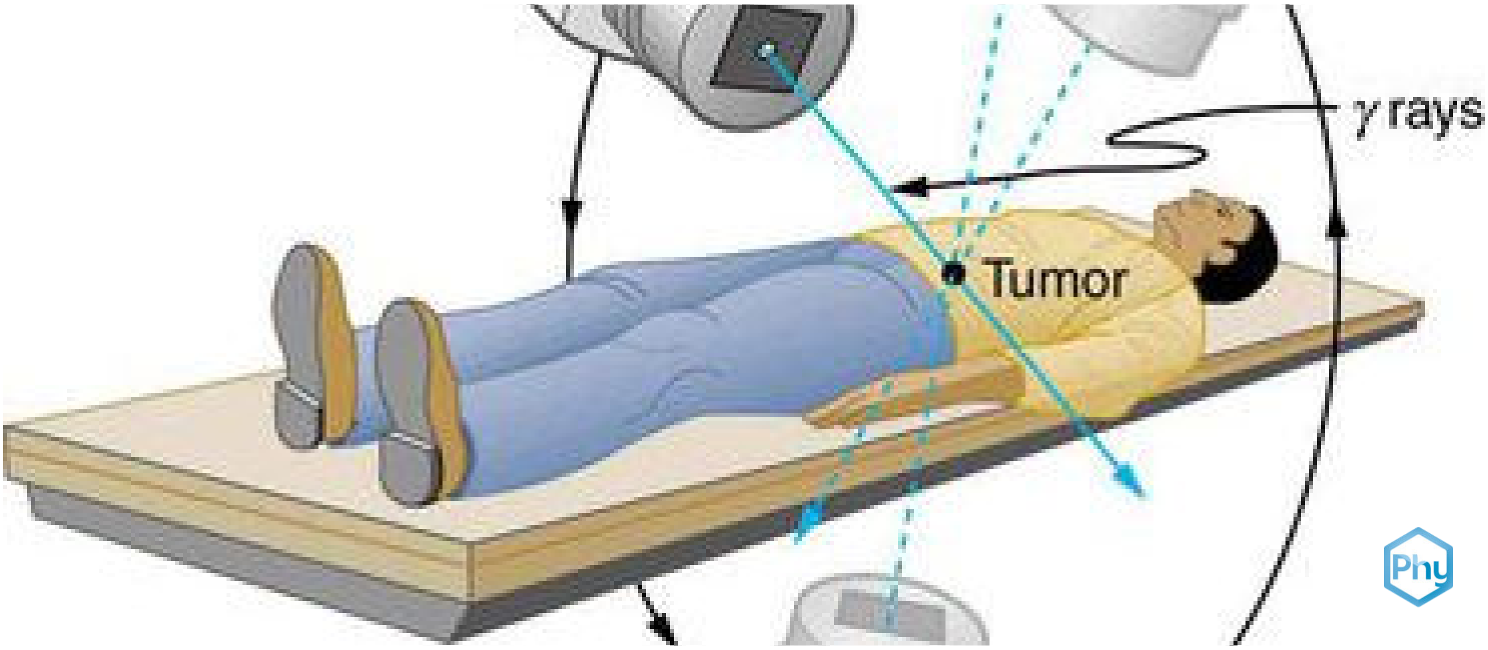
Energy dependence of the gamma absorption coefficient / Gamma spectroscopy



Physics | Modern Physics | Nuclear & particle physics

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/5f0ecef0b6127b0003044870

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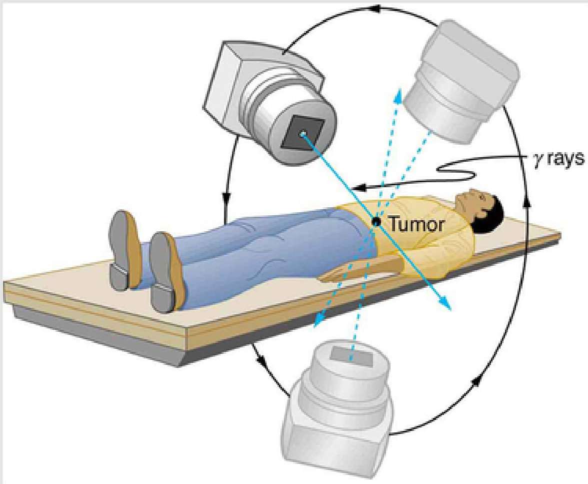
General information

Application



Radiotherapy

Gamma radiation is applied in:

- Leak detection: Gamma rays help engineers to detect leaks in underground pipes without digging up.
- Radiotherapy: Gamma beams are focused at the tumour to kill cancerous cells. The beams are aimed from different angles to concentrate the radiation in order to reduce the damage to surrounding tissues.
- Irradiation: Sterilising medical instruments and removing decay-causing bacteria from foods.

