Compton Scattering

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In this experiment, brass and aluminum scatterers were used to demonstrate the Compton Scattering effect. In both situations, we found that the relative energy and intensity of scattered photons dropped with increasing scattering angle. We calculated the calibration factor for each example, and the results are 2.71×10^{32} for aluminum and 5.05×10^{32} for brass. Additionally, we determined the rest mass of electrons, which was 450.99 ± 0.11 KeV on average.

I. THEORY

Compton scattering, as seen in Figure 1, is the scattering of photons by charged particles. The dispersed photon has less energy when the entering photon transfers some of its energy to the electron. has a lower frequency and a longer wavelength, per Planck's formula. Only the scattering angle for a specific target particle determines the wavelength shift in this type of scattering. According to the Compton formula, the wavelength shift increases with the scattering angle:

$$\lambda_\theta - \lambda_o = \frac{h}{m_e c}(1 - cos\theta) \tag{1}$$

Where, λ_o is the incident wavelength of the photon, λ_θ is the scattered wavelength of the photon, h is Planck's constant,m_e is the rest mass of the electron,c is the speed of light and θ is the scattering angle of the photon.

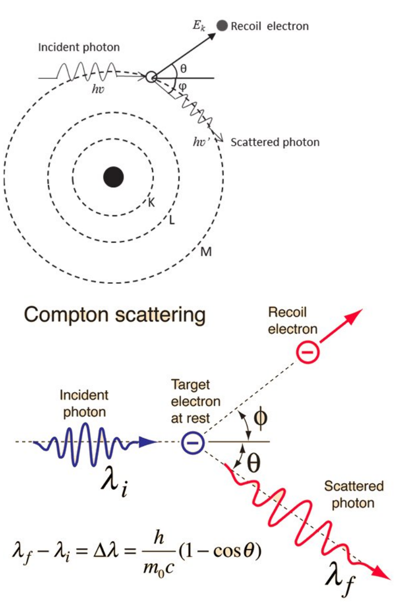

FIG. 1: Compton scattering

The value $\frac{h}{m_e c} = 0.02426$Å is called the Compton wavelength of the electron. In terms of energy, Equation 1 can be written as:

$$E_\theta = E_o \frac{1}{1 + \gamma(1 - cos\theta)} \tag{2}$$

where E_θ and E_o are energy of incident and scattered photons respectively and $\gamma = \frac{E_o}{m_e c^2}$. For high energy photons with ($\lambda \ll 0.02$Å or $E \gg 511keV$), the wavelength of the scattered radiation is always of the order of the Compton wavelength, whereas for low energy photons ($E \ll 511keV$), the Compton shift is very small. In a nutshell, in a non-relativistic energy domain, the results of Compton scattering approach those anticipated by classical Thompson scattering.

Using quantum mechanical calculations, Klein-Nishina correctly formulated the differential Compton scattering cross-section formula. This equation is written as follows:

$$\begin{aligned} \frac{d\sigma}{d\Omega} =& r_o^2 \frac{1 + cos^2\theta}{2(1 + \gamma(1 - cos\theta))^2} \times \\ & \left(1 + \frac{\gamma^2(1 - cos\theta)^2}{(1 + cos^2\theta)(1 + \gamma(1 - cos\theta))}\right) \end{aligned} \tag{3}$$

where, $r_o = \frac{e}{4\pi\epsilon_o m_e c^2} = 2.8179 \times 10^{-15}$ is the classical electron radius.

For dispersed photons, gamma rays from a Cs^{137} source are used in this experiment. A calibrated scintillation detector set at varying scattering angles determines differences in incoming and scattered energy and wavelength of photons. By computing the calibration factor C using the method below, the relative intensities $I\theta$ of the scattered radiation peaks may be compared with the predictions of the Klein-Nishina formula for the differential effective cross-section $\frac{d\sigma}{d\Omega}$. Thus:

$$C = \frac{1}{n} \sum_{\theta=0}^{n} \frac{I_\theta}{(\frac{d\sigma}{d\Omega})} \tag{4}$$

angle θ	change in energy(keV)	change in wavelength($10^{-12}m$)
30	552.7	2.248959653
45	464.2	2.677725118
60	395.6	3.14206269
90	385.7	3.222711952
120	216.6	5.738688827

TABLE I: Change in energy and wavelength as a function of scattering angle for aluminum

