Compton Scattering Procedure

(***Make sure you have completed and passed the Radiation Safety Course in Skillport - check syllabus***)

Objective: Understand the principles of Compton Scattering through the determination of electron mass at rest. Based on these physical principles, the electron mass is determined by measuring the energy of the scattered photons as a function of scattering angle. Using the calculated electron mass, we will plot the differential cross-section of the Cesium-137 source.

This lab uses a scintillation detector, which is a sodium iodide crystal that is hit with high energy photons (γ-rays) such that electrons become excited, change energy states, and emit photons. This emission is detected with a photodetector. The setup of the detector is shown in Figure 1.

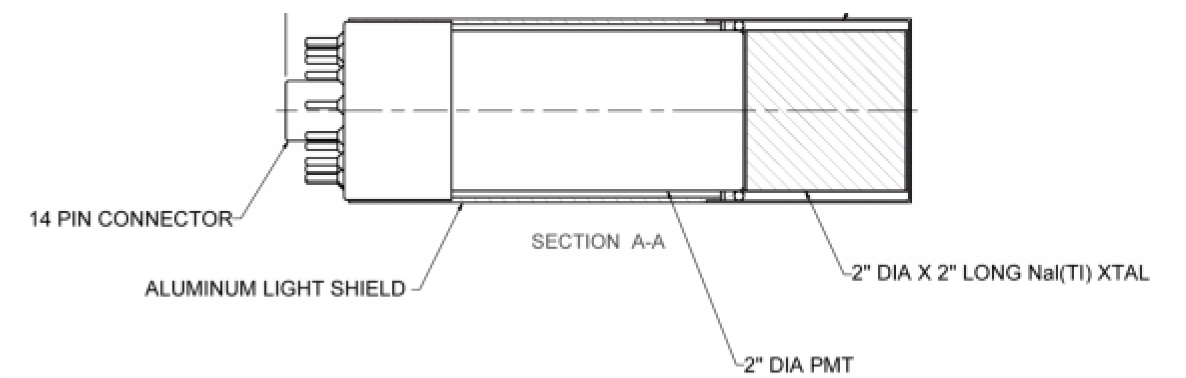


Figure 1: Sodium iodide scintillation detector and PMT

The photomultiplier tube (PMT) amplifies the signal by means of the photoelectric effect. The connector is attached to a multichannel analyzer (MCA) which sends data to the MAESTRO 7 software. MAESTRO 7 allows for us to compare distributions, and export and analyze γ-ray spectra, which you will be doing for this lab. The manual (a *.PDF file) for MAESTRO 7 can be found in the folder: C:\Experimental Physics\Compton Scattering. The mechanics of the scintillation detector are further discussed in the Theory portion of this lab.

Additional Equipment:

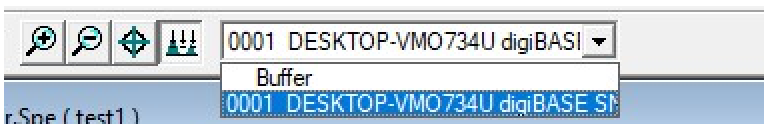
- Copper square sheets
- Aluminum scattering rod
- “Unknown" scattering rod
- Ruler
- Disposable gloves
- USB flash-drive

Important: Make sure the front face of the scintillator is positioned inside the lead housing about 2-3 cm from the front.

Starting MAESTRO 7

The software counts incoming photons of certain energy, and displays them in a histogram. The x-axis corresponds to channel, which you will calibrate to correspond to energy. The height of pulse signal from the scintillation counter corresponds to the energy of incident γ-ray, the distribution of the pulse is a spectrum of the ray. Although, the channel number along the horizontal axis is proportional to the γ-ray photon's energy, calibration of the axis is necessary to obtain the absolute value of the energy.

- Start MAESTRO for Windows
- Verify from the pull down menu on the right of the toolbar, that the detector is set to "0001 DESKTOP-VMO..."



- Go to **Acquire > MCB Properties** and verify:
  - **High Voltage**: turned ON, Target 900V.
  - **Amplifier**: gain 0.6, shaping time 0.75 microseconds
  - **ADC**: conversion gain 1024, low-level disc 7, high level disc 1023
  - **Presets**: real time 120s, live time 120s
- **Calculate > Calibration**, Destroy Calibration

Background Scan

A background scan will be taken by hand and subtracted from all measurements as a means of taking into account background radiation.

