# TYBSc [Semester-6] Physics

# US06CPHY23 Nuclear Physics

## UNIT- 4 Part 2 Lecture 1

## Radiation Detectors

# Radiation Detectors

# Radiation Detectors



- Introduction
  - Gas filled detectors
  - Ionization Chamber
  - Geiger-Muller Counters
  - Cloud Chamber
  - Bubble Chamber
  - Spark Chamber

**Recommended Books:**

Nuclear and Particle Physics (2nd edition)
V K Mittal, R C Verma and S C Gupta
PHI Learning Pvt. Ltd.

# Radiation Detectors

- **Introduction:**

- If we perform any nuclear physics related experiment or apply nuclear science to any problem, **nuclear radiation detectors** or **radiation detectors** or simply **detectors** play vital role in such measurements.

# Radiation Detectors



- Nuclear radiation is a general term and it includes variety of energetic particles like electrons, protons, $\alpha$-particles, heavy ions or neutral radiations like neutrons, X-rays or $\gamma$-rays etc.

# Radiation Detectors



- The development of radiation detectors started with the discovery of radioactivity by **Henry Becquerel** in 1896. He noticed that the radiation emitted by uranium salt blacken photosensitive paper.

- Almost at the same time Roentgen discovered X-rays. X-rays were also found to blacken photosensitive paper. So, the first radiation detector was a photosensitive paper or X-ray film and was extremely simple.

# Radiation Detectors

- In the beginning of the twentieth century, Rutherford used flashes of light or scintillations produced in ZnS as nuclear radiation detector.
- These simple detectors used at that time were very primitive.
- They could simply indicate the presence or absence of radiations.

# Radiation Detectors

- Nowadays it is not sufficient only to detect the presence or absence of radiations but one would also like to know the **nature of radiation**, i.e., whether the radiations are electrons, protons $\alpha$-particles, X-rays, $\gamma$ –rays, etc.

- On top of that, accurate **energy and momentum measurements** are often required.

# Radiation Detectors

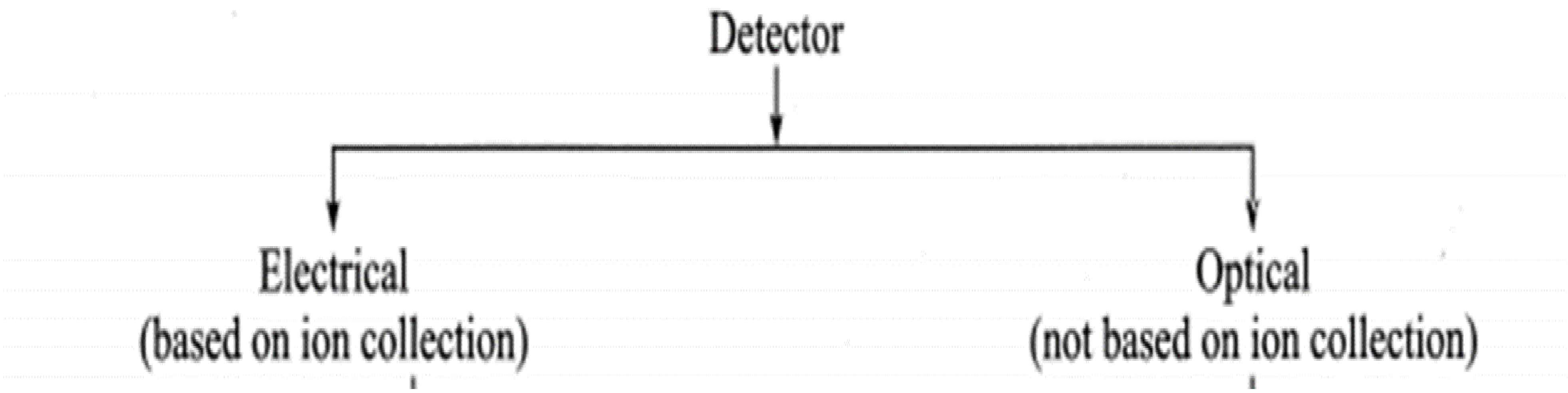


- In some applications an exact knowledge of the **spatial coordinates of the particle trajectories** is also of interest.

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

# Radiation Detectors

- Classification of the detectors: It depends upon type of signal is provided by the detector.
- The signal can be an **electrical signal** or **visible light.**



# Radiation Detectors

- Electrical signal based on ion collection or
- Optical which are based on the visible light emitted by the detector.
- Also, signal can form the image of the trajectory of charged particle.

