Practical No 22

INTERACTION OF β RADIATION WITH MATTER

The aim

The aim of the practical is to determine the parameters characterizing a given absorbent for the β radiation, using a semiconductor G-M counter. These parameters are: linear attenuation coefficient (μ), mass attenuation coefficient (μ_m), half-value layer ($d_{\frac{1}{2}}$) and range (Z) of β radiation in a given absorbent. After having determined the values of the above parameters, using empirical formulas it is possible to estimate the value of the maximum energy of electrons emitted by the uranium glass.

Equipment

semiconductor Geiger-Müller counter.

Uranium glass contains approximately 2% of the uranium isotope U-238. This isotope is a source of ionizing radiation containing mainly α and β corpuscular radiation accompanied by a negligible amount of electromagnetic γ radiation. Uranium isotope ${}^{238}_{92}U$ with half-life $T_{\frac{1}{2}} = 4.5 \cdot 10^9$years, as a result of one α transformation and two β transformations turns into the uranium isotope ${}^{234}_{92}U$ with half-life decay $T_{\frac{1}{2}} = 2.5 \cdot 10^5$ years. The intermediate products of the above-mentioned transformations are two isotopes with a relatively short half-life, approximately 24 days and 7 hours, respectively. Several successive radioactive of α and β decays result in the appearance of a stable lead isotope ${}^{206}_{82}Pb$. The process of successive radioactive decay described above is called the uranium-radium radioactive series.

The intensity of ionizing radiation emitted by uranium glass is comparable to the intensity of ionizing radiation emitted by granite.

Due to the fact that the α radiation range in the air is less than 3 cm, it can be assumed that in the used Geiger-Müller (G-M) counter, apart from the background radiation, will practically register only the β radiation, i.e. electrons.

SOURCES OF IONIZING RADIATION WILL BE PROVIDED BY THE TUTOR

I. Measurements of the background radiation and the source radiation

Procedure:

1. Turn on the G-M counter and wait about 1 minute. Background radiation measurement should be carried out in the absence of radiation sources in the vicinity of the G-M counter.

2. The number of recorded counts will be displayed on the G-M meter monitor and it is given in CPM (Counts Per Minute) units.
   a. within 60 seconds, every 15 seconds, read the number of counts displayed on the G-M counter monitor and write it into the **Table 1**.
   b. calculate the average value (N_b) of recorded background radiation pulses.

Is is clear that the measured N value is the sum of the number of pulses of background radiation and radiation emitted by the source. This fact should be taken into accounr while calculating the results.

II. Comparison of radiation values emitted by glass uranium glass and by granite

Procedure:

1. Place the source of ionizing radiation, provided by the tutor (uranium glass), at a distance of 10 cm from the G-M meter and wait for 1 minute Within 60 seconds, every 15 seconds, read a number of counts measured by the G-M counter. Calculate the average value (N) of the counts, analogously to the background radiation. and write it down into **Table 2**.
2. Remove the uranium glass and place a piece of granite at the same distance from the counter. Carry out the measurements in the same way as for uranium glass.

III. Measurements using absorbents

Procedure:

1. Place the ionizing radiation source (uranium glass) at a distance of 13 cm from the G-M counter.
2. Attach ONE sheet of paper to the holder and place it between the radiation source and the G-M counter (as close to the G-M counter as possible).
3. Wait 1 minute and then, within 60 seconds, every 15 seconds, read and write the G-M counter counts into **table 3**. Then, successively increase the number of paper sheets mounted in the holder to: 3, 5, 7, 9 and 11. After each addition place the sheets in front of the G-M counter, WAIT 1 minute before reading the counts by the G-M counter. Calculate the mean value of the number (N_P) of recorded pulses for each number of absorbent paper sheets
4. Repeat the measurements with organic glass (Plexiglas) plates and write down the data in **table 5**.

Data for absorbents needed for the calculation		
Name of absorbent	density (ϱ) of absorbent $\left(\frac{kg}{m^3}\right)$	Thickness of absorbent (m)
Paper	0.852×10^3	0.10×10^{-3}
Plexiglas	1.180×10^3	0.75×10^{-3}

IV. Processing of the obtained data

1. To determine the linear attenuation coefficient, the following formula should be used:

$$\boldsymbol{N = N_0 e^{-\mu d}}$$

where N is the number of pulses after the radiation has passed through the given absorbent, N_0 is the number of pulses without the absorbent, d is the thickness of the absorbent.

The above formula should be converted to a useful form that represents a linear function with a slope μ:

$$\boldsymbol{lnN_x(d) = lnN_0 - \mu d}$$

where N_0 is the number of registered electrons from the ionizing radiation source in the absence of an absorbent and $N_x(d)$ is the number of registered electrons after having passed through a given absorbent x with thickness d. You have to keep in mind that the actual N value representing radiation emitted by the source should be reduced by background radiation (N_b).

