Gamma ray absorption

The radioactive decay is the process in which unstable atomic nuclei transform into the stable one by emitting particles and electromagnetic radiation. The stability of nucleus is determined by the binding energy per nucleon. The nucleus is stable if the binding energy per nucleus is about 8 MeV. Such nuclei mainly have the mass number smaller then 208. The nuclei with bigger mass number have the binding energy smaller then 8 MeV, and they are considered unstable. Nuclei are being stabilized by nuclear transformations emitting α and/or β particles and γ electromagnetic radiation.

Particle emission

α particle is very stable formation of two protons and two neutrons (helium nuclei), therefore two times positively charged

β^- particle is electron released from nuclei after neutron to proton transformation

$$^1_0n \rightarrow ^1_1p + \beta^-$$

β^+ particle is positron, carrier of positive unit charge, and is released from nuclei after proton to neutron transformation

$$^1_1p \rightarrow ^1_0n + \beta^+$$

The number of protons is changed by particle emission, and as result a new nucleus is formed. The formed nucleus is very often stabilized by emission of γ electromagnetic radiation. Radioactive radiation can be detected by interaction with electrons in atoms and molecules of materials through which radiation passes. In fact, the part of energy of radiation is transferred to electrons in matter and causes the change of their energetic state. That is the reason why the intensity of radioactive radiation decreases when passing through the matter. The radiation intensity is the amount of radioactive radiation energy that in one second passes through the area of one square metre.

The decrease in intensity of γ radiation when passing thought the matter is described by exponential law

$$I = I_0 e^{-(\mu/\rho)d} , \qquad \textbf{(1)}$$

where I is intensity of radiation which passed thorough the absorber of thickness d and mass coefficient of absorption μ/ρ (μ is linear coefficient of absorption, a ρ is density of absorber). The unit of mass coefficient of absorption is (g^{-1}cm^2). The thickness d is product of linear thickness (cm) and the density of absorber (g cm^{-3}) and is expressed in g cm^{-2}. I_0 is the intensity of radiation which passed through the absorber of thickness 0 g cm^{-2}, i.e. the intensity of radiation which entered the absorber.

The half-thickness of absorber $d_{1/2}$ is useful unit to determine the energy of γ quantum. That unit is defined as the thickness of absorber for which the intensity of output radiation is two times smaller then the intensity of input radiation. Therefore,

$$I = I_0 / 2 = I_0 e^{-(\mu/\rho)d_{1/2}} ,$$

$$d_{1/2} = \frac{\ln 2}{\mu/\rho} \qquad \textbf{(2)}$$

The half-thickness of matter depends on the energy of γ quantum (Figure 1).

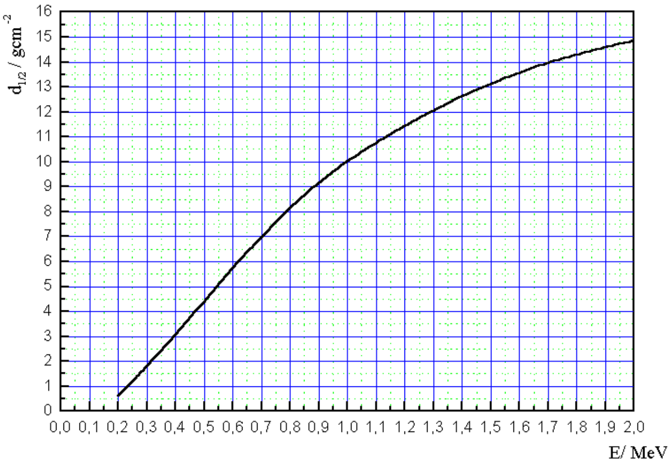

Figure 1

That information is needed to determine the energy of γ quantum which is released by the observed radioactive nucleus.

Exercise 1.

Determine the energy of γ quantum emitted from the radioactive source, by measuring the absorption in lead

Equation (1) can be written in form

$$N = N_0 e^{-(\mu/\rho)d}, \qquad \textbf{(3)}$$

where N_0 is the number of γ photons of defined energy which have entered the absorber in one second and N is the number of photons which have exited the from absorber in one second.

Dependence of transmitted photons on thickness of the absorber for the specific γ source is shown in the Figure 2.

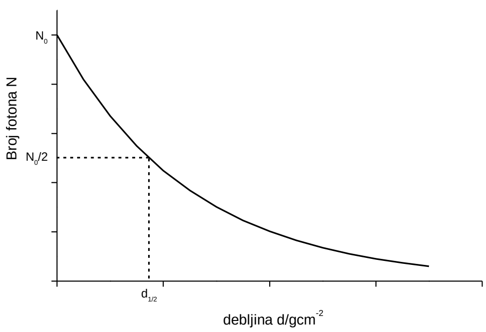

Figure 2

The half-thickness of absorber can be determined from that function by reading out the value of X-axis for which Y-axis is $N_0/2$.

