Experiment: Ionizing Radiation

This lab manual combines two (sub-)experiments: “Radioactive Decay of Radon” (also known as Radon) and “Radioactive Decay Counting Data” (also known as Geiger).

These two experiments are described on the following pages (Radon pp. 2-9, Geiger pp. 10-15).

Each experiment will be done in a single week, with the order depending on your section and subsection.

You will complete your Log Book for both experiments, but only create a Full Lab Report for “Radioactive Decay Counting Data”. The Full Lab Report length limit is 12 pages, not including the Cover page and Appendix.

Sub-experiment: Ionizing Radiation – Radioactive Decay of Radon

Goals

- Understand the origins of the exponential rate of decay of radionuclides.
- Measure radioactive decay rates to determine the half-life of a radioactive sample.
- Use an exponential fitting function to extract a half-life from measurement data.

Personal Protective Equipment & Safety

In addition to the standard safety rules for Second-year Physics Lab Courses, this lab involves electronic equipment with cable connections that should already be set up and a sealed, low-yield radioactive source (thorium oxide powder radiating at $< 74\,\mathrm{kBq}$; at a distance of 30 cm and over 3 hours, you would receive $< 1.3\%$ of the annual Canadian effective dose limit for the public). The Physics Undergraduate Labs (UGL) will supply personal protective equipment upon request. The following safety rules will be in effect for this lab:

- No food or drink will be allowed in the labs.
- Wear long pants, a dress, or the equivalent.
- Wear close-toed shoes.
- If you would like safety goggles or a lab coat, request them from your TA or bring your own.
- If you would like Nitrile gloves, request them from your TA.
- If you would like a mask, request one from your TA.
- Always turn power supplies off before setting up new electronic circuits.
- In the very unlikely case that an electroscope shatters, do not ingest or inhale the thorium-oxide powder and wash your hands thoroughly.

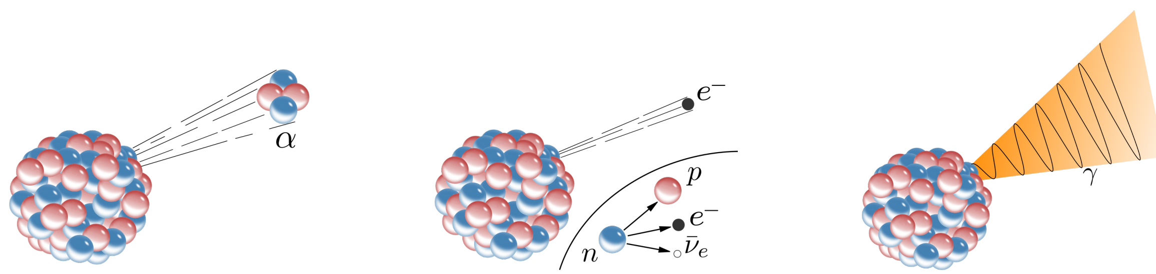
Required, Suggested, & Optional Equipment for Students

- Lab Book #1 & Pens (Required)
- Ruler (Suggested)
- Lab Coat (Optional); Either UGL-Supplied or Student-Owned
- Safety Goggles (Optional); Either UGL-Supplied or Student-Owned
- Nitrile Gloves (Optional); Either UGL-Supplied or Student-Owned
- Mask (Optional); Either UGL-Supplied or Student-Owned
- USB key (Optional)
- Laptop (Optional)

Background

Nuclear structure

Nuclei are composed of protons and neutrons, which together are called nucleons. These nucleons are bound together in a region on the order of 10^{-14} m (10 fm) by a force that acts between all nucleons, known as the "strong force." This force acts over only a very short range ($\sim$ 2 fm) and counteracts the repulsive Coulomb force between protons. Since the strong force acts between both neutrons and protons, the presence of neutrons increases the overall attractive force in the nucleus (overcoming the repulsive Coulomb forces) — up to a point — eventually the strong force "saturates" and the addition of more neutrons no longer increases the stability of the nucleus. The most stable configurations, it turns out, are those where the neutron number is approximately the same, or slightly bigger (for heavier nuclei) than the proton number. Together, these factors determine which nuclei are stable, and which are not. Unstable nuclei will tend to decay by one of three mechanisms: alpha-decay; beta-decay; or gamma-decay.



(a) (b) (c)

Figure 1: Nuclear decay processes: (a) Alpha (α-particle) decay; (b) Beta (β-particle — an electron or a positron) decay; and (c) Gamma (high-energy photon γ) decay. Credit: Inductiveload, Public domain, via Wikimedia Commons; https://commons.wikimedia.org/wiki/File:Alpha_Decay.svg, https://commons.wikimedia.org/wiki/File:Beta-minus_Decay.svg, https://commons.wikimedia.org/wiki/File:Gamma_Decay.svg.

