Experiment 14

MEASUREMENT OF THE ABSORPTION COEFFICIENT FOR γ-RAYS

The absorption law for γ-rays passing through a solid is studied. The absorption coefficients for lead and aluminium are measured.

INTRODUCTION

1. The intensity of a beam of γ-rays decreases as the beam penetrates a solid due to its absorption. The intensity of the beam is the number of quanta crossing a unit area per sec. If the incident beam intensity is I_0, it is attenuated after penetrating a thickness x and becomes equal to I(x) (figure 14.1).

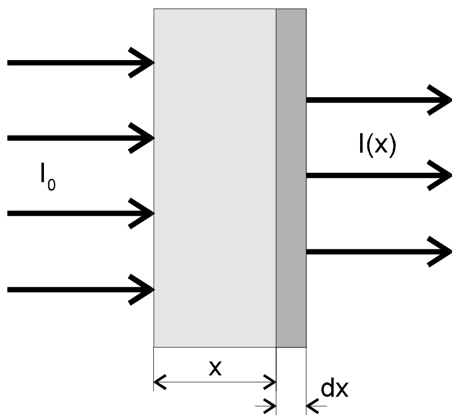

Fig. 14.1. Absorption of a beam of γ-rays having an incident intensity of I_0. I(x) is the attenuated intensity of the beam after penetrating a solid of thickness x

The number of atoms in the layer of thickness dx at x in the solid is equal to n S dx, where S is the area of the solid perpendicular to the beam and n is the density of atoms in the solid. Each atom in the solid represents an area σ_a for an incident quantum to be absorbed which is called the cross section. The probability of a quantum being removed from the beam by one atom is equal to

$\frac{\sigma_a}{S}$, the ratio of the atomic cross section to the area of the layer. The decrease of the intensity I(x) due to absorption along dx is then equal to

$$dI = -I(x)\frac{\sigma_a}{S}(n\,S\,dx) = -I(x)\sigma_a n\,dx \tag{14.1}$$

Integrating equation (14.1) over x leads to the result that

$$I(x) = I_0 e^{-\sigma_a n x} = I_0 e^{-\mu x} \tag{14.2}$$

where μ, the linear absorption coefficient is given by,

$$\mu = \sigma_a n \tag{14.3}$$

The intensity of the attenuated beam decreases exponentially with increasing thickness of the solid.

Attenuation of the γ-rays intensity is a result of different processes involving their interaction with matter. These processes are: γ-ray photoelectric effect, scattering of γ-rays and electron-positron pair production. In the photoelectric effect the incident quantum is absorbed by the atom leading to the ejection of an electron. An electron can be ejected from a given subshell of an atom if the energy of the quantum is greater then the binding energy of the electron. The process of pair production takes place when the energy of the quantum exceeds the rest mass energy of the electron and positron pair and is equal to $2m_ec^2 = 1.02$MeV. The excess energy $h\nu - 2m_ec^2$ appears as the kinetic energy of the particles. Pair production takes place in the Coulomb field of a nucleus because then the total momentum can be conserved. The above processes depend on the energy of the γ-rays which implies that the cross section σ_a is a function of their energy as also is the absorption coefficient μ.

2. To detect γ-rays and also α- and β-particles Geiger-Müller tubes are widely used. These contain a fine central wire A, an anode (figure 14.2) which is held at a high positive voltage with respect to a surrounding cylinder C, which is the cathode. Some tubes have a thin mica end window to allow the α- and β-particles to enter the tube. The tube is filled with gas, usually argon, under a pressure lower than atmospheric pressure. The α-, β- or γ-radiation produces ionization processes in the tube during which one or more electrons are liberated. These electrons are accelerated in the direction of the anode and produce secondary ionization of the gas atoms by collisions. This process repeats and an avalanche of electrons is created which can be detected as an

electrical pulse at the anode. These pulses may then be counted by an external counter.

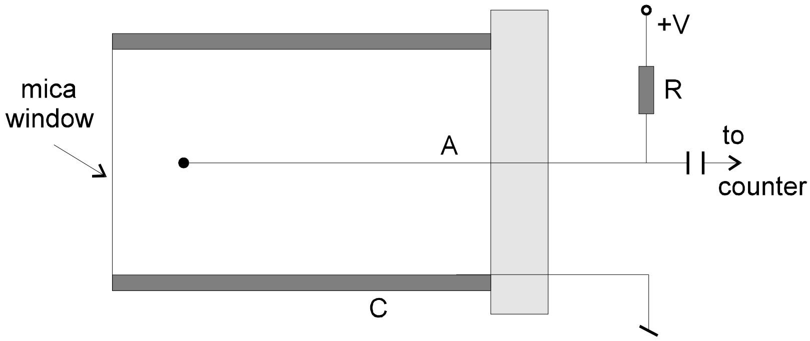

Fig. 14.2. Schematic diagram of a Geiger-Müller tube with a mica end window. A indicates an anode and C a cylindrical cathode of the tube

APPARATUS AND METHOD

The absorption of γ-rays is studied using the experimental arrangement shown in figure 14.3

