Law of distance and absorption of Gamma or Beta rays (Item No.: P2524101)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
ILIAS	Physik	Hochschule	Moderne Physik	Kernphysik - Radioaktivität

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	1 Hour	2 Hours	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Radioactive radiation, beta-decay, conservation of parity, antineutrino, gamma quanta, half-value thickness, absorption coefficient, term diagram, pair formation, Compton effect, photoelectric effect, conservation of angular momentum, forbidden transition, weak interaction, dead time

Overview

Short desciption

Principle

The inverse square law of distance is demonstrated with the gamma radiation from a $^{60}\mathrm{Co}$ preparation, the half-value thickness and absorption coefficient of various materials determined with the narrow beam system and the corresponding mass attenuation coefficient calculated.

Fig. 1: Experimental set-up for measuring the half-value thickness of different materials.

Equipment

Position No.	Material	Order No.	Quantity
1	Radioactive sources, set	09047-50	1
2	Geiger-Müller-Counter	13606-99	1
3	Geiger-Mueller counter tube, 15 mm (type B)	09005-00	1
4	Absorption material, lead	09029-01	1
5	Absorption plates for beta rays	09024-00	1
6	Absorption material, aluminium	09029-03	1
7	Absorption material, concrete	09029-05	1
8	Plate holder on fix. magnet	09204-00	1
9	Base plate for radioactivity	09200-00	1
10	Absorption material, iron	09029-02	1
11	Vernier calliper stainless steel 0-160 mm, 1/20	03010-00	1
12	Counter tube holder on fixating magnet	09201-00	1
13	Source holder on fixing magnet	09202-00	1

Tasks

1. To measure the impulse counting rate as a function of the distance between the source and the counter tube.
2. To determine the half-value thickness $\mathrm{d}_{1/2}$ and the absorption coefficient μ of a number of materials by measuring the impulse counting rate as a function of the thickness of the irradiated material. Lead, iron, aluminium, concrete and Plexiglas are used as absorbers.
3. To calculate the mass attenuation coefficient from the measured values.

Set-up

According to Fig. 1.
The distance between the front edge of the source rod and the counting tube window is approximately 4 cm; consequently, the absorption plates can be easily inserted into the radiation path.

Theory and evaluation

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The cobalt isotope ${}^{60}_{27}\mathrm{Co}$ has a half-life of 5.26 years; it undergoes beta-decay to yield the stable nickel isotope ${}^{60}_{28}\mathrm{Ni}$– see Fig. 2.

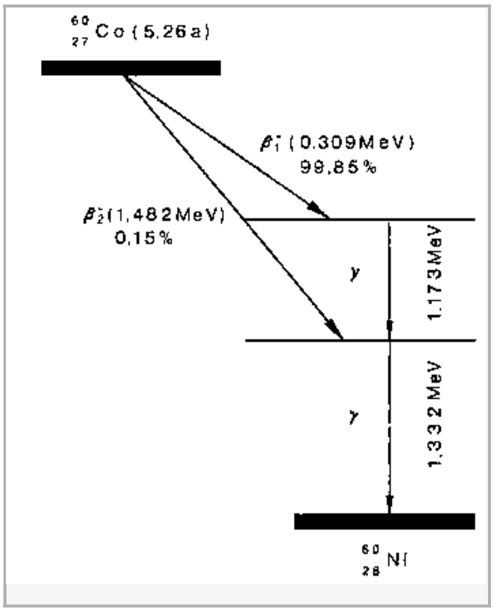

Fig. 2: Term diagram of ${}^{60}_{27}\mathrm{Co}$

As with most beta emitters, disintegration leads at first to daughter nuclei in an excited state, which change to the ground state with the emission of gamma quanta. Whereas the energy levels of the beta electrons can assume any value up to the maximum because of the antineutrinos involved, the gamma quanta which participate in the same transition process have uniform energy, with the result that the gamma spectrum consists of two discrete, sharp lines (Fig. 2).

