Determining the Efficiency of a Geiger-Müller Tube

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Introduction

The percent efficiency (ε) of a Geiger-Müller (G-M) tube can be defined by the following ratio:

$$\varepsilon = \frac{Number\ of\ Detected\ Counts}{Number\ of\ Radiation\ Disintegrations} \times 100\%$$

While the defining equation is innocent looking enough, a G-M tube doesn't count every disintegration produced by the source of the radiation. There are a number of reasons for this, including the following:

- Many particles do not strike the tube at all, since they are emitted uniformly from the radiation source in all directions. It is therefore necessary to consider the geometric relationship between the source of the radiation and the end window of the G-M tube when computing the efficiency of a G-M tube.

- A G-M tube uses a gas to absorb the energy from the radiation. Since gases are not very dense, some of the radiation passes right through the G-M tube.

- There is a time interval that follows the production of a count in a G-M tube during which no other counts can be detected, even though radiation may have entered the tube. This time interval is known as the resolving time.

- Different kinds of radiation have different odds of being counted by the G-M tube. Alpha particles are not particularly energetic—their source must be kept close to the end window of the G-M tube, or they will be stopped in a short distance in air. Alpha particles may also be absorbed by the walls of the cylinder that encloses the gas—not even making it into the G-M tube at all. Gamma radiation, itself, has a small probability of ionizing the gas in the G-M tube because it is detected essentially when it scatters electrons in the metal cylinder surrounding the gas into the tube. Beta particles that enter the tube have the largest odds of ionizing the gas in the tube. As a result of these facts, a G-M tube tends to be much more efficient for detecting beta particles than it is for detecting gamma radiation. Efficiency of a G-M tube therefore varies significantly, dependent upon the nature of the source of the radiation.

Computation of the efficiency of a G-M tube is a great laboratory exercise for physics students, as it pulls together a variety of concepts regarding radiation:

- Measurement of background radiation, so that it can be subtracted from radiation counts for a given sample

- Understanding what a Curie (Ci) is as a measure of the activity of a radioactive sample, and how to convert it to disintegrations per second
- Determining the present decay rate of a radioactive sample based upon knowing its date of production and half-life
- Considering the geometric relationship between a radioactive source and the G-M window to correctly determine the number of radiation particles incident on the G-M tube window
- Understanding differences in the nature of alpha, beta, and gamma radiation

Experimental Setup

Figure 1 shows the setup for this investigation. The source of radioactivity is placed a measured distance d = 26 mm in front of the center of the G-M tube end window. The radius of the G-M end window on the Vernier Radiation Monitor is measured as x = 6.125 mm. The radioactive source is held up vertically by an easily constructed wood holder, and the Vernier Radiation Monitor is mounted to the wood with black friction tape. The Vernier Radiation Monitor is connected to a LabQuest 2 (or any other compatible data-collection interface) via its attached cable.

Figure 1

Data Collection Procedure

Two different radiation sources were used—a beta source (Sr-90) and a gamma source (Co-60). This allows students to learn how the efficiency of a G-M tube is affected by the type of radiation, the primary goal of this investigation. Radiation counts are collected for ten one-minute intervals each for background, Sr-90, and Co-60. Although a larger number of intervals would provide somewhat better estimates for the average, keeping the number of one-minute intervals to ten allows the student to complete data collection in a single lab period. The ten counts for each of the two sources are then averaged and reduced by the average background count—although the background count in this investigation was negligible compared to the source radiation counts. The Logger *Pro* graph shown in Figure 2 summarizes the data.

