Introduction to Geiger Counters

A Geiger counter (Geiger-Muller tube) is a device used for the detection and measurement of all types of radiation: alpha, beta and gamma radiation. Basically it consists of a pair of electrodes surrounded by a gas. The electrodes have a high voltage across them. The gas used is usually Helium or Argon. When radiation enters the tube it can ionize the gas. The ions (and electrons) are attracted to the electrodes and an electric current is produced. A scaler counts the current pulses, and one obtains a "count" whenever radiation ionizes the gas.

The apparatus consists of two parts, the tube and the (counter + power supply). The Geiger-Mueller tube is usually cylindrical, with a wire down the center. The (counter + power supply) have voltage controls and timer options. A high voltage is established across the cylinder and the wire as shown in the figure.

When ionizing radiation such as an alpha, beta or gamma particle enters the tube, it can ionize some of the gas molecules in the tube. From these ionized atoms, an electron is knocked out of the atom, and the remaining atom is positively charged. The high voltage in the tube produces an electric field inside the tube. The electrons that were knocked out of the atom are attracted to the positive electrode, and the positively charged ions are attracted to the negative electrode. This produces a pulse of current in the wires connecting the electrodes, and this pulse is counted. After the pulse is counted, the charged ions become neutralized, and the Geiger counter is ready to record another pulse. In order for the Geiger counter tube to restore itself quickly to its original state after radiation has entered, a gas is added to the tube.

For proper use of the Geiger counter, one must have the appropriate voltage across the electrodes. If the voltage is too low, the electric field in the tube is too weak to cause a current pulse. If the voltage is too high, the tube will undergo continuous discharge, and the tube can be damaged. Usually the manufacture recommends the correct voltage to use for the tube. Larger tubes require larger voltages to produce the necessary electric fields inside the tube. In class we will do an experiment to determine the proper operating voltage. First we will place a radioactive isotope in from of the Geiger-Mueller tube. Then, we will slowly vary the voltage across the tube and measure the counting rate. In the figure I have inclded a graph of what we might expect to see when the voltage is increased across the tube.

For low voltages, no counts are recorded. This is because the electric field is too weak for even one pulse to be recorded. As the voltage is increased, eventually one obtains a counting rate. The voltage at which the G-M tube just begins to count is called the starting potential. The counting rate quickly rises as the voltage is increased. For our equipment, the rise is so fast, that the graph looks like a "step"

