

TYBSc [Semester-6] Physics

US06CPHY23 Nuclear Physics

UNIT- 4 Part 2 Lecture 2

1

Radiation Detectors

Radiation Detectors

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- **Purpose of detectors:**
 - Presence or absence of radiations
 - Nature of radiation
 - Energy and momentum measurements
 - Spatial coordinates of the particle trajectories

Radiation Detectors

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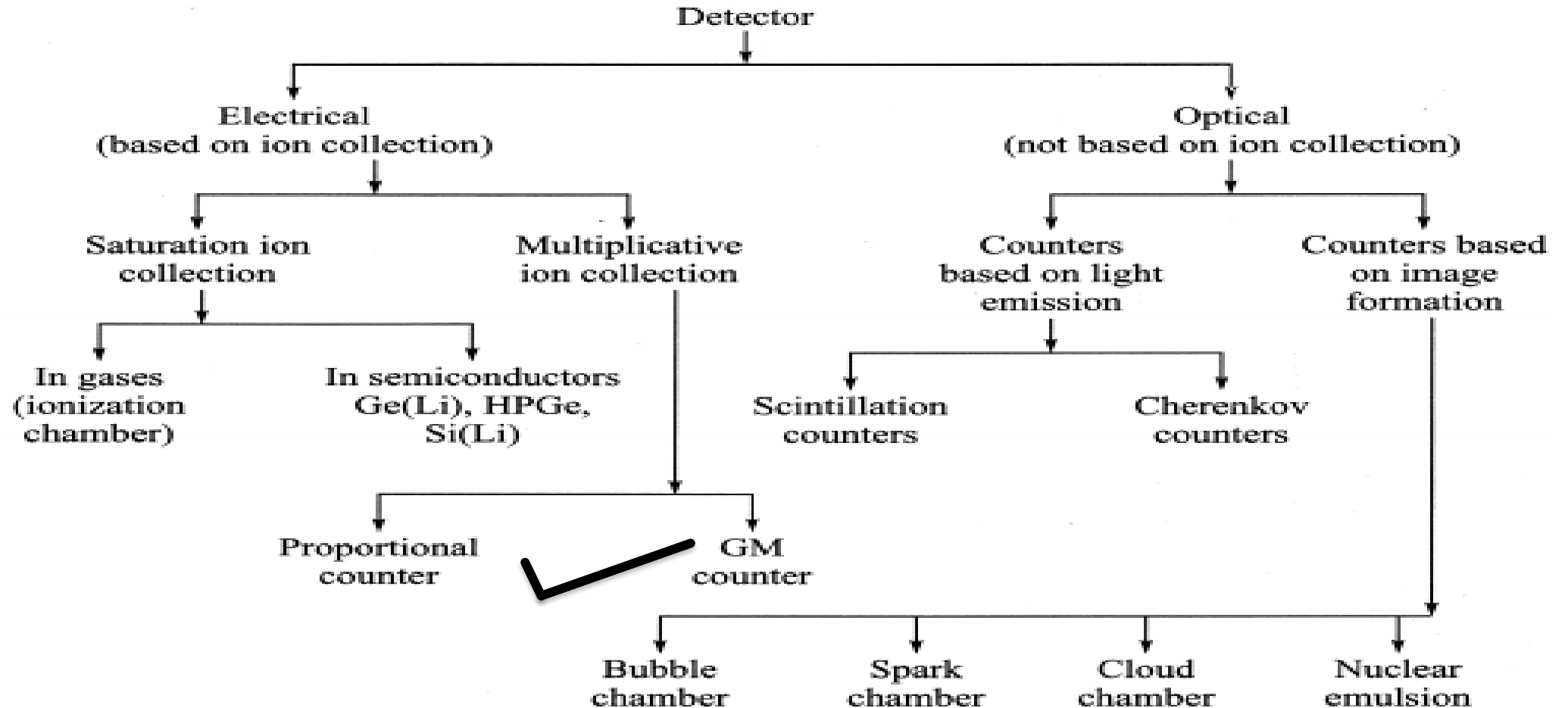
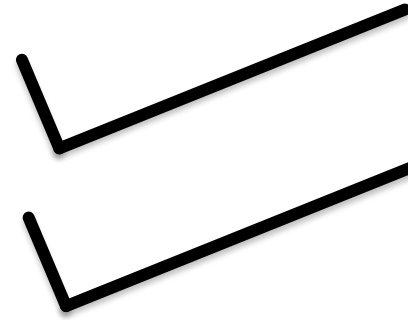


Figure 7.1 Classification of detectors according to signals produced.

