The Islamia University of Bahawalpur

DEPARTMENT OF PHYSICS

Physics Lab-V (Phy-01505/Phy-21105) and VI (Phy-01604/Phy-21205)

Geiger Muller (GM) Counter

Purpose:

The purpose of this experiment is to make the students familiar with the Geiger Muller counter, a widely used pulse counting instrument that uses gas amplification which makes it remarkably simple and sensitive but whose simple construction makes it relatively inexpensive. The experiments that are designed to accomplish this purpose deal with the operating plateau of the Geiger tube, half-life determinations, resolving-time corrections and the basic nuclear considerations involved.

Description:

Basically the Geiger counter consists of two electrodes with a gas at a reduced pressure between the electrodes (**Fig. 1**). The outer electrode (called cathode) is usually a cylinder while the inner electrode (called anode) is a thin wire positioned in the center of the cylinder. The voltage between these two electrodes is maintained at such a value that virtually any ionizing particle entering the Geiger tube will cause an electrical avalanche within the tube. The Geiger tube used in this experiment is called **an end-window tube** because this has a thin window at one end through which the ionizing radiation enters.

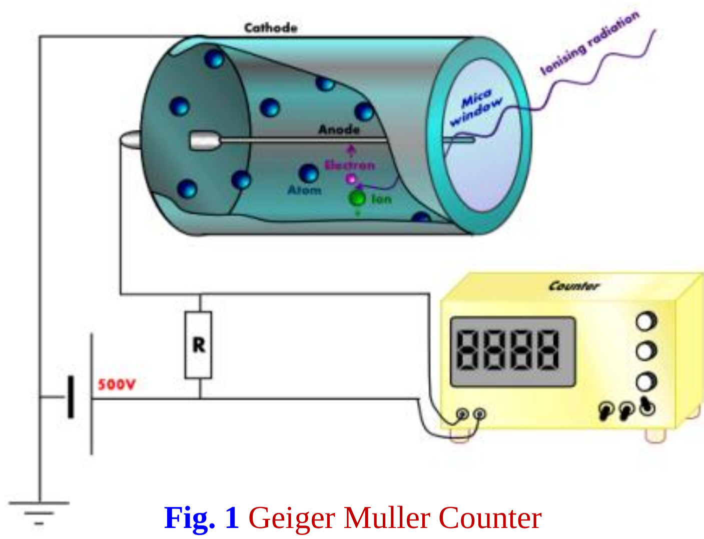


Fig. 1 Geiger Muller Counter

The Geiger counter does not differentiate between kinds of particles or energies, it tells only that certain number of particles (Betas and Gammas for this experiment) entered the detector using its operation. The voltage pulse from the avalanche is typically greater than 1 volt in amplitude. These pulses are large enough that they are counted in the scalar directly without any amplification.

Part-1: Measurement of Operating Conditions [Operating Voltage (V_{op})] of GM Tube

The purpose of this experiment is to determine the voltage plateau for the Geiger tube and establish a reasonable operating point for the tube. **Fig. 2** shows a counts-vs.-voltage curve for a typical tube that has an operating point in the vicinity of 400 volts (This value is different for different Geiger tubes).

The region between R_1 and R_2 (corresponding to voltages V_1 and V_2) is called the Geiger region or plateau region. Voltage greater than V_2 causes continuous discharge in the tube and will definitely shorten the life of the tube.

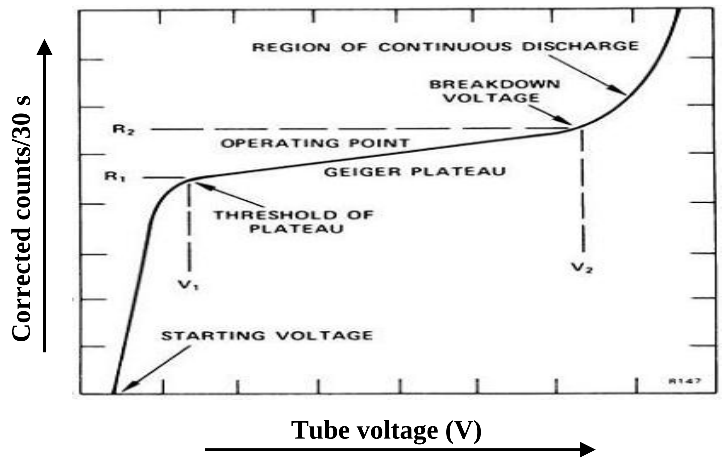


Fig. 2 Geiger Tube Plateau

Procedure:

1. Connect the Geiger tube with the scalar.
2. Place the Beta source Sr^{90} at the distance of approximately 5 cm from the window of Geiger tube.
3. Increase the (+ve) high voltage until the scalar just begins registering counts. This point is called starting voltage. In **Fig. 2** starting voltage is greater than 360 volts.
4. Reset the scalar and note the counts for 100 s, increase the high voltage by 20-volts and note the counts again for 100 s.
5. Continue making measurements at 20-volts interval until you have enough data to plot a curve on a linear graph paper similar to the **Fig. 2**. The region between V_1 and V_2 is usually less than 200 volts. A sharp rise in a counting rate will be observed if you go to just above V_2. When this happens the upper end of the plateau has been reached. Reduce the voltage to V_2 immediately. Choose the operating point for the tube at about 50% to 70% of plateau range.
6. Evaluate your Geiger tube by measuring the slope of plateau from the graph, it should be less than 10%. Slope of the plateau is defined as,

$$\text{Slope} = \left[\frac{R_2 - R_1}{R_1}\right]\left[\frac{100}{V_2 - V_1}\right]\% \text{ .... (1)}$$

Background counts/counts without source

No. of Obs.	Tube voltage (V)	Counts/100 s			Mean counts
		1	2	3	
1	300				
2	320				
3	340				
.	.				
.	.				
.	.				
.	500				

Reading with source/Sr-90

No. of Obs.	Tube voltage (V)	Counts/100 s			Mean counts	Corrected counts [with source-without source]
		1	2	3		
1	300					
2	320					
3	340					
.	.					
.	.					
.	.					
.	500					

$$V_{op} = \frac{V_1 + V_2}{2} = \_\_\_\_\_\_ \text{ volts}$$

Part-2: Resolving Time Correction for the GM Counter

Purpose:

Once an ionization avalanche has produced a discharge in the tube, no pulse can be generated at the output of the tube until the ionization is cleared from the tube. This time interval during which no pulse can be recorded is called the dead time of the counter.

During the dead time no current can be received and the particles coming in this interval are lost. An account has to be made of these lost counts to get the true counts.

In some experiments we use fast electronics (nano-seconds). The Geiger counter, however, is a slow device, when used for counting rates above 5000 counts/min, it is necessary to make a dead time correction to obtain the true counting rate. The double source technique is used to determine this dead time.

Procedure:

1. Place the source S_1 (Sr^{90}) 5 cm from the window and make a 100 s count. Record the number of counts. Define this count to be R_1.
2. Place the source S_2 (Co^{60}) 5 cm from the window and make a 100 s count. Record the number of counts. Define this count to be R_2.
3. Place both sources S_1 and S_2 simultaneously at the same distance and observe the counts for 100 s. Define this quantity to be R_T.
4. Calculate the resolving time, T_R of GM tube with the following formula:

$$T_R = \frac{R_1 + R_2 - R_T}{2R_1R_2} \text{ min/counts} \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (2)$$

The true counting rate then can be determined for an observed counting rate R_o, from the following formula,

$$R = \frac{R_o}{1 - R_oT_R} \text{ counts/min} \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3)$$

Note: Dead time correction should be used to correct any counting rate that is above 5000 counts/min.

Part-3: Random Nature of the Radioactive Radiations being emitted from a Radioactive Source

Purpose:

Radioactive decay process is quite random and follows the laws of statistics (or chance). The process cannot be speeded up or slowed down by any physical or chemical change (e.g. heating, cooling, applying pressure, electric or magnetic fields etc.).

Procedure:

1. Set the operating voltage equal to the one calculated in part-1.
2. Place the source (Sr^{90}) 5 cm from the window and record the counts against 10 s interval.
3. Repeat the above step 99 times and feed the data in table below.

