Compton scattering

Number	138850-EN	*Topic*	Nuclear physics, relativistic mechanics		
Version	2017-02-21 / HS	*Type*	Student exercise	*Suggested for* grade 12+	*p.* 1/4

Objectives

Demonstrating the energy loss of gamma quanta by Compton scattering.
Verification of the theoretical expression for the energy of the scattered gamma quanta.

Principle

The equipment makes it possible to study Compton scattering by two angles: 60° and 90°. For each angle a couple of aluminium shells are used, whose geometry ensures that only gamma quanta that are scattered in precisely the desired angle, hits the detector.
Most of the direct radiation is absorbed by a lead absorber, placed directly between source and detector.

The energy of the gamma quanta is measured by a small scintillation detector and a multichannel analyser.

Equipment

(See detailed list of equipment on the last page)

519000 Compton scattering kit

Gamma source (Cs-137)

Stand material (as shown – please also read the hardware compatibility section on the last page)

Scintillation detector, multichannel analyser

(This lab manual requires a basic knowledge of the operation of multichannel analyser and the corresponding software!)

Remember the following rule:

The connection to the detector must **not** be changed while the multichannel analyser is powered:

First connect both cables for the detector – **next**, plug in the USB cable.

When finished, unplug the USB cable **first** – the cables for the detector are unplugged **last**.

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Procedure

1 – Calibration

To perform an energy calibration, it is best to have sources with gamma energies in the range in question. With a Cs-137 source you have the extremes covered: 662 keV (gamma) and 32 keV (X-rays). Should you have access to a radioactive mineral sample, there is a good chance to find three clear peaks from Pb-214 at 242, 295 and 352 keV, as well as one from Bi-214 at 609 keV.

Place the Cs-137 source close by the detector and adjust the settings to make the spectrum spread out on the x axis – with room to spare at high energies. Run the program for a while to reduce uncertainties so you can determine the position of the photo peak precisely. Use the fit facilities of the software and write down the channel number.
Repeat for the other energies to be used.

After performing the calibration, it can be saved.

Note! Avoid changing the hardware parameters for the rest of the experiment!

2 – Setting up

The finger screws on the source holder and the saddles should all point to the same side of the rail.

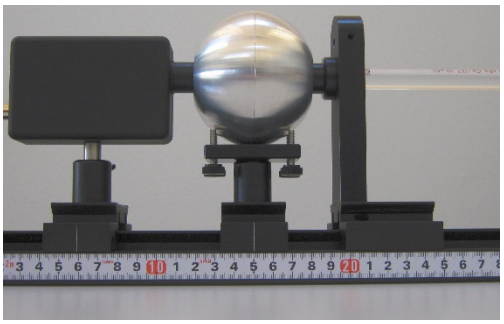
Adjust the height of the lead absorber and the detector to fit that of the source. Align the absorber carefully to make it parallel to the rail.

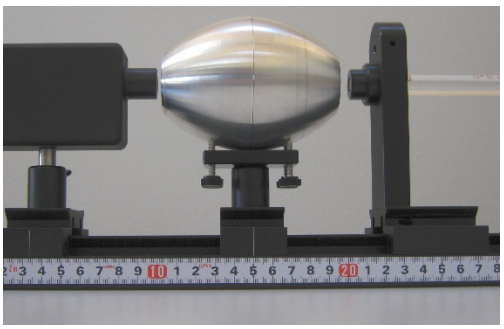
For the Risø source, the following apply *) :
The radioactive material is placed 3.5 mm from the front of the source holder when the source is screwed taut into the holder.
There is 1 mm from the front of the detector housing to the CsI crystal inside. The crystal is 15 mm long. Hence the distance from the front to the centre of the crystal is 8.5 mm.

The distance from the centre of the setup to the peripheral points (i.e. positions of source, resp. detector) is 36.7 mm for 90° scattering and 62.7 mm for 60°.