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Other information (1/2)

Prior knowledge

Gamma rays are produced during gamma decay, which normally occurs after alpha or beta decay. The daughter nucleus that results from alpha or beta decay is often left in an excited state. It will subsequently relax to a lower energy state by emitting a gamma photon, this process is known as gamma decay.

Scientific principle

The intensity of γ-radiation decreases when it passes through solid matter. The attenuation can be the result of Compton scattering, the photoelectric effect or the pair production. An absorption coefficient can be attributed to each of the three phenomena. These absorption coefficients, as well as the total absorption, are highly energy-dependent. The energy dependence of the total absorption coefficient for aluminium is measured in the range below 1.3 MeV.

Other information (1/2)

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Other information (2/2)

Learning objective

To understand the interaction of γ-radiation with matters in relation to its energy.

Tasks

1. Record spectra of the isotopes ^{22}Na and ^{241}Am and determine useful energy windows for the absorption experiment.
2. Record the number of incidents during a fixed time in a chosen energy window (integration measurement) in dependence on absorber layer thickness between source and detector for different energy windows.

Safety instructions

For this experiment the general instructions for safe experimentation in science lessons apply.

Excessive exposure to gamma radiation can be harmful. Keep your hands out of the beam at all times.

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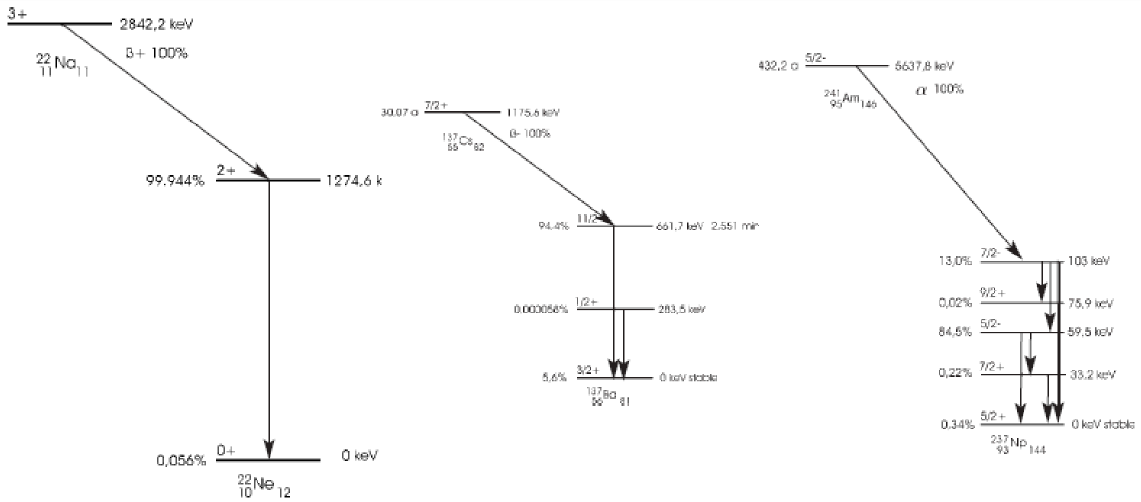
Theory (1/6)

In the decay schemes of the used nuclides, the proportions of the energy scale are not displayed correctly and the term scheme of ^{237}Np is strongly simplified – in the experiment only the 59.5 keV radiation of ^{237}Np is of importance.

It is to be kept in mind that (in the case of ^{137}Ba the exited states of the daughter nuclides can also disintegrate by inner conversion leading to a strong 32 keV X-ray line.

The α-particles, the electrons and positrons are stopped in the sources, the latter giving rise to 511 keV annihilation radiation. Only the generated photons reach the detector.