Radiation Detectors

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- Gas filled detectors
- Ionization chamber
- Geiger-Mueller counter
- Cloud chamber
- Bubble chamber
- Spark chamber



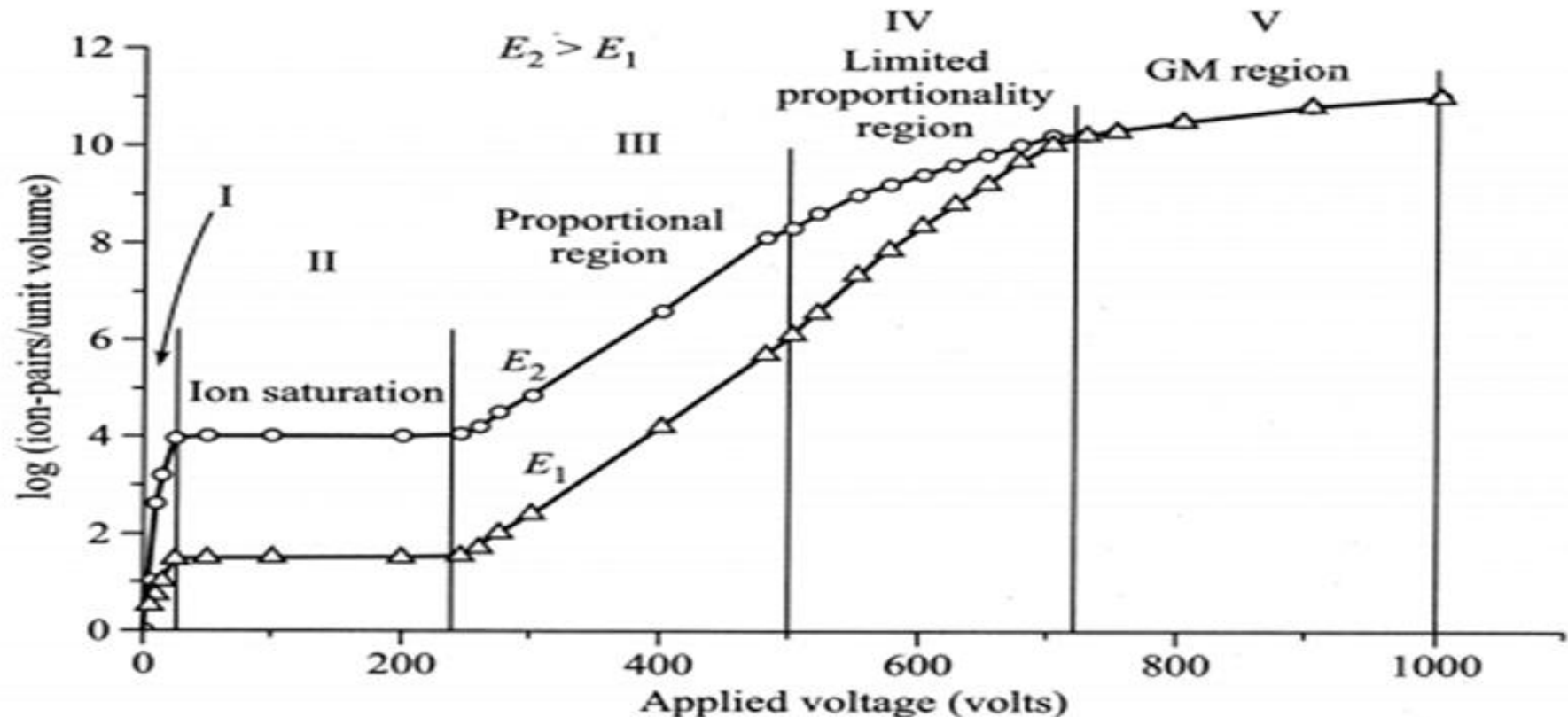
Electrical

Optical

Region V (~800 V to ~1000 V)

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- This region is known as **Geiger Müller region** and detectors operating in this region are known as **Geiger Müller counters** or simply **GM counters**.





7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5 GEIGER-MÜLLER (GM) COUNTERS

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- It is a radiation detection and measuring instrument.
- It consists of a gas-filled tube (usually inert gases or halogens) containing electrodes, between which there is an electrical voltage, but no current flowing.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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- When ionizing radiation passes through the tube, a short, intense pulse of current passes from the **negative electrode** to the **positive electrode** and is measured or counted.
- The number of pulses per second measures the **intensity of the radiation field**.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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- It was named after **Hans Geiger** and **W. Muller**, who invented it in the 1920s.
- It is sometimes called simply a **Geiger counter** or a **GM counter**.
- It is the most commonly used as **portable radiation instrument**.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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- It is very **useful**, **cheap** and **robust** counter.
- It can only **detect the presence** and **intensity/flux of radiation**.
- Geiger counters are not only used to detect ionizing radiation, usually **alpha** and **beta** radiation, but also other types of radiation as well.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.1 Principle

