Determination of the Dead Time and Randomness of Nuclear Disintegration for a Geiger-Muller Tube Using two Radioactive Source Co^{60} and Sr^{90}

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Abstract

This study utilized standard two-source Co^{60} and Sr^{90} to determine the dead time and randomness of nuclear disintegration of a Geiger Muller (GM) tube. The experimental result obtained from this research was 22 ms dead time of a GM counter (τ). In order to understand random nuclear disintegration, the value of the standard deviation residual ($\sigma_{residual}$), which represents the experimental mean square deviation, was determined for the radiation activity of the Co^{60} source to be 15, which was then compared with the theoretically expected standard deviation ($\sigma_{expected}$) of 15.71. These values indicate a correlation between the two values with a relative standard deviation (RSD) error of 5%. The value of the standard error residual ($\delta_{residual}$) was also estimated to be 3.35, and compared with the expected standard error value ($\delta_{expected}$) of 3.51. The values were consistent with a relative standard deviation error of 5%, and the errors can be attributed to the random nature of nuclear decay.

Key Words: Geiger Muller, Dead Time, Standard deviation, Standard error, Radiation.

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Introductions

The Geiger Muller (GM) counter is commonly used for monitoring radiation [1], [2] due to its reliability and cost-effectiveness [3]. Most experiments can be set up using a GM counter system, such as the determination of a GM's plateau voltage range, the detector's dead time, and radioactivity half-life [4], [5]. The GM counter is classified as a filled gas detector [6].

When a charged particle enters the GM tube, it produces an ion pair consisting of a positive ion and an electron [7]. The electrons are attracted to the central wire anode, while the ions are attracted to the cathodes, which leaves a sheath of positive ions. This also increases the radius of the anode (gradually) over time. The sheath distorts the electric field in the region, which produces a smaller potential gradient near the wire, and unless this sheath is removed to its outer radius, the value of the potential will be dictated by the applied voltage [6], [8].

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The counter becomes sensitive for some time, and this period is known as the dead time. Incidentally, one dead time is regarded as negligible, which means that the loss of count depends on the rate of particle emission from the source and its corresponding activity [9]. Fig. 1 shows the schematic of the GM tube and its associated electronics.

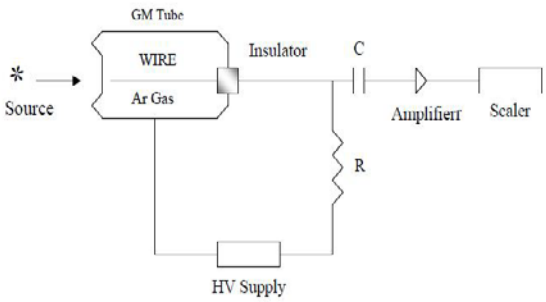


Fig. 1. Schematic diagram of the GM tube and the associated electronics

There are two critical characteristic curves exhibited by Geiger counters; the first is the familiar plateau curve, which is a plot of the recorded counting rate when the applied voltage varies. The GM counter is connected to a device capable of indicating only relatively large pulses, but not small ones. Until the voltage reaches the value indicated as the starting potential, the pulses are too small to be detected. The applied voltage at which the counting system first records pulses is known as the starting voltage. However, with increasing potential, the gas amplification increases and the number of pulses increase rapidly to a flat portion of the curve called the plateau [8], [10], which is the Geiger tube region where the count rate is nearly independent of the potential difference across the tube. Beyond the plateau, the applied electric field is high(er); therefore, the continuous discharge takes place in the tube, and the count rate increases rapidly. Fig. 2 illustrates the counting rate versus the applied voltage behavior on a GM counter. It is essential to recognize the behavior of charge creation and collection as it is closely related to the dead time phenomenon [11].

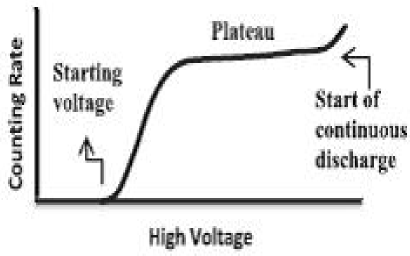


Fig. 2. Plateau of Geiger Muller tube

The Dead Time of a GM

Let $\overline{R}$ be the number of particles entering the GM tube per second and the counter is showing counts per second. If the dead time of the counter is $R\tau$ as the number of particles entering GM tube per second is R, the total number of counted particles is $R\overline{R}\tau$, thus [10], [12], [13]:

$$\overline{R} - R = R\overline{R}\tau \quad (1)$$

If there are two different sources S_1 and S_2. Suppose the sources are placed together in such a way that total number particles entering the tube per second is R_2 and if the time count rate shown by the counter is R_3, then we have[10,13]:

$$(\overline{R}_1 + \overline{R}_2) - \overline{R}_3 = \overline{R}_1 + \overline{R}_2 - R_3 \quad (2)$$

