

ALPHA BETA AND GAMMA RADIATION LAB

Introduction

Unstable atomic nuclei may decay into less energetic nuclei by emission of alpha, beta, and gamma radiation. These forms of radiation are now known to consist of He4 nuclei, electrons (or positrons), and high-energy photons respectively. Which types of decay a nucleus may undergo depends on how it is unstable. Many materials may emit more than one form of radiation. This is especially true when the original parent radioactive nuclei produce daughter nuclei that are also radioactive. Such *decay chains* will be investigated further in one of the next labs, Airborne Radiation: The Radon Decay Chain. In such cases the various forms of radiation can be separated by a magnetic field as shown in Figure 1.

Nuclei with atomic numbers (number of protons, Z) greater than 83 may all theoretically undergo alpha decay (however, the rate of alpha decay may be so slow for some nuclei as to be effectively forever.) In alpha decay, a helium nucleus consisting of two protons and two neutrons, is emitted, reducing the atomic number of the original nucleus by two and its atomic mass by four.

Nuclei may also be unstable when they have too many or too few neutrons compared to protons. If there is an abundance of neutrons one may change into a proton while emitting an electron and antineutrino. The high-energy electron is called a beta particle and this process is called \mathbf{b}^- decay. When there are too many protons one may change into a neutron and emit a positron (negative electron) and a neutrino. The positron, which in this case is called a \mathbf{b}^+ particle is rarely detected directly. It usually quickly finds an electron and the two annihilate each other producing a pair of high-energy photons called gamma rays.

Gamma radiation may also occur when beta or alpha decay leaves a nucleus in a high-energy state. Just as an electron in a high-energy atomic orbital may decay into a lower energy state by emitting a photon, a nucleus may also emit photons when changing from higher to lower energy states that in this case are called gamma rays.

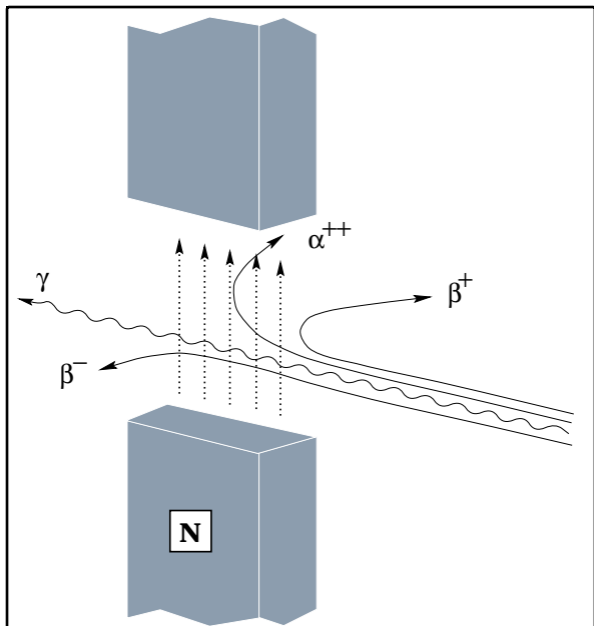


Figure 1

Deflection of Charged Particles by
a Magnetic Field

The following next few sections of this lab describe the particular properties of alpha, beta, and gamma radiation. Also discussed are a set of experiments for each radiation type. As for some basic knowledge necessary for the lab, such as experimental apparatus (Geiger-Müller Meters and Radiation Event Counting Software), the random nature of nuclear radiation emission, the natural decrease in intensity as radiation spreads out from a source, and concerns from the background radiation, please read the **Appendices**.

ALPHA RADIATION

PROPERTIES OF ALPHA RADIATION

Alpha particles consist of two protons and two neutrons the same as the nucleus of a helium atom. This was confirmed with an experiment performed by Rutherford and Royds in 1909. They placed a bit of radon inside a thin walled glass tube. This tube was surrounded by a second tube, in which a vacuum had been created using a mercury column, as shown in Figure 2. Alpha particles emitted by the radon passed through the first glass wall and became trapped in the second tube. By raising the level of the mercury Rutherford and Royds concentrated the alpha particles in the top portion of the tube. The concentrated alpha particles were found to have the same spectroscopic signature as helium.

Alpha particles emitted from a single type of source are monoenergetic. That is they are all emitted with the same kinetic energy. Depending on the source this energy ranges from 3-8 MeV corresponding to velocities of $1.4-2 \cdot 10^7$ m/s. Due to their double charge alpha particles interact strongly with the electrons of the molecules of the material they travel through. These 'collisions' often tear the electrons away leaving an ion pair trail along the alpha particles path. Sometimes the electron is knocked away with enough speed that it may ionize some more molecules and is then called a delta ray (see Figure 3.) Because alpha particles have so high a mass, collisions with electrons have little effect on their direction of travel. Therefore they travel in a fairly straight line. It takes between 25-40 electron Volts to strip away an electron (a value of 32.5eV is usually used for air) so each collision saps a little of the alpha particles kinetic energy. Dividing the energy of a normal alpha particle by the ionization energy it is seen that around 100,000 ion pairs are created. Quite a few! Although alpha particles are not very penetrating they may cause a lot of damage to a material at the depth they reach.

Since all alpha particle from a single source type are emitted with the same energy one might expect them to penetrate to the same depth in a

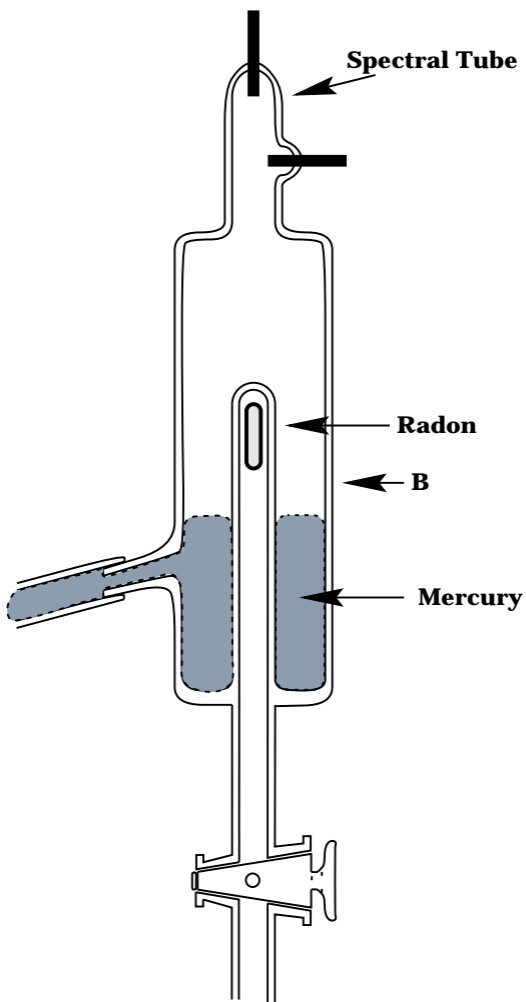


Figure 2 Apparatus used by Rutherford to discover that alpha particles are He^4 nuclei.