Radioactive decay

The three main nuclear decay processes are illustrated in Fig. 1. Alpha decay is the emission of a helium nucleus (2 protons + 2 neutrons), known as an α-particle (Fig. 1a); beta decay is the emission of an electron or a positron (also known as a β-particle), which itself is created when a neutron decays to a proton, electron, and electron neutrino (β^- decay; Fig. 1b), or when a proton decays to a neutron, positron, and electron neutrino (β^+ decay); and gamma-decay is the emission of a high-energy photon (also known as a γ), which causes a reduction in the internal energy of the nucleus (the energy of the nucleus could be in an excited state because of a previous decay process that left it there, or due to a high-energy collision with another particle) (Fig. 1c).

Radioactive decay is a random process that depends on the details of the binding energy in each nucleus, and in each case, the probability that one of the decay processes happens is completely random — there is no way of knowing if a particle will decay, and it has no "memory" of having decayed in the past. Let us consider N nuclei in their original state. For a collection of many nuclei, therefore, the change in the number of nuclei in their original state $\Delta N = N(t_2) - N(t_1)$ per interval of time $\Delta t = t_2 - t_1$ is constant, and depends only on how many nuclei remain in their original state (i.e., if each has an equal chance of decaying at any time, the number of decays at any time will depend only on how many particles are present):

$$\frac{\Delta N}{\Delta t} = -kN \rightarrow \frac{dN}{dt} = -kN, \tag{1}$$

where k is a rate constant that describes the probability for decay and is a property of each type of nucleus. Here, k is defined as a positive constant, and the minus sign accounts for the fact that the number is decreasing as a function of time: ΔN is negative. Note that the number of decay products, N_d (α-particles, β-particles, or photons) produced in Δt is equal to the number of nuclei that decay in that time: $\Delta N_\mathrm{d} = -\Delta N$, so this equation also describes the rate of production of these particles. This relationship can be expressed as a differential in the limit of small Δt, which allows us to solve for N as a function of time:

$$\begin{aligned} \frac{dN}{N} &= -\, k dt, \\ \rightarrow N(t) &= N(0)\exp(-kt). \end{aligned} \tag{2}$$

To give k a physical meaning, it is often transformed into its inverse, which represents a time. The "half-life" $\tau_{1/2}$ is related to this constant; it is the time after which half of the original nuclei in the sample have decayed $N(\tau_{1/2})/N(0) = 1/2$ and $\tau_{1/2} = \ln(2)/k$.

Experimentally, it is often the *rate* of either nuclear decay or decay-product production that is measured. From the solution in Eq. 2, we see that the rate has the same exponential dependence on time:

$$\frac{\Delta N}{\Delta t} \rightarrow \frac{dN}{dt} = -kN(0)\exp(-kt). \tag{3}$$

The goal of this experiment is to determine the half-life of radon. Rather than measuring the time dependence of the number of radon nuclei directly, the goal is to measure the time-dependence of the *rate* of the radioactive decay, which also depends on the same time-constant.

Decay series

In nature, there are three series of radioactive decays that occur naturally. Each of these series is named after the long-lived radioactive isotope that has a half-life that is longer than any of the subsequently produced particles — the short-lived isotopes in the chain are also referred to as "descendents". These three natural series begin with Uranium-238 (^{238}U), Uranium-235 (^{235}U) and Thorium-232 (^{232}Th). In this experiment, we will look at one of the decay processes in the ^{232}Th series, which has a half-life that can be easily measured during the time of our lab.

Thorium-232 occurs naturally in the Earth's crust, and has a half-life of 1.405×10^{10} years. It goes through six alpha- and four beta-decays xbefore becoming a stable lead isotope, Lead-208 (^{208}Pb). The steps in this decay series, with their half-lives, are listed in Table 1.

Due to the dramatically different timescales for these processes, we can attribute changes that happen on one particular timescale to the process associated with it. In the case of this experiment, the $^{220}_{86}\mathrm{Rn} \rightarrow \alpha + ^{216}_{84}\mathrm{Po}$ process, with its 55 s half-life, is the one to which we will be sensitive.

