UNIT - III

Introduction :-

* Thermal sensors are temperature sensors, and also called thermodynamic sensors based on their operating principles.
* Physical Quantity Q is expressed as its magnitude in number N and in U ⇒ $Q = NU$ ----- (1)
* Primary sensor – is the possibility to relate temperature T directly in the eq: (1) from the first principle.
* Secondary sensors – relationship between Q & T is largely empirical.

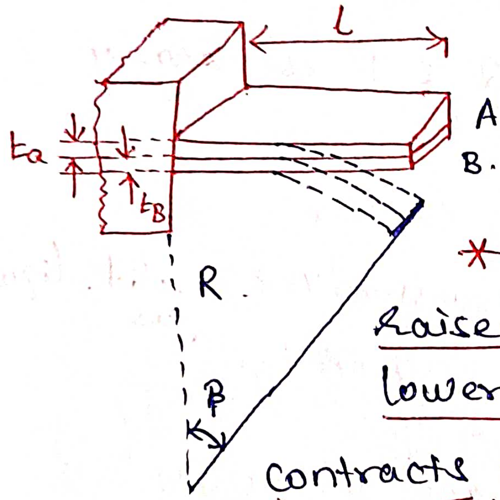
Primary sensor	Secondary sensor.
→ Gas thermometer.	→ Thermal expansion type – Solid, liquid gas.
→ Vapour pressure type	→ Resistance thermometer
→ Acoustic type.	→ Thermo emf type.
→ Refractive index thermometer	→ Diodes, transistors, or Junction semiconductor types.
→ Dielectric Constant type.	→ Quartz crystal thermometer.
→ magnetic type.	→ NQR thermometer
→ Nuclear orientation type	→ ultrasonic type.
→ Spectroscopic techniques.	

* There are different kinds of heat flux sensors which measure heat flux in terms of temperature difference.
* Special types – Pneumatic type, Pyroelectric type.

Thermal Expansion Type Thermometric Sensors :-

* The solid expansion type bimetallic sensor uses the diff in thermal expansion co-eff of different metals.

Two metal strips A and B of thickness t_A and t_B and thermal expansion coeff α_A and α_B are firmly bonded together at a temp → the lowest or reference temp → to form a cantilever or helix with one end fixed.



* when the temp of cantilever or helix is raised – by heating (or) lowered – by cooling → one strip expands or contracts more & free end of either of the two moves

* The cantilever bends into a circular arc with radius of curvature R

$$R = \frac{t_A + t_B \left[3\left(1+\frac{t_B}{t_A}\right)^2 + \left(1+\left(\frac{t_B}{t_A}\right)\left(\frac{Y_B}{Y_A}\right)\right) \left\{ \left(\frac{t_B}{t_A}\right)^2 + \frac{t_A Y_A}{t_B Y_B} \right\} \right]}{6(\alpha_A - \alpha_B)(T_h - T_b)\left(1+\frac{t_B}{t_A}\right)^2}$$

where Y – Young's modulus
T_h – raised temp
T_b – bonding temp.

* using $t_A = t_B = t$ and $Y_A \approx Y_B$.

$$R = \frac{4t}{3(\alpha_A - \alpha_B)(T_h - T_b)}$$

* Angular deflection β per unit temp change → sensitivity is

$$S_T^{\beta} = \frac{\beta}{(T_h - T_b)} = 3l\,\frac{\alpha_A - \alpha_B}{4t}$$

where
l – length of cantilever

* for measurement - Thermometer should be immersed upto the meniscus in the capillary → for varying temp's the thermometer has to be moved.

* Alternatively the entire thermometer is immersed or only the bulb is immersed.

* Correction has to be applied for the mercury column above the immersion line bcoz the column is at a different temp t_c than the measured value t_m.

The correction term is $\Delta t = \gamma_d n (t_m - t_c)$

where γ_d – differential thermal expansion co-eff of volume b/w mercury & glass — $1.6 \times 10^{-5}/°C$

n – no. of degrees indicated by the column → degrees

* Industrial type liquid filled in system – consists of a metallic bulb attached to metallic capillary.

