**Compton Scattering Experiment**

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**Abstract**

We measured the energy difference of photons before and after Compton scattering using a Cesium-137 radiation source and two scattering rings made of different materials. We investigated the best model to explain the Compton effect and the dependence of the measured energy difference of photons on the material of the scattering ring. Gamma rays produced from the radiation source were scattered by the scattering ring, and it was detected by thallium-doped Sodium Iodide scintillator. The detected photons went through a photomultiplier tube and the signal was sent to Maestro. The difference in photon energy before and after scattering was measured while changing the scattering angle of the photons, and Compton peak was observed. The measured energy difference data corresponding to the scattering angle was compared with classical model and relativistic model. It was confirmed that the relativistic model explains the data better than the classical model. As for the material dependency investigation, energy difference data from two different material rings were compared to each other to see if there is difference between materials, and it was confirmed that the measured energy difference does not depend on scattering ring material. Possible source of error in measured energy includes the error in calibration. Due to the sensitivity in a software, Maestro, there could be a systematic error in calibrating energy and thus contributed to error in measuring energy difference.

**Introduction**

The nature of light as either a wave or particle has been highly discussed in the physics community. Newton was the first to propose that light was a group of particles since sunlight was able to split into different wavelengths when it went through a prism. However, at the same time Grimaldi and Huygens while studying the diffraction of light noticed the wave-like behavior of light. This discussion went back and forth, with experiments such as Young’s double slit experiment that shows the wave-like behavior of light and it was not until the end of the 19th century that Einstein brought back the idea of light behaving like a particle [1]. Einstein and Planck were the first to describe the wave-particle duality of light, but the experiment performed by Arthur H. Compton in 1920 was the first to prove it. His analysis of the interaction between light and electrons showed that the wavelength of the scattered light was different from the wavelength of incident light, which implies that light must carry momentum such as a particle. The results of Compton’s experiment also reinforced Einstein’s theory of special relativity, since a relativistic model would be needed in order to accurately portray his results.

**Theory**

We consider the experimental setup shown in Fig.1. The scattering angle of photon,∅ is given by

where r is the distance from the center of the scattering ring to the average of the inner and the outer radius of the ring as indicated in Fig.1.

Here, we will derive two types of models: relativistic model and classical model.

Diagram

Description automatically generated

Figure1: A diagram of the setup, which includes a radiation source, a Thallium-doped Sodium Iodide detector with lead shielding, a scattering ring, and a photomultiplier. The geometrical parameters of the experimental setup are also indicated, where∅ is the scattering angle, is the wavelength of an incident photon, γ’ is the wavelength of a scattered photon, and L is the height from the radiation source to the scattering ring.

Arrow

Description automatically generated with low confidence

Figure2: Geometry of Compton scattering is indicated. Incident photon with wavelength collides with electron resulting recoiling electron with angle of and scattered photon of wavelength and angle .

We start with relativistic model. From the geometry of Compton scattering model shown in Fig.2, momentum conservation of x component and y component, and energy conservation can be written by

where and are the wavelength of the incident and scattered photon, c is the speed of light, and h is Planck’s constant, m is the mass of electron, is the momentum of scattered electron, and are angle of scattered photon and electron. We introduce relativistic energy of electron, given by

Using - and solve for , we get

Energy and wavelength of photon are related by

Combining (5) and (6) gives relativistic Compton scattering model,

WhereE is the energy of a photon before scattering, and ΔE is the energy difference of a photon before and after scattering.

In classical model, we use classical energy,

Combining (1)-(3) and (7), and solving for results results

Using (6) and (8) gives classical Compton scattering model,

**Methods and Equipment**

A radioactive Cesium-137 source was placed above a scattering ring, as shown in Fig.1, to allow the gamma rays produced from the source to scatter off the ring. Photons that were scattered by the ring were detected by the Thallium-doped Sodium Iodide scintillator. The geometry of the apparatus and the lead shielding ensured that only photons scattered at a specific angle would reach the detector. A two-step calibration was performed with only the Cesium-137 source in the detector, and we used the 661 keV photopeak produced by the Cesium source and the 74 keV peak produced from the lead shielding to calibrate the bin number to the correct energy in the program Maestro [3]. Two energy spectra were taken at each scattering angle, one with no scattering ring for ten minutes as a background spectrum, and another with the scattering ring for ten minutes. The result after background subtraction was a single peak due to Compton scattering. Measurements were taken from 13 to 25 centimeters in increments of one centimeter and this process was performed for both aluminum and copper rings.

**Results and Analysis**

We analyzed the background subtracted spectra using Mathematica gaussian nonlinear model fit technique. Gaussian equation,

was used as the model for counts against energy for a single peak, where  A1, A2 and A3 are fitting parameters, and x is a bin number. The centroid of the energy peak was found from A2, and its uncertainty (𝛿E) was calculated based on Poisson distribution,

where N ring and N bg are the total number of counts in the energy range of the Compton peak with a scattering ring and the area of background. The uncertainty in angle was propagated from geometrical parameter of the setup.

We obtained the results shown in Fig.2, which shows the relativistic model (7), the classical model (9), the data obtained using copper ring, and the data obtained using aluminum ring. As this graph shows, the data from this experiment are better explained by the relativistic model, and this is especially true for large angles. Also, it shows there is no dependence of the measured energy difference of photons on the material of the scattering ring.

Chart, line chart

Description automatically generated

Fig.3 Resulting graph shows this experimental data is well explained by relativistic model rather than classical model.

**Conclusion**

The results show that the Compton Effect is a relativistic phenomenon and is independent of the material of the scattering ring. There is a deviation between the relativistic and classical model at large scattering angles and our data at large scattering angles was best fitted with the relativistic model. This shows the importance of taking relativistic energy and momentum into consideration for the Compton effect. In addition, the comparison of the aluminum scattering ring and the copper scattering ring show that the material of the ring does not affect the change in energy of photons due to Compton scattering, which proves that the only factor that affects the change in energy in the scattering angle. Even though our results agreed with the expected results, there were still some improvements that could be made. Future improvements include an individual calibration for each scan using the known energy of the photopeak since there was a malfunction in the Maestro program that caused an error in the calibration of the energy associated with each bin.

**Reference**

[1] Jones, Andrew Zimmerman, ThoughtCo, *Wave Particle Duality and How It Works*., thoughtco.com/wave-particle-duality-2699037.

[2] Steve Feller, Sandeep Giri, Nicholas Zakrasek, et al, The Physics Teacher, *A Non-Relativistic Look at the Compton Effect.*

[3] Knoll, Glenn F. *Radiation Detection and Measurement*. John Wiley and Sons, 1979. Pp. 287-282, Chapter 10.