Determining the Resolving Time of a Geiger-Müller Tube

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Introduction

Learning some of the inner-workings (depicted in Figure 1) of a Geiger-Müller (G-M) tube can be a valuable experience for the student of physics. The LND 712 (or equivalent) tube in the Vernier Radiation Monitor (VRM-BTD) contains an inert gas, typically neon, at a low pressure on the order of 0.1 atm. The tube, itself, is a metal cylinder, has a thin wire along its axis, and a thin mica end window through which radiation from a radioactive source can enter. The metal cylinder has a negative voltage compared to the central wire, which has a positive voltage. This potential difference is about 500 volts. When alpha, beta, or gamma radiation collides with the gas atoms in the tube, a number of atoms are ionized into free electrons and positive ions. These free electrons and positive ions gain energy and collide with additional atoms, releasing more electrons and positive ions in what is referred to as an avalanche. Electrons are attracted to the central wire, while the positive ions are attracted to the cylindrical wall, and the avalanche produces a pulse of current that is detectable and can be registered by a counting mechanism. The G-M tube in the Vernier Radiation Monitor also contains a halogen that serves as a quencher to stop the avalanche.

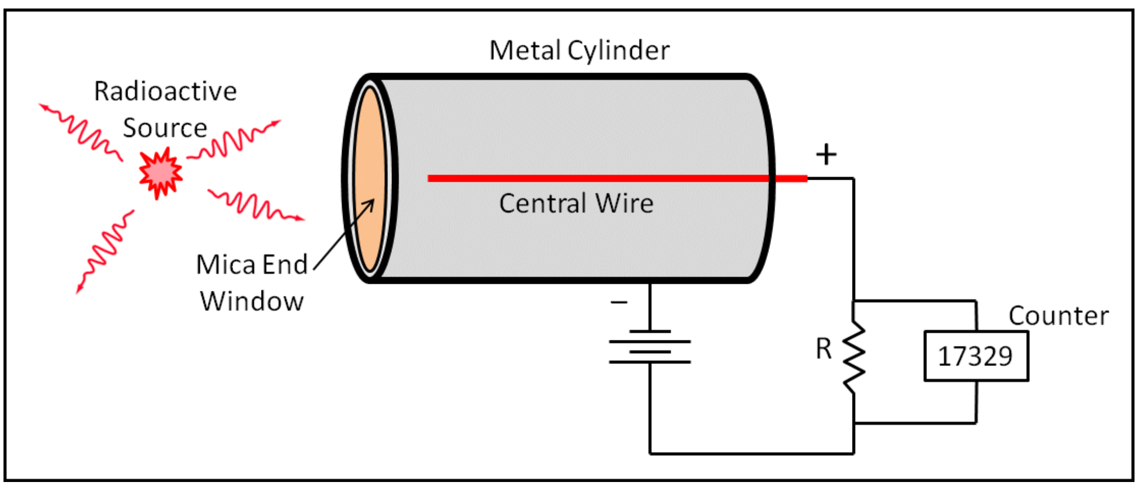

Figure 1

The recommended operating voltage for the LND 712 tube is 500 volts. When a G-M tube is properly functioning, it will have a plateau in which the counting rate remains almost constant over a range of applied voltage (see Figure 2). This range for the LND 712 is from 450 to 650 volts. The low end of this plateau is approximately the threshold voltage at which counting starts. Beyond the high end of the plateau, the counting rate rapidly increases until the counter has a continuous discharge.

