G-M counter, counting statistics and absorption cross-section

Introduction:

Geiger-Müller (GM) counters were invented by H. Geiger and E.W. Müller in 1928, and are used to detect radioactive particles. A typical GM Counter consists of a GM tube having a thin end window (e.g. made of mica), a high voltage supply for the tube, a scalar to record the number of particles detected by the tube, and a timer which will stop the action of the scalar at the end of a preset interval.

The sensitivity of the GM tube is such that any particle capable of ionizing a single atom of the filling gas of the tube will initiate an avalanche of electrons and ions in the tube. The collection of the charge thus produced results in the formation of a pulse of voltage at the output of the tube. The amplitude of this pulse, on the order of a volt or so, is sufficient to operate the scalar circuit with little or no further amplification. The pulse amplitude is largely independent of the properties of the particle detected, and gives therefore little information as to the nature of the particle. Even so, the GM Counter is a versatile device which may be used for counting alpha particles, beta particles, and gamma rays, albeit with varying degrees of efficiency.

Objectives:
1. To determine the plateau and optimal operating voltage of a Geiger-Müller counter.
2. To determine the resolving time of a GM counter.
3. To investigate the statistics related to measurements with a Geiger counter. Specifically, the Poisson and Gaussian distributions will be compared.
4. To determine the efficiency of a Geiger-Muller counter.
5. To investigate the relationship between absorber materials (atomic number), absorption thickness and backscattering.
6. To verify the inverse square relationship between the distance and intensity of radiation.
7. To investigate the attenuation of radiation via the absorption of beta particles.
8. To determine the maximum energy of decay of a beta particle.
9. To measure the half-life of meta-stable Barium-137.

Apparatus:

- Set-up for ST-350 Counter
- GM Tube and stand
- shelf stand, serial cable, and a source holder
- Radioactive Source (e.g., Cs-137, Sr-90, or Co-60)

Figure 1: ST350 setup with sources and absorber kits

Principle of the Method

All nuclear radiations, whether they are charged particles or gamma rays, it will ionize atoms/molecules while passing through a gaseous medium. This ionizing property of a nuclear radiation is utilized for its detection. Geiger-Muller counter, commonly called as G-M counter or simply as Geiger tube is one of the oldest and widely used radiation detectors. It consists of a metallic tube with a thin wire mounted along its axis. The wire is insulated from the tube using a ceramic feed-through (Fig. 1). The central wire (anode) is kept at a positive potential of a few hundreds of volt or more with respect to the metallic tube, which is grounded. The tube is filled with argon gas mixed with 5-10% of ethyl alcohol or halogens (chlorine or bromine).

When an ionizing radiation enters the Geiger tube some of the energy of the radiation may get transferred to a gas molecule within the tube. This absorption of energy results in ionization, producing an electron-ion pair (primary ions). The liberated electrons move

towards the central wire and positive ions towards the negatively charged cylinder. The electrons now cause further ionization by virtue of the acceleration due to the intense electric field. These secondary ions may produce other ions and these in turn still other ions before reaching the electrodes. This cascading effect produces an avalanche of ions. In an avalanche created by a single original electron many excited gas molecules are formed by electron collisions in addition to secondary ions. In a very short time of few nanoseconds these excited molecules return to ground state through emission of photons in the visible or ultraviolet region. These photons are the key element in the propagation of the chain reaction that makes up the Giger discharge. If one of these photons interacts by photoelectric absorption in some other region of the tube a new electron is liberated creating an avalanche at a different location in the tube. The arrival of these avalanches at the anode causes a drop in the potential between the central wire and the cylinder. This process gives rise to a very large pulse with an amplitude independent of the type and energy of the incident radiation. The pulse is communicated to the amplifier through an appropriate RC circuit, and then to a counter which is called as scaler. Suitable arrangements are made to measure the counts for a preset time interval. The schematic diagram of the G-M tube and the associated electronic components is given in Fig. 2.
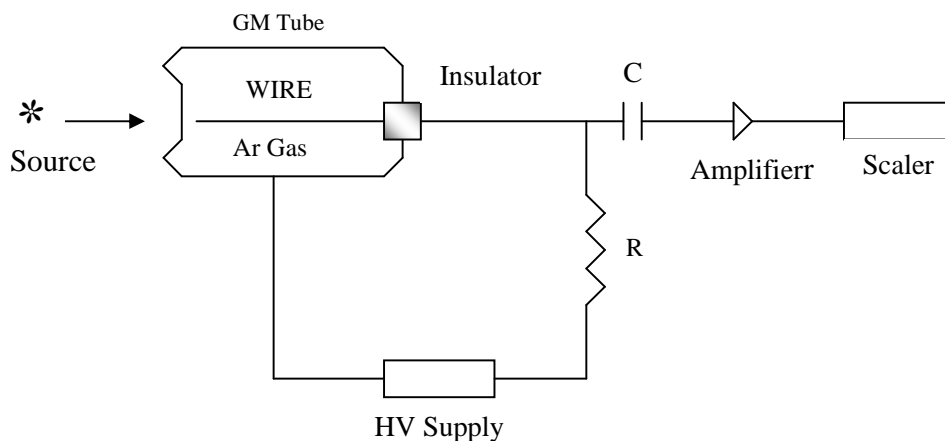

Figure 2: Schematic diagram of the G-M tube and the associated electronics

Dead Time

In nearly all detector systems, there will be a minimum amount of time that separates two events in order that they may be recorded as two separate pulses. In some cases the limiting time may be set by processes in the detector itself, while in other cases the limit may arise due to the

delays associated with the electronics. This minimum time separation is usually called the *dead time* of the counting system. Because of the random nature of radioactive decay, there is always some probability that a true event will be lost because it occurs too quickly following a preceding event. Two models of dead time are in common use, categorized on the basis of paralyzable and nonparalyzable response of the detector. The fundamental assumptions of the two models are illustrated in Fig. 3. At the center of the figure, a time scale is shown on which six randomly spaced events in the detector are indicated. At the bottom of the figure is the corresponding dead time behaviour of a detector to be nonparalyzable. A fixed time τ is assumed to follow each true event that occurs during the "live period" of the detector. True events that occur during the dead period are lost and assumed to have no effect whatsoever on the behaviour of the detector. In the example shown the nonparalyzable detector would record four counts from the six true events. In contrast, the behaviour of a paralyzable detector is shown along the top line of Fig. 3. The same dead time τ is assumed to follow each true interaction that occurs during the live period of the detector. True events that occur during the dead period are not recorded but they extend the dead time by another period τ following the lost event. In the example shown, only three counts are recorded for the six true events. The two models predict the same first-order losses and differ only when true event rates are high. They are in some sense two extremes of idealized system behavior, and real counting system will often display a behavior that is intermediate between these extremes . The detailed behavior of a specific counting system may depend on the physical processes taking place in the detector itself or on delays introduced by the pulse processing and recording electronics.