Theory (2/6)



Decay schemes of ^{22}Na , ^{137}Cs and ^{241}Am

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Theory (3/6)

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The γ- and X-ray quanta coming from the sources (α- and β-particles cannot leave covered sources) passing through matter may undergo mainly these reactions:

- They may be diffracted on a crystal lattice without energy loss, which is here therefore not counted for as absorption.
- They may be absorbed by an electron transferring all the energy and momentum to the electron which is called photoelectric effect. In case of condensed matter, thereafter the electron looses its energy in short time ($< 10^{-11}\ s$) on a short path (1 mm) to the surrounding matter producing mostly heat but maybe also some Cherenkov radiation and a path of ions or exited states of nearby lattice impurities which afterwards recombine partly emitting visible light. The photoelectric effect is dominant for small γ-energies but the cross-section for photoelectric effect strongly decreases for high energies – the likelihood of an electron to swallow a photon completely is only high if the photon has far less energy than $m_e c^2$.

Theory (4/6)

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- Else the γ-quanta may interact with electrons exchanging momentum and energy with an electron in an elastic scattering process which is called Compton scattering. In this process, they loose energy and so this process is counted as absorption – the γ-quanta are no longer found in the energy window where they were emitted. This process contributes to the most to the total absorption coefficient in the energy range where the photon's energy is comparable to the electron's resting energy $m_e c^2$ (billiard is played with balls of comparable weights).
- If the γ-quanta have more energy than $2 m_e c^2 = 1022 keV 2$, with surrounding matter as third partner for momentum conservation, pair production of an electron-positron pair is possible. This process gets more likely with increasing energy – the excess energy separating the reaction products. From the following annihilation of the positron with another electron originate two γ-quanta of 511 keV (or with far less probability three γ-quanta with in average 341 keV each).

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Theory (5/6)

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For each of the processes the fraction of γ-quanta undergoing an interaction per passed layer thickness Δx is constant, it's a reaction probability μ per layer thickness Δx for a fixed γ-energy. For small Δx the absorbed part I_a of the initial intensity (proportional to the number of γ-quanta per unit time) is

$$I_a = \mu \cdot I(x) \cdot \Delta x$$

and

$$I(x + \Delta x) = I(x) - I_a = I(x) - \mu\,\Delta x \cdot I(x)$$

thus

$$\frac{dI}{dx} lim\,\Delta x \to 0 = \frac{I(x+\Delta x) - I(x)}{\Delta x} = -\mu \cdot I(x)$$

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Equipment

Position	Material	Item No.	Quantity
1	Gamma detector	09101-00	1
2	PHYWE high precision power supply 1.5 kV DC	09107-99	1
3	PHYWE Multichannel Analyser (MCA)	13727-99	1
4	measure Software multi channel analyser	14452-61	1
5	Vernier calliper stainless steel 0-160 mm, 1/20	03010-00	1
6	Base plate for radioactivity	09200-00	1
7	Source holder on fixing magnet	09202-00	1
8	Plate holder on fixing magnet	09203-00	1
9	Absorption material, aluminium	09029-03	1
10	Lab jack, 160 x 130 mm	02074-00	1
11	Radioactive source Na-22, 74 kBq	09047-52	1
12	Radioactive source Am-241, 370 kBq	09090-11	1
13	High-voltage connecting cable	09101-10	1
14	Screened cable, BNC, l = 750 mm	07542-11	1

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11	Radioactive source Na-22, 74 kBq	09047-52	1
12	Radioactive source Am-241, 370 kBq	09090-11	1

Additional equipment

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Position	Material	Quantity
1	PC	1

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Setup and procedure

Setup (1/2)

Experiment setup

Set up the experiment as shown in the figure.

Before turning on the operating unit for the scintillation counter, connect the high voltage cable correctly to operating unit and photomultiplier and read the instructions in the manual of the gamma-detector.

Set the voltage of the operating unit to 1.0 kV.

Connect the MCA to the computer's USB port and start the "measure" program.

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Setup (2/2)

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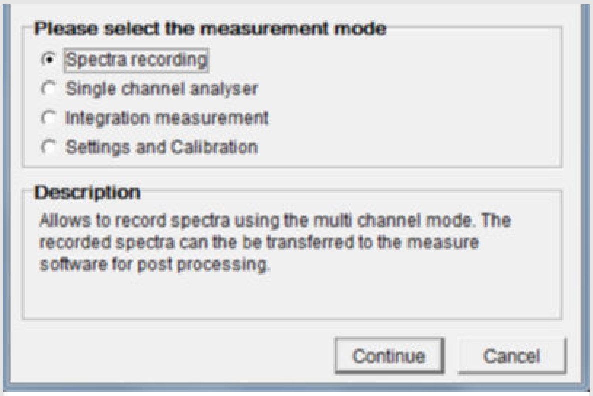
Select the Gauge "Multi Channel Analyzer" and you will receive the start window, as shown in the figure.