# Radiation Detectors

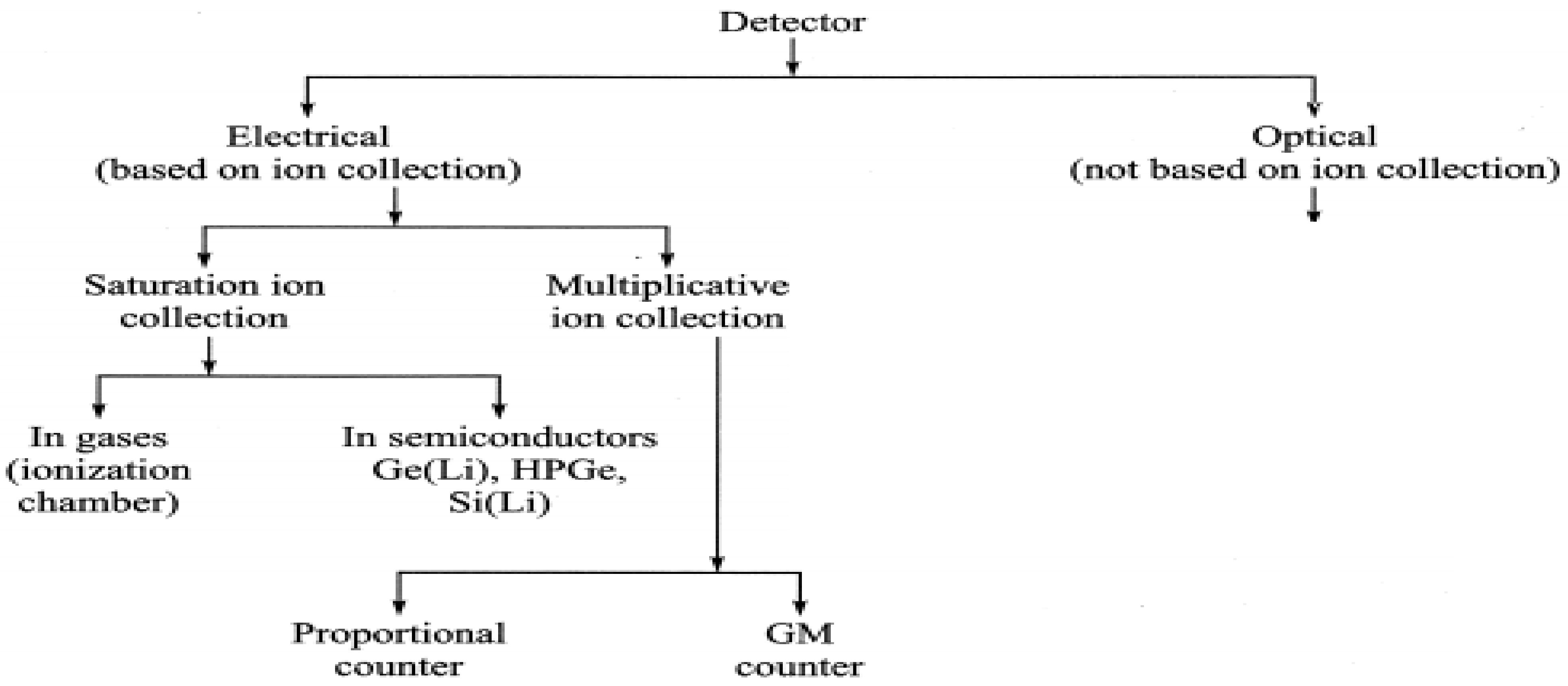



**Figure 7.1** Classification of detectors according to signals produced.

# Radiation Detectors

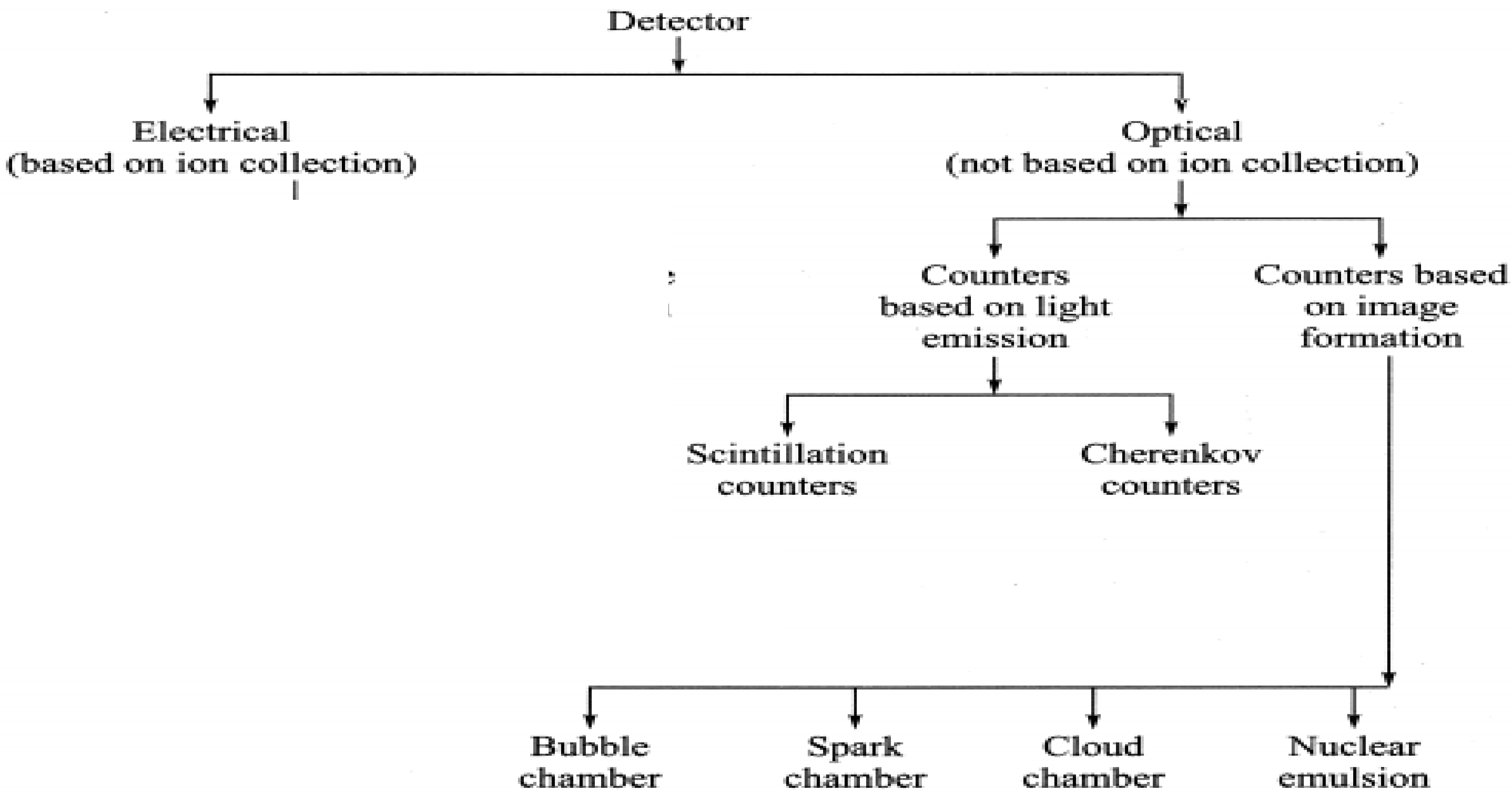



**Figure 7.1** Classification of detectors according to signals produced.

# Radiation Detectors

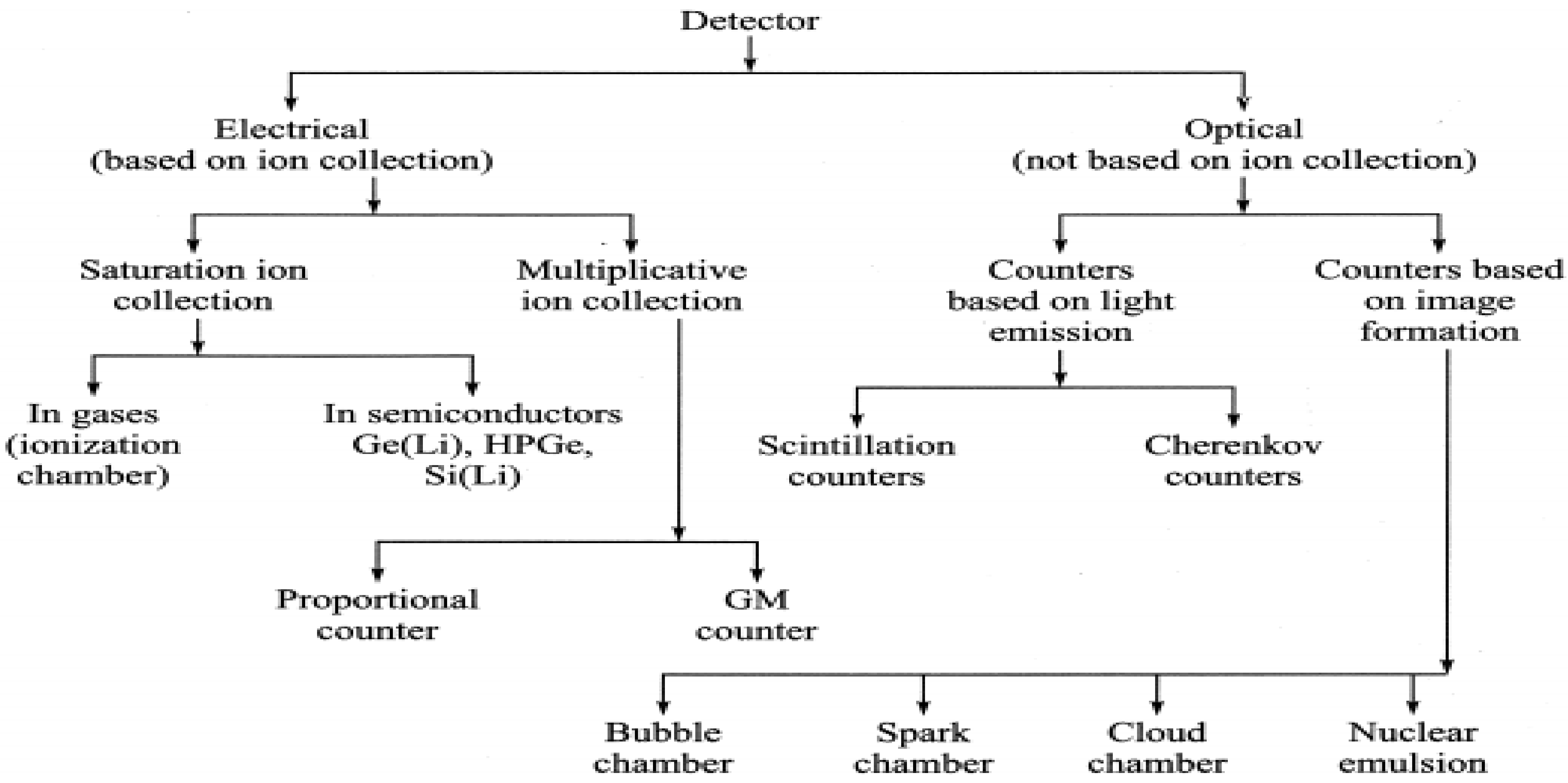



**Figure 7.1** Classification of detectors according to signals produced.

# Radiation Detectors



- Nuclear particles or radiations cannot be directly detected but rather only through their interactions with matter.

- In case of X-rays and $\gamma$-rays, the main interaction processes are
  - photoelectric effect,
  - Compton effect and
  - pair production.

# Radiation Detectors

- The electron produced in these processes can be observed through their ***ionization*** or ***excitation*** in the sensitive volume of the detector.

- In case of charged particles main mode of interaction with matter is ionization and excitation of electrons in the matter.

# Radiation Detectors



- In ***ionization*** the incident particle transfers an amount of energy equal to the ionization energy of the atoms/molecule to permit the ionization process to occur. In this process an ion electron pair is created.

- In most of the materials used for radiation detectors, the **ionization energy** for the least tightly bound electron is between **10 eV and 20 eV**.

# Radiation Detectors



- In ***excitation process***, an electron is elevated to a higher bound state in the atom/molecule without completely removed.
- Later on, the excited electron may emit visible light and return to its original state.

# Radiation Detectors

- We shall discuss the following radiation detectors:
  - Gas filled detectors
  - Ionization chamber
  - Geiger-Muller counter
  - Cloud chamber
  - Bubble chamber
  - Spark chamber

# 7.2 GAS-FILLED DETECTORS

# 7.2 GAS-FILLED DETECTORS

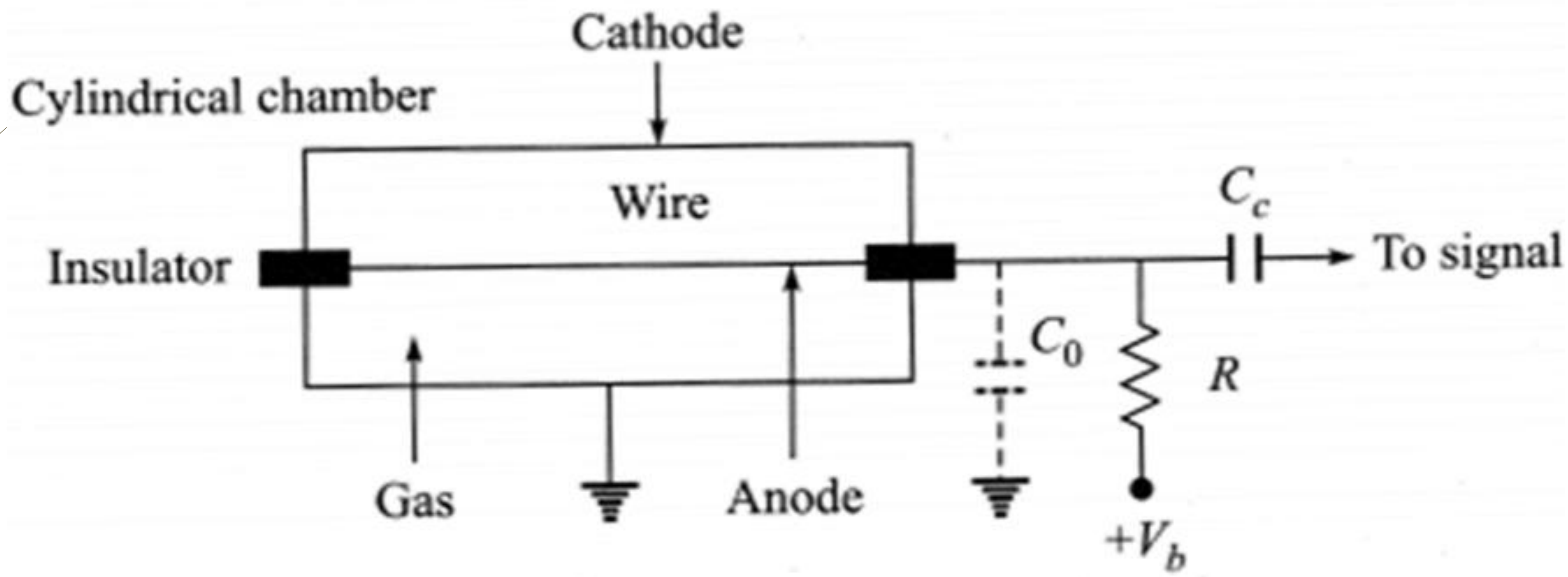


## 7.2.1 Principle

- They are based on the **principle of ionization** and **excitation** caused by charged particles while passing through a gas.

# 7.2 GAS-FILLED DETECTORS

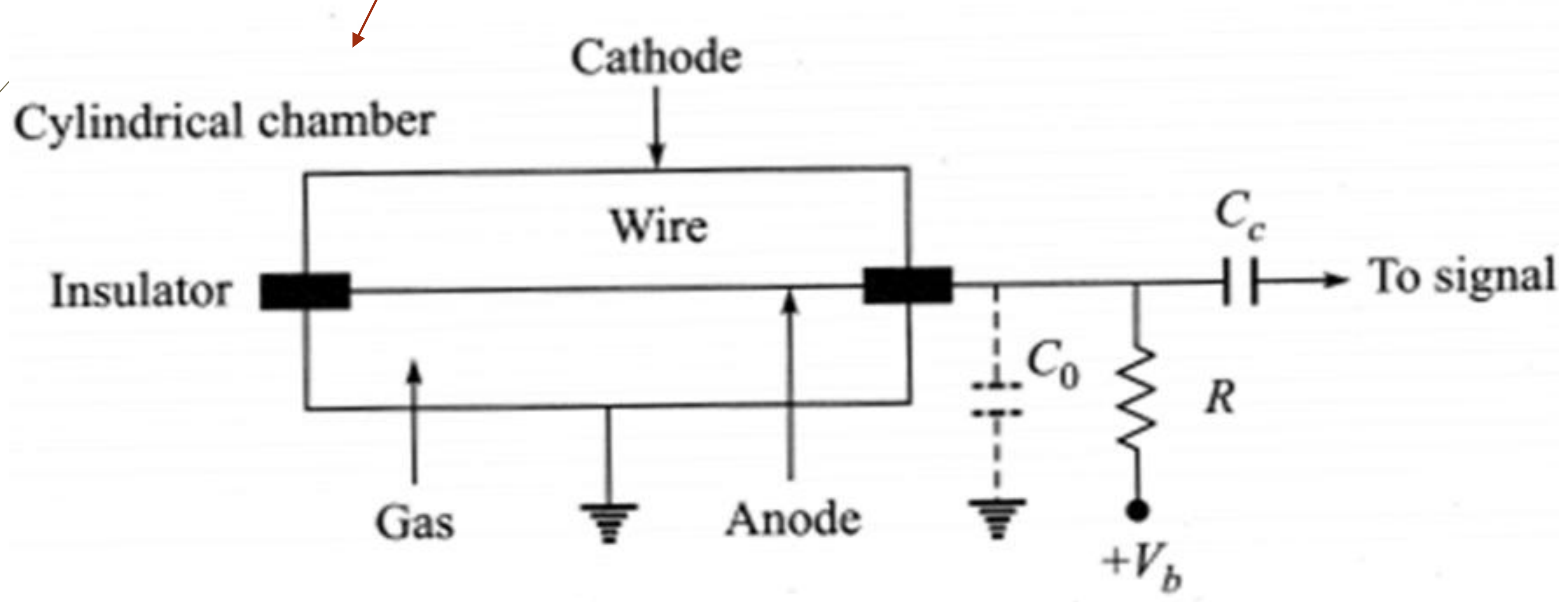
- Systematic diagram of a gas-filled detector is shown in Figure.