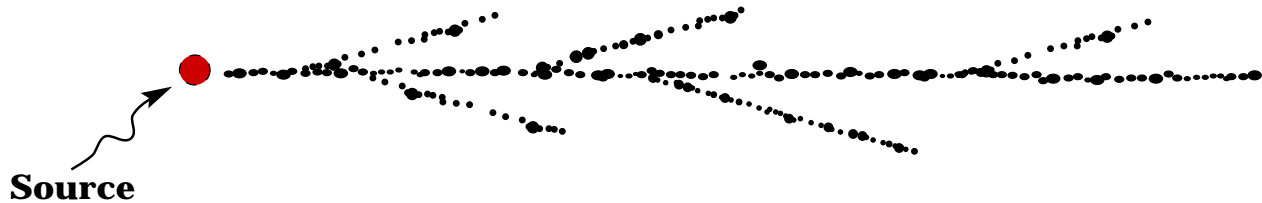


Figure 3 Delta Rays

Alpha particles interact or 'collide' with electrons of atoms they pass, via coulombic attraction. This often tears electrons away ionizing the atoms. Sometimes the electrons are knocked away with such force that they may ionize other atoms in their path in which case they are called delta rays.

given material. This is close to true. However, slight variations in the random collisions experienced along the path cause a slight 'straggling' around the mean penetration range with a Gaussian distribution. The radiation intensity vs. depth and corresponding penetration depth histogram are graphed in Figure 4. As an alpha particle penetrates more deeply it is continually slowed down by each collision. As its speed slows the alpha particle stays in the vicinity of each electron passed a little longer. Extra interaction time increases the chance that the electron will be dislodged. Figure 5 shows the dependency of the interaction strength on the kinetic energy ($1/2 mv^2$) of an alpha particle. Alpha particles have a range of 2-8 cm in air depending on their initial velocity as shown in Figure 6. This may be expressed by the formula,

$$V_o^3 = a R \quad (1)$$

where V_o is velocity, $a \approx 10^{27}$, and R is the range. If R is expressed in centimeters and energy E in MeV then $R \approx E$.

The penetration power of alpha particles into a material is often characterized by the materials *linear relative stopping power* which relates the average penetration depth to that in air,

$$S_{\text{material}} = \frac{R_{\text{air}}}{R_{\text{mat}}} . \quad (2)$$

Penetration depth is nearly inversely proportional to material density,

$$R_{\text{air}} \rho_{\text{air}} = R_{\text{mat}} \rho_{\text{mat}} . \quad (3)$$

Therefore the linear relative stopping power may be expressed by relative density to air,

$$S_{\text{material}} = \frac{\rho_{\text{mat}}}{\rho_{\text{air}}} . \quad (4)$$

For aluminum,

$$S_{\text{AL}} = \frac{\rho_{\text{AL}}}{\rho_{\text{air}}} = \frac{2.74 \cdot 10^3}{1.29} = 2.1 \cdot 10^3 . \quad (5)$$

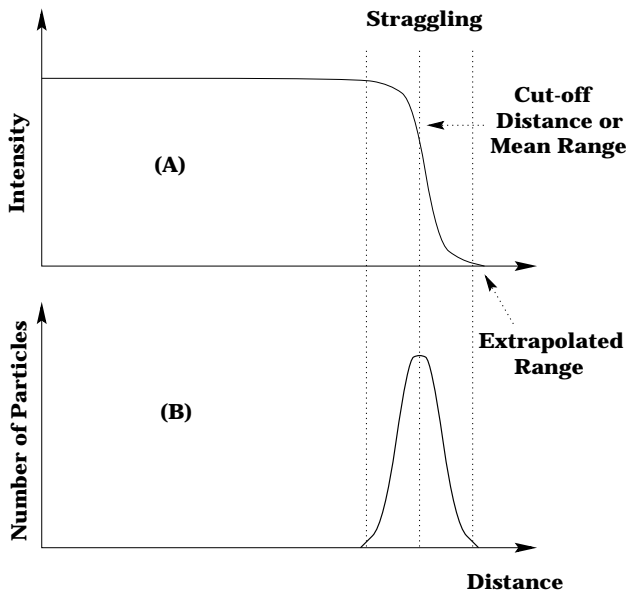


Figure 4 Alpha Radiation Penetration

Alpha particles from a single type of source are monoenergetic meaning they all have the same energy. Therefore there is a fairly well defined depth to which the particles penetrate into a material. Due to random variations in the series of collisions experienced by each particle there is a slight *straggling* of penetration depths around the mean.

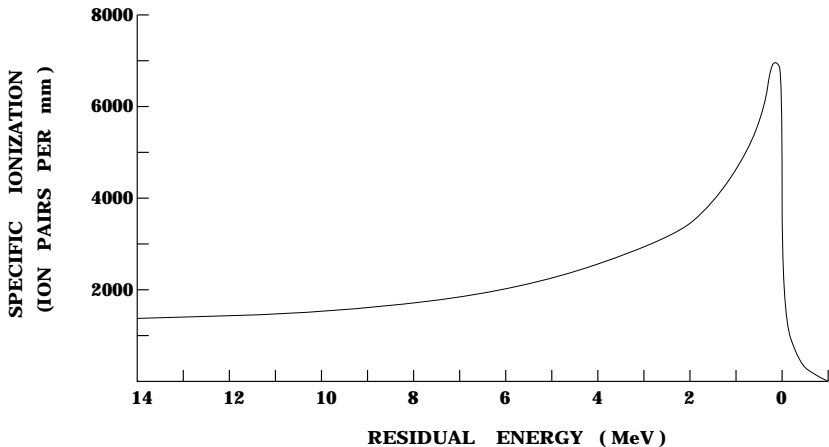


Figure 5 Bragg Curve for Alpha Particles

This curve shows the specific ionization as a function of alpha particle energy. Specific ionization is defined as the number of pairs produced per unit length of path and characterizes the interaction strength of the alpha particle with atoms it passes. At slower speeds and thus lower energies the alpha particle spends more time in the vicinity of each atom it passes giving it a greater opportunity to attract an electron.

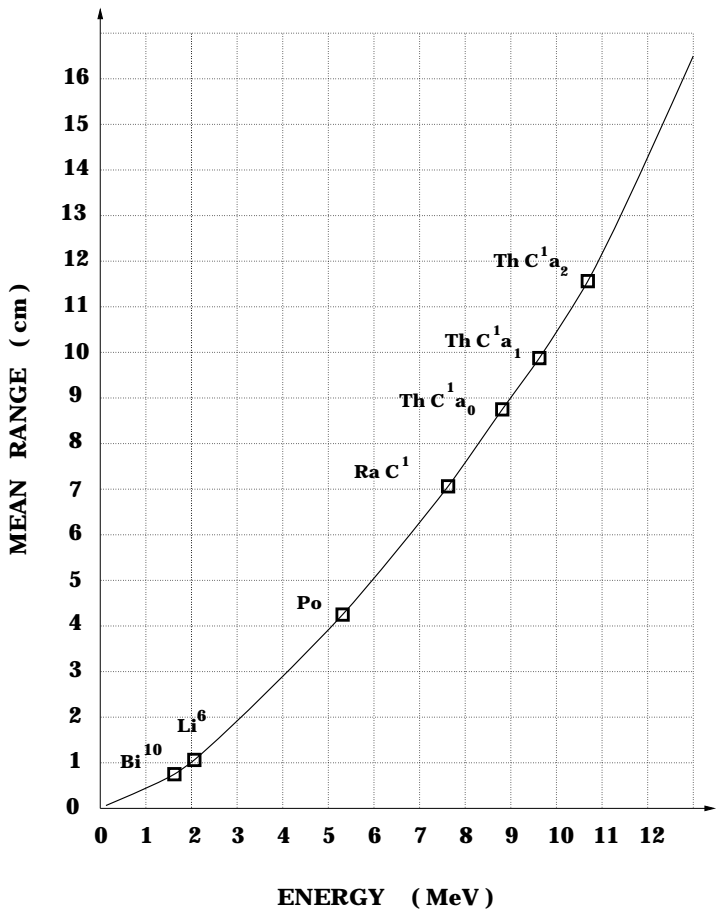


Figure 6 Range of Alpha Particles in Air

ALPHA RADIATION EXPERIMENT

Polonium²¹⁰ (Po²¹⁰) will be used as your alpha radiation source. It emits alpha particles with an energy of 5.4 MeV. You will be measuring the range of alpha particles in air by detecting the variation in count rate as a function of distance between the source and Geiger-Müller detector window. As discussed in an earlier section of this handout (The Inverse Square Law), since the source emits radiation evenly in all directions, neglecting absorption, the count rate should decrease as the reciprocal of distance d from the source squared. This factor will need to be accounted for (by multiplying count rate by d^2) in order to see the true absorption by air. As stated before the range in air in centimeters is approximately the same as the energy of the alpha particles in mega-electron Volts. Therefore a sharp drop in count rate should be expected as the source is moved through a distance of about five centimeters away from the Geiger counter. Remember to measure and subtract the background as discussed in the earlier section of this handout, Background Radiation.