If the system dead time is τ, and the measured count rate is m, then the true count rate n predicted by the two models can be expressed as

Nonparalyzable Model : $n = \dfrac{m}{1 - m\tau}$.   (1)

Paralyzable Model   : $m = ne^{-n\tau}$.   (2)

The derivations of the above results are given in Ref. 1. You may show that for low counting rates ($n << \dfrac{1}{\tau}$) both models give the same expression for n. In the present experiment we will utilize the nonparalyzable model in the calculation of true counts and the dead time τ.
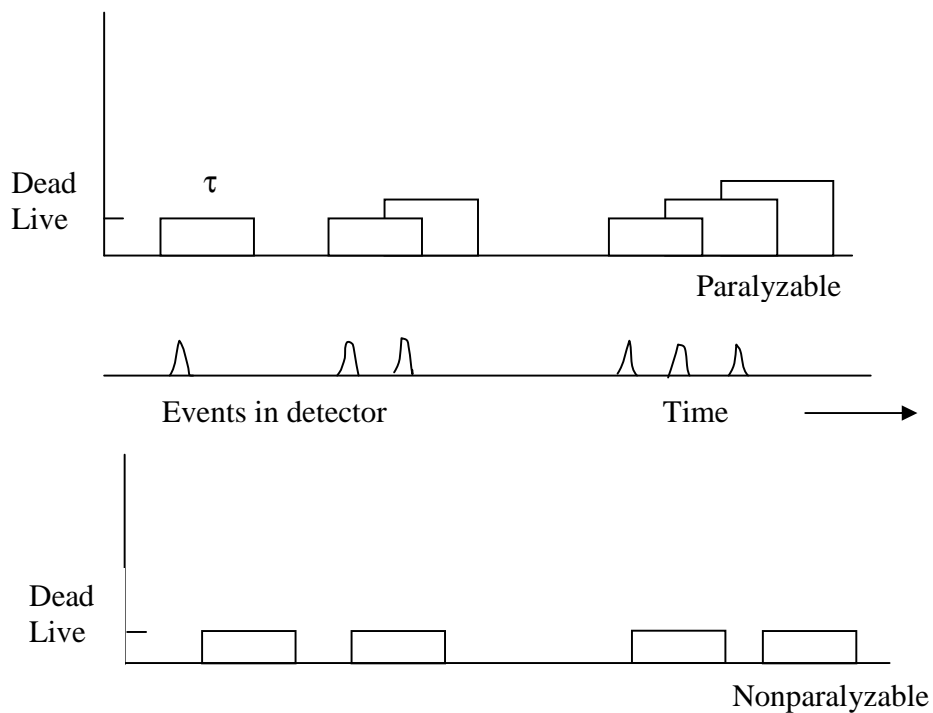
Fig 3: Illustration of two assumed models of dead time behavior of a radiation detector.

Setting up the equipment:

Warning! Dangerous voltages can exist at the GM and SCINT connectors. Ensure that the high voltage is set to zero or that the instrument is OFF before connecting or disconnecting a detector.

1. Connect the ST360 to its AC adapter.

2. Connect a GM tube to the GM connector via a BNC cable.

3. Enter the HIGH VOLTAGE mode and set the high voltage to the recommended value for the GM tube.

4. Place the radioactive source close to the GM tube's window.

5. Using the Operating Mode information described above, set the unit up to perform the desired function.

6. Press the COUNT button to start data acquisition, the STOP button to halt data acquisition (providing Preset Time is not being used), and the RESET button to reset the time and data to zero.

Experiments #1:

1. Operating plateau for the Geiger tube

The purpose of this experiment is to determine the voltage plateau for the Geiger tube and to establish a reasonable operating point for the tube. Fig. 3 shows count rate vs. voltage curve for a typical Geiger tube that has an operating point in the vicinity of 500 V.
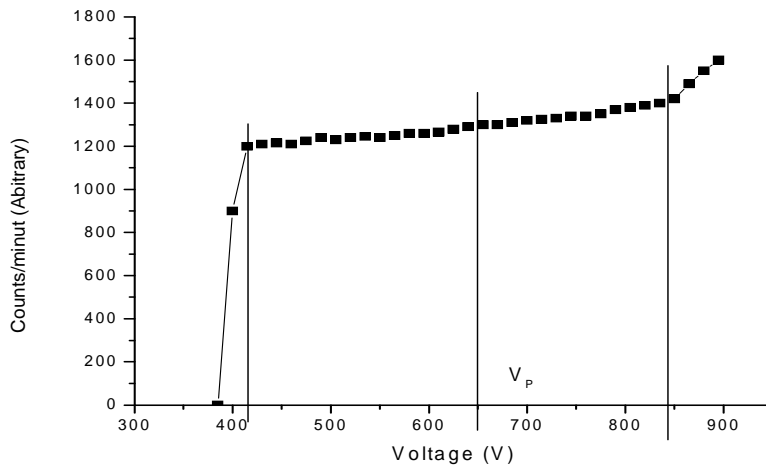
Fig. 3: Determination of operating voltage

Procedure

(i)   After setting up the equipment as described above place a γ source (^{137}Cs, ^{90}Sr, or ^{60}Co) in the lead castle at a suitable distance from the window of the Geiger tube.

