E. K. A. Advanced Physics Laboratory

Statistics of Counting with a Geiger Counter

Artificial Radioactivity

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1 Introduction

1.1 Geiger Counters

The Geiger Müller detector (GM tube) for ionizing particles operations on the principle of gas multiplication of the initial small number of electrons freed by ionizing particles they encounter. Relativistic charged particles lose $\sim 1300\,\mathrm{eV}$ of energy per cm in Argon at room temperature and atmospheric pressure. Typical gas in a GM tube is Argon at $^1/_{10}\,\mathrm{atm}$, resulting in $130\,\mathrm{eV}$ of energy loss per cm. An electron-ion pair is formed on average once per $\sim 25\,\mathrm{eV}$ of energy loss, resulting in ~ 10 free electrons in the gas of the GM tube. The electric field in the tube accelerates the initial electrons, which in turn collide with the gas atoms to produce more electron-ion pairs. If the field is large enough, the multiplication becomes regenerative, a self sustaining chain reaction and, helped by de-excitation UV photons, ionization of the gas spreads to the whole length of the GM tube. In the GM tube, the field is large only around the central thin wire (since $E \propto {}^1/_r$), so this is the region where electron multiplication occurs. The negative electric charge of the electrons is collected by the anode (central wire), which remains surrounded by the positive charge of the ions from the avalanche of ionizations near the wire, resulting in a decrease of the electric field and a termination of the multiplication mechanism. The GM tube becomes insensitive to particles until the positive charge has drifted significantly towards the cathode (outside wall of tube), which requires tens to hundreds of μs. The multiplication mechanism is further controlled by quenching components (alcohols or halogens). These components also prevent restart of the regenerative discharge by absorbing de-excitation UV photons and by positive charge transfer from the Argon ions. The GM tube was the first detector sensitive to single particles

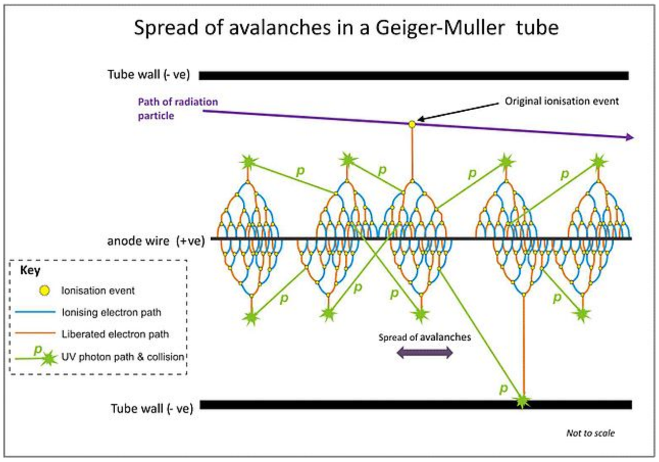

Figure 1: The cascade of ionizing electrons. Source: http://commons.wikimedia.org/wiki/File:Spread_of_avalanches_in_G-M_tube.jpg

because of the large electric signal it produces. Its limitations are the loss of information about the initial energy deposit and the fact that the detector does not respond to a second particle traversing it until the positive ion cloud is largely swept out (called the "dead time").

1.2 Lab Goals

Use the GM tube to study the statistics of counting, both in the Poisson and Gaussian regimes. Then, measure the dead time, using the Rainwater and Wu references. Finally, study artificial radioactivity induced by slow neutron capture by measuring the lifetimes of the short-lived, unstable isotopes produced by irradiated Indium.

2 Experimental Setup

2.1 Equipment

There are three pieces of apparatus necessary for this experiment: the GM tube in the lead enclosure, the voltage controller (Bee Research GS-1100A), and the computer. We have already discussed the GM tube. The *voltage controller* adjusts the potential difference between the two ends of the GM tube; a higher voltage gives a more sensitive detector and larger output signals. However, there is a limit to the voltage a GM tube can handle. The current tube is rated at 1100 V, which means you should **NEVER** increase the voltage above 1000 V, although it is OK to take all data at 950 V, or short measurements at 1000 V. The *computer* contains software for recording and analyzing the data using the open-source audio software Audacity and the custom-written analysis software GC Analysis. Refer to the software manual for information on recording and analyzing data.

2.2 Connections

The GM tube and voltage controller should already be connected; there is no need for you to adjust any connections between the GM tube and the voltage controller. The voltage controller might not be connected to the computer. To connect them, simply plug the standard audio plug into the computer's *microphone* or *audio input* port (not the headphone port).

To test the connection, put one of the sources in the GM tube and close the door to the enclosure. Slowly turn the voltage controller to 950 V, pausing at each increment for one second so as not to stress the GM tube's components. Open Audacity on the computer, ensure the appropriate microphone is selected, and then click the Record button (red circle). If everything is connected appropriately and the Audacity settings are correct, you should see a very narrow spike in the Audacity waveform for each particle the GM tube detects. Stop the recording after a few seconds and play it back. If you hear a series of clicks, everything is connected. If instead you hear sounds from the room, then the incorrect microphone is selected. If you hear nothing, it is possible the incorrect microphone is selected, or else there is a problem with a physical connection between the GM tube and the computer.

2.3 Measure the GM Tube Plateau

Although the sensitivity of the GM tube is in general dependent on the voltage, the ideal operating voltage is when the sensitivity is almost independent of the voltage—when changing the voltage has a small affect on the count rate. To measure where the plateau is, take a series of short measurements of the count rate (5 s each should be sufficient) of a high count rate sample at each voltage between 0 V and 1000 V. Plot the count rate as a function of voltage, and observe the decrease in slope (plateau) that begins somewhere between 800 V and 900 V. Why should you take data at 950 V, above the start of the plateau?

Remember, **NEVER** increase the voltage above 1000 V, since the GM tube will break!

3 Measurements

3.1 Dead Time

Read the Parts 1 and 2 of the Rainwater and Wu article. Recall that the dead time is a period of insensitivity to new incoming particles because the anode is temporarily shielded by the ions from the previous cascade of electrons. Measure the dead time (and the error on your measurement) of the GM tube using the procedure outlined in the Rainwater and Wu article. The analysis software on the computer will give you access to the total number of counts (including background) from a sample.

3.2 Poisson Statistics

The Poisson distribution describes the probability of detecting n events in a specified time (or space, or some other) range if they occur a known average of N times in that same range. The distribution is

$$\frac{1}{n!}N^n e^{-N} \tag{1}$$

and is also useful in situations such as calculating the chances of finding n impurities in a sample of material when they occur with a known average density N.

To see the Poisson distribution, take a 1000 s measurement of a low-count-rate source, between roughly 2 Hz and 5 Hz, and histogram the count rate using 1 s samples, so that you have 1000 data points for the detection of n counts in a second and an expected average of N counts in a second. The ratio of two points on your histogram corresponds to the ratio of the probabilities that the corresponding number of counts will be detected in one second. Check a few ratios to see whether your results agree with the Poisson distribution, or normalize your histogram and check agreement directly. Plot a Poisson distribution with the same mean as your data superimposed on your histogram.

3.3 Gaussian Statistics

In the large N limit, the Poisson distribution converges to the Gaussian or normal distribution. Consequently, if we use a source with a high count rate, we should see a Gaussian distribution of number of counts in a second. Use a source with a count rate roughly between 100 Hz and 1000 Hz, and take a 1000 s measurement. Again, histogram the count rate using 1 s samples. Use a graph to compare your results with a Gaussian distribution.

3.4 Time Interval Distribution

What sort of distributions do you expect for the time intervals between consecutive counts for a small count rate and for a large count rate? Compare the actual results with expectation.

3.5 Artificial Radioactivity

With an appropriate understanding of the GM tube operation, we can use it to study artificial radioactivity induced in materials by slow neutron capture. This can result in two or more distinct activities (isotopes, or equivalently, decay rates). Irradiating ^{116}In results in two activities with lifetimes $\sim 14\,\mathrm{s}$ and $\sim 1\,\mathrm{hr}$. When the two lifetimes are very different, as in this case, one can simplify the measurements by using a short measurement period for the short lifetime immediately after activation—remember, 14 s goes by very quickly! Since the decay rate is proportional to $e^{t/14\,\mathrm{s}}$, and $e^{-10} \approx 4.5 \times 10^{-5}$, measuring the disintegration rate of the irradiated sample for longer than 3 min will not give more information about the short lifetime. Similarly, we can avoid effects from the short-lived activity by waiting 5 min after irradiation before beginning measurements of the long-lived activity. With this information in mind, measure the long and short lifetimes of irradiated ^{116}In with assistance from the TA or supervisor.

If time remains, try the following measurement on silver. If natural silver (approximately 50% ^{108}Ag and 50% ^{110}Ag is irradiated with slow neutrons, its 109 and 111 isotopes are produced. Their lifetimes are about 2.4 min and 24 s. Try to extract both lifetimes from a single set of measurements by performing a fit to the data. Further information, including error measurement, is given in *Techniques for Nuclear and Particle Physics Experiments*, by W.R. Leo (Springer, 1994).