The distance between the source and counter may be varied by placing the source on a plate and inserting it into the slots at different levels in the Geiger meter holder (see Figure 7.) Make sure to count for a long enough period of time in order to get good data. Remember count accuracy is equal to about plus or minus the square-root of counts. The computer counting programs you may use are described further in the *Radiation Experiments Auxiliary Handout: Geiger Counters and Radiation Event Counting Software*. An example of how the data from this experiment might be tabulated is given in Table 1. Discuss the results.

BETA RADIATION

PROPERTIES OF BETA RADIATION

Beta particles have been experimentally shown to be electrons emitted from a nucleus. The velocity of an electron is related to the energy with which it was emitted. Emission of a beta particle is always accompanied by a neutrino emission. The energy given off by the decaying nucleus is split between the electron and neutrino according to momentum conservation. As a result the energy of beta radiation is continuously distributed from zero up to the total decay energy given off by the nucleus (in which case the neutrino receives zero kinetic energy.) The energy spectrum of beta particles is explored further in the 335 *Beta Energy Spectrum Lab*. As shown in Figure 8 the average energy received

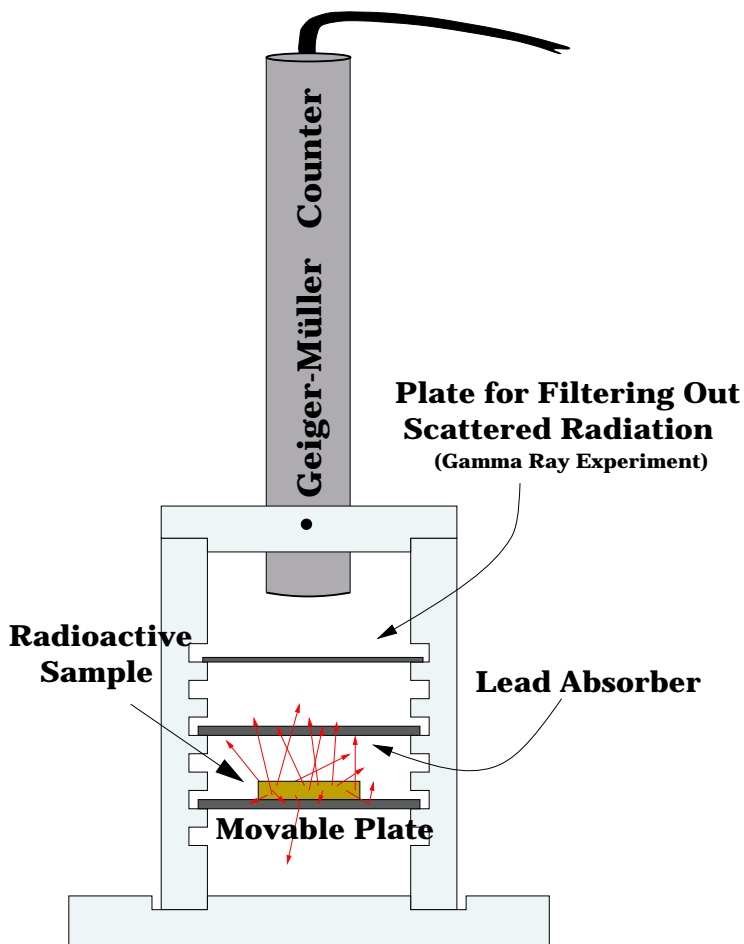


Figure 7 Arrangement of Geiger Counter, Source, and Absorbing Material

The distance of the source from the counter may be varied by moving the sample shelf to different slot levels. The absorbing material and filtering material used in the beta and gamma particle experiments may be placed on higher slots as shown in the figure.

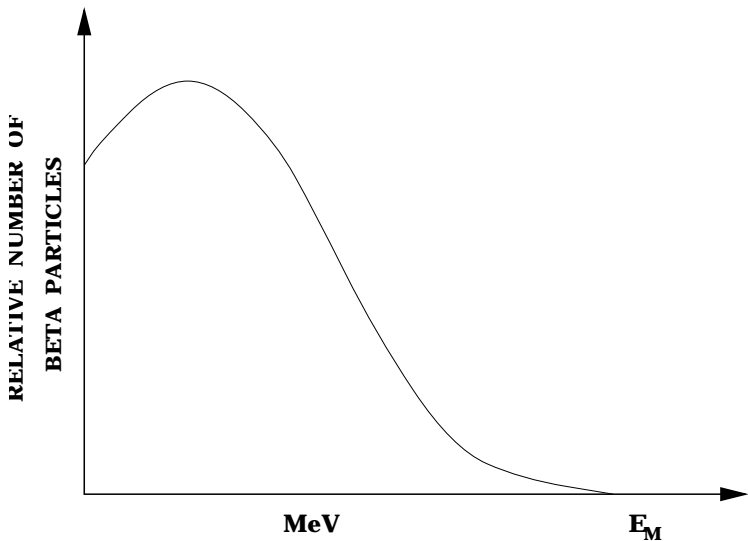


Figure 8 Beta Radiation Energy Spectrum

The kinetic energy given off by a nucleus during beta decay is split between the electron (positron) and anti-neutrino (neutrino) formed by the decay process. As a result beta particles have a wide distribution of energies ranging from zero up to a maximum of the total energy given off by the nucleus.

by the beta particle is between one fourth and one third the maximum energy (the maximum being the total energy given off by the nucleus.)

Because of their small mass and the energies involved in nuclear decay, beta particles often are emitted at relativistic speeds. The total energy of a particle is given by Einstein's formula,

$$E = m c^2 . \quad (6)$$

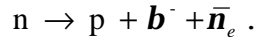
The effective mass m is related to the rest mass m_0 by,

$$m = \frac{m_0}{\sqrt{1 - \mathbf{b}^2}} , \quad (7)$$

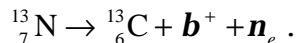
where $\mathbf{b} = \frac{v}{c}$; v is the velocity of the particle, and c is the velocity of light. Subtracting the rest energy $U = m_0 c^2$ from the total energy gives the kinetic energy,

$$\text{K.E.} = (m - m_0) c^2 = m_0 c^2 \left(\frac{1}{\sqrt{1 - \mathbf{b}^2}} - 1 \right) . \quad (8)$$

Beta decay may occur in two ways. In \mathbf{b}^- decay a neutron decays into a proton, an electron (beta particle) and an anti-neutrino. This is given by the equation,



neutron has a slightly higher rest mass than a proton. As a result a proton cannot decay into a neutron without absorbing some energy from an outside source. The extra energy of an unstable nucleus can provide the energy needed to turn a proton into a neutron if this change puts the nucleus into a lower energy state. Such a process is called \mathbf{b}^+ decay. As the nucleus changes into a new nucleus with one less proton and one more neutron it also emits a positron and a neutrino,



Positrons usually quickly annihilate with a nearby electron producing a pair of gamma rays in the process.