High Voltage

ground

GEIGER - MUELLER
TUBE

Counts

PLATEAU REGION

continuous DISCHARGE

STARTING VOLTAGE V_0

operating voltage $\sim V_0 + 50$

Volts
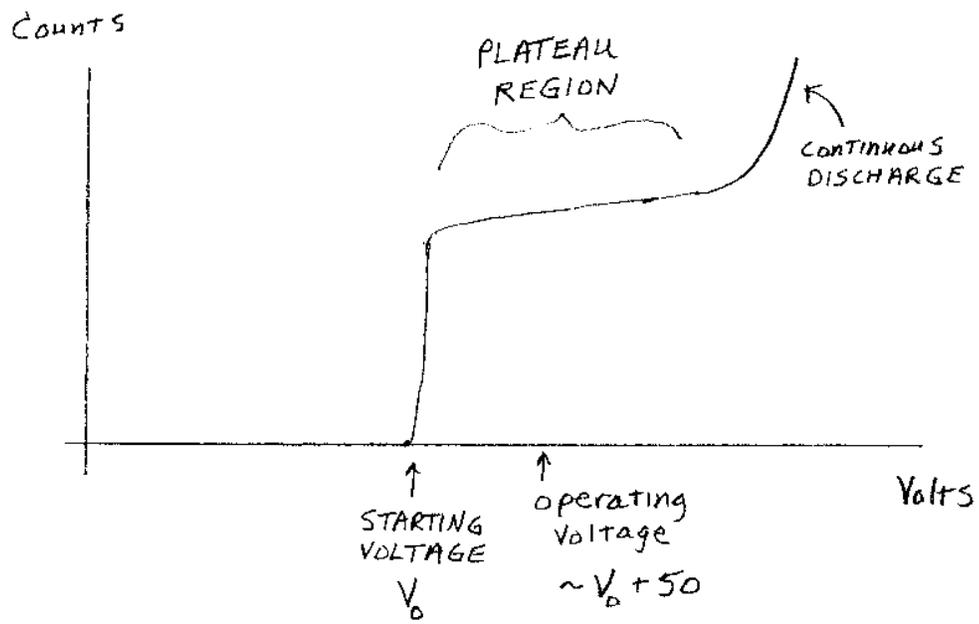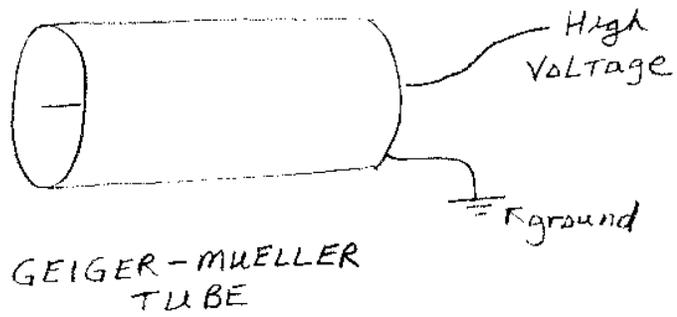
potential. After the quick rise, the counting rate levels off. This range of voltages is termed the "plateau" region. Eventually, the voltage becomes too high and we have continuous discharge. The threshold voltage is the voltage where the plateau region begins. Proper operation is when the voltage is in the plateau region of the curve. For best operation, the voltage should be selected fairly close to the threshold voltage, and within the first 1/4 of the way into the plateau region. A rule we follow with the G-M tubes in our lab is the following: for the larger tubes to set the operating voltage about 75 Volts above the starting potential; for the smaller tubes to set the operating voltage about 50 volts above the starting potential.

In the plateau region the graph of counting rate vs. voltage is in general not completely flat. The plateau is not a perfect plateau. In fact, the slope of the curve in the plateau region is a measure of the quality of the G-M tube. For a good G-M tube, the plateau region should rise at a rate less than 10 percent per 100 volts. That is, for a change of 100 volts, (Δcounting rate)/(average counting rate) should be less than 0.1. An excellent tube could have the plateau slope as low as 3 percent per 100 volts.

Efficiency of the Geiger-counter:

The efficiency of a detector is given by the ratio of the (number of particles of radiation detected)/(number of particles of radiation emitted):

$$\varepsilon \equiv \frac{number\ of\ particles\ of\ radiation\ detected}{number\ of\ particles\ of\ radiation\ emitted} \tag{1}$$

This definition for the efficiency of a detector is also used for our other detectors. In class we will measure the efficiency of our Geiger counter system and find that it is quite small. The reason that the efficiency is small for a G-M tube is that a gas is used to absorb the energy. A gas is not very dense, so most of the radiation passes right through the tube. Unless alpha particles are very energetic, they will be absorbed in the cylinder that encloses the gas and never even make it into the G-M tube. If beta particles enter the tube they have the best chance to cause ionization. Gamma particles themselves have a very small chance of ionizing the gas in the tube. Gamma particles are detected when they scatter an electron in the metal cylinder around the gas into the tube. So although the Geiger counter can detect all three types of radiation, it is most efficient for beta particles and not very efficient for gamma particles. Our scintillation detectors will prove to be much more efficient for detecting specific radiation.

Some of the advantages of using a Geiger Counter are:

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1. They are relatively inexpensive

2. They are durable and easily portable

3. They can detect all types of radiation

Some of the disadvantages of using a Geiger Counter are:

1. They cannot differentiate which type of radiation is being detected.

2. They cannot be used to determine the exact energy of the detected radiation

3. They have a very low efficiency

Resolving time (Dead time)

   After a count has been recorded, it takes the G-M tube a certain amount of time to reset itself to be ready to record the next count. The resolving time or "dead time", T, of a detector is the time it takes for the detector to "reset" itself. Since the detector is "not operating" while it is being reset, the measured activity is not the true activity of the sample. If the counting rate is high, then the effect of dead time is very important.
   In our experiments in Phy432L, we will estimate the dead time by examining the discharge pulse of the tube. If there is time, we can also examine the series of times between successive Geiger Counter pulses. This is somewhat different than the conventional methods used in other student labs which don't have the capability to examine the discharge or measure the time between successive pulses. Below, I discuss the conventional method for both correcting for dead time and measuring it.