# 7.2 GAS-FILLED DETECTORS

## 7.2.2 Construction and Working:

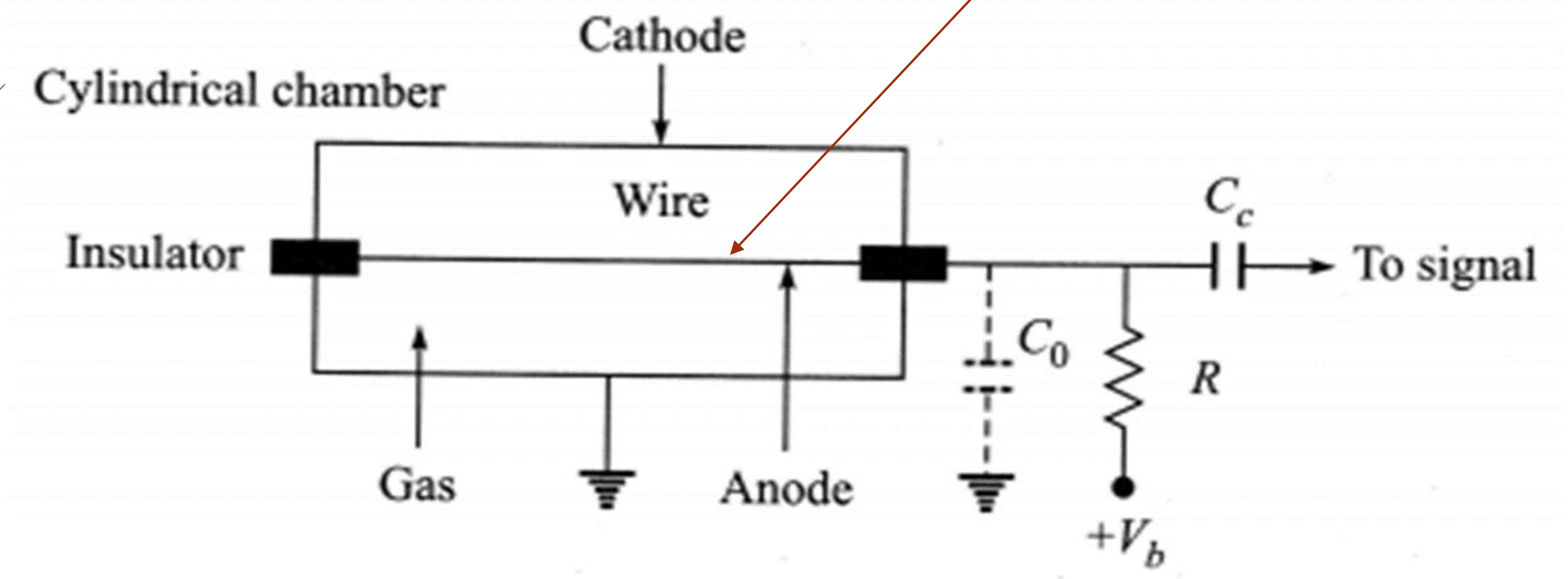
- It consists of a cylindrical gas-filled chamber.



# 7.2 GAS-FILLED DETECTORS

## 7.2.2 Construction and Working:

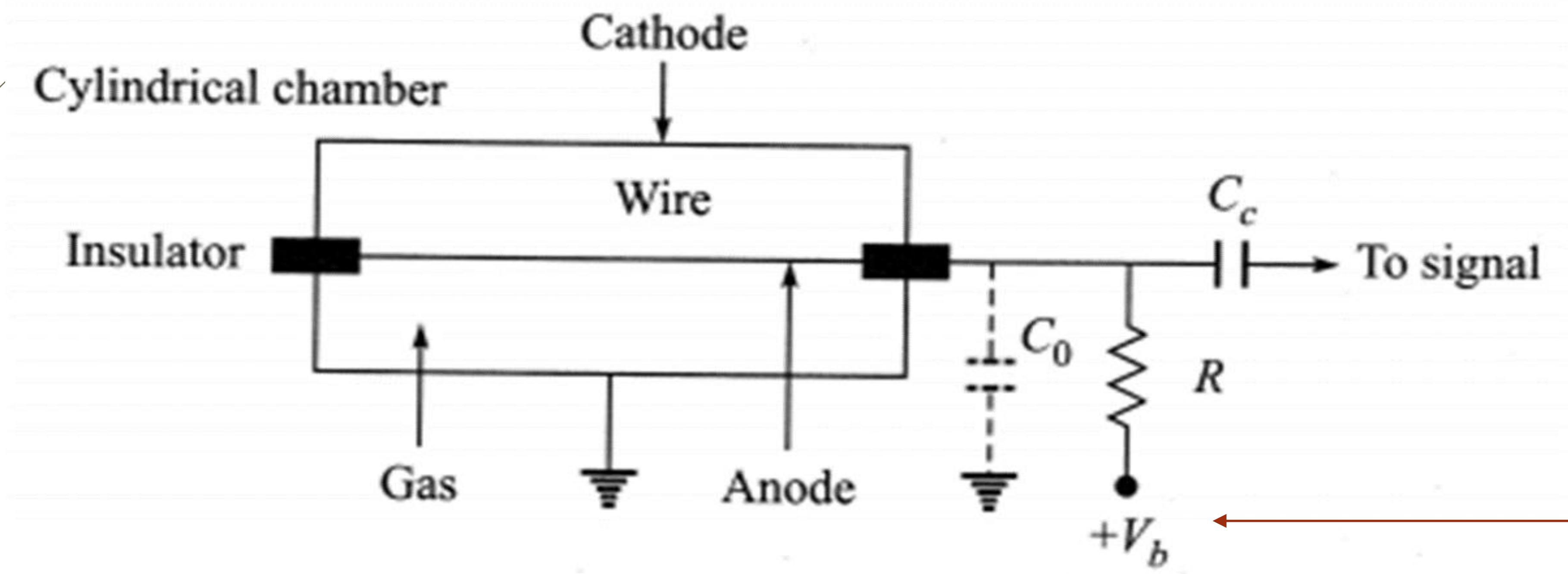
- A thin wire is placed along its axis and is well insulated from the walls of the chamber.



# 7.2 GAS-FILLED DETECTORS

## 7.2.2 Construction and Working:

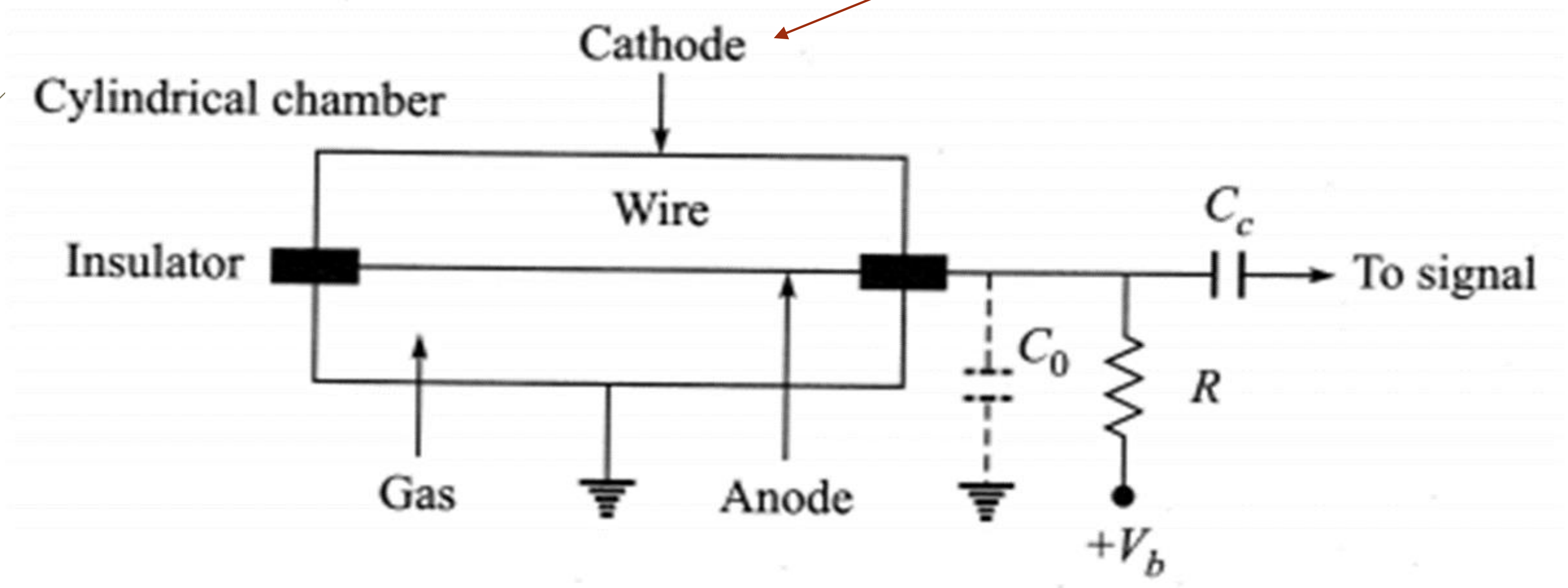
- **Anode:** Positive potential applied to the central wire through an external resistance *R*



# 7.2 GAS-FILLED DETECTORS

## 7.2.2 Construction and Working:

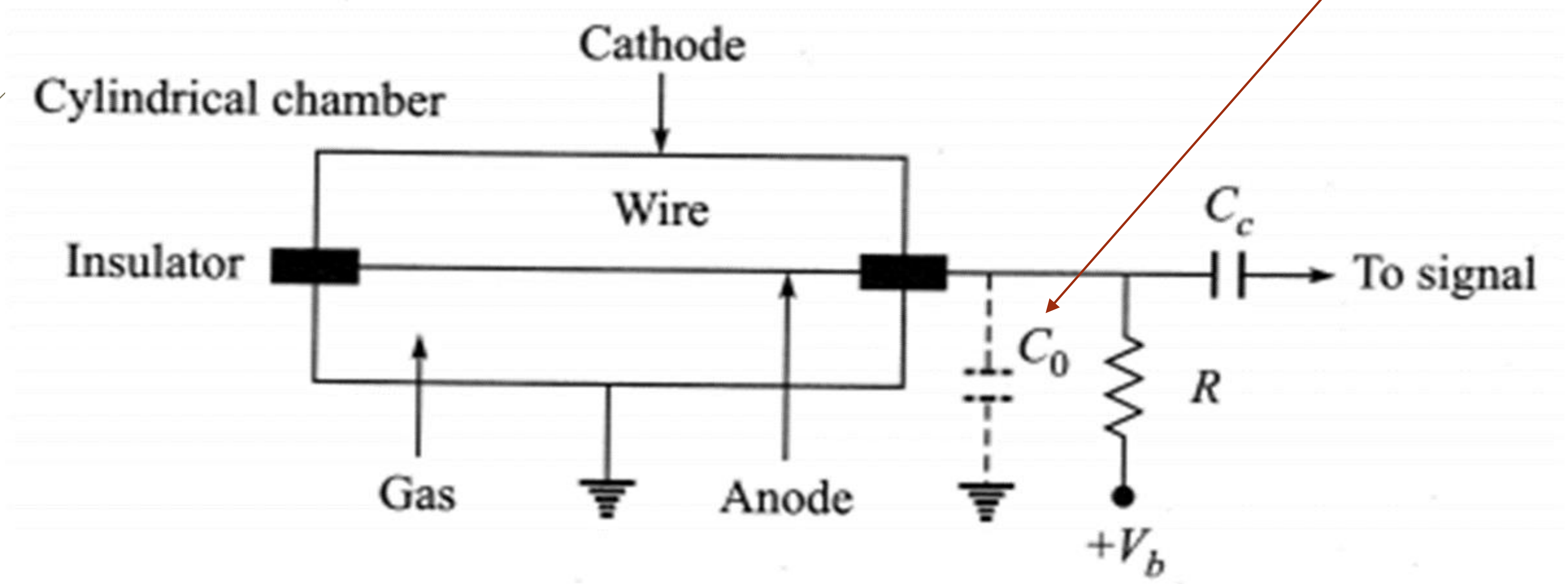
- **Cathode :** The cylindrical chamber is grounded and it acts as an anode.