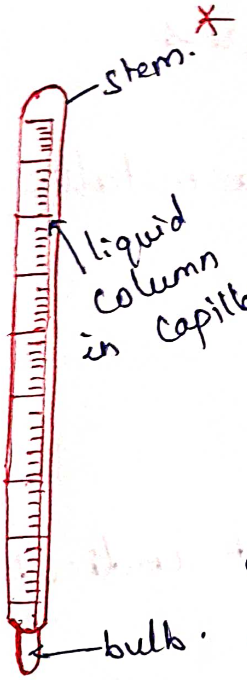
* other end of capillary fitted with a Bourdon.

* expansion of liquid in bulb → transmitted to Bourdon

* No. of compensations are necessary to obtain correct indication by the measurement system using such a sensor.

* Correction methods – available on standard text on Industrial Instrumentation.

* S_T^{β} increases linearly with length & inversely with strip thickness
* Element B – made of invar (Ni-Fe alloy) of $\alpha_B = 1.7 \times 10^{-6}/°c$ which is quite low.
* Element A – brass or steel of different alloying compositions.
* Such sensors work precisely & in range of −50 to −400°c (not accurately)
* In different control applications – spiral & disc forms are also made instead of cantilever & helix forms.
* Liquid in glass thermometer :- Liquid – mercury is used.
  * with mercury – Thermometer is basic temp measuring unit → used in home (clinical thermometer) in lab & in industries



* It utilizes the expansion property of the liquid kept in bulb
* capillary → closed at the far end is attached to the bulb thro' which the expanded liquid rises & the temp is measured with calibrated scale indication in mm.
* The range of mercury thermometer is −35 to −300 and the upper limit is 357°c → boiling point.
* The range can be extended upto 600°c by filing the volume above mercury with pressurized dry nitrogen.
* The volume of the bulb is made 100 to 400 times larger than the capillary volume.

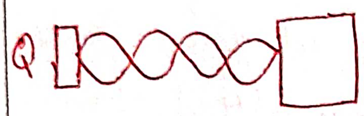
Acoustic Temperature Sensor :-

* When a longitudinal wave propagates thro' an ideal gas, it has a speed C_i given by $C_i = \left[\frac{\gamma R T}{M}\right]^{1/2}$

M - molecular weight of gas
γ - C_p/C_v - Ratio of specific heats

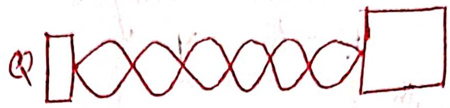
* gas & Measuring velocity C_i known - then Temperature is given by.

$$T = \frac{M C_i^2}{\gamma R}$$

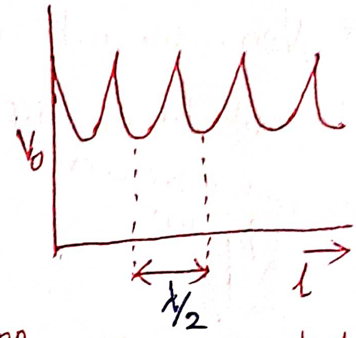


$L \rightarrow\!| \; d = \frac{3\lambda}{2} \; |\!\leftarrow$

(1) System (normal)



(2) System with changed position of piston for maintaining resonance.



(3) crystal output peak position.

* A quartz crystal excited to its resonance freq is used to transmit wave through a gas (He) column, to be faced by a piston.
* The wave is reflected at the piston surface to form the pattern shown in fig.
* Length L - when path length L has multiple no. of half wavelengths & gas column is set to resonance at each such half wavelength gap with piston moving away from crystal at each resonance peak, the crystal gives out maximum energy & hence the voltage V_Q across the crystal defines peaks.
* If the piston moves by a distance d to give n such peaks $d = n\lambda/2$ from which c_i is determined & Temp T.
* The piston movement must be accurately monitored to within say 1 μm.