- It works on the principle that **avalanche spreads along the whole length of the central wire.**
- The amplification does not depend on the initial ionization produced by the ionizing particle.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.2 Construction

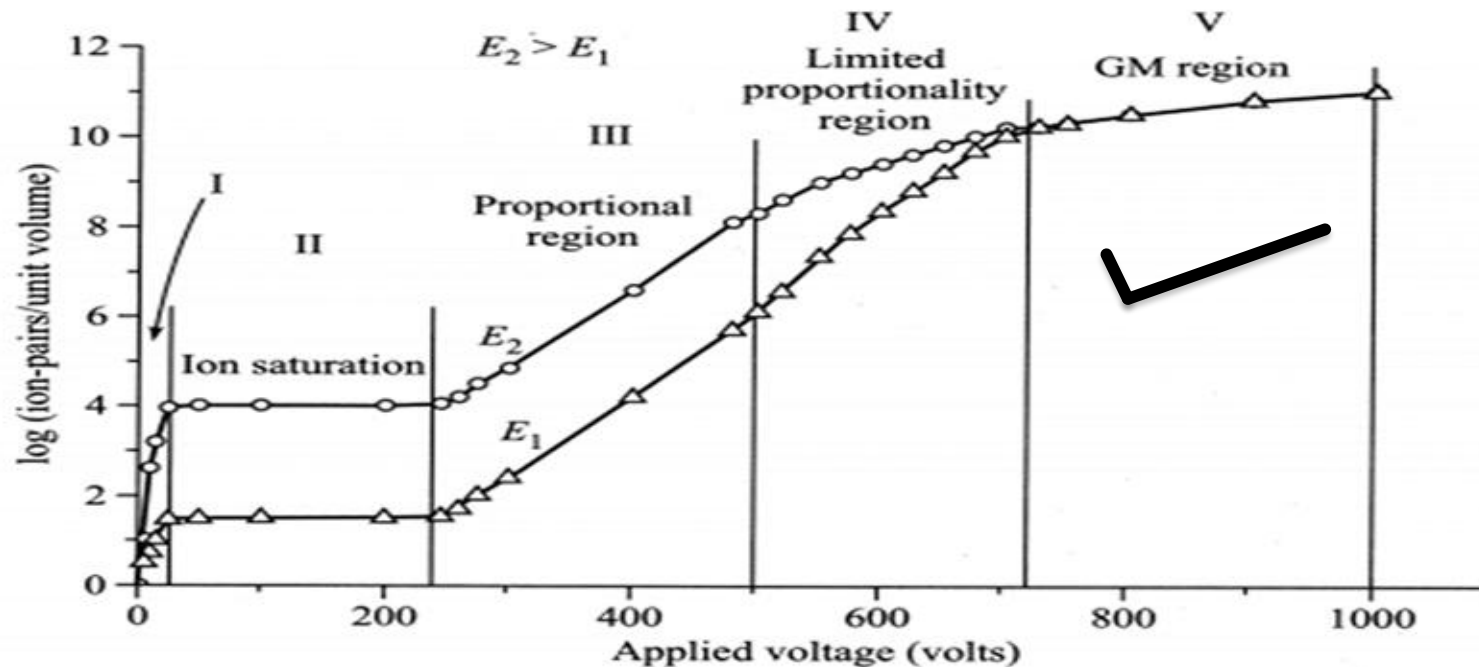
The schematic diagram of GM counter is identical to that of a **proportional counter** and is shown in Figure.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.2 Construction

- If we continue to increase the voltage across the electrodes, then we pass from the **proportional region** through the region of **limited proportionality** to the **GM region**.



7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.2 Construction

- In this case, the electron cascade spreads from the immediate neighborhood of the initial track, until it encompasses the whole length of the anode.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.2 Construction

- The resulting pulse is thus **very much larger in amplitude** than that obtained from a proportional counter, but is obviously **independent of the initial particle energy**.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.2 Construction

- About pulses from a GM tube
- All pulses from a GM tube are of the **same amplitude.**
- It does not depend on the number of original ion-pairs that started the process or is independent of the energy brought into the tube by the incident particle. Therefore, **a GM counter cannot be used for measuring energy of the radiations.**