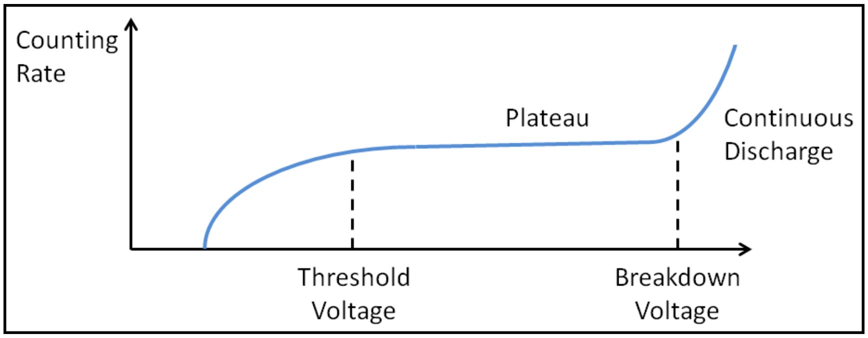

Figure 2

Resolving Time

The primary ionizing event caused by alpha, beta, or gamma radiation in a G-M tube, as discussed earlier, causes an avalanche with electrons traveling toward the central wire (anode) and positive ions toward the outer cylinder (cathode). Since the positive ions are heavier than the electrons, they require more time to reach the cathode. During this time interval, the G-M tube will not respond to any additional incident radiation—any additional radiation will not be counted. *Dead time* is defined as the time from the start of an initial ionizing event until the avalanching stops. *Recovery time* is the time needed for complete recovery of the electronics after the dead time. *Resolving time* is the sum of the dead time and recovery time—the minimum time interval required between two successive primary ionizing events, so that they will be counted individually by the counter. It may therefore be necessary to apply corrections to counting rates in order to compensate for this resolving time, *particularly when counting rates are very high.* Under the condition of high counting rates, typically exceeding 8000 counts per minute (or about 130 counts/s), measured counts will be too low if corrections are not made for resolving time.

The resolving time for a G-M tube can be determined by using a set of split sources of radiation, as shown Figure 3. Let $\mathbf{S_A}$ and $\mathbf{S_B}$ be the two sources, and let T be the resolving time of the G-M tube. Let n_A be the number of counts per second for $\mathbf{S_A}$ alone. Similarly, let n_B be the number of counts/second recorded for $\mathbf{S_B}$ alone. Finally, let n_{AB} be the number of counts/second when $\mathbf{S_A}$ and $\mathbf{S_B}$ are both present.

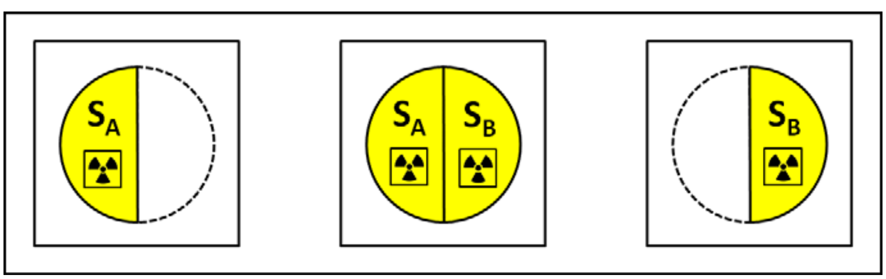

Figure 3

Considering the measurements with $\mathbf{S_A}$ alone, the G-M tube is inoperative for a time $n_A T$ seconds, meaning that in a time $(1 - n_A T)$ seconds, n_A counts have been observed. Therefore, the actual count rate N_A should be

$$N_A = \frac{n_A}{1 - n_A T}$$

Similarly, the actual count rate N_B for source $\mathbf{S_B}$ alone should be

$$N_B = \frac{n_B}{1 - n_B T}$$

and the actual count rate N_{AB} with both sources combined should be

$$N_{AB} = \frac{n_{AB}}{1 - n_{AB} T}$$

For the *actual* count rates, $N_{AB} = N_A + N_B$. (For the observed rates, $n_{AB} < n_A + n_B$, since the G-M tube is dead more often than with $\mathbf{S_A}$ and $\mathbf{S_B}$ separately.) Substituting the above expressions for N_A, N_B, and N_{AB} into this equation, neglecting higher order terms of T, and assuming that background counts are negligible compared to the observed count rates, it is found after a bit of algebra that

$$T = \frac{n_A + n_B - n_{AB}}{2\, n_A\, n_B}$$

The resolving time T can be determined by measuring the observed count rates n_A, n_B, and n_{AB}.

Experiment Considerations

It is critical that the positions of $\mathbf{S_A}$ and $\mathbf{S_B}$ with respect to the G-M tube end window when measured alone be identical to their positions with respect to the G-M tube end window when measured together. Spectrum Techniques, identified as a scientific supply house in the Vernier Radiation Monitor User Manual, has a set of sources designed specifically for determining the resolving time of a G-M tube. This set consists of three half-disks, two of which each contain 5 µCi of thallium-204 (Tl-204), and a third half-disk with no activity to help in maintaining constant geometry during the experiment. This disc set has a product code RSS-2 and can be purchased directly from Spectrum Techniques for $105 (price as of February 8, 2013).

