TYBSc [Semester-6] Physics

US06CPHY23 Nuclear Physics

UNIT- 4 Part 2 Lecture 2

Radiation Detectors

Radiation Detectors

- **Purpose of detectors:**

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

Radiation Detectors

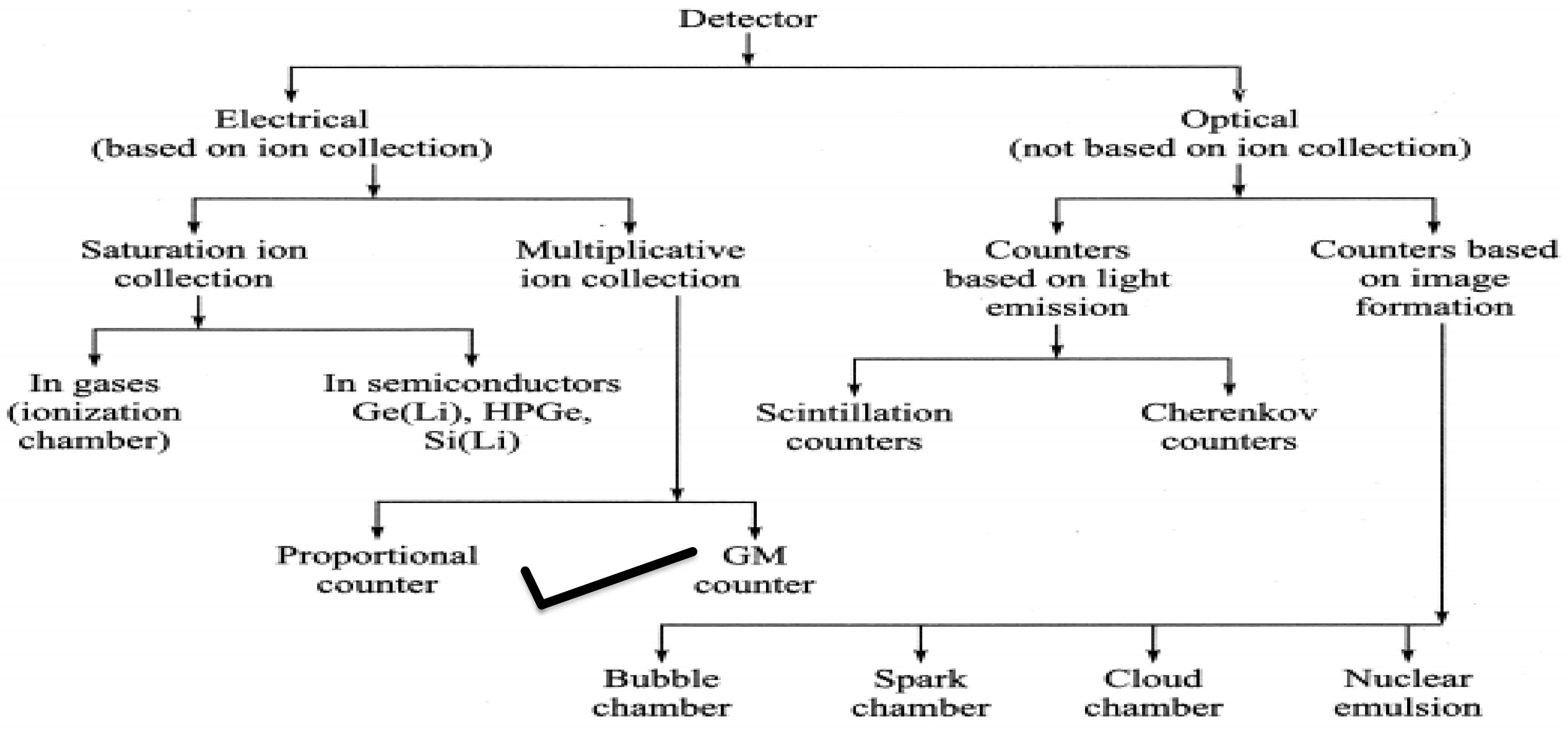


Figure 7.1 Classification of detectors according to signals produced.

