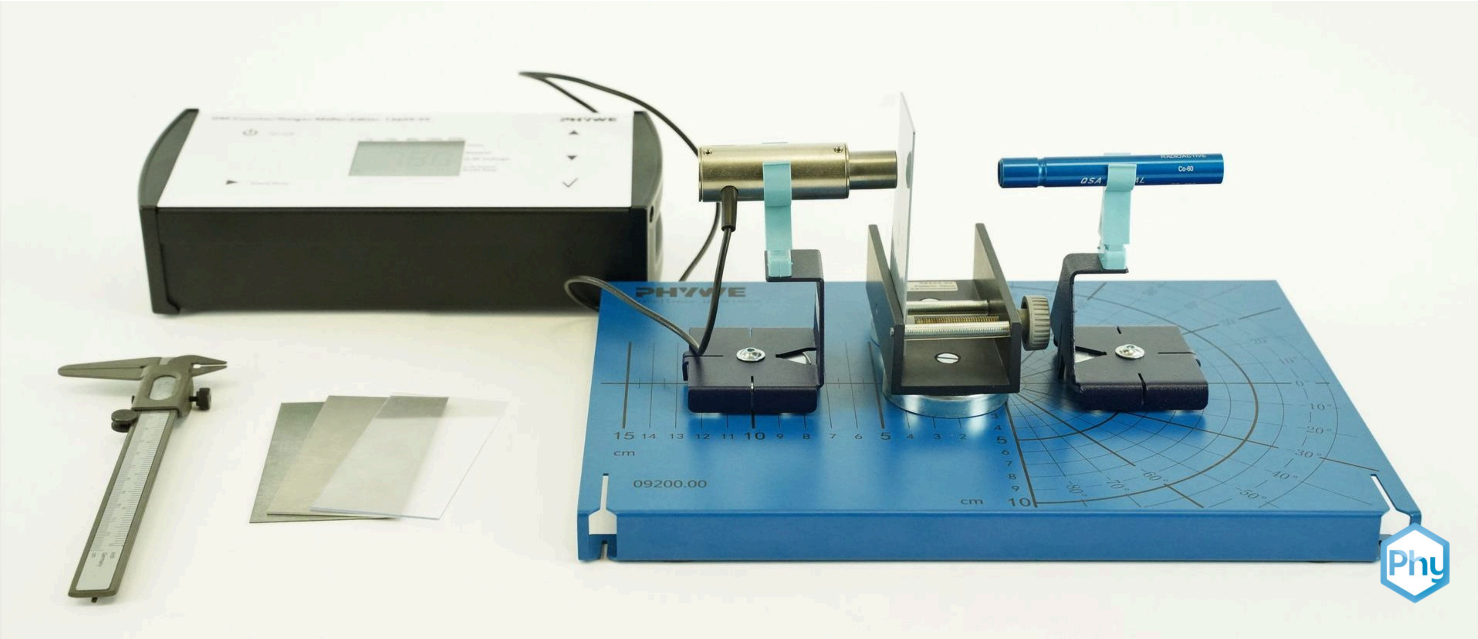
Distance law and absorbtion of Gamma- and Betaradiation with Cobra SMARTsense



Physics | Modern Physics | Radioactivity

Difficulty level	Group size	Preparation time	Execution time
-	-	-	-

This content can also be found online at:

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General information

Application

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Nuclear lab

The Distance Law states that radiation intensity decreases as you move farther away from the source. Absorption refers to the reduction of gamma and beta radiation as it passes through materials. These concepts are crucial for radiation safety and determining appropriate shielding and barriers to protect against radiation exposure.

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Other information (1/2)

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Prior knowledge

Absorption of gamma rays depends upon the density of the material that the gamma rays are travelling through. Gamma rays deposit their energy inside a material in many ways: photoelectric effect, pair production, and Compton effect.

Scientific principle

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

Other information (2/2)

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Learning objective

Understanding the influences of the material density and the distance on the absorption of gamma rays.

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 $d_{1/2}$ 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.

