

INTERACTION OF GAMMA RADIATION WITH MATTER

The purpose of this experiment is to measure the attenuation of gamma rays in matter. The technique is to measure the number of gamma rays per unit time passing through an absorber as a function of the absorber thickness. The attenuation will be shown to decrease exponentially as a function of the thickness of the material. The rate of attenuation will be characterized by an absorption coefficient. The technical problem is the separation of the gamma radiation from other kinds of radioactivity.

DISCUSSION

I. SOURCE OF GAMMA RAYS AND ISOLATION FROM OTHER RADIOACTIVITY

Nuclei which are unstable (or radioactive) have decay products which may include electrons and positrons, also called betas, gammas, and alpha particles. We have studied beta decay in experiment #6. Alphas are actually He nuclei and were significant in Rutherford's scattering experiments to determine the nuclear nature of atoms. Gamma rays originate in a nucleus which is excited to an energy level which is higher than its ordinary ground state. The excited nucleus will eventually decay to a lower level with the emission of a single photon which carries off exactly the energy difference between the two levels. Nuclei do not usually exist in excited states, but these states may come about from the decay of another nucleus. One such example is shown in Fig. 1. Cs^{137} decays with the emission of an electron (β^-) to an excited state of Ba^{137} 92% of the time with a half life of 27 years. The Ba^{137} decays down to the ground state with the emission of a gamma ray of energy 0.662 MeV with a half-life of 2.6 minutes (See Experiment #5). Every gamma ray, therefore is accompanied by the above electron. 8% of the time Cs^{137} decays directly to the ground state of Ba^{137} with the emission of a beta having $K_E = 1.18$ MeV.

In this experiment, we wish to study the gamma radiation resulting from the above decay and its ability to penetrate matter. However, there is a problem because our Geiger counter is not able to distinguish between the beta and gamma rays which are emitted when Cs^{137} decays. Because photons have no charge, we cannot use magnetic or electric fields to deflect them, as with the beta ray spectrometer. However, as we will see in Experiment #8, the range of charged particles in matter is very small compared to that of gamma rays. If we insert a 2 mm thick iron plate in the path of the radiation, we can stop even the 1.18 MeV electrons completely. On the other hand, as we shall see in the next section, we can expect that this will not reduce the

energy of the photons at all, and will reduce the number of photons in the beam only slightly. Therefore, after passing the radiation from the Cs^{137} through the 2 mm absorber we have a pure photon beam of energy 0.662 MeV.

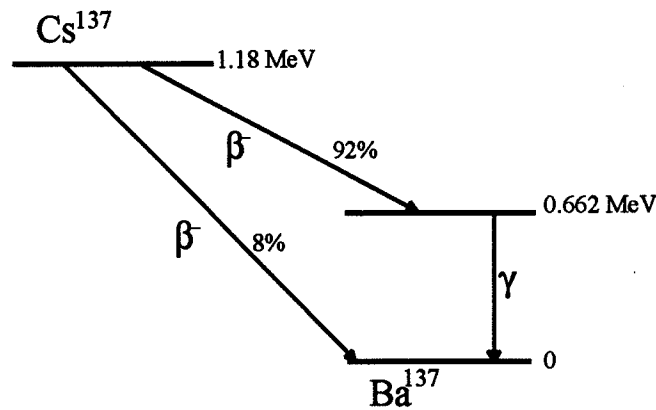


Figure 1. Energy levels and decay scheme of Cs^{137} to Ba^{137} .

II. INTERACTION OF GAMMA RADIATION WITH MATTER

The main difference between the passage of charged particles through matter and the passage of uncharged particles through matter is that a charged particle is subjected to a Coulombic force whenever it comes near another charged particle in the material. It ionizes atoms in the material and loses a small amount of energy in each such "collision". Gamma rays, on the other hand, interact only when they come in contact with something and during that interaction are either annihilated or scattered so that they are taken out of the incident beam. A gamma ray, therefore, either passes through the material intact or is lost, while a charged particle loses some energy with each encounter and comes through with a lower energy than it started. Indeed if the material is thick enough, the charged particle may be degraded until it stops. The distance required to stop a charged particle is called the "range".