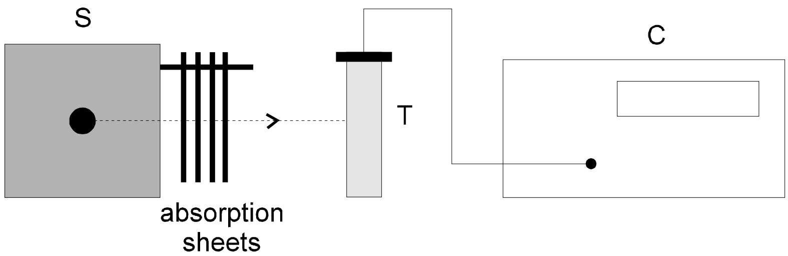

Fig. 14.3. Schematic diagram of the experimental setup used to measure the absorption coefficients for γ-rays. S is a radiation source, T is a Geiger-Müller tube and C is a pulse counter

The Geiger-Müller tube T which is connected to a counter C is placed close to a radiation source S. It records the intensity of the radiation by measuring the number of counts N_t in a given time Δt. In the experiment a series of measurements of the number of counts (for the same time Δt) is taken for an increasing number of metal (lead or aluminium) sheets being placed between the radiation source and the tube. Background counts, N_b, of the tube are also recorded with the radiation source well screened. These background counts are substracted from the data obtained for different values of the thickness of the absorbing metal.

From equation (14.2), for constant Δt, the number of true counts is

$$N = N_t - N_b = N_0 e^{-\mu x} \tag{14.4}$$

or, taking logarithms

$$\ln N = \ln N_0 - \mu x \tag{14.5}$$

A plot of N against x on a semi-logarithmic scale yields a straight line the gradient of which is equal to the absorption coefficient μ (figure 14.4). Using values of N_2, N_1, and x_2, x_1 read out from the plot for two points lying on the straight line μ can be calculated from

$$\mu = -\frac{\ln N_2 - \ln N_1}{x_2 - x_1} \tag{14.6}$$

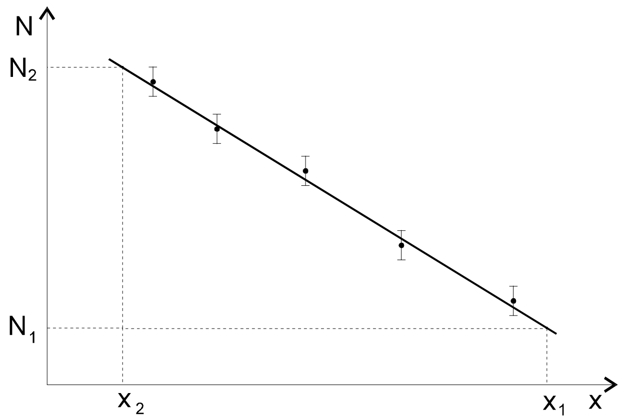

Fig. 14.4. A graph of the number of true counts N as a function of the thickness of the absorbing metal x. A logarithmic scale is used for N

μ can be also obtained using the least-squares fitting of equation (14.5) with a linear dependence between lnN and x. Here the absorption coefficient is given by

$$\mu = \frac{\left(\sum_{i=1}^{k} x_i\right)\left(\sum_{i=1}^{k} \ln N_i\right) - k\left(\sum_{i=1}^{k} x_i \ln N_i\right)}{k\left(\sum_{i=1}^{k} x_i^2\right) - \left(\sum_{i=1}^{k} x_i\right)^2} \tag{14.7}$$

where k is the number of measured points.

MEASUREMENTS

1. Find the absorption coefficient of the γ-rays for the materials provided. Calculate the coefficient using both methods, described by equations (14.6) and (14.7). Compare the results.

ANALYSIS OF ERRORS

The decay of the radioactive element is described by a Poisson distribution which gives the probability of observing N decays in a given time interval. The standard deviation of the mean value of N counts is equal to

$$\sigma_N = \sqrt{N} \tag{14.8}$$

These errors are to be calculated for each measured number of counts and indicated on the plot. The error in the absorption coefficient can be obtained from a plot of lnN against x using a graphical method.

For the value of μ obtained using the least-squares fitting procedure the standard deviation σ_μ is calculated from the expression

$$\sigma_\mu^2 = \frac{k}{k-2} \frac{\sum_{i=1}^{k} \left[\ln N_i - \left(\ln N_0 - \mu x_i \right) \right]^2}{k \left(\sum_{i=1}^{k} x_i^2 \right) - \left(\sum_{i=1}^{k} x_i \right)^2} \tag{14.9}$$

QUESTIONS

1. Describe the similarities and differences between the three types of radiation α-, β- and γ-rays.
2. The thickness of an absorbing material which reduces the incoming intensity of radiation by half is equal to $D_{1/2}$. Express $D_{1/2}$ in terms of the absorption coefficient μ.
3. What are the sources of the γ- and x-rays?
4. Compare the γ-ray photoelectric effect with the optical photoelectric effect (the effect for ultraviolet light).