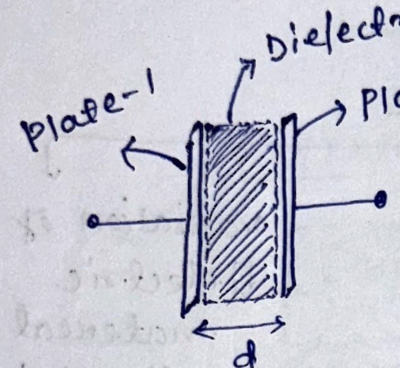
After Midsem

Capacitive Transducer

→ Transduction element → Capacitive nature

→ Parallel plate capacitor

$$C = \epsilon_0 \epsilon_r \frac{A}{d}$$



$$C = \frac{\epsilon A}{d}$$

$$\epsilon = \epsilon_0 \epsilon_r$$

C → Capacitance in Farads

A → Area of overlap of the two plates (m^2)

ϵ_0 → Permittivity of free space (vacuum permittivity)

8.854×10^{-12} F/m

ϵ_r → Relative permittivity (or dielectric constant) of the material in betn the plates ($\epsilon_r \approx 1$ for air)

ϵ → Absolute permittivity or permittivity

↳ Measures the electric polarizability of a dielectric.

↳ A material with high permittivity polarizes more in response to an applied electric field than a material with low permittivity, thereby storing more energy in the material.

d → distance betn two plates (m)

→ Capacitance may vary $\left\langle \begin{array}{l} \epsilon \\ A \\ d \end{array} \right.$

So, we can make capacitive transducer in three types

$$\left.\begin{array}{l} \to \epsilon \\ \to A \\ \to d \end{array}\right\} \text{change.}$$

→ Capacitive Transducer

- variation of distance betn the plates
- variation of the shared area of the plates
- Variation of dielectric material (or, dielectric const)

→ Input can be
I/P ↳ Displacement, pressure, Force.

O/P output → change in capacitance.

Mechanical Energy → [Capacitive Transducer] → Electrical Energy

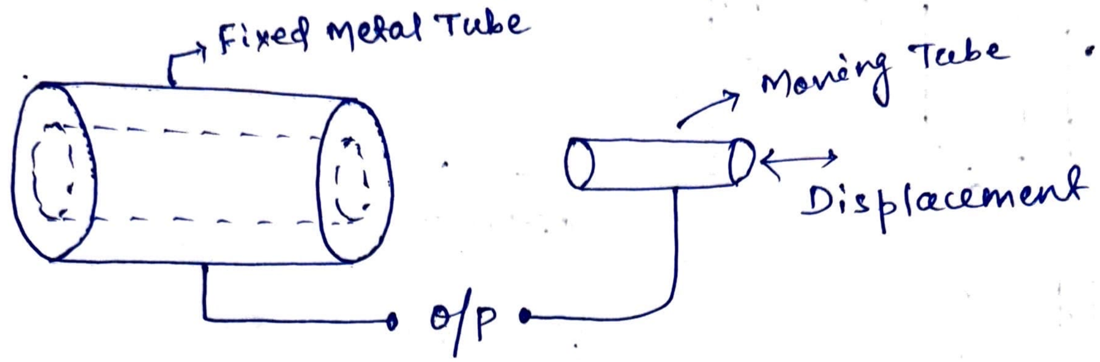
→ Capacitive Reactance

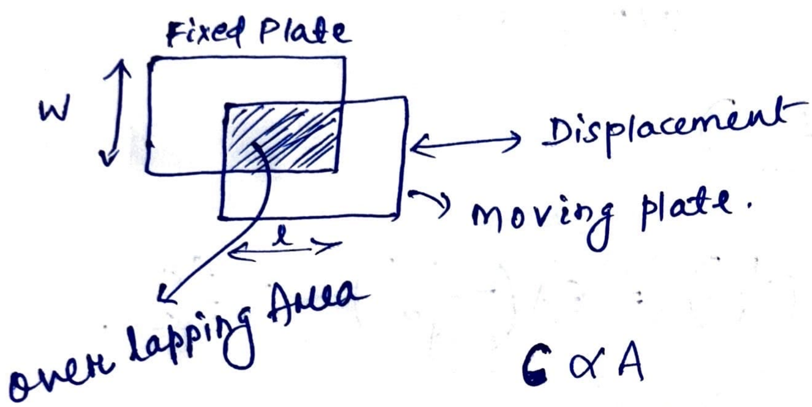
$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

If 'C' changes 'X_C' changes.
↳ change in voltage is observed.

→ $C \propto A$ $\quad C \propto \epsilon$.
$C \propto \frac{1}{d}$

By changing Over lapping Area of plates





$C \propto A$

Completely overlap $\rightarrow$ Max^m A

Max C

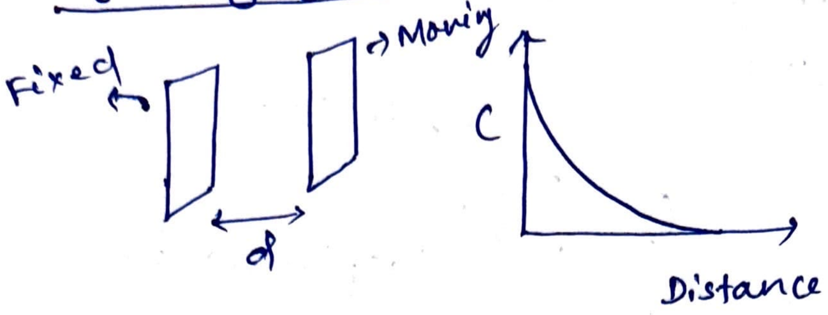
$\left.\begin{array}{l} W \rightarrow \text{fixed} \\ l \rightarrow \text{changing} \end{array}\right\} A \rightarrow \text{changing}$

$$S = \frac{\partial C}{\partial l}$$

$$C = \frac{\epsilon W l}{d}$$

$$S = \frac{\epsilon W}{d} \frac{\partial l}{\partial l} = \frac{\epsilon W}{d} \rightarrow \text{const.}$$

By changing the distance bet^n plates



$d \downarrow \; C \uparrow$

$d \uparrow \; C \downarrow$

$$S = \frac{O/P}{I/P} = \frac{\partial C}{\partial d}$$

$$S = \frac{\partial}{\partial d}\left(\frac{\epsilon A}{d}\right)$$

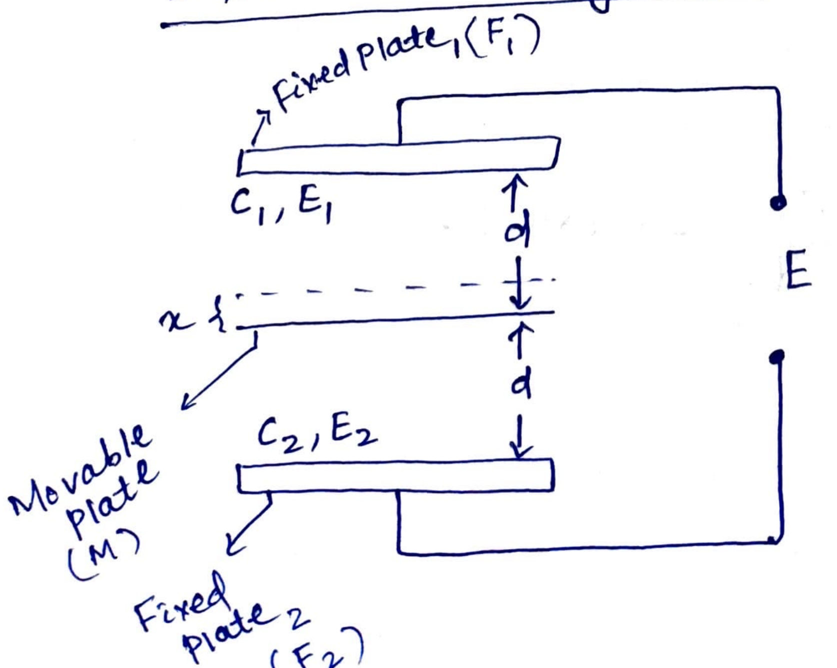
$$= \epsilon A \frac{\partial}{\partial d}\left(\frac{1}{d}\right) = \epsilon A\left(-\frac{1}{d^2}\right) = -\frac{\epsilon A}{d^2}.$$

↳ Not const.
since $d \rightarrow$ not const here.

→ Non-linear in nature.

→ To get linear characteristic we've to make a differential arrangement.

Differential Arrangement:-



2 fixed plates, one movable plate is placed at the center.

