Intermediate lab: Compton Effect

**Abstract**

This experiment is intended to verify the Compton Scattering equation. The expected result somewhat falls within the uncertainty range of the experimental result: at large scatter angles, the expected results are slightly out of 1 sigma range; at small scatter angles, the expected results agree well with our experiment results. The uncertainty range is quite large, which makes this experiment not very effective to confirm the Compton Scattering equation. Improvements of this experiment is needed, a more precise calibration procedure should improve our results.

**Introduction**

When a photon interacts with a free electron, according to classic theory, electromagnetic wave(photons) will cause the electron to radiate new electromagnetic wave with the same wavelength as the incident wave. However, experiment observation conducted by Arthur Compton in 1920s had confirmed that the process will cause electrons emitting photons with different wavelength, and the wavelength depends on the scattered angle of photon. This result is a strong support to Einstein’s photon particle theory.

The theoretical description of the Compton scattering can be summarized by this equation:

latex-image-1

Where E’ is the energy of the scattered photon, E is the original photon energy, and θ is the scatter angle.

**Experiment**

To verify correctness of the equation above, we use a source photon of known energy, then measure the scattered photon’s energy at different angles. After we acquired the several sets of data at different angel, we can compare the experimental result and the result predicted by the equation above.

The way to measure the photon energy is to use a spectrometer. The spectrometer we used cannot measure photon energy directly, it detects photons energy by reporting a channel value, this channel value is a linear function of the energy. The spectrometer detects all the photons in the environments, channels that has more photon detected have higher counts. Photons that emitted by radioactive source or scatted by the scatter rod will form a peak in the count vs channel plot. The peak channel is the channel we want.

First we need to calibrate the spectrometer, i.e., to find out the function of channel value vs. photon energy. To do this, we use a set of photon source with known energy. The source we used is a Cs-137 and a Co-60 radioactive source. The Cs-137 radiates a known photon energy with 662 keV, and the Co-60 radiates photon with 1173 keV and 1333 keV energy. We use the spectrometer to measure each of these energy’s corresponding channel value, then use fitHEP.py to make linear fit of the channel vs energy function.

Then we start the scattering procedure. We use a Cs-137 radioactive source as the incident photon source, photons emitted by the source then scattered by an aluminum rod. We position the spectrometer detector at different scatter angles to measure the scattered photon energy. Since the scattered photons are a small number compared to the environment photons, we need to take two measurement, one with scattering effect, one without scattering effect. The measurement without scattering effect is the background, we then subtract the latter data from the former data to get the net counts. The peak channel of the net counts corresponds to the scattered photons. We uses python program fitPEAK.py(in the appendix folder) to find peak channels and their errors.

Finally we use the channel-energy function and the channel values we get from the above procedure to calculate scattered photons’ energy, then compare it with theoretical value.

**Analysis**

Below is the calibration result, where the first 3 rows are measured before the scattering procedure, and the last 3 rows are measured after the scattering procedure:

|  |  |
| --- | --- |
| channel | Energy(keV) |
| 884.3±28.9 | 662 |
| 1457±21.5 | 1173 |
| 1568±20.3 | 1333 |
| 848.3±27.5 | 662 |
| 1414±22.9 | 1173 |
| 1526±20.7 | 1333 |

The first 3 rows and last 3 rows each gives a fitted function, we then combine the 2 function to get the average function of the two:

Where C is channel value, E is energy.

After the Compton scattering procedure, we got the following results:

|  |  |  |
| --- | --- | --- |
| Angle(degree) | Peak channel | Standard deviation |
| 120 | 295.6±.4 | 17.1±.4 |
| 90 | 376.4±.4 | 22.6±.5 |
| 75 | 438.9±.6 | 25.9±.7 |
| 60 | 521.2±.6 | 29.9±.6 |
| 45 | 618.7±.7 | 32.6±.9 |
| 30 | 723.8±.6 | 35.9±.8 |
| 15 | 810.9±.7 | 32.7±1.3 |

**Results**

Substituting the above peak channel into the channel vs energy function from calibration will yield experimental value of E’. Then using the general propagation of error formula to calculate the error of E’. Detail calculation is done by the calculation.xlsx file. The angle vs energy result is this:

|  |  |  |
| --- | --- | --- |
| Angle | Experimental E’ | Expectation E’ |
| 120 | 94±108 | 224.9215426 |
| 90 | 173±110 | 288.3904518 |
| 75 | 234±112 | 337.7207783 |
| 60 | 315±115 | 401.760095 |
| 45 | 410±118 | 479.9038876 |
| 30 | 512±122 | 564.0936698 |
| 15 | 597±125 | 634.0127385 |

**Conclusions**

Most of the experimental result is within one sigma of the expectation value, except for the data of 120 and 90 degrees, which are slightly beyond one sigma range. The result shows that at smaller scatter angle, the experimental value agree well with the expectation value, however at large angle, it suggests some potential disagreement. Our experiment gives a large uncertainty range. This uncertainty comes from mostly the calibration error, where we only have 3 sets of data to fit the function. This gives a large uncertainty of the fitted function’s parameters, more specifically the y interception error. I think if we used more radioactive source to run more calibration procedures, it might give a better uncertainty range and a better fitted function.

**Reference**

PHYS:3756, intermediate lab manual, Compton Effect v\_3, the University of Iowa.

Stephen. T.. Thornton, Andre Rex. Modern Physics for Scientists and Engineers, 4th edition, Cengage Learning, 2012.

Appendix

See the attached folder.

File explanation

#w.csv: raw data acquired through scattering with scatter rod at (180-#) degree scatter angle.

#wo.csv: raw data acquired without scatter rod at (180-#) degree angle (background data.)

#raw.csv: extracted useful data from #w.csv and #wo.csv, used for plotting overall counts vs channel in the runData.doc.

#.csv: further extracted data from #raw.csv, used for gaussian fit to find peak channel.

Calculation.xlsx: used for calculate experimental E’ and it’s uncertainties, as well as expectation E.

CalibBefore.csv: raw data acquired from calibration run, before the Compton Scatter procedure.

CalibBefore – peak#.csv: extracted data from CalibBefore.csv. This contains 1 of the 3 peaks contained in CalibBefore.csv, used for gaussian fit.

CalibBeforeChvsEn.txt: data used for least square fit, to get the channel and energy relationship function.

CalibAfter.csv: raw data of calibration, acquired after Compton Scatter procedure.

CalibAfter – peak#.csv: similar to CalibBefore – peak#.csv.

CalibAfterChvsEn.txt: similar to CalibBeforeChvsEn.txt.

draw\_e1.py: python program used to plot plots.

FitPeak\_e1.py: python program used to do gaussian fit.

fitHEP\_e1.py: used for least square fit.

CalibData.doc: collected processed data by the FitPeak\_e1.py, from calibration runs.

runData.doc: collected processed data by draw\_e1.py and fitHEP\_e1.py, from Compton Scattering runs.