Ionization by alpha-particles

The kinetic energy of the alpha particle emitted in the nuclear decay process can be quite large, due to the electrostatic repulsion of the positively charge alpha-particle with the positive nucleus, and the mass of the alpha-particle. In the $^{220}_{86}\mathrm{Rn} \rightarrow \alpha + ^{216}_{84}\mathrm{Po}$ process, 6.404 MeV are released as kinetic energy. Typically, these particles will collide with whatever is around them, and can easily cause the ionization of those particles, by causing the emission of electrons from those atoms and molecules. This ionization is a measure of the alpha-particle's existence, since they themselves do not travel far before being absorbed.

nuclide	decay mode	decay product	half-life
${}^{232}_{90}$Th	α	${}^{288}_{88}$Ra	1.41×10^{10} years
${}^{228}_{88}$Ra	β^-	${}^{228}_{89}$Ac	5.77 years
${}^{228}_{89}$Ac	β^-	${}^{228}_{90}$Th	6.13 hours
${}^{228}_{90}$Th	α	${}^{224}_{88}$Ra	1.9 years
${}^{224}_{88}$Ra	α	${}^{220}_{86}$Rn	3.6 days
${}^{220}_{86}$Rn	α	${}^{216}_{84}$Po	55 s
${}^{216}_{84}$Po	α	${}^{212}_{82}$Pb	0.15 s
${}^{212}_{82}$Pb	β^-	${}^{212}_{83}$Bi	10.0 hours
The ${}^{212}_{83}$Bi decay branch follows two paths:			
Path 1 occurs with 64% probability:			
${}^{212}_{83}$Bi	β^-	${}^{212}_{84}$Po	60.6 minutes
${}^{212}_{84}$Po	α	${}^{208}_{82}$Pb	299 ns
Path 2 occurs with 36% probability:			
${}^{212}_{83}$Bi	α	${}^{208}_{81}$Ti	60.6 minutes
${}^{208}_{81}$Ti	β^-	${}^{208}_{82}$Pb	3.1 minutes

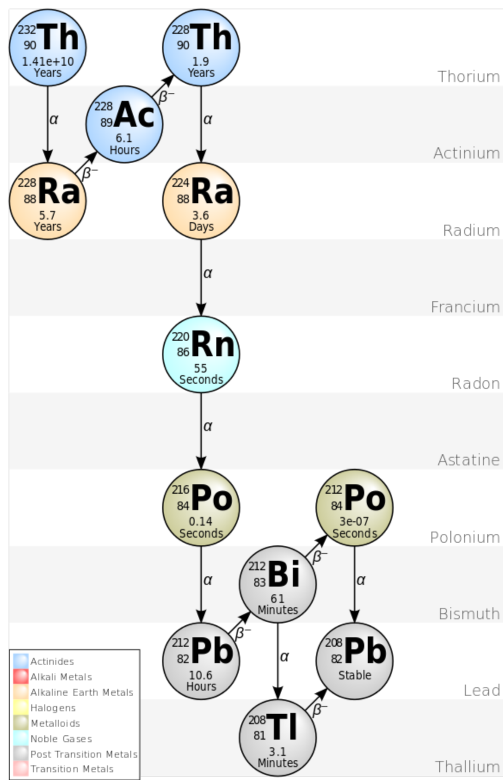
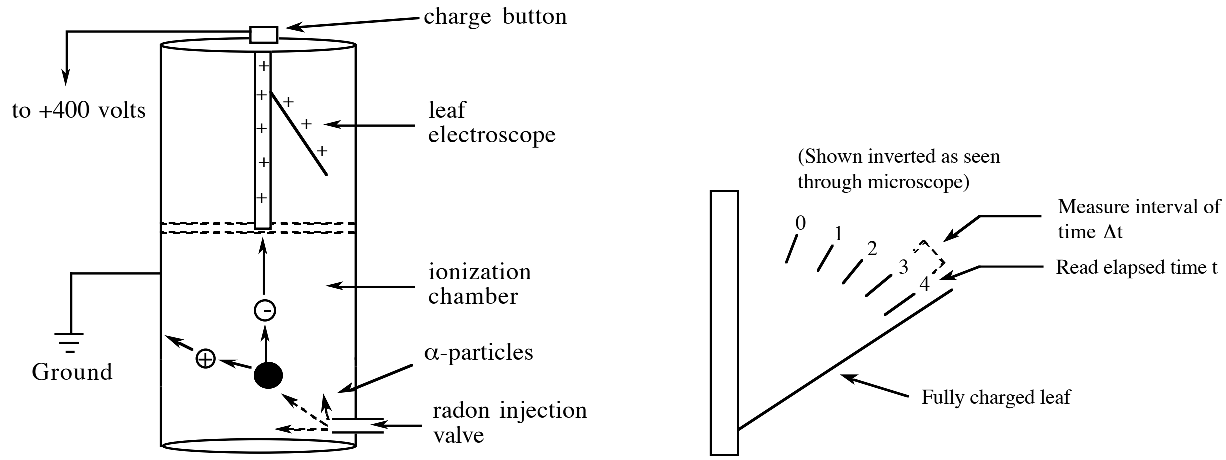


Table 1: (*left*) Thorium-232 decay series. The figure (*right*) displaying this decay series is used with permission under CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=16983885, author http://commons.wikimedia.org/wiki/User:BatesIsBack

Methods

Apparatus

The apparatus for this experiment consists of a radiation source, an ionization chamber, and an electroscope. The radiation source is thorium oxide powder, which contains $^{232}_{90}$Th. One of its decay processes is the $^{220}_{86}\text{Rn} \to \alpha + {}^{216}_{84}\text{Po}$ process discussed above. Radon-220 is a gas, and can be released into the ionization chamber by a pump that opens and closes a valve connected to the source.