- With all of the lead housings closed, and the detector pointed away from the Cs-137 housing, conduct the background scan:
  - **Acquire > Clear**
  - **Acquire > Start**, or click "GO" - a green icon (top left hand corner). The scan will take 120s and will stop on its own.
- Export the data as ASCII SPE by going to **File > Save As**, which can be read into Jupyter Notebook as a text file. Repeat this measurement three (3) times. Save the data for your analysis and generate the average.. Make sure to subtract this average background measurement from **<u>all</u>** energy spectra.

Energy Calibration (Note that is differs from the one in the MAESTRO-7 Manual)
The channels in the MCA correspond to a particular photon energy. The procedure for calibrating the channel so that we can "read-off" the relevant photopeak energy accurately involves using radioactive sources (Cs-137 & Ba-133) with documented photopeaks (gamma ray energies). The curve fit is performed using Python code. We will not attempt to use the MAESTRO-7 software to perform the energy calibration.

- Remove the scattering rod from the scintillation setup.
- Open the Cs-137 (see Figure A.1 in the Appendix section) housing and align the scintillator with the source. Do not touch the cesium source.
- **Acquire > Clear**
- **Acquire > Start**, or click "GO" - a green icon (top left hand corner).
- When the scan is complete, close the housing, and save the scan.
- Repeat this process for Barium-133 in the red case using the disc holder (See Figure A.2 on how to access the red case and Figure A.3 (left) showing the disc holder) . You may only have one source out at a time.
- These saved scans should enable you to associate the channel # (x-axis) to the energy of a known photopeak. At least three photopeaks are identifiable from both scans. The appropriate curve fit should be applied enabling you to convert channel #s to gamma ray energies. Pay close attention to the errors generated from the curve fit as you will need these later on in your error propagation analysis. This will be particularly important in the Compton Scattering portion of this lab.

Measurements

Section I: Inverse square relationship
Radiation obeys the inverse square law where intensity, or in this case counts of photons, is a factor of *r*. This can be measured by varying the distance between the source and the detector.

- Point the detector away from the Cs-137 housing to limit background radiation.
- Place the barium source in the holder.
- Run scans as a function of distance from the front of the detector, each time moving the barium source and measuring the new distance. Collect data from at least 6 different positions. For each distance, conduct 3 scans and average these scans. This will lead to more accurate results.
- Put the Ba-133 source back in the housing.
- In performing the analysis you will need to generate the following information:
    - The height of one of the photopeaks of Ba-133 as a function of distance
    - The area under one of the photopeaks of Ba-133 as a function of distance. Use the gaussian fit in computing the area.

- Use both sets of data to perform separate curve fits to uncover the functional relationship of radiation vs distance. Compare both approaches.

Section II: Attenuation

Attenuation describes the transmission probability $T = e^{-\mu x}$ of a material as a function of the thickness x where μ is the attenuation coefficient of the material. You will be using the copper sheets.

- Using the Cs-137 source, conduct a scan without scattering.
- Place one sheet of the metallic attenuation material in the holder.
- Record the thickness of the material.Get an average value for the thickness and associated uncertainty by measuring each sheet.
- Run the software, generate and save the spectrum
- Add another sheet of the attenuation material after completing the scan.
- Close the lead housing to shield the Cs-137 source.

Section III: Compton Scattering measurement

The goal of this section is to derive the mass of an electron through means of the Compton Effect by measuring the shift in energy (shift in x-direction) of the peaks of the Cesium-137 γ-ray spectrum as a function of scattering angle θ. θ is marked on the table with respect to the cesium housing.

- Open the Cesium-137 housing.
- Use two small lead bricks to collimate the beam of photons (displayed in Figure 2) exiting the Cs-137 source. Let the instructor align these two bricks for you. This stops any unscattered photons from hitting the detector.