# 7.2 GAS-FILLED DETECTORS

## 7.2.2 Construction and Working:

- Capacity of the electrodes and stray capacities of the connecting wire etc. constitutes the total capacity $C_0$



# 7.2 GAS-FILLED DETECTORS

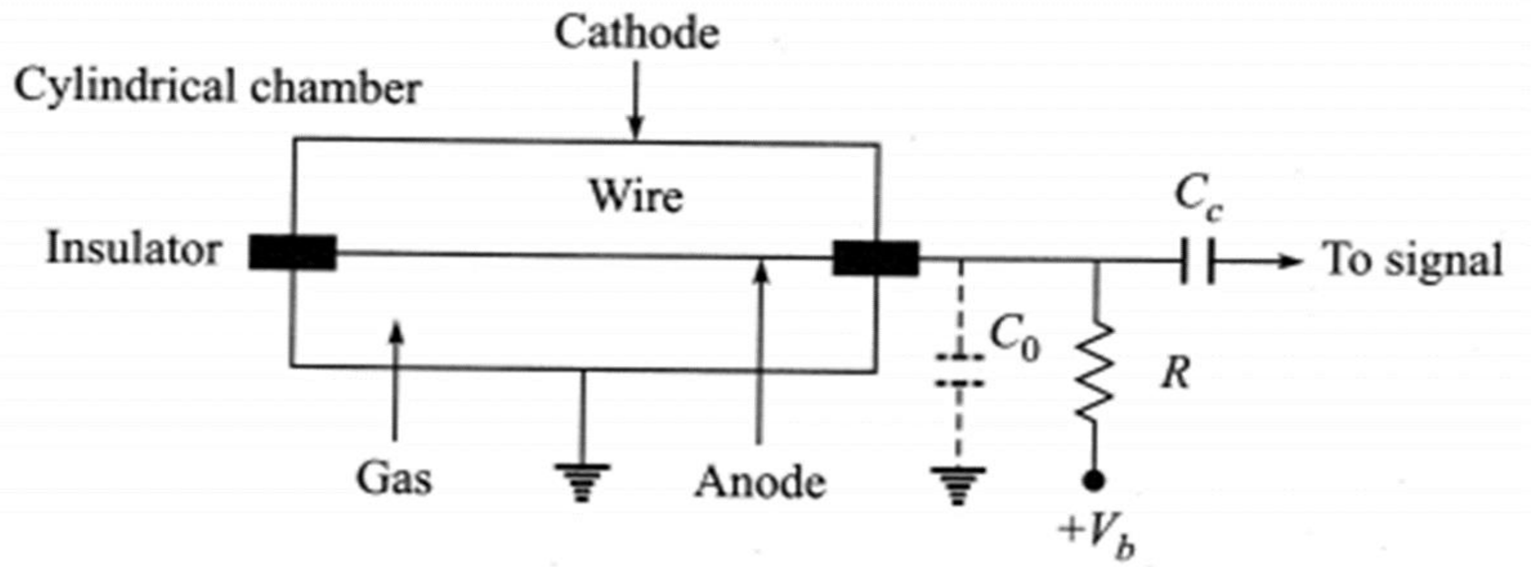
## 7.2.2 Construction and Working:

- When a nuclear radiation (like electrons, $\alpha$-particles, etc.) enters the chamber, it ionizes the gas present in the chamber thus creating number of positive ions and electrons called *ion-pairs*.

# 7.2 GAS-FILLED DETECTORS

## 7.2.2 Construction and Working:

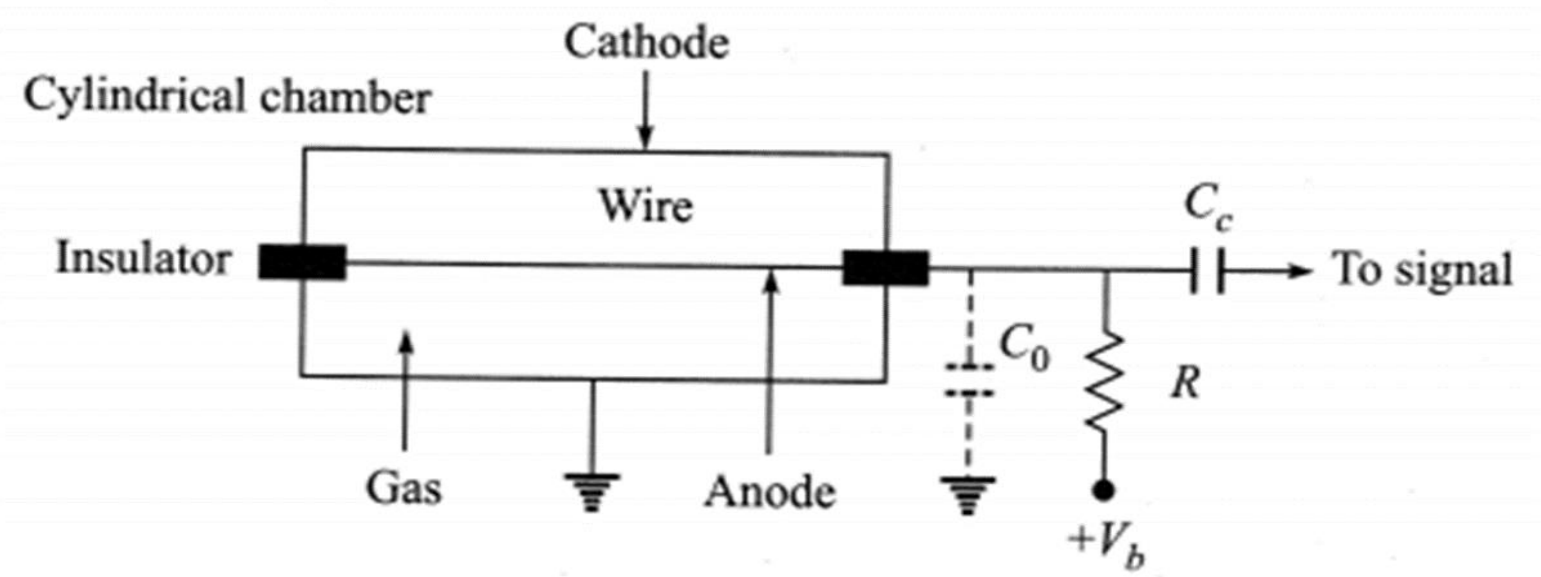
- If there is **no electric field present** i.e. $V_b = 0$, the ion-pairs just created recombine forming neutral atoms molecules.



# 7.2 GAS-FILLED DETECTORS

## 7.2.2 Construction and Working:

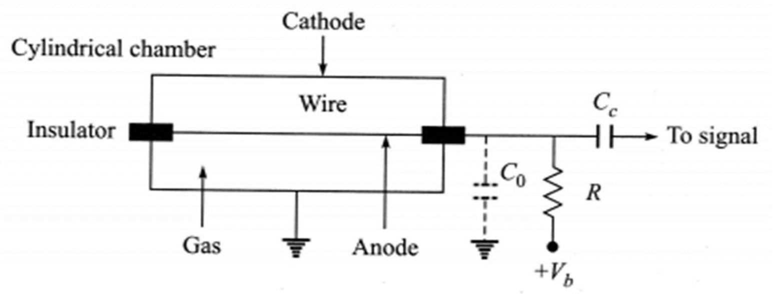
- In the presence of the applied electric field (***V**$_b$* **> 0**), the **positive ions** move along the radial electric lines of force i.e. towards the **cathode** or outer walls of the chamber.



# 7.2 GAS-FILLED DETECTORS

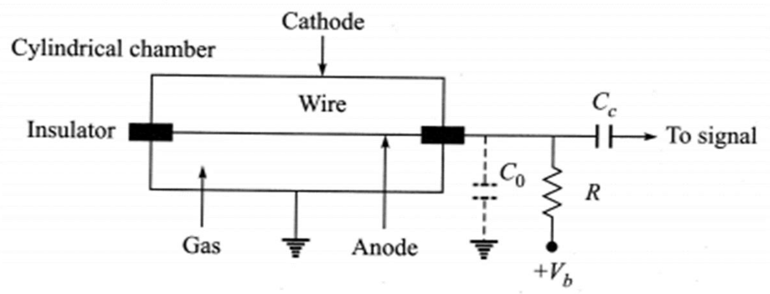
## 7.2.2 Construction and Working:

- Similarly, electron move toward the anode or central wire.
- Electrons being lighter than positive ions move at a much higher drift velocity (~$10^6$ cm/s).
- The net effect of this is that a charge Q gets collected on the anode, and this charges the capacitor $C_0$ to a potential of Q/ $C_0$.



## 7.2.2 Construction and Working:

- This change is the potential drops across *R* and gives rise to an electric pulse.
- Thus, when a charged particle passes through the gas present in the detector, the detector gives rise to a pulse, which is processed by external electronic circuit.



## 1.2.3 Concept of Average Energy Required for Creating Electron-Ion Pair (*W*-value)

- A charged particle interacts with gas either through ionization or excitation.
- In **ionization** an electron-ion pair is created. The electrons so liberated when they reach the anode give information that a radiation has entered the detector.

# 7.2 GAS-FILLED DETECTORS

## 1.2.3 Concept of Average Energy Required for Creating Electron-Ion Pair (*W*-value)

- In **excitation** no such pair is formed. The energy consumed in excitation is wasted, as during excitation no electron reaches the anode.
- Therefore, the average energy lost by the incident particle in creating one ion pair (defined as ***W*-value**) is always greater than the ionization energy of that gas.

## 1.2.3 Concept of Average Energy Required for Creating Electron-Ion Pair (*W*-value)

- The *W*-value is a function of the **gas** present in the detector, **type of radiation** and its **energy**.
- However, experiments show that *W*-value is not a strong function of any of these parameters.
- Table 2 shows ionization potential $I_p$ and *W*-value for fast electrons and $\alpha$-particles for some of the commonly used gases in the radiation detectors.

# 7.2 GAS-FILLED DETECTORS



**TABLE 7.1** $I_p$ and $W$-values for some gases

| *Gas* | $I_p$ (eV) | $W$ (eV/ion-pair) | |
|---|---|---|---|
| | | *Fast electrons* | *α-particles* |
| $H_2$ | 15.6 | 36.5 | 36.4 |
| He | 24.5 | 41.3 | 42.7 |
| $N_2$ | 15.5 | 34.8 | 36.4 |
| Ar | 15.7 | 26.4 | 26.3 |
| Air | – | 33.8 | 35.1 |
| $CH_4$ | 14.5 | 27.3 | 29.1 |

TABLE 7.1 $I_p$ and $W$-Values for some gases

- In most of the cases $W$ lies between **25 eV and 35 eV per ion-pair.**

## 1.2.3 Concept of Average Energy Required for Creating Electron-Ion Pair (*W*-value)

- Let us calculate the number of ion-pairs created, when a radiation of particular energy passes through a given gas.
- Suppose, **1 MeV** $\alpha$-particle is completely stopped within the gas with *W*-value **30 eV/ion-pair**.
- Then, the number of ion-pairs created