No. of obs.	Counts/10 s		Mean counts a	$\bar{x} - a$	$(\bar{x} - a)^2$	$f_g(a) = \frac{1}{2\pi\sigma^2} e^{\frac{-(\bar{x}-a)^2}{2\sigma^2}}$
	1	2				
1						
2						
3						
.						
.						
.						
50						

$$\bar{x} = \frac{\sum a}{50} = \_\_\_\_\_\_\_\_\_\_$$

$$\sigma = \sqrt{\frac{\sum(\bar{x} - a)^2}{50}}$$

$$\sigma = \pm \_\_\_\_\_\_\_\_\_\_$$

$$\bar{x} + \sigma = \_\_\_\_\_\_\_\_\_\_$$

$$\bar{x} - \sigma = \_\_\_\_\_\_\_\_\_\_$$

$$\text{\%age accuracy of the data} = \frac{values\ in\ between\ (\bar{x}-\sigma) and\ (\bar{x}+\sigma)}{50}$$

$$\text{\%age accuracy of the data} = \frac{32}{50} = 0.64\ or\ 64\%\quad \text{(For example)}$$

Actual value = 68.3%

$$\text{\%age error} = \frac{calculated\ value - actual\ value}{actual\ value} \times 100\%$$

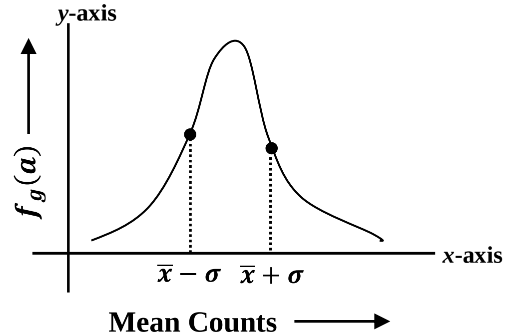


Fig. 3 Gaussian distribution Function

Part-4: Measurement of Linear Absorption Coefficient of γ-particles through Pb-sheets.

Purpose:

When gamma radiation passes through matter, it undergoes absorption primarily by Compton, Photoelectric and Pair-production interactions. The intensity of the radiation is thus decreased as a function of distance in the absorbing medium (as shown in **Fig. 4**).

The mathematical expression for the intensity I is given by the following expression,

$$I = I_o\, e^{-\mu x} \quad \ldots\ldots\ldots\ldots. (4)$$

Where,

I_o = original intensity of the beam.

I = intensity transmission through an absorber of a thickness x.

μ = linear absorption coefficient for the absorbing medium.

If we rearrange the equation-4 and take the logarithm of both sides, then we have

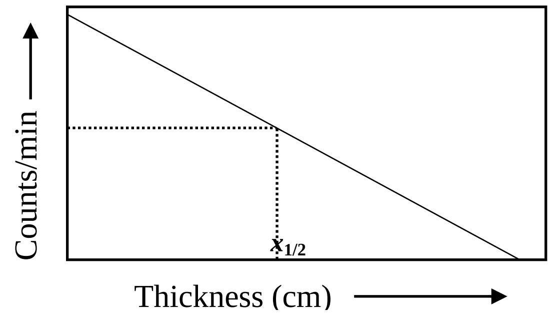


Fig. 4 Graph between Thickness & Intensity

$$ln\left[\frac{I}{I_o}\right] = -\mu x$$

$$\frac{1}{x} ln\left[\frac{I}{I_o}\right] = -\mu \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The half value layer (HVL) of the absorbing medium is defined as that thickness $x_{1/2}$ which will cut the initial intensity in half. That is $I/I_o = 0.5$, if we substitute this value in equation-5 then we have.

$$ln(0.5) = -\mu x_{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

$$x_{1/2} = 0.693/\mu$$

Or, $$\mu = 0.693/x_{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

Experimentally, the usual procedure is to measure $x_{1/2}$ and then calculate the μ from the above equation.