(ii)   Find the voltage at which the GM tube just starts counting (~400V). Starting from this voltage take the number of counts N(V) for 30 s, thrice at each voltage V, in steps of 20 volts.   You will go over a plateau and should   stop   increasing the voltage as soon as the number of counts starts increasing very rapidly.

(iii)   Plot N(V) versus V. Choose a voltage on the central region of the plateau of N(V) vs. V curve. Perform all subsequent measurements (described below) at this voltage.

Table 1:

Date Table for Geiger plateau lab

Voltage (V)	Counts	Count rate
	…+…+…+	

Voltage (V)	Counts	Count rate

Don't forget to hand in this data sheet with a graph of the data

Experiments #2:

2. <u>Measurement of resolving (dead) time τ</u>

A commonly used method for dead time measurements is known as *two source method.* The method is based on observing the counting rate from two sources individually and in combination. Because the counting losses are nonlinear, the observed rate due to the combined sources will be less than the sum of the rates due to the two sources counted individually, and the dead time can be calculated from the discrepancy.

Procedure

(i)   To find the dead time we have to use two γ sources say S_1 (^{137}Cs) and S_2 (^{60}Co). While performing the experiment as per the steps given below, care must be exercised not to

move the source already in place and consideration must be given to the possibility that the presence of a second source will scatter radiation into the detector which would not ordinarily be counted from the first source alone. In order to keep the scattering unchanged, a dummy second source without activity is normally put in place when the sources are counted individually.

(ii)   Keep source S_1 in one of the pits in the source holder made for this purpose. Keep a dummy source in the second pit. Record the counts for a preset time (say 300 s).

(iii) Without removing source S_1 remove the dummy source from the second pit and keep the source S_2 in its place. Record the number of counts for the combined sources S_1 and S_2 for the same preset time as in (ii).

(iv) Remove source S_1 and measure the counts due to source S_2 alone, for the same preset time as in (ii).

(v)   Remove source S_2 as well and record the background counts for the same period.

Calculate the count rates in all the cases. Let n_1, n_2 and n_{12} be the true counts (sample plus background), with sources S_1, S_2 and (S_1 +S_2), respectively. Let m_1, m_2 and m_{12} represent the corresponding observed rates. Also let n_b and m_b be the true and measured background rates with both the sources removed. Assuming the nonparalyzable model, the dead time τ is given by (see Ref. 1 for details)

$$\tau = \frac{X(1-\sqrt{1-Z})}{Y} \; , \tag{3}$$

where $$X \equiv m_1 m_2 - m_b m_{12} \; , \tag{4}$$

$$Y \equiv m_1 m_2 (m_{12} + m_b) - m_b m_{12}(m_1 + m_2) \; , \tag{5}$$

and $$Z \equiv \frac{Y(m_1 + m_2 - m_{12} - m_b)}{X^2} \; . \tag{6}$$

Table 2:

Data sheet for resolving time lab

	n	m	τ	Error (%)
S1				
S2				
S12				

1. What is your GM tube's resolving (or dead) time? Does it fall within the accepted 1 μs to 100 μs range?

2. Is the percent of correction the same for all your values? Should it be? Why or why not?

Experiments #3:

3. <u>Statistics of radioactive decay process (Counting statistics)</u>

Radioactive decay is a random process. Consequently, any measurement based on observing the radiation emitted in a nuclear decay is subject to some degree of statistical fluctuations. These inherent fluctuations are unavoidable in all nuclear measurements. The term *counting statistics* includes the framework of statistical analysis required to process the results of nuclear counting experiments and to make predictions about the expected precision of quantities derived from these measurements.

Although each measurement (number of decays in a given interval) for a radioactive sample is independent of all previous measurements (due to randomness of the process), for a large number of individual measurements the deviation of the individual count rates from the *average count rate* behaves in a predictable manner. Small deviations from the average are much more likely than large deviations. These statistical fluctuations in the nuclear decay can be understood from the statistical models utilizing Poisson distribution or Gaussian (Normal) distribution. If we observe a given radioactive nucleus for a time t and define the *success* as "the nucleus decays during the process" then the probability of success "p" is given by $(1-e^{-\lambda t})$. The Poisson distribution applies when the success probability p is small and the number successes (i.e. number of counts measured) is also small (say <30). In practical terms, this condition implies that we have chosen an observation time that is small compared with the half-life of the source. When the average number of successes becomes relatively large (say > 30) we can utilize the Gaussian model of distribution. Since in most of the cases the count rates are reasonably large (few tens of counts per second) the Gaussian model has become widely applicable to many problems in counting statistics. On the other hand the Poisson distribution is applicable in the case of background counts. The details of experimental, Poisson and Gaussian distributions are given below.

Experimental distribution function

We assume that we have a collection of N independent measurements of the same physical quantity. In this particular case the quantity is the number of counts recorded by the detector in a specific time interval. We denote the result of these N measurements as

$$y_1, \ y_2, \ y_3 \ \ldots\ldots\ldots\ldots y_i\ldots\ldots y_N \ .$$

The experimental mean is given by

$$\bar{y} \equiv \frac{\sum\limits_{i=1}^{N} y_i}{N} \quad . \tag{7}$$

The data set is conveniently represented by a frequency distribution function *F(y)*. The value of *F(y)* is the relative frequency with which the number appears in the collection of data. By definition

$$F(y) \equiv \frac{number \ of \ occurrences \ of \ the \ value \ y \ [\equiv v(y)]}{number \ of \ measurements \ (= N)} \quad . \tag{8}$$

A plot of *F(y)* versus *y* gives the frequency distribution of the data (The number of occurrences can also be calculated by choosing a suitable interval for the values of *y*).