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working

Geiger Discharge

- In a typical **Townsend avalanche** created by a single original electron, **many excited gas molecules** are formed by electron collisions in addition to secondary ions.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- Within usually a few **nanoseconds** (ns), these excited molecules return to their ground state through the emission of **ultraviolet** (UV) or **visible photons**.
- These photons may be reabsorbed in the gas by photoelectric absorption involving less tightly bound electrons creating new free electrons.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- Alternatively, the photons may reach the cathode wall where it could release a free electron upon absorption.
- In both cases, the newly created free electrons move towards the **anode** and trigger another avalanche.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- In a Geiger discharge, a rapid propagation of the chain reaction leads to many avalanches along the anode.
- Secondary ions are, therefore, formed throughout the region that surrounds the anode.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- The Geiger discharge, therefore, grows to envelop the entire anode wire, regardless of the position at which the primary event occurred.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- The process that leads to the termination of a Geiger discharge is due to creation of a **positive ion sheath** along with each electron in an avalanche.
- The **mobility of these ions** is much slower than that of the free electrons.
- **Positive ions** are essentially motionless during the time needed to collect all the free electrons.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- When the concentration of these positive ions is sufficiently high, their presence reduces the magnitude of the electric field near the anode.
- Because the ions represent a **positive space charge**, the region between the ions and anode will have an electric field below some critical value.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- This sheet of positive space charge eventually terminates the ***Geiger discharge***.
- Suppose a GM tube is filled with a **single gas** such as **Ar**. After the **primary Geiger discharge** is terminated, the positive Ar ions slowly arrive at the cathode. Here they are neutralized by combining with electrons from the cathode.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- In this process, an amount of energy equal to the ionization energy of the gas minus the work function of the cathode is liberated.
- If this energy exceeds the cathode work function, it is possible for another free electron to emerge from the cathode.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- This **electron** then **drifts towards the anode** and triggers another avalanche. The entire cycle is now repeated and GM counter once initially triggered would produce a continuous output of multiple pulses.
- For this reason, special precautions must be taken in GM counter to prevent possibility of multiple pulses.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- One method of preventing multiple pulses is known as *external quenching*.
- In external quenching, resistor R (Figure 7.5) is chosen to be **very high** of the order of **$10^8 \Omega$** , so that the **time constant of the charge collection circuit is of the order of milliseconds**.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- This external resistance method of quenching has the **disadvantage** of requiring several milliseconds for the anode to reach to near normal voltage and, therefore, full Geiger discharges for each event are produced only at a **very low counting rates**.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- It is much more common to prevent the possibility of multiple pulses through ***internal quenching***, which is accomplished by adding a **second component** called ***quench*** gas to the primary filled gas.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- It is chosen to have a **lower ionization potential** and a **more complex molecular structure** than the primary gas component and is present with a typical concentration of **5 -10%**.
- Commonly used quenching gases are **methane, ethane, ethyl alcohol, Cl_2 , Br_2** etc.
- Ionization potential of Ar is **15.7 eV** while that of ethyl alcohol it is **11.3 eV**.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- Since the ionization potential of quenching gas is lower than that of argon, positive Ar ions while moving towards the cathode, encounters a quench gas molecule (say ethyl alcohol) attract electrons of the quench gas, and become neutral.
- The quench gas becomes positively charged. As a result, the ions moving towards cathode consists mostly of alcohol ions.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- These alcohol ions do not give rise to secondary avalanche, when they get neutralized at the cathode.
- These alcohol ions dissociate after becoming neutral at the cathode.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- Therefore, GM tubes using **polyatomic gas** as quench gas have limited lifetime between **10^8 and 10^{10} counts** depending upon the **number molecules of the polyatomic gas present** in the GM tube.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Discharge*

- To overcome the problem of limited lifetime some tubes use halogens (Cl_2 , or Br_2) as quench gas.
- Although halogen molecules also dissociate when carrying out their quenching function, they recombine at a later time.
- In principle, halogen quenched tubes have an infinite lifetime.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Plateau*

- In Figure 7.7 a plot of count rate versus the anode voltage is shown.
- In this figure, the **source of radiations** is kept at a **fixed distance from the counter**.
- The potential difference at which the counting just starts is called ***threshold potential***.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working Geiger Plateau

- The typical threshold potential depends upon the gas and its pressure in the counter.
- It generally varies between **400 and 900 volts**.