The impulse counting rate $N^{(r)}$ per area A around a pointsource decreases in inverse proportion to the square of the distance provided the gamma quanta can spread out in straight lines and are not deflected from their track by interactions.

$r_2 = 2 \cdot r_1$ $\qquad A_2 = 4 \cdot A_1 = \left[\frac{r_2}{r_1}\right]^2$

The reason for this is that, as shown by Fig. 3, the area of a sphere round the source through with a beam of rays passes, increases as the square of the distance r. In vacuum (in air), therefore

$$\frac{N^{(r)}}{A} = \frac{N^{(0)}}{A} \cdot \frac{1}{4\pi} r^{-2}$$

If we plot the counting rate $N^{(r)}$ versus the distance r on a loglog scale, we obtain a straight line of slope –2.

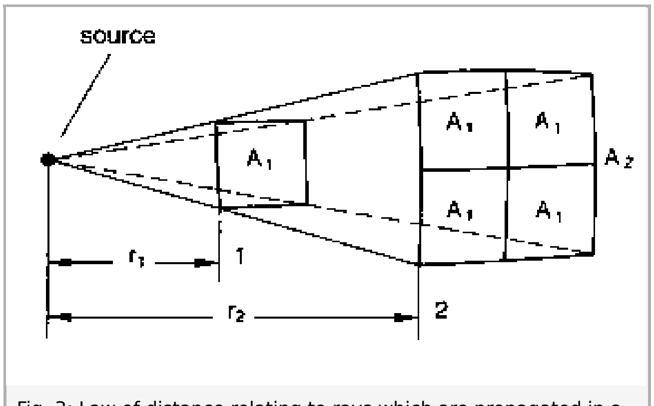

Fig. 3: Law of distance relating to rays which are propagated in a straight line from a point source.

From the regression lines from the measured values in Fig. 4, applying the exponential expression

$$N_{(r)} = a \cdot r^b$$

we obtain the value

$b = -2.07 \pm 0.01$

for the exponent.

This thus proves the applicability of the inverse square law.

The attenuation of the gamma rays when they pass through an absorber of thickness d is expressed by the exponential law

$N_{(d)} = N_{(0)} \cdot e^{-\mu d}$

where $N(d)$ is the impulse counting rate after absorption in the absorber, and $N(0)$ is the impulse counting rate when no absorption takes place: μ is the absorption coefficient of the absorber material and depends on the energy of the gamma quantum.

The absorption of the gamma rays is brought about by three independent effects – the Compton effect, the photelectric effect and pairformation.
The relative contributions of these three effects to total absorption depends primarily on the energy of the quanta and on the atomic number of the absorber (Fig. 5).

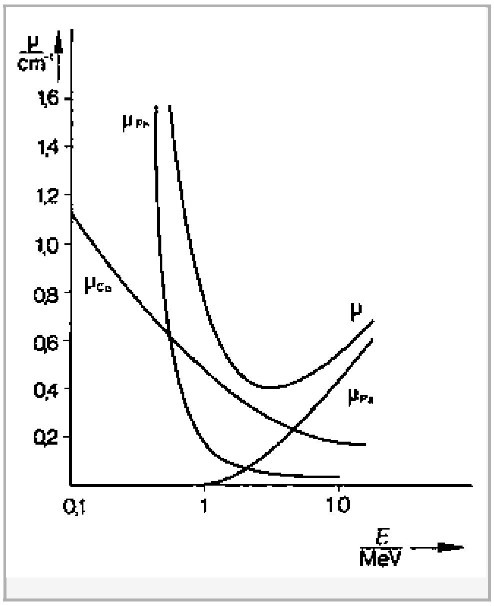

Fig. 5: Absorption of gamma rays by leads as a function of the energy ($\mu_{\mathrm{Co}} =$ fraction due to Compton effect, $\mu_{\mathrm{Ph}} =$ fraction due to photoelectric effect, $\mu_{\mathrm{Pa}} =$ fraction due to pair formation). The total absorption coefficient (attenuation coefficient) is
$\mu = \mu_{\mathrm{Co}} + \mu_{\mathrm{Ph}} + \mu_{\mathrm{Pa}}$