Radiation Detectors

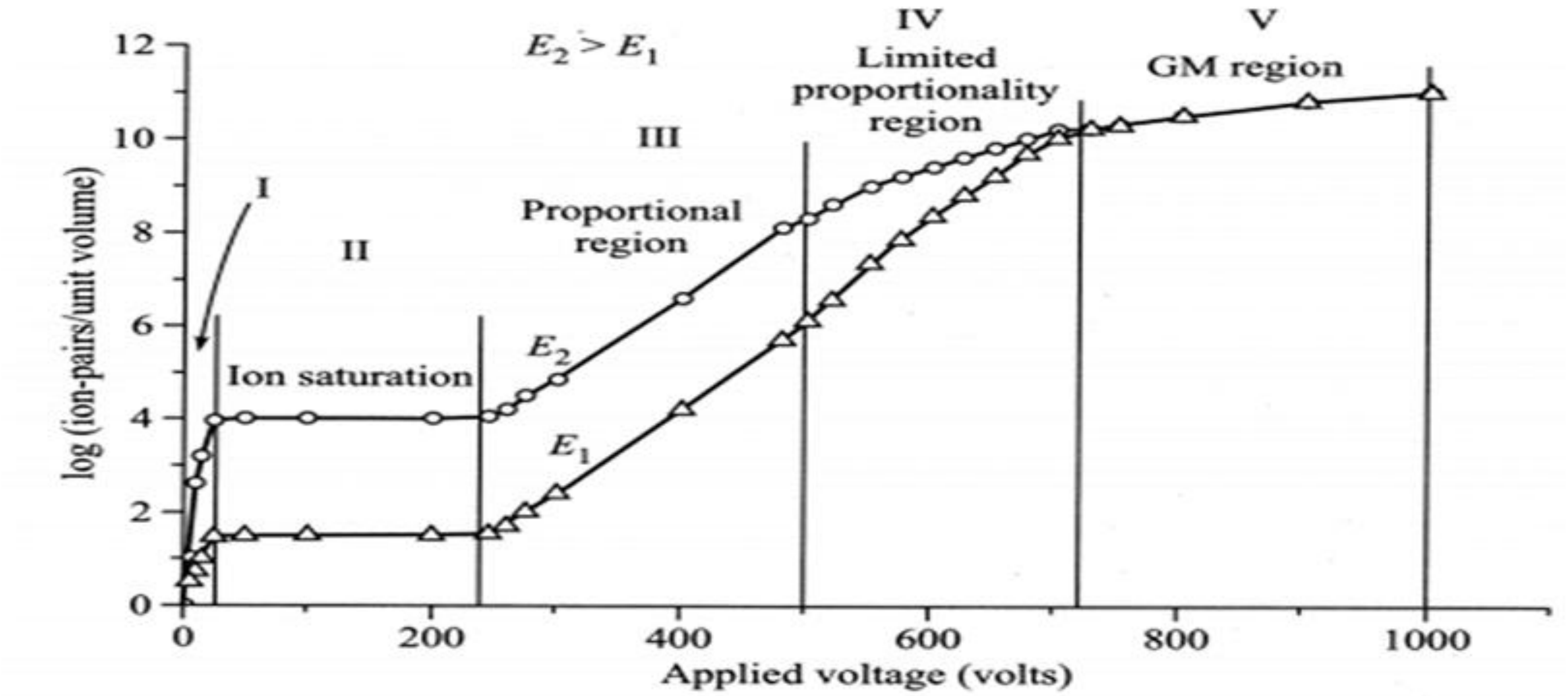
- Gas filled detectors ✓
- Ionization chamber ✓
- Geiger-Mueller counter
- Cloud chamber
- Bubble chamber
- Spark chamber

Gas filled detectors, Ionization chamber, Geiger-Mueller counter: **Electrical**

Cloud chamber, Bubble chamber, Spark chamber: **Optical**

Region V (~800 V to ~1000 V)

