Energy dependence of the γ-absorption coefficient

LEP 5.2.42

Related topics

Compton scattering, photo effect, formation of pairs, absorption coefficient, radioactive decay, γ-spectroscopy.

Principle and task

The intensity of γ-radiation decreases when it passes through solid matter. The attenuation can be the result of Compton scattering, the photo effect or the formation of pairs. 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 in the range below 1.3 MeV is verified.

Equipment

Radioactive sources, set	09047.50	1
Americium-241 source, 370 kBq	09090.11	1
Source Cs-137, 37 kBq	09096.01	1
Absorption material, aluminium	09029.03	1
Gamma detector	09101.00	1
Operating unit f. gamma detector	09101.93	1
High-voltage connecting cable	09101.10	1
Pulse height analyser	13725.93	1
Geiger-Müller-Counter	13606.99	1
Oscilloscope, 20 MHz, 2 channels	11454.93	1
xyt recorder	11416.97	1
Stopwatch, digital, 1/100 sec.	03071.01	1
Vernier caliper	03010.00	1
Lead block, 200×100×50 mm	09029.11	4
Lead brick with hole	09021.00	2
Source holder on fixing magnet	09202.00	1
Barrel base -PASS-	02006.55	1
Adapter,BNC-socket/4 mm plug pair	07542.27	1
Screened cable, BNC, l 750 mm	07542.11	5
Connecting cord, 750 mm, red	07362.01	2
Connecting cord, 750 mm, blue	07362.04	2

