Compton Scattering

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Abstract

This paper is written as the *first* of four mandatory repports during the course *Experimental Physics III.*

In the experiment we will be working with ...

At last ....

This resulted in ... in confirmation of the theory

1 Introduction

In 1923, American physicist Arthur Holly Compton demonstrated the particle–like nature of electromagnetic radiation by the effect now known as the Compton effect. Compton conducted experiments in which high energy photons, such as x–rays and gamma–rays, were scattered by atomic electrons. When the incoming photon gives parts of its energy to the electron, then the scattered photon has lower energy and according to The Planck Hypothesis, lower frequensies and longer wavelength. The Compton effect is significant as it supported the photoelectric effect in the early twenties, and demonstrated that light cannot be explained purely as a wave phenomenon but rather as a duality of both wave and particle. This experiment serves to illustrate the Compton effect.

2 Theory

Compton Scattering

Compton scattering occurs when a beam of lightparticles, known as photons, collides with a solid target, in such a way the photon collides with a bounded electron. The scattering process can be seen on **??**. If the photon has an energy higher than the binding energy of the electron, both the electron and the photon scatters. Then the difference between the energy of the incomming and the scattered photon is described by the Compton shift;

$$\lambda - \lambda_0 = \frac{h}{m_e c}(1 - \cos(\theta))$$

Where λ is the wavelength of the incoming photon, λ_0 is the wavelength of the scattered photon, h is Plancks constant, m_e is the mass

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of an electron, c is the speed of light and θ is the angle in which the photon is scattered. The derivation can be found in the . Another effect closely related to this experiment is the photoelectric effect. In contrast to the Compton effect, the photon energy is fully absorbed and goes to two things; freeing the electron from its bounded state, and accelerating the electron. The freed electron is called a photoelectron. This interaction can of course not happen, if the photon do not have enough energy to free the electron.

FiXme: appendix

3   Hazards

This experiment has primarily 3 major hazards to be aware of, as listed below

- High Voltage (HV). High severity, low risk. Turn off the power, and let it cool before switching it off on the O/I button. Especial care, if wearing a pacemaker or the alike.

- Lead poisoning. Low Severity, low risk. Do not touch the lead blocks. If necessary, use glows and wash hands. Do not eat or drink in the laboratory.

- Radioactivity. Low severity, low risk. Be careful when handling the radiation sources. Do not eat or drink in the laboratory.

4   Experimental Setup

The following equipment, as described in this section, can be seen on

FiXme: fig: setup

BGO   In the experiment, there will be two detectors, the first of which is called the BGO1–scintillator. This is where the Compton scattering is occuring. When the photon arrives at the BGO–scintillator, the BGO–crystal absorbs the photon and therefore gets excited.

After a short period of time, the crystal will emit a new photon, essentially releasing almost all the energy absorbed, at an angle. After the Compton Scattering, the photon is absorbed by the second detector, which leads us to our next item of equipment.

NaI   The second detector is the NaI2–scintillator. Whereas the BGO almost emits all energy absorbed, the NaI absorbs the rest of the photon energy. Otherwise they are principly described by the same mechanics. Nonetheless, it is this important difference between the two detectors, that makes the photon detectable as a readable signal, but to do so, the energy has to be amplified.

Photo Amplifier   The photo amplifier is a necessity to read the photon energy as a pulse. High–Voltage power suply To conduct the experiment, the high voltage power suply is a necesity as well.

5   Data

6   Discussion

7   Conclusion

References

Griffiths, David J. *Introduction to Electrodynamics.* Cambridge, 2017. ISBN: 978-1-108-42041-9.

Jensen, Jens Ledet. *Statistik viden fra data.* Aarhus Universitetsforlag, 2012. ISBN: 978-87-7124-0245.

8   Appendix

Logbook

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1 Overview

On this page, the reader will find the whole experiment summed up on a single page. It should be used to get an overview before the reader moves on to the rest of the lab script. It does not tell the reader why you need to do these procedures, but this can be found in the following pages. It is suggested that you have this page at hand, while you are doing the experiment.

2 Calibration

The calibration relates the channelnumbers, which is the output of the detector program, to measured photon energy.

1. Measure the activity of the calibration sources with a Geiger-counter.

2. Choose fitting calibration sources, measure these with the NaI detector. Measure the Cs-137 radiation source with the BGO detector. 30-60 minutes should be enough for these measurements.

3. Identify and read the channel number of the calibration sources photo-peaks of the calibration sources, for both the BGO detector and the NaI detector.