$F_1 - M \Rightarrow C_1, E_1$ → voltage developed

$F_2 - M \Rightarrow C_2, E_2$

Movable plate at center

$\Rightarrow C_1 = C_2, \quad E_1 = E_2 = \frac{E}{2}$

$$E_1 = \frac{C_2}{C_1 + C_2} \cdot E, \quad E_2 = \frac{C_1}{C_1 + C_2} E$$

$$C_1 = C_2 = \frac{\epsilon A}{d}$$

Let, movable plate moved upware → x distance

$\Rightarrow$ New distance $= d - x \quad (F_1 - M)$

$F_2 - M \Rightarrow d + x$

$$\Rightarrow C_1 = \frac{\epsilon A}{d - x}, \quad C_2 = \frac{\epsilon A}{d + x}$$

$$\Rightarrow E_1 = \frac{\epsilon A/(d+x)}{\frac{\epsilon A}{(d-x)} + \frac{\epsilon A}{(d+x)}} E = \frac{\epsilon A (d-x)}{\epsilon A (d+x) + \epsilon A (d-x)} E$$

$$= \frac{(d-x) E}{d + x + d - x} = \frac{d-x}{2d} E$$

$$E_2 = \frac{d+x}{2d} E$$

Differential o/p voltage $\Rightarrow \Delta E = E_2 - E_1$

$$\Delta E = \frac{(d+x)}{2d} E - \frac{(d-x)}{2d} E = \frac{E}{2d}(d + x - d + x)$$

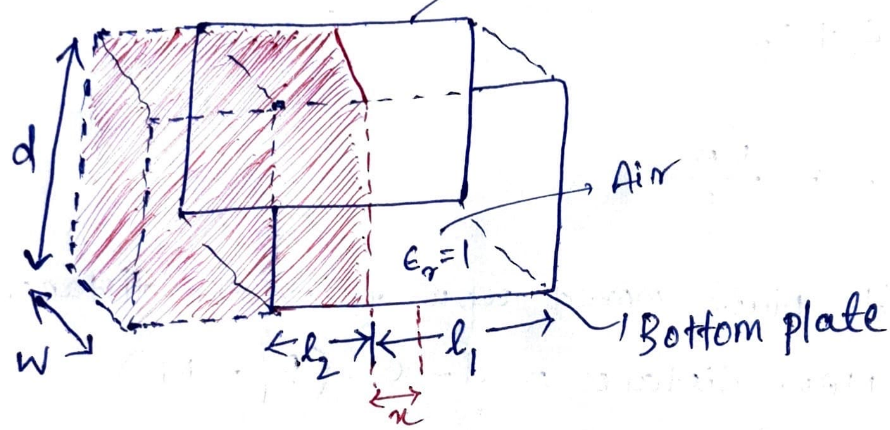
$$= \frac{Ex}{d}$$

$$\Delta E = \frac{Ex}{d}$$

$\Delta E \propto x \rightarrow$ Linear Rel^n

$$S = \frac{\partial E}{\partial x} = \frac{E}{d} \rightarrow \text{Linear.}$$

* Variation of Dielectric Constant for Measurement of Displacement



Till $l_2 \rightarrow$ Dielectric

$l_1 \rightarrow$ Air

$$C = \frac{\epsilon A}{d} = \frac{\epsilon l W}{d}$$

$$C = \frac{\epsilon_0 l_1 W}{d} + \frac{\epsilon_0 \epsilon_r l_2 W}{d}$$

$$= \frac{\epsilon_0 W}{d}\left[l_1 + \epsilon_r l_2\right]$$

$x \rightarrow$ distance moved

$\text{Air}_{\text{New}} \rightarrow l_1 - x$

$\text{Dielectric}_{\text{New}} \rightarrow l_2 + x$

ew Capacitance $\rightarrow C + \Delta C$

$$C + \Delta C = \frac{\epsilon_0 (l_1 - x) W}{d} + \frac{\epsilon_0 \epsilon_r (l_2 + x) W}{d}$$

$$= \frac{\epsilon_0 W}{d} \left[(l_1 - x) + \epsilon_r (l_2 + x) \right]$$

$$= \frac{\epsilon_0 W}{d} \left[l_1 - x + \epsilon_r l_2 + \epsilon_r x \right]$$

$$= \frac{\epsilon_0 W}{d} \left[(l_1 + \epsilon_r l_2) + x(\epsilon_r - 1) \right]$$

$$= \frac{\epsilon_0 W}{d} (l_1 + \epsilon_r l_2) + \frac{\epsilon_0 W}{d} x (\epsilon_r - 1)$$

$$= C + \frac{\epsilon_0 W x}{d} (\epsilon_r - 1)$$

$$\Rightarrow \quad \Delta C = \frac{\epsilon_0 W x}{d} (\epsilon_r - 1)$$

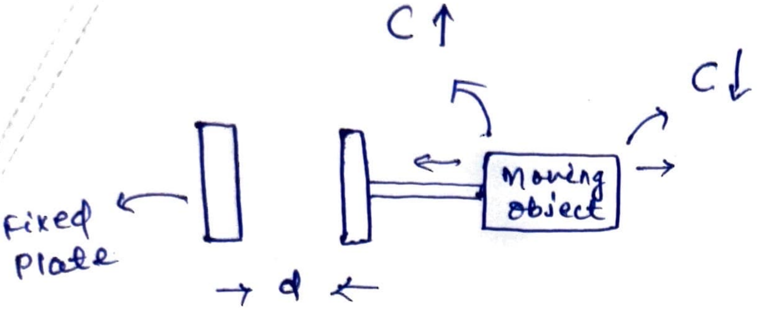
$$\boxed{\Delta C \propto x}$$

Advantage

1) For operation low force is required
2) Highly sensitive
3) Good frequency response
4) Low loading effect (Since they have high input impedance)
5) Small power is required.
6) Resolution is good.
7) Effect of stray magnetic field is low.

Disadvantage

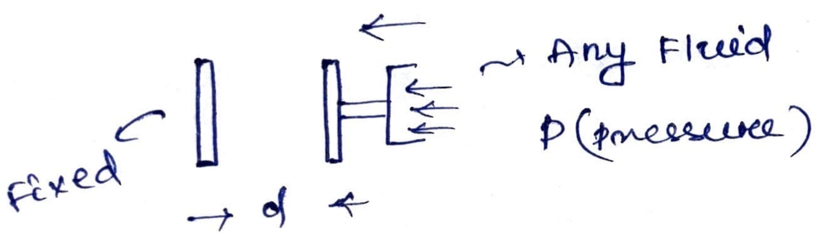
1) Metallic part should be insulated. To reduce stray capacitance frame should be earthed.
2) Edge effect reduces linearity.
3) For small capacitance loading effect is produced.



$$C = \frac{\epsilon A}{d}$$

* Pressure can be used to vary the distance betn two plates and measure the change in capacitance by a suitable electric circuit.

Capacitance $\propto$ pressure (Capacitive pressure Transducer)



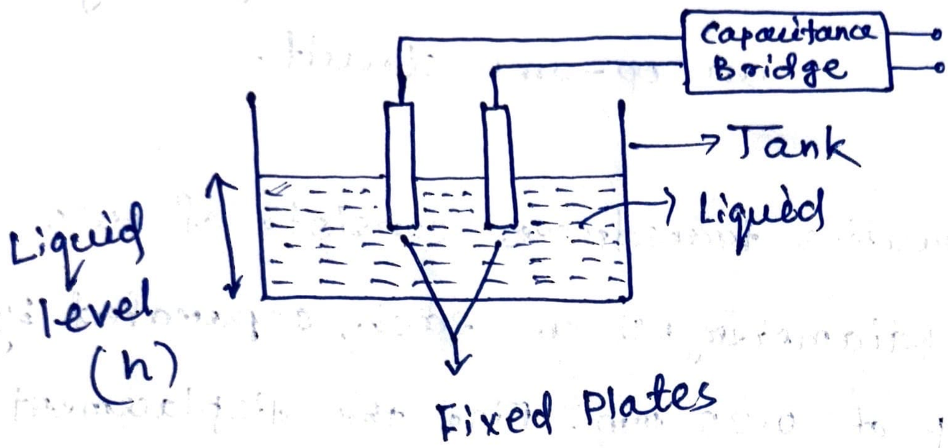
Pressure Applied
$d \downarrow \Rightarrow C \uparrow$

Decrease pressure
$d \uparrow \Rightarrow C \downarrow$

$\boxed{\text{change in capacitance} \longrightarrow \text{Measure of pressure}}$

Liquid level Measurement by Capacitive Transducer

↓



Increase/decrease in liquid level

↓

Dielectric medium changes

↓

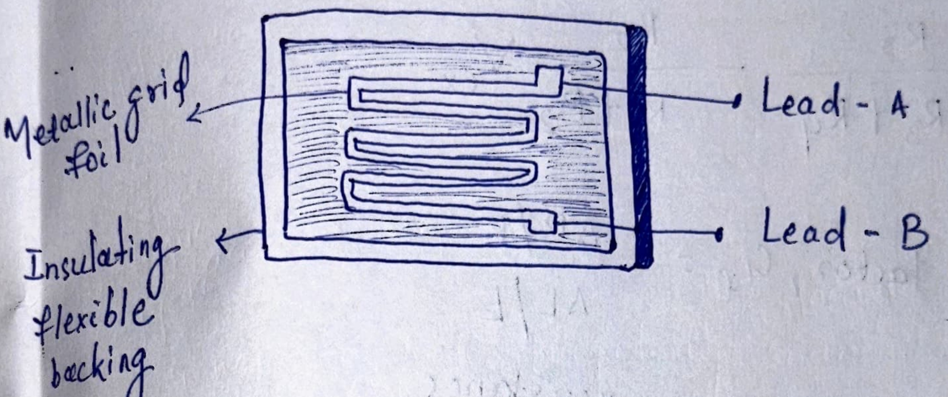
Capacitance changes.

> Change in capacitance with change in medium

✓ Strain Gauge
↳ Used to measure strain on diverse structure.

✓ when external force is applied on the strain gauge its resistance changes & strain gauge operates.