The interactions of gamma rays with matter are of three main kinds:

1. Photoelectric Effect, where an electron absorbs the photon and, if the photon frequency is high enough, is ejected from the material with a kinetic energy $E_K = h\nu - \Phi$, where Φ is the work function

of the material;

2. Compton Scattering, where a photon collides with another charged particle, usually an electron, and is scattered through an angle ϕ coming out with a lower energy and a new wavelength; and
3. Pair Production, where a photon interacts near a large atom, completely disappears and a pair of particles, an electron and a positron, appear.

The photoelectric effect predominates at low energies, 10 - 1000 eV, Compton scattering is predominant from 1000 eV to 2 MeV, and pair production predominates above that energy. Regardless of the mechanism, the discussion given below is appropriate for predicting the behavior of a beam of photons as it passes through matter.

If N_0 photons are sent into a material of thickness x then the decrease in the number of photons in any section of the material of thickness dx is proportional to the number of atoms it might encounter (which is directly proportional to the thickness) and to the number of photons in the beam, N . (Fig. 1) The mathematical

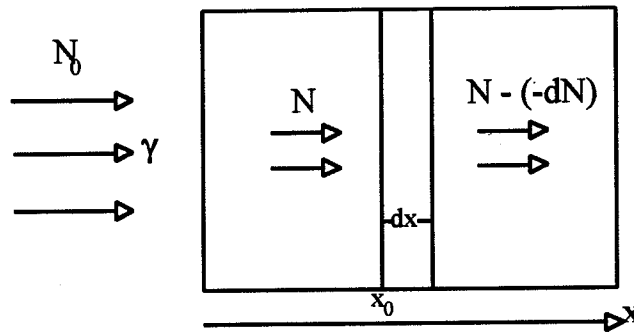


Figure 1. N_0 photons enter a material of thickness x . N photons in the material reach the distance x_0 , and $N - (-dN)$ pass through to $x_0 + dx$.

statement of the above is

$$dN = -\mu N dx \tag{1}$$

where μ is the proportionality constant and N is the number entering dx . The minus sign shows that there is a decrease in N .

If we now collect terms in Eqn. (1), it becomes

$$\frac{dN}{N} = -\mu dx. \quad (2)$$

Integrating Eqn. (2), we get

$$\ln N = -\mu x + C. \quad (3)$$

At $x = 0$, $N = N_0$; therefore we can solve for C in terms of x_0 and N_0 . Eqn. 3 then becomes

$$\ln N - \ln N_0 = \ln \frac{N}{N_0} = -\mu x. \quad (4)$$

Raising both sides to powers of e , Eqn. (4) becomes

$$e^{\ln(\frac{N}{N_0})} = e^{-\mu x} \text{ or } N = N_0 e^{-\mu x}. \quad (5)$$

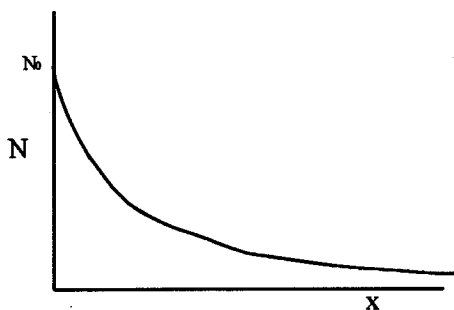


Figure 2a. Plot of N versus x for $N = N_0 e^{-\mu x}$.