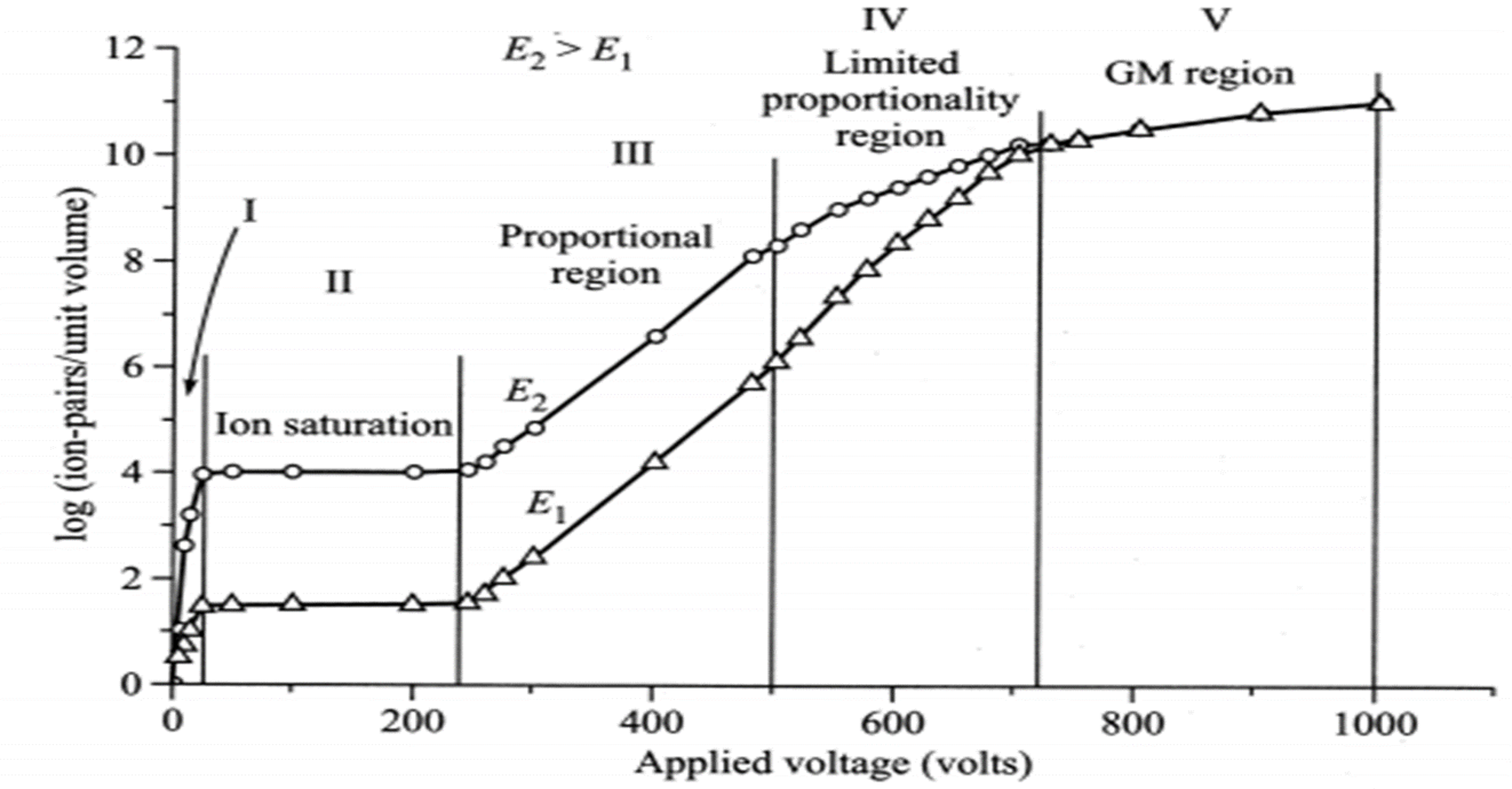
$$= \frac{10^6\ eV}{30 \frac{eV}{ion-pair}} \approx 33000\ ion-pair$$

# 7.2 GAS-FILLED DETECTORS

## 1.2.3 Concept of Average Energy Required for Creating Electron-Ion Pair (*W*-value)

- If **3 MeV** $\alpha$-particle is completely stopped within the gas, it creates = 3x 33,000 ≈ 99,000 ≈ 1,00,000 ion-pairs.
- This shows that the energy deposited by the incident radiation is directly proportional to the number of ion-pairs created.
- Hence, there is a possibility of determining the energy of incident radiation, if we can determine the number of ion-pairs created.

# 7.2 GAS-FILLED DETECTORS



# 7.2 GAS-FILLED DETECTORS

## 1.2.3 Concept of Average Energy Required for Creating Electron-Ion Pair (*W*-value)

- The variation of the logarithm of the number of ion-pairs formed or pulse height, which is across the resistor *R*, with applied voltage *V* for a gas detector is sketched in Figure 7.3.
- Two curves are shown in the figure corresponding to two different amount of energies brought in the gas.

# 7.2 GAS-FILLED DETECTORS

## 1.2.3 Concept of Average Energy Required for Creating Electron-Ion Pair (*W*-value)

- Lower curve marked as $E_1$ is for less-energetic particles while the upper curve marked as $E_2$ is for higher energy particles entering the gas detector.
- In the diagram symbols (o and ∇) are the measured values and line through the points is only a guide for the eye.

## 1.2.3 Concept of Average Energy Required for Creating Electron-Ion Pair (*W*-value)

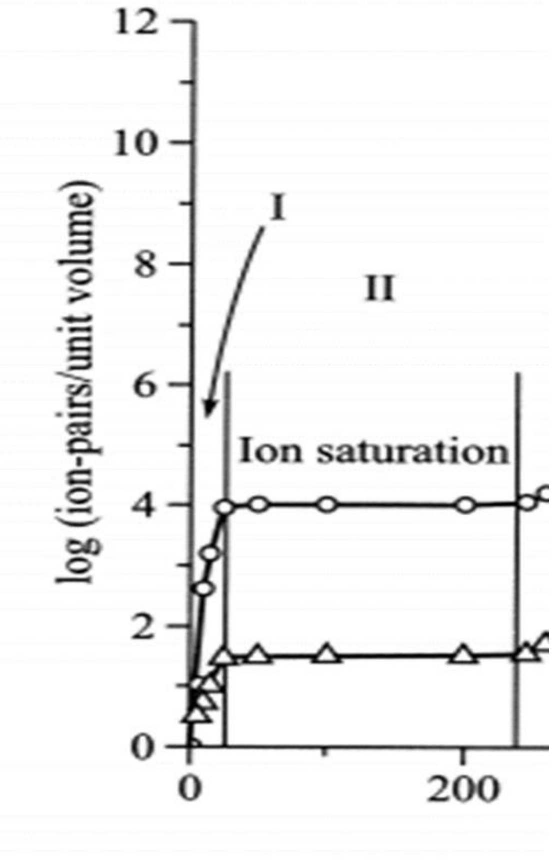
- Both these curves have been drawn when the pressure inside the chamber is about 0.5 torr (1 torr = 1mm of Hg) and the spacing between anode and cathode is 5 mm.

- In this diagram there are five regions marked as I, II, III, IV and V.
- Details of various regions are given as under.

# 7.2 GAS-FILLED DETECTORS

**Region I (~ 0 V to ~ 30 V)**

- In this region, the applied voltage is not sufficient to overcome the recombination of ion-pairs formed.
- As voltage is increased from 0 V to 30 V, more and more electrons start reaching the central anode and hence the pulse height is increasing in this region.



# 7.2 GAS-FILLED DETECTORS

## 1.2.3 Concept of Average Energy Required for Creating Electron-Ion Pair (*W*-value)

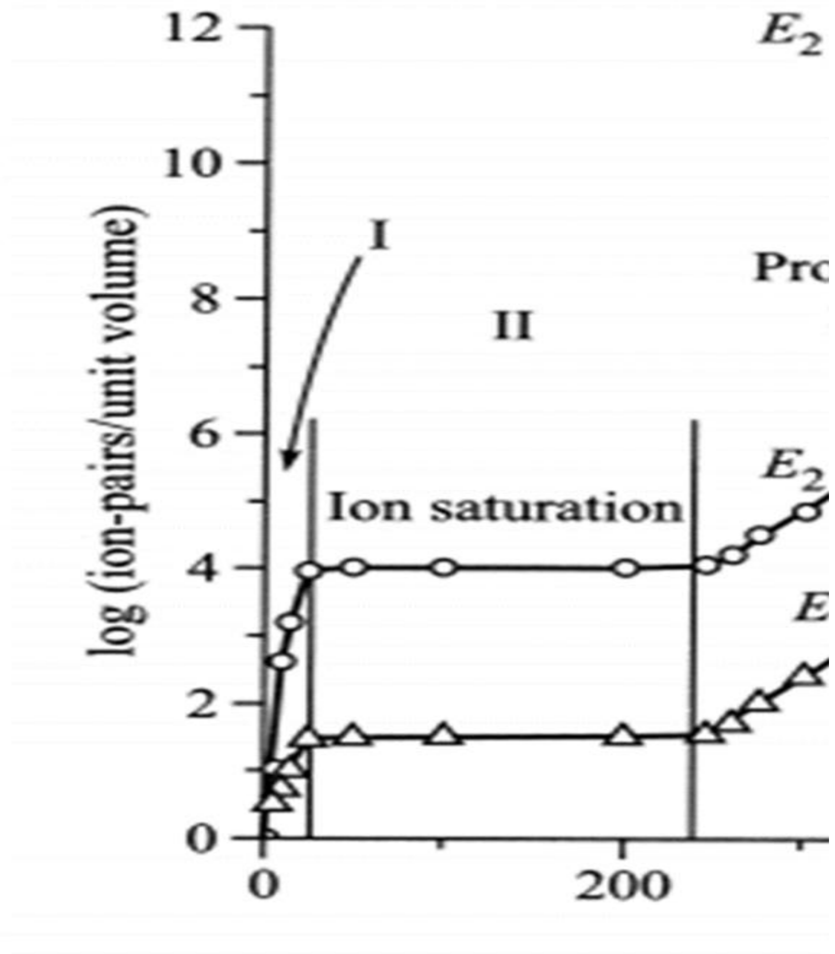
**Region I (~ 0 V to ~ 30 V)**

- In this region, the applied voltage is not sufficient to overcome the recombination of ion-pairs formed.
- As voltage is increased from 0 V to 30 V, more and more electrons start reaching the central anode and hence the pulse height is increasing in this region.

# 7.2 GAS-FILLED DETECTORS

**Region II (~ 30 V to ~ 250 V)**

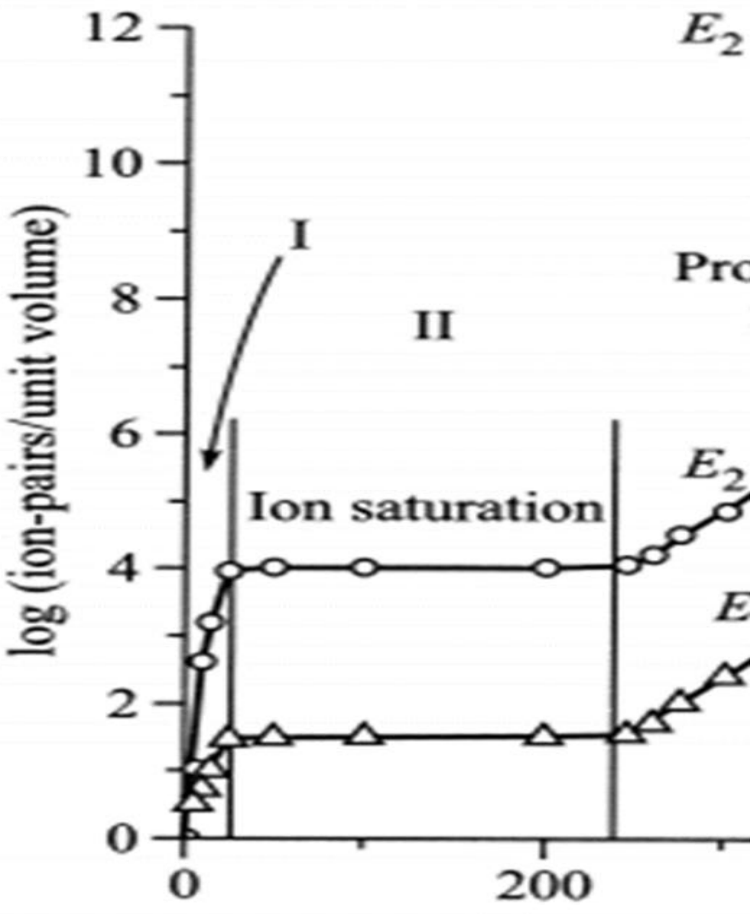
- In this region, the curves are almost **flat** which signifies the collection of all the ion-pairs formed initially.
- Depending upon the energy of incident radiation about $10^1$ to $10^4$ ion-pairs are formed in this region due to primary radiation and they all are collected by the respective electrodes resulting in flattening of the curve.



# 7.2 GAS-FILLED DETECTORS

**Region II (~ 30 V to ~ 250 V)**

- This region is known as ***ionization region*** and detectors operating in this region are called ***ionization chambers.***
- The output pulses produced are of low amplitude of the order of few mV.