* In non ideal gas correction as per Van der waal's equation

$$V - b\left(P + \frac{a}{V}\right) = MRT.$$

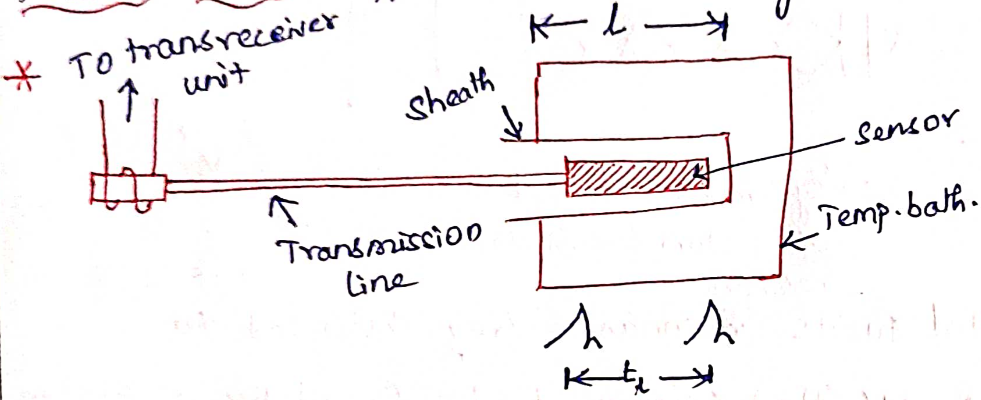
where M - molecular weight of gas
a & b - functions of molecular const

* The Corrected velocity C_c is then given by.

$$C_c = \sqrt{\frac{\gamma RT}{M}\left[1 + \frac{\alpha P}{RT}\right]}$$

α - function of a, b, T & V

* Nonresonant acoustic sensor utilizes the pulse-echo transit time difference which changes with temperature.

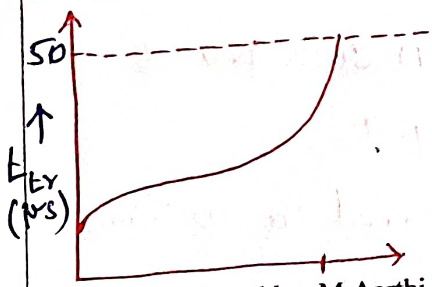


* An ultrasonic pulse is transmitted thro' the sensor, a part of which is reflected at the entrance & part at the end

* The reflected pulses are received by the transreceiver coil at an interval of t_{tr} called the transit time.

* The pulse that travels the entire length of the sensor is delayed more/less depending on the change in the sensor temperature.

* The temp dependence is a function of path length l, sensor material, temp Range, & vibration mode even if the first echo is considered.



* Sensor wire diameter varies from 0.03-3 mm & spacing b/w restrictions varies from 05-10 mm is a sensor length of 15-50 mm & a no. of echos can then be produced.

* There should not be any inhomogeneity in material faced by wave except for restrictions.

Thermosensors using Semiconductor Devices :-

* Thermoelectric effects occur in semiconductor as well.
* Seebeck effect in Silicon & exploitation for thermal sensing are investigated & is given by.