BETA INTERACTIONS

Beta particles may interact with both the nuclei and electrons of a material they pass through. A beta particle is said to have collided

with a nucleus when it is strongly deflected by the nuclei's Coulombic field (see Figure 9.) If the collision is elastic the process is called Rutherford scattering and the energy of the electron undergoes little change. The same type of result is seen if one throws a ping-pong ball at a bowling ball. As a result of momentum conservation the ping-pong ball changes direction (a large change in momentum) but imparts little of its energy to the bowling ball. Most back scattering of electrons is due to Rutherford scattering.

As electrons are accelerated or decelerated by the Coulombic field of a nucleus, electromagnetic radiation called *bremsstrahlung* is produced (see Figure 10.) This type of collision is inelastic. Only about one percent of the energy of a beta particle beam incident on a target is converted into bremsstrahlung radiation. The percentage increases with atomic number of the target atoms.

Beta particles may also interact with orbital electrons via their mutually repulsive charge. This often ionizes atoms by knocking their electrons out of orbit producing characteristic X-rays when higher orbital electrons decay down to the empty state (see Figure 11.)

Although absorption of beta particles by a material is a random process, on a macroscopic scale (for which random fluctuations have averaged out) the intensity of an electron beam is found to exponentially decay with distance traveled according to the formula.

$$I = I_0 e^{-u' r X} \quad (9)$$

In equation 9, X is distance traveled, ρ is the density of the absorber and u' is the mass absorption coefficient (see Figure 12.) This is closely similar to the absorption of light and gamma rays. Often a material may be characterized by its half-thickness which is the thickness of material needed to reduce the intensity of a beam by one half. If a beam is passed through two half-thicknesses of material the emission on the other side would be one fourth of the original intensity. With three half-thicknesses intensity is reduced to one eighth as shown in Figure 13.

In actuality the resulting intensity measured by a Geiger counter is slightly dependent on the position of the absorbing material between the beta source and the detector. This is because some beta particles not initially emitted toward the detector window may be scattered back into it as they pass through the absorber. As a result the total detected radiation increases slightly as the position of the absorber with respect to the detector and source. This effect also causes deviation from equation 9 as shown in Figure 14. This effect may be ameliorated if the experiment is set up with 'good geometry' as discussed further in the gamma radiation section and shown in Figure 15.

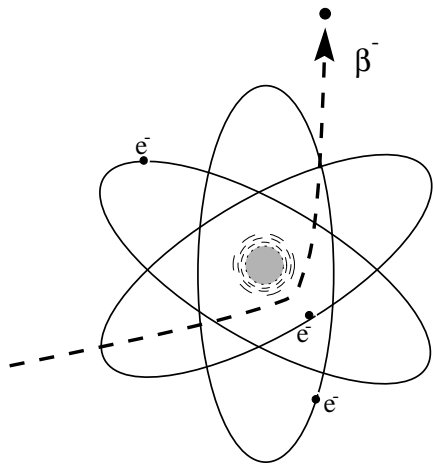


Figure 9
Rutherford Scattering

Elastic scattering of a beta particle by coulombic interaction with the nuclei. The beta particle undergoes a sharp change in direction but little change in energy.

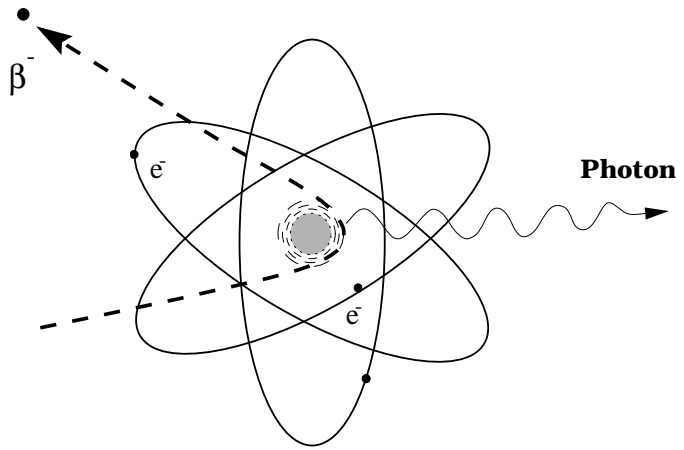


Figure 10 Bremsstrahlung Radiation

When a beta particle is slowed down by the coulombic field of an atom it passes, electromagnetic radiation called bremsstrahlung is produced. This type of collision is inelastic and the energy of the bremsstrahlung radiation equals the energy lost by the beta particle.

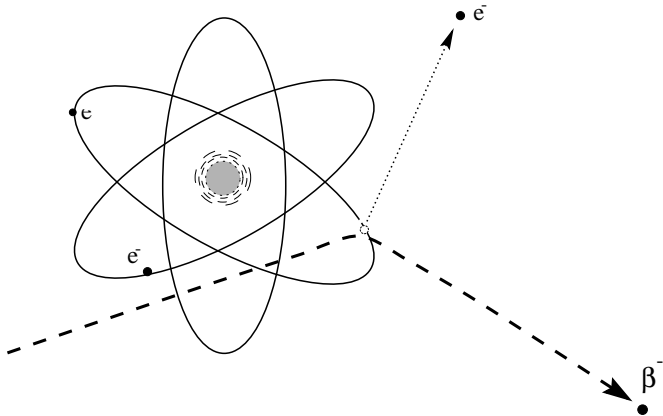


Figure 11

Ionization of Electrons by Beta Particle

Beta particles may also interact with the orbital electrons of atoms often expelling them completely and ionizing the atoms.

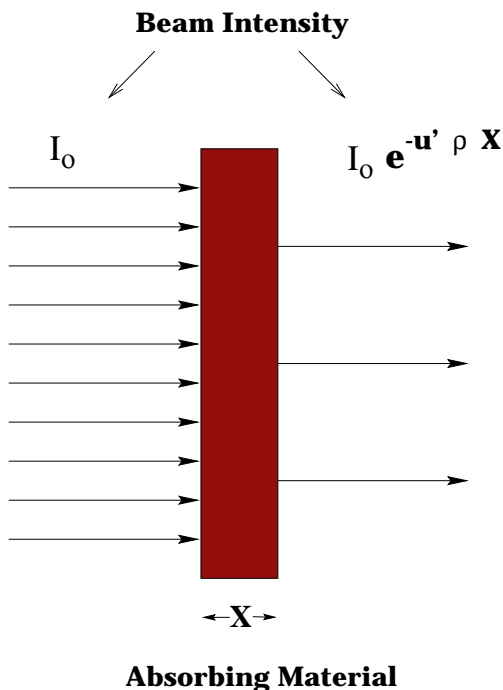
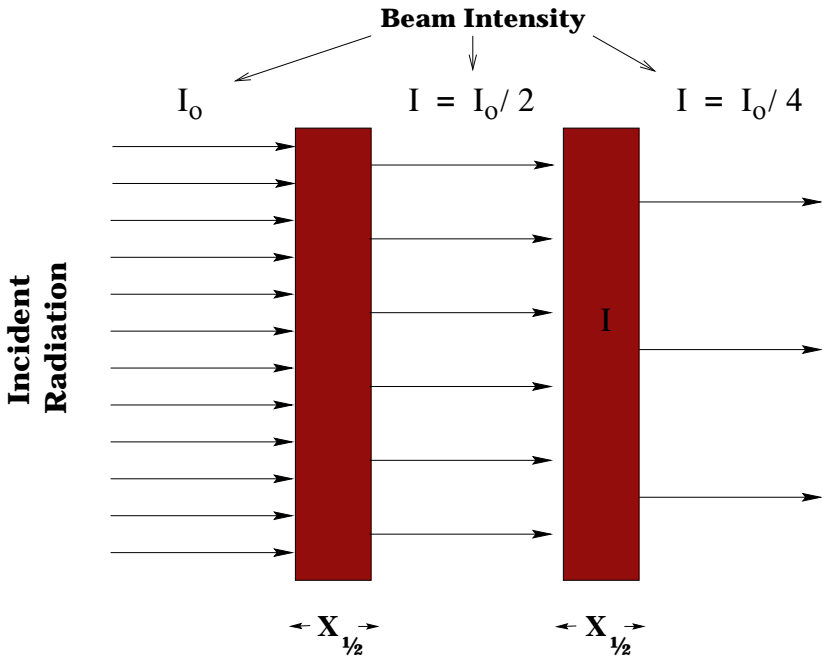


Figure 12 Linear Absorption of Beta and Gamma Radiation

After passing through an absorbing material the intensity of beta and gamma radiation is proportional to the original intensity by the negative exponential of the material's thickness times the material's absorption coefficient.



