Nuclear Counting

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Section 1
(Dated: 1:30 pm Monday October 21, 2013)

I. ABSTRACT

II. INTRODUCTION

The Geiger-Mueller tube is one of the oldest radiation detector types in existence, it was introduced by Geiger and Mueller in 1928 hence the name. It was one of the most popular tools for detecting radiation due to its simplicity, the low cost of manufacturing, and its ease of operation.

We will be investigating the properties of the G-M tube using β-particle emitting sources, such as the counting plateau, the point at which the count rate is very loosely proportional to the change in voltage to the tube by measuring the count rate for a set sample at different voltages of operation. We will also be measuring the dead time of the tube using the two source method, measuring the count rate of each source individually then together for a set of voltages then averaging the results. The two source method allows a series of equations related to the dead time to be built and used to solve for T, the dead time. Knowing the dead time is important because this is a period during which the tube cannot register new counts. Knowing this allows us to better describe the radioactivity of the sources being measured and comparing strong sources with weak sources.

Also using the G-M tube we will investigate the properties of radioactive sources, like the random nature of radiation by measuring the number of counts in a set time for many trials and applying our measurements to statistical laws to radioactive emission rates of sources. We will also look at the ability of Aluminium to absorb β-particles from a source and use this to determine the range of β-particles in Aluminium, as well as the maximum energy of emitted particles from our sources by measuring the count rate of a source behind an aluminium blocker for of different widths, and plotting the count rate values versus the thickness of the absorber.

Knowing these properties can lead to many important advances in manufacturing for medical, commercial, and scientific equipment as radioactivity and nuclear power is becoming more prolific in our society today and probably even more so in our future.

III. THEORETICAL BACKGROUND

The Geiger-Mueller Counter

The Geiger-Mueller tube consists of a sealed tube with a window on the bottom face that allows particles into the tube, with a wire running down the middle inside. The tube is filled with usually a noble gas (due to its filled outer electron shell) and to a lesser degree, a quenching gas whose purpose will be explained shortly. An external circuit is usually part of the tube operation as an external quenching mechanism as well.

During operation, the tube and the wire are charged, to create an electric field inside the tube, with the tube being the cathode and the wire the anode. With the electric field inside the tube at a radius r given by:

$$E(r) = \frac{V}{rln(\frac{b}{a})} \tag{1}$$

where $a \equiv$ anode wire radius, $b \equiv$ cathode inner radius, and $V \equiv$voltage between the anode and cathode.

The process which the G-M tube detects ionizing radiation, is the process where the noble gases inside the tube are ionized producing an electron and a positive gas ion, which travel to the anode and cathode respectively. This electrical pulse in the unit can be detected as an ionization event, or a count from a radioactive source. For the pulses to be have a significant enough voltage to measure the G-M tube relies on the phenomenon of gas multiplication to amplify the effect of a single ionization event.

When an electron and ion pair are created, and in the large potential E-field of the G-M tube start to travel to their respective electrodes, the electron can hit another neutral noble atom producing another electron and ion pair, resulting in two electrons which may repeat this process toward the anode. This process is called a Townsend avalanche. However, the gas molecules will quickly return to their ground state, emitting a photon which can ionize another atom within the tube or liberate an electron from the tube wall, each of which result in another avalanche of electrons, which in turn, can create other avalanches within the G-M tube. This is the process of gas multiplication which can turn a single ionization event from a β-particle into many events, creating an electrical pulse strong enough to easily detect, this process is roughly illustrated in Fig.1.

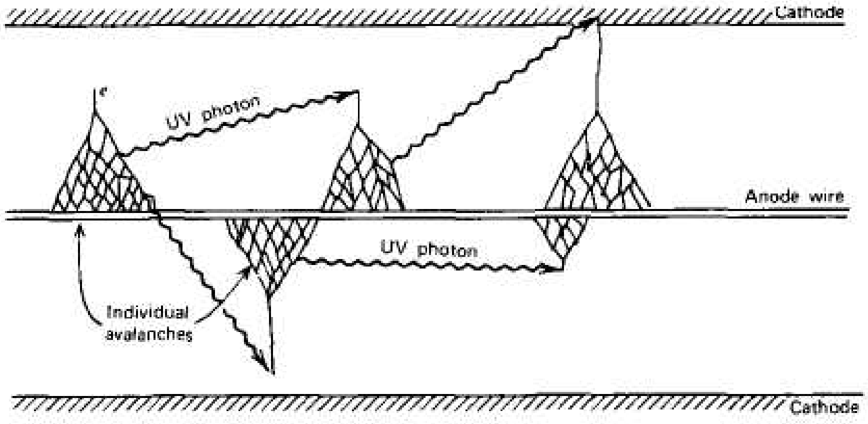

FIG. 1: Illustration of individual Townsend avalanches and the mechanism of gas multiplication in a crossection of a G-M tube, with the other cathode tube walls illustrated on the top and bottom, and the anode wire down the middle [1]

Since the time required to spread these avalanches is short and they only begin when the free electron and drifted to within a few mean free paths of the anode wire, the time it takes for the avalanches to grow in both directions along the wire only takes a small fraction of a microsecond. Since positive ions travel much slower than the electrons do, due to their mass, a high concentration of positive ions collect and sufficiently nullify the E field in the vicinity of the wire, and free electrons will no longer have a high enough ionization potential to create more avalanches until the cloud of positive ions travel outward to the cathode and equilibrium is restored to the tube, to a sufficient degree to create avalanches again during an ionization event. This period where the tube cannot create more avalanches is called the Dead Time as shown in Fig.2.

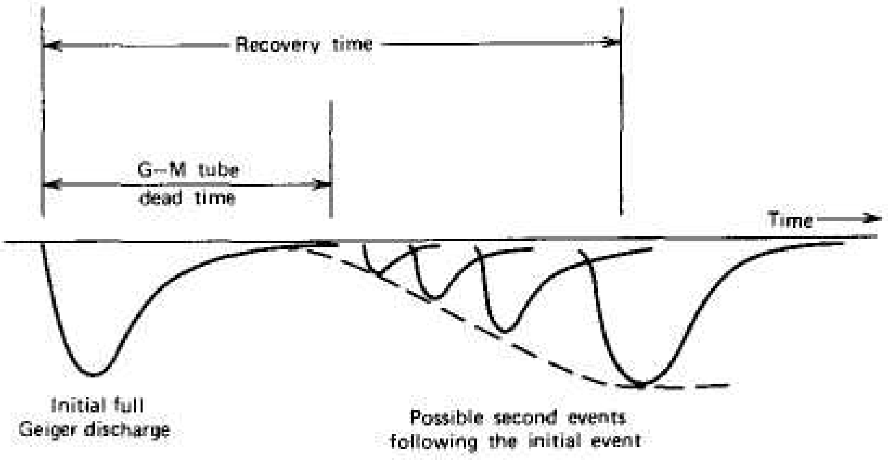

FIG. 2: Graph representing the dead time of a G-M tube, and it's subsequent recovery thereafter, and the amplitude of possible subsequent pulses during the recovery time [2]

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[1] Image from Radiation Detection and Measurement, by Glenn F.Knoll, © John Wiley, N.J
[2] Image from Radiation Detection and Measurement, by Glenn F.Knoll, © John Wiley, N.J

The gasses inside the G-M tube is largely filled with a noble gas because of their neutral charge in inert nature, in our case the noble gas filling the G-M tubes is Neon. A secondary gas is also put into the tube for the purpose of internal quenching. After a discharge, as the positive ions are drifting toward the inner tube wall and becoming neutralized by combining with an electron from the cathode surface, if the difference of that atoms ionization energy and work function of the cathode is greater than the work function of the cathode surface, there is a small chance that an extra electron can be liberated which can cause a Townsend avalanche leading to the G-M discharging again. To fix this there is the process of quenching, externally through a circuit which happens after discharging, the circuit reduces the high voltage applied to the tube for a small fixed time after the pulse using a capacitor circuit, this stops the process of gas multiplication so secondary avalanches cannot be formed. There is also the method if internal quenching, which uses a quench gas (as mentioned previously) in lower concentrations with the primary noble fill gas (about 5-10%) which has a lower ionization potential, its purpose is to stop multiple pulsing through charge transfer collisions. As the positive ions of the primary gas, while drifting toward the cathode, collide with the quench gas molecules, because of the lower ionization energy the positive charge is transferred to the quench gas molecule and the primary gas atom becomes neutral. If the concentration of the quench gas is sufficient, only quench gas molecules will be neutralized at the tube surface and because of the lower ionization energy the probability of dissociation is larger than the liberation of a free electron. In our case, a Halogen gas is used as the quench gas.

When looking at the charge on the tube versus the count rate, it is obvious that when the charge is below a certain threshold that there will be no recorded count rate, when the count are first recorded this is called the starting voltage, and the count rate increases rapidly as the voltage is increased up to a point where the rate plateaus. Increases the voltage doesn't change the count rate by any significant amount. There will be a point though, a critical voltage value above this where the G-M tube will continuously discharge, which may damage the tube. This plateau generally has a slope of 2-10% per 100V.

Determination of the Dead Time

If we assume a β-particle emitter gives N counts per second, with zero dead time, and n counts per second with a counter with a dead time of T seconds. So the counter cannot detect nT counts within this period, so the dead time is equivalent to:

$$N_i - n_i = N_i n_i T \tag{2}$$

Using two sources, we can build up a system of equations for the count rates with each source individually and one with the two sources measured together. Solving for T we can find T to be:

$$T \approx \frac{n_1 + n_2 - n_3}{2n_1 n_2} \tag{3}$$

with a factor of $O(nT)^2$ to be omitted, and it is assumed at the counts are generally equally space in time.

Random Nature of Radioactive Decay

Due to the random nature of radioactive decay, only the mean count rate can accurately describe the count rate over large period of time. The count rate over time follows a Poisson distribution, which can be approximated with a Gaussian distribution. σ, is the square root of the averages of the squares of the deviations from the mean count m, which is equal to the square root of the mean count. The probability of the relative error between t and $t + dt$:

$$P_o(t)dt = \frac{e^{-\frac{t^2}{2}} dt}{\sqrt{2\pi}} \tag{4}$$

where,

$$t = \frac{n - m}{\sigma} \tag{5}$$

and n $\equiv$ measured count, and m $\equiv$ mean count, and sigma $\equiv$ square root of the mean count.

Absorption and Range of β-Particles in Aluminium

The ability of a material to absorb or block radiation to a first approximation is independent of atomic number, the ability proportional to the thickness of the material in terms of density. For example, 0.5 mm of lead absorbs beta particles about the same as 2 mm of aluminium, since they both have a thickness of 570 mg/cm^3. Using aluminium is easier to use at small thicknesses because lead has a very low ductility, while aluminium is, meaning the absorbers can me more accurately made.

If the count rate versus the absorber thickness is graphed, with the count rate on a logarithmic scale, a graph such as Fig.3 will be seen. The tail of the graph is due to γ radiation, also known as bremsstrahlung radiation produced from the β-particles being absorbed in the aluminium. The graph can be extrapolated downward (also shown in Fig.3) to a point which represents the the thickness where the maximum energy of the particles emitted from the source are completely blocked.

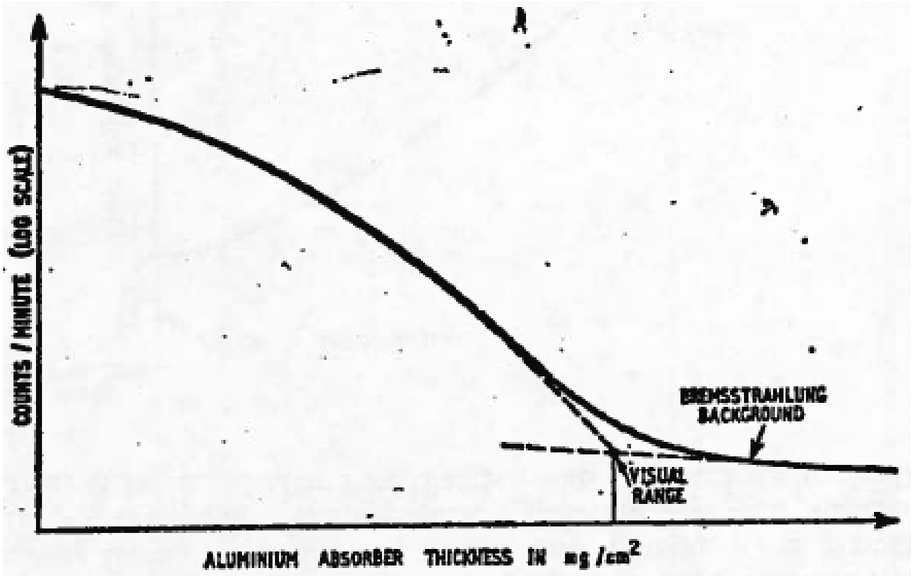

FIG. 3: Log count rate versus absorber thickness [3]

IV. EXPERIMENTAL DESIGN AND PROCEDURE

V. ANALYSIS

VI. CONCLUSION

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[3] Image from Counting Systems handout, Brown

VII. REFERENCES

Brown. Counting Systems Handout. 8p.

Glenn F. Knoll. Radiation Detection and Measurement. Fourth Edition. Hoboken, N.J: John Wiley, 2010. 860p.

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