The standard deviation of the distribution is given by

$$\sigma_{\mathrm{exp}} = \left(\frac{1}{N} \sum\limits_{i=1}^{N} (y_i - \bar{y})^2 \right)^{1/2} . \tag{9}$$

Notes regarding σ_{exp} and $\bar{y}$

Remember that Eq. (9) is applicable to the quantities directly measured in the experiment and not to the derived quantities. To illustrate, in the present experiment if you measure the number of counts for a preset time interval (say 30 s) and call it y_i. Then Eq. (9) is applicable to these counts only and not to the counting rates calculated using these values. To determine the deviations for the derived quantities proper error propagation methods should be used.

To be precise, $\bar{y}$ is the true mean value determined from a set having infinitely large number of measurements and cannot be determined experimentally as such. However for a reasonably large set of measurements the value of $\bar{y}$ can be set equal to $\bar{y}$ (Eq. (7)).

The Poisson distribution

As mentioned above it is applicable when $p \ll 1$ and the number of successes are very few.

$$P(y) = \frac{(\bar{y})^y e^{-\bar{y}}}{y!} \quad .$$ (10)

In this case the standard deviation is given by

$$\sigma_p = \sqrt{\bar{y}} \quad .$$ (11)

The Normal or Gaussian distribution

When $p \ll 1$ and the successes are large one can model the experimental data using the Normal distribution which is also called Gaussian distribution (as per R.D. Evans it is erroneous to call this as Gaussian because its derivation by Gauss (1809) was antedated by those of Laplace (1774) and DeMoivre (1735)). This is given by

$$P(y) = \frac{1}{\sqrt{2\pi \, \bar{y}}} \exp\left(-\frac{(y-\bar{y})^2}{2\bar{y}}\right) \quad .$$ (12)

The standard deviation in this case is the same as that for the Poisson distribution

$$\sigma_G = \sqrt{\bar{y}} \quad .$$ (13)

We will denote both σ_p and σ_G as σ_{th}.

Applications of statistical models in nuclear physics

There are two major applications of counting statistics in nuclear measurements. The first application involves the use of statistical analysis to determine whether a set of multiple measurements of the same physical quantity shows an amount of internal fluctuation that is consistent with statistical predictions. In this case the motivation is to determine whether a particular counting system is functioning normally. The second application is more important in which we examine these methods to make a prediction about the uncertainty one should associate with a single measurement. The following procedure and analysis will give you a feel as to how an experimental distribution in a nuclear counting experiment looks like and how does it compare with theoretical distributions.

Procedure

(i)   Set the operating voltage of the Geiger counter at its proper value.

(ii)   Don't put any source in the lead castle. Also remove all the sources in the vicinity of the castle.

(iii)   Take 100 independent readings of the background counts for a preset time of 10 s. (To set Preset time 10 sec. follow step (ii) of initial procedure).

(iv)   Save the data by pressing **STORE** key. While taking 100 independent reading set ITERATION (Step (iii) of initial procedure) to 1.

(v)   Place one of the γ sources (^{137}Cs or ^{60}Co) far enough away from the window of the Giger tube so that approximately 2000 counts are recorded in a time period of 30 s. Take 100 independent readings of the counts for a preset time of 30 s.

(vi)   Save the data by pressing **STORE** key. While taking 100 independent reading set ITERATION (Step (v) of initial procedure) to 1.

(vii)   Transfer the data on PC and plot the required function.

Analysis of Background counts (data set (iii) above)

(viii)   Determine frequency of occurrence $\nu(y)$ which is the number of measurements in which $y = 0, 1, 2, 3, 4$ ….counts have been observed and plot the experimental distribution $\nu(y)$ versus y.

(ix)   Calculate the average number of counts $\bar{y}$ and the Poisson distribution

$$P(y) = \frac{(\bar{y})^{y} e^{-\bar{y}}}{y\,!}.$$

    Compare this distribution with the experimental distribution.

(x)   Calculate σ_{exp} *and* σ_{th} and compare. The comparison gives clue to the reliability of the measuring equipment. If σ_{exp} is larger than σ_{th}, it means that additional fluctuations have been introduced by the apparatus, such as spurious counts due to voltage surges, sparks in the tube or change of the background during the course of the experiment which can occur when you handle the sources (move from one place to another) while the measurements are going on.

(xi) Determine the actual number of intervals for which the absolute value of the deviation from the average is larger than the standard deviation $\sigma = \sqrt{y}$ and the probable error 0.6745σ. Compare with theory.

Analysis of the counts taken with the source data set (v) above

(xii) Carry out the analysis following steps (viii) to (xi) above. However, in this case use Gaussian distribution. Also, in order to represent the distribution in the best possible manner, frequency of occurrence may be calculated by choosing equally spaced, non-overlapping, contiguous intervals for the counts. The width of the interval can be anywhere from 2 to 10 counts or more depending on the data set.

(xiii) In addition, you may use different methods of testing the "Gaussian" nature of an experimental data which are illustrated in the book : Measurement systems, Applications and Design (4th edition) by E. O. Doebelin, pages 44-58

Table 3: Data Sheet for Statistics Lab

Run #	Counts

Run #	Counts

Data Set	Mean	Gaussian σ	Poisson σ
Background			
Cs-137			

Experiments #4:

4. Efficiency of a Geiger-Muller counter

From earlier experiments, you should have learned that a GM tube does not count all the particles, which are emitted from a source (like, dead time). In addition, some of the particles do not strike the tube at all, because they are emitted uniformly in all directions from the source. In this experiment, you will calculate the efficiency of a GM tube counting system for different isotopes by comparing the measured count rate to the disintegration rate (activity) of the source.

To find the disintegration rate, change from microCuries (μCi) to disintegrations per minute (dpm). The disintegrations per minute unit is equivalent to the counts per minute from the GM tube, because each disintegration represents a particle emitted.

The conversion factor is:

$$1 \text{ Ci} = 2.22 \times 10^{12} \ dpm \text{ or } 1 \text{ μCi} = 2.22 \times 10^{6} \ dpm \tag{1}$$

Multiply this by the activity of the source and you have the expected counts per minute of the source. We will use this procedure to find the efficiency of the GM tube, by using a fairly simple formula. You want to find the percent of the counts you observe versus the counts you expect, so you can express this as

$$\% \text{ Efficiency} = r(100)/CK \tag{2}$$

In this formula, r is the measured activity in cpm, C is the expected activity of the source in μCi, and K is the conversion factor from Equation 1.

