table. Next, remove the cover shield from the collimator on the 5 mCi ^{137}Cs source enclosure.
10. Position the NaI(TI) detector at θ = 60°. This is the position at which the lowest counting rate will be recorded. Set the preset live time on the digiBASE at 100 seconds, and acquire a spectrum for that live time.
11. Set a Region of Interest (ROI) across the entire photopeak from the valley on the lower energy side to the baseline on the higher energy side. Sum the counts in the photopeak using the ROI integration feature of the MAESTRO software. Read the "Net Area" which reports the area above any background under the peak. The background should be negligible.

Table IV-10.2. Gamma- and X-ray Energies from the RSS8 Source Kit.

Isotope	Half Life	X-ray Series	X-ray Energies (keV)	Gamma-Ray Energies (keV)
^{22}Na	950.8d			511
				1275
^{54}Mn	312.3d	Cr K	5.414	835
			5.405	
			5.946	
^{57}Co	271.79 d	Fe K	6.403	14
			6.390	122
			7.057	136.5
^{60}Co	5.272 y			1173
				1333
^{65}Zn	244.26 d	Cu K	8.047	1116
			8.027	
			8.904	
			8.976	
^{109}Cd	462.6 d	Ag K	22.162	88
			21.988	
			24.942	
			25.454	
^{133}Ba	3862 d	Cs K	30.970	80
			30.623	303
			34.984	356
			35.819	
^{137}Cs	30.17 y	Ba K	32.191	662
			31.815	
			36.376	
			37.255	

12. From the result in step 11, determine the preset live time necessary to accumulate at least 1,000 net counts in the photopeak. Use this preset live time for acquiring the spectra at each of the angles in Table IV-10.1. Note that the spectrum will not be measured at 0° because of an excessive counting rate from the unscattered radiation from the source. No measurement will be made at 180° because the lead shields make that angle inaccessible.
13. For each of the angles in Table IV-10.1 (except 0° and 180°), acquire a spectrum for the preset live time determined in step 12. In each case, set an ROI across the photopeak as described in step 11. Using the MAESTRO features, measure the peak position (centroid) and the net area of the peak. Record those numbers in the 3rd and 5th columns of Table IV-10.1. Measure the FWHM of each photopeak and record that value in Table IV-10.1. You may wish to save a copy of each spectrum on the hard disk, in case you find a reason later to re-examine the raw data. As predicted by equation (4), the photopeak energy will decrease as θ increases. Figure IV-10.12 shows an example of two spectra obtained at 20° and 120°, but at twice the conversion gain called for in step 11.
14. At the completion of the measurements, replace the shield over the source collimator opening to shut off the flux of gamma rays.

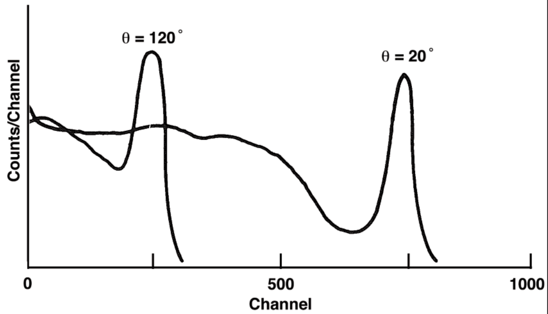

Fig. IV-10.12. Overlapped Spectra Obtained at Two Scattering Angles.

EXERCISES

a. Plot the $E_{\gamma'}$ values calculated from Equation (4) versus θ on linear graph paper. Add your measured values of $E_{\gamma'}$ together with ±1-sigma error bars from equation (6). Explain the reasons for any discrepancies between the theoretical and measured values for $E_{\gamma'}$.

b. Plot your measured values of $1/E_{\gamma'}$ versus $(1 - \cos\theta)$ on a linear graph. Equation (6) gives the predicted standard deviation in the measured $E_{\gamma'}$. Convert that standard deviation into the corresponding error for $1/E_{\gamma'}$, and add the appropriate error bars to your points on the graph. Draw a best fit straight line through your measured points. Read the slope of the straight line and its intercept from the graph. Explain any discrepancy between those graphical values and the prediction from equation (5b). Your graph should look similar to Figure IV-10.13.