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Safety instructions

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

For H- and P-phrases please consult the safety data sheet of the respective chemical.

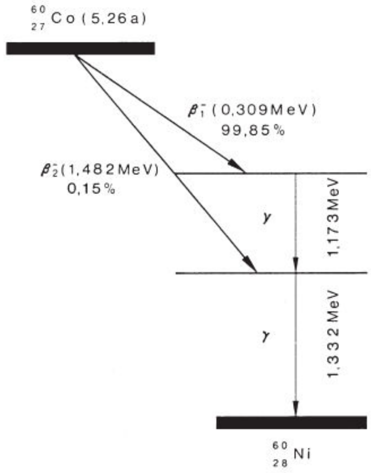
Radioactive substances can be hazardous to your health! Always reduce the time spent handling radioactive substances to a minimum. The source should only be removed from the storage container for the duration of the experiment

Since even small distance changes in this experiment lead to considerable changes in counting rates, care should be taken that the counter tube, radiation source and plate holder are not moved when changing the backscatter plates.

Theory (1/6)

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

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.



Term diagram of $^{60}_{27}Co$

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Theory (2/6)

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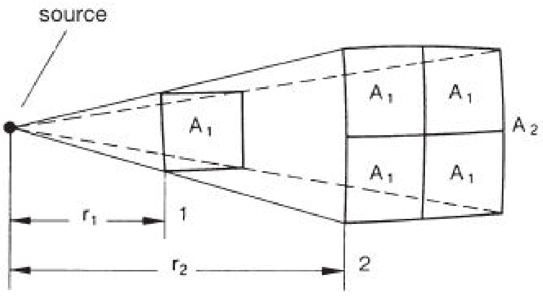
The impulse counting rate N(r) per area A around a pointsource decreases in inverse proportion to the square of the distance provided the gamma quanta can spread out in straight lines and are not deflected from their track by interactions.

$$r_2 = 2 \cdot r_1$$

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

The reason for this is that the area of a sphere round the source through with a beam of rays passes, increases as the square of the distance *r*.



Law of distance relating to rays

Theory (3/6)

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In vacuum (in air), therefore

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

If we plot the counting rate $N^{(r)}$ versus the distance *r* on a log scale, we obtain a straight line of slope –2. From the regression lines from the measured values, 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.

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Theory (4/6)

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.

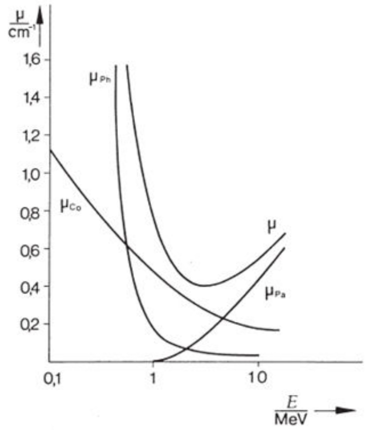
The absorption of the gamma rays is brought about by three independent effects – the Compton effect, the photelectric effect and pairformation.

Theory (5/6)

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.

Absorption of gamma rays by leads as a function of the energy (μ_{Co} = fraction due to Compton effect, μ_{Ph} = fraction due to photoelectric effect, μ_{Pa} = fraction due to pair formation).

The total absorption coefficient (attenuation coefficient) is $\mu = \mu_{Co} + \mu_{Ph} + \mu_{Pa}$)



Absorption of gamma rays by leads as a function of the energy

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Theory (6/6)

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, the following values for (\frac{\mu}{\rho} \,\) and for $d_{1/2}$, with the relevant standard errors, using the exponential expression

$$N = a\,e^{bd}$$

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Equipment

Position	Material	Item No.	Quantity
1	Cobra SMARTsense- Radioactivity (Bluetooth + USB)	12937-01	1
2	Vernier calliper stainless steel 0-160 mm, 1/20	03010-00	1
3	Absorption plates for beta rays	09024-00	1
4	Base plate for radioactivity	09200-00	1
5	Counter tube holder on fixating magnet	09201-00	1
6	Source holder on fixing magnet	09202-00	1
7	Plate holder on fix. magnet	09204-00	1
8	Absorption material, lead	09029-01	1
9	Absorption material, iron	09029-02	1
10	Absorption material, aluminium	09029-03	1
11	Absorption material, concrete	09029-05	1
12	Radioactive sources, set	09047-40	1