Procedure:

1. Setup the Geiger counter as you have in the previous experiments. Set the Voltage of the GM tube to its optimal operating voltage, which should be around 900 Volts.

2. Set Runs to zero and set Preset Time to 60 to measure activity in cpm.

3. First do a run without a radioactive source to determine your background level.

4. Next, place one of the radioactive sources (Po-210, Sr-90, Co-60) in the top shelf and begin taking data.

5. Repeat this for each of your other two sources. Remember that the first run is a background number.

6. (OPTIONAL) From the Preset menu, change the Preset Time to 300, and take data for all three sources again.

7. Save your data to disk or to a data table before exiting the ST350 program.

Data Sheet for GM Tube Efficiency Lab

Date time: ……………………   Run duration: ………….

Source	Counts	Corr. Counts	Expected Cunts	Efficiency

Date time: ………………………   Run duration: ………….

Source	Counts	Corr. Counts	Expected Cunts	Efficiency

Are your results reasonable? How do you know? You should have numbers above zero but below 10 if you performed the experiment correctly.

Experiments #5:

5. <u>**Absorption of gamma rays in materials**</u>

When gamma rays pass through a foil a certain fraction of them is removed from the primary beam. If N is the number of gamma rays which enter a medium the number that emerge through thickness x is

$$N = N_o e^{-\mu x}, \tag{14}$$

where μ is called as the absorption coefficient of the medium. We therefore have

$$\ln N = -\mu x + \ln N_o \tag{15}$$

A plot of lnN vs x is thus a straight line where the slope gives μ. Find μ for Al and Cu using Cs-137 and Co-60 source. Compare your results with those reported in the literature (see page 686 of Ref. 2)

μ is also called as linear attenuation coefficient. The absorption of gamma rays in matter can also be characterized by mass absorption coefficient (μ_m). Eq. (14) then becomes

$$N = N_o e^{-\mu_m \rho_s} ,$$ (16)

where μ_m is the mass attenuation coefficient ($m^2 kg^{-1}$) and ρ_s is the mass per unit area of the absorber.

The probability of interaction is given in terms of the total cross-section σ which is the summation of individual cross-sections related to the photoelectric effect, the Compton effect and the pair production and is written as

$$\sigma = \sigma_{PE} + Z\sigma_C + \sigma_{PP} .$$ (17)

The factor Z in the second term embodies the assumption that all the atomic electrons contribute individually (and incoherently) to Compton scattering. For gamma ray energies above K-shell ionization energy of the atom, the Compton effect is more dominant and for the purpose of the present experiment the first and the third terms of Eq. (17) can be neglected. The cross-section σ_C is related to the absorption coefficient μ by

$$\sigma_C = \frac{\mu}{n_e}$$ (18)

where n_e is the number of electrons per unit volume in the material. Using Eq. (18) find the value of σ_C (express it in the units of barn (1 barn = 10^{-28} m^2)). Compare the values obtained for Cu and Al and give your comments on the findings.

Data : Density of Aluminum : 2.7 x 10^3 kg m^{-3} , Z =13.
Density of Copper : 8.92 x 10^3 kg m^{-3}, Z= 29.
Avogadro Number : 6.023 x 10^{26} molecule per kg mole .

Radiation is emitted from a source in all directions. The radiation emitted within the angle subtended by the window of the GM tube is the only radiation counted. Most radiation is emitted away from the tube but it strikes matter. When it does so, the direction of its path may be deflected. This deflection is known as scattering. Most particles undergo multiple scattering passing through matter. Beta particles especially may be scattered through large angles. Radiation scattered through approximately 1800 is said to be backscattered. For Geiger counters, the fraction of radiation emitted away from the GM tube that strikes the material supporting the sample. It is deflected toward the tube window and is counted.

A beta particle entering matter undergoes a series of collisions with mostly nuclei and sometimes orbital electrons. A collision between particles does not occur in the same manner we picture them in the macroscopic world. There are very little contact collisions, but instead the term, collision, refers to any interaction, coulombic or otherwise. (A coulombic interaction is an electrical attraction or repulsion that changes the path of the particle's motion.) A collision may be elastic or inelastic, but in either 50 case the result is not only a change in direction but usually a decrease in the energy of the beta particle as well (inelastic).

In the first part of the experiment, we will investigate the effect of the size of the nucleus on backscattering since this would seem most likely effect the number of backscattered beta particles. This can be determined by using absorbers as backing materials. Even though the metal pieces you will use are called absorbers, in this experiment, they will also be used to deflect radiation upward into the GM tube. To eliminate any other effects, the absorbers will be the same thickness but different atomic number (and thus different sized nuclei). In the second part of the experiment, you will use absorbers of the same material (atomic number) and different thickness. This is a common experimental technique, fixing one variable and varying another to investigate each one individually

Normally when we think of thickness, we think of linear thickness that can be measured in a linear unit such as inches or centimeters. However, in nuclear and particle physics, thickness refers to areal thickness. This is the thickness of the absorbers in mg/cm^2. The absorptive power of a material is dependent on its density and thickness, so the product of these two quantities is given as the total absorber thickness, or areal thickness. We determine areal thickness with the equation:

Density (mg/cm^3) $\times$ thickness (cm) = Absorber thickness (mg/cm^2)   (19)

You will determine the dependence that absorber thickness has on backscattering.

Procedure:

Part I – Atomic Number Dependence

1. Setup the Geiger counter as you have in the previous experiments. Set the Voltage of the GM tube to its optimal operating voltage, which should be around 900 Volts.
2. From the Preset menu, set Runs to zero and set Preset Time to 60.
3. First do a run without a radioactive source to determine your background level.