(a) (b)

Figure 2: (*a*) An overview of the Radioactive Decay of Radon apparatus. The radon injection valve is operated by a hand-pump that is not pictured. (*b*) The leaf electroscope as viewed through the microscope.

Ionization chamber

The ionization chamber contains air, which will be ionized to liberate free electrons when alpha-particles are released into it. Since the electrons can travel through the air much farther than the alpha-particles, due to their size, their charge can be detected by the electroscope.

Electroscope

An electroscope is a simple instrument for detecting charge. This version, the gold-leaf electroscope, includes a vertical metal rod to which a thin “leaf” of gold is attached at the top. When charge is collected on the connected rod and leaf, they will repel each other due to electrostatic forces. The degree of repulsion will be proportional to the charge sitting on these metal components, and a measure of this charge can be determined by the angle of the leaf with respect to the rod. A numeric scale is included to quantify the position of the leaf, and a microscope objective can be used to view the position. This objective may need to be focussed.

In this apparatus, the electroscope may be positively charged by applying a large voltage between the case of the apparatus and the metal rod. A high voltage power supply can be connected via the red and black leads (red to + and black to GND). An additional lead should connect the COMMON terminals on the power supply to the GROUND terminal. A charge button connects the power supply to the rod, and can be used to transfer positive charge to the rod. The power supply should typically be set to no more than about 400 V. If the power supply is not on, the charge button can be used to ground the rod.

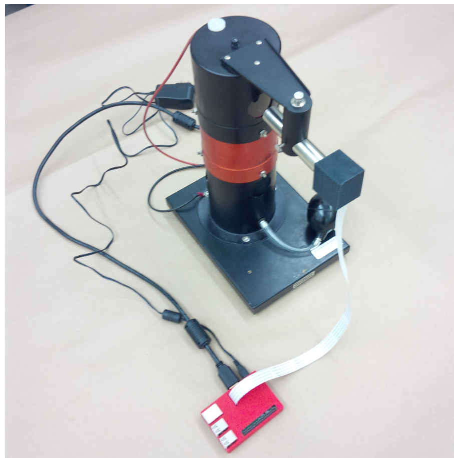


Figure 3: Pi camera on the Radon decay electroscope.

Timers

Two digital timers are used in this experiment. Use one timer to measure the time since radon was released (the post-release time); only reset the timer when new radon is injected into the ionization chamber. For each rate measurement, you should read the time at the beginning of your chosen interval (e.g., for the interval of marks 4–3, read the elapsed time when the leaf hits mark 4). Use the other timer to measure the duration of time the gold leaf travels through your chosen interval (i.e., the time needed to measure the rate; for the interval of marks 4–3, start the timer when the leaf hits mark 4 and stop the timer when it hits mark 3.) Reset the rate timer each time you recharge the electroscope.

Raspberry Pi cameras

Pi cameras might be available (**NOTE:** This may not be present due to the cameras being used for other labs) as an alternative to looking through the telescope by eye, see Figure 3 above). If the apparatus appears to be working stably enough (returning the leaf close to the same starting point every time you recharge using the momentary contact switch — this is not guaranteed; it depends on cleanliness inside the chamber and, in particular, around the contacts of the switch), then you can consider placing your own fiducial reference marks on the flat screen monitor (Post-It™ flags will be available for this purpose) to define a custom ΔQ interval that might be superior to the suggested (mark 4, mark 3) interval.

The Raspberry Pi camera can be run via command prompt in an LXTerminal window, (the icon beside the *Start* menu that looks like a monitor) by entering:

“raspivid -vs -t 0 -w 1291 -h 962 -p 10,40,1291,962”

The above options to raspivid create a 1291×962 resolution (e.g., 1/4 the resolution capacity of the first-generation Raspberry Pi Camera Modules) video-stabilized live-capture that previews nicely onto the monitors in the laboratory. This capture will run until you cancel it (e.g., by pressing "Control-c" in the LXTerminal window).

