Geiger-Mueller Counters

- All pulses from a Geiger tube are of the same amplitude regardless of the original number of ion pairs that initiated the process.

The Geiger Discharge

- In a single Townsend avalanche created by a single electron, many excited gas molecules are formed by electron collision in addition to secondary ions.
- Excited molecules return to the ground state via photon emission with wavelengths from visible to UV.
- The photons may ionize weaker bound electrons or produce an electron through absorption with the cathode wall where it could release another free electron.
- The newly freed electron migrates toward the anode and triggers another avalanche (Fig. 7.1).
- For a proportional chamber, gas multiplication factor $M \sim 10^2$-10^4, and with the number of excited molecules in an avalanche n_0' and probability of photoelectric absorption, p: $n_0' p << 1$.
- For a Geiger tube $n_0' p \geq 1$ and $M \sim 10^6$-10^8 so many more critical particles are formed.
- Photons preferentially create free electrons near the original avalanche, and these electrons drift into the high field region near the anode and create more avalanches.
- The rapid propagation of chain reaction leads to many avalanches and secondary positive ions are formed throughout the cylindrical multiplying region surrounding the anode.
- Similar to the proportional chamber, the discharge is limited by the number of positive ions near the anode reducing the electric field.
- So each pulse has the same charge regardless of the number of ion pairs created by the incident radiation. Pulse heights are therefore similar, regardless of incident energy.
- Pulse amplitude increases proportional (roughly) with the overvoltage (the difference between applied voltage and the minimum voltage required to initiate the Geiger discharge). Page 203 shows this relationship.

Fill Gas

- Fill gas requirements for Geiger tubes are similar to proportional counters.
- Gasses that form negative ions are avoided (Oxygen), noble gases are widely used (He and Ar are popular), and a second gas is introduced for the purpose of quenching.

- Full Geiger discharge requires a certain minimum ε/p (electric field to pressure) ratio. Less voltage may be applied by reducing the pressure.

Quenching

- After the primary discharge the positive ions drift towards the cathode and are neutralized by an electron there. However there may still be excess energy remaining and can liberate and electron, which is accelerated toward the anode starting avalanche sequence and Geiger discharge.
- There are two methods to quenching, internal and external.
- External quenching is produced by lowering the potential (V_0) across the tube after each pulse (for a fixed time) which is too low to support further gas multiplication.
- Duration of low V_0 > transit time of positive ions + transit time of the electron to the anode.
- Figure 7.2 shows an equivalent counting circuit for a Geiger-Mueller tube. The product of the resistance (R) and the capacitance (C) (which is usually only the inherent capacitance of the tube and electronics) determines the time constant of the restoration to V_0 of higher voltage following the Geiger discharge. Thus one can choose R to set an appropriate low voltage time period.
- Internal quenching is the result of adding a second fill gas with a lower ionizing potential, generally present in 5-10% concentration.
- The extra energy of the positive ion recombination at the cathode is more likely to go into the disassociation of the quenching gas than into more electrons liberated from the cathode wall.

Time Behavior

Pulse Profile:

- Exhibits a fast rise ($\sim 10^{-6}$ s) due to electrons and a much slower rise due to the movement of the slow positive ion drift.
- Time constants are chosen to be much less than 100 μs which eliminate the slow rising portion of the pulse leaving only the fast leading edge.

Dead Time:

- The buildup of positive ion space charge terminates the Geiger discharge.
- After some time, the charges drift away from the anode, partially restoring the ε, allowing for less than full amplitude Geiger discharge, illustrated in Fig. 7.4.
- The dead time is defined as the period between an initial pulse and the time at which a second discharge can form (regardless of size).
- Dead time is generally ~50-100 μs.

- Resolving time-elapsed time required to develop a second discharge of acceptable amplitude.
- Recovery time-the time interval required for a tube to return to its original state and become capable of producing a second pulse of full amplitude.

The Geiger Counting Plateau

- Figure 7.5 shows the establishment of a counting plateau for a G-M tube, note how the low amplitude on the pulse height spectrum on the left causes a finite slope of the plateau on the counting curve.
- Starting voltage-minimum applied voltage at which pulses are first registered by the counting system.
- Knee-transition between the rapid rise of the counting curve and the plateau.
- Continuous discharge region-the voltage is high enough to have coronal discharges (from sharp irregularities on the anode wire) or multiple pulsing through failure of the quenching mechanism.
- The low amplitude tail stems from two sources:
    1) The regions near the end of the tube may have lower than normal electric field strength and discharges originating here may be smaller than normal.
    2) Pulses during recovery time will also be abnormally small.
- The plateau may have some hysteresis due to slow moving charges which may influence the electric field configuration.
- Organic quench tubes have slopes ~2-3% per 100 V, halogen quench tubes are larger.

Design Features

- End window type- entrance windows must be thin enough to allow entrance of β^- or α's. Window material may be mica or other materials that can maintain its strength in thin sections.
- Anode can be straight, circular, or needle. The needle is advantageous since $\varepsilon \propto 1/r^2$ for needle instead of $1/r$.
- Continuous flow Geiger counters can produce high counting efficiencies for very soft radiation like low-energy heavy charged particles of soft β^- particles.
- Noting the block diagram of Fig. 7.7 which shows several important features including the parallel configuration of R and C's which determine the time constant for the detection circuit.
- A secondary attenuation of time constant RC's (a coupling capacitor to block the high voltage from pre-amp or amp, must be large in comparison with the pulse duration to prevent attenuation of the pulse amplitude).

Counting Efficiency

- For a charged particle the efficiency is essentially 100%.

- For α's and β's the window thickness may be of some concern but windows of 1.5 mg/cm^2 specifically for α detection to promote penetration, and β^-'s can use a thicker window (longer range) although some back scattering will occur.
- Using an appropriate gas (^{3}He), neutrons can be detected, but generally a proportion counter is used for neutron detection.
- For γ-rays, if the reaction occurs in the chamber wall, and is close enough to the inner wall surface; the secondary electron can reach the gas and form a Geiger discharge.
- There are two factors involved with the efficiency of γ-ray detection:
    1) The probability that the γ will interact with the chamber wall and produce a secondary electron, this probability increases with increasing atomic number of the material.
    2) The probability that the secondary electron reaches the fill gas before the end of its track in the wall. So the inner wall of the chamber producing secondary electrons should have a thickness less than or equal to the maximum range of the secondary electrons in the material (Fig 7.8).
- Note that the fill gas does not contribute appreciably to the high energy γ-ray interactions (low-density).
- Fig. 7.9 demonstrates the material dependence of the efficiency of γ's normally incident on the cathode.
- If the γ energy is low enough, the interactions (direct) of the fill gas may no longer be negligible. Using fill gases of higher atomic number and as high a pressure as possible will lead to better efficiency (gases are usually Xe or Kr).

<u>Time-to-First-Count Method</u>

- Fig. 7.10 illustrates the time-to-first-count method of determining the event rate count of a G-M tube.
- After a discharge, the voltage is dropped for a minimum "wait time" (1-2 ms). This time is chosen to be longer than the recovery time of the tube (at reduced voltage).
- Define $\bar{t}$ to be the average time interval between detector turn-on and the next event, and $I_1(t)$ is the distribution function for intervals between adjacent random events. Then:

$$\bar{t} = \frac{\int_0^\infty t I_1(t)dt}{\int_0^\infty I_1(t)dt} = \frac{1}{r},$$

where r is the true event rate, or $r = \frac{1}{\bar{t}}$.

G-M Survey Meters

- A G-M meter will scale linearly with exposure rate at a given energy, but not with the varying energy of the γ's.
- One would ideally want an efficiency vs. energy curve that would exactly match a plot of exposure per γ-ray photon vs. energy.
- To help to this effect a thin sheet of lead and/or tin can provide a first order energy compensation. The metal will preferentially absorb low-energy γ's providing a good match with the exposure vs. energy curve.
- The ratio of the two curves at a given energy gives a measure of the correction factor that should be applied to the survey meter readings.
- Fig. 7.11 gives a plot of the correction factor vs. γ-ray energy for 2 commercial survey meters.
- The sensitivity in these plots is the indicated exposure rate divided by the true exposure rate.
- So if one divides the indicated exposure rate by the sensitivity for a given energy, the true count rate is the result.