For recording of spectra you may bring one of the sources in direct vicinity to the detector – for the 370 kBq source you better keep some distance since the counting rate should not exceed 800 cts/s by far.



Start window of the MCA

Procedure (1/5)

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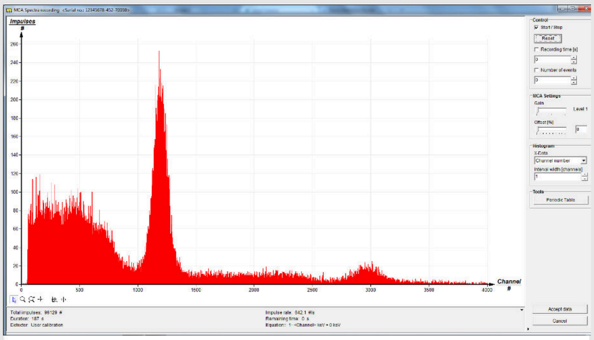
Start with the ^{22}Na source. Select "Spectra recording" (see previous figure) and click on "Continue". Set the "Gain" to "Level 1", set the "Offset" to 0 %, choose "Channel number" as x-Data and start data recording.

The 1275 keV peak should be observable in full at the right side of the spectrum. If not, alter the high voltage setting on the detector operating unit. If you are not sure, start with low settings and increase the high voltage, until the 1275keV peak wanders to the right side of the soectrum.

If the impulse exceeds 800cts/s, increase the distance between source and detector. After adjustment of the high voltage leave it unchanged throughout the experiment.



Window for spectrum recording - here the spectrum of ^{22}Na with gain level 1

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Procedure (2/5)

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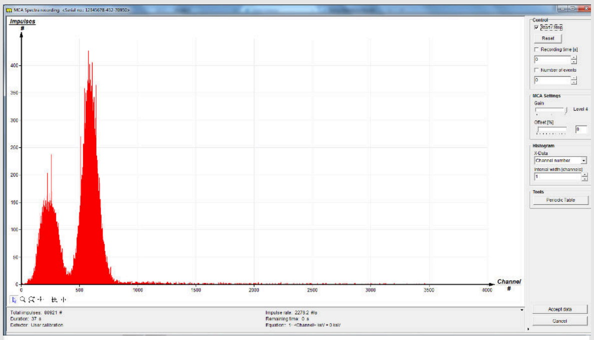
Note down the channel number ranges of the 511 keV annihilation peak and the 1275 keV γ-peak – the windows you are to determine may be as broad as the photo peaks are.

Use the "Mark" tool on the lower left of the window for channel evaluation.

Then set the amplification to "Level 4" and record a spectrum of ^{241}Am – the (\gamma\)-peak at 60 keV is also suitable for the measurement. The chosen window might be channel 430 to channel760.



Window for spectrum recording - here the spectrum of ^{241}Am with gain level 4

Procedure (3/5)

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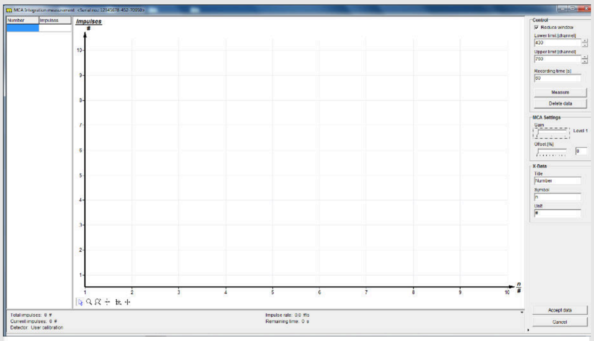
Now start the Gauge "Multi Channel Analyzer" again and choose the program part "Integration measurement" from the start window of the MCA and you will receive the integration measurement window.

Select a source and set the lower and upper limit of the channel to the values you have determined for the peak of interest before. Select a gate time of at least 60 s. Check radiation and photomultiplier dark count rate background in the chosen window to be negligible by performing one measurement without a source and delete the data.

Then place the source about at least 15 cm from the detector and make sure, that source and detector are well aligned.