✓

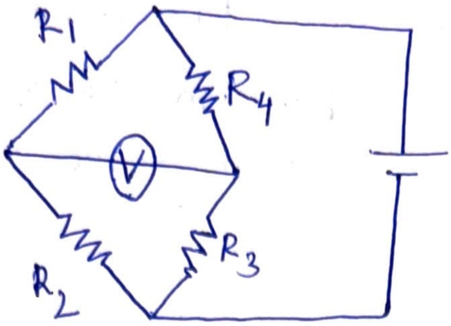


↳ (As a supporting structure)

* Insulating flexible backing
↳ supporting structure
↳ metallic foil attached to the backing and connected to leads
↓
Leads are connected to wheatstone bridge to measure the variation of resistance.

when shape of object deformed due to force, Pressure, etc.
↳ As a result, the resistance of metallic foil changes.
↓
change in resistance is measured by whetstone bridge.

That is related to gauge factor.



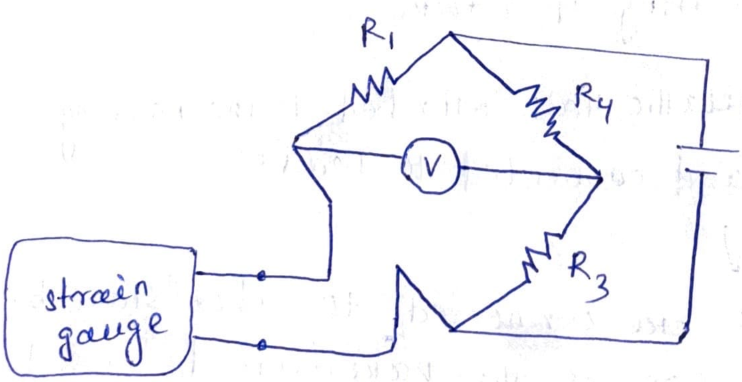
$$V = \left(\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2} \right) V_{ex}$$

$$\text{Gauge factor, } G_f = \frac{\Delta R / R}{\Delta L / L}$$

ΔR → change in resistance

R → Initial resistance without strain

L → Initial length without strain.



Application

→ Used in geotechnical engineering to measure the strain on dams, tunnels, etc.

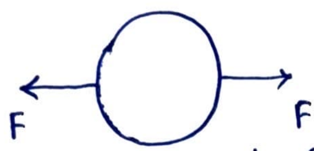
Strain Gauge

strain (Mechanical signal) → change in resistance (Electrical signal)

$$\text{strain} = \frac{\text{change in dimension}}{\text{original dimension}}$$

$$\text{stress} = \frac{F}{A}$$

$$R = \frac{\rho L}{A}$$



↓ (Longitudinal strain) → Length change

(Lateral strain) → Area change

$L \uparrow \; A \downarrow$

$$S = \frac{F}{A} \quad , \quad \text{strain}_L = \frac{\Delta L}{L}$$

$$\text{strain}_A = \frac{\Delta A}{A}$$

$$R = \frac{\rho L}{A}$$

$$\Rightarrow \frac{dR}{ds} = \frac{d}{ds}\left(\frac{\rho L}{A}\right) = \frac{d}{ds}\left(\frac{1}{A}\rho L\right)$$

$$= \frac{\rho}{A}\frac{dL}{ds} + \rho L \frac{d}{ds}\left(\frac{1}{A}\right) + \frac{L}{A}\frac{d\rho}{ds}$$

$$= \frac{\rho}{A}\frac{dL}{ds} - \frac{\rho L}{A^2}\frac{dA}{ds} + \frac{L}{A}\frac{d\rho}{ds}$$

$$\left[\frac{d}{ds}\left(\frac{1}{A}\right) = \frac{d}{dA}\left(\frac{1}{A}\right)\cdot\frac{dA}{ds} = -\frac{1}{A^2}\frac{dA}{ds}\right]$$

$$\Rightarrow \frac{1}{R}\frac{dR}{ds} = \frac{\rho}{AR}\frac{dL}{ds} - \frac{\rho L}{A^2 R}\frac{dA}{ds} + \frac{L}{AR}\frac{d\rho}{ds}$$

$$\frac{1}{R}\frac{dR}{ds} = \frac{\rho}{A\frac{\rho L}{A}}\frac{dL}{ds} - \frac{\rho L}{A^2\frac{\rho L}{A}}\frac{dA}{ds} + \frac{L}{A\frac{\rho L}{A}}\frac{d\rho}{ds}$$

$$= \frac{1}{L}\frac{dL}{ds} - \frac{1}{A}\frac{dA}{ds} + \frac{1}{\rho}\frac{d\rho}{ds}$$

$A = \pi r^2$ (circular wire)

$$r = \frac{D}{2}$$

$$A = \frac{\pi D^2}{4}$$

$$\frac{dA}{ds} = \frac{\pi}{4} \times 2D \times \frac{dD}{ds}$$

$$\Rightarrow \frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{dL}{ds} - \frac{1}{\frac{\pi D^2}{4}} \times \frac{\pi}{4} \times 2D\frac{dD}{ds} + \frac{1}{\rho}\frac{d\rho}{ds}$$

$$= \frac{1}{L}\frac{dL}{ds} - \frac{2}{D}\frac{dD}{ds} + \frac{1}{\rho}\frac{d\rho}{ds}$$

$$\text{Poisson Ratio} = \frac{-\text{Lateral strain}}{\text{Longitudinal strain}}$$

$$\nu = -\frac{dA/A}{dL/L}$$

$$= -\frac{dD/D}{dL/L}$$

$$\frac{dD}{D} = -\nu\frac{dL}{L}$$

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{dL}{ds} + \frac{2\nu}{L}\frac{dL}{ds} + \frac{1}{\rho}\frac{d\rho}{ds}$$

$$= \frac{1}{L}\frac{dL}{ds}(1+2\nu) + \frac{1}{\rho}\frac{d\rho}{ds}$$

Gauge Factor $= \dfrac{\Delta R/R}{\Delta L/L}$

$$G_f = \frac{\Delta R/R}{\Delta L/L}$$

$$\frac{\Delta R}{R} = G_f \frac{\Delta L}{L}$$

For small change, $d \to \Delta$

$$\frac{1}{R}\frac{\Delta R}{\Delta S} = \frac{1}{L}\frac{\Delta L}{\Delta S} + \frac{2r}{L}\frac{\Delta L}{\Delta S} + \frac{1}{\rho}\frac{\Delta \rho}{\Delta S}$$

$$\Rightarrow \frac{\Delta R}{R} = \frac{\Delta L}{L} + 2r\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho}$$

$\dfrac{\Delta L}{L} \to$ Divide

$$\Rightarrow G_f = 1 + 2r + \left(\frac{\Delta \rho}{\rho} \times \frac{L}{\Delta L}\right)$$

ϵ = strain $= \Delta L/L$

$$\Rightarrow G_f = 1 + 2r + \underbrace{\left(\frac{\Delta \rho/\rho}{\epsilon}\right)}_{\text{small}}$$

so, $G_f = 1 + 2r$

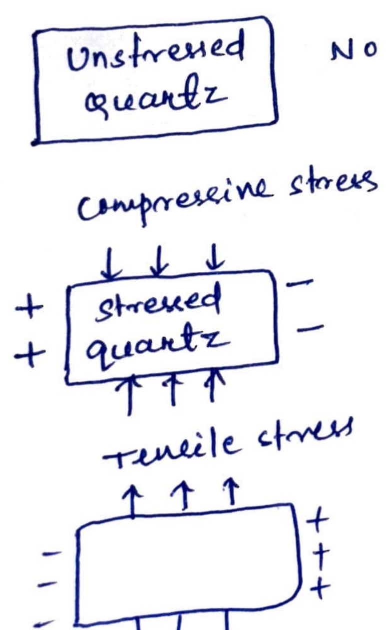
Young's modulus, $E = \dfrac{\text{stress}}{\text{strain}}$ Hooke's law

$r = \dfrac{\text{Lateral strain}}{\text{Longitudinal strain}}$ poisson's Ratio

Piezoelectric Transducer

Lecture - 16

- Types of transducer used to convert force or mechanical Pressure in electrical signal.
- Piezoelectric transducer is used to measure physical quantities like force, pressure, stress.
- When force is applied to piezoelectric material then it converts force into electrical voltage that can be easily measured by digital meter.
- In piezoelectric transducer quartz crystal material is used which has special characteristics.
- The voltage is a function of force or pressure applied to it.
- Piezoelectric crystals are electrically neutral.
- A piezoelectric transducer is based on the principle of the piezoelectric effect.
- The piezoelectric effect states that when mechanical stress or forces are applied on quartz crystal, it produces electrical charges on the quartz crystal surface.



No charges induced

High stress → High voltage

Since, the voltage will be a f^n of the force or pressure applied to it, we can infer what the force/pressure was by the voltage reading.

Application of a force 'F' causes deformation x_i Producing a charge 'Q'.

Charge sensitivity constant, $S = \frac{Q}{x_i}$

$\Rightarrow Q = S x_i$

$S \rightarrow$ CSC

$\Rightarrow$ A crystal behaves like a capacitor, carrying a charge across it. If the voltage across crystal is E_0 and C is capacitance,

$q = CV$ $\rightarrow$ $E_0 = \frac{Q}{C} = \frac{S x_i}{C} = k x_i$

$k = \frac{S}{C}$

$\hookrightarrow$ Voltage sensitivity constant.