**Absorbing Material with Thickness
Equal to the 'Half Thickness'**

Figure 13 Half-Thickness of an Absorbing Material.

The half-thickness of a material $X_{1/2}$ is defined as the thickness needed to reduce the intensity of a particular type of radiation by half.

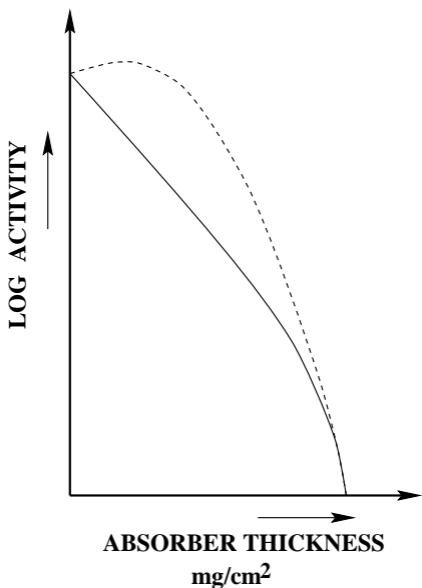


Figure 14 Deviation
From Linear Absorption

The absorbing materials scatters some particles into the detector window that would not normally have entered. This causes a deviation from linear absorption as shown above and the total detected radiation is also found to vary slightly as the absorber is moved to different positions between the radiation source and detector.

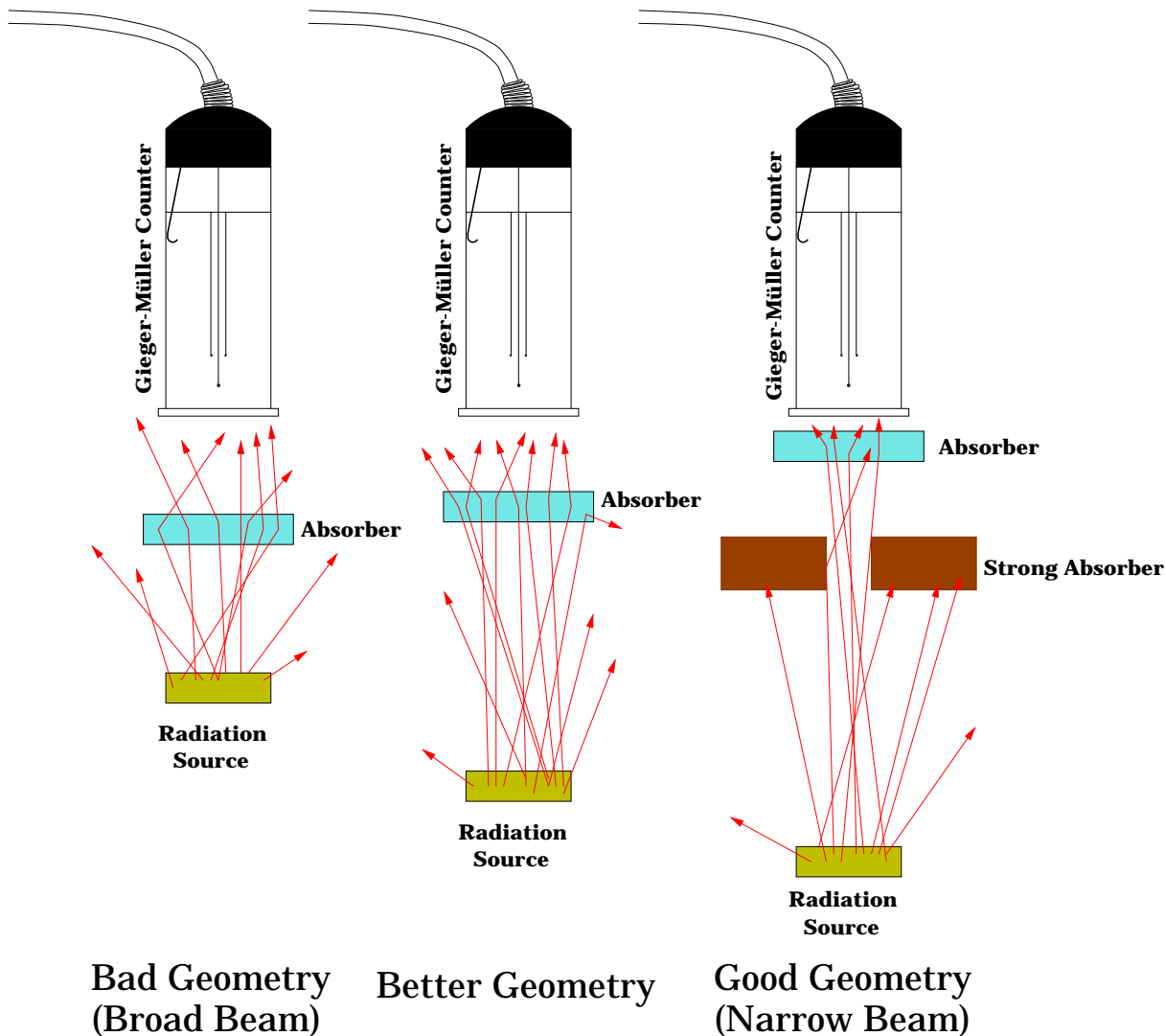


Figure 15 Good Detection Geometry

The absorbing materials scatters some particles in different directions causing some particle to go toward the detector window that would not normally have entered. This effect can be partially eliminated from an experiment using 'good detection geometry.'

BETA RADIATION EXPERIMENT

The beta source is either Thallium²⁰⁴ (TL²⁰⁴) or Strontium⁹⁰ (St⁹⁰). In this experiment we will be calculating the half thickness of aluminum. You will have many thin films of aluminum of varying thickness (1, 2.5, 10, 20 microns) which you can stack together to get a large range of thickness. As in the alpha radiation experiment the source emits in all directions so you will need to account for decreases in count rate due to $\frac{1}{(\text{distance})^2}$ loss if the distance between source and detector is changed. You will also need to subtract the background rate.

It is probably easiest to place the source on the lowest rung of the Geiger meter holder and leave it there. Then the aluminum films may be stacked together on the intermediate rungs. Again make sure that enough counts are measured at each thickness in order to get accurate count rates. About five minutes is a good time.

Tabulate the count rate versus absorber thickness using a chart like the one suggested in Table 2. Does it follow a decaying exponential curve? Make a linear-least-squares fit to the data and calculate the half thickness. This may be easily performed using MatLab or with some calculators. You can check out Dr. Erlenmeyer's Least-Squares fit web (<http://www.astro.nwu.edu/PAGES/erlenmeyer.html>) and the corresponding Theory page (<http://www.astro.nwu.edu/PAGES/lsgerr.htm>) for more details.

It is possible for the count rate to get so low that it is below the background. At this point some of the count rate samples will give estimated rates below zero due to noise fluctuations. This data obviously is unphysical and indicates that the number of counts is so low that the data is completely inaccurate and basically useless. Either longer counting times are needed to reduce the relative noise level and obtain better measurements or data past this point should be neglected.