Correcting for the Resolving time:

We define the following variables:

T = the resolving time or dead time of the detector
t_r = the real time that the detector is operating. This is the actual time that the detector is on. It is our counting time. tr does not depend on the dead time of the detector, but on how long we actually record counts.
t_l = the live time that the detector is operating. This is the time that the detector is

able to record counts. t_l depends on the dead time of the detector.
C = the total number of counts that we record.
n = the measured counting rate, $n = C/t_r$
N = the true counting rate, $N = C/t_l$

Note that the ratio n/N is equal to:

$$\frac{n}{N} = \frac{C/t_r}{C/t_i} = \frac{t_l}{t_r} \tag{2}$$

This means that the fraction of the counts that we record is the ratio of the "live time" to the "real time". This ratio is the fraction of the time that the detector is able to record counts. The key relationship we need is between the real time, live time, and dead time. To a good approximation, the live time is equal to the real time minus C times the dead time T:

$$t_l = t_r - CT \tag{3}$$

This is true since CT is the total time that the detector is unable to record counts during the counting time t_r. We can solve for N in terms of n and T by combining the two equations above. First divide the second equation by t_r:

$$\frac{t_l}{t_r} = 1 - \frac{CT}{t_r} = 1 - nT \tag{4}$$

From the first equation, we see that the left side is equal to n/N:

$$\frac{n}{N} = 1 - nT \tag{5}$$

Solving for N, we obtain the equation:

$$N = \frac{n}{1 - nT} \tag{6}$$

This is the equation we need to determine the true counting rate from the measured one. Notice that N is always larger than n. Also note that the product nT is the key parameter in determining by how much the true counting rate increases from the measured counting rate. For small values of the nT, the product nT (unitless) is the fractional increase that N is of n. For values of $nT < 0.01$ dead time is not important, and are less than a 1% effect. Dead time changes the measured value for the counting rate by 5% when $nT = 0.05$. The product nT is small when either the counting rate n is small, or the deat time T is small.

Measuring the Resolving Time

We can get an estimate of the resolving time of our detector by performing the following measurements, called the "two source" method for estimating detector dead time. First we determine the counting rate with one source alone, call this counting rate n_1. Then we add a second source next to the first one and determine the counting rate with both sources together. Call this counting rate n_{12}. Finally, we take away source 1 and measure the counting rate with source 2 alone. We call this counting rate n_2.

You might think that the measured counting times n_{12} should equal n_1 plus n_2. If there were no dead time this would be true. However, with dead time, n_{12} is less than the sum of $n_1 + n_2$. This is because with both sources present the detector is "dead" more often than when the sources are being counted alone. The true counting times do add up:

$$N_{12} = N_1 + N_2 \tag{7}$$

since these are the counting rates corrected for dead time. Substituting the expressions for the measured counting times into the above equation gives:

$$\frac{n_{12}}{1 - n_{12}T} = \frac{n_1}{1 - n_1 T} + \frac{n_2}{1 - n_2 T} \tag{8}$$

An approximate solution to these equations is given by

$$T \approx \frac{n_1 + n_2 - n_{12}}{2 n_1 n_2} \tag{9}$$

You can imagine the difficulties in obtaining a precise value for T using the "two source" method. One needs to be very careful that the positions of source 1 and 2 with respect to the detector alone is the same as the positions of these sources when they are measured together. Also, since n_{12} is not much smaller than $n_1 + n_2$, one needs to measure all three quantities very accurately. For this one needs many counts, since the relative statistical error equals $1/\sqrt{N_{tot}}$, where N_{tot} is the total number of counts. For sufficient accuracy one needs to use an active source for a long time. The values that we usually obtain in our experiments range from 100 to 500μsec. The dead time of the G-M tube is also available from the manufacturer, and are between 100 and 300μsec. As the G-M tube ages, the dead time can increase. Although dead time will not play a big role in our experiments, one always needs to consider it and make the appropriate corrections.