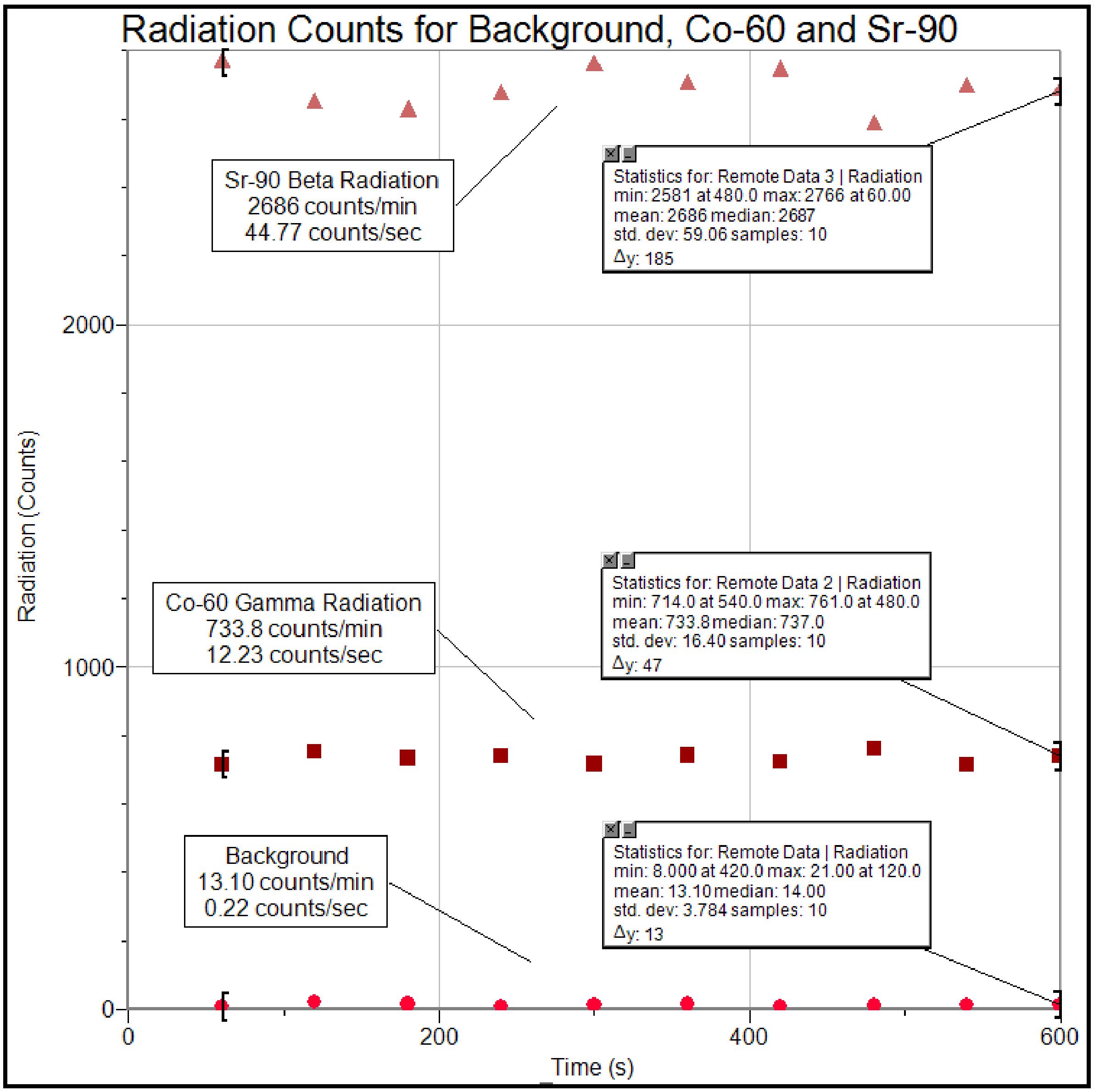

Figure 2

Determining the Current Activity of the Radiation Sources

Because the activity of the radiation sources decreases over time following production of the samples, it is necessary to compute the current activity of each sample in decays per second. The decay rate, *R,* at time, *t,* is given by the equation

$$R(t) = R_o e^{-\lambda t}$$

R_o is the activity at time of production and the decay constant $\lambda = ln\ 2 / t_{½}$, where $t_{½}$ is the half-life of the source radiation.

This investigation was done in February 2013, and the samples were produced in April 2010, as shown in Figure 3:

Figure 3

There are 34 months between April 2010 and February 2013, corresponding to t = 34/12 ≈ 2.83 years. For the Co-60 source, R_o = 1 μ Ci, and $t_{½}$ = 5.27 years. A little work on the calculator reveals that the current activity is 0.689 μ Ci. Since 1 Ci = 3.7 x 10^{10} decays/s, the current activity of the Co-60 source turns out to be 25,490 per second. Similar calculations reveal that the current activity of the Sr-90 source is about 3,456 per second. These figures will be needed later and are summarized here:

Current Activity of the Sources:

Co-60 → 25,490 per second
Sr-90 → 3,456 per second

Radiation Source/G-M Window Geometry

Figure 4 will help in understanding the geometric relationship between the radiation source and the end window of the G-M tube. The distance from the radioactive source to the center of the G-M end window is *d*. The radius of the end window is *x*. We can then imagine a sphere of radius *r* surrounding the radioactive source. The top cap of this sphere cuts the G-M end window as shown in the dashed circle. Assuming that the source radiates uniformly in all directions, it is only the portion of the emitted radiation that goes through the sphere's top cap that will also be incident upon the G-M tube window.