- 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

7.5 GEIGER-MÜLLER (GM) COUNTERS

- 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

- 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

- 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

- Ii 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

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

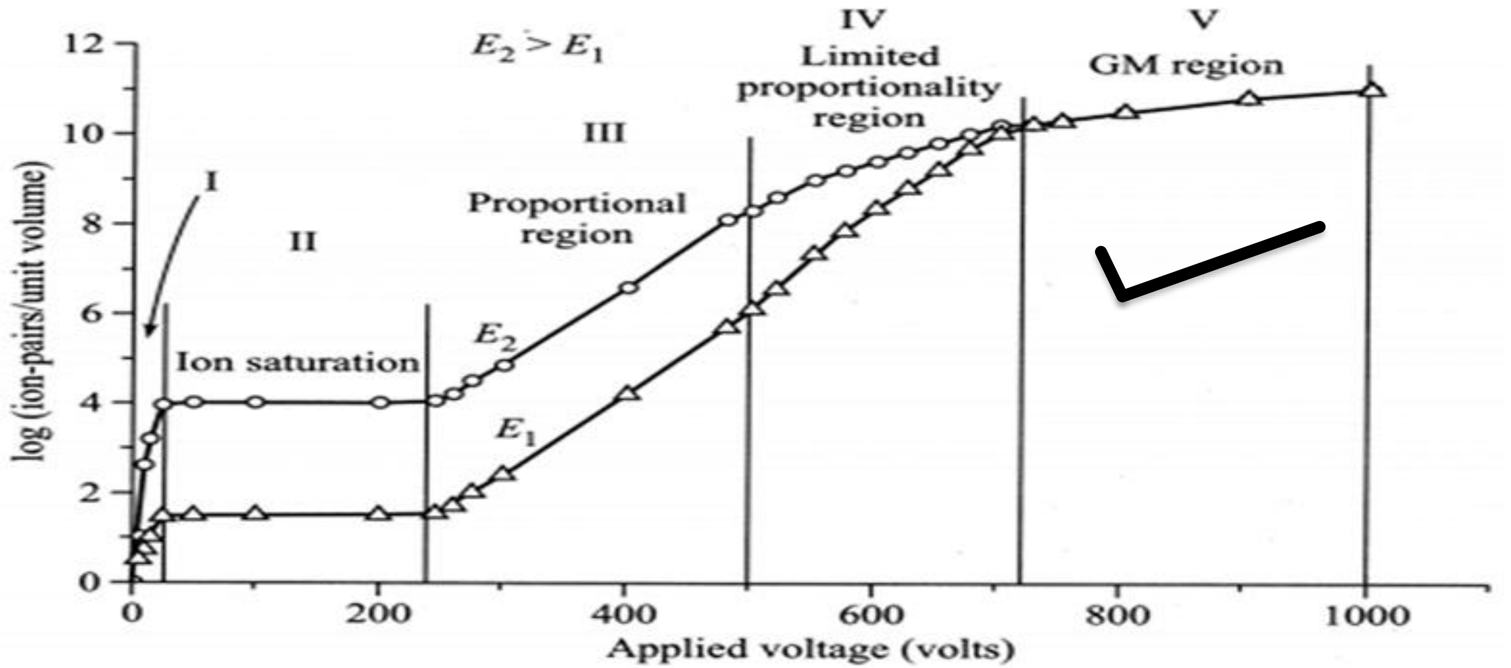
7.5.2 Construction

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

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

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

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

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

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

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

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.

7.5.3 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

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.

7.5.3 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.

7.5.3 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

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

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

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

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 Ω**, so that the time constant of the charge collection circuit is of the order of milliseconds.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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

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

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

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.

7.5.3 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

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

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

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

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.