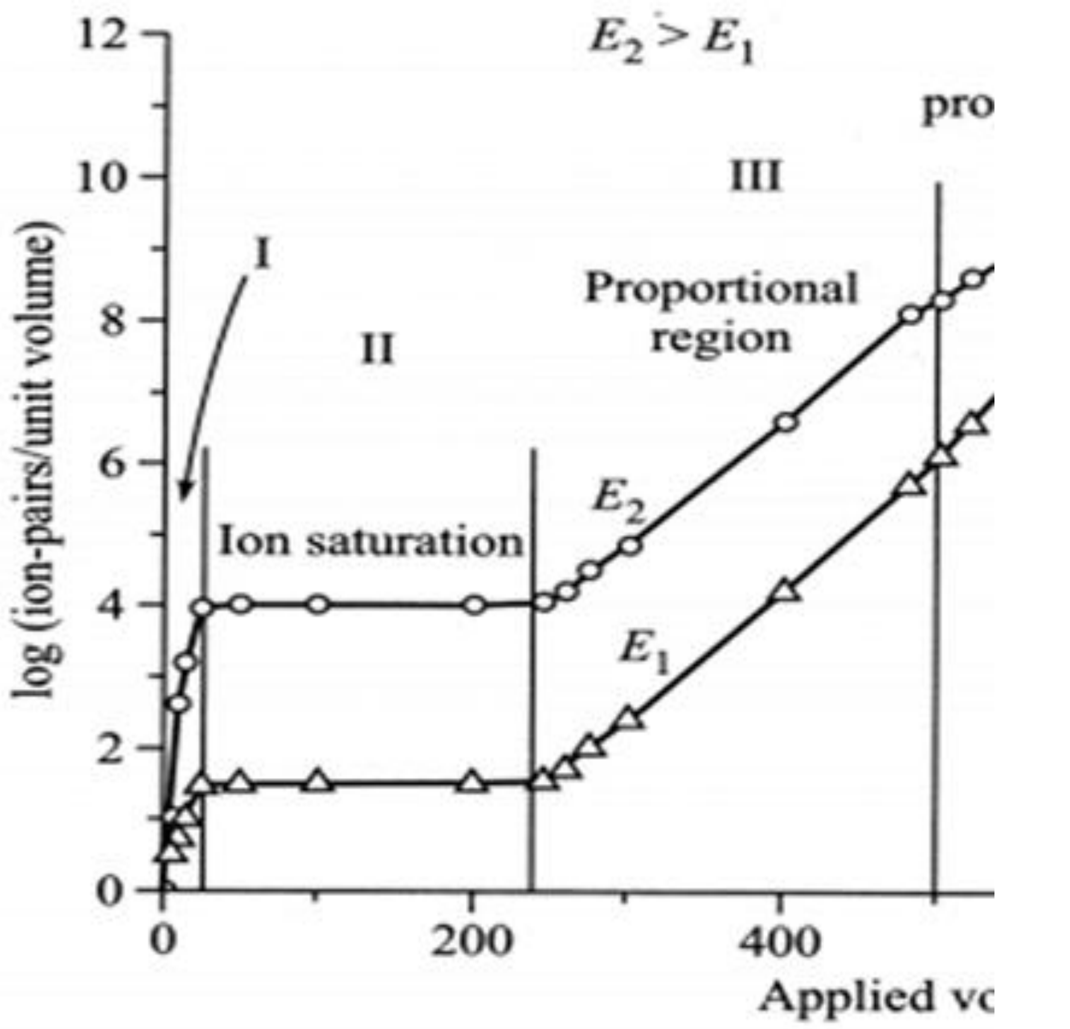


# 7.2 GAS-FILLED DETECTORS



**Region III (~200 V to ~500 V)**

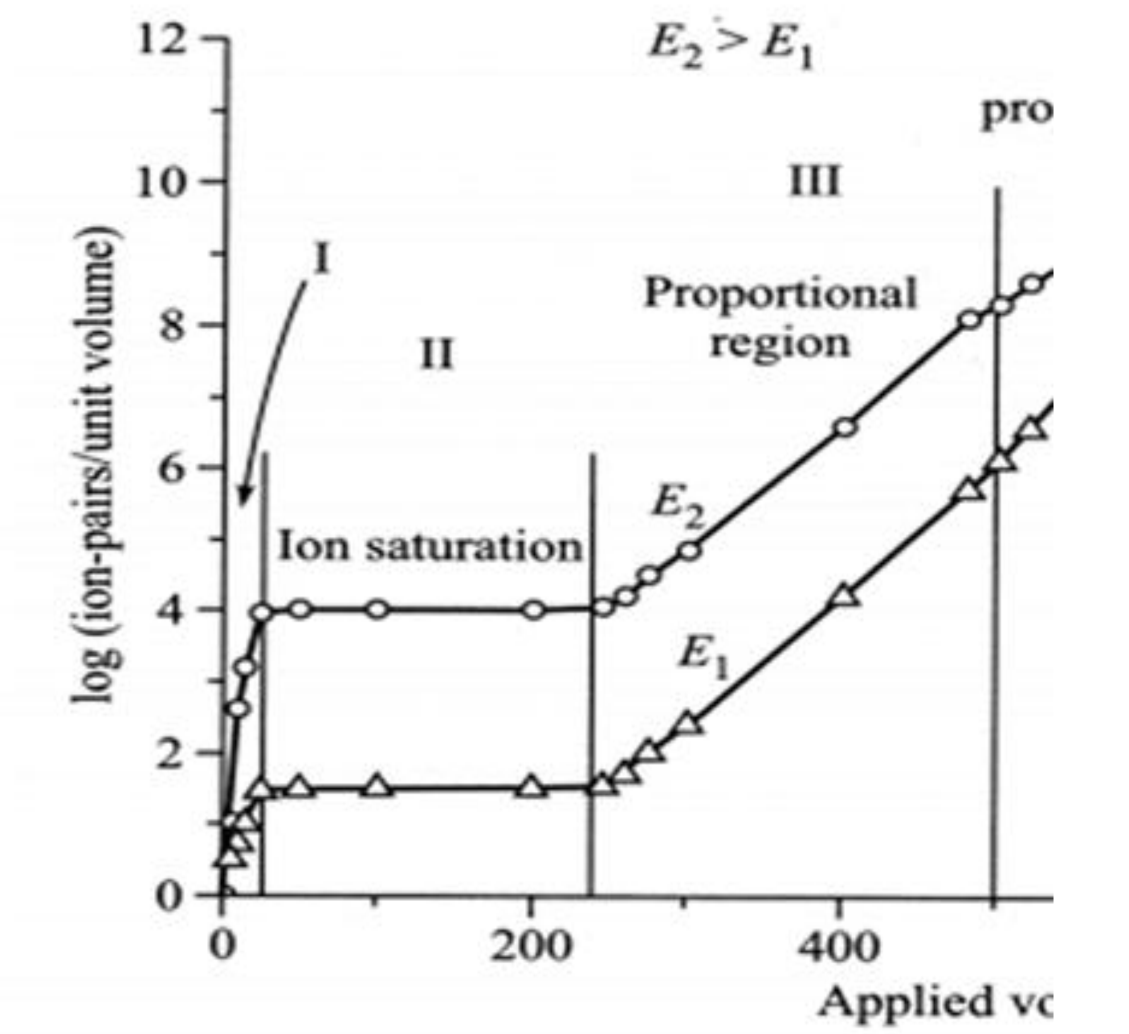
- Here the production and collection of the ion-pairs increase rapidly with the applied voltage (this phenomenon is known as gas multiplication).



# 7.2 GAS-FILLED DETECTORS

## Region III (~200 V to ~500 V)

- So, as long as the curves remains approximately parallel, the charge collected in proportional to the amount of the charge produced in the initial event which in turn is proportional to the energy of the incident radiation.

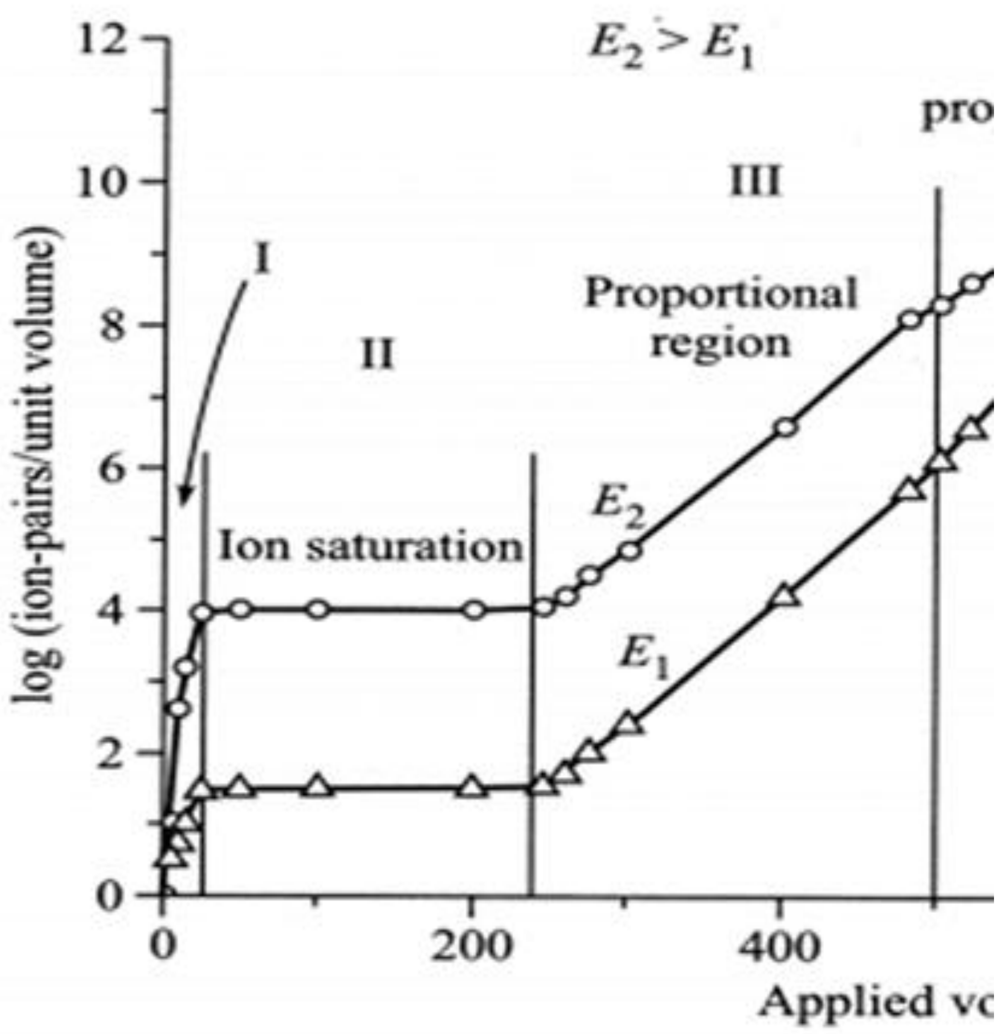


# 7.2 GAS-FILLED DETECTORS



**Region III (~200 V to ~500 V)**

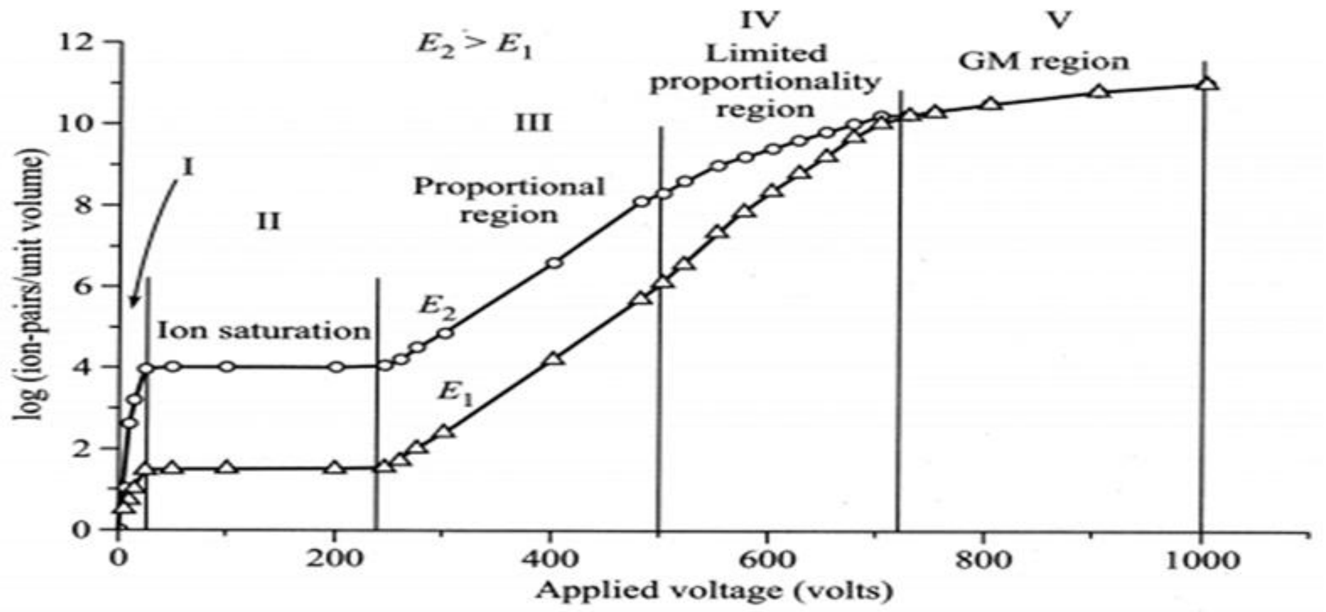
- This region is known as ***proportional region*** and the detectors operating in this region are known ***proportional counters.***