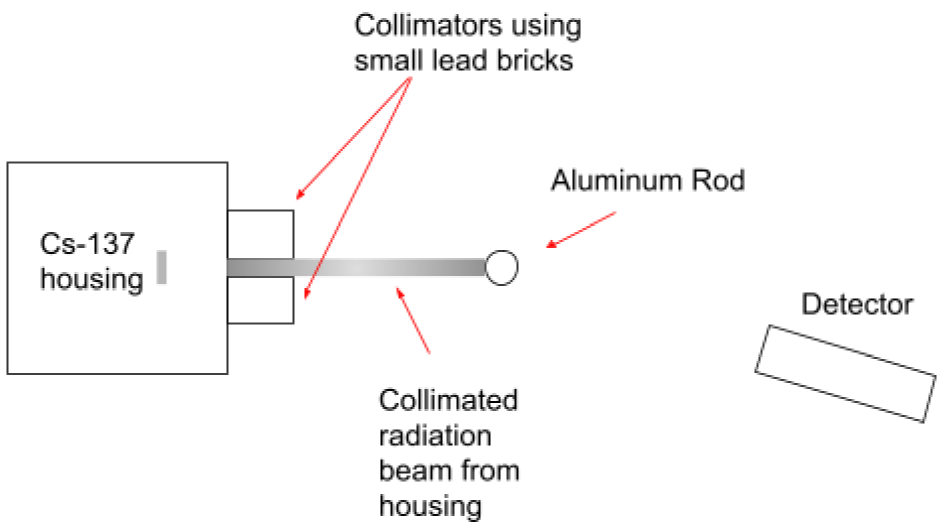


Figure 2: Top view of Cs-137 housing with collimators and detector

- With the aluminum scattering rod not in the setup, and the detector at 0°, run and collect a scan. This represents the incident spectrum on the scintillator and will be used later in computing the differential cross-section
- Put the aluminum scattering rod (see Figure A.3 for an image of the aluminum scattering rod) back into the scintillation setup.
- As a function of θ, conduct 5-6 scans in the range of 20° to 80°. You may be able to go as far as 110^{o} and still generate usable energy spectrum in your analyss. For each angle, collect a scan without the aluminum rod in the holder. This "background" scan will be subtracted from the original scan to minimize the effect of noise in the resultant energy spectrum
    - Export the spectra as ASCII SPE files.
- Replace the aluminum scattering rod with the unknown material scattering rod (see Figure A.3). Repeat the procedure that was used for the aluminum scattering rod to generate the equivalent Compton Scattering dataset for this material. This will be used in attempting to deduce the atomic composition of the unknown material described in Section IV.
- Remove the lead collimators and close the cesium housing.

Section IV: Measuring the differential cross-section of the Aluminum and Unknown Rod and calculating the classical radius of the electron and

Using the previous measurement of the Compton Scattering Effect, we can calculate both the classical radius of the electron and the differential cross-section of the scattering from both aluminum and the unknown material.

- Record the volume and mass of both rods.
- Record the distance from the center of the scattering rod to the front of the detector.
- **Find the decays/second of the background radiation at the detector with the aluminum scattering rod not in the setup, and the detector at** 0°.
- Use the energy spectrum from Section III where the detector was placed at 0º without the aluminum rod, to find the decays/s due only to the cesium source, I, at the detector by integrating under the photopeak. This will be used to estimate the photon flux at the scattering rod. Consult the Compton Scattering Theory document on how to do the relevant calculations.

To include in the Report:

Section I:

- Include a curve-fit showing that the number of detected decays follows the inverse-square law as a function of distance. Fit the data from Section I (of the Compton Lab Instructions Manual) to the function function $\frac{1}{r^{a}}$where a is the free parameter. Don't forget to include a scaling constant to the curve-fit. Include appropriate error bars.

Section II:

- Determine the attenuation coefficient of the aluminum sheets of Section II by fitting a curve to the transmission probability as a function of thickness.
- Note that attenuation describes the transmission probability $T = e^{-\mu x}$ of a material as a function of the thickness x where μ is the attenuation coefficient of the material.

Section III:

- Fit a gaussian to the shifting photopeaks. The energy is the x-value where the peak occurs.
- Fit a curve to the shifting photopeak energy as a function of scattering angle θ from the data collected in Section III (E') and find the rest mass of an electron.
- Include a plot of the data collected and of the curve fit.

Section IV:

- Use a curve-fit to determine the classical radius of an electron using data from the aluminum rod and applying the relevant equations found in the Compton Theory Document using both approaches of estimating the gamma-ray flux at the scattering rod.
- Include a plot of $\frac{d\sigma}{d\Omega}$ as a function of scattering angle θ using the measurements made in Section III of this Instruction Manual.
- Repeat the process of using the computed differential cross-section for the unknown metal scattering rod to deduce the composition of the unknown material. (*Note: You do not need to determine the classical radius of an electron from the data using the unknown metal scattering rod*)

APPENDIX:

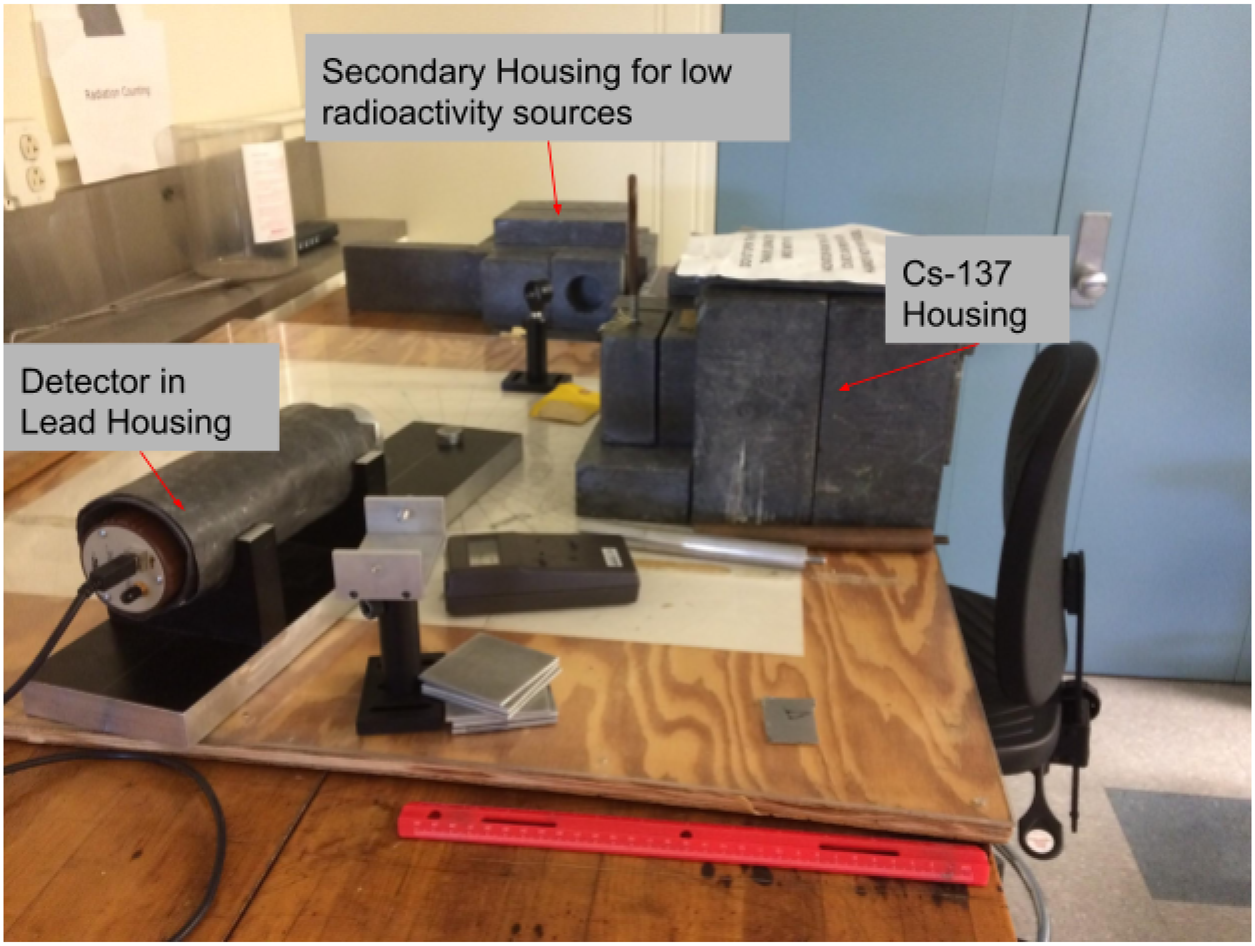


Figure A.1: Experimental Setup showing major components of experiment

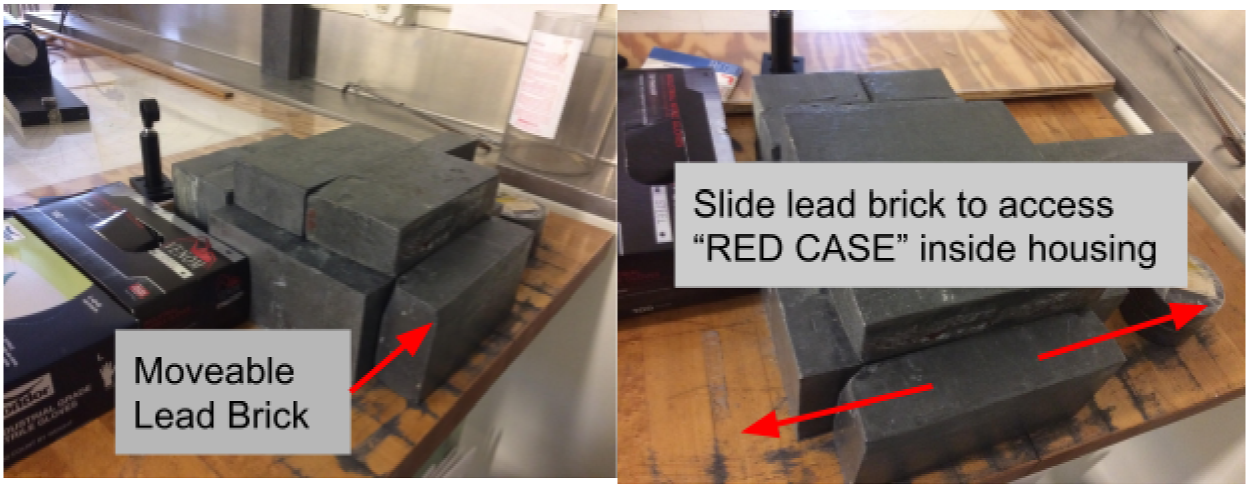