GAMMA RADIATION

PROPERTIES OF GAMMA RADIATION

Gamma radiation consists of extremely high energy photons with wavelengths usually much smaller than 10^{-10} meters (compare to $\approx 10^{-6}$ meters for visible light.) Gamma emission is usually preceded by an alpha or beta emission that leaves the nucleus in an excited state. An excited nucleus may change to a lower energy state by emitting a photon that in this case is called a gamma ray. This is similar to emission of a photon when an electron changes from a higher to lower orbital. The spacing between nuclear energy states is on the order of millions of electron Volts (compared to electron volts for electron orbitals.) Substituting the energy of a photon $E=hf$ into the wavelength-frequency relation $c=f\lambda$ gives,

$$\lambda = \frac{c}{f} = \frac{hc}{E} = \frac{1240 \text{ MeV} \cdot \text{femtometers}}{1 \text{ MeV}} = 1240 \text{ fm} . \quad (10)$$

As for visible light, absorption of gamma rays by a material is closely linear. That is for every unit of distance the radiation travels through the material an equal fraction of the remaining light is absorbed. For example suppose the radiation is passed through a series of absorbing plates each of the same material and thickness. Also suppose each plate is of a thickness that it absorbs half the gamma rays passing through it, i.e. the half-thickness. After the first plate the intensity is half of the original. Passing through the second plate half the remaining rays are removed leaving one fourth the original. After the third plate only one eighth is left and so on (see Figure 14). This is an exponential type decay that may be expressed by Lambert's law,

$$I(X) = I_0 e^{-\mu X} \quad (11)$$

or

$$\ln(I/I_0) = -\mu X . \quad (12)$$

where μ is the linear absorption coefficient. The half-thickness of a material is thus given by,

$$I(X_{1/2}) = 0.5 I_0 = I_0 e^{-\mu X_{1/2}} \quad (13)$$

and

$$X_{1/2} = \frac{-\ln(1/2)}{\mu} = \frac{0.693}{\mu} .$$

Absorption of gamma rays occurs by several means, the most prominent being the photoelectric effect at low energies, the Compton effect at intermediate energies and pair production at high energies. The linear absorption coefficient is a sum of the coefficients for each of these processes.

$$\mu = \tau \text{ (photoelectric)} + \sigma \text{ (Compton)} + K \text{ (pair production)} \quad (14)$$

Beam energy is also lost in negligible amounts to Rayleigh scattering, Bragg scattering, photodisintegration, and nuclear resonance scattering.

Photoelectric absorption occurs when a gamma ray ionizes an atom. The photoelectric absorption rate τ is proportional to the density of the material and also increases strongly with atomic number,

$$\tau = 0.0089 \rho \frac{Z^{4.1}}{A} I^n. \quad (15)$$

In equation (15) ρ is the density of the material, Z is atomic number, A is atomic mass, λ is wavelength and the number n is equal to three for Nitrogen, Oxygen, and Carbon and 2.85 for all other elements with atomic numbers less than iron. Photoelectric absorption is strongest at longer wavelengths (i.e. less energetic gamma rays) and increases very rapidly with atomic number.

When a gamma ray disintegrates into an electron positron pair it is called pair production. For this to occur the energy of the gamma ray must be greater than the resting energy of an electron and a positron, $hf \geq 2 \cdot 0.51 \text{ MeV}$. The pair formation coefficient is given by,

$$K = a N Z^2 (E - 1.02 \text{ MeV}), \quad (16)$$

where a is a constant, N is Avogadro's number, and Z is the atomic number.

Loss by Compton scattering consists of two components,

$$S = S_a + S_b, \quad (17)$$

where S_a is the scattering component due to energy loss via collisions with electrons and S_b is energy loss due to scattering of photons scattered away from the beam direction. The S_b loss is strongly dependent on the geometry of the source, absorber and detector. This is because in some geometries many gamma rays that were not initially headed toward the detector window may be redirected into it by Compton

scattering. For 'narrow beam' geometries this is unlikely, but for broad beams or wide radiation sources and when the absorber is not directly against the detector window count rates will be found to be slightly higher due to the redirected rays (see Figure 15). Because of this effect the total absorption coefficient μ is often divided into a 'true' absorption component and a scattered component.

$$m = (t + K + s_a) + s_b \quad (18)$$

Total = True + Scatter

'Good geometry' must be established in order to measure the total absorption coefficient accurately.

GAMMA RADIATION EXPERIMENT

In this experiment the half-thickness of aluminum and lead will be measured for the gamma rays emitted by a Cobalt⁶⁰ (Co⁶⁰) source which radiates at 1.1MeV and 1.3MeV. It is suggested that a thin piece of aluminum is placed as close to the detector window as possible as shown in Figure 7. This will help to absorb and filter out some of the unwanted scattered radiation. Otherwise this experiment is identical to the beta radiation experiment except that thicker plates will be used since gamma radiation is more penetrating.

- 1) Measure the count rate at many different thicknesses for both lead and aluminum and compile a data table similar to Table 2. As in the beta decay experiment use the method of linear least-squares fitting to calculate the half-thicknesses. Which has the higher half-thickness, aluminum or lead? Why?
- 2) Is there any absorption due to photon pair production for this source?
- 3) At lower energies the most loss is due to the photoelectric effect which is proportional to the density of the material. Divide the half-thicknesses you found for aluminum and lead by their respective densities (2.7 g/cm³ for aluminum and 11.4 g/cm³ for lead.) This gives the half-thickness in (g/cm²) which is often used as a more true parameter of the absorption strength of a material type since it accounts for variations in density from sample to sample. Does the lead or the aluminum sample have the higher adjusted (g/cm²) half-thickness? Why?
- 4) Compare the half-thicknesses calculated in Question 3 to Figures 16 and 17. What type of geometry matches this experiment?

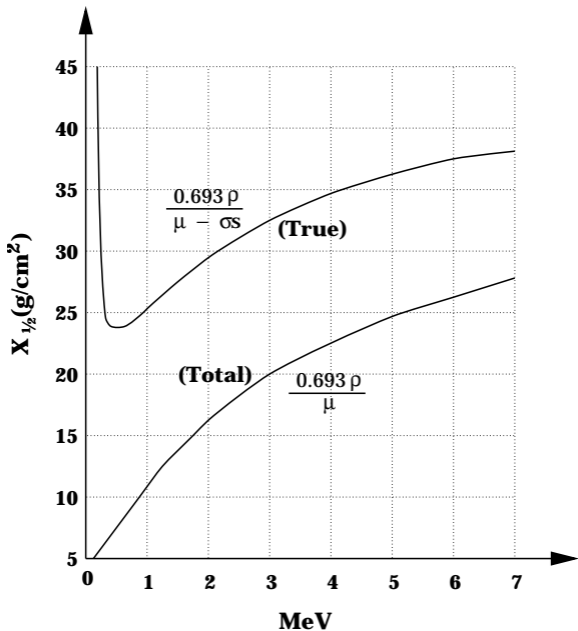


Figure 16 Half-Thickness Widths for Aluminum Absorbers

"True" represents the lower limit for broad-beam geometry. "Total" represents the upper limit for narrow-beam geometry. All values should fall between these limits.