# 7.2 GAS-FILLED DETECTORS

## Region IV (~500 V to ~700 V)

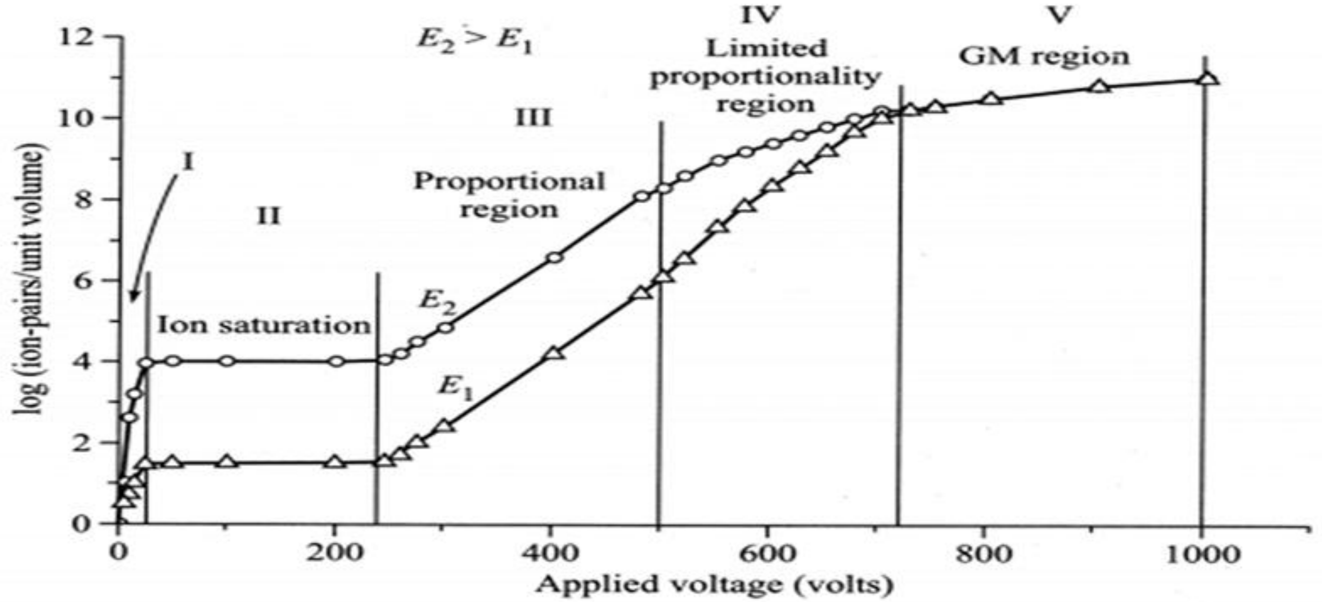
- In this region, larger amount of ionization is produced, but with less discrimination between the ion-ion pairs due to two different energy radiation. This region is known as ***region of limited proportionality*** and generally no detector operates in this region



# 7.2 GAS-FILLED DETECTORS

**Region V (~800 V to ~1000 V)**

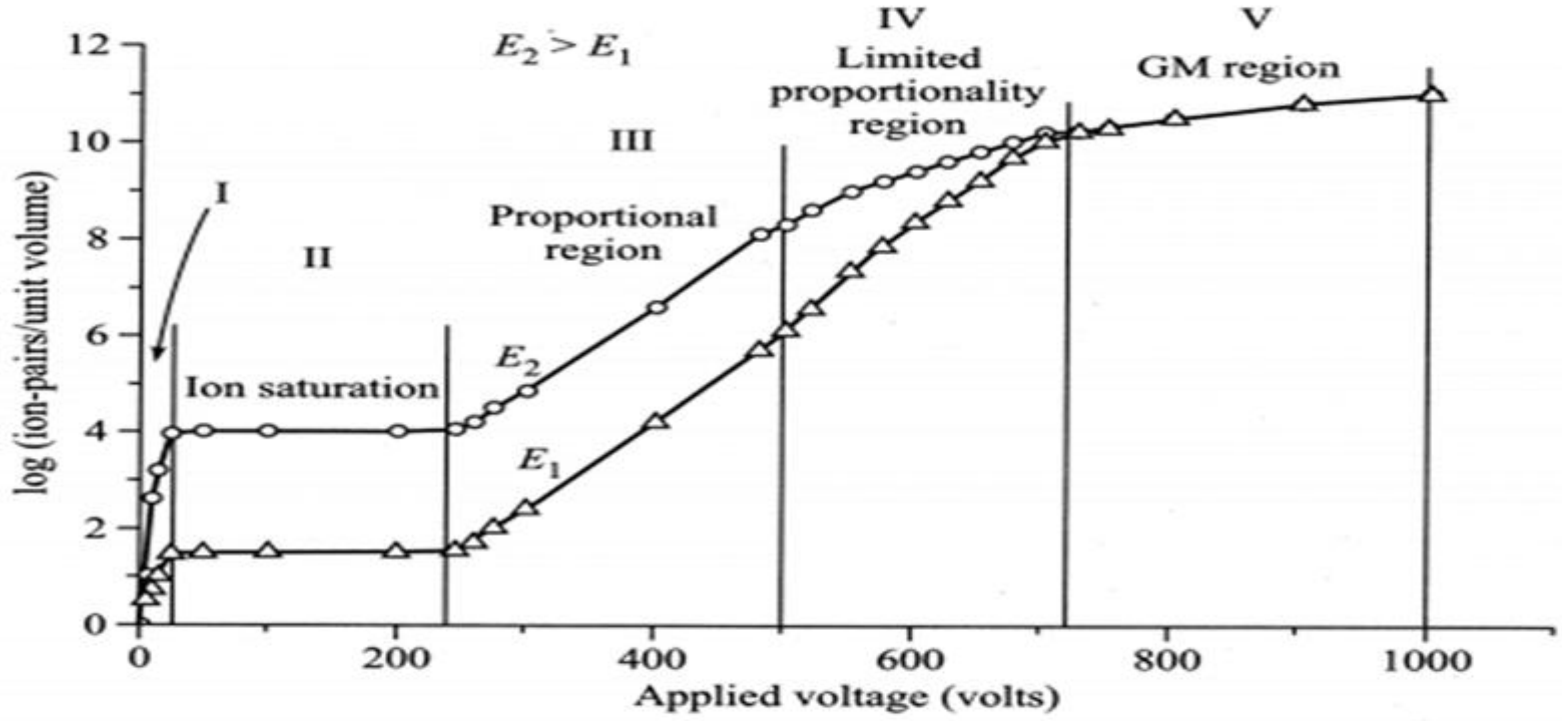
- In this voltage range, there is approximately flat region, also known as plateau and the number of ion-pairs formed ~$10^9$ to $10^{10}$ ion-pairs per unit volume. This number is independent of the amount of initial ionization.



# 7.2 GAS-FILLED DETECTORS

**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**.

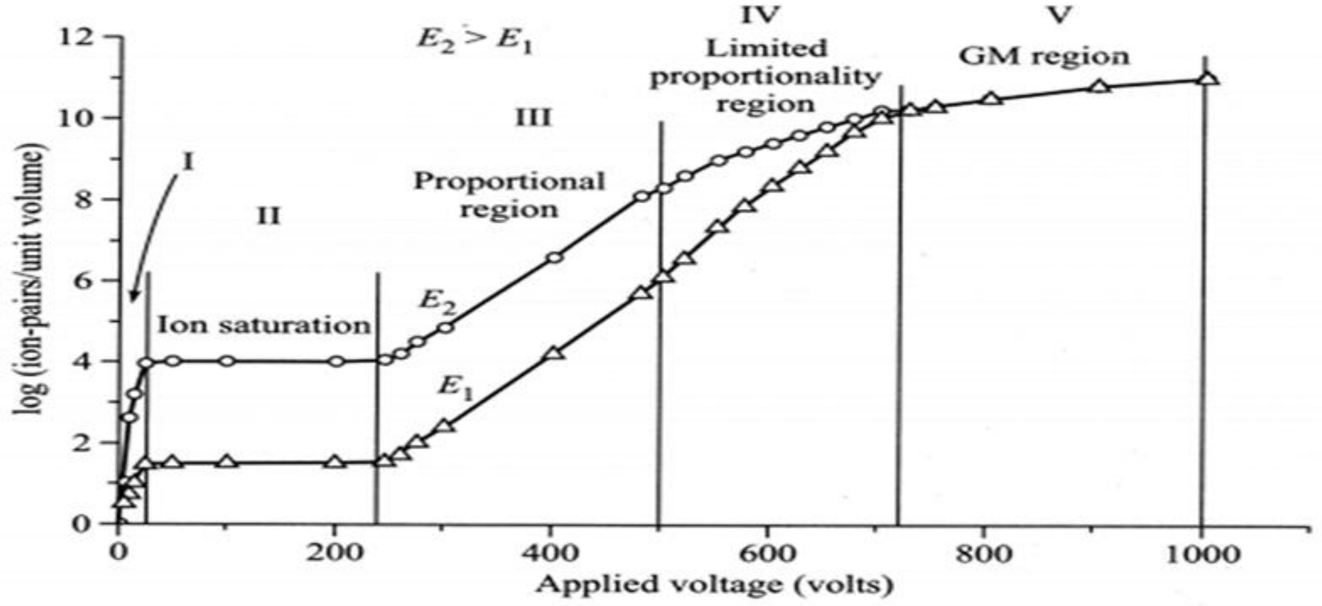


# 7.2 GAS-FILLED DETECTORS



**Region V (~800 V to ~1000 V)**

- As is evident from the discussion above there are three gas-filled detectors name ionization chamber, proportional counter and GM counter.



# 7.3 IONIZATION CHAMBER

# 7.3 IONIZATION CHAMBER

- An ionization chamber is an instrument to measure the number of ions within a medium usually gas or air.

- It consists of a gas-filled enclosure between two conducting electrodes.

# 7.3 IONIZATION CHAMBER

- When gas between the electrodes is ionized by any means such as by alpha particles, beta particles, X-ray or other radioactive emission, the ions move to the electrodes of the opposite polarity, thus creating an ionization current which may be measured by a galvanometer or electrometer.

# 7.3 IONIZATION CHAMBER

- Ionization chambers are widely used in many fields
- They provide an output that is proportional to dose.
- A greater operating lifetime than standard Geiger tubes (in Geiger Tubes the gas eventually breaks down).