Reln betn force (F) and deformation (x_i)

$F = Y A \frac{x_i}{t}$

t → Thickness of piezoelectric material

Y → Young's Modulus

charge sensitivity constant,

$$S = \frac{Q}{x_i} = \left(\frac{Q}{F}\right)\left(\frac{F}{x_i}\right)$$

$$\frac{F}{x_i} = \frac{YA}{t}$$

$$\Rightarrow S = \left(\frac{Q}{F}\right)\left(\frac{YA}{t}\right)$$

Application of Piezoelectric Transducers

↓

Ultrasonic Transmitters

↓

Sinusoidal voltage at a frequency

↓

Causes sinusoidal vibration

↓

Results in a sound wave being emitted at the chosen frequency.

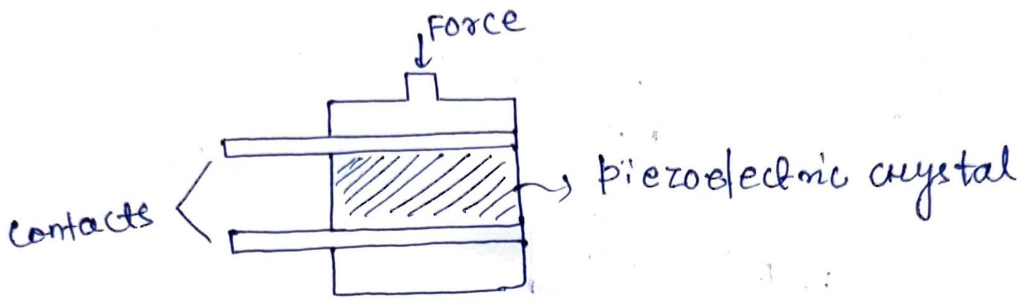
Piezoelectric principle is invertible

↓

Thus, if we apply voltage to a piezoelectric material, there will be distortion in the piezoelectric material.

* Force Sensor using piezoelectric Transducer

↓



Two plates → Betⁿ them piezoelectric crystal

Force Applied from one side

↓

Piezoelectric material deformed

↓

Surface charge is accumulated

↓

Behave like a capacitor

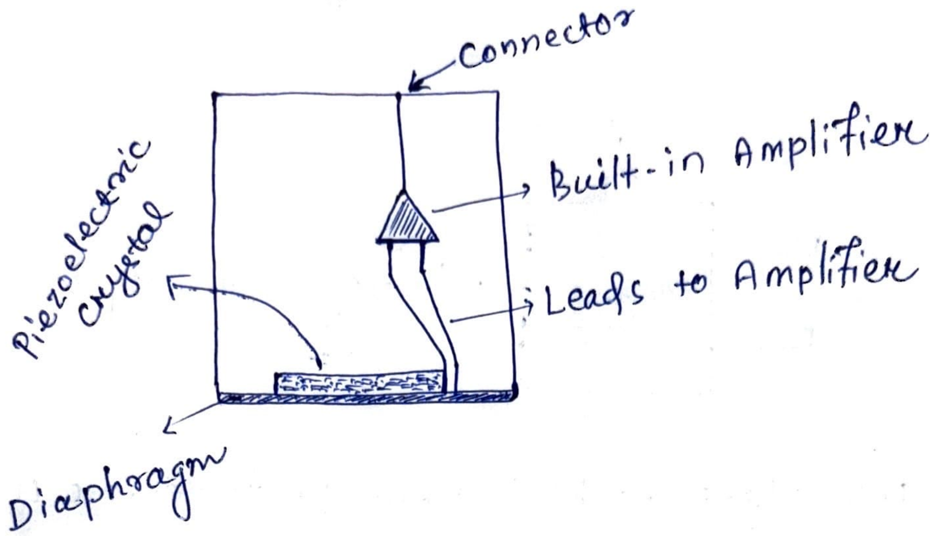
↓

Measure the output voltage by using electrical circuit.

↓

Eqv. force can be measured.

* Piezoelectric pressure sensors



Piezoelectric crystals produce a voltage betⁿ their opposite faces when a force or pressure is applied to the crystal. This voltage (in the range of microvolt) can be amplified and the device used as a pressure sensor.

A piezoelectric crystal is mechanically attached to ~~a~~ metal diaphragm. One side of the diaphragm is connected to the process fluid to sense pressure. A voltage is then produced because the crystal is mechanically deformed by fluid pressure.

Thermistor

- Most of the theremistors aree made up of semiconductor device, so it has high negative temp. coefficient.

Negative temp coeff. → $R_{semi} \propto \frac{1}{Temp}$. → semiconductor

+ve temp. coeff., $R \propto Temp$

↳ conductor

- Thermistor is a heat sensing device whose resistance changes rapidly with temperature.

Application → (a) To measure the temp.

(b) To protect the circuit (device) from high temp.

PI

Lecture-18

Pressure Measuring instruments

$P = \frac{F}{A}$
- $N/m^2 \rightarrow$ Pa
- bar
- Atm $\rightarrow$ 1 atm = 760 mm Hg
- Torr

For instrumentation

↳ Pressure range = 3 to 15 psi (Used for pneumatic controls)

1 psi = 6.894 KPa

3 psi ≈ 21 kpa

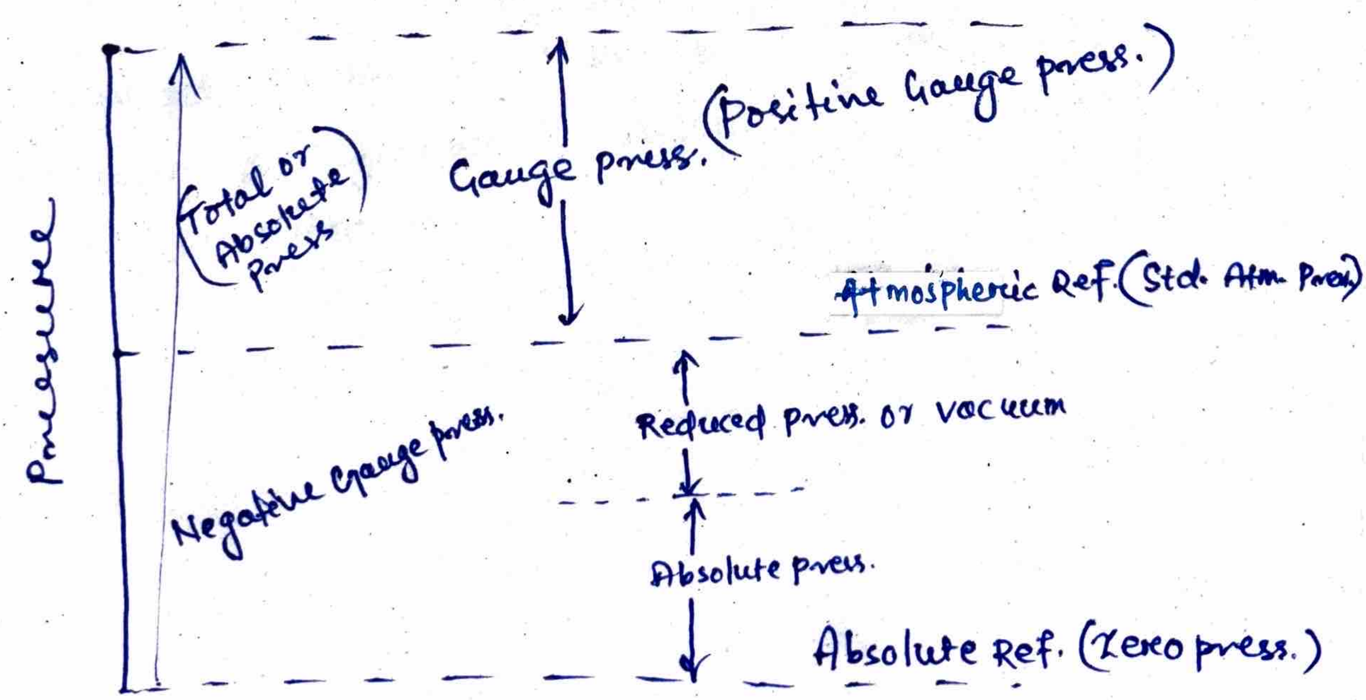
15 psi ≃ 105 kPa

1 psi = 0.068 Atm press.

1 Atm = 14.7 psi

$1\ Pa = 1\ N/m^2 = 1\ kg \cdot m/s^2 = 10\ dynes/cm^2$

1 atm = 1.01325 bars = 76 mm Hg ≈

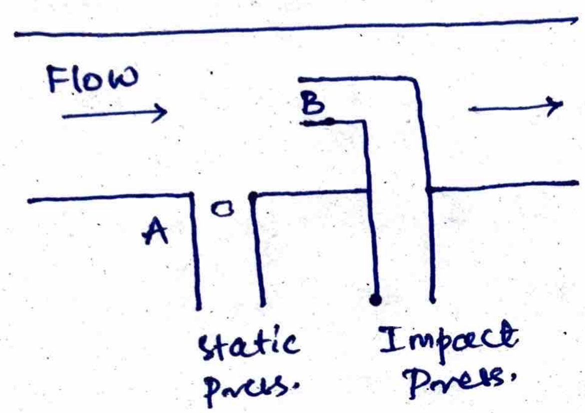


Press. above atmosphere → Positive Gauge press.

" " " → Vaccum (-ve Gauge press.)

Absolute press. is measured from a perfect Vaccum.

* Static / Dynamic / Impact pressure



- Static pressure is the pressure of the fluids or gases which are stationary (Point - A)
- Dynamic pressure is the pressure exerted by a fluid or gas when it impacts on a surface or an object due to its motion or flow (Point : B - A) → (Press diff)
- Impact press. (total press.) is the sum of static & dynamic pressures on a surface or object (point - B)

Pressure Measurements

Classification- I

Convert press ⟶ Force

A force can be measured by balancing against a known/standard force.