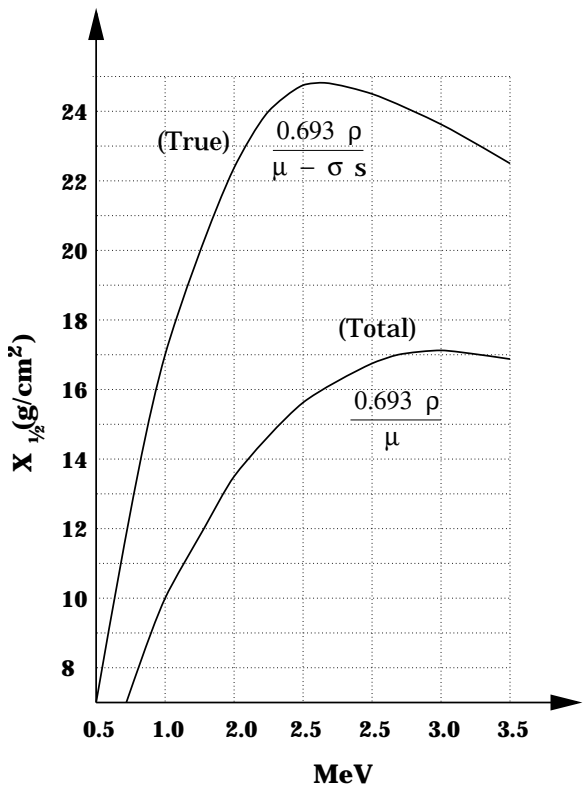


Figure 17 Half-Thickness Widths for Lead Absorbers

"True" represents the lower limit for broad-beam geometry. "Total" represents the upper limit for narrow-beam geometry. All values should fall between these limits.

Appendices

I. GEIGER MÜLLER COUNTERS AND RADIATION EVENT COUNTING SOFTWARE

GEIGER-MÜLLER COUNTERS

Geiger-Müller (G-M) counters are used to detect individual radioactive particles. When a particle is detected a current pulse is generated which may be counted or otherwise processed by an electronic circuit or computer. A Geiger-Müller usually consists of an airtight metal or glass cylinder closed at both ends and filled with a gas that is easily ionized (usually helium or argon) as shown in Figure 18. One of the ends is usually very thin and acts as a window through which radiation may pass into the device. A wire which runs lengthwise down the center of the tube is positively charged with a relatively high voltage and acts as an anode. The casing acts as the cathode (negative).

If the tube is of glass it is covered with a metallic conductive coating on the inside. The anode and cathode are connected by wires to an electronic circuit which maintains a high voltage between them.

When alpha, beta, or gamma particles enter the Geiger-Müller counter they will often ionize some of the atoms of gas inside. Due to the large field created between the anode and cathode the resulting positive ions and negative electrons accelerate toward the cathode and anode respectively. Gaining speed they collide with and ionize other atoms producing an avalanche of ions and electrons. The resulting discharge current causes the voltage between the anode and cathode to drop. A separate circuit of the Geiger counter detects such voltage drops registering them as a radiation event.

One main question remains, however. Once the avalanche of ionizing collisions starts, what stops or *quenches* it? This may be performed electronically by quickly lowering the cathode-anode voltage shortly after the particle is detected so that the field no longer accelerates the electrons and ions. This is the *external quenching* method. Another method, *internal quenching*, uses a slight concentration of some polyatomic gas in the mixture inside the tube. Electrons and ions that collide with the quenching gas molecules are slowed and absorbed, often breaking down the gas molecules in the process. When organic particles are used (*organic quenching*) the G-M tubes must be replaced after around

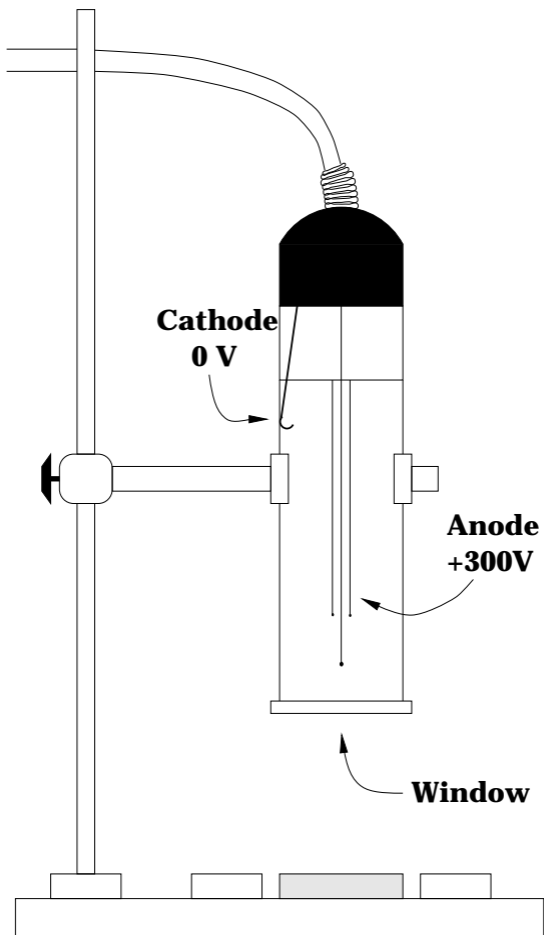


Figure 18 Geiger-Müller Counter

a hundred million counts. Halogen molecules that naturally recombine after breaking apart may also be used (halogen quenching.)

Although the Geiger counter used in the 335 Modern Physics experiments has a fixed anode to cathode voltage, on some counters this voltage must be set for optimum detection efficiency. Figure 19 shows the dependency of the measured count rate on the applied voltage. One sees that no counts are registered until a minimum starting potential is applied. The count rate quickly rises as the voltage is increased beyond the starting potential. It then levels off to a nearly flat plateau after the *threshold potential*. It is in this plateau region that detection is most efficient and for which count rate varies the least with voltage fluctuations. G-M counters are also usually operated in the lower 25% sub-area of the plateau in order to extend the life of the tube. The count rate swiftly rises as the applied voltage is increased beyond the plateau region. Increasing it much further leads to continuous discharge as the gas in the tube is completely ionized (like in a fluorescent light.) This will most likely cause permanent damage to the tube.

RADIATION EVENT COUNTING SOFTWARE

The Geiger counter you will be using with this lab is connected directly to a box which provides the anode/cathode voltage source and which also detects the drop in voltage that results when a radiation event causes a current avalanche. When an event is detected this box sends a signal to a computer which may then process the counting statistics.

To use the Geiger counters with the computer software:

1. Connect the Geiger counter to the voltage box and the voltage box to the computer.
2. Turn on the voltage supply and set to 450 volts.
3. Turn on the computer and type 'GCI<return>' at the DOS prompt.
4. Daedalon software will come up with a menu of several different counting options.

1. Nuclear Counters and Timers
2. Automatic Nuclear Counter
3. Auto Counter and Frequency Sort
4. Auto Counter and Frequency Display
5. Exit Program - Go to DOS

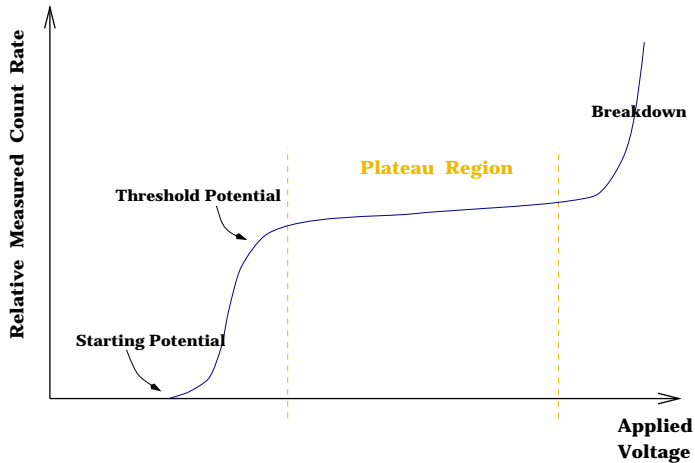


Figure 19 Detection Efficiency of a Geiger Counter as a Function of Applied Voltage

For this and other labs you will be interested in the first two options which are described below.