II. OBSERVATION AND CALCULATION

A. Aluminium scatterer

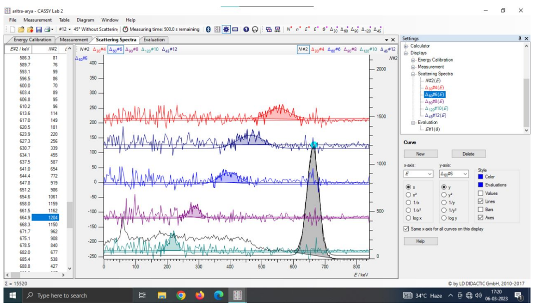

FIG. 2: Measurement spectra

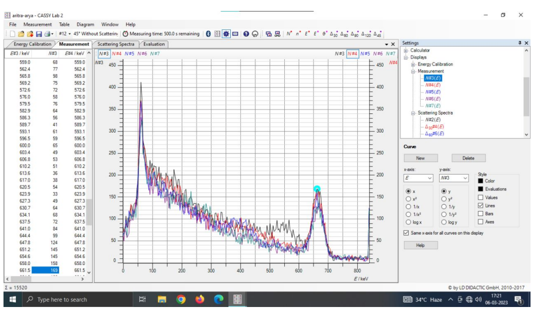

FIG. 3: Scattering spectra

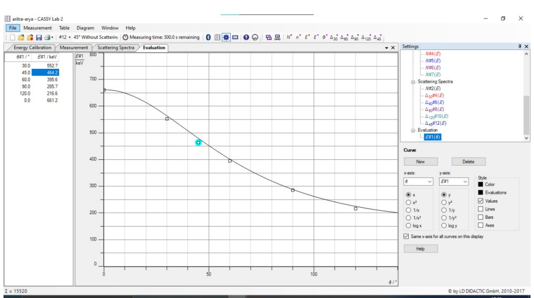

FIG. 4: Energy calibration spectra

angle θ	differential cross-section($10^{-30}m^2$)	relative intensity
30	6.075	802
45	3.348	738
60	2.2	697
90	1.3047	381
120	0.5581	221

TABLE II: Evaluation of differential cross-sections and relative intensities for Aluminium

From Table 2 and Equation 4, we have the calibration factor for aluminum is:

$$C = 2.71 \times 10^{32}$$

By analysing the energy calibration spectra we get $m_e = 482.38KeV$.

B. Brass scatterer

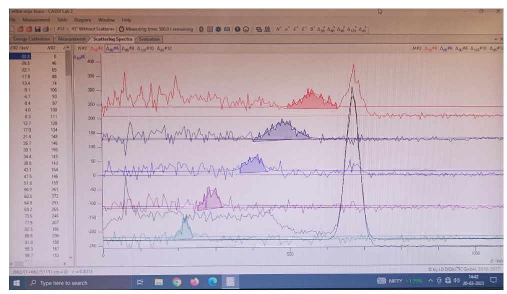

FIG. 5: Measurement spectra

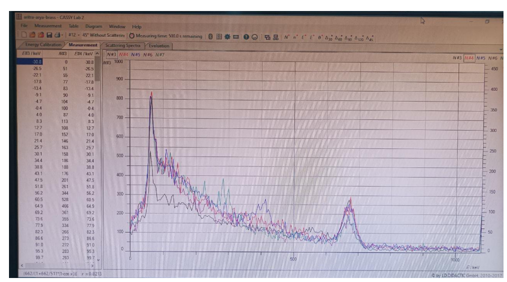

FIG. 6: Scattering spectra

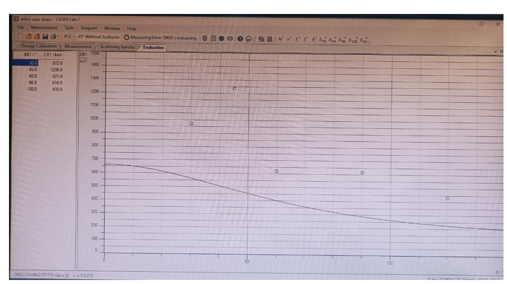

FIG. 7: Energy calibration spectra

angle θ	change in energy(keV)	change in wavelength($10^{-12}m$)
30	559.4	2.222023597
45	481.2	2.58312552
60	402.4	3.088966203
90	289.8	4.289164941
120	218.4	5.691391941

TABLE III: Change in energy and wavelength as a function of scattering angle for brass

angle θ	differential cross-section($10^{-30}m^2$)	relative intensity
30	6.075	1705
45	3.348	1229
60	2.2	925
90	1.3047	617
120	0.5581	550

TABLE IV: Evaluation of differential cross-sections and relative intensities for Aluminium

From Table 4 and Equation 4, we have the calibration factor for brass is:

$$C = 5.05 \times 10^{32}$$

From energy calibration spectra, we have the rest mass of electron $m_e = 419.6Kev$

III. ERROR

The expected value of m_e is $0.511MeV$, but for each case the observed value is much greater than the expected value.

$$\Delta m_e = \frac{|m_e(observed) - m_e(theory)|}{m_e(theory)}$$

thus we have, for aluminum: $\Delta m_e = 0.056$ and for brass, $\Delta m_e = 0.1788$

We made an error of 11.7% in our calculations. This might be because we put the lead block in the wrong place. It could be too close to the scattering body and not let all the scattered photons pass. This is shown by the reduced peaks in the scattering spectra. We can fix this by moving the lead block further away from the scattering body.

IV. CONCLUSION

We investigated electron Compton scattering in this experiment. We can see from the data that the intensity and energy of photons drop as the scattering angle rises, which is consistent with the Compton formula. We discover that the detector's calibration factors fluctuate depending on the substance. Brass has a calibration factor around double that of aluminium, implying that relative intensity for specific cross-sections is greater for brass than aluminum. We also computed the rest mass of electrons with substantial error, which may be reduced by using the lead box with prudence. Thus, the following formula may be used to calculate the rest mass of charged particles such as electrons.

[1] SPS (2022). Lab manual. *Website*. `https://www.niser.ac.in/sps/sites/default/files/basic_page/p341_2023/compton_scattering.pdf`.