Integration measurement window

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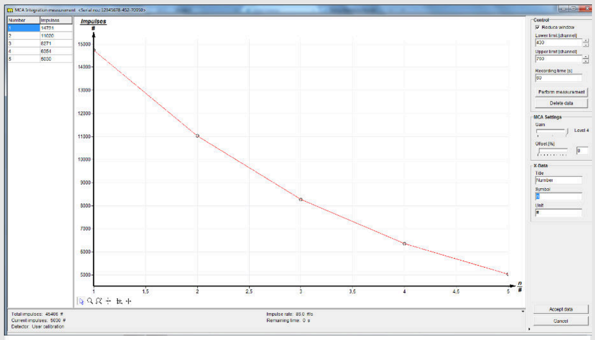
Procedure (4/5)

Place aluminium absorber layers in steps of e.g. 5 mm midway between source and middle point of the detector crystal without moving source or detector (placing thin absorbers into the plate holder and thick absorbers onto the supporting blocks) and perform measurements for layers up to 25 mm.

The geometry is of importance because scattering on the metal crystal lattice occours and the counting rate may be altered by the presence of metal even without absorption or Compton-scattering.

Change the x-data in the data table of the integration measurement window from number to the appropriate values in mm. Then click on the "Accept data" button.



Example of the integration measurement

Procedure (5/5)

In the measure program use the "Display options" button to set the scaling of the measurement on the "Channels" chart to "logarithmic". A linear dependence of the logarithm of counts on absorber layer thickness should be visible.

Save the measurement file to your hard disk drive. Do so for the photo peaks of 1275 keV, 511 keV and 60 keV. (Recording spectra for a defined time, "Accept data" and integrating over the peak with "Mark" tool and "Show integral" button and background subtraction has to be done here for correct intensity values for each absorption layer thickness – the Compton background is the result of higher energetic photons in the detector that get less attenuated.)

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Evaluation (1/4)

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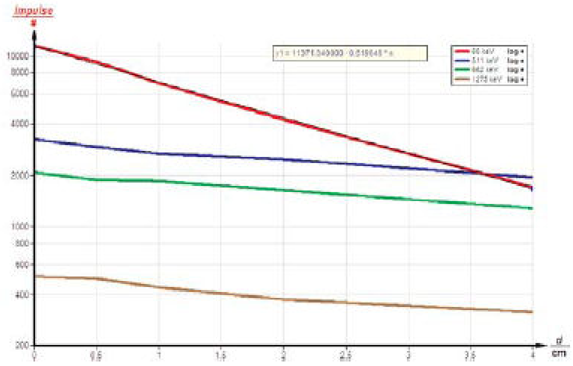

Results for aluminium

Use the "Regression" tool to determine the base of the exponential function in the recorded measurements. The number of shown decimal digits can be altered with the "Information" button.

In the figure, the base reads 0.619646(± 0.01), thus

$$\mu = (0.48 \pm 0.915)\, cm^{-1}$$

Evaluation (2/4)

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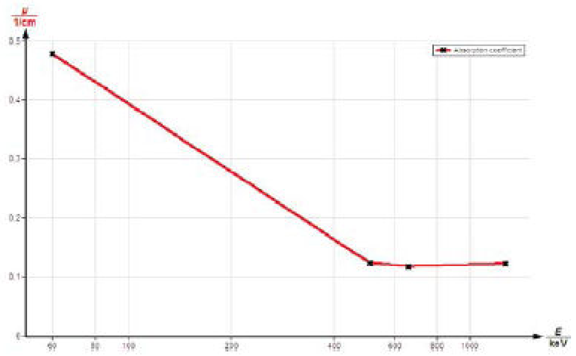
Figure shows a possible result of μ in dependence of the energy.



Absorption coefficient μ vs. energy

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Evaluation (3/4)

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Fill in the blank:

The probability for absorption of gamma rays through matter is proportional to the ______ of the material. For the larger linear ______ coefficient, the probability of an interaction in the material is ______ and the beam attenuates in a ______ distance.

- shorter
- higher
- absorption
- thickness

Check

Evaluation (4/4)

PHYWE

The absorption of gamma rays in matter is dependant on:

- [ ] Energy of gamma rays
- [ ] Density of the matter
- [ ] Thickness of the material
- [ ] Atomic number of the matter

Check

Interaction of gamma rays with matter is ruled by:

- [ ] Coulomb scattering
- [ ] Compton scattering
- [ ] Pair production
- [ ] Photoelectric effect

Check

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