Figure 4 provides some information regarding Tl-204 and its radioactive decay. It is the most stable radioisotope of thallium, having a half-life of 3.78 years. With its high initial activity of 5 µCi at production, it should provide sufficient activity for several years before needing replacement. The predominant mode of decay, at 97.08%, is β^- decay. In beta minus decay, an electron is emitted from the Tl-204 nucleus, changing the neutron to a proton, and transmuting the nuclide to Pb-204. Beta minus decay is more efficiently detected by a G-M tube than gamma radiation, a plus when doing an experiment to determine the resolving time of a G-M tube, where high decay rates result in increased dead-time frequency. (See “Determining the Efficiency of a Geiger-Müller Tube,” another innovative use for the Vernier Radiation Monitor.)

Once again, while other sufficienty high decay rate sources can be used, the important thing is keeping the geometry between the two indivdual sources, the combined sources, and the G-M tube constant. Other considerations include:

- Since n_{AB} may not be much smaller than $n_A + n_B$, it is a good idea to take a number of readings for each of these, and use the average values when computing the dead time, T.
- LND, Inc. indicates that the minimum dead time for their LND 712 tube is 90 microseconds. So values for resolving time on the order of a few hundred microseconds are typical for this experiment.
- The dead time for a G-M tube can increase with the age of the tube.

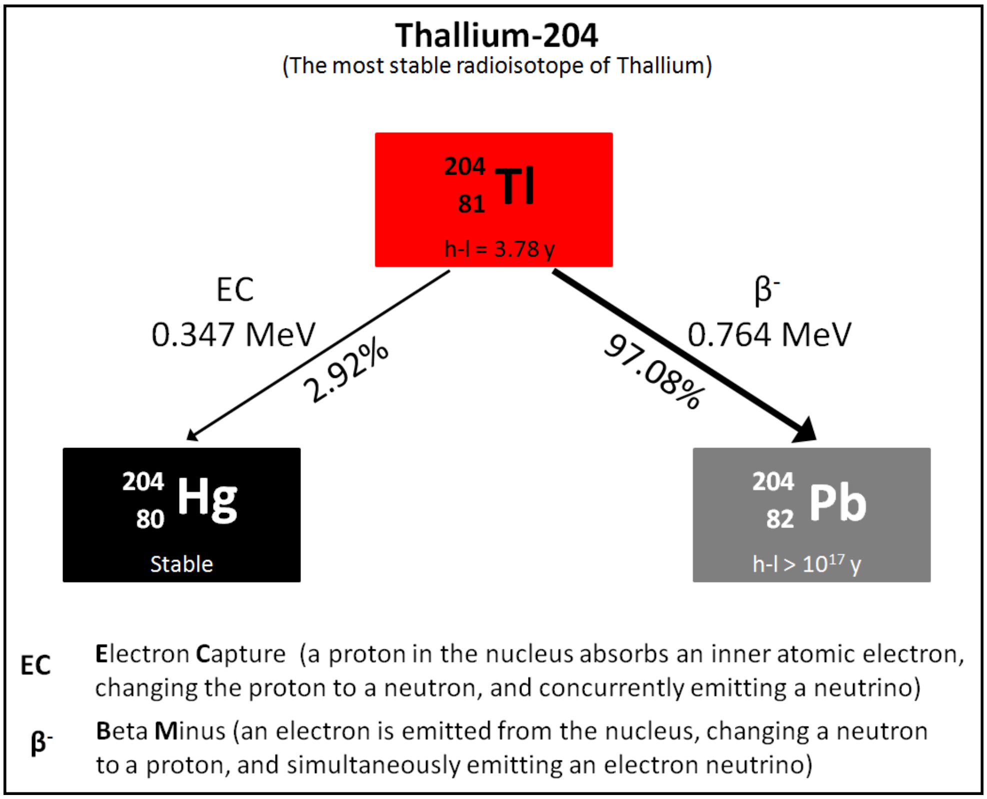

Figure 4

Experimental Setup

Figure 5 shows the Tl-204 resolving time disk set from Spectrum Technologies. Each half-disk is one inch in diameter. The label sides for the discs are shown in the picture, but the underside of each Tl-204 disk contains the radioactive source and should be placed facing the G-M tube. The blank disk is used to help keep constant geometry during the investigation. The radioactive sources were labeled **A** and **B** after receiving them to avoid errors during the investigation.

Figure 5

Figure 6 shows how the Vernier Radiation Monitor is set up in relation to the sources. A ring stand is used along with a buret clamp to hold the Vernier Radiation Monitor. It is probably also a good idea to clamp the ring stand to the edge of the lab table to provide stability and to avoid accidental small movements that might change the geometry. A one-inch circle is drawn along with a diameter on an index card, and the index card is taped to the table so that it will not slide around when moving the radioactive sources. The end-window of the G-M tube is placed directly above the circle on the card. The distance between the G-M window and radioactive source will depend upon how active the source is. Remember that activities exceeding 8000 counts/min (or 130 counts/s) are best for experiments determining resolving time.

