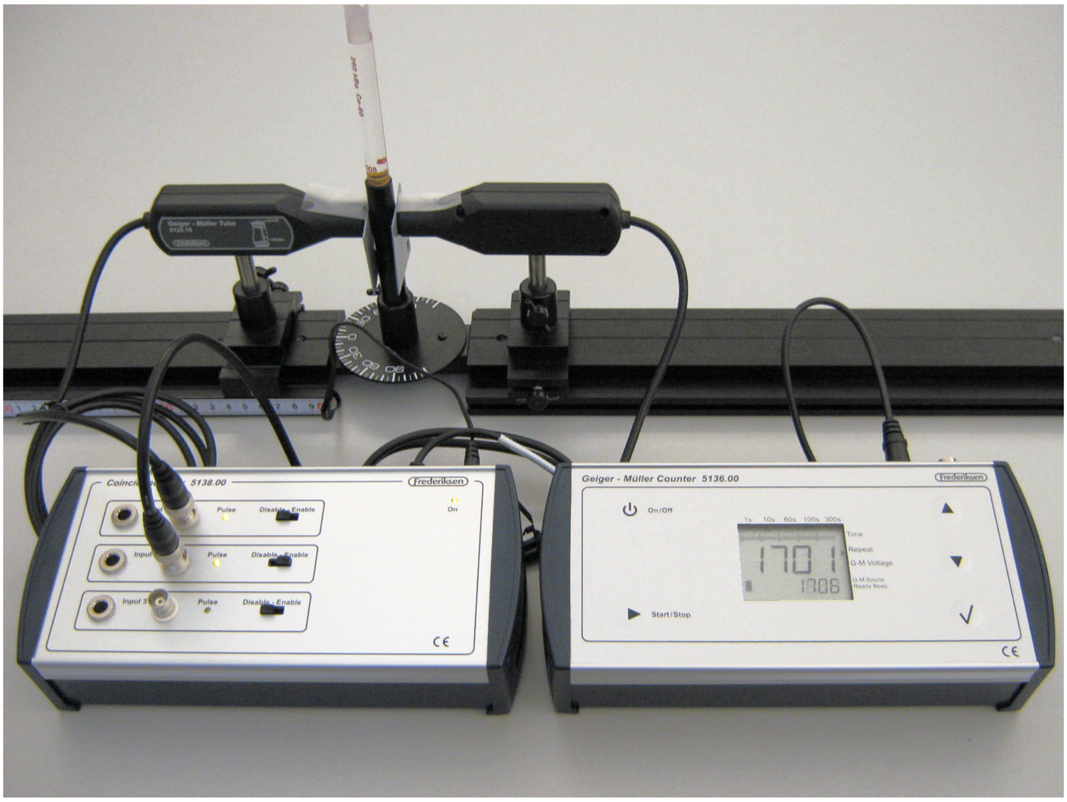
Frederiksen
Passion for science

The gamma cascade from Co-60

Number	138710-EN	*Topic*	Radioactivity				
Version	2017-10-05 / HS	*Type*	Student exercise	*Suggested for*	grade 12+	*p.*	1/4



Objective

To demonstrate that two gamma quanta are emitted simultaneously when a Co-60 nucleus decays.

Principle

Two Geiger tubes are connected to a coincidence box. The tubes are placed on either side of the source. You will discover that radiation from the Co-60 source is detected in both Geiger tubes simultaneously far more often that what can be explained by mere chance.

As a control experiment, the measurement is repeated with Cs-137 where only a single gamma quantum is emitted per decay.

Equipment

(Detailed equipment list on p. 4)

Sources: Co-60 and Cs-137
Two identical Geiger tubes
Coincidence box
Counter (Or possibly datalogging equipment)
Stand material

Procedure

The two detectors are connected to input 1 and 2 on the coincidence box. Set the *Enable/Disable* switches to *Enable* input 1 and *Disable* input 2. The unused input 3 must be *Disable*d during the complete experiment.

Connect the output from the coincidence box to the counter, and select a counting period of 10 seconds. If the count rate is less than 1500 count per 10 s, you can choose to increase the period to 60 s.

To minimise the influence of scattered radiation, place a thin lead absorber in front of both tubes. The absorbers can simply be fixed by self-adhesive tape. Place the source symmetrically between the tubes and keep the distances as small as possible.

The photo shows the source mounted in holder 514195 in a joint link 294650 which ensures the symmetry.

When measurements begin, there must be no change in geometry and no changes to the electric connections.
Leave the cables plugged in.

Measure the counts at input 1 in 5 minutes in total (write down all individual counts and the counting period).
Repeat with input 2 – i.e. *Disable* input 1 and *Enable* input 2.