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Setup and procedure

Setup (1/2)

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To measure with the Cobra SMARTsense sensors, the PHYWE measureAPP is required. The app can be downloaded free of charge from the respective app store (QR codes below). Please check that Bluetooth is enabled on your device (smartphone, tablet, desktop PC) before starting the app.

Android	iOS	Windows

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Setup (2/2)

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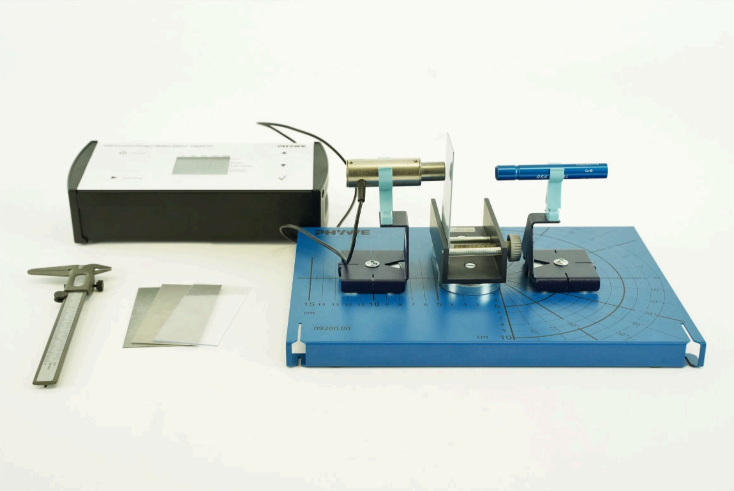

Experimental set-up

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.

Procedure

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Measure the thickness of all absorption materials with vernier callipers.

Start the counter, measure and record the number of counts for each absorption material.

Repeat the whole experiment twice for each of material.

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Evaluation (1/5)

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

$\mu = 0.62\, cm^{-1}$ $d_{1/2} = 1.12\, cm^{-1}$

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

$s_\mu = 0.009\, cm^{-1}$ $s_{d_{1/2}} = 0.02\, cm$

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

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

$\mu = 0.15\, cm^{-1}$ $d_{1/2} = 4.6\, cm^{-1}$

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

$s_\mu = 0.01\, cm^{-1}$ $s_{d_{1/2}} = 0.03\, cm$

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

Evaluation (2/5)

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

$\mu = 0.394\, cm^{-1}$ $d_{1/2} = 1.76\, cm^{-1}$

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

$s_\mu = 0.006\, cm^{-1}$ $s_{d_{1/2}} = 0.03\, cm$

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

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

$\mu = 0.124\, cm^{-1}$ $d_{1/2} = 5.6\, cm^{-1}$

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

$s_\mu = 0.009\, cm^{-1}$ $s_{d_{1/2}} = 0.04\, cm$

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

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Evaluation (3/5)

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

$\mu = 0.078\, cm^{-1}$ $\quad d_{1/2} = 8.9\, cm^{-1}$

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

$s_\mu = 0.004\, cm^{-1}$ $\quad s_{d_{1/2}} = 0.05\, cm$

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

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.

Evaluation (4/5)

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Fill in the missing words

The intensity of radiation passing through any unit area (directly facing the point source) is ______ proportional to the ______ of the distance from the point source.

Check

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Evaluation (5/5)

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The absorption of radioactive rays in matter is dependant on:

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

Check

Interaction of gamma rays with matter is ruled by:

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

Check

Slide	Score / Total
Slide 20: Question 1	**0/2**
Slide 21: Multiple tasks	**0/7**

Total Score 0 / 9

Show solutions   Retry

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