4. Find the relation between channel number and photon energy, in each detector.

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3   Coincidence measurement

The measurement of coincidence between the two detectors is where the effects of Compton-scattering can be seen.

1. Set up the program for coincidence measurements. Choose an angle to measure at.

2. Let the measurement run for preferably more than 10 hours.

3. Use the calibration values to merge the datafiles from the two detectors with ROOT-script TTree- Builder.c.

4. Use the given scripts to plot the cloudplot for the measurement.

5. Identify the area of the cloudplot where Compton-scattering has happened in the BGO-detector, and the Photoelectric effect has happened in the NaI-detector. Read the scattered-photon energy.

6. repeat steps 1 through 5 for differing angles.

7. Compare the measured shift in energy with the theoretical value given by the Compton effect. Results

4   Results

1. Plot the coincidence measurements as cloudplots, and identify the overlap between Compton- scattering in the first detector (BGO), and photoeletric effect in the second detector (NaI).

2. Interpret the movement of this area at varying angles.

5   Experimental Procedure

Before you begin

You should find the characteristic energy diagrams for those atoms you have chosen to investigate. It is the γ–peaks of theese atoms you later will have to compare with. When we did the experiment, we found the energy diagrams for $Cs - 137$ (1 peak), $Na - 22$ (2 peaks) and $Co - 60$ (2 peaks). All information can be found at `http://www.nndc.bnl.gov/`.

Calibration

The scintillators do not themselves measure the energy of the photons, but the power supply converts the signals to a channel number, which corresponds to a discrete energy. The purpose of the calibration is to convert the given channelnumbers from the AC–converter to a specific energy. To do so, it is necesary to compare the data of measurements, with the known energies at a given photopeak. You can find an illustrated review of the following description in the appendix.

Hardware

1. Check that both detectors are linked to the power supply, and make sure to note which channel each of their cabels are connected to. The power supply should also be connected to the computer.

2. Extend the arm between the BGO and the NaI in an angle relative to the BGO.

Software

1. To set up the software for the calibration, open MC2Analyser.

2. Go to "Acquisition Setup", make sure the Online Spectrum is ticked, click "New Board Connection".

3. "Device Conection" will open in a new window. Click "connect".

4. Now turn "PWR" on.

5. Go to "Acquisition Setup", click "Coincidences", and make sure that all spaces are unticked and the drop downs are all on "NONE". Press "Apply". Go to output, and fill in a directory and the name of the filename to save data.

6. At last, click "RUN". Let it run for as long as possible, a couple of hours or more.

The calibration has to be done for both the BGO and the NaI–detector. For the calibration of the BGO–detector, use the $Cs-137$ source encaptured within the lead enclosement. DO NOT start fiddling with the lead enclosement! For the calibration of the NaI–detector, place a radioactive source on top of it. The γ-radiation source can be varied. Ask your lab-instructor for the other sources. It is recommended to use a Geiger–counter to find the most active radiation sources. From our experience, the $Co-60$ was great as opposed to the $Na-22$, which could barely show any photopeak with the background effects of a $Cs-137$ radiation source. Let the calibration run for at least 30 minutes.

Nonetheless, the longer it runs, the more precise. When the calibration is done, click "Stop" and remember to reset curve before continuing with the rest of the experiment. Now it is time to open the "Histogram" script in MatLab – you will find the instructions for the script written in MatLab. To convert the arbitary unit to a unit of energy, it is necesary to calculate the linear proportionality constant, κ.

$$E_{\text{source}} = \kappa E_{\text{Channel}}$$

The conversion factor should not be material dependent, but this might be a point of interest to investigate further. To find κ, you should first find the γ–peaks for each radiation source and then use then use the matlabcaliscript. When calculated, the κ–factor is constant for all measurements.

Practical/ Technical notes

One should be aware of the following:

    I The optical breadboard with all its components is very heavy, so take care when taking it out of the cabinet and back again.

    II Remember laser light can be harmful, so be careful also with parasitical beams!

    III Remember not to touch any optics on the surfaces on which light in impinging!

    IV Do only apply voltages in the range 0-10V to the control input of the piezodriver, and do not drive it at a frequency of more than 200 Hz. Hence, check and adjust the output of the function generator with the Pico Scope before connecting it to the piezo-driver. The voltage delivered to the piezo should be a factor of 10 higher than the control voltage (check backside of the piezo-driver).

    V Remember to take clear pictures of you various setups, including the electronic wiring.

    VI At the end of each experimental session, remember to safely fix all the optical elements to the breadboard in positions similar to those on Fig. 1., and bring everything back in good order in the cabinets!