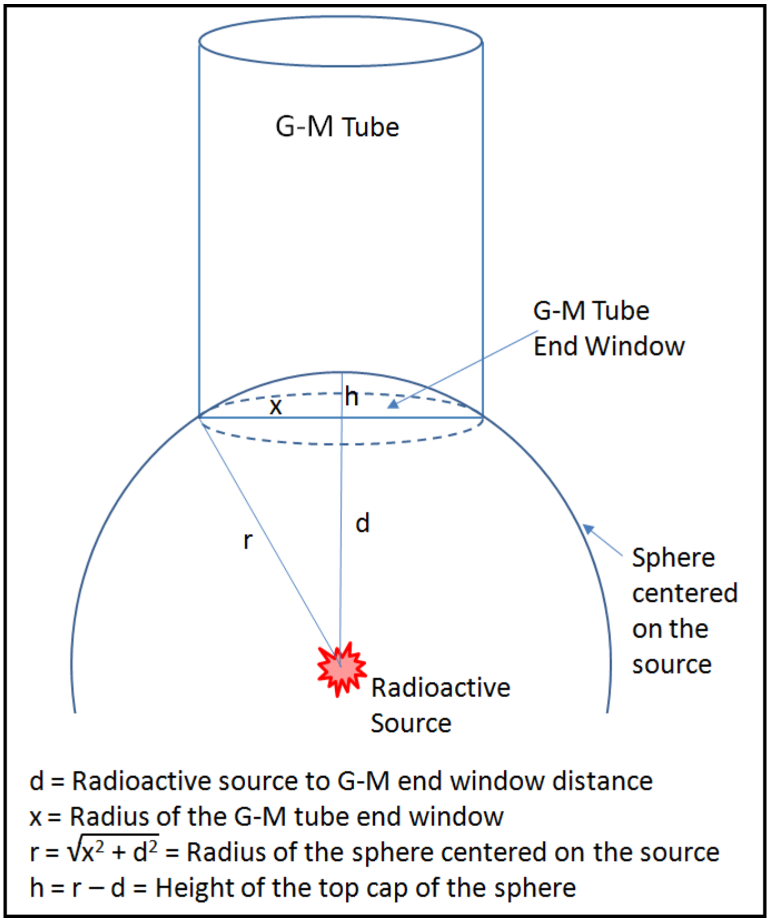

Figure 4

Mathematical tables tell us that the area of the top cap of the sphere is $2\pi rh$, where h is the height of the end cap of the sphere, as shown in the diagram. The area of the sphere is $4\pi r^2$. Therefore, the fraction of the emitted radiation that hits the G-M end window is given by the following:

$$\frac{2\pi rh}{4\pi r^2} = \frac{h}{2r} = \frac{r-d}{2r} = \frac{1}{2} - \frac{d}{2r} = \frac{1}{2} - \frac{d}{2\sqrt{x^2 + d^2}}$$

If the radiation source distance d is zero—that is, the source is right against the G-M tube end window, the above equation tells us that half of the emitted radiation would be incident upon the end window. This makes intuitive sense as half of the imaginary sphere surrounding the source would form the cap of the sphere. As d gets larger and larger, the fraction of the radiation that hits the end window decreases. The nice thing about this formula is that it is correct for all distances, which is particularly important when the source is fairly close to the end window. As indicated in the *Experimental Setup* section of this document, x = 6.125 mm and d = 26 mm for our investigation. The above formula then tells us that the fraction of source radiation incident on the G-M end window is 0.0133. This figure will be needed in the next section and is repeated here for reference:

Fraction of source radiation incident on the G-M end window = 0.0133

Calculation of the G-M Tube Efficiency

Recalling that the percent efficiency (ε) of a Geiger-Müller (G-M) tube can be defined by the following ratio, everything is now in place to compute the efficiency:

$$\varepsilon = \frac{Number\ of\ Detected\ Counts}{Number\ of\ Radiation\ Disintegrations} \times 100\%$$

The *number of detected counts* is the counts/s for the radiation source minus the background counts/s. The *number of radiation disintegrations* is the current activity of the source multiplied by the fraction of the source radiation incident on the G-M end window.

$$Efficiency\ for\ Sr-90\ (Beta\ Activity) = \frac{44.77 - 0.22}{3456 * 0.0133} \times 100\% = 96.9\%$$

$$Efficiency\ for\ Co-60\ (Gamma\ Activity) = \frac{12.23 - 0.22}{25{,}490 * 0.0133} \times 100\% = 3.54\%$$

Our results verify the fact that efficiency is highly dependent upon the nature of the radiation from the source. It is not uncommon for beta efficiency to get close to 100%, while gamma efficiency may only be a few percent. Some reasons for these differences were discussed in the *Introduction* section of this document.

Further Investigations

- Repeat the investigation but with the radiation sources closer to or farther from the G-M tube end window.
- Do the investigation with an alpha radiation source, such as Po-210. Keep in mind that alpha particles are quickly absorbed by air and even by the walls of the G-M tube.
- Do the investigation with an "unknown" Sr-90 or Co-60 source provided by your instructor, with the geometry the same as in the original investigation. This time, however, use the efficiency value you calculated in the original investigation to determine the current activity of the unknown source in μ Ci.