Procedure

1. Investigate how the electroscope works. Hitting the small button on top of the apparatus (the "charge button") connects the power supply to the metal rod. When the power supply is off, this can be used to discharge the electroscope. Turn on the power supply and charge the electroscope by pressing the charge button. Vary the voltage, press the charge button, and note the position of the gold leaf, as observed through the microscope.

2. Investigate the effect of radon in the system. After charging the electroscope, squeeze the hand pump to open the valve between the source and the ionization chamber.

   Questions to be answered:

   - What is the effect of the radon on the electroscope?
   - What happens if you again charge the electroscope (by pressing the charge button) after the release of radon?
   - What happens if you squeeze the pump multiple times?
   - Consider the *change* in the charge on the electroscope ΔQ as the leaf passes, say, from mark 4 to mark 3. If you recharge the electroscope and again let the leaf fall, how does ΔQ compare each time you allow the leaf to fall? How does the time change as a function of time after the release of radon?
   - As mentioned above, the goal of this experiment is to measure the time-rate-of-change of the radioactive nuclei, dN/dt in the apparatus. How does this rate compare to the time-rate-of-change of the *charge* dQ/dt measured by the electroscope?
   - How do you expect this rate to vary as a function of time after the release of radon into the apparatus?
   - It is best if you develop the necessary timing to run the chamber efficiently. We suggest you pump enough radon into the ionization chamber so that the very first measurement of time for the leaf to pass through your chosen ΔQ is less than 5 seconds.

3. Measure the time-dependence of the rate-of-change in charge dQ/dt on the electroscope using the two timers given. One timer will help determine the rate, while the other timer will determine the time since the release of radon into the chamber.

   - To measure the rate-of-change of charge at a specific post-release time, approximate the rate at that time as $\Delta Q/\Delta t$, where ΔQ is a change in charge and Δt is a change in time.
   - Note that the absolute value of the rates does not need to be known to determine the time constant; only the *relative* rate must be determined. Therefore, we can choose a specific ΔQ for every rate measurement, and measure Δt as a function of time after the release of radon into the chamber.
   - Use Timer 1 to measure the total elapsed time, t, since the radon injection ($t = 0$ at the time of injection).
   - Use Timer 2 to measure the rate, as a function of the time on Timer 1. To do this, choose a fixed ΔQ that will be used for all measurements, and use Timer 2 to determine Δt at several post-injection times, t. The electroscope may be recharged as many times as necessary. We suggest that for each injection of radon your first Δt is less than 5 seconds and your last Δt is approximately greater than 50 seconds.

4. After the radon is depleted from the ionizing chamber (think about the implications of radon's half-life), you may rerelease radon and repeat the experiment as many times as needed. You will need data from several injections of radon, each with multiple recharge/discharge cycles.

Analysis

Lab Book Evaluation

For both sub-experiments you will be completing a full analysis in your lab book, where these will be evaluated under the standard "Lab Book" rubric. You will not be completing a Lab Report for this sub-experiment.

Required Analysis in the Post-Lab Section of the Lab Book

1. Relate the time-rate-of-change of charge on the electroscope to the decay rate of radioactive nuclei, and justify why the time constant for these two processes is identical.
2. Using Eq. 3 as the starting point, make a plot and perform a fit to determine the rate constant, k. For your analysis, it should not be necessary to use the value of ΔN nor the value of $N(0)$; briefly explain why this is the case. Determine a rate constant for each injection of radon.
3. From the fit results, determine the half-life $\tau_{1/2}$ of the radioactive process you observed, taking the weighted average of half-lifes that you derive from individual injections of radon. Note, you do not need to include a graph for each measured decay in the final reporting; you can choose a representative one (if all of the decays were about the same, explaining that this is a representative decay) or the best one (if one stands out from the rest, show it and explain why you chose it).
4. Approximating each segment of the decay curve as linear will introduce a systematic error that becomes progressively larger as Δt grows in comparison to the true $\tau_{1/2}$. Predict whether this systematic error in the analysis will tend to make the experimentally-deduced $\tau_{1/2}$ smaller or larger than the true value.

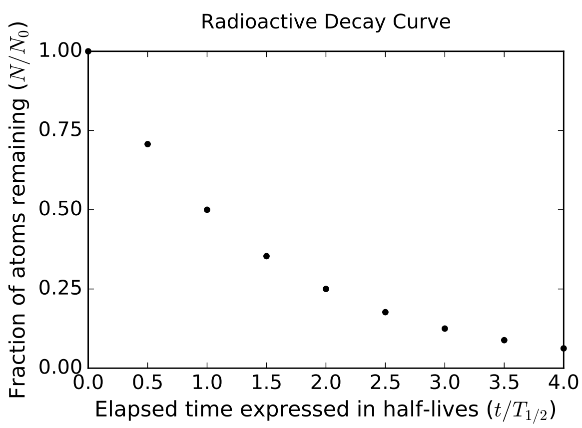


Figure 4: An exponential decay curve with the time axis labelled in units of a half life, $\tau_{1/2}$. The y-axis represents the *fraction* of atoms remaining, N/N_0. This figure shows data taken at a regular interval of Δt; however, remember that your Δt will be changing as t increases. Also note that you will be measuring $\Delta N/\Delta t$ as a function of time.