$$\Delta E = \alpha_s \Delta T$$

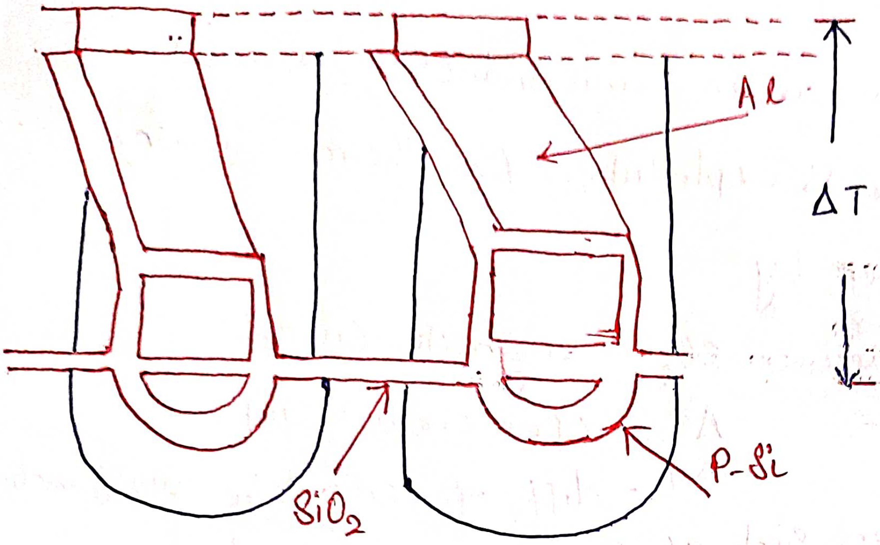
where α_s - seebeck co-eff
ΔE - open circuit emf
ΔT - diff of temp b/w two Junctions.

* α_s - depend on many factors such as Femi energy / conduction band edge energy, Conduction band density of states, electron or hole density in doped materials, Boltzmann constant
* It is approximated as a function of electrical resistivity for a prescribed range of temp. & the relation is

$$\alpha_s = \frac{\lambda k}{T} \ln(\rho/\rho_0)$$

where λ - const of approx value 2.6
ρ_0 - $5\times10^{-6}\ \Omega m$.

* α_s have highest value at room temp with least concentration b/w donor & acceptance atoms -(ie) with smallest density of mobile charge carriers.
* Integrated devices - fabricated as Thermal sensors.
* <u>Thermopiles</u> :- consist of series connected Si and Al couples. Silicon strips - fabricated by any of the diffusion, epitaxy or ion implantation processes.

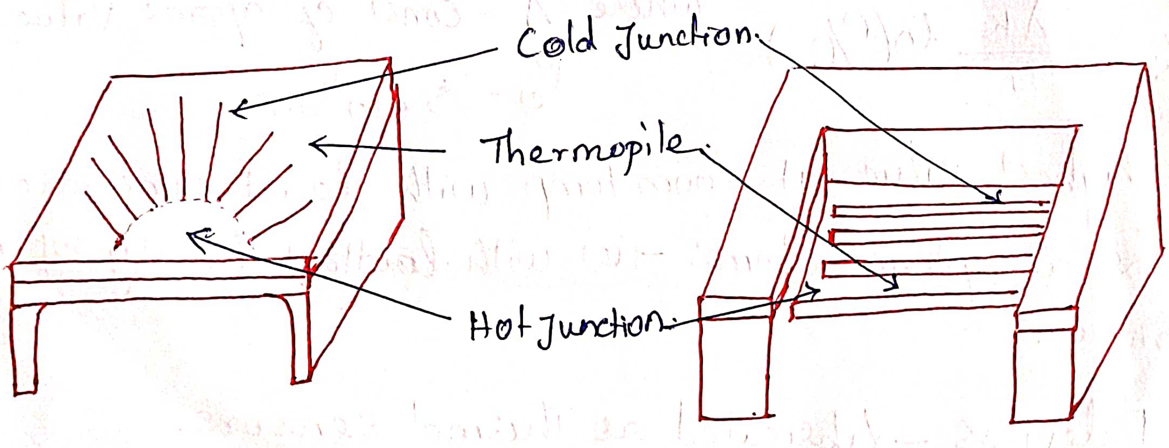


* This is extended to Polysilicon (B-doped) - Gold Thermocouples.

* for Si → α_s has been found to vary from 250–1200 µV/K depending on IC fabrication & material

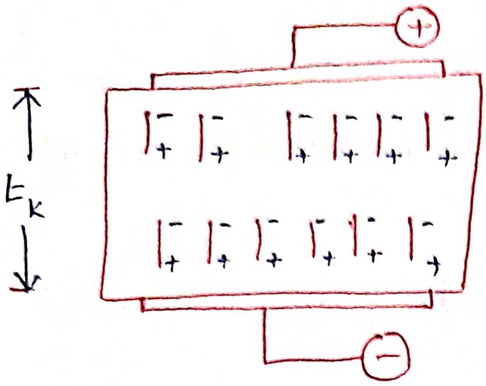
n-Si epi-layer.