When the source S_2 is removed, keeping S_1 , the observed count rate is R_1, and vice versa:

$$R_1 - R = R\overline{R}_1\tau \quad (3)$$

$$R_2 - R = R\overline{R}_2\tau \quad (4)$$

By eliminating $\overline{R}_1$ and $\overline{R}_2$ from eqs. (3) & (4) and reflecting the higher order terms, we obtain:

$$\tau = \frac{R_1 + R_2 - R_3}{2R_1R_2} \quad (5)$$

Where: R_1 = Count rate with source S_1.
R_2 = Count rate with source S_2 .
R_3 = Count rate with source S_1+S_2 .

Randomness of Nuclear Disintegration

To study the random of radioactive disintegration, the count rate observed for any radioactive source with any counting system is the average count rate. It is not possible to obtain the actual count rate due to the random nature of radioactive decay, which also varies from source to source. If we consider that the strength of the given radioactive source remains constant for a considerable amount of time and if the series of counts N_1 , N_2 ,....N are taken in successive equal time intervals, then each count N will differ from mean count $\overline{N}$, and can becalculated from the absolute result [5], [14], [15].

For the randomness of nuclear disintegration:

$$\bar{N} = \frac{\sum N_i}{n}$$

The standard deviation residual, $\sigma_{residual}$, is the most likely an error in a single observation, and is defined as:

$$\sigma_{residual}{}^2 = \sum_{i=1}^{n} \frac{(N_i - \bar{N})^2}{n-1} (6)$$

The standard deviation expected, $\sigma_{expected}$, is defined as :

$$\sigma_{expected} = \sqrt{\bar{N}}\ (7)$$

The standard error is defined as :

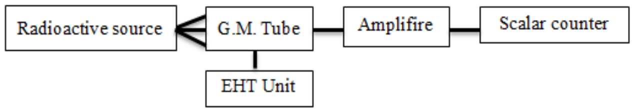
$$\delta_{residual} = \sqrt{\frac{\sigma_{resi}{}^2}{n}} (8)$$

$$\delta_{expected} = \sqrt{\frac{\bar{N}}{n}}\ (9)$$

Where: n= totals number of observation.
$\bar{N}$ = mean of count.
N_i = count observed.

MATERIALS AND METHODS

An experimental setup was prepared, as per Scheme 1. The dead time of a GM tube (Model ST360 Counter) was determined using a double-source slot plate method and applied voltage, and 20 observations were taken from the Co^{60}sourceS$_1$(1μCi, half-life of 5.26 y, type of decay β^-, and energy decay of0.31MeV)at count per 30 secs. After removing S_1, 20 observation were taken from theSr^{90} source S_2(0.1μCi, half-life of 28 y, type of decay β^-, and energy decay 0.6MeV)at count per 30 secs, then 20 observation were taken for the(S_1&S_2)) at count per 30 secs.



Scheme 1. Block diagram

Results and Calculations

The counting measurements of the Co^{60} and Sr^{90} sources were taken for 30 secs after a decay period using a GM counter, with the operating voltage set to 450 V. The variations in the counting rate are shown in Table 1 as a function of decay times. The maximum observed counting rate of the GM detector was ~624 count per 30 secs for both sources due to the dead time effect.

Table 1. Observation table for dead time

Operating voltage 4*150 = 450 volt			
Obs. No.	For source Co^{60} count/30 sec	For source Sr^{90} count/30 sec	For Co^{60}+Sr^{90} count/30 sec
1	242	244	572
2	240	256	624
3	221	223	565
4	230	240	594
5	228	246	580
6	239	252	595
7	239	232	552
8	254	264	619
9	249	251	557
10	251	265	605
11	259	253	581
12	271	265	555
13	237	265	572
14	227	253	597
15	252	218	582
16	248	247	600
17	255	249	587
18	258	238	590
19	256	245	602
20	281	265	602
	Mean count for Co^{60} $\sum N_i = 4937$ $\bar{N} = \frac{4937}{20} = 246.85$	Mean count for Sr^{90} $\sum N_i = 4971$ $\bar{N} = \frac{4971}{20} = 248.55$	Mean count for Co^{60}+Sr^{90} $\sum N_i = 11731$ $\bar{N} = \frac{11731}{20} = 586.55$