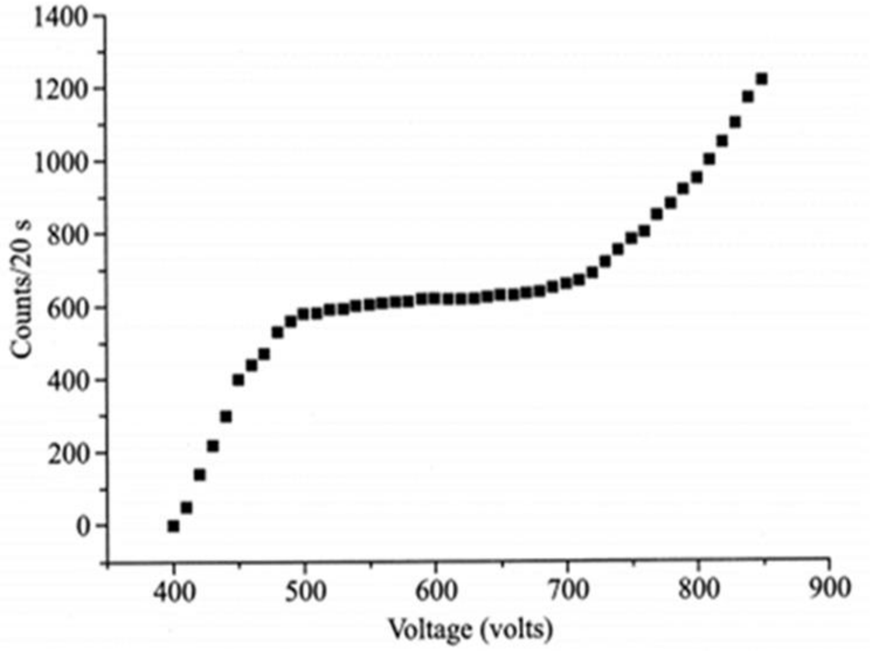


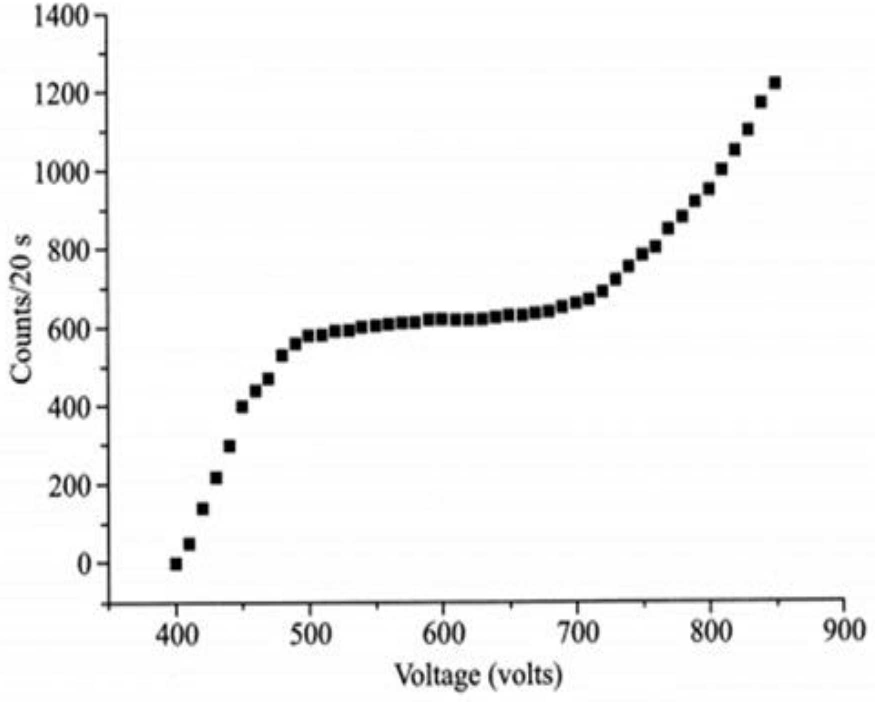
Figure 7.7 Plateau curve of a GM counter.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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.



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7.5 GEIGER-MÜLLER (GM) COUNTERS

7.5.3 Working

Geiger Plateau

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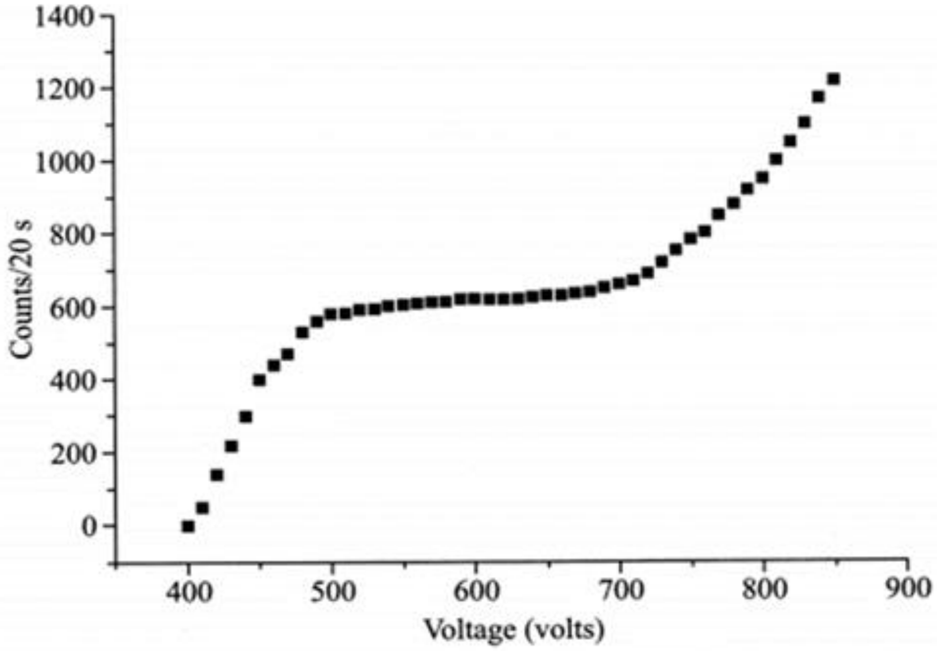