* for Al → α_s has been found to be around 240 µV/K
* Semiconductor with high figure of merit compared to metals.
* Types of Thermopiles.



Pyroelectric Thermal Sensors :-

* It comprises of a type of ferroelectric material that are non centrosymmetric & ferroelectricity is attributed to electric polarization on polar axis.
* The direction of polarization can be changed by application of electric field.
* Remanent Polarization occurs because of permanent electric dipole in primitive unit cell of the crystal.
* Pyroelectricity - electric polarization exhibited by permanent dipoles in material with temp.
* materials with polar point symmetry exhibits pyroelectricity. out of 32 possible group symmetries 10 possess pyroelectricity.
* materials are mainly ceramics, The dipoles are in random orientation in material & net electric output is zero & at ambient temperature the orientation are fixed.
* when temp is raised beyond curie (or) critical temperature the molecules with dipoles are free to rotate.
* when a slice of pyroelectric ceramic is placed b/w pair of electrodes & given with an electric field with temp above curie points, the molecules in material orient themselves in direction parallel to the applied field with opposite polarity of the dipoles.
* persists even when the field is removed.



* The amount of polarization is proportional to applied field.

$$P = \sigma E$$

P - Polarization.
E - applied field.
σ - const.

* The dipoles oscillate about parallel orientation & if temp raised the oscillation angle increases.
* If the dipole length is l with charges $\pm q$ then electric moment m is $m = ql$
* if dipole oscillates with average angle θ, its effective length is given by. $l_e = l \cos\theta$
* Thus electric moment of polarization reduces as it becomes.

$$m = ql\cos\theta$$

* The magnetic moment of entire slice is the sum of moments of all the dipoles

$$M = P_v A t_K$$

A - electrode area
t_K - slice thickness.
P_v - dipole moment per unit volume.

* charge Q at ceramic surface as collected by electrodes is

$$Q = P_v A$$

since $M = Q t_K$ = dipole moment.

* with rising temperature P_v is lessened as also Q. → if temp change ΔT occurs charge changes by ΔQ,

$$\frac{dQ}{dT} = \left(\frac{dP_v}{dT}\right) A = \phi A$$

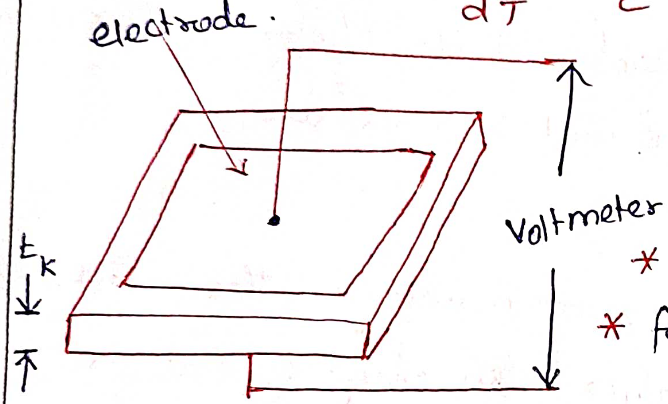
where dP_v/dT - Pyroelectri[c] coeff ϕ.

* Bcoz of dielectric nature of the ceramic, the capacitance developed due to ceramic slice – b/w a pair of electrodes of Area A has a value C

* The voltage change measured b/w the electrode pair becoz of change in temp. $\frac{dV}{dT} = \frac{1}{C}\frac{dQ}{dT} = \frac{\phi A}{C}$

ϕ – nonlinear func of temp.