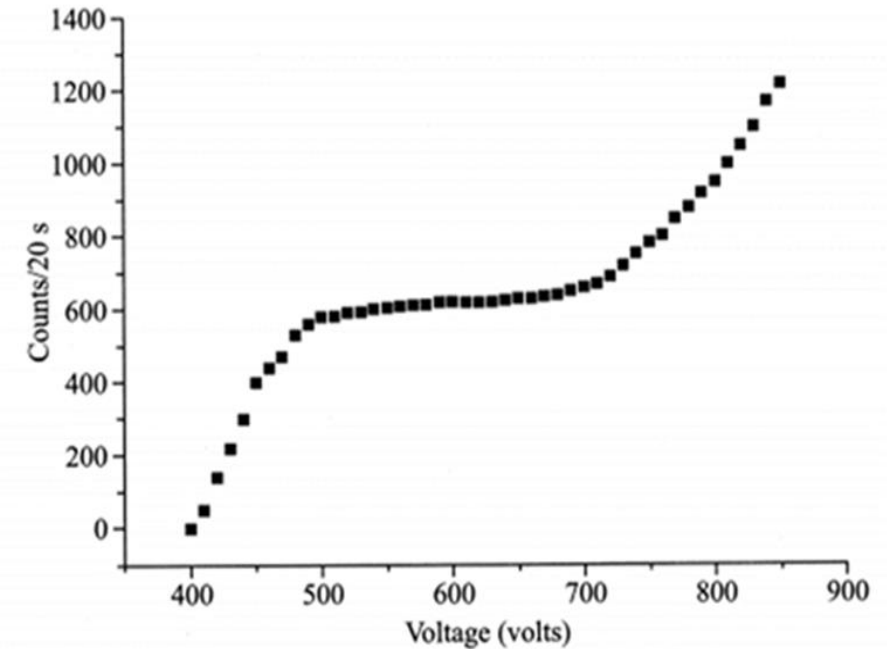


Figure 7.7 Plateau curve of a GM counter.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working- *Geiger Plateau*

- After a very rise, the counting rate remains almost constant with increasing voltage.
- This **flat region** is known as the **plateau**, where the **number of counts recorded per second** remains independent of applied voltage.

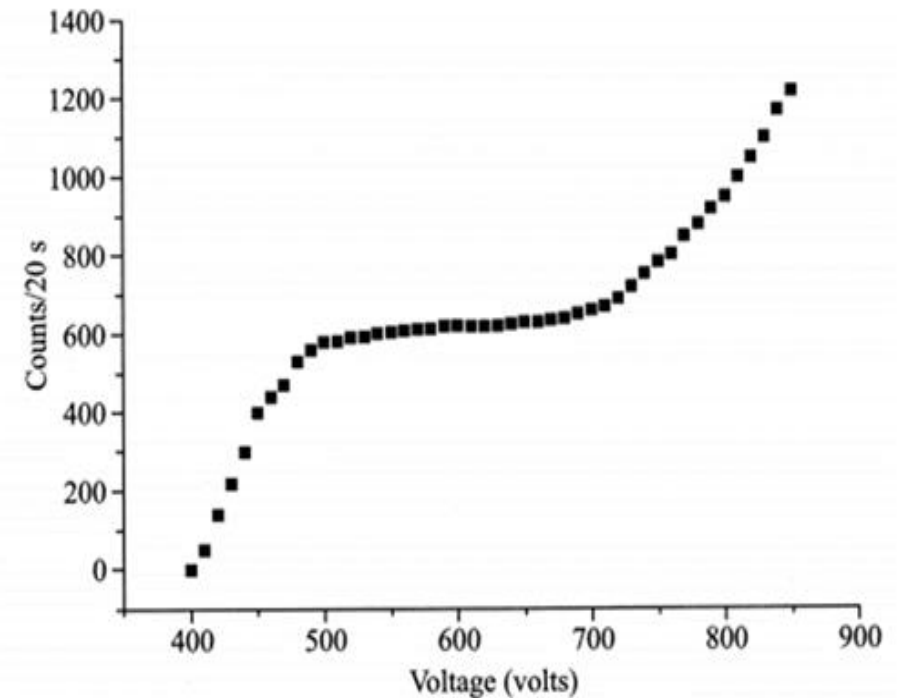


Figure 7.7 Plateau curve of a GM counter.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working *Geiger Plateau*

This **flat region** is known as the **plateau**, where the **number of counts recorded per second remains independent of applied voltage.**