2. In order to determine the value of the slope of the above function, the absolute value of which is the value of the linear attenuation coefficient μ, draw a graph (line of the best fit) from the data in **Table 5**, for paper, and from the data in **Table 6**, for Plexiglas. The scale of the ordinate (vertical axis) should start with a value less than lnN_t. To determine the value of the slope, a trigonometric reduction formula should be used: $tg(90^o + \alpha) = -ctg\alpha$.
3. After having determined the value of the linear attenuation coefficient, calculate the value of the mass attenuation coefficient for a given absorbent using the following formula:

$$\boldsymbol{\mu_m = \frac{\mu}{\varrho}},$$

where ϱ is the density of a given absorbent.

4. Calculate the half-value layer for the tested absorbents, using the formula:

$$\boldsymbol{d_{\frac{1}{2}} = \frac{ln2}{\mu}}$$

5. Calculate the range value (Z) of electrons in the tested absorbents. For this purpose, find the zero of the function *lnNx=f(d)*, using the graphs prepared earlier (point 2). The value of absorbent thickness d at that point is the value of the range of electrons in a given absorbent.

6. The maximum energy of electrons can be calculated on the basis of empirical formulas:

$$E_{max}[MeV] = 1{,}92 \cdot (Z_d)^{0.725} \quad for \quad 0.02\ \frac{g}{cm^2} < \boldsymbol{Z_d} < 0.4\ \frac{g}{cm^2}$$

$$E_{max}[MeV] = 1{,}75 \cdot Z_d + 0.281 \quad for \quad \boldsymbol{Z_d} > 0.4\ \frac{g}{cm^2},$$

where $Z_d = Z \cdot \varrho$ is the maximum range of electrons expressed in units of $\frac{g}{cm^2}$. During calculation of Z_d, express the range Z in [cm] and multiply it by the absorbent density expressed in $\frac{g}{cm^3}$.

The calculated values of the parameters for β radiation should be written in Table 7.

<u>Theoretical knowledge required</u>

1. Radioactive series
2. Radioactive decays α, β^-, β^+
3. The principle of working the G-M counter

   a. gaseous
   b. semiconductor
4. Describe the law of absorption of ionizing radiation
5. The ability to transform the equation of attenuation of ionizing radiation to the form of a linear function
6. Interpretation of the linear and mass attenuation coefficient
7. The ability to derive the formula for the half-value thickness from the equation of attenuation ionizing radiation
8. Definition of the half-value thickness
9. Method of determining the range of electrons in an absorbent
10. Interaction of ionizing radiation with matter: Compton effect, photoelectric effect, creation of pairs: positron-electron.

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Department of
Biophysics and Neuroscience</td><td colspan="2">Practical No 22

Interaction of β radiation with matter.</td></tr>
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I.

Tabela 1

seconds	**Number of registered counts for background radiation (CPM)**
0	
15	
30	
45	
60	
Average value N_b	

II.

Table 2

Seconds	Number of registered counts (CPM)	
	Uranium glass	**Granite**
0		
15		
30		
45		
60		
Average value N		
$N - N_b$		

III.

Table 3

Seconds	Number N_P registered of electrons (CPM). PAPER absorbent					
	1 sheet	**3 sheets**	**5 sheets**	**7 sheets**	**9 sheets**	**11 sheets**
0						
15						
30						
45						
60						
Average value of N_P						
N_P-N_b						

Table 4

Seconds	Number N_{Px} registered of electrons (CPM). PLEXIGLAS absorbent				
	1 plate	**2 plates**	**3 plates**	**4 plates**	**5 plates**
0					
15					
30					
45					
60					
Average value N_{Px} registered of electrons					
N_{PX} - N_b					

IV.

Table 5

Number of sheets	$N_P - N_b$	$ln(N_P-N_b)$	Thickness of PAPER absorbent **d (m)**
1			
3			
5			
7			
9			
11			

Tabela 7

Number of plates	$N_{PX} - N_b$	$ln(N_{PX}-N_b)$	Thickness of PLEXIGLAS absorbent **d (m)**
1			
2			
3			
4			
5			

Table 7

Name of absorbent	$\mu\ \left(\frac{1}{m}\right)$	$\mu_m\ \left(\frac{m^2}{kg}\right)$	$d_{\frac{1}{2}}$ **(m)**	**Z (m)**	$Z_d\ \left(\frac{g}{cm^2}\right)$	E_{max} **(MeV)**
Paper						
Plexiglas						

1. Determine and write down which investigated source of ionizing radiation, from the same distance from the G-M counter, shows higher intensity of transmitted ionizing radiation, uranium glass or granite:

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2. By analyzing the calculated value of appropriate parameters, determine and justify which one of the absorbents can better protect against β radiation:

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