

Experiment N7

PHOTON ABSORPTION IN MATTER

References:

Segre, Experimental Nuclear Physics.

Chase and Rabinowitz, Radioisotope Methodology, QC784.C4.

Background:

The photon is an electromagnetic field traveling at the speed of light. Thus it can be expected to interact with charged matter through which it may pass. Different aspects of this interaction are known under different names. In the *photoelectric effect* it is the interaction with the electrons that are most tightly bound to nuclei that make the greater contribution. In *Compton scattering* it is the interactions with the least tightly bound electrons that are important. *Pair production* is the result of the interaction of the photon with a virtual electron-positron pair, formed in the Coulomb field of the nucleus. The photon provides enough energy to convert the virtual pair to a real electron-positron pair. How much each of these contributes to the total interaction varies with the energy of the photon and with the nuclear charge Z of the atoms involved in the interaction.

Object:

In this experiment you will measure the interaction probability for photons with several different energies in different absorbing materials. The resulting absorption coefficients will be compared with existing theoretical and experimental information.

The Absorption Coefficient:

The instruction manual includes a detailed treatment of the theoretical background for each interaction described above. Only the essential features of the experiment will be described here. Absorbers are inserted between a radioactive source and a gamma sensitive detector. For the latter we shall use a scintillation counter, since it is sensitive to the gamma ray energy. The count rate is determined for several different absorber thicknesses. As one might expect, that rate will decrease exponentially as the thickness increases. The reason for this is that a single interaction completely removes the photon from the beam. (This is unlike the case of a charged particle going through matter. There the charged particle loses energy through many small energy transfers, not a single transfer that removes the particle from the beam.) One has simply to measure the rate as a function of absorber thickness and deduce the *absorption coefficient*.

The reason for the exponential behavior can be explained as follows: Assume that there is simply a certain probability per atom that the photon will interact with the atom and be removed from the beam. This would mean that the number Δn removed from the beam in traversing a slab of the absorber with a thickness Δx should simply be proportional to the number of photons in the beam. (See Fig 1.) We can write this as:

$$(1) \quad \Delta n / \Delta x \propto n$$

or

$$(2) \quad \Delta n / \Delta x = -\mu n$$

were μ is the constant of proportionality. The minus sign indicates that the number of photons n is decreasing by the amount Δn . This can be rewritten as:

$$(3) \quad \Delta n/n = -\mu \Delta x$$

where the left-hand side of the equation represents the fraction of the incident beam that is removed in traversing the thickness Δx . We can now think of stacking up a bunch of slabs, each with a thickness Δx , through which the beam passes. By summing the right-hand side of this equation we will end with μ times the thickness of the absorber x . The sum over the left-hand side of the equation tells us the fraction of the incident photons were removed from the beam by traversing the thickness x . We can carry out these sums more easily by using the power of calculus. To do this we need to think of the thickness of the slabs as going to zero while more slabs are added to maintain the total thickness. We may then replace the infinitesimals in this expression with differentials:

$$(4) \quad dn/n = -\mu dx$$

and then carry out the sum using the integral:

$$(5) \quad \int_{n_0}^n \frac{dn}{n} = \int_0^x \mu dx$$

The result of carrying out the integration gives:

$$(6) \quad \ln(n) - \ln(n_0) = \ln(n/n_0) = -\mu x$$

Since, $e^{\ln(y)} = y$ this can be reduced to:

$$(7) \quad \frac{n(x)}{n_0} = e^{-\mu x} \quad \text{or} \quad n(x) = n_0 e^{-\mu x}$$

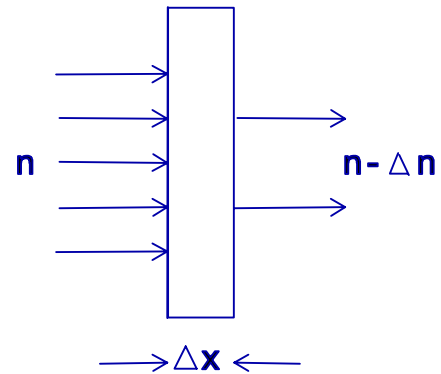


Figure 1

That is, beginning with a beam of n_0 photons, the number of photons $n(x)$ that emerge after traversing a thickness x will decrease exponentially with x .