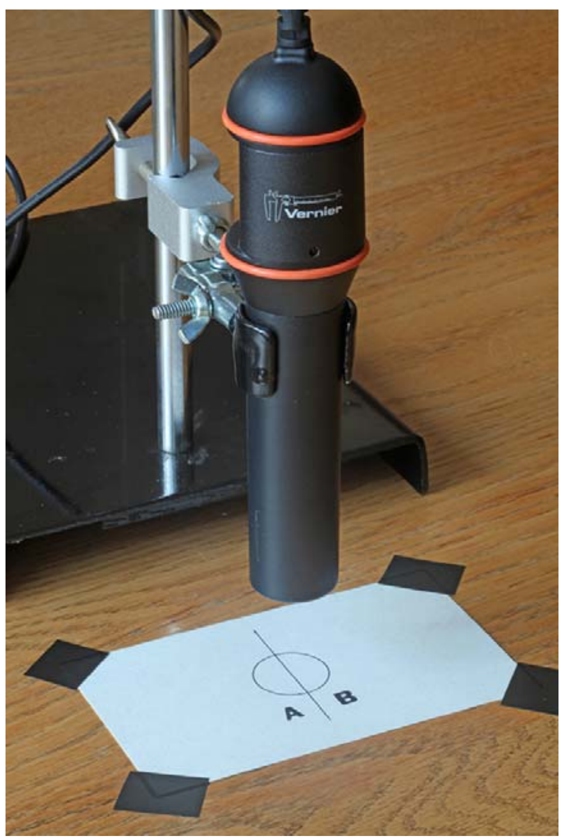

Figure 6

Experimental Procedure

In order to allow students to complete data collection during a lab period, 15 one-minute intervals are used and averaged to obtain counts/s for source **A** alone, sources **A** and **B** combined, and finally for source **B** alone. The graph from Logger *Pro* shown in Figure 7 provides data for the case where the G-M window to radiation source distance is 15 mm.