When the exponential function is drawn in semi-logarithmic proportion, the graph is a straight line (Figure 3).

$$\log N = \log N_0 - \mu/\rho \cdot \log e \cdot d \ , \qquad \textbf{(4)}$$

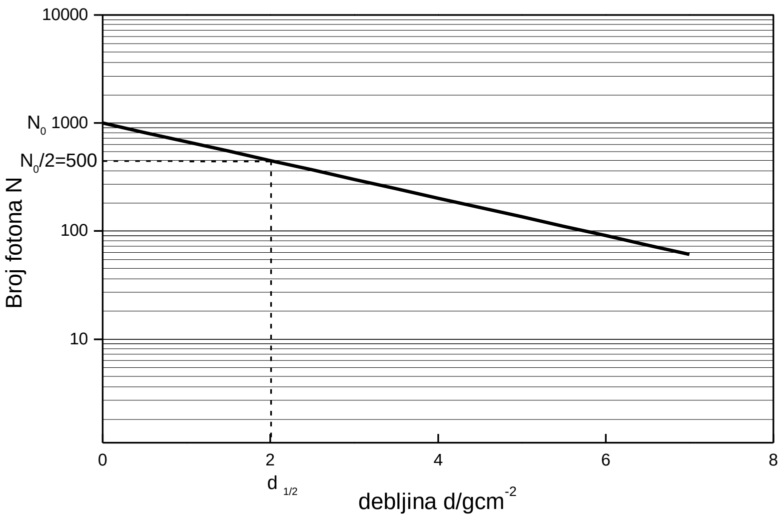

Figure 3

Such a display is more convenient because the function (3) is determined by fewer points and hence the half-thickness too.

The determination of half-thickness of absorber from Figure 3 enables determination of the energy of emitted γ quantum from Figure 1.

Device description

The main parts of device for measuring absorption of γ radiation are shown in the

Figure 4. These are the Geiger-Müller's (G-M) counter (1), the lead tower (2) with shelves for source (3) and the absorbers (4) and the electrical counter (5).

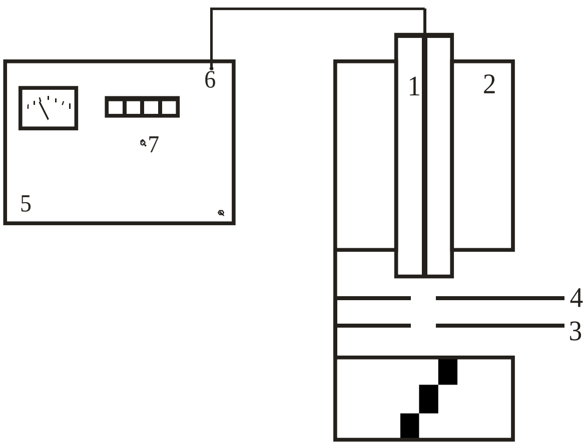

Figure 4

The G-M counter is evacuated glass cylinder with two concentric electrodes. One is cylindrical cathode and the other is the bar anode placed in the axis of cathode. The process of ionization of molecules of gas is applied to detect radioactive radiation with G-M counter. G-M counter is filled with mixture of the rare gases, and electrodes are connected to the high direct current voltage. The working voltage of G-M counter in this exercise is 375V. When γ radiation enters the G-M, the atoms and the molecules of gas are being ionidized, and therefore they travel to appropriate electrodes. The electric impulse is created which is registered on the electronic device. The impulse value does not depend on the type or the energy of radioactive radiation. On the electronic counter we read the number of beats (6) which is proportional to the number of quanta of γ radiation which have entered the G-M counter.

G-M counter is positioned in the lead tower to protect the counter from the background radiation and to precisely define the entrance area of radioactive radiation. The investigated source is placed on the bottom shelf (3), under the window of the counter. On the upper shelf the one of the absorbers is placed. It is important to say that the G-M counter counts particle and electromagnetic radiation, but does not make difference among them.

Measurement

Adjust the working voltage of counter to 375 V, and put counter to zero by pressing the button (7).

First measure the background radiation, which is always present in room. Measure it with closed tower shelves without source and without absorber in it. Ionization caused by background radiation measure for 10 minutes. Turn on the stop-watch and counter at the same time. Calculate background radiation in one minute.

Put the γ source in the bottom shelf of the tower, and in the upper shelf put one by one 5 lead absorbers. For every absorber measure the number of beats for five minutes. That number is proportional to the number of photons which have passed thorough the absorber. Write down the results in the in table. If the number of beats of background radiation is subtracted from the measured number of beats, you will get the beats generated only by γ photons radiation from source.

Draw in semi-logarithmic graph the dependence of number $(N-b)$ on the thickness of absorber. Graphically determine N_0 and half-thickness of lead according the Figure 3. Read from the graph (Figure 1) the energy of γ quantum of observed radioactive source.

Background radiation

In 10 min	In 1 min
B =	b =

Measurements of transmitted radiation

d / g cm^{-2}	N' in 5 min	N in 1 min	$N-b$
1,4			
2,2			
3,4			
4,3			
6,9			

$N_0 =$

$d_{1/2} =$ gcm^{-2}

$E = h\nu =$ MeV

Calculate the mass coefficient of absorption from equation (2).

$\mu/\rho =$ g^{-1}cm^{2}