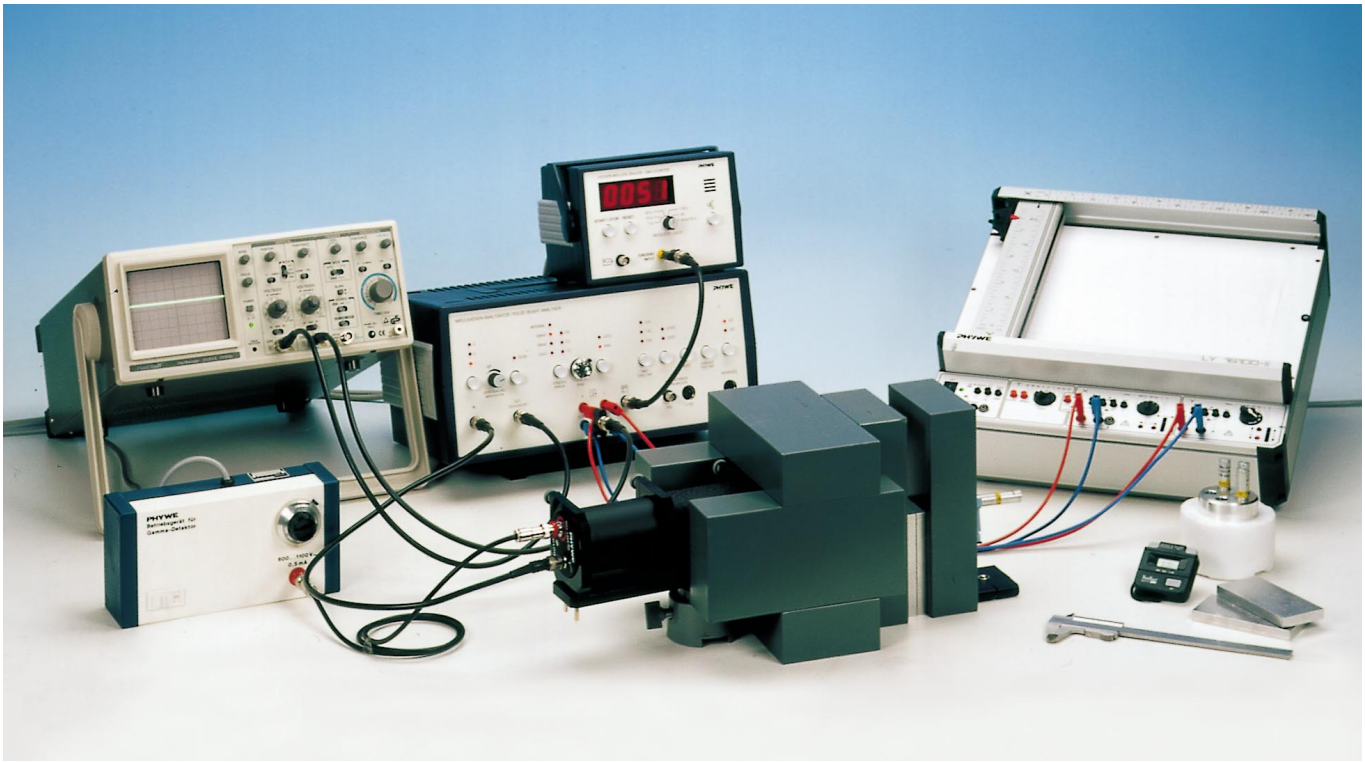
Problems

1. For each of the emitting isotopes Na^{22}, Cs^{137} and Am^{241} the γ-spectrum is traced and a threshold energy, E_{thres}, just below the photo-peak in the high energy range determined.
2. Using the scintillation counter in conjunction with the pulse height analyser as a monochromator, the γ-intensity is measured as a function of the thickness of different aluminium layers. The three γ-emitting isotopes are used successively as the source, assuming that the energy of the emitted γ-radiation is known.

Set-up and procedure

The experiment is set up as shown in Fig. 1. To eliminate Compton scattered radiation as completely as possible, two lead diaphragm are used, one in front and one behind the absorber. The first diaphragm ensures a parallel beam of γ-radiation while the second diaphragm prevents the strong Compton scattered radiation from reaching the γ-detector. The remaining lead-shielding blocks reduce the background radiation to a minimum.

Fig. 1: Experimental set-up: Energy Dependence of the γ-absorption Coefficient.



The operation unit for the γ-detector was set as follows:

γ-source	scale reading of operating unit
Na^{22}	2.7
Cs^{137}	3.4
Am^{241}	7.8

The γ-detector is connected to the input of the pulse height analyser, which first of all amplifies the incoming pulses. The x-output socket of the pulse height analyser is branched to the oscilloscope. The vertical amplification of the oscilloscope should be 2 V/cm and the time basis 2 μsec/div. A proper triggering level must be chosen. If the coarse amplification of the pulse height analyser is now set to "1" and the fine amplification to the medium range, the γ-detector pulses appear quite clearly on the oscilloscope if the γ-source is kept in front of the detector. A massing-up of pulses on the screen indicates the presence of a spectral line. The pulses should never exceed a height of 10 V. The pulse height analyser is then connected to the x/y recorder and with its output Discriminator to the timer.

The x/y recorder should be set as follows:

x-deviation: 10 mV/cm, variable
y-deviation: 1 V/cm, variable

Initially the x-deviation is adjusted by means of the potentiometer setting "variable" in such a way that any 10 V pulses will be recorded at the right end of the paper (for this: release the button "Man", press energy window 500 mV and gently turn the "Basis" dial to 10). Once this has been carried out, the x-deviation should not be changed anymore. The y-deviation has to be adjusted by means of the appropriate potentiometer setting "variable" as a function of the source intensity. For spectrum-tracing, the sources are used without lead shielding in front of the γ-detector at a distance of about 10 cm.

During all spectrum measurements, the width of the energy window remains constant at 500 mV. The clock period is 0.8 sec. Before starting the spectrum measurements, it has to be ensured that the cycle-switch at the rear of the pulse height analyser is set to "intern".