The tape measure on the rail comes in handy! There is a centre marking on the saddles; for the source holder, you can use the edge of the bottom plate – see figure. In practical work, use these distances *) :

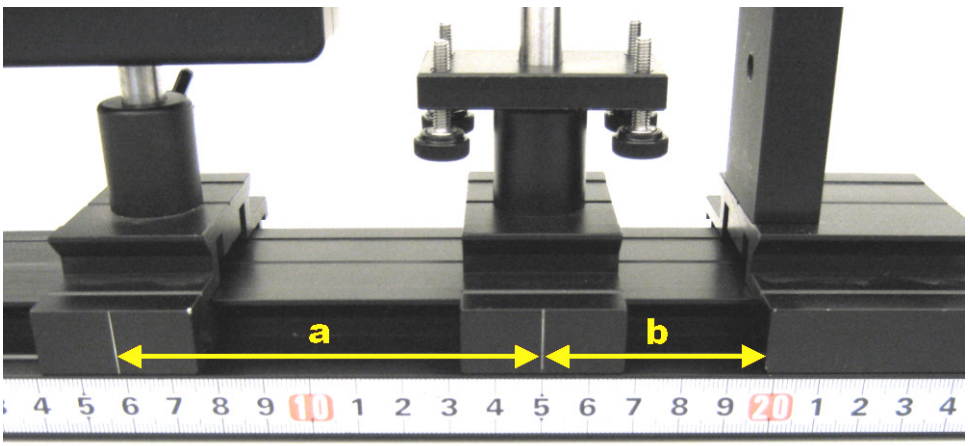
Angle	(a) *From* saddle, centre *to* saddle, detector	(b) *From* saddle, centre *to* edge, source holder
90°:	91 mm	48.5 mm
60°:	117 mm	74.5 mm





At least for 90° you must move source and detector a little when mounting and removing the shells. Write down all positions to make it easy to return to the right conditions.

Adjust the finger screws to make the edges of the shells vertical, making them fit opposite one another. The source and the detector must be on the centre line of the shells. (The settings are different for the two sets of shells – finish the work with one scattering angle before commencing on the other.)



*) If another type of source is used, please adjust the measure “b” accordingly.

3 – Reference spectrum

After adjusting the finger screws, remove the shells. Now you are ready for taking a reference spectrum. This spectrum includes not only background radiation but also radiation that is Compton scattered, e.g. on the table top – as well as a small contribution that penetrates the lead absorber.

The reference spectrum is to be loaded into the software as a background spectrum, allowing us later to subtract it from the spectrum when the shells are in place. The uncertainties of the counts in the reference spectrum will directly affect the end result, so you must measure for as long time as you will use on the "real" spectrum. With a 370 kBq Cs-137 source, 10 minutes will typically be sufficient to make the software perform a precise fit of the photo peak.

The reference spectrum depends on the geometry. When you later adjust the setup for another scattering angle, a new reference spectrum must be made.

Name the files with reference spectra so that you will easily recognize them again.

4 – Spectrum of Compton scattered radiation

Put the shells back on the centre holder again. You may need to move source and detector away to do so; make sure they are returned to precisely the same position.

Record the spectrum for approx. as long time as was used for the reference. The gross spectrum now recorded contains the Compton scattered radiation plus roughly the same contribution from background, scattered quanta from the table top etc. as is present in the reference spectrum. (The only difference being radiation that is reflected in the shells.)

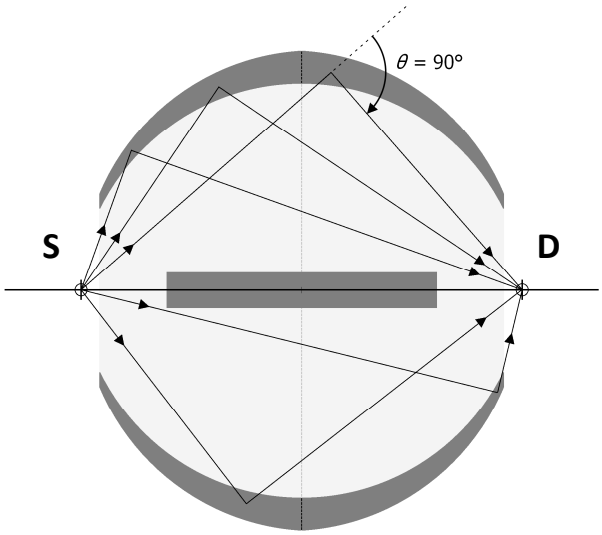
Specify the reference spectrum file as a background spectrum in the program. The difference spectrum can then be viewed while it accumulates. Differences in measuring time are taken into account.