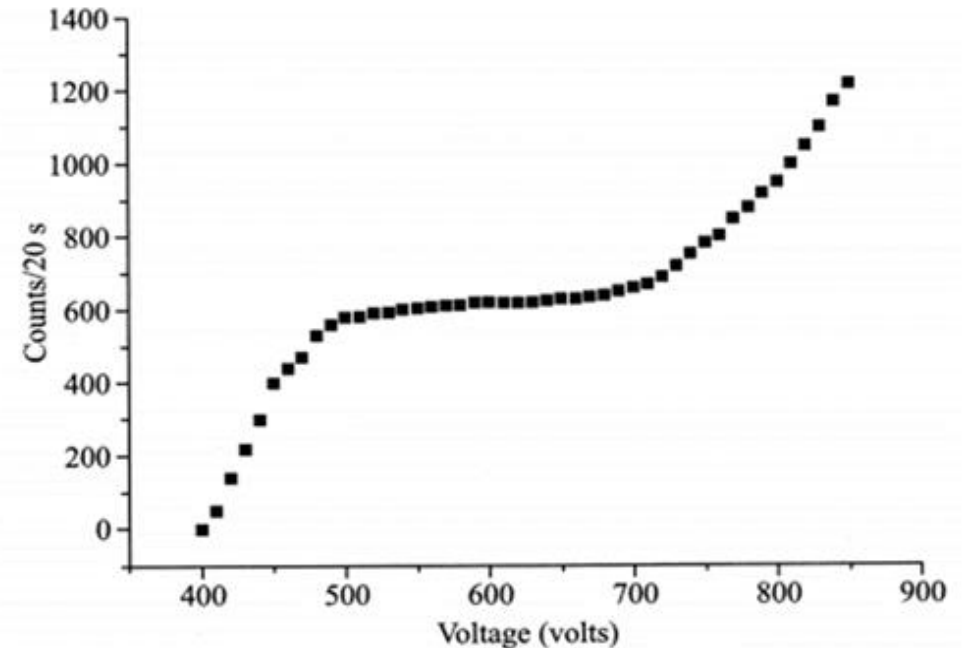


Figure 7.7 Plateau curve of a GM counter.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working- *Geiger Plateau*

- This region is also called **Geiger region**.
- The length of the plateau is about **100 to 300 volts**.
- When the plateau region becomes **shorter** and **steeper**, it means that the *GM tube is nearing the end of its useful life*.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working- *Geiger Plateau*

- If a Geiger-Müller counter is operated in this region, it eliminates the need for a **costly highly regulated power supply.**

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working- *Dead Time*

- The dead time of a GM tube is the period between the initial pulse and time at which a second pulse regardless of its size can be developed.
- This time is the time taken by the positive ions to reach the cathode.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.3 Working- *Dead Time*

- It is generally of the order of **50 - 100 μs** .
- The counter requires another short time before it fully recovers. This time is known as **recovery time**.
- During the recovery time pulses of **shorter height formed** which are **not counted**.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.4 Main Uses

- It can detect even very small activities (due to large multiplication factor), these are extensively used for detecting *X-rays*, *β -particles*, *α -particles*, etc.
- For *γ -ray detection*, we require *bigger size* GM tubes.
- They are one of the *cheapest* kinds of nuclear radiation detectors.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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7.5.5 Main Drawback

- The major drawback of GM counters is that they cannot be used to measure the energy of radiations.

Differences between ionization chamber and GM counter

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Sr. No	Ionization chamber	GM counter
1	It operates in the ionization region (region II, Figure (7.3)).	It operates in the GM region (region V, Figure 7.3).

Differences between ionization chamber and GM counter

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1	It operates in the ionization region (region II, Figure (7.3)).	It operates in the GM region (region V, Figure 7.3).
2	It operates at relatively low voltages (~30 V to ~250 V).	It operates at much higher voltages (~800 V to ~1000 V).

Differences between ionization chamber and GM counter

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Differences between ionization chamber and GM counter

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3	The output pulse height is low, so an amplifier is needed.	The output pulse height is large, so no amplifier is needed.
4	Power supply used to feed voltage to ionization chamber must be highly regulated.	Power supply used to feed voltage to a GM counter need not be regulated.

7.8 CLOUD CHAMBER

7.8 CLOUD CHAMBER

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- It is one of the detectors, which provides **visual trajectory** of a **charged particle** like electron, proton, α -particles, etc.
- Cloud chamber also known as **Wilson Chamber** was built by CTR Wilson in **1911**.