(i) Balancing against a column of liquid of known density

→ Various manometers

(ii) Balancing against a known force

Piston type, Ring balance, Bell Type.

(iii) Balancing the force produced on a known area against the stress in an elastic medium.

Bourdon Tubes, Diaphragm types.

Classification - II

Based on the range of press. measurement.

- Moderate press. measurement
- Very high " "
- High vacuum (Very low press) measurement.

Moderate press. Measurement

- **Liquid column Elements**
  - Barometer
  - various Manometer
- **Mechanical displacement type**
  - Ring balance manometer
  - Bell-type manometer
- **Elastic press. transducer**
  - Bourdon tube
  - Diaphragm type
  - Bellows gauge
- **Electrical press Transducer**
  - Resistance type
  - potentiometer device
  - Inductive type
  - Capacitive type
  - piezoelectric type.

Very high press. Measurements

- Electric Gauges based on change of resistance of Manganin or gold-chrome wire.

High Vacuum Measurement

- McLeod Gauge
- Thermal conductivity Gauge
- Ionization Gauge
- Knudsen Gauge

Indicative Range of Instruments

✓ Below 1 mm of Hg → Manometers and low press. Gauge

1 mm Hg → 0.00131 Atm. pr.

✓ Betⁿ 1 mm Hg to 1000 Atm
↓
Bourdon tube, Diaphragm Gauge, Bellows

✓ High vacuum (up to 10^{-9} torr)

(1 Atm = 760 Torr)

McLeod Gauge

(1 Atm = 760 mm Hg)

Thermal conductivity Gauge

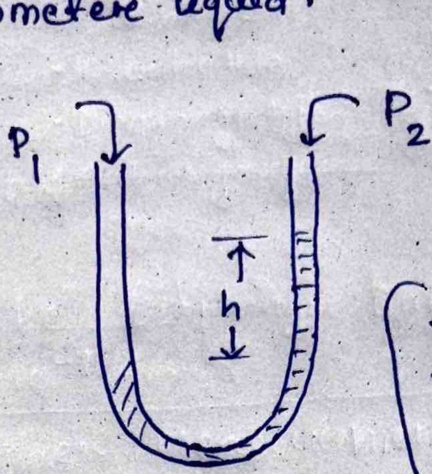
Ionization Gauge

✓ High pressure (1000 Atm & Above)

↳ Electrical resistance type.

U-tube Manometer

- U-shaped glass tubes partially filled with a liquid known as manometere liquid.



$P_1 > P_2$

$\Rightarrow P_1 - P_2 = \rho g h$

If connected to same press. source $h = 0$

A scale graduated in pressure units is attached to read h.

✓ one limb to Atmosphere, another connected to pressure source ↳ Gauge press. measurement

✓ If both the limbs are connected to two different pressure sources
↳ Differential pressure.

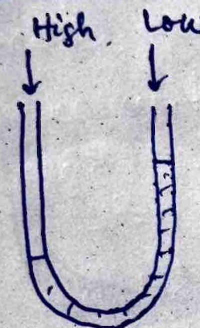
✓ If one limb → vaccum (completely evacuated)
other → press. source
↳ Measuring Absolute press.

Manometer fluid specifications
- ✓ should not wet the wall
- ✓ should " absorb gas
- ✓ " " chemically
- ✓ should have low vapor press
- ✓ " move freely.

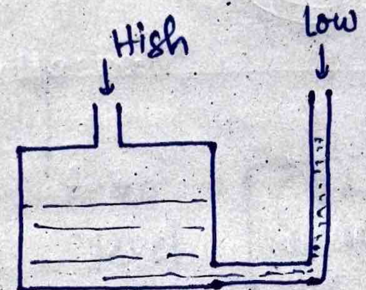
Common Manometer liquids

→ water (evaporation loss)
→ Aniline
→ Carbon tetrachloride
→ Bromoform
→ Mercury
→ transformer oil

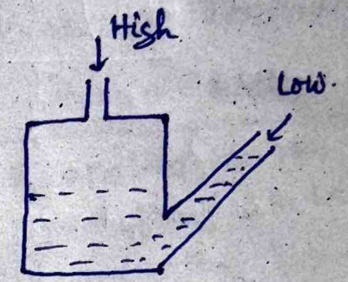
Various types of Manometers



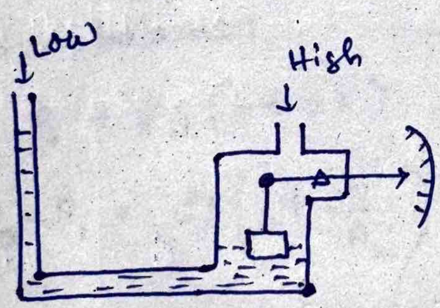
U-tube Manometer



Well (Reservoir) Manometer



Inclined Manometer



→ In a well-type manometer

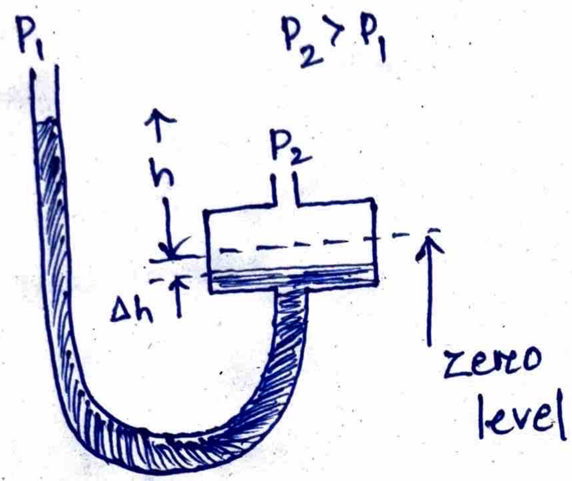
↓

One leg replaced by large dia well.

Since CSA of the well is larger than other leg, when press. is applied to the well, the manometer liquid in the well lowers only slightly compared to the liquid rise in the other leg.

As a result, the p. diff. can be indicated only by the height of the column (liquid column) in one leg. This makes the instrument easier to be used than the U-tube manometer.

Well type Manometer



A_1 = Area of vertical leg

A_2 = Area of well

$P_1 \rightarrow$ Press. at vertical leg

$P_2 \rightarrow$ " " well

(when P_2 applied let the level of liquid go by Δh in the well)

vol^m balance : $A_2 \Delta h = A_1 h \Rightarrow \Delta h = \frac{A_1}{A_2} h$

for static balance:

$P_2 = P_1 + \rho g (h + \Delta h)$

$\Rightarrow P_2 - P_1 = \rho g \left(1 + \frac{A_1}{A_2}\right) h$

($h \rightarrow$ in the vertical leg)

(Initially at zero level)

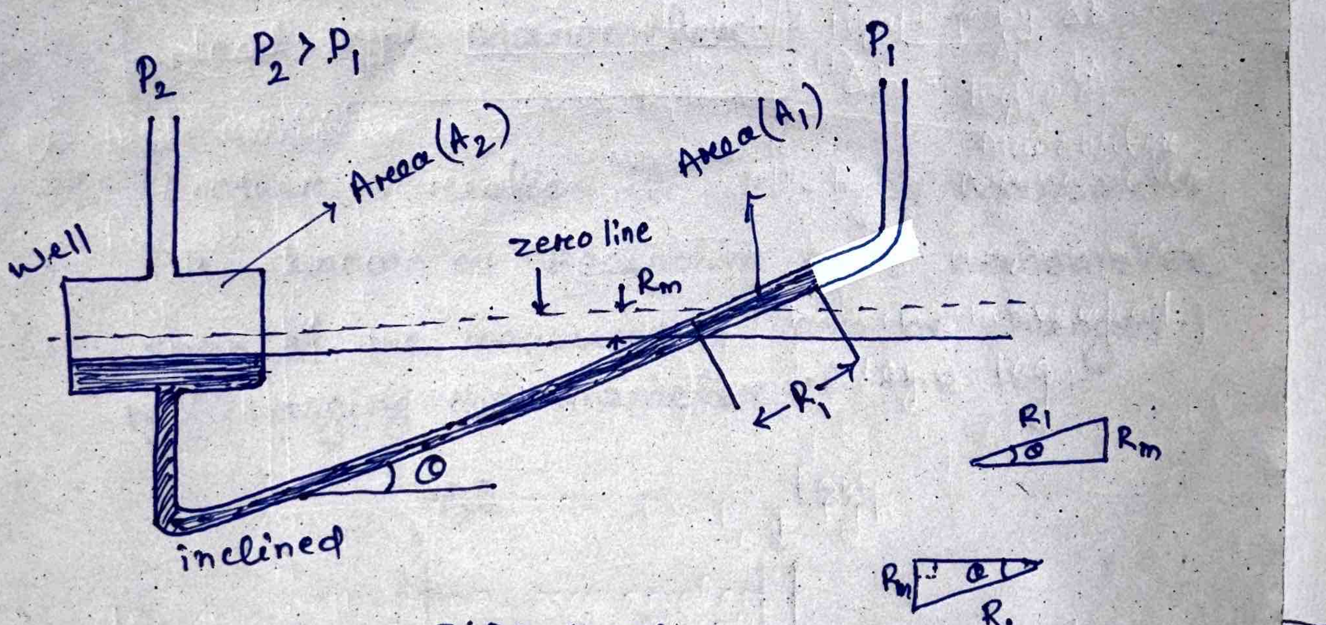
If $\frac{A_1}{A_2} << 1$, then $P_2 - P_1 = \rho g h$

If the area of well is 500 or more times higher than the area of veretical leg, the error involved in neglecting the area term is negligible.

$\rightarrow$ Convention.

Inclined tube Manometer

- Inclined tube Manometer or draft gauge is a variation on the well-type manometer in which one leg of the tube is inclined to increase measurement sensitivity.
- Inclined manometers can measure low pressures. The low pressure arm is inclined, so that the fluid has a longer distance to travel than in a vertical tube for the same pressure change. This gives a magnified scale and thus increases sensitivity of the manometer.



P_2 & P_1 → Diff press.

↳ Mercury level goes down by R_m

Since, the tube is inclined

↳ The change in the inclined tube (leg) ⟶ R_1

$$\sin\theta = \frac{p}{h} = \frac{R_m}{R_1}$$

$$\Rightarrow R_m = R_1 \sin\theta$$

For static balance,

$$P_2 - P_1 = \rho g \left(1 + \frac{A_1}{A_2}\right) R_m$$

$$\Rightarrow P_2 - P_1 = \rho g \left(1 + \frac{A_1}{A_2}\right) R_1 (\sin\theta)$$

If $A_2 >>> A_1 \Rightarrow \frac{A_1}{A_2} <<< 1$

$$\Rightarrow P_2 - P_1 = \rho g R_1 (\sin\theta)$$

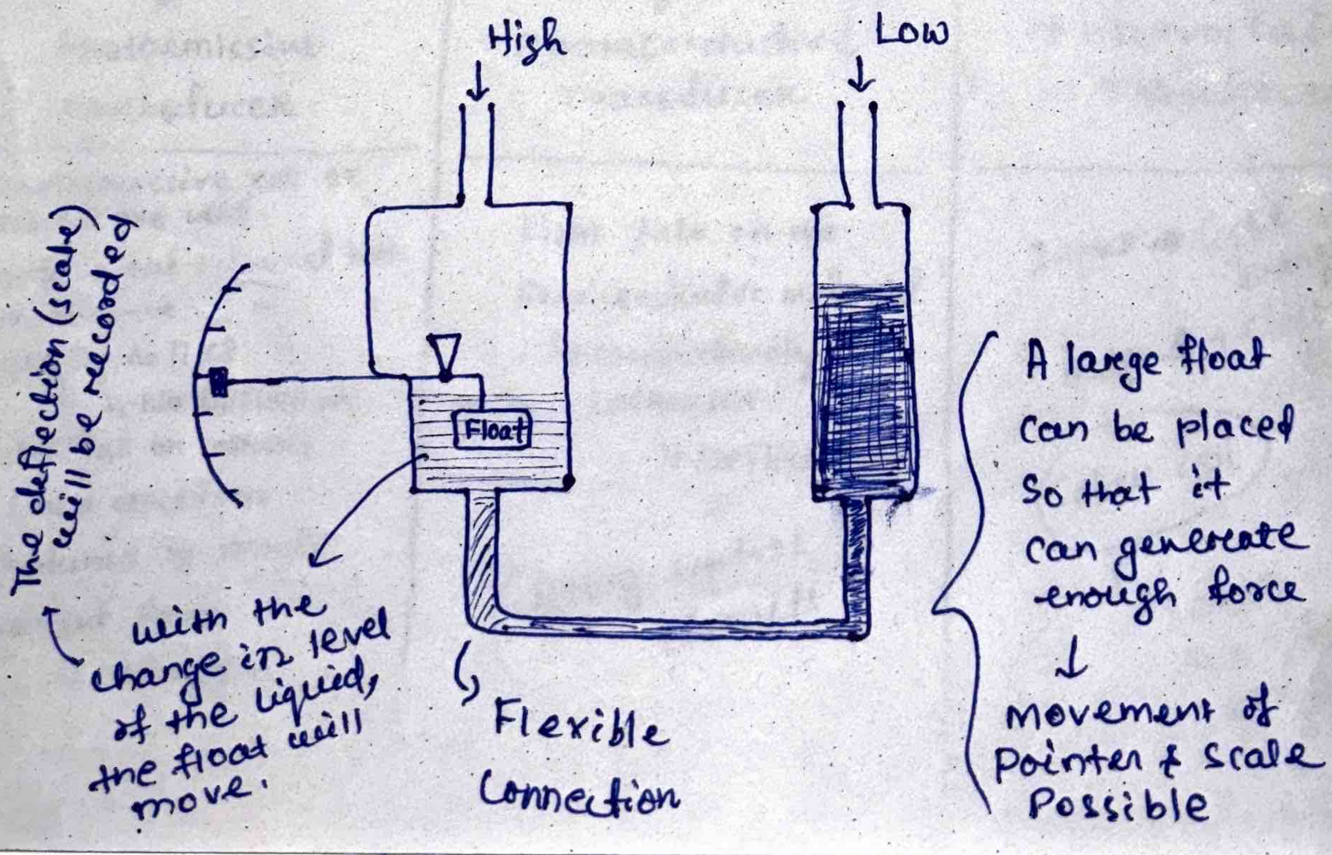
The scale of the manometer can be extended greatly by decreasing the angle of the inclined leg θ to a small value.

Float type Manometer

→ Another variation of well-type Manometer

→ Also known as Recording type manometer

→ span of the measurement can be changed by changing the diameter of the leg.



Lecture - 19 (PI) 28/3/24 ①

Dead weight pg

1) Gauge is attached to the stem (B)
2) Place a weight on vertical piston (A)
3) Move the adjusting piston 'C' to ensure that the weight and piston are supported by oil and it's floating freely.
4) Record the gauge reading and the weight.
5) Repeat steps 2 to 5 for increasing & decreasing order of weights.

Reservoir, vertical piston, Adjusting piston

↓

All are connected

Attach a pressure Gauge.

Dead weight → Used to calibrate the pressure Gauge.

✓ Used for calibrating pressure transducers, sensors.

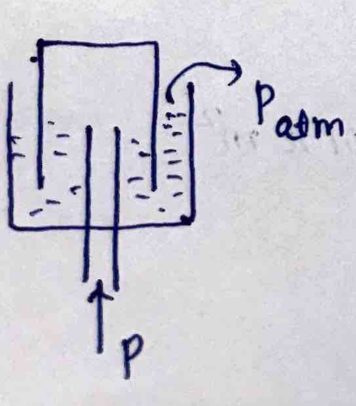
✓ High pressure Applications.

Bell Type Pressure Gauge

✓ Consists of → Inverted container → Immersed in a sealing liquid.

✓ Sealing liquid forms two chambers.

✓ The pressure to be measured is applied to the inside of the bell, the motion ~~of~~ which is opposed by a restricting spring.



⇒ The measured pressure is the gauge pressure.

$P_{atm} + P$ → Create displacement.

Bell Type Differential pressure Gauge

Sealed chamber

$P_1 = P_2 \rightarrow$ No movement

change in P_1 & P_2 $\longrightarrow$ Deflection.

Lecture - 20 (Process Instrumentation)

Pressure Measurement

Bourdon tubes (Elastic Element Type Pressure Gage)

High Vacuum Measurements

McLeod Gauge
Ionization Gauge
Thermal conductivity Gauge
Knudsen Gauge.

McLeod Vacuum Gauge (To measure low pressure)

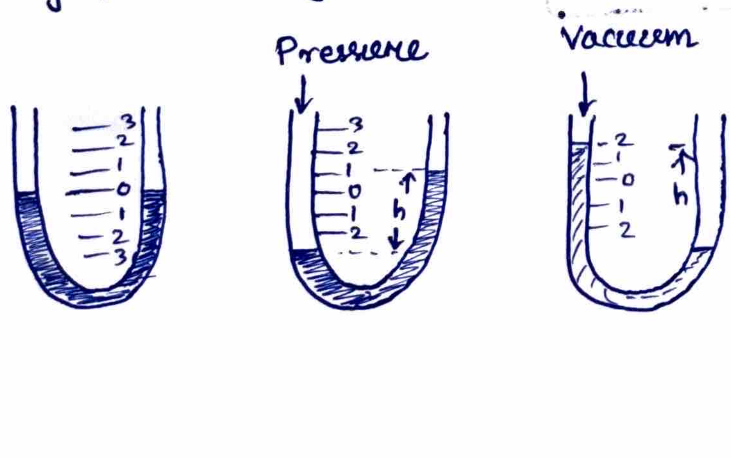
Range : 0.001 to 10 pa.

Pressure in terms of head,

$$P = \frac{F}{A} = \frac{mg}{A} = \frac{\rho V g}{A} = \frac{\rho A h g}{A} = \rho g h$$

$$\boxed{P = \rho g h}$$

$h \rightarrow$ height of the liquid column
$g \rightarrow$ gravitational const.
$\rho \rightarrow$ Density of liquid.



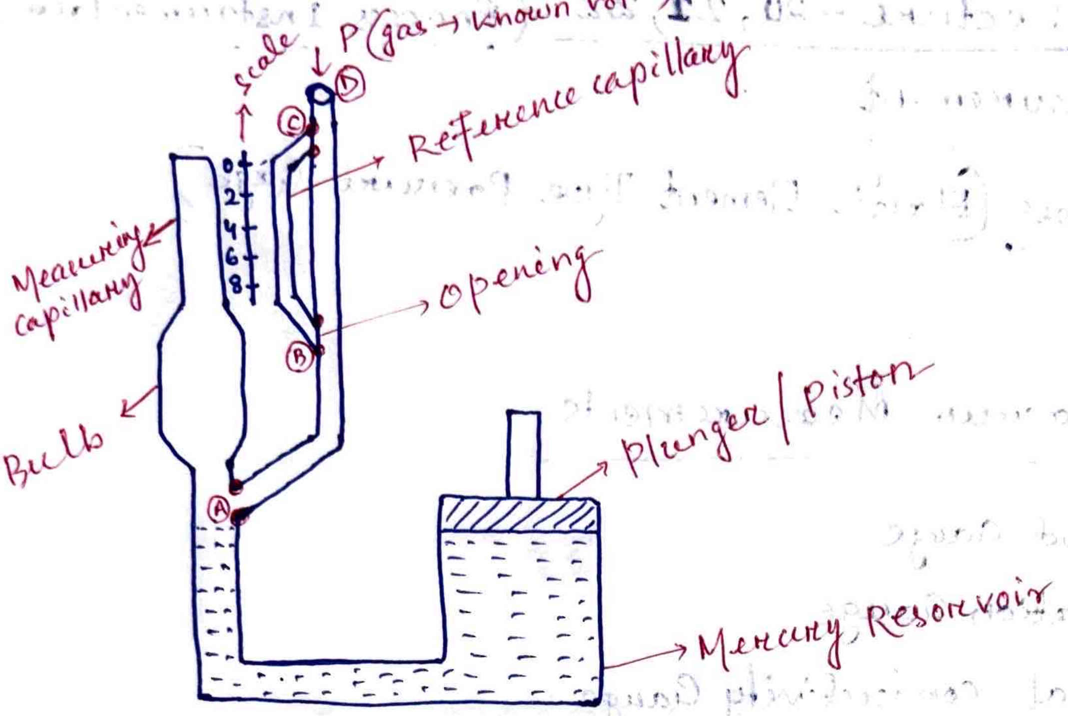

scale
P (gas → known vol^n)
D
C
Reference capillary
0
2
4
6
8
Measuring capillary
Opening
B
Bulb
Plunger | Piston
A
Mercury Resorvoir

Fig-1

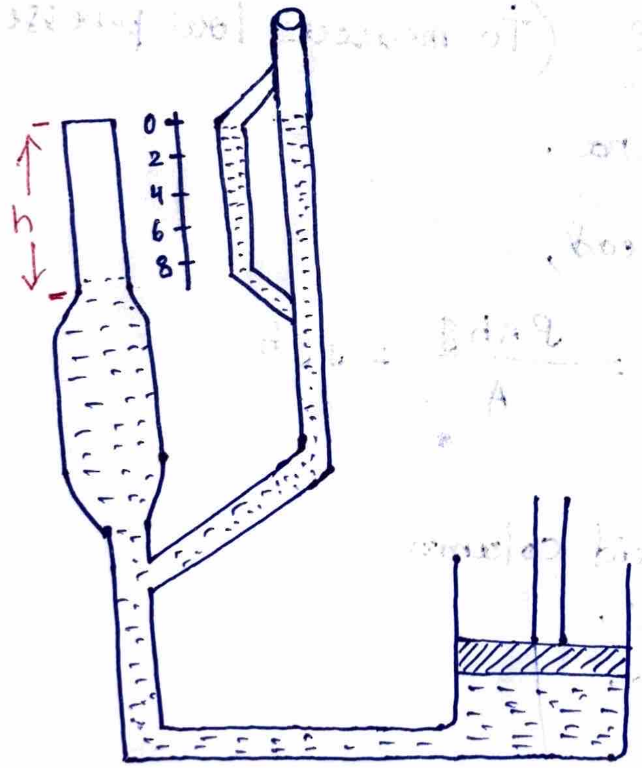

h
0
2
4
6
8

Fig-2

1. Measuring capillary
2. Reference capillary
3. 3- openings. (opening A, B & C)
4. Mercury Reservoir
5. Plunger/ Piston
6. Common Scale for Measuring capillary & Reference capillary.

Step-1 → Pull plunger upward
↳ Pull till all the mercury comes below opening (A)
↳ A kind of suction.

Step-2 → known volume of gas is taken at opening (D)
↳ Need to measure the pressure of the corresponding gas.

↓

Vol^m known
Pressure unknown (has to be measured)

Step-3 The gas filled through opening (D) will go down & go through opening (A) & will be entrapped in the measuring capillary.

Step-4 ✓ Fig → 2 → The plunger is pushed down
The mercury will rise in both the measuring & reference capillary.
✓ The gas in Measuring capillary will get compressed.

Step-5 Compress till the Mercury in Reference capillary rises till '0' mark.

Boyle's Law

↳ $P \propto \frac{1}{V} \Rightarrow PV = \text{const.}$

$\Rightarrow P_1 V_1 = P_2 V_2$

Let, P_1 → Pressure to be measured (gas)

V_1 → known vol^m of gas through reference capillary.

P_2 → Pressure of gas inside Measuring capillary

V_2 → vol^m of gas " Measuring "

A → Area of measuring capillary

h → height of gas in M. cap.

$\Rightarrow V_2 = Ah$

$P_2 = P_1 + \rho_m g h$ (ρ_m → Density of Mercury)

$\Rightarrow P_1 V_1 = (P_1 + \rho_m g h) Ah$

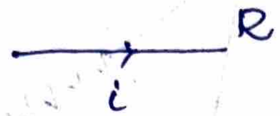
$\Rightarrow P_1 V_1 - P_1 Ah = \rho_m g A h^2$

$$\Rightarrow \boxed{P_1 = \frac{\rho_m g A h^2}{(V_1 - Ah)}}$$

Lecture - 21

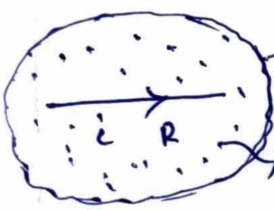
Pirani Vacuum Gauge → Low pressure Measuring Device

① Let, any wire



flow i → It will have some resistance.

⇒ Temp ↑



→ created environment

→ More no. of molecules. (High press.)

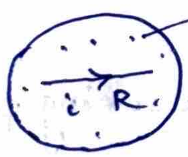
Current 'i' flows → Resistance ↑

⇒ Temp ↑

Heat dissipation will be more since more no. of molecules are present.

↙

⇒ wire will be less hot



Less molecules. (Low press.)

'i' flow → R↑ ⇒ T↑

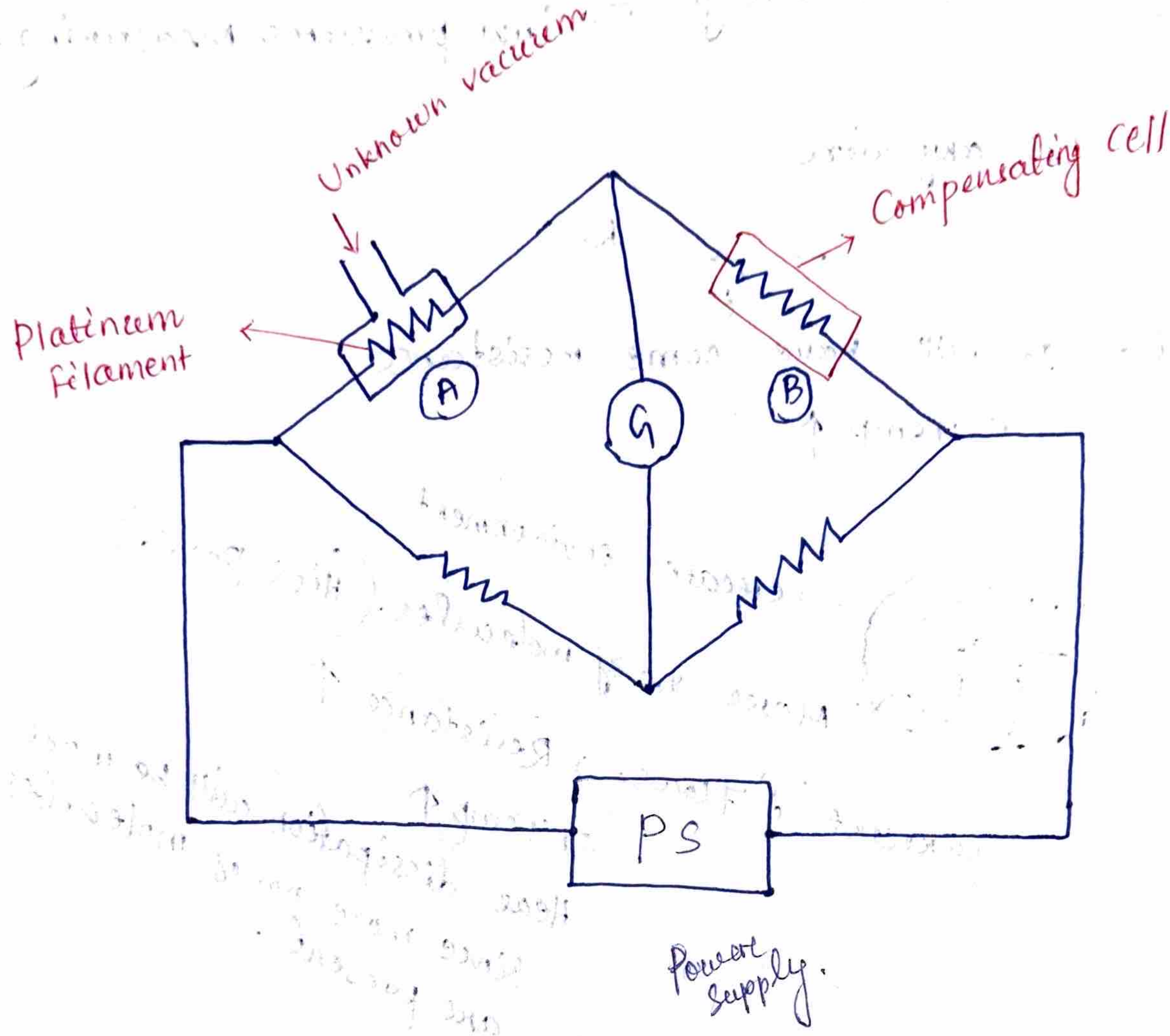
Heat dissipation will be less since less no. of molecules are present

⇒ Wire will be more hot.

⇒ High press, Temp (Resistance)

< Low press, Temp (Resistance)

If we can measure the resistance, the value of pressure can be obtained.



Necessity of compensating cell

↳ we are correlating temp with resistance

↓

then measuring pressure

In this case, Environmental factors may affect (Environmental temp.) the original measurement.

↳ Temp will have effect on A

So, same material has been installed at B

⇒ Same effect will be on A & B

Then we can cancel out the effect of (B) from (A).

↗

To cancel the atmospheric effect.

✓ Power supply is given

✓ (A) → Filament will be heated up

↓

Gas molecules in the surrounding, Temp. ↑ or ↓

↓

The Reading at the Galvanometer will change.

Since, the resistance will change with the change in temperature.

↓

Can be converted to 'pressure' form

↓ How

'i' flows

R_1

T_1

'i' flows

R_2

T_2

If, $T_1 > T_2$

Heat dissipation more

↓

More molecule

↓

High press.

Heat dissipation less

↓

Less molecule

↓

Low press.

Temperature Measuring Instruments

Thermal Expansion Methods	Thermoelectric Sensors	Electrical Resistance Sensors	Radiation Methods
① Solid expansion ↳ Bimetallic Thermometer ② Liquid Expansion ↳ Liquid-in-glass Thermometer, Pressure Thermometer ③ Gas Expansion ↳ Gas thermometer, Vapor pressure Thermometer	① Thermocouples	① Resistance Temperature Detectors (RTDs), ② Thermistors	① Total Radiation Pyrometer ② Optical pyrometer

Thermoelectric Sensors, Thermocouples

✓ Thermocouple is a thermoelectric transducer used for temperature measurements. It's an active transducer that converts the change in temperature (thermal energy) directly into electrical energy.

✓ Working principle

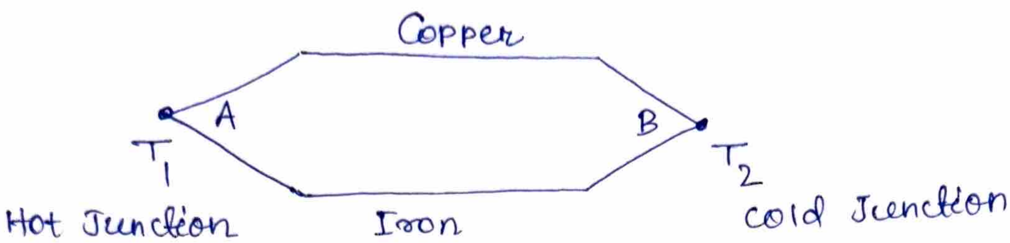
↓ Seebeck Effect

↓ Peltier Effect

↓ Thomson Effect.

✓ Seebeck Effect

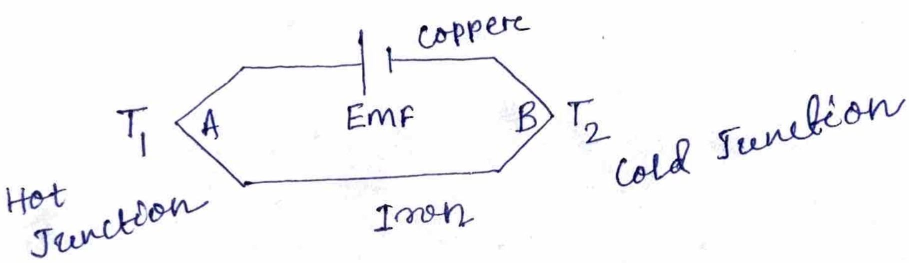
When two different metals are joined together at two junctions, an emf is generated at the two junctions. The amount of Emf generated is different for different combination of metals.



$T_1 - T_2 = \Delta T \longrightarrow$ Will generate EMF

Peltier Effect

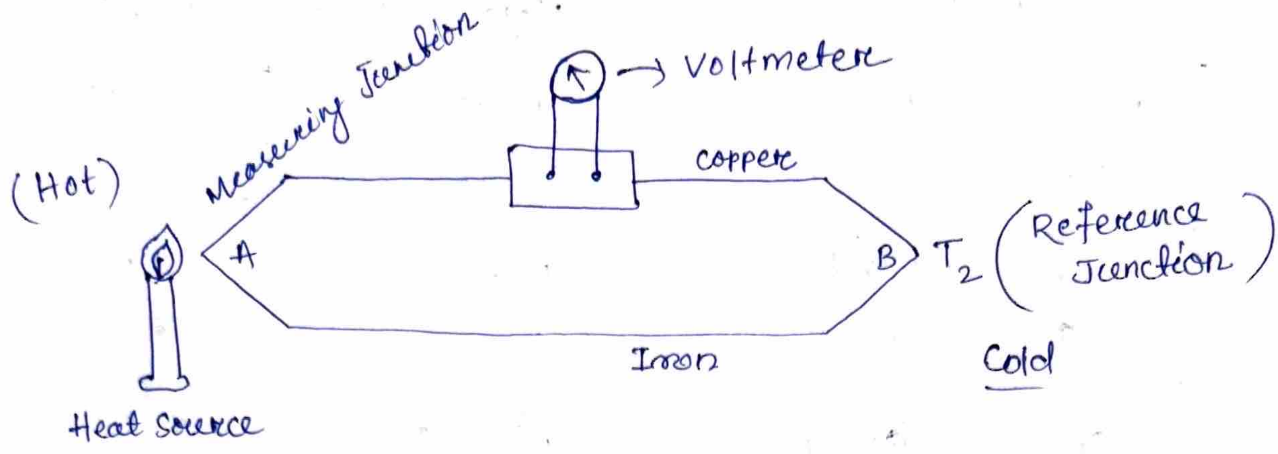
When two dissimilar metals are joined togethere to form two junctions and emf is applied within the circuit, it causes temperature difference been the junctions of the two materials.



$\Delta T = T_1 - T_2$

Thomson Effect

when two dissimilar metals are joined togethere to form two junctions, the potential exists within the ~~circuit~~ circuit due to temp. gradient along the entire length of the conductor within the circuit.



✓ For practical Applications, Reference junction is kept at room temp.

✓ Heat source is applied at junction A, where the temperature has to be measured.

✓ (A) → T_1
(B) → T_2 〉 Temp. diff. will be generated
↓
⇒ EMF exist
↓
Measured by voltmeter

✓ There is a rel^n bet^n measured temp. and output voltage

$$\boxed{\Delta V = S\left(T_h - T_c\right)}$$

ΔV → voltage bet^n two dissimilar metal rods (junction)
↳ (A-B) → junction

S = Seebeck coeff. (V/K)

T_h → Temp. of hot junction

T_c → Temp. of cold junction

Types	Positive Lead	Negative Lead	Temp. Range
R	Platinum - Rhodium 87% - 13%	Platinum	0 - 1500°C
S	Platinum - Rhodium 90% - 10%	Platinum	0 - 1500°C
K	Chromel (90% Ni, 10% Cr)	Alumel	-200°C - 1300°C
T	Copper	Constantan	-200°C - 350°C
J	Iron	Constantan	-150°C - 750°C

Desirable properties of Thermocouples for industrial use

1. should produce relatively large thermal EMF.
   - EMF of most thermocouple is about 10 to 50 mV.
2. Precision of calibration & low drift.
3. should be resistant to corrosion, oxidation and contamination.
   Ensure long life
4. Linear relation of EMF with temperature.
   - Linear scale as well as easy reference junction compensation.

Electrical Resistance Sensors (Temp. Measuring Instruments)

- Resistance Temp. Detectors (RTD)
- Thermistors.
- The electrical resistance of many materials changes with temperature in a reproducible manner. The change in resistance can be measured by a bridge circuit and thus can be related to temperature.

- Conductors (Metals) $\longrightarrow$ RTD
- Semiconductors $\longrightarrow$ Thermistor

] Variation of electrical resistance with change in temp.

- RTD $\rightarrow$ Tungsten, Platinum, Copper, Nickel.

Resistance Temperature Detectors (RTDs)

The resistance of a metallic resistance element changes with temperature in a specific manner. Therefore, the temperature can be measured by measuring the change in resistance of the element. The resistance measurement can be performed by a bridge circuit.

$$R = R_0\left(1 + \alpha_1 T + \alpha_2 T^2 + \cdots + \alpha_n T^n\right)$$

R = Resistance at T, (Ω)

R_0 = Resistance at ref T_0, (Ω)