Important Notes: Read carefully the Lab Book Guidelines to include In-Lab and Post-Lab Notes. Make sure you add your observations about the experiment and discussion/conclusion requested for each tasks. In addition, don't forget to include setup detail including diagram (with appropriate and clear labels/captions), uncertainties including distance uncertainty, tilt consideration, and justifications.

Sub-experiment: Ionizing Radiation – Radioactive Decay Counting Data

Goals

- Use a Geiger-Mueller Tube to collect radioactive decay counting data.
- Learn how to interpret radioactive decay counting data.
- Gain familiarity with the statistics of discrete random events as described by the Poisson probability distribution function.
- Work with either low count rate data (single digit occurrences per observation on average, which reveal the asymmetry of the distribution) OR higher count rate data (double or triple digit occurrences per observation, where the asymmetry is expected to become unnoticeable and the shape indistinguishable from Gaussian, but crucially the Poisson distribution function has only one fit parameter, the mean value of the distribution).

Personal Protective Equipment & Safety

In addition to the standard safety rules for Second-year Physics Lab Courses, this lab involves electronic equipment with cable connections that should already be set up and three low-yield radioactive sources sealed (two Cesium-137 radiating at $< 185\,\mathrm{kBq}$ each, and one Strontium-90 radiating at $< 3.7\,\mathrm{kBq}$. The Sr-90 source is distributed to keep the sets together, but is not used in this experiment. At a distance of 30 cm and over 3 hours, you would receive $< 1.1\%$ of the annual Canadian effective dose limit for the public. The Physics Undergraduate Labs (UGL) will supply personal protective equipment upon request. The following safety rules will be in effect for this lab:

- No food or drink will be allowed in the labs.
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- If you would like Nitrile gloves, request them from your TA.
- Always turn power supplies off before setting up new electronic circuits.

Required, Suggested, & Optional Equipment for Students

- Lab Book #1 & Pens (Required)
- Ruler (Suggested)
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- Safety Goggles (Optional); Either UGL-Supplied or Student-Owned
- Nitrile Gloves (Optional); Either UGL-Supplied or Student-Owned
- USB key (Optional)
- Laptop (Optional)

Background

In many experiments in physics, one counts individual occurrences of an event. For instance, when throwing darts at a dartboard, one might count how many times your darts landed in a bin. The statistics of counting do not follow a Gaussian probability distribution; instead they follow a Poisson probability distribution. Here we will use the radioactive decay to provide events that can be either individually counted in a single observation, or where multiple events can occur within a single observation but still demonstrate the highly useful nature of the Poisson distribution function.

The Poisson Distribution

As radioactive disintegration is a random process, the number of disintegrations occurring in a certain time interval can be described by a probability. When repeated measurements of the number of events occurring in a given time interval are taken, different values for the number of disintegrations will be observed. The number of such events should be distributed statistically about a mean value according to a Poisson distribution, given by (Hughes&Hase Eqn. 3.11):

$$P(N; \bar{N}) = \frac{\bar{N}^N}{N!} e^{-\bar{N}}, \tag{4}$$

where $P(N; \bar{N})$ is the probability for observing N events in a time interval, while $\bar{N}$ would be the average (mean) number of events recorded in this interval assuming the same measurement was repeated many times. The number of occurrences N in a given measurement can only be a positive integer or zero. The mean number of occurrences over many measurements, $\bar{N}$, must be positive but isn't restricted to integers. As discussed in Ch. 3 of the textbook, the Poisson distribution can be derived as a special case of the binomial distribution where the probability of an event (an atom decaying) is very small and the sample size (number of atoms) is very large. It also can be shown that the standard deviation from the mean for many repeated measurements is equal to $\sqrt{\bar{N}}$.

Unlike the Gaussian distribution, the Poisson distribution is not symmetrical about the mean, instead tending to be skewed toward lower N values. For higher counting rates ($\bar{N} \gg 1$) the Poisson distribution evolves towards Gaussian in shape, still with mean and standard deviation $\bar{N}$, $\sqrt{\bar{N}}$.