4. Next, place the radioactive source in the second shelf from the top and take data.

5. Place an absorber piece, or disk, in the source holder and place the source directly on top of it.

6. Repeat this for all of the various absorbers (different materials) including the unknown. (Plastic is poly-carbonate** – Z = 6, Aluminum – Z = 13, Copper – Z = 29, Tin – Z =50, and Lead – Z = 82)

7. Record the data to a file on disk or into a data table.

Part I – Thickness Dependence

8. Repeat 1-5 Setup the Geiger counter as you have in the previous experiments.

9. Place the source on a different thickness of the absorber and insert into the second shelf.

10. Repeat for at least three other absorber thicknesses and record the data to a file.

Data Sheet for Backscattering Lab

Date time: ……………………   Run duration: ………….

Element (Z)	Counts	Corr. Counts	% backscattering

Date time: ……………………   Run duration: ………….

Thickness (mg/cm^2)	Counts	Corr. Counts	% backscattering

What is your conclusion about the dependence of backscattering on atomic number? How about on thickness?

Experiments #6:

6. Inverse square relationship between the distance and intensity of radiation:

As a source is moved away from the detector, the intensity, or amount of detected radiation, decreases. You may have observed this effect in a previous experiment. If not, you have observed a similar effect in your life. The farther you move away from a friend, the harder it is to hear them. Or the farther you move away from a light source, the harder it is to see. Basically, nature provides many examples (including light, sound, and radiation) that follow an inverse square law.

What an inverse square law says is that as you double the distance between source and detector, intensity goes down by a factor of four. If you triple the distance, intensity would decrease by a factor of nine. If you quadruple the distance, the intensity would decrease by a factor of 16, and so on and so on. As a result, if you move to a distance d away from the window of the GM counter, then the intensity of radiation decreases by a factor $1/d^2$.

Procedure:

1. Setup the Geiger counter as you have in the previous experiments. Set the voltage of the GM tube to its optimal operating voltage, which should be around 900 Volts.

2. From the Preset menu, set Runs to zero and set Preset Time to 30.

3. First do a run without a radioactive source to determine your background level.

4. Next, place the radioactive source in the top shelf and begin taking data. In this position, the source is 2 cm from the GM tube's actual detector components.

5. Move the source down one shelf each time and take another run. You should see the data accumulating in the Data window. After all ten shelves have been used, save the data onto disk or record in a data table. Remember that the first run is a background number.

Table 6:

Data Sheet for inverse square law Lab

Date time: ……………………… Run duration: ………….

Counts	Corr. Counts	Distance	$1/d^2$

Use your graph to determine if the data does indeed obey inverse square law.

Experiments #7:

7. Absorption of beta particles

Beta particles are electrons that are emitted from an atom when a neutron decays by the weak force. The neutron (n) becomes a proton (p), an electron (e⁻), and an anti-neutrino ($\overline{\nu}$). When an electron originates in the nucleus, it is called a beta particle.

$$n \rightarrow p + e^- + \overline{\nu} \qquad (1)$$

Unlike alpha particles which are emitted from the nucleus with the same energy (~5 MeV), beta particles are emitted with a range of energies lying between 0 MeV and the maximum energy for a given radioactive isotope. The velocity of a beta particle is dependent on its energy, and

velocities range from zero to about 2.9 x 10^8 m/s, nearly the speed of light. So the beta particles do not all have the same kinetic energy and thus they do not all have the same range. When the range varies over different values, this is called range straggling. It represents the different energy losses all of the beta particles have given their different initial values. Figure 6 shows a typical absorption curve for beta particles, which illustrates the range straggling.
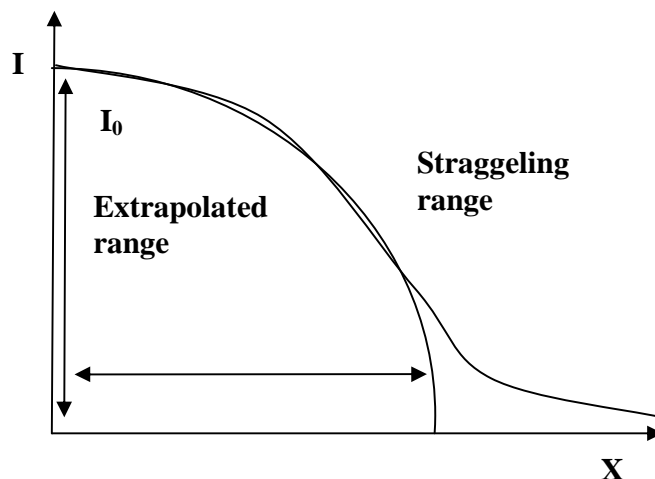

Figure 6: Typical absorption curve for beta particles. Plot is of intensity (activity) vs. absorber thickness (x).

Procedure:

1. Setup the Geiger counter as you have in previous experiments. Set the Voltage of the GM tube to its optimal operating voltage, which should be around 900 Volts.
2. From the Preset menu, set Runs to zero and set Preset Time to 60.
3. First do a run without a radioactive source to determine your background level.
4. Next, place the radioactive source in the second shelf from the top and begin taking data.
5. Place an absorber piece in the top shelf and take another run of data.
6. Repeat this minimum of 5 more times with absorbers of increasing thickness.

Table 7:

Data Sheet for inverse square law Lab

Date time: ………………………   Run duration: ………….

Counts	Corr. Counts	Thickness	In (Counts)

You should be able to characterize the relationship between beta particle activity and absorber thicknesses.

Experiments #8:

8. <u>Maximum energy of decay of a beta particle</u>

When beta particles are emitted from a nucleus, they are emitted over a wide range of energies. Recall that this is different from alpha particles, which are emitted monoenergetically. The maximum energy of the emitted beta particles is a characteristic signature for different radioisotopes.

In this experiment, you will find the range of beta particles by measuring their attenuation with absorbers and extrapolating the absorption curve. The range R will then be substituted into the formula

$$E_b = 1.84R + 0.212 \qquad\qquad (1)$$

where R is in g/cm^2. (Note that the units for R are not the same as the absorber thicknesses. You must convert at the end.) See Figure 7 for an example of an energy curve for beta particles.