We can see from the $\frac{\mu}{E}$ curves in Fig. 6 that lead is particularly suitable as an absorber of gamma rays of low or high energy.
The attenuation of gamma rays therefore takes place predominantly in the electron shell of the absorber atoms. The absorption coefficient μ should therefore be proportional to the number of electrons in the shell per unit volume, or approximately proportional to the density ρ of the material.
The mass attenuation coefficient $\frac{\mu}{\rho}$ is therefore roughly the same for the different materials.

The half-value thickness $d_{1/2}$ of a material is defined as the thickness at which the impulse counting rate is reduced by half, and can be calculated from the absorption coefficient in accordance with

$d_{1/2} = \frac{\ln 2}{\mu}$

From the regression lines from the measured values in Fig. 6 we obtain the following values for $\frac{\mu}{\rho}$ and for $d_{1/2}$ and μ/ρ , with the relevant standard errors, using the exponential expression

$N = ae^{bd}$

Lead: $(\rho = 11.34\, gcm^{-3})$

$$\mu = 0.62\, cm^{-1} \qquad s_{\mu} = 0.009\, cm^{-1}$$

$$d_{1/2} = 1.12\, cm^{-1} \qquad s_{d_{1/2}} = 0.02\, cm$$

$$\frac{\mu}{\rho} = 0.055\, cm^2 g^{-1} \qquad s_{\frac{\mu}{\rho}} = 0.001\, cm^2 g^{-1}$$

Aluminium: $(\rho = 2.96\, gcm^{-3})$

$\mu = 0.15\, cm^{-1}$ $\quad s_{\mu} = 0.01\, cm^{-1}$

$d_{1/2} = 4.6\, cm^{-1}$ $\quad s_{d_{1/2}} = 0.3\, cm$

$\frac{\mu}{\rho} = 0.056\, cm^2 g^{-1}$ $\quad s_{\frac{\mu}{\rho}} = 0.004\, cm^2 g^{-1}$

Iron: $(\rho = 7.86\, gcm^{-3})$

$\mu = 0.394\, cm^{-1}$ $\quad s_{\mu} = 0.006\, cm^{-1}$

$d_{1/2} = 1.76\, cm^{-1}$ $\quad s_{d_{1/2}} = 0.03\, cm$

$\frac{\mu}{\rho} = 0.050\, cm^2 g^{-1}$ $\quad s_{\frac{\mu}{\rho}} = 0.001\, cm^2 g^{-1}$

Concrete: $(\rho = 2.35\, gcm^{-3})$

$\mu = 0.124\, cm^{-1}$ $\quad s_{\mu} = 0.009\, cm^{-1}$

$d_{1/2} = 5.6\, cm^{-1}$ $\quad s_{d_{1/2}} = 0.4\, cm$

$\frac{\mu}{\rho} = 0.053\, cm^2 g^{-1}$ $\quad s_{\frac{\mu}{\rho}} = 0.004\, cm^2 g^{-1}$

Plexiglas: $(\rho = 1.119\, gcm^{-3})$

$\mu = 0.078\, cm^{-1}$ $\quad s_{\mu} = 0.004\, cm^{-1}$

$d_{1/2} = 8.9\, cm^{-1}$ $\quad s_{d_{1/2}} = 0.5\, cm$

$\frac{\mu}{\rho} = 0.066\, cm^2 g^{-1}$ $\quad s_{\frac{\mu}{\rho}} = 0.003\, cm^2 g^{-1}$

Comment

The procedure and evaluation are shown here in an exemplary experiment for γ-quanta; however, they can also be performed in an analogous manner for electrons. In the latter case, the Sr-90 source rod from the radioactive sources set (09047.50) and the absorption plate set for β-radiation (09024.00) must be used.

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