Procedure:

1. Set the voltage of the tube at its operating value (calculated in Part-1).
2. Place the gamma source, say Co^{60} about 5 cm from the window of the tube, and make a 100 s count. Record the number of counts.
3. Place the first sheet of lead of minimum thickness between the source and the G.M tube, and take another 100 s count and record the value.
4. Place the second sheet of higher thickness and make another 100 s count.
5. Continue taking 100 s counts with different sheets of increasing thickness, until the number of counts is 25% of the number recorded without the absorber.
6. Make a 100 s background run and subtract this value from each of the above counts.
7. Note the density thickness of lead given in **gm/cm^2**, convert it into thickness (by dividing density thickness to density of lead) and plot a graph between the corrected counts as a function of absorber thickness. The density thickness is defined as the product of density in **gm/cm^3** times the thickness in **cm** of the absorber. Draw the best straight line through the points and determine $x_{1/2}$ and hence μ.
8. The linear absorption coefficient **μ** and the mass absorption coefficient **μ_m** are related as,

$$\boldsymbol{\mu = \mu_m \rho} \text{ cm}^{-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

Part-5: Measurement of Linear Absorption Coefficient of β-particles through Al-sheets.

Procedure:

1. Set the voltage of the tube at its operating value (calculated in Part-1).
2. Place the beta source, say Sr^{90} about 5 cm from the window of the tube, and make a 100 s count. Record the number of counts.
3. Place the first sheet of aluminum of minimum thickness between the source and the G.M tube, and take another 100 s count and record the value.
4. Place the second sheet of higher thickness and make another 100 s count.
5. Continue taking 100 s counts with different sheets of increasing thickness, until the number of counts is 25% of the number recorded without the absorber.
6. Make a 100 s background run and subtract this value from each of the above counts.
7. Note the density thickness of aluminum given in **mg/cm^2**, convert it into thickness (by dividing density thickness to density of aluminum) and complete the table given on next page.

$$\mu = \left|\frac{lny_1 - lny_2}{x_2 - x_1}\right| = \_\_\_\_\_\_\_\_\_\_ cm^{-1}$$

No. of obs.	Surface density of Al-plates (mg/cm^2)	Thickness of Al plates	Counts/100 s			Mean counts	ln (mean counts)
			1	2	3		
1							
2							
3							
.							
.							
.							

Part-6: Measurement of the maximum energy of β-particles

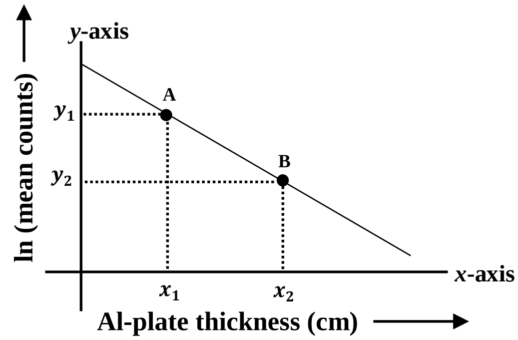


Fig. 5 Thickness vs. ln (mean counts) plot.

Procedure:

1. Use the data of previous part and draw a graph between surface density (ρ_o) given in mgcm^{-2} and mean counts.
2. Follow the steps given below.

741 mg/cm^2 yields β-particles of energy = 1.5 MeV

1 -- = 1.5/741 MeV

ρ -- = $\frac{1.5}{741} \times \rho$ MeV

(maximum energy of β-particles)