Background Radiation

Low levels of radiation occur naturally on Earth, present from radioactive materials embedded in Earth's crust or in the atmosphere and cosmic radiation passing through the atmosphere. These decays are also measured by the Geiger counter, meaning that whenever experimental counts are low it is necessary to account for this background radiation. The correction is quite simple as the background count simply needs to be subtracted from the experimental value.

Methods

Apparatus

This experiment uses a Geiger-Mueller (G-M) tube connected to a SPECTECH ST 350 counting device.

Geiger-Mueller Tubes

The rate of emission of radiation is measured using a G-M tube in conjunction with an electronic counter that registers each incident decay particle. Each radiation particle produces a voltage pulse as it passes through the tube, a gas-filled cylinder containing a straight central wire that produces a high positive voltage directed to the outer surface of the tube. A schematic of the G-M tube is shown in Figure 5.

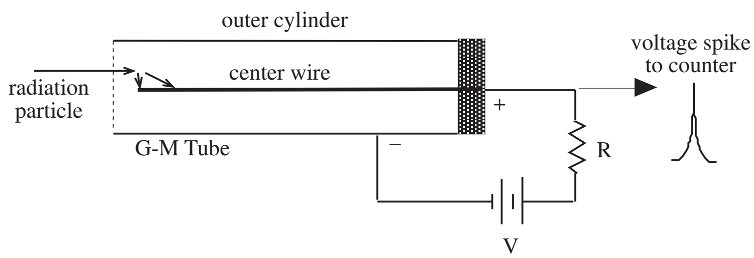

Figure 5: Graph of counting rate versus applied voltage for a Geiger Mueller tube.

The voltage spike measured on the counter occurs when a beta particle or a gamma photon enters the tube (alpha particles cannot penetrate the metal structure). Some atoms comprising the gas within become ionized, producing electrons and positive ions. These charges are then accelerated by the voltage toward opposite electrodes, causing further ionization in the process. Thus, when the electrodes are reached, a large current flows out of the tube. However, the current quickly drops to zero once all the particles have reached an electrode, the end result of which is that a single voltage spike occurs across the resistor, which is subsequently registered by the electronic counter. For each successive radiation particle, the same process occurs, producing an associated voltage spike.

However, whenever a voltage spike is produced in the tube, it takes a short time $(100 - 400\ \mu\text{s})$ for the tube to recover to its initial state. This time of recovery is known as the dead-time of the tube since the tube can not effectively count any more radiation particles during this time period. At low counting rates, the effect of dead-time is negligible; at high counting rates, the tube misses a larger percentage of the particles, reducing the number of observed counts. Thus, the dead-time of a tube must be measured and accounted for.

To determine the dead-time, τ_{dead}, of a Geiger tube, the counting rate C for two sources must be measured. First, the counting rate is obtained for one gamma source, then a second gamma source is placed directly beside it to measure the combined rate (they must be the same distance away from the counter). Finally, the first source is removed such that the second source's counting rate can be measured. Due to dead-time, the count rate $C_{1\&2}$ for both sources together would be slightly less than the sum of the count rates $(C_1 + C_2)$ of the individual sources, yielding an equation for the dead-time:

$$\tau_{dead} = \frac{(C_1 + C_2) - C_{1\&2}}{2C_1C_2} \tag{5}$$

where τ_{dead} is in seconds and the C_n variables all measure counts/s.

SPECTECH ST 350 Counting Device

The SPECTECH uses a *Display Function* dial to select various modes on the device. The *Preset* buttons are used to change settings. The *Count*, *Stop*, and *Reset* buttons are used to run the device.

The SPECTECH powers the G-M tube for a specified time interval that can be entered by turning the dial to Time and using the *Preset* buttons to select the desired interval as shown on the display (measured in seconds). Use the *Count* button to run the device, turning the dial to *Counts* to display the results on the screen. Note that when the time interval is changed after a run, the *Reset* button should be pressed immediately before doing anything else on the SPECTECH.

The Geiger Plateau

For the G-M tube to be operated effectively, a voltage must be applied across the tube. This voltage must be properly set before any measurements are taken. If the voltage is too low, the passage of radiation into the tube will not cause a voltage pulse. But if the voltage is set too high, the tube will discharge spontaneously and register counts in the absence of radiation. A characteristic curve for a G-M tube can be obtained by graphing the counting rate versus applied voltage, as shown in Figure 6.