Theory and evaluation

The decrease of the intensity of γ-radiation with initial intensity I_0 along a distance x of solid matter is described by the relation

$$I = I_0 e^{-\mu x} \qquad (1)$$

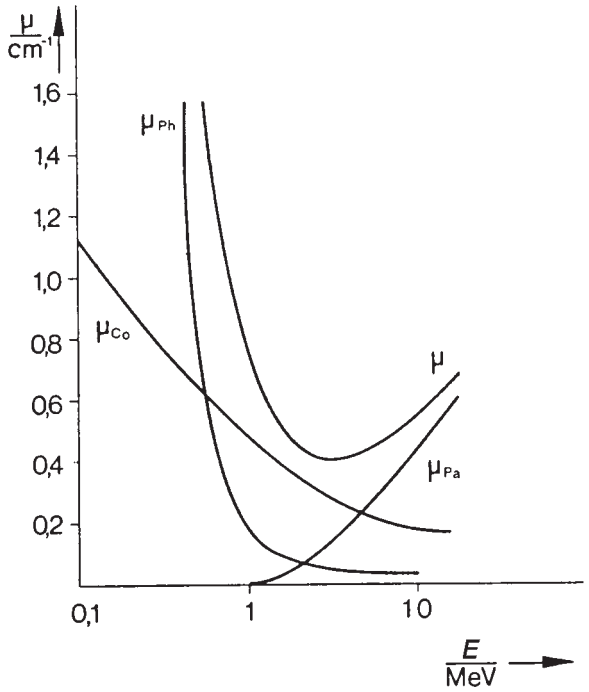
where μ is the total absorption coefficient. In the lower energy range, e.g. below 1.3 MeV, μ is the sum of only two absorption coefficients due to the photo effect and the Compton scattering within the absorber.

$$\mu = \mu_{PH} + \mu_{co} \qquad (2)$$

μ_{PH}: absorption coefficient due to photo effect

μ_{co}: absorption coefficient due to Compton scattering

Fig. 2: Gamma-absorption coefficients as a function of energy for lead.



The present experimental set-up (diaphragm!) guarantees that all those γ-quanta which communicate their total energy to the electrons of the absorbing material as well as an appreciable part of those which undergo Compton scattering (partial loss of energy → change of direction) will not reach the detector. They must be considered as "absorbed", e.g. eliminated from the γ-radiation flux.

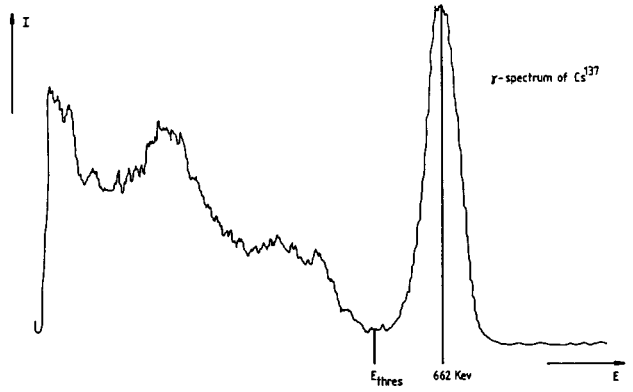
Fig. 2 shows the three absorption coefficients (Compton scattering, photo effect, formation of paris) and the total absorption coefficient for lead as a function of energy.

The left part of the graph representing the total absorption coefficient will be verified for aluminium.

1. Using the automatic plotting mechanisms of the pulse height analyser (push buttons "Auto" and "Start") the γ-spectra are recorded for the three γ-emitters. To illustrate this the γ-spectrum of Cs^{137} is shown in Fig. 3. Cs^{137} (actually Ba^{137}) has a spectral line of 662 KeV. All quanta of this energy reaching the scintillation counter can eventually contribute to the photo-peak within the counter material.

2. After a particular spectrum has been recorded, the automatic plotting mechanism is stopped and the pulse height analyser switched to "Man". Then – using the dial "Basis" – the pen of the recorder is moved till it coincides with the lowest point just in front of the photo-peak in the high energy range. The width of the energy window is then changed from 500 mV to "Integral". From this moment on the output of the pulse height analyser to the 4 decade counter consists only of pulses with energies greater than the threshold energy E_{thres} (see Fig. 3). The pulse height analyser in connection with the

Fig. 3: Gamma-spectrum of Cs^{137}.



geometrical arrangement (diaphragm) now acts as a kind of monochromator, e.g. only those γ-quanta which reach the scintillation counter without loss of energy executing a photo effect within the counter will be recorded.

When working with Na^{22} as the emitter, care must be taken in selecting the threshold energy for the 1275 KeV line as there is a second spectral line at 511 KeV.