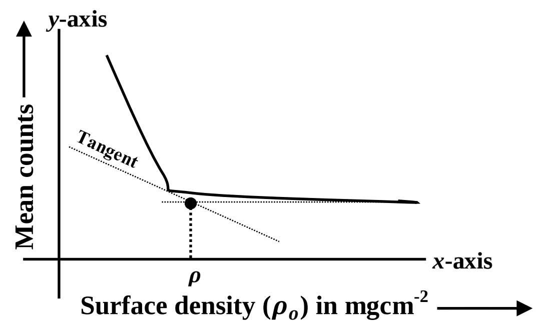


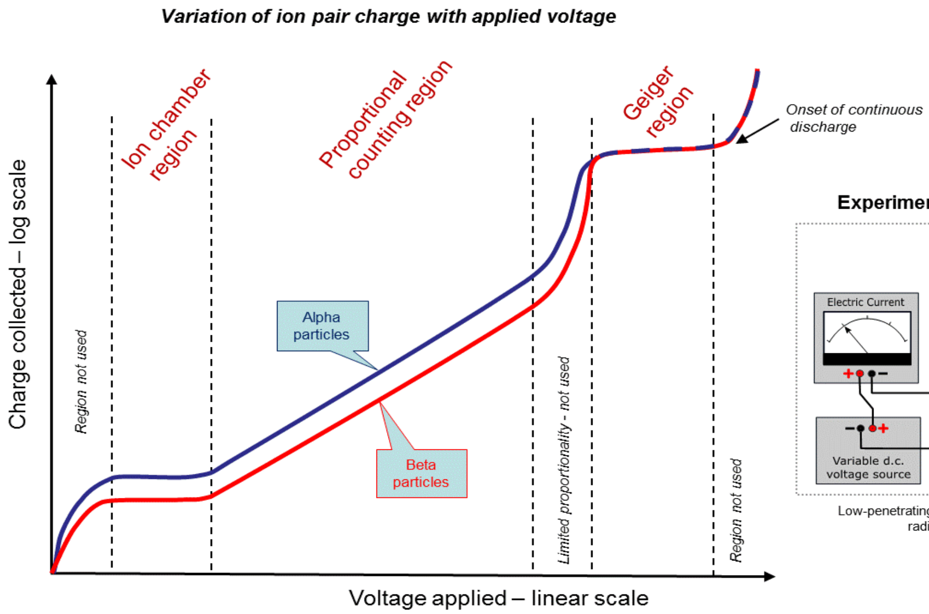
Fig. 6 Surface density vs. mean counts plot.

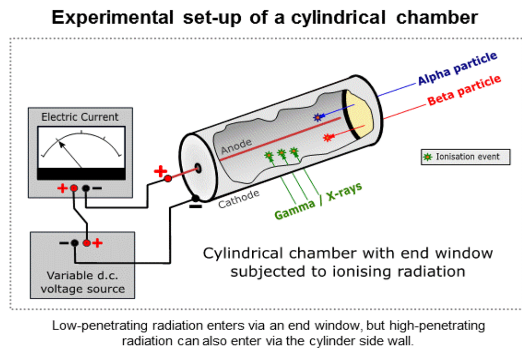
THEORY

Geiger–Müller tube

The **Geiger–Müller tube** or **G–M tube** is the sensing element of the Geiger counter instrument used for the detection of ionizing radiation. It was named after Hans Geiger, who invented the principle in 1908, and Walther Müller, who collaborated with Geiger in developing the technique further in 1928 to produce a practical tube that could detect a number of different radiation types.

It is a gaseous ionization detector and uses the Townsend avalanche phenomenon to produce an easily detectable electronic pulse from as little as a single ionising event due to a radiation particle. It is used for the detection of gamma radiation, X-rays, and alpha and beta particles. It can also be adapted to detect neutrons. The tube operates in the "Geiger" region of ion pair generation. This is shown on the accompanying plot for gaseous detectors showing ion current against applied voltage. Whilst it is a robust and inexpensive detector, the G–M is unable to measure high radiation rates efficiently, has a finite life in high radiation areas and cannot measure incident radiation energy, so no spectral information can be generated and there is no discrimination between radiation types, such as between alpha and beta particles.



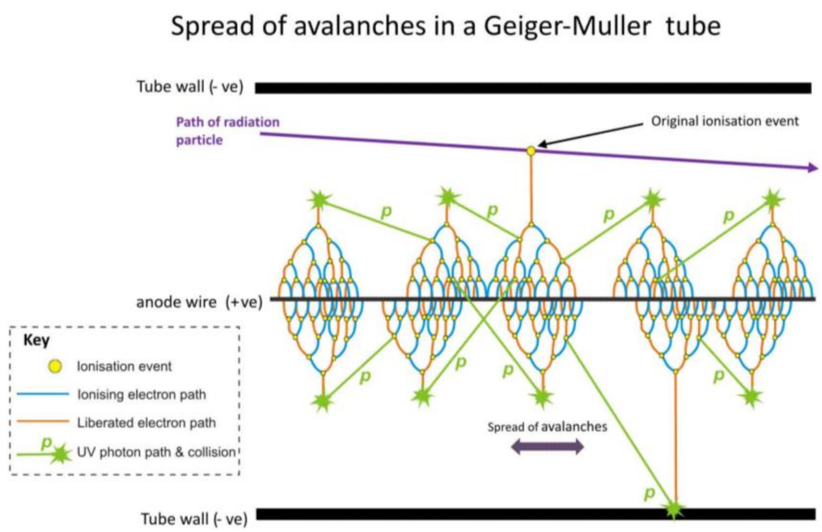


Principle of Operation

The tube consists of a chamber filled with a gas mixture at a low pressure of about 0.1 **atmosphere**. The chamber contains two electrodes, between which there is a potential difference of several hundred **volts**. The walls of the tube are either metal or have their inside surface coated with a conductor to form the **cathode**, while the **anode** is a **wire** in the center of the chamber.