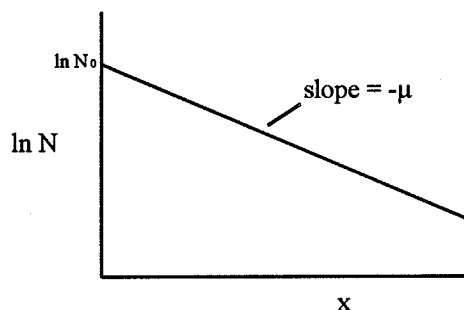


Figure 2b. Plot of $\ln N$ versus x .

Fig. 2a is a plot of N versus x as given in Eqn. (5). Fig. 2b is a plot of the $\ln N$ versus x as given in Eqn. (4). In Fig. 2b the curve is a straight line having slope $-\mu$. Later we will plot the data as in Fig. 2b so that we may extract the coefficient μ directly. μ is called the absorption coefficient.

THE EXPERIMENT

Using a Cs^{137} source, set up the scaling equipment and plateau the Geiger-Müller tube as usual.

I. ABSORPTION MEASUREMENTS IN STEEL

Mount the Geiger-Müller tube in a ring stand holder so that its center is about 2.5 inches above the table (See Fig. 4). With no source present measure the number of counts in a two-minute interval. This is a background measurement and must be subtracted from each subsequent measurement to get the true rate.

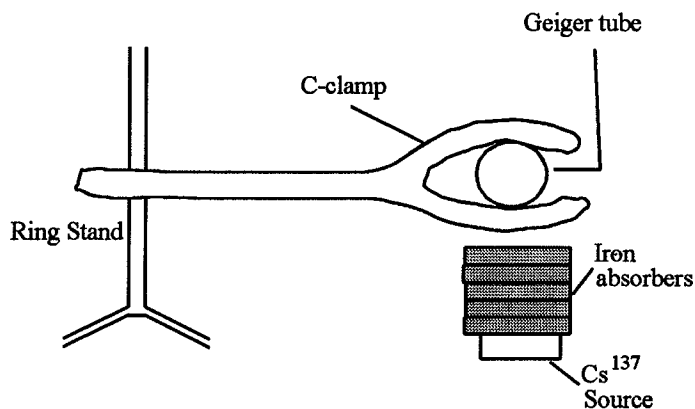


Figure 4. Experimental set-up for attenuation measurements.

Next put the Cs^{137} source in place with one of the thin steel absorbers to stop the betas. In this condition we should have a pure photon beam coming towards the Geiger-Müller tube. Considering this to be zero thickness measure the rate for thicknesses 0, 1, 2 ... absorbers up to a total thickness of about ~ 5 cm. A time interval of 30 seconds is suggested. However, for the sake of precision make sure that your number of counts for 0 thickness is 200 or above, and adjust your time interval accordingly. Make a table for recording the data

with columns for the time interval used, thickness, the results of Trials 1 and 2, the background correction, and the corrected counts for Trials 1 and 2 along with their uncertainties. Use the procedure described in Experiments #5 and #6 to determine the error in the corrected number of counts.

II. DETERMINATION OF THE ABSORPTION COEFFICIENT

For each absorber thickness average the corrected results of Trials 1 and 2 and combine the uncertainties to get the uncertainty of the average. Give a sample calculation and tabulate the results for the thickness used. Remember that with the first absorber the thickness is = 0.

Plot on semi- \log_{10} paper N versus x . Include the error bars. Draw a straight line which best approximates the data taking into account the error bars and determine the absorption coefficient. Make an estimate of the error of your value by determining an upper and lower limit for μ from your graph.

- Q.1. From your value of μ , determine the thickness of iron required to stop half of the incoming photons. Is this value reasonable given the number of iron plates you used? Based on this value, can you justify our assumption that the 2mm thick iron plate only slightly degraded the photon beam?

PRELAB QUESTIONS

- Q.1 What is gamma decay?
- Q.2 Which of the three possible processes will the photons from the Cs^{137} decay undergo when they interact with the iron?
- Q.3 Why is the interaction of gamma rays with matter fundamentally different from that of alpha rays and beta rays?
- Q.4 How is this difference seen in practice?