Figure 7.7 Plateau curve of a GM counter.

7.5 GEIGER-MÜLLER (GM) COUNTERS

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

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

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

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

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

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

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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3	The output pulse height is low, so an amplifier is needed.	The output pulse height is large, so no amplifier is needed.

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

- 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.

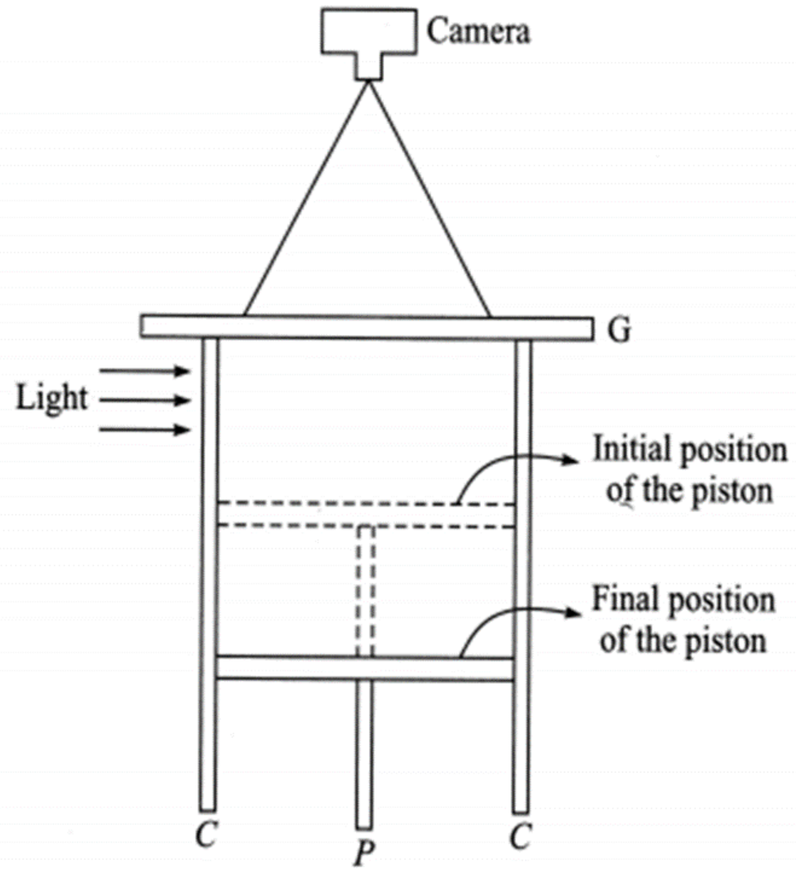

Figure 7.18 A simplified diagram of cloud chamber.

7.8 CLOUD CHAMBER

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

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

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

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.