When ionizing radiation strikes the tube, some molecules of the gas are ionized, either directly by the incident radiation or indirectly by means of secondary electrons produced in the walls of the tube. This creates positively charged **ions** and **electrons**, known as ion pairs, in the fill gas. The strong electric field created by the tube's electrodes accelerates the positive ions towards the cathode and the electrons towards the anode. Close to the anode in the "avalanche region" the electrons gain sufficient energy to ionize additional gas molecules and create a large number of electron **avalanches** which spread along the anode and effectively throughout the avalanche region. This is the "gas multiplication" effect which gives the tube its key characteristic of being able to produce a significant output pulse from a single ionizing event.

If there were to be only one avalanche per original ionizing event, then the number of excited molecules would be in the order of 10^6 to 10^8. However the production of *multiple avalanches* results in an increased multiplication factor which can produce 10^9 to 10^{10} ion pairs.



The creation of multiple avalanches is due to the production of UV photons in the original avalanche, which are not affected by the electric field and move laterally to the axis of the anode to instigate further ionizing events by collision with gas molecules. These collisions produce further avalanches, which in turn produce more photons, and thereby more avalanches in a chain reaction which spreads laterally through the fill gas, and envelops the anode wire. The accompanying diagram shows this graphically. The speed of propagation of the avalanches is typically 2–4 cm per microsecond, so that for common sizes of tubes the complete ionization of the gas around the anode takes just a few microseconds. This short, intense pulse of current can be measured as a *count event* in the form of a voltage pulse developed across an external electrical resistor. This can be in the order of volts, thus making further electronic processing simple.

Pressure of the fill gas is important in the generation of avalanches. Too low a pressure and the efficiency of interaction with incident radiation is reduced. Too high a pressure, and the “mean free path” for collisions between accelerated electrons and the fill gas is too small, and the electrons cannot gather enough energy between each collision to cause ionization of the gas. The energy gained by electrons is proportional to the ratio “e/p”, where “e” is the electric field strength at that point in the gas, and “p” is the gas pressure.

Gas Mixtures

The components of the gas fill mixture are an inert gas such as **helium**, **argon** or **neon** which is ionized by incident radiation, and a "quench" gas of 5–10% of an organic vapor or a halogen gas to prevent spurious pulsing by quenching the electron avalanches. This combination of gases is known as a Penning mixture and makes use of the Penning ionization effect.

Geiger Plateau

The *Geiger plateau* is the voltage range in which the GM tube operates in its correct mode. If a G–M tube is exposed to a steady radiation source and the applied voltage is increased from zero, it follows the plot of ion current shown in this article. In the "Geiger region" the gradient flattens; this is the Geiger plateau.

Quenching and Dead time

The ideal G–M tube should produce a single pulse for every single ionizing event due to radiation. It should not give spurious pulses, and should recover quickly to the passive state, ready for the next radiation event. However, when positive argon ions reach the cathode and become neutral atoms by gaining electrons, the atoms can be elevated to enhanced energy levels. These atoms then return to their ground state by emitting photons which in turn produce further ionization and thereby spurious secondary discharges. If nothing were done to counteract this, ionization would be prolonged and could even escalate. The prolonged avalanche would increase the "dead time" when new events cannot be detected, and could become continuous and damage the tube. Some form of quenching of the ionization is therefore essential to reduce the dead time and protect the tube, and a number of quenching techniques are used.

Radioactive Half-Life

The radioactive half-life for a given radioisotope is the time for half the radioactive nuclei in any sample to undergo radioactive decay. After two half-lives, there will be one fourth the original sample, after three half-lives one eight the original sample, and so forth.

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