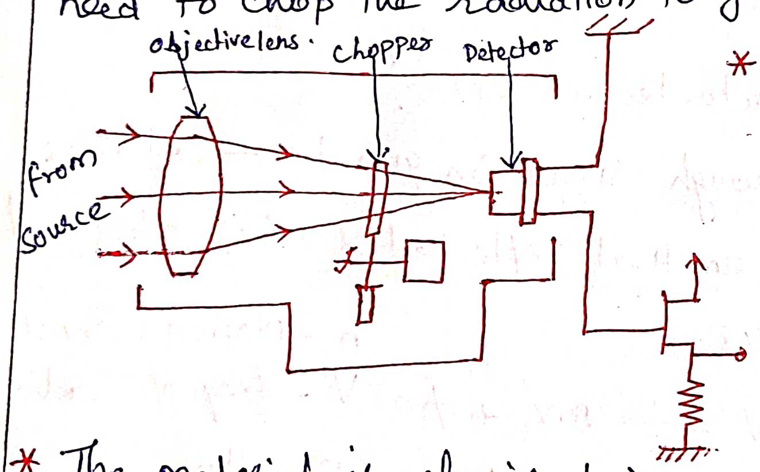
$\phi = 0$ at curie temp



* $\frac{dV}{dT} = \frac{\phi A}{C}\frac{dT}{dt}$

* Measure current $i = \phi A \frac{dT}{dt}$

* for measuring constant radiance, need to chop the radiation to generate the variation required.



* The commonly used materials are

→ Triglycerine fluoberylate

→ Triglycerine sulphate (TGT)

→ plumbum zinc Titanate (PZT)

* The material is classified in terms of its Figure of merit F

$$F = \frac{\phi}{C_v \rho \varepsilon}$$

* figure of merit → Varies for different ways for different applications.

* for eg: application in Video Camera $F_v = \frac{\phi}{\rho C_v \sqrt{\varepsilon \tan \delta}}$

where δ – dielectric loss of material.

Introduction to Radiation Sensors.

* Radiation Sensors - Development of Instrumentation & measurement systems for Industry & Scientific work has widened the use of Sensors.

* Sensing radiation other than optical or photonic has also acquired an important place.

* The radiations like Infrared, ultraviolet, visible, photon type, x rays and nuclear radiations such as α, β and γ rays are of commercial importance.

* According to radiation ranges, freq (or) wavelength, the electrodes change is size & shape & the electrolyte also changes, that is becomes gas, liquid or solid.

* These sensors are based on photoelectric effect.

* Radiation energy propagates through space in quanta — collides with matter — then photons are emitted, reflected & other absorbed depending on material characteristics.

h - planck's const
V - freq of radiation

* The incident photon energy $h\nu = \frac{1}{2} mv^2 + \phi e$

where $mv^2/2$ → energy of electron emitted from the atom

ϕe → energy required to release the electron.

work function

Charge of electron.

Characterisctics :-

* The important characteristics for Photo detectors are.
  - → work function.
  - → spectral sensitivity & spectral threshold.
  - → quantum yield & quantum voltage.
  - → time lag
  - → drift, fatigue
  - → Static & dynamic responses.
  - → Linearity.

Work function :-

* The Energy E, spent in overcoming the surface attractive force is given by. $E = \phi e$

  e - electronic charge.
  ϕ - work function.

* work function ϕ - is a physical constant for a given material expressed in electron volts.

* For metallic elements - work function is observed to be smaller for higher atomic number.

* Alkali metals - have single electron on the outermost orbit so that the force keeping this electron in its orbit is smallest and a low work function is enough to dislodge it completely from atom.

* The kinetic energy of the photoelectron is dependent on incident photon energy which is transmitted to electron.
* The intensity of incident radiation determines the no. of electrons released.
* If the photon energy is sufficient to raise an electron to a vacant conductivity band level, the electrical conductivity of the material increases.
*

Inner photoelectric effect :- The incident radiation energy $h\nu$ is sufficient to transfer an electron into vacant conductivity level of the substance. This leads to increased photo electric conductance of the substance.

Outer photoelectric effect :- $h\nu$ is high enough so that electron be detached & emitted from the material.