For the dead time of the GM tube counter, using the result from Table(1):

i) For Co^{60}

$$R_1 = \frac{\bar{N}}{30} = \frac{246.85}{30} = 8.23\ count/sec$$

ii) For Sr^{90}

$$R_2 = \frac{\bar{N}}{30} = \frac{248.55}{30} = 8.285\ count/sec$$

iii) For $Co^{60} + Sr^{90}$

$$R_3 = \frac{\bar{N}}{30} = \frac{586.55}{30} = 19.55\ count/sec$$

By using eq.5, we can determinethe dead time for GM tube:

$$T = \frac{(R_1 + R_2) - R_3}{2R_1R_2} = \frac{(8.23 + 8.285) - 19.55}{2 * 8.23 * 8.285} = \frac{3.035}{136.37} = 0.022\ sec = 22ms$$

Table 2. Observation table for standard deviation

Obs. No.	N_i for Co^{60} count/30sec	$N_i - \bar{N}$	$(N_i - \bar{N})^2$
1	242	-4.85	23.53
2	240	-6.85	46.92
3	221	-25.85	668.22
4	230	-16.85	283.92
5	228	-18.85	355.32
6	239	-7.85	61.62
7	239	-7.85	61.62
8	254	7.15	51.12
9	249	2.15	4.62
10	251	4.15	17.22
11	259	12.15	147.62
12	271	24.15	583.22
13	237	-9.85	97.02
14	227	-19.85	394.02
15	252	5.15	26.52
16	248	1.15	1.32
17	255	8.15	66.42
18	258	11.15	124.32
19	256	9.15	83.72
20	281	34.15	1166.22

By using eqs.6, 7, and 8, we can calculate the standard deviation residual and the randomness of nuclear disintegration, and its corresponding standard error:

$$\sigma_{residual}{}^2 = \sum_{i=1}^{n} \frac{(N_i - \bar{N})^2}{n-1} \rightarrow \sigma_{residual} = \{\sum_{i=1}^{n} \frac{(N_i - \bar{N})^2}{n-1}\}^{1/2} = [\frac{4264.51}{20-1}]^{1/2} = 15$$

$$\sigma_{expected} = \sqrt{\bar{N}} = \sqrt{246.85} = 15.71$$

$$\delta_{residual} = \sqrt{\frac{\sigma_{resi}{}^2}{n}} = \frac{15}{\sqrt{20}} = 3.35$$

$$\delta_{expected} = \sqrt{\frac{\bar{N}}{n}} = \sqrt{\frac{246.85}{20}} = 3.51$$

DISCUSSION AND CONCLUSIONS

According to the results, the process of radioactive decay is random and unpredictable within a material, which means that the measurement of the count rate for each radioactive source is independent of each other. When taking a large number of individual measurements, it is possible to predict the deviation of the individual rates from the average of the counting rate, where the counting rate, N, is given from independent measurements by counting the statistics for nuclear radiation.

Practically, the deviation of the values of the count from the value of the mean count in the unit of timecan be predicted usingthe statistical count of nuclear radiation.

By comparing the counting values of the practical results obtained in Table 1, some values were found to be higher than the mean of count, N_{ave}. At the same time, some were smaller than N_{ave}, with smaller deviations more likely to occur from more significant deviations.

The measured data were fitted using the mean count rate relations of the dead time (Table 1), as per eq. 5. τ = 22 ns described the dead time of a GM being studied. The actual dead time of a GM counter is dependent on the counting rate.

The value of $\sigma_{residual}$ can be calculated by using eq.6 for the radiation activity of sourceCo^{60} and was determined to be15. This value was then compared to the theoretically $\sigma_{expected}$, calculated using eq. 7, and determined to be 15.71. Both values are correlated, with a relative standard deviation (RSD) error of 5%.

The value of the standard error residual ($\delta_{residual}$)was calculated using eq.8 for the source

Co^{60} and was found to be 3.35. This value was compared with the expected standard error ($\delta_{expected}$)value, calculated using eq.9, and found to be 3.51. The values were consistent, with a relative standard deviation (RSD) error of 5%.

These errors result from the random nature of the nuclear decay of the element, as well as errors related to the same source and indeterminate errors resulting from the effects that occur during measurement, such as self-absorption and dispersion, which was processed using standard tables.

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Authors' Contributions

All authors contributed equally to this manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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