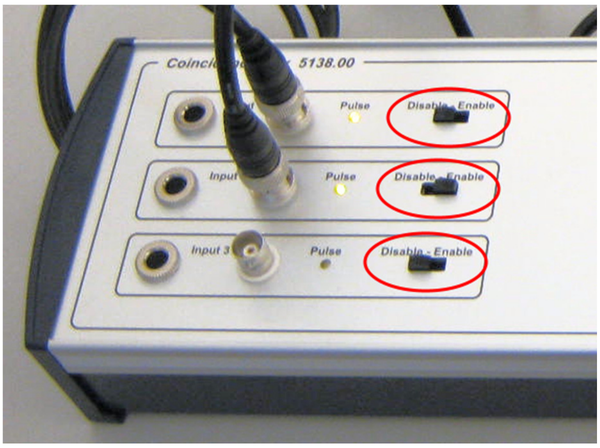
To find the count rate in coincidence, switch to *Enable*d for both input 1 and 2.

The count rate is markedly lower than before (typically 2-3 counts per 100 s). It can be convenient to increase the counting period on the counter – remember to write down the new period.
Record coincidence counts as long as practically possible – an hour is appropriate.

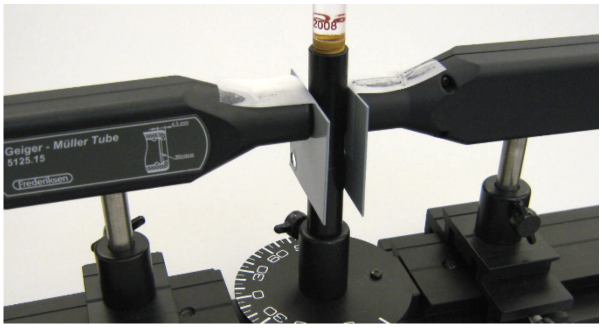
Control experiment

As a check on both the equipment and the theory, you should perform an experiment where correlated gamma rays are *not* expected. For instance you can use a Cs-137 source which only emits *one* gamma quantum per decay. The measurement procedure is exactly as for the original experiment.

Gamma radiation from this source has a lower energy than from the Co-60 source and the efficiency of the Geiger tube is lower. This results in a somewhat lower count rate than for Co-60. In other words, if you want the same precision it takes longer time to perform the control experiment than the actual measurement on Co-60.



Enable switches (– see text)



Absorbers in front of the Geiger tubes

Using a PC (optional)

To record the counts, the Geiger counter 513610 (or older model 513600) can be used with the PC program Datalyse (download English version for free from datalyse.dk).
This requires a special cable, to be purchased separately.

In Datalyse, select the device “Geiger Müller Counter” and experiment type “Half Life”.

The output pulses from the coincidence box can also be counted with datalogging equipment; the jack plug directly fits Pasco’s digital interface PS-2159.

Theory

As can be seen from the decay scheme, each beta decay of Co-60 is followed – within about 1 ps – by a cascade of two gamma quants with energies 1.17 MeV resp. 1.33 MeV. One pico-second is many times faster than what we can resolve with this equipment and we can hence consider the gamma quanta to be emitted exactly simultaneously.

By using normal Geiger tubes we cannot distinguish the quanta by their energy – in order to demonstrate the existence of the cascade, we must therefore pursue the simultaneity.

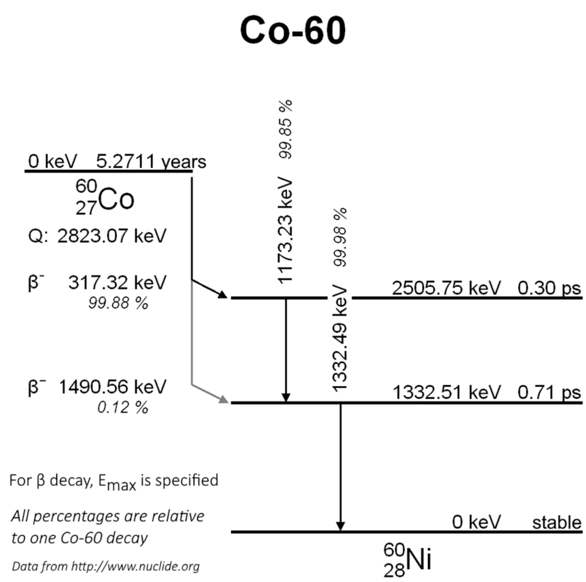
Experimentally this is found with two Geiger tubes and a coincidence box with a time window τ. If the distance between two events is less than τ, they are registered as simultaneous. For Frederiksen's coincidence box (513800), $\tau = 1.00\ \mu s$.