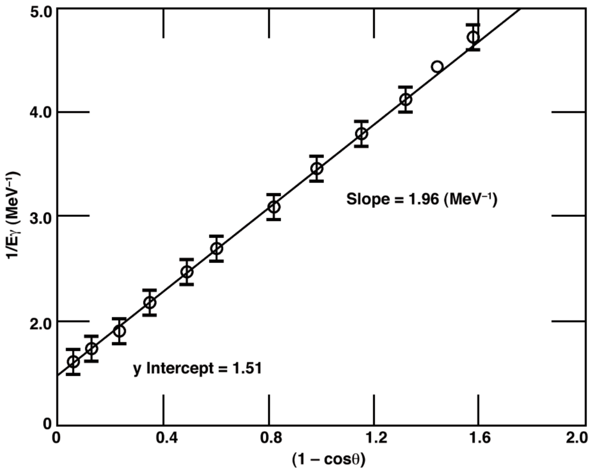

Fig. IV-10.13. A Typical Graph for $1/E_{\gamma'}$ versus $(1 - \cos\theta)$ for ^{137}Cs.

Table IV-10.3. Typical Tabulated Values for Equation (5b) and Fig. IV-10.13.

Angle (θ)	$1/E_{\gamma'}$ (MeV^{-1})	$1 - \cos\theta$
0	1.51	0
10	1.54	0.015
20	1.63	0.060
30	1.77	0.133
40	1.97	0.234
50	2.20	0.357
60	2.49	0.500
70	2.79	0.658
80	3.12	0.826
90	3.46	1.00
100	3.80	1.17
110	4.13	1.34
120	4.44	1.50
130	4.72	1.64

EXPERIMENT IV-10.2. Simple Compton Scattering: Cross-Section Determination

Purpose

The data collected in Experiment IV-10.1 will be used to calculate the measured scattering cross-section and compare it to the theoretical cross-section.

Relevant Information

Theoretical Differential Cross-Section

The differential cross-section for Compton scattering, first proposed by Klein and Nishina, is discussed in ref. 1. The theoretical expression for unpolarized gamma rays has the following form:

$$\frac{d\sigma}{d\Omega} = \frac{r_0^2}{2}\left\{\frac{1 + \cos^2\theta}{[1 + \alpha(1 - \cos\theta)]^2}\right\}\left\{1 + \frac{\alpha^2(1 - \cos\theta)^2}{[1 + \cos^2\theta][1 + \alpha(1 - \cos\theta)]}\right\} \qquad (7a)$$

Equation (7a) is the differential cross-section for scattering from a single electron, and is expressed in units of cm^2/steradian. It represents the effective differential area, $d\sigma$, of the electron as a target for scattering the gamma-ray photon at the angle θ into an infinitessimal solid angle, $d\Omega$. The new parameters in equation (7a) are the classical electron radius

$$r_0 = 2.82 \times 10^{-11}\ \text{cm} \qquad (7b)$$

And the normalized (dimensionless) energy

$$\alpha = \frac{E_\gamma}{m_0 c^2} = \frac{0.662\ \text{MeV}}{0.511\ \text{MeV}} = 1.296 \text{ for } ^{137}\text{Cs} \qquad (7c)$$

Experimentally Measured Differential Cross-Section

The data already collected in Experiment IV-10.1 can be used to calculate the measured differential scattering cross-section by employing equation (8).

$$\left[\frac{d\sigma}{d\Omega}\right]_{\text{measured}} = \frac{\Sigma_{\gamma'}}{n_e\, I\, \Delta\Omega\, t_L\, \varepsilon} \qquad (8a)$$

Where n_e is the number of electrons in the portion of the scatterer illuminated by the incident gamma rays. For a scatterer composed of multiple elements, n_e can be calculated from the basic parameters for the material, i.e.,

$$n_e = \rho\, V\, N_A \sum_i w_i \frac{Z_i}{M_i} \qquad (8b)$$

Where:

ρ is the density of the scatterer in g/cm^3,
V is the volume (in cm^3) of the scatterer that is illuminated by the incident gamma rays,
N_A is Avogadro's Number (6.022×10^{23}),
Z_i is the atomic number of the i^{th} element in the scatterer,
M_i is the gram atomic weight of the i^{th} element in the scatterer, and
w_i is the concentration of the i^{th} element in the scatterer, expressed as a weight fraction.