The spectrum is not linear and "tails" off at high energy, which means that there are very few beta particles (This effect is seen with the phenomenon of range straggling, which was observed in the absorption curve in the previous experiment). The reason is that most of the beta particles cannot penetrate the absorber and most of the counts are background counts. Thus, one must assume linearity and extrapolate the line to the x-axis. There are two options to finding this x-intercept. The first is to find an equation for the best-fit line of the data in slope-intercept form, y = mx + b. Then set y = 0 and solve for the x value, since the x-intercept is the point on the line

where the y – coordinate is zero. The second method is to take a copy of the plot and use a rule to continue the linear part of the data through the x-axis and finding that point.
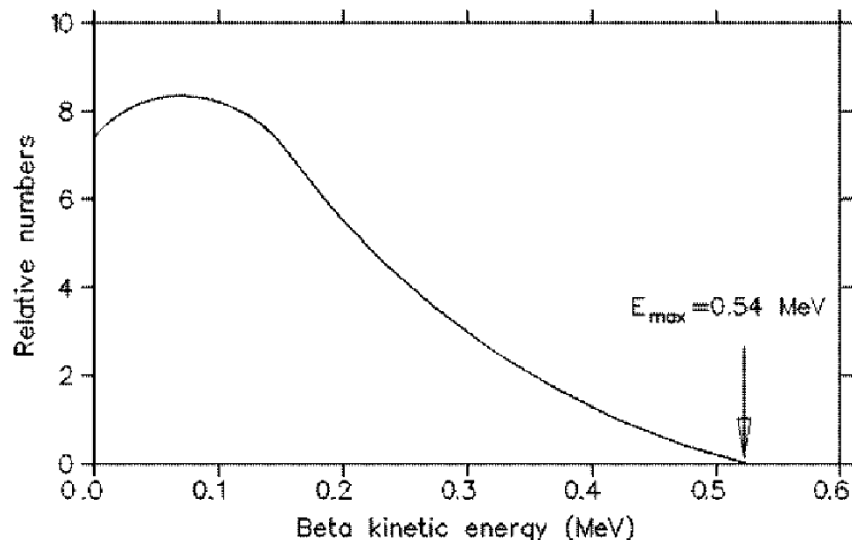

Figure 7: Typical plot of beta particle energy curve.

Procedure:

1. Set up the Geiger counter as you have in the previous experiments. Set the Voltage of the GM tube to its optimal operating voltage, which should be around 900 Volts.
2. From the Preset menu, set Runs to three and set Preset Time to 60.
3. First do a run without any absorber and with a radioactive source. Place the source in the second shelf and begin taking data. No background reading is taken because ^{204}Tl and ^{90}Sr are relatively strong beta sources (high count rates) and the background will be negligible (20-40 cpm).
4. Next, place the first absorber in the top shelf, directly above the source, and begin taking data.
5. Change your absorber each time for as many absorbers as the instructor gives to you. You should see the data accumulating in the Data window. After all the absorbers have been used, save the data onto disk or record in a data table.

Table 8:

Data Sheet for Beta Energy Lab

Date time: ……………………   Run duration: ………….

Counts	Corr. Counts	Thickness	ln (Counts)

Equation for line: y=

For y=0,   x= ……………………………. mg/cm^2

Conversion   x= ………………………….g/cm^2 (This is the range)

Use E = 1.84*R+0.212

    E= ………………………….MeV

You should have found the value for the maximum energy of a beat particle from your source and the percent error of this result when compared to the literature value. However, this percent error is not a good way to determine experimental error. As discussed in a previous lab, the best way to determine error is to use the standard deviation. So, calculate s for your value of E – you will have to use propagation of errors.

Experiments #9:

9. **Half life of Ba-137**

The decay of radioactive atoms occurs at a constant rate. There is no way to slow it down. The rate of decay is also a constant fixed rate regardless of the amount of radioactive atoms present. That is because there are only two choices for each atom, decay or don't decay. Thus, the amount of radioactive atoms we have on hand at any time is undergoing a consistent, continuous change.

The change in the number of radioactive atoms is a very orderly process. If we know the number of atoms present and their decay constant (probability of decay per unit time), then we can calculate how many atoms will remain at any future time. This can be written as the equation

$$N(t) = N - \lambda N \Delta t , \qquad\qquad (1)$$

where N(t) is the number of atoms that will be present at time t, N is the number of atoms present currently, λ is the decay constant, and Δt is the elapsed time. If the number of radioactive atoms remaining is plotted against time, curves like those in Figure 8 can be obtained. The decay constant can be obtained from the slope of these curves (discussed more below).
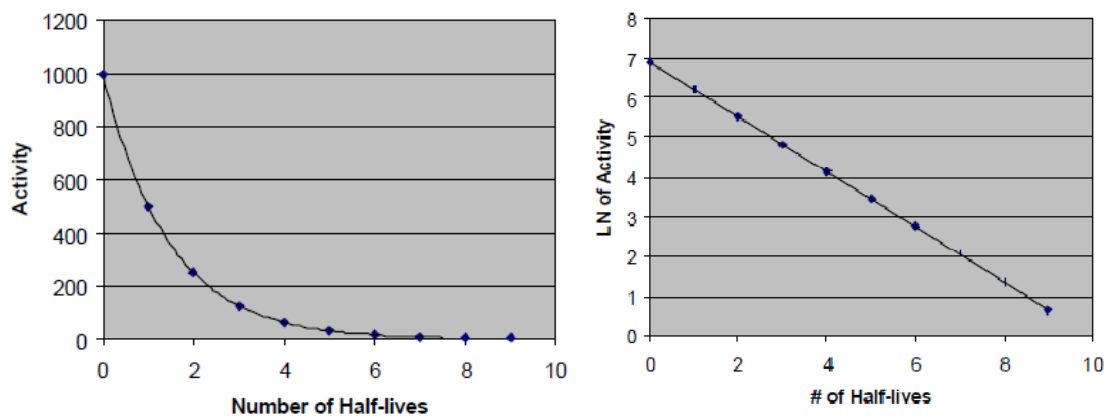

Figure 8: Exponential and Linear decay curves shown respectively

A more common way of expressing the decay of radioactive atoms is the half-life. The half-life of a radioactive isotope is the time required for the disintegration of one-half of the atoms in the original sample. In the graphs in Figure 8, 1000 atoms were present at t = 0. At the end of one half-life, 500 atoms were present. At the end of two halflives, 250 atoms were present, one-quarter of the original sample.

activity, since activity $= \frac{\# \ of \ counts}{time} = \frac{\# \ of \ atoms}{time}$. (Each count of a GM tube represents one atom decaying and releasing one particle or ray of radiation.)