Using the supply voltages as shown in Tab. 1 leads to the correct threshold energies when the dial "Basis" was set as follows:

γ-source	position of dial "Basis"
Na^{22}	8.4
Cs^{137}	6.0
Am^{241}	3.0

Tab. 2

After the threshold energy has been determined and fixed for a particular emitter, scintillation counter and emitter are arranged as shown in Fig. 1.

Using the stop watch the "monochromatic" intensities are measured as a function of the absorber thickness for time intervals between 2 and 6 minutes.

The one-minute intensities, corrected for background radiation, are shown in Tab. 3. Fig. 4 is a graphical representation of the same results.

d[mm]	Na^{22} [mm^{-1}]	Cs^{137} [min^{-1}]	Am^{241} [min^{-1}]
0	279	3745	7089
5	272	3343	4823
10	244	3073	3567
15	221	2748	2549
20	224	2531	1759
25	198	2340	1178
30	193	2116	900

Tab. 3

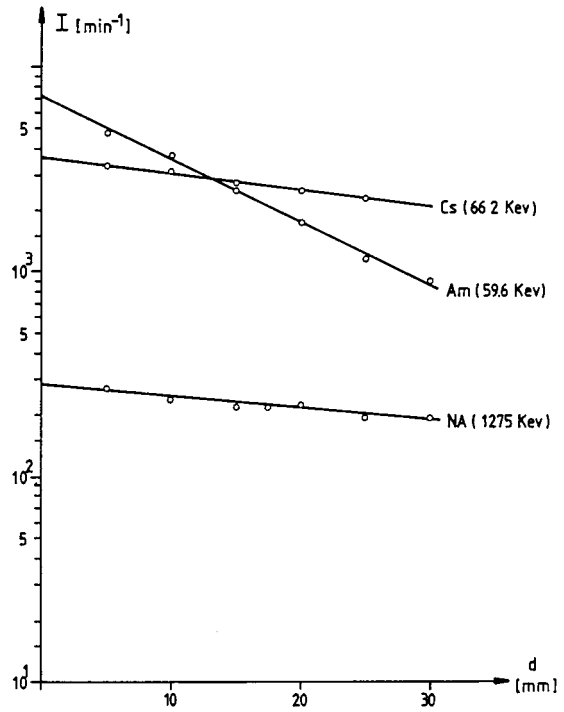
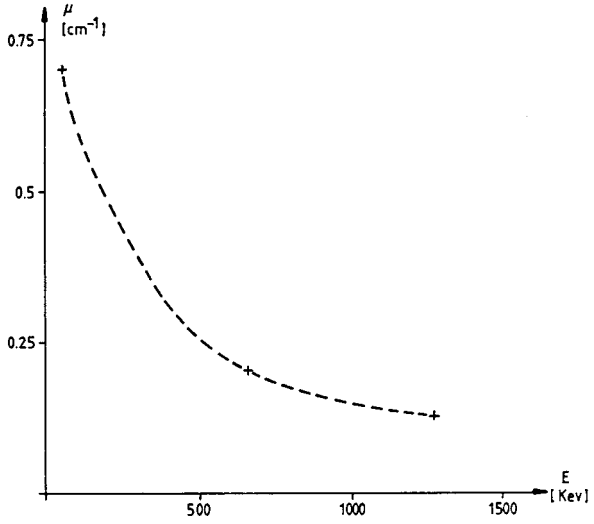


Fig. 4: Gamma-intensity as a function of absorber thickness with the gamma energy as parameter.

Fig. 5: Total gamma-absorption coefficient as a function of the energy.



From the slope of the straight lines, we find for the total absorption coefficient the values shown in the following table:

γ-source	energy of spectral line	total absorption coefficient	
	[keV]	μ [cm^{-1}]	$\mu_{Literature}$ [cm^{-1}]
Na^{22}	1275	0.126	0.15
Cs^{137}	662	0.196	0.20
Am^{241}	59.6	0.699	0.68

Tab. 3

In Fig. 5 the results of Tab. 4 have been illustrared.