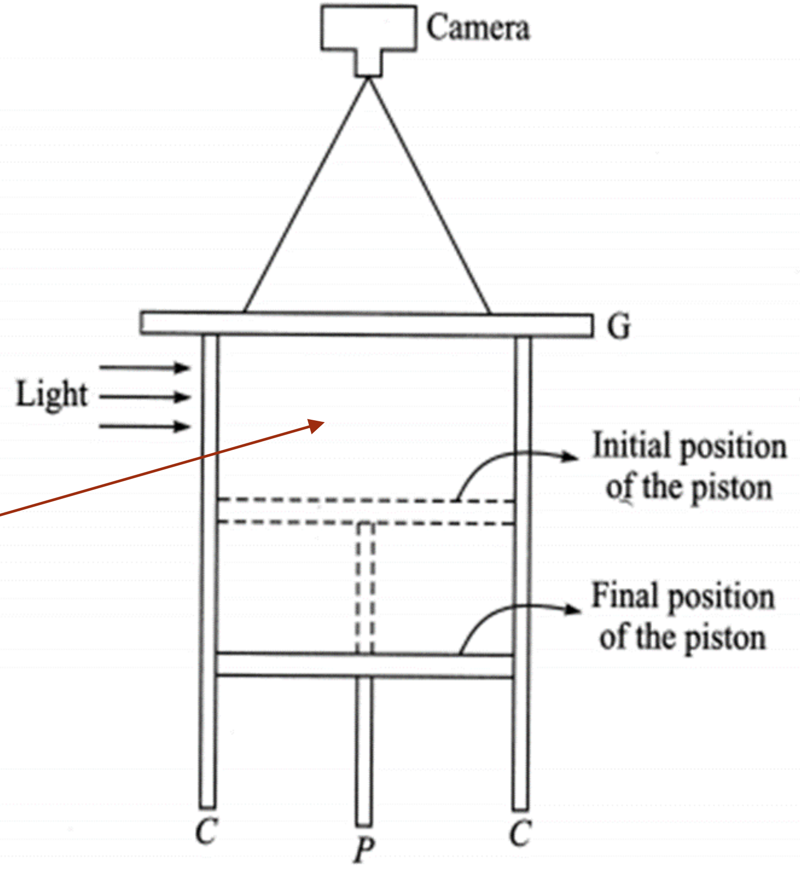

Figure 7.18 A simplified diagram of cloud chamber.

7.8 CLOUD CHAMBER

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.

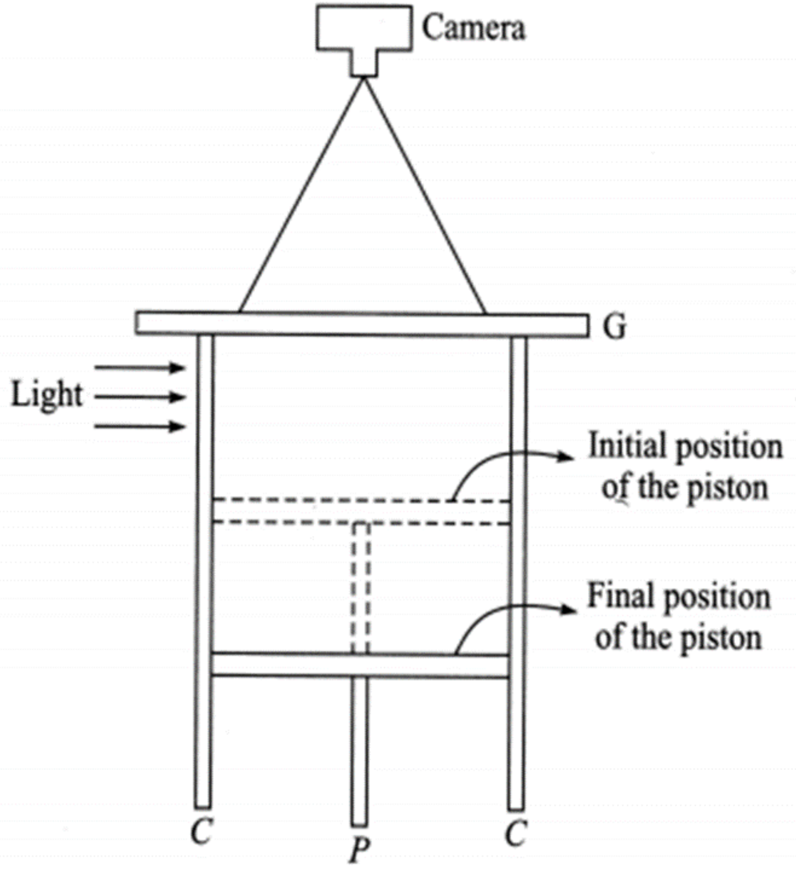

Figure 7.18 A simplified diagram of cloud chamber.

7.8 CLOUD CHAMBER

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

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

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

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

7.8.4 Advantages (2)

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

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).

7.8 CLOUD CHAMBER

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.

7.8.5 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