Figure A.2: Method of accessing RED CASE in Secondary Radioactive Source Housing

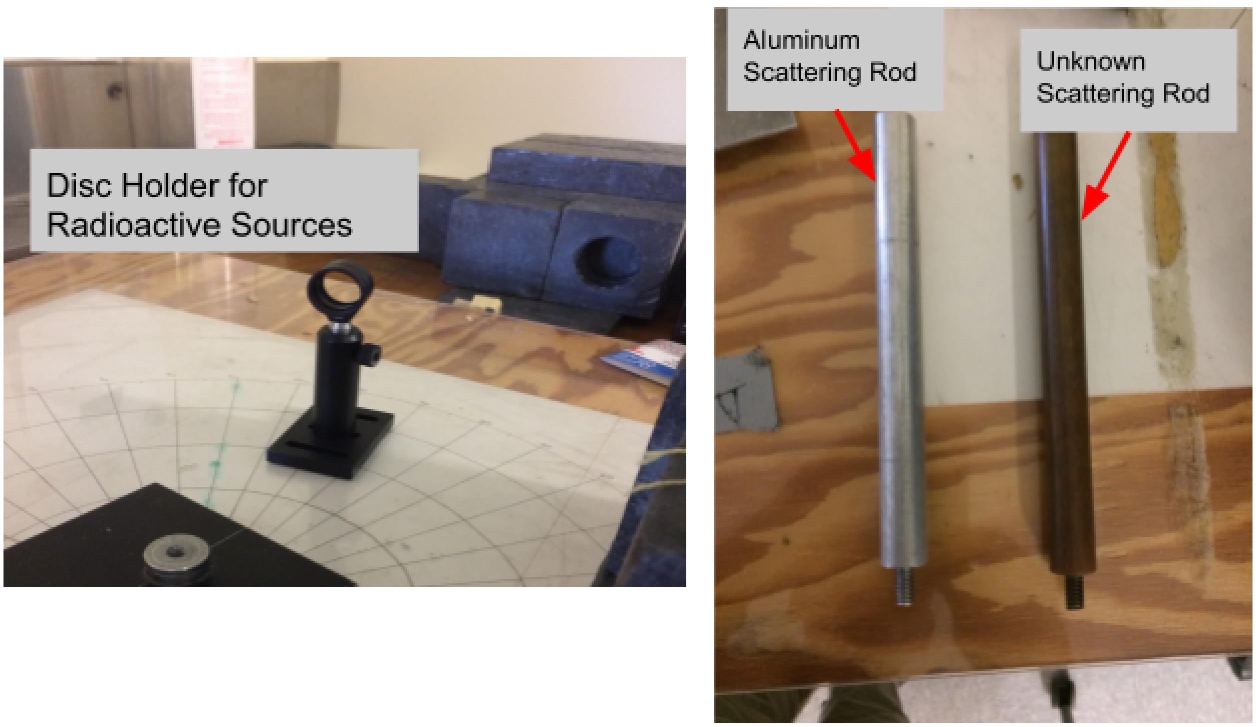


Figure A.3: Images of Radioactive Source Holder and both types of Scattering Rods