Geiger counters

- Used to measure all types of radiations such as α - particles, β - particles and γ - rays using ionization effect.

- Has high sensitivity and large output
- Available at a cheap price and in any shape/size required.
- The lifetime can be extended by using halogen gas filling.

Construction

- GM tube is the main block of geiger counter, which is the sensing element that detects radiation.

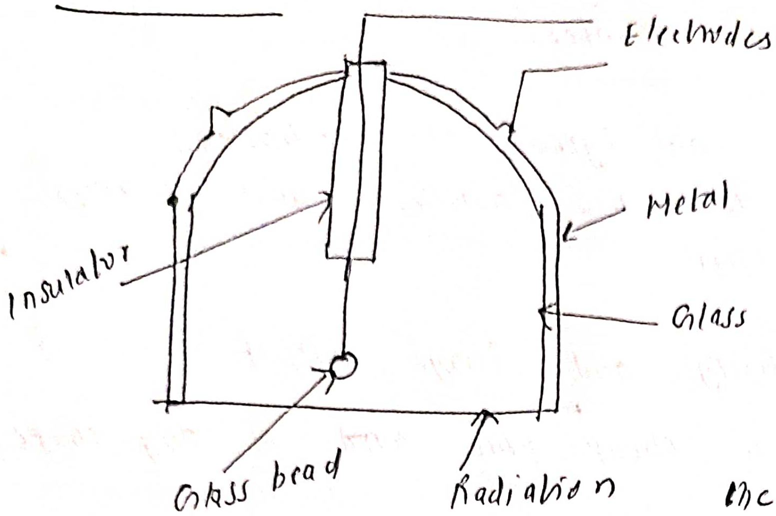
- The tube is filled with an inert gas such as helium, neon or argon at low pressure to which high voltage is applied.

- Tube briefly conducts electrical charge when a particle or photon of incident radiation makes gas conductive by ionization.

Commercially available varieties are:

i) end window type
ii) cylindrical type
iii) needle type.

End- window type

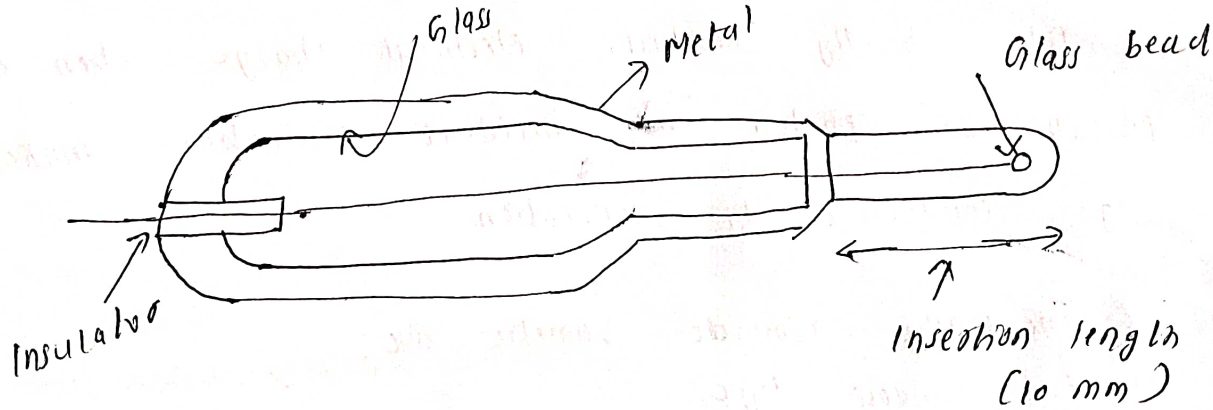


- In this type, a metal - coated glass tube of cylindrical form has a thin tungsten wire of 0.003 - 0.01 cm diameter passing through the centre acting as collector electrode with body as the other.

- The end window is usually made of mica sheet of thickness less than $1 mg/cm^2$. To avoid spark over central electrode, it terminates into glass bead. Radiation is received by end- window.