Save the spectrum as a *spectrum experiment*. The file will then contain both the gross spectrum and the reference spectrum (as background spectrum).

Theory

The equipment utilizes a well-known geometric theorem about center and periphery angles of the circle. In this context it states that if source and detector are placed as two points S and D on a circle, then all points on the arc between them will "see" the same angle from S to D.

If this arc is now rotated around an axis through S and D, it will form an infinitely thin version of the shells in this kit. In order to avoid infinitely small count, the shells are made a little thicker – the price for this is a slightly imprecisely determined angle.



The figure shows the situation for the angle 90°. (For this angle only, the points S and D lie on a diameter.)

Originally, Compton discovered that the wavelength of x-rays that was scattered on loosely bound electrons changed by an amount that only depended on the scattering angle.
When working with gamma radiation it is natural to consider energies instead of wavelengths.

The result can be expressed like this:

$$E' = \frac{E}{1 + \frac{E}{m_0 \cdot c^2} \cdot (1 - \cos(\theta))}$$

Here, E' is the energy of the scattered gamma quantum, E is the energy of the incoming quantum, θ is the scattering angle, m_0 is the rest mass of the electron and c is the speed of light.

(The above formula can be deduced from conservation of energy and momentum, using relativistic formulae.)

Calculations

Use the table value of the gamma energy from a Cs-137 source to calculate the energy of the scattered quanta for both scattering angles.

Discussion and evaluation

Compare the theoretical and measured values for the energies of the scattered gamma quanta.

Evaluate any differences in conjunction with the uncertainties on the energies of the photo peaks as reported by the software when fitting their positions.

Teacher's notes

Concepts used

Compton scattering
(Relativistic mechanics)

About the equipment

The manual to the multichannel analyser and the accompanying software should be at hand.

Please note that the source holder that comes with the experiment bench 514100 cannot be used In this setup.

Didactic considerations

The basic operation of the multichannel analyser or the software is not covered by this lab manual.
If the students are not familiar with the equipment, an introduction is needed before the present exercise begins.

Consider Frederiksen's experiment
138810-EN "Gamma Spectroscopy, the Cs-137 source" which gives such an introduction.

If the equipment is set up and calibrated in advance – and provided that the students are familiar with the software – the exercise *can* be completed in 45 minutes. At least twice the time is clearly advisable. As mentioned, you will need at least 10 minutes per spectrum when using a fresh 370 kBq Cs-137 source.

About the software

It is crucial that the software is installed **in advance** on the PC to be used. Otherwise you risk wasting precious class time on installation.

The program gives hardly any problems but in newer Windows versions, installing the USB driver requires you to carefully follow the procedure outlined in the included Quick Start Guide (version 1.25 from Nov. 2015 - or later).

This guide is not intended as a substitute for the program manual, which should be available.

Note: It is strongly recommended that you subscribe to our mailing list for program updates. write to: **info@frederiksen.eu**

Detailed list of equipment

518000 Multichannel analyser
518500 Scintillation detector for 518000
519000 Compton scattering kit

514102 Rail for experiment bench, 40 cm
294610 Saddle with Ø 10 mm hole (**2 used**)

Source holder *):
514180 Source holder, bench, simple, Risø source
or
514185 Source holder, bench, simple, disc source
or
514187 Source holder, bench, simple, cyl. source

Also required

PC with software (GaSp) ***and related USB driver***

Cs-137 source, like: 510030 Gamma source, Risø **)

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*) 514180 (for Risø sources) is shown on p. 1.
514185 is for Ø 25 mm disc sources:
514187 is for Ø 12 mm cylindrical sources (below):

Please note that the latter two types of radioactive sources are not provided by Frederiksen Scientific.

**) This gamma source is included with the 510000 Radioactive sources, Risø, complete set.

Stand material, other options

The rail and *one* saddle is included in our 514100/ 514120/514110 Mounting bench. One more saddle and the special version of the source holder ("simple") *must be added* for this experiment.

The mounting bench provides a stable platform for a range of other nuclear physics experiments.

514100 Mounting bench for Risø sources
514120 Mounting bench for disc sources
514110 Mounting bench for cylindrical sources