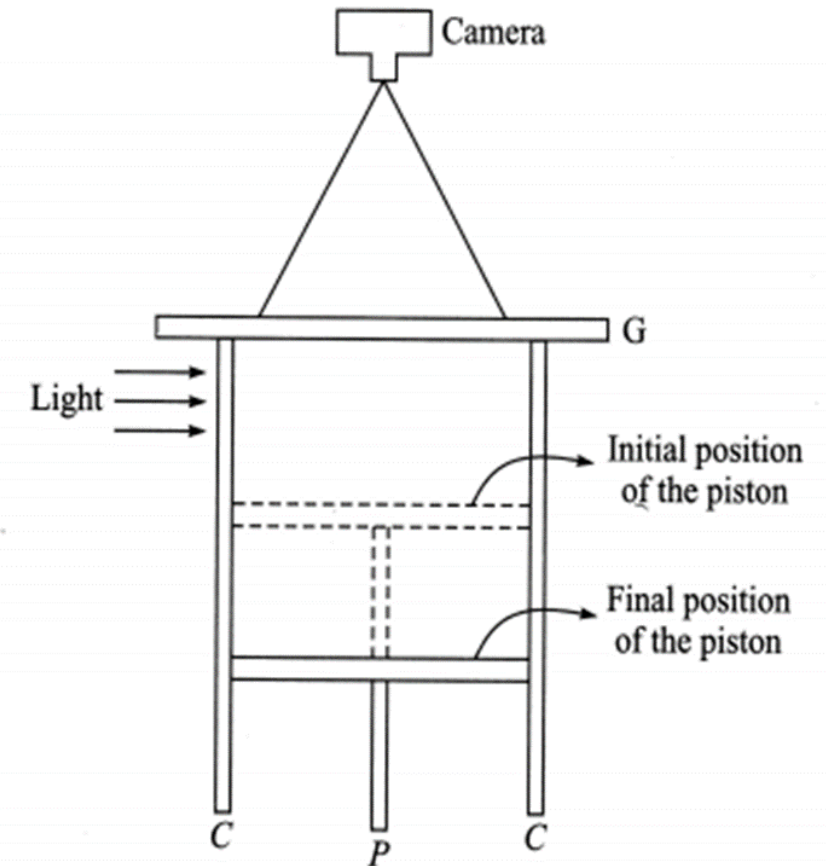


Figure 7.18 A simplified diagram of cloud chamber.

7.8 CLOUD CHAMBER

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7.8.1 Principle

- It is based on the principle that when dust-free air saturated with vapours of a liquid (like **water**, **alcohol**, **ether**, etc.) is allowed to expand adiabatically, **supersaturation** occurs.

7.8 CLOUD CHAMBER

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7.8.1 Principle

- If at this stage an ionizing particle enters the chamber and creates ion-pairs, tiny droplets of liquid condense on these ions and form a **visible track** along the path of the ionizing radiation.
- These **visible tracks can be photographed.**

7.8 CLOUD CHAMBER

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7.8.1 Principle

- In some cases, cloud chamber is subjected to a strong magnetic or electric field.
- Such a field causes the charged particles to travel in curved path. The curvature of the curved path gives information about the mass and charged of the ionization particle.

7.8 CLOUD CHAMBER

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7.8.3 Working

- Air saturated with given liquid is taken in the space between the movable piston P and glass plate G.
- The pressure inside the chamber is kept high.

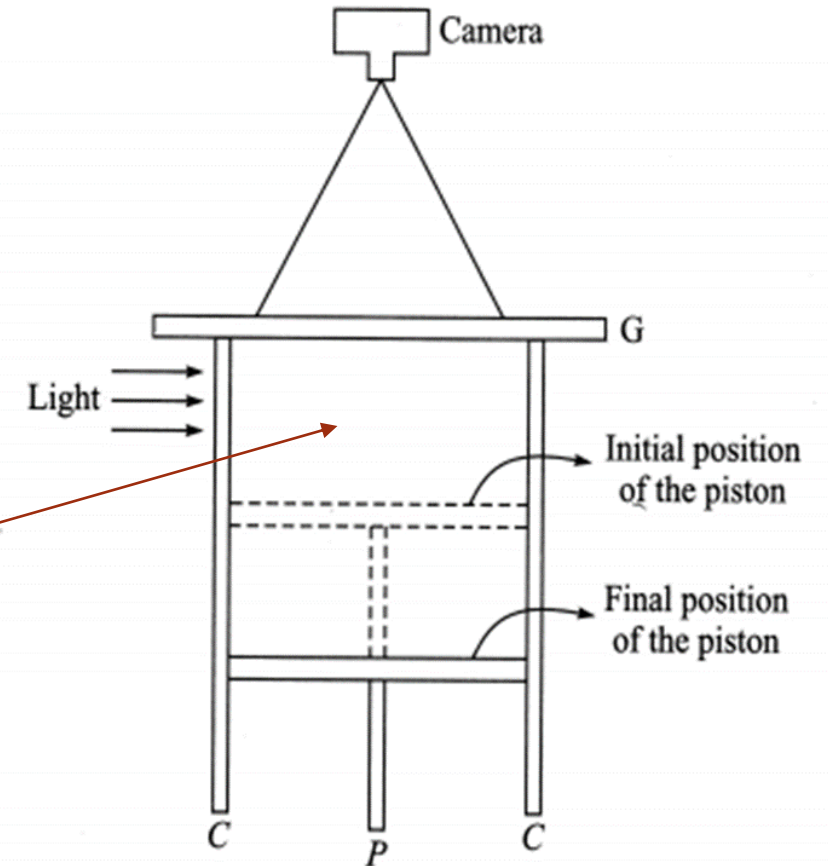


Figure 7.18 A simplified diagram of cloud chamber.