By definition, the weight fractions for all elements in the scatterer sum to unity.

$$\sum_i w_i = 1 \qquad (8c)$$

The variable, I, is the number of incident gamma rays per cm² per second at the scattering sample. It can be calculated from

$$I = \frac{A_0 f}{4\pi R_1^2} \qquad (8d)$$

Where A_0 is the activity of the source (5 mCi), f is the fraction of the decays that result in the emission of 662 keV gamma-rays (0.851) and R_1 is the distance from the source to the center of the scatterer.

The solid angle subtended by the NaI(Tl) detector at the scatterer is computed from

$$\Delta\Omega = \frac{\pi\left(\frac{D}{2}\right)^2}{R_2^2} \qquad (8e)$$

Where D = 5.08 cm is the diameter of the NaI(Tl) scintillation crystal, and R_2 is the distance from the center of the scatterer to the front surface of the NaI(Tl) detector.

$\Sigma_{\gamma'}$ is the total number of counts in the photopeak for the scattered gamma ray acquired during the live time, t_L. The intrinsic photopeak efficiency, ϵ, can be obtained from Fig. IV-10.14.

Note that Figure IV-10.14 differs from the virtually identical graph in Experiment 3. There were no measured values at 0.124 MeV in the original graph for the 2" x 2" and 3" x 3" detector sizes. For the purposes of Experiment IV-10, these points have been interpolated between ϵ = 1.00 and the measured value on the 1.5" x 1.5" curve. Although adequate for this experiment, the interpolated values are not reliable for more general use.

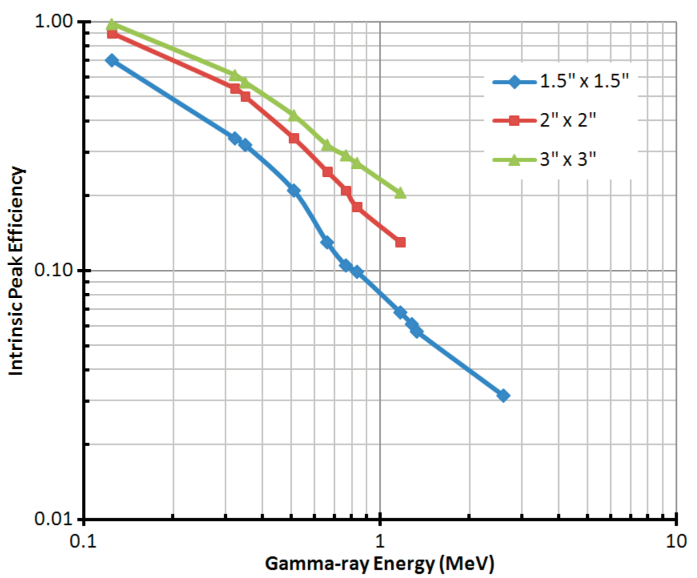

Fig. IV-10.14. The Intrinsic Photopeak Efficiency, ϵ, for Three Sizes of NaI(Tl) Detectors. CAVEAT: The points for 0.124 MeV on the 2" x 2" and 3" x 3" lines are interpolated between 1.00 and the measured value for the 1.5" x 1.5" curve.

For convenience, the elemental composition for the aluminum rod alloy is listed in Table IV-10.4. According to the ASTM standard, the composition can vary over the range in columns 2 and 3. For the purposes of this experiment, the mean of the maximum and minimum concentrations has been tabulated in column 4. The calculation in equation (8b) can be simplified further by ignoring elements with concentrations <0.6%. That approximation would elevate the Al concentration to 98.4%. Note that the weight fraction used in equation (8b) is simply the percent concentration divided by 100%.

Table IV-10.4. The Composition of the Aluminum Scatterer.