1. Nuclear Counters and Timers

This program provides two clocks and a counter. The first clock runs continuously measuring total time elapsed. The second clock measures the duration of individual counting intervals. Once the program is started both clocks run and the counter tallies the radiation events detected until the <spacebar> is hit. At this point the 'interval clock' and counter both freeze until either 'c' for continue or 'b' for begin again is pressed. Pressing 'c' resets the 'interval clock' and the counter (but not the 'total time clock') and counting resumes. Pressing 'b' resets the timer and both clocks, essentially restarting the program.

This program is very flexible and gives the user a lot of latitude in deciding how to measure count rates. However, one must be diligent in keeping track of times/counts and taking count/rate samples according to the method decided upon. Background count rates (rate of events detected when no sample is present) and counting over long time intervals are most easily taken using this program. It may also be used to measure the amount of time for a given amount of events to occur.

2. Automatic Nuclear Counter

This program measures the number of counts that occur during each of up to 160 consecutive time intervals or 'bins'. The length of each bin period in seconds must divide evenly into 60. As the counts for each bin are tallied they are displayed on the screen. After the last bin count is made the program waits for you to copy down the data before clearing the screen. If more than 160 bins are desired one may quickly restart the program to continue for another 160 bins. To minimize the pause between the sets, start copying down the data well before the end of a set so the data for the last few bins may be jotted down just as the set of 160 is finished. Then the data may be cleared and another set started right away.

Since the smallest time interval that may be covered by a single bin is one minute, the number of counts measured may be quite small. Although, for quick decay times one minute time resolution may be nice it may also give unacceptable accuracy in estimating the emission rate over a period of time ($\sqrt{\text{number of counts} \times \text{interval duration}}$). In order to obtain better data add the count numbers of several consecutive bins together to effectively create longer intervals. Remember that the actual number of counts tends to vary by plus or minus the square root of the average number of counts. This means that if 100 counts were measured during a time interval then the actual average is probably between 90 and 110 counts.

A series of count data usually consists of a set of count numbers along with the corresponding interval starting and ending times. When plotting the data or matching it to a curve the data is usually transformed into a set of count rates = (number of counts/interval duration) and times corresponding to the midpoint of each counting interval. These represent the estimated *instantaneous* count rates at each sample point. Note that in this transformation some information has been lost. If there are pauses between the ending points and starting points of consecutive time intervals or if the intervals vary in duration it is especially important to use the interval midpoint rather than the beginning or end.

When the count rates are low or change quickly, there are a few fancy tricks one can use to get better data or nicer plots. Shorter time intervals may be used while the count rate is high to get more sample points. Then as the material decays and count rates decrease the interval lengths may be increased or the time needed to get a certain number of counts may be measured. This maintains the statistical accuracy of the data by keeping count numbers high.

Alternatively, short intervals may be used then added together within a sliding window. The first five bins are added, then the second through sixth are added, then the third through eighth and so on. This method keeps both the accuracy and number of sample points in a plot high. However, the effective number of samples is still low since the averaging window smoothes out fluctuations in the count rate. So the new set of data doesn't actually have more information it just looks nicer.

II. DECAY STATISTICS

Nuclear decays occur as random events. Each unstable nucleus in a radioactive sample has a constant slight probability of decaying during every infinitesimal in time. The number of decays occurring during a finite period of time in a sample follow Poisson statistics. For Poisson statistics if λ is the average number of decays per second then the probability that there will be n decays during a time interval of duration t is,

$$\begin{aligned} \text{Prob. of } n \text{ decays} &= \frac{(It)^n e^{-It}}{n!}, \\ \text{during } t \text{ seconds} & \end{aligned} \quad (19)$$

where $n!$ means n factorial, i.e., $n! = (n)*(n-1)*(n-2)* \dots *(2)*(1)$.

The standard deviation of the number of decays occurring during a time period is equal to the square-root of the average number of decays. Remember from statistics class that the standard deviation is defined as

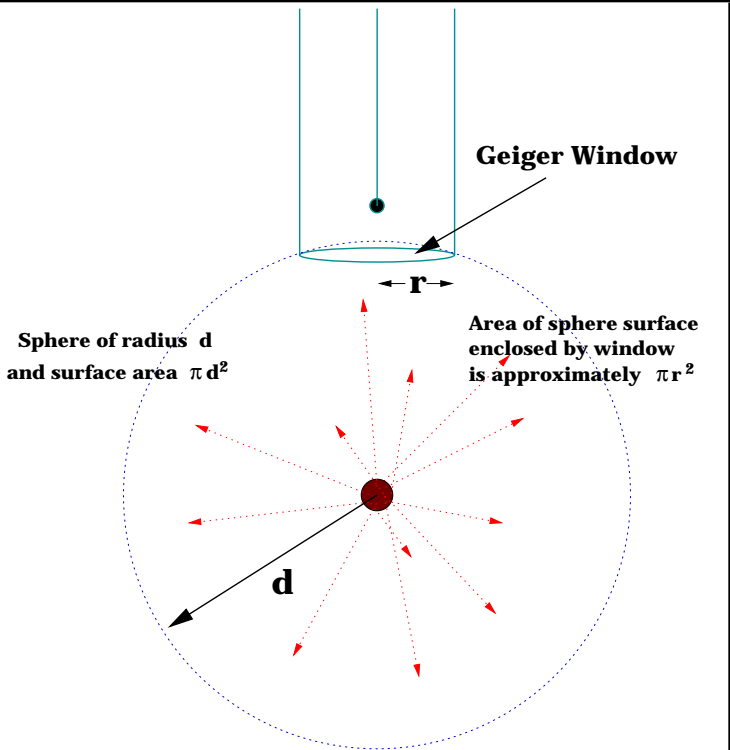


Figure 20 Inverse Square Law

The fraction of the total emissions emitted toward the detector window is inversely proportional to the square of the distance between the source and window.

Although, subtracting the background count rate data from the measured count rate gives a better idea of the amount of a source's emission rate, since both the source and background emissions are random events one can never know exactly how many of the counts were due to each source. This introduces some extra uncertainty or noise into the data. Since the background radiation also follows Poisson statistics the uncertainty will be about the square-root of the average number of background counts. For example suppose intervals of five minutes are used to sample the emission rate of a source. A background radiation check produces one thousand one hundred and four background counts measured over one hundred minutes. This produces an estimate of fifty five and one fifth counts per five minutes with a standard deviation or uncertainty of about seven and a half counts $\sqrt{55.2} = 7.43$. If during one of the five-minute intervals 324 counts are measured, the total uncertainty is $\approx \sqrt{324} = 18$ with the number of counts due to the source being around $324 - 55.2 \pm 7 \approx 269 \pm 7$. Note that uncertainties from different sources add as follows,

$$\mathbf{s}_{\text{Total}}^2 = \mathbf{s}_{\text{Source1}}^2 + \mathbf{s}_{\text{Source2}}^2 + \mathbf{s}_{\text{Source3}}^2 + \dots, \quad (25)$$

or as in this case if the average source rate is 269 counts per minute,

$$\mathbf{s}_{\text{Total}}^2 = \mathbf{s}_{\text{Source}}^2 + \mathbf{s}_{\text{Background}}^2 = (\sqrt{269} = 16.4)^2 + (7.43)^2 = 269 + 55, \quad (26)$$

giving,

$$\mathbf{s}_{\text{Total}}^2 = 18 (= \sqrt{324}).$$

The effects of noise added by background radiation on count rate accuracy can be reduced by increasing the ratio of experimental source rates to the background level. Shielding the experiment from outside sources, moving the counter closer to the source and using larger or more radioactive sources will all improve this ratio.