7.8 CLOUD CHAMBER

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7.8.3 Working

- The pressure in the chamber is lowered by moving the piston down suddenly due to which the temperature of the saturated liquid falls and vapours become super saturated.

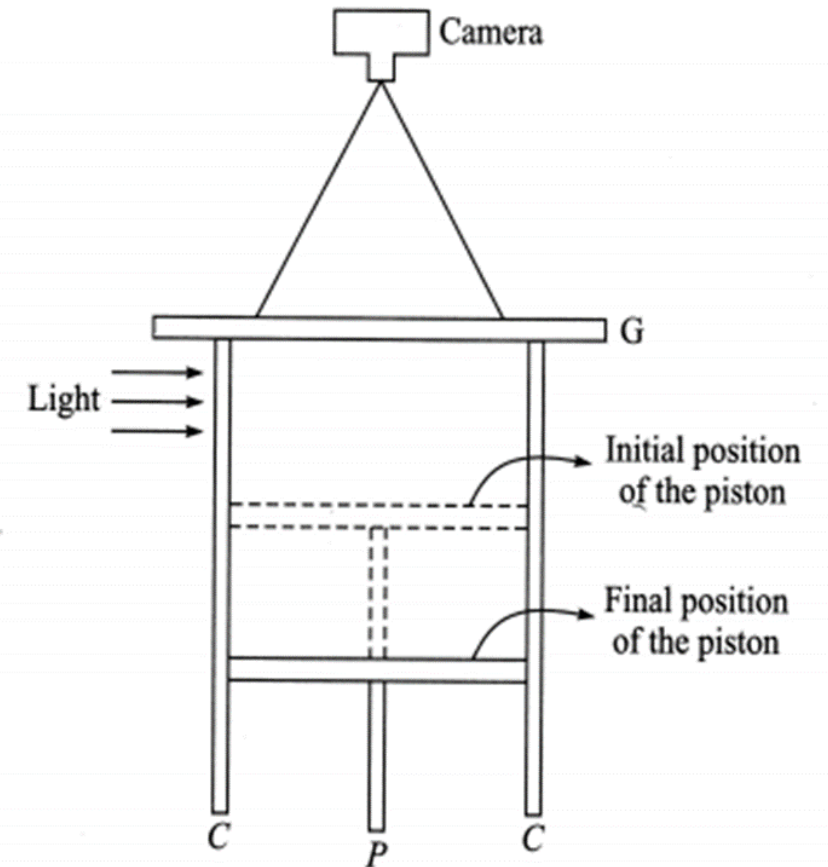


Figure 7.18 A simplified diagram of cloud chamber.

7.8 CLOUD CHAMBER

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7.8.3 Working

- If at this moment, a charged particle passes through the chamber, it will produce **ion-pairs**.
- The supersaturated vapours condense on the ions and a trail of droplets along the path of the charged particle is seen.
- These tracks are known as ***cloud tracks***.

7.8 CLOUD CHAMBER

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7.8.3 Working

- These tracks have distinctive shapes.
- for example,
 - an α -particle track is broad and straight.
 - an electron's trajectory is thinner and shows a zig-zag trajectory.

7.8 CLOUD CHAMBER

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7.8.3 Working

- If the chamber is illuminated with light, a camera can take a photograph of the track, which appears as a **white line** on a dark background.
- When a **vertical magnetic field is applied**, positively and negatively charged particles curve in opposite directions.

7.8 CLOUD CHAMBER

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7.8.4 Advantages (1)

When subjected to electric or magnetic field, cloud chamber is used to find **charge on the ionizing particles** and their **momentum**.

7.8 CLOUD CHAMBER

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7.8.4 Advantages (2)

With cloud chamber, the range of high energy particles can easily be determined.

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7.8.4 Advantages (3)

By seeing the **broadness of a cloud track**, we can immediately get an idea whether the track is due to **heavy particle** (like α -particle) or **light particle** (like electron).

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7.8.5 Limitations (1)

If the energy of the ionizing particle is **high**, it may not completely stop in the cloud chamber and may come out of the chamber. So, we will not get **full information about the particle**.

7.8 CLOUD CHAMBER

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7.8.5 Limitations (2)

The recovery time of the cloud chamber is relatively very long 10-60 seconds after the expansion, so it may miss many ionizing particles.

Next Lecture.....

7.9 BUBBLE CHAMBER

7.10 SPARK CHAMBER

Thanks