Cylindrical GM counters

The radiation is received by side walls. Even in the case of needle type GM counter, the insertion in a narrow channel is required.



- The GM counter chamber uses a gas at a low pressure of about 0.1 – 0.15 kg/cm^3 that consists of 90% inert gas such as Ar and Ne and 10% ethyl alcohol or other organic vapours like methane. This mixture ensures charge transit through electrons only.

- The discharge occurs and the bulk of electrons in it is collected by anode.

- The positive ion sheath or cloud reduces the field and stops the discharge. This is known as quenching of discharge.

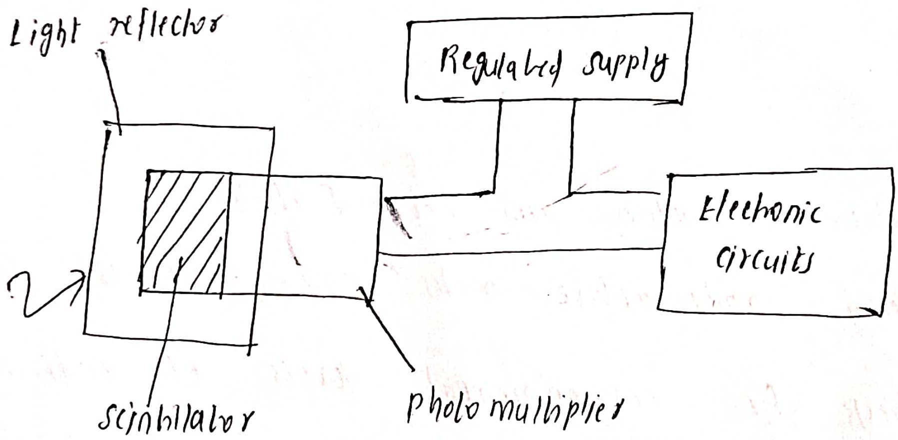
Applications.

(1) For detection of alpha and beta particles
(2) To detect radio active rocks and minerals
(3) To check for environmental levels of radioactivity
(4) For fire and police, first responders to analyse for making initial determination of radiation risk.

Scintillation Detectors

- Certain single crystals of organic or inorganic materials, activated glasses / liquids, or plastic fluors have the property that when high energy radiation, they produce very short duration light pulses or flashes called "scintillations". These materials are known as "scintillators".

- The counter consists of
  - (i) scintillator
  - (ii) photo multiplier that converts light flashes into electrical pulses.
  - (iii) Electronic circuits which consists of amplifier, pulse shaper, scaler, discriminator.



- A fraction f_a of radiation energy received by scintillator is absorbed for conversion into light and fraction f_e of this is converted into light.

- The fraction f_c of this light is then transmitted to photo cathode.

- The spectral matching between crystal and photomultiplier converts a fraction f_c into photo electrons.

→ Thus, if radiation energy received by crystal is E, the no. of photo electrons produced is n,

$$n = K_1 K_2 E$$

K_1 - dimensional constant.

$$K_2 = f_a f_e f_c f_e$$

For photo multiplier multiplication factor A_m, its output in quantity of charge Q_m is given by,

$$Q_m = K_1 K_2 A_m eE$$

e - charge of an electron.

- Absorbed energy is converted into light by luminescence. The excited crystal emits photo radiation and returns to normal condition again and in the process, a time lapse, known as decay time occurs.

Based on materials used, scintillators are classified into organic or Inorganic.

NaI(Tl) - denotes thallium activated sodium iodide or sodium iodide with thallium additive.

NaI (pure) and CsI (pure) - used with better light o/p and less decay time but only at temp. below 80K.

In organic scintillators have high atomic weight and radiation such as γ and x- rays interact with 3 diff. mechanisms.

(i) Photo electric effect - where a light pulse is produced normally in proportion to primary energy

(ii) compton effect - where a large portion of energy is scattered, amount of which is dependent on angle of incidence and scatter

(iii) pair production - in which kinetic energy received is less than incident energy.
This difference in energy is used for producing the pair.