ASTM Aluminum Alloy 606-T651
Density = 2.7 g/cm³

Element	Min. Weight %	Max. Weight %	Nominal (Mean) Weight %
Al	95.8	98.6	97.23
Mg	0.8	1.2	1.00
Si	0.4	0.8	0.60
Fe		0.7	0.35
Cu	0.15	0.4	0.25
Cr	0.04	0.35	0.20
Zn		0.25	0.13
Mn		0.15	0.08
Ti		0.15	0.08
Other		0.15	0.08

Procedure

The data for this experiment has already been measured and recorded in Experiment IV-10.1.

EXERCISES

a. Compute $d\sigma/d\Omega$ from Eq. (7) for the values of θ used in Table IV-10.1. (A spreadsheet is quite valuable for this calculation, although not absolutely necessary).

b. Plot the theoretical $d\sigma/d\Omega$ versus θ on a linear graph.

c. Use the data measured in Experiment IV-10.1 with equations (8) to calculate $[d\sigma/d\Omega]_{measured}$, and plot your measured values on the graph from step b.

d. Estimate the standard deviation in your measured values based on counting statistics. Add the error bars to the points on the graph in step c to represent the ±1-sigma predicted errors.

e. Discuss possible reasons for any discrepancies between the theoretical and measured differential cross-sections.

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APPENDIX IV-10-A: Installing the 5 mCi ^{137}Cs Source in the Shielded Collimator and Checking Alignment

Installing the Source in the Shielded Enclosure

The shielded collimator enclosure and the 5 mCi ^{137}Cs radioactive source are shipped separately from their manufacturers. Installation of the source into the shielded collimator needs to be implemented by the Laboratory Manager prior to use in any experiments. Observe the above caution about handling this high-activity source. Use the following procedure for installing the source.

1. Remove the cover shield that is secured over the collimator window.
2. Remove any screws that are retaining the front of the collimator section to the main body of the enclosure.
3. Withdraw the collimator and the attached tube from the well in the enclosure.
4. At the end of the tube that is remote from the square collimator window, there is a hole drilled in the circular end-plate along the center line of the tube. The diameter of this hole is slightly larger than 0.25 inches (6.35 mm), and accepts the similar outer diameter of the source capsule.

5. Loosen the clamp at the entrance to this hole, and insert the source capsule with its active end towards the collimator window. Make sure the source capsule is inserted until it is stopped by the lip at the end of the hole. The lip ensures the proper insertion depth.
6. Tighten the clamp so that the source capsule cannot move from its proper position.
7. Insert the source, tube and collimator assembly into the well in the shielded enclosure.
8. Reinstall the retaining screw(s) to hold the collimator/source assembly in the shielded enclosure.
9. Place the shielded cover over the collimator opening, and secure it with a lock and key.
10. Using a radiation dosimeter capable of reading exposure rates as low as 0.1 mR/hr. with gamma-ray energies in the range of 100 to 662 keV, survey the entire outside of the enclosure to determine the exposure rate at the surface of the enclosure. Verify that there are no intolerable exposure rates from gaps in the shielding.
11. When not employed in the experiment, store the source and enclosure in a secure location.

Checking Alignment in the Compton Scattering Experiment

The mechanical keying features on the Angular Correlation Table and the 5 mCi ^{137}Cs source enclosure/collimator should provide proper alignment for the Compton Scattering Experiment. The centerline of the source collimator and the centerline of the NaI(Tl) detector should lie in the same scattering plane. Where that plane intersects the vertical centerline of the aluminum scattering rod or the plastic scintillator rod defines the desired center of the collimated gamma-ray beam at the scatterer. The collimated gamma-ray beam should extend ±1 inch (±2.54 cm) in the vertical direction around that centerline. The beam should also extend ±1 inch (±2.54 cm) in the horizontal plane with respect to the vertical centerline of the scattering rod.

This alignment can be checked using the plastic scintillator. To measure the horizontal limits of the gamma-ray beam, move the plastic scintillator horizontally across the beam while monitoring the counting rate. To measure the vertical extent of the gamma-ray beam, use the plastic scintillator with its long axis in the horizontal plane, and scan in the vertical direction, while monitoring the counting rate. The distance resolution with this method will be approximately determined by the diameter of the plastic scintillator.

Specifications subject to change
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