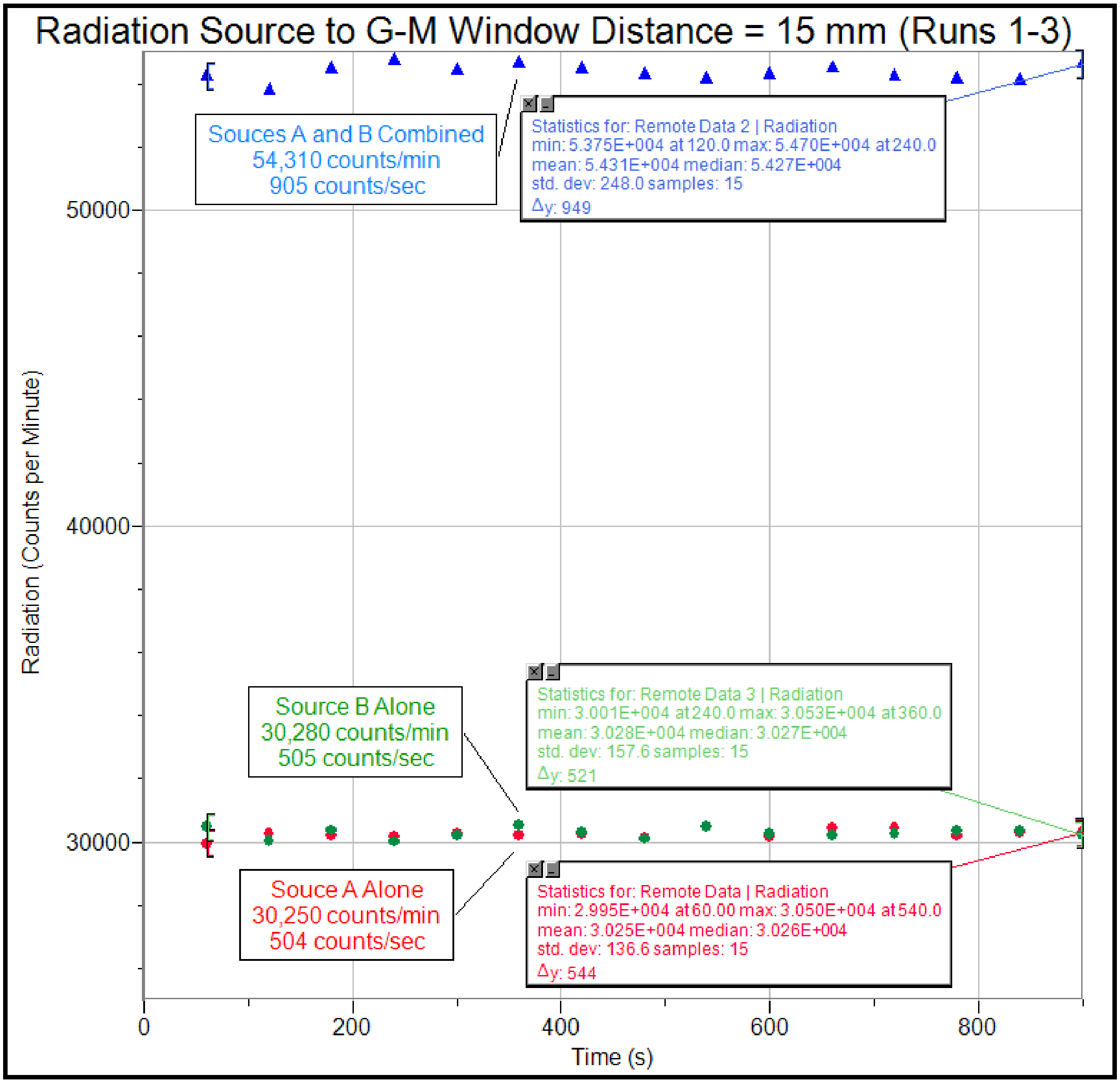

Figure 7

The Logger *Pro* graph shows that sources $\mathbf{S_A}$ and $\mathbf{S_B}$, being nearly identical in activity and symmetrically placed with respect to the G-M tube, produce count rates that are nearly the same. Sources $\mathbf{S_A}$ and $\mathbf{S_B}$ combined produce a count rate that is somewhat less than the sum of the rates for $\mathbf{S_A}$ and $\mathbf{S_B}$ alone, as expected based upon earlier discussion.

Discussion of Results

The table shown in Figure 8 summarizes the resulting values for resolving time of the G-M tube for several radiation source to G-M window distances.

Source-GM Tube Distance (mm)	n_A (counts/sec)	n_B (counts/sec)	n_{AB} (counts/sec)	Resolving Time T (sec)	T (µsec)
3	1350	1680	2350	0.000150	150
8	939	1128	1771	0.000140	140
8	970	901	1665	0.000118	118
15	504	505	905	0.000204	204
26	222	226	429	0.000184	184
35	137	134	263	0.000211	211
44	86	85	168	0.000206	206
53	61	62	122	0.000110	110
53	59	61	118	0.000230	230
				Average→	175

Figure 8

The results highlighted in yellow (the last three rows) represent source-GM tube distances that provide counts less than 8000 counts/min (i.e., < 133 counts/s). In these cases the sum of n_A and n_B is barely above n_{AB}. The result is a lot of variability from one run to another. These count rates are really too low to guarantee reasonable accuracy.

The results highlighted in red (the first three rows) represent source-GM tube distances that are less than a centimeter. In these cases, the count rates are quite high, on the order of 1000 or more counts/s. However, since the sources are very close to the G-M window, even a small misplacement of a source can alter the geometry and, hence, the resulting value for resolving time. Extra care is necessary to keep the geometry constant. (Note that for the source-GM tube distance of 3 mm shown in the top row of the table, the source was almost in contact with the Vernier Radiation Monitor.)

The results highlighted in green (rows 4–6) represent intermediate source GM-tube distances and show fairly consistent resolving times averaging around 200 µs.

In conclusion, it would probably be best to spend a few minutes before the lab finding a source-GM tube distance range that provides counting rates exceeding 8000 counts/min, but not so great that slight deviations from constant geometry would be an issue. Then ask the students to set the distance somewhere in this range during their experiment.

Additional Investigations

- Calculate the corrected count rates N_A, N_B, and N_{AB} corresponding to the observed rates n_A, n_B, and n_{AB}, respectively, using the equations discussed earlier.
- Construct a graph of percent loss in counts *vs*. observed count rate n using the value of resolving time that you determined in your experiment and the formula

$$Percent\ Loss\ in\ Counts\ = \frac{N-n}{n} \times 100\%$$

  where N is the corrected count rate.