Looking back at Equation (1) in a slightly rearranged form

$$N(t) - N = - \lambda N \Delta t. \qquad\qquad (2)$$

But *N(t)-N* is just the change in the number of radioactive isotopes of the original type present, so we can define

$$\Delta N = N(t) - N = -\lambda N \Delta t \ . \tag{3}$$

Dividing both sides of the equation gives

$$\frac{\Delta N}{\Delta t} = -\lambda N \tag{4}$$

but in calculus, we write changes, especially small, or infinitesimal, changes as

$$\frac{dN}{dt} = -\lambda N. \tag{5}$$

This is a separable differential equation that becomes

$$\frac{dN}{N} = -\lambda dt, \tag{6}$$

which can be solved by integrating both sides. When we do this we impose limits for the integrals, and pull λ out of the integral because it is a constant. The limits for dN'/N' are from N_o to N, which is from the initial number of particles (N_o) to the new amount of particles (N). The limits for dt are from the beginning, where $t=0$, to the end

$$\int_{N_0}^{N} \frac{dN'}{N'} = -\lambda \int_0^t dt' \tag{7}$$

The solution to this equation is

$$\ln(N) - \ln(N_0) = -\lambda t \tag{8}$$

Solving for ln(N), gives

$$\ln(N) = \ln(N_0) - \lambda t \tag{9}$$

Thus, if we plot the natural log of the number of atoms (or activity) versus time, we will get a straight line with slope = -l and y-intercept = $\ln(N_0)$. This would allow us to find the decay constant. Why?

We will need the decay constant in the next step, which is to find the half-life of the radioactive isotope we are studying. Starting from Equation (8) and applying a simple logarithmic identity, we get

$$ln\left(\frac{N}{N_0}\right) = -\lambda t \tag{10}$$

If we are considering the half-life, then N is one-half of No (reduced ratio) and t is $t_{1/2}$. This changes our equation to be

$$ln\left(\frac{1}{2}\right) = -\lambda t_{1/2} \tag{11}$$

Applying the reverse of our previous logarithmic identity, we get

$$\ln(1) - ln(2) = -\lambda t_{1/2} \tag{12}$$

The ln(1) = 0, so now we have $\quad -ln(2) = -\lambda t_{1/2}$ \hfill (13)

Finally, we can solve for the half-time

$$t_{1/2} = \frac{ln(2)}{\lambda}$$

14)

Procedure:

1. Setup the Geiger counter as you have in the previous experiments. Set the Voltage of the GM tube to its optimal operating voltage, which should be around 900 Volts.
2. From the Preset menu, set Runs to zero and set Preset Time to 30.
3. First do a run without a radioactive source to determine your background level.
4. Next, from the Preset menu, set the Runs to 31. (This will take 30 more runs so the total number of runs is 31.)
5. From the isotope generator, obtain 10-12 drops of Ba-137m. Place the radioactive source in the second shelf from the top and begin taking data.
6. Record the data to a file on disk or into a data table.
7. You may wish to do a second trial if time allows.

Table 9:

Data Sheet for Half Life

Date time: ……………………   Run duration: ………….

Time	Counts	Corr. Counts	In (Counts)
30			
60			
90			
120			
..			
..			
..			
660			
690			
720			

Data	λ	t$_{1/2}$	Error	# of σ 's
First Half				
Second Half				
whole				

The variable λ is the decay coefficient. If you assumed you plotted Equation (9), then the slope from the linear regression is the negative of λ

$$\lambda = -(slope) . \qquad (15)$$

From Equation (14), you can calculate the half-life:

$$t_{\frac{1}{2}} = \frac{\ln (2)}{\lambda} \approx \frac{0.693}{\lambda} \qquad (16)$$

If you perform the proper error propagation, then you will end up with a final equation of

$$\frac{\sigma_{t1/2}}{t_{1/2}} = \frac{\sigma_\lambda}{\lambda} \qquad (17)$$

Rearranging this equation to calculate $\sigma_{t1/2}$ gives

$$\sigma_{t1/2} = \frac{\sigma_\lambda}{\lambda}.t_{1/2} \qquad (18)$$

Now, to find the number of σ's that your result is away from the true value of t1/2 = 153 s, we use the following equation

$$\#of\ \sigma'\ s = \frac{|measured-true|}{\sigma_{t1/2}} \qquad (19)$$

What you measure is the distance from your result to the true value and then see how many standard deviations that is. The rule of thumb is that the result should be no more than 2 σ's away from the true value to be statistically good.

Sources of errors:

- What are the sources of error in each of the experiment?

Precautions:

1. While performing an experiment with one radioactive source other sources should not be present nearby. They should be put behind the lead shield.
2. Handle the radioactive sources with care. Don't touch in bare hand to the center of samples.
3. While handling the liquid radioactive samples please use hand gloves.

4. Don't put your mobile near to the detector. It may add some counts to the signal.

Questions:

1. What is the difference between Proportional counter and GM Tube?
2. What is the use of quench gas in GM Tube?
3. Write down the difference between dead time and paralysis time?
4. Comment on the different statistical distributions?
5. How absorption coefficient varies with density?

V. References

1. Glenn F. Knoll, "Radiation Detectors and Measurement", Chapters 3 and 7.

2. R.D. Evans, "The Atomic Nucleus", page 688.

3. R. M. Singru, "Introduction to Experimental Nuclear Physics".

4. Instruction Manual of G.M. Counting System TYPE: ST 360.