However, that two events are characterised as simultaneous is no guarantee that they are otherwise related – it could be gamma quanta from two different decays that by chance hit the two detectors within the time interval τ. Luckily it is simple to calculate the rate of these *random coincidences*:

Let the count rates for the two individual detectors be r_1 resp. r_2. The count rate for random coincidences r_{RND} is then given by the expression

$$r_{RND} = 2 \cdot \tau \cdot r_1 \cdot r_2$$

Note: It is important to enter count *rates* (i.e. counts *per second*) and not just raw counts.



Calculations

The following must be done for each of the two measurement series (Co-60 and Cs-137):

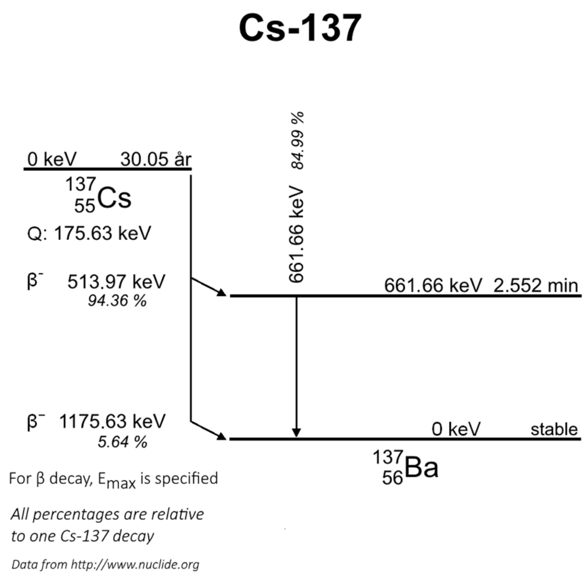
From the three measurement series, calculate the average count rates r_1, r_2 and r_{12} (for resp. the two detectors alone and in coincidence).

Finally, calculate the count rate for random coincidences and (by subtraction) the number of genuine coincidences.

Discussion and evaluation

Present the results and discuss if the measurements on the two sources represent markedly different behaviours.

In case the coincidence count rate for Cs-137 differs significantly from 0: Try to give a physical explanation of that.



Teacher's notes

Count rates

The count rate in coincidence may appear surprisingly low.
The reason is among other the low gamma ray sensitivity of Geiger tubes. Assume for instance that the efficiency is 2 %. Then the efficiency for two tubes in coincidence becomes $0{,}02^2 = 0{,}0004$ or 0,04 %.

The solid angle of the detectors likewise inters squared as the two gamma quanta are only weakly spatially correlated (as opposed to e.g. the quanta from positron annihilation).

Using absorbers

As mentioned, the two Geiger tubes are used with thin lead absorbers. These will lower coincidences with X-rays, Compton-scattered radiation etc. Without lead absorbers, the number of these (genuine) coincidences can reach about 25 % of all registered coincidences from Cs-137.

Estimating uncertainties

Especially in the ("zero") experiment with Cs-137 you should have some idea about the uncertainties. Otherwise it is hard to asses an experiment where the expected value is zero.

The coincidence window

The coincidence box is adjusted to $\tau = 1\ \mu s \pm 3$ %. If this precision is not sufficient, you can find the value experimentally by using the formula for random coincidences. To ensure that coincidences are truly random, use two sources – and a large distance between the tubes.

Background radiation

Random coincidences occur completely independent of the origin of the radiation – background radiation contributes on par with radiation from the sources. Therefore, there is no background radiation correction in the formula for r_{RND}.
(When sources are this close, the correction to the raw count can be neglected anyway.)

In coincidence a few incidents will occur where background radiation or a cosmic ray particle shower hits both Geiger tubes. For example, we have measured 3 coincidences in one hour without any sources. If you wish to correct for this effect – and if a correction is to be statistically meaningful – you will need to measure over very long periods. You could e.g. let a PC collect data for 24 hours.

In case larger tubes are used, the sensitivity to background coincidences will increase.

Spreadsheet

A spreadsheet has been prepared for the data processing and uncertainty calculations. Go to www.frederiksen.eu and search for item No. 513800.

Detailed equipment list

Specifically for the experiment

510035	Co-60 source
510030	Cs-137 source
512515	Geiger tube on rod, BNC-plug (Qty. 2) (other types OK, but two identical tubes must be used)
513800	Coincidence box
513610	Geiger counter (or 513600
512565	USB communication adapter for 513610 (if PC is used)
514010	Pb-absorbers, approx. 1mm (Qty. 2) (included with 514006, 514100 or 514005)

Stand material – e.g. the following:

294650	Joint link for mounting bench
514195	Source holder for joint link
514102	Rail for mounting bench, 40 cm (Qty. 2)

Consumables

Adhesive tape for fixing absorber plates