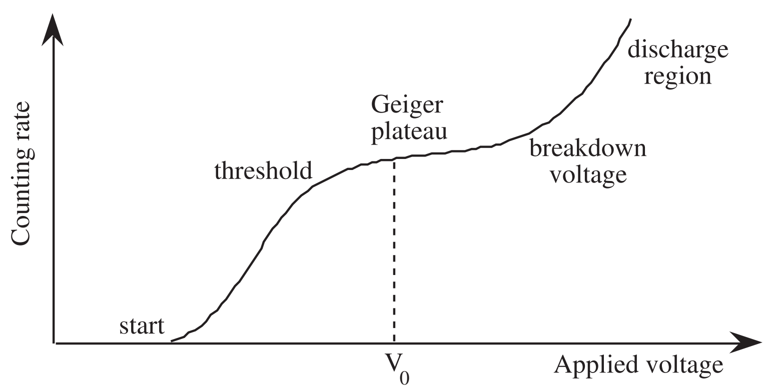

Figure 6: Geiger voltage curve.

The region where the number of counts is approximately linear and changes very little with voltage is called the Geiger Plateau. It is optimal to select an operating voltage V_0 along the plateau, typically 150 V above the threshold. This both improves the accuracy and lifetime of the device.

Procedure

Dead-Time

1. To determine the operating voltage of the G-M Tube, place a Cesium-137 source ~ 5 cm away from the Geiger tube. Increase the High Voltage setting until the Activity light begins to blink. Then increase the voltage by another 150 V. Record the operating voltage and avoid changing it for the rest of the experiment.
2. Place each Cesium-137 source close enough to the tube such that the count rate from each source at the same distance is greater than 100 counts/s using 10.00 second intervals. Record the counts for both sources and the source distance.
3. Once the source distance has been determined, set the timer to count for 100.00 seconds to improve the accuracy of the counter. Place the first Cesium-137 source on the track and measure the detected counts, aiming to have a result greater than 10,000 counts. Ensure that the second source is far enough away so as to avoid contributing any excess radiation.
4. Now, position the second Cesium-137 source beside the first source and measure the counts, then remove the first source without disturbing the second source, measuring the counts of only the second source.
5. Repeat Steps 3–4 again such that at least two sets of the three measurements are collected.

Statistical Decay

You have two options to choose from.

’Low’ count rate option:

1. Place a gamma source a sufficiently far distance from the Geiger tube so that the average count rate is 1–2 counts/s. Obtain 100 measurements of the observed counts over 10 second intervals.
2. Remove the gamma source and collect background counts until you can report the background count rate to a fractional uncertainty of 0.1.

‘High’ count rate option:

1. Place the gamma source close enough to the Geiger tube to obtain a count rate of ~ 20 counts/s or more. Obtain 100 measurements of the observed counts over 10 second intervals.
2. Remove the gamma source and collect background counts until you can report the background count rate to a fractional uncertainty of 0.1.

Analysis

Lab Book and Lab Report Evaluation

For this experiment you will be completing standard analysis in your lab book, where this will be evaluated under the standard "Lab Book" rubric. You will also be completing a "Full Lab Report", where this will be evaluated under the standard "Lab Report" rubric. The Full Lab Report is 12 pages maximum where the length limit **does NOT** include the Cover page and Appendix.

Important Notes: Read carefully the Lab Book Guidelines to include In-Lab and Post-Lab Notes. Make sure you add your observations about the experiment and discussion/conclusion requested for each tasks. In addition, don't forget to include setup detail including diagram (with appropriate and clear labels/captions), uncertainties including apparatus uncertainty and justifications.

Required Analyses

- ◇ Estimate the dead-time, τ, of the G-M tube using Equation 5.
- ◇ Create a histogram of your measurements (as in the Dartboard Statistics experiment). Exercise 3.7 in Hughes & Hase gives an example of histogrammed radioactive decay counting data.
- ◇ Use the sample script `PoissonDataPlotandUnweightedFit.py` as a starting point for the analysis compare your observations to the Poisson distribution.
- ◇ Determine the background counting rate $C_B = \frac{N_B}{T}$ and its uncertainty.
- ◇ Determine the counting rate $\bar{C} = \frac{\bar{N}}{T}$ and its associated error for the average number of counts.
- ◇ Correct for the background counting rate to calculate the counting rate $\bar{C}'$ of the gamma source and its uncertainty.

Additional discussion and derivation required in the Lab Report

1. Justify the choice to keep V_0 constant during this experiment.
2. Suppose that N counts were recorded by the detector. If the counter is "dead" for τ seconds after each count, then the tube is dead for $N\tau$ counts. Derive an expression for the true count rate in terms of the measured count rate C and the dead-time of the tube. Using your value of τ, calculate the dead-time corrected count rate $\bar{C}'$ if the observed rates were 200 counts/s, 100 counts/s and 50 counts/s. Below what rate is the effect of dead-time insignificant $(\leq 1\%)$ and, thus, neglectable? You may assume that $C_B = 0$ for this exercise, but should state that in your Report.
3. Explain whether it is necessary to account for the tube dead-time for the 100 statistical measurements.