The absorption coefficient μ is then the reciprocal of the thickness that would reduce the number of photons a factor of by $1/e = 0.368$. This would mean that the dimensions of μ would be cm^{-1} if we were to follow the customary practice. It is also common to express the thickness of the absorber in terms of the weight of a unit area of a slab of that thickness. Thus, a thickness x cm would be expressed as a thickness in gm/cm^2 with the conversion factor given by the relationship:

$$x (\text{gm/cm}^2) = \rho (\text{gm/cm}^3) x (\text{cm})$$

where ρ is the density of the absorber. Accordingly, the absorption coefficient will be expressed in (cm^2/gm) . In this form it is frequently called the *mass absorption coefficient*. (One reason for

using this measure of thickness is that different materials with the same thickness in gm/cm^2 will have nearly the same number of electrons. In as far as electrons are responsible for the interactions the absorption coefficients will be about the same when the photons have the same energy.)

Procedure:

The experiment consists of measuring the beam intensity for several different thicknesses of an absorber and extracting the absorption coefficient. It turns out that there are some geometrical effects that can complicate measurements. For example, some photons do not lose enough energy or are not deflected through a large enough angle to be counted even though there has been an interaction. At the same time other photons that might have missed the detector without the absorber, may interact and scatter into the detector. There are two basic approaches used, one called the *poor geometry* configuration, where the detector is close to the source and scattering out is roughly balanced by scattering into the beam defined by the detector. In the *good geometry* configuration the beam is frequently defined by using a hole in a thick piece of lead, placed midway between the source and detector. The absorbers are placed on top of the hole. The distance between the source and the detector is generally greater than is used in the poor geometry configuration. This reduces scattering back into the detector and eliminates more of the photons that do undergo a small angle scattering. These differences are illustrated in Fig 2.

Although it takes only two points, one with zero absorber thickness and another with an absorber in place, to determine the absorption coefficient, it is a good idea to make measurements with several absorber thicknesses. This will establish the exponential behavior and will turn up the most appropriate thickness to use. You wouldn't want the thickness to be too narrow, so that $n(x)$ is very close to n_0 , or too thick an absorber, so that $n(x)$ is very close to zero, as in either case the counting statistics would become a serious limiting factor in the precision that can be obtained.

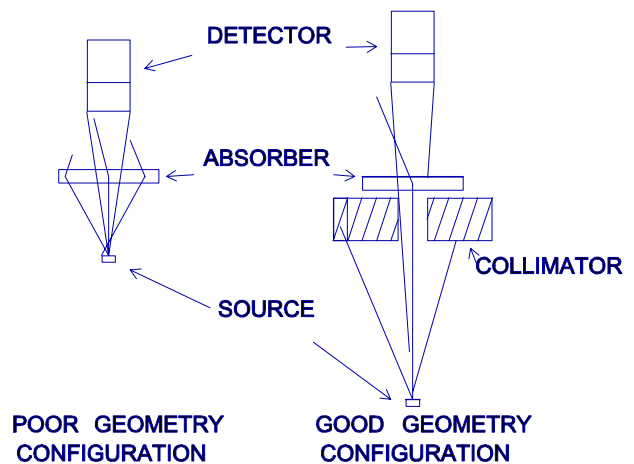


Figure 2

Find the absorption coefficient for three different photon energies using both lead and aluminum absorbers. Start with the 662 KeV photon that is emitted by the Cesium-137 source for photons with a typical mid-range energy. Then use the 1240 KeV photon emitted by a Sodium-22 source, or the 1332 KeV photons emitted by a Cobalt-60 source to find the absorption coefficient for a relatively high energy photon. Finally, use the 136 KeV photon emitted by the Cobalt-57 source, or the 81 KeV photon emitted by the Barium-133 source, to find the absorption coefficient for a relatively low energy photon. You need to set the pulse-height analyzer up to give you the number of counts in the photopeak for each of these sources. This means establishing the photopeak and then setting up the region-of-interest (ROI) and using the computer calculation (<Alt-C>,<Alt-A>) to find the total number of counts in the photopeak. (This process is developed more fully in Experiment N3. Ask for help if this is not clear.)