# 7.3 IONIZATION CHAMBER

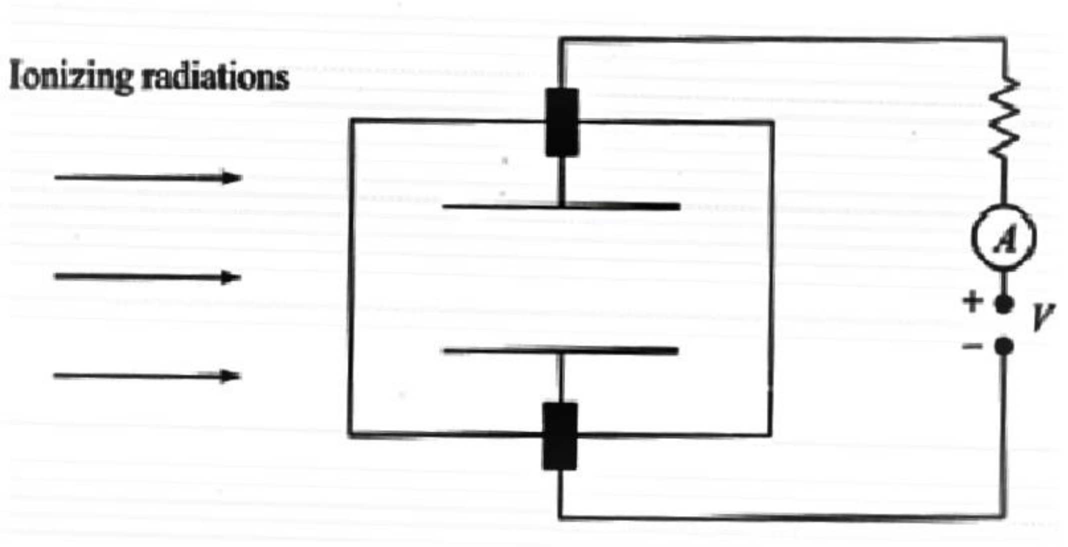
## 7.3.1 Principle

- The ionization chamber works on the principle that charged particles passing through matter remove electrons from the atoms process called ***ionization***.
- If voltage is applied across this ionized matter the electrons drift to one side and the leftover positively charged ions drift to the other.

# 7.3 IONIZATION CHAMBER

## 7.3.2 Construction

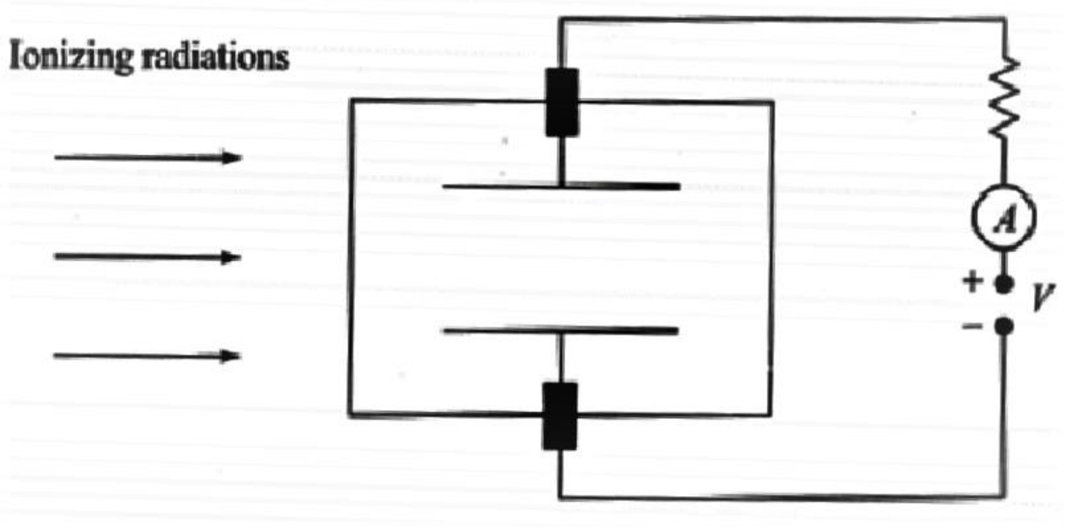
- One of the simplest gas-filled detectors is ionization chamber, which measures the ionization produced when an energetic charged particle passes through a gas.



# 7.3 IONIZATION CHAMBER

## 7.3.2 Construction

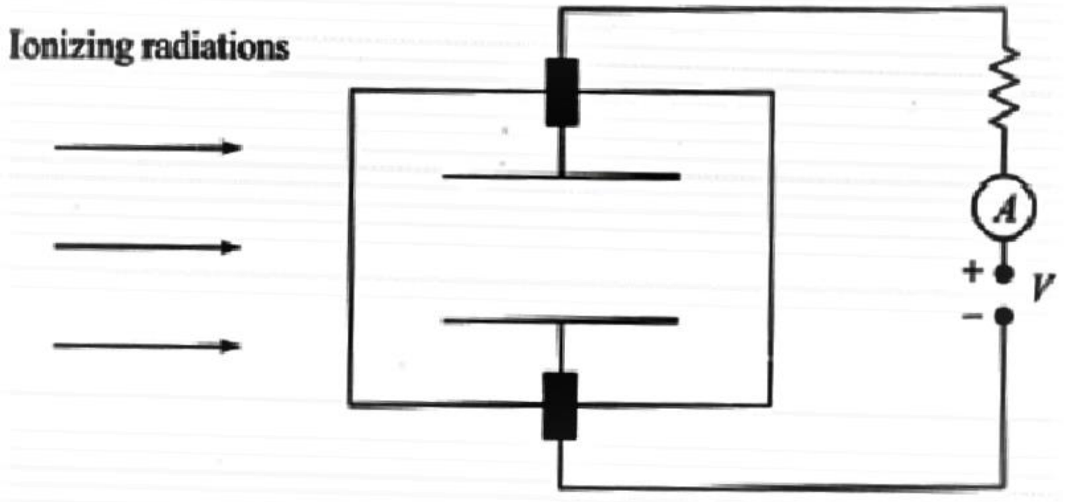
- It consists of two parallel plate electrodes separated by a distance *d*. This electrode combination forms a capacitor with capacity *C*.



# 7.3 IONIZATION CHAMBER

## 7.3.2 Construction

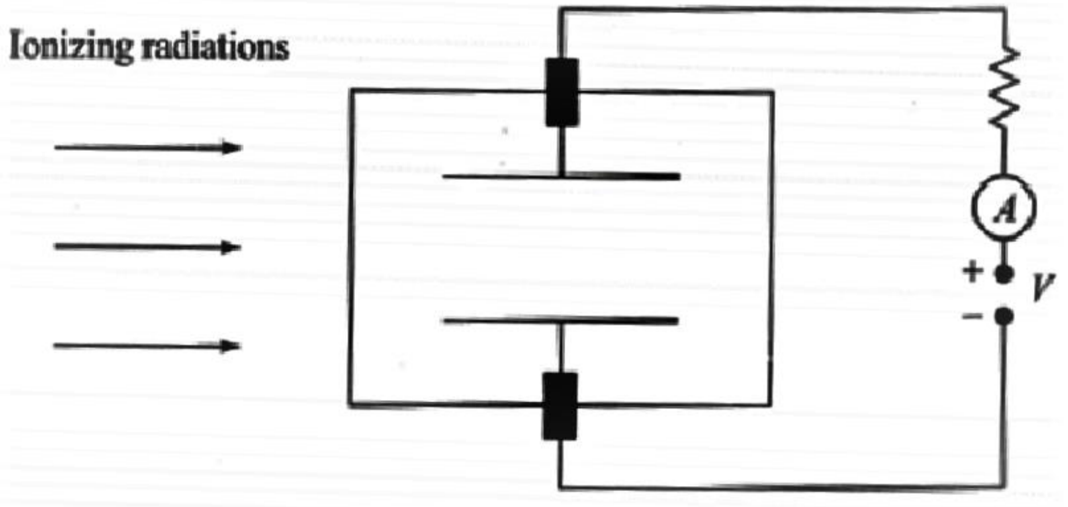
- High voltage is applied across these plates through a large bias resistance ***R***.
- This voltage sets up an electric field across the two plates.



# 7.3 IONIZATION CHAMBER

## 7.3.2 Construction

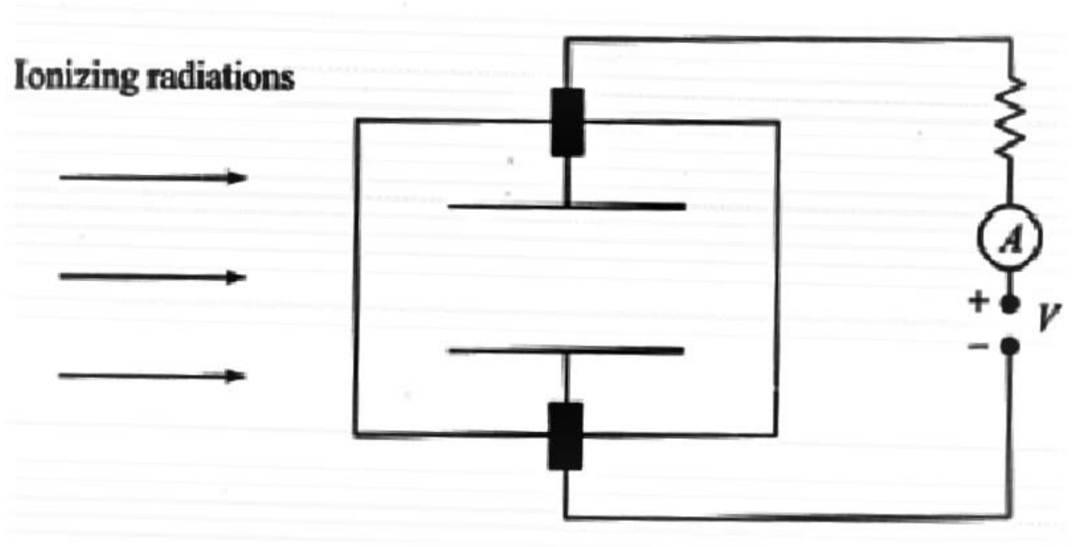
- These plates are enclosed in a chamber and the chamber is filled with a desired gas.



# 7.3 IONIZATION CHAMBER

## 7.3.2 Construction

- Most common gas in ionization chamber is air.
- Other gases used in such a detector are He, Ne, isobutene, etc.



# 7.3 IONIZATION CHAMBER

## 7.3.3 Working

As an example, let us consider that a 3.5 MeV α- particle is moving in an ionization chamber, filled with air.

Air has *W*-value ~35 eV. This α-particle produces

$$= \frac{3.5 \times 10^6\, eV}{35\, \frac{eV}{ion-pair}} \approx 10^5\, ion - pair$$

# 7.3 IONIZATION CHAMBER

## 7.3.3 Working

- Let us suppose that the source is emitting about $10^5$ $\alpha$-particles per second.
- This produces a current of

$$1.6 \times 10^{-19} \times 10^5 \times 10^4 \approx 1.6 \times 10^{-10}\ A$$

- This current though is small but still can be measured with most of current metres.

# 7.3 IONIZATION CHAMBER

## 7.3.3 Working

- Under the influence of electric field, electrons and ions move towards their respective electrodes.
- For a voltage gradient of 100 V $cm^{-1}$, ions move at about 1 m/s in air at STP and take about 0.02 seconds to cross a gap of ~2 cm.
- Electrons being lighter move about 1000 times faster and are collected at anode quickly.

# 7.3 IONIZATION CHAMBER

## 7.3.3 Working

- The slow movement of positive ions means that the ionization chamber is inoperative till all the +ve ions get neutralized at the cathode.

# 7.3 IONIZATION CHAMBER



## 7.3.4 Main Uses

The ionization chambers are mostly used as

- Radiation survey instruments,
- For calibrating or measuring the activity of radioactive sources,
- Measuring radioactive gases, etc.

# 7.3 IONIZATION CHAMBER

## 7.3.5 Main Drawback

- These detectors are not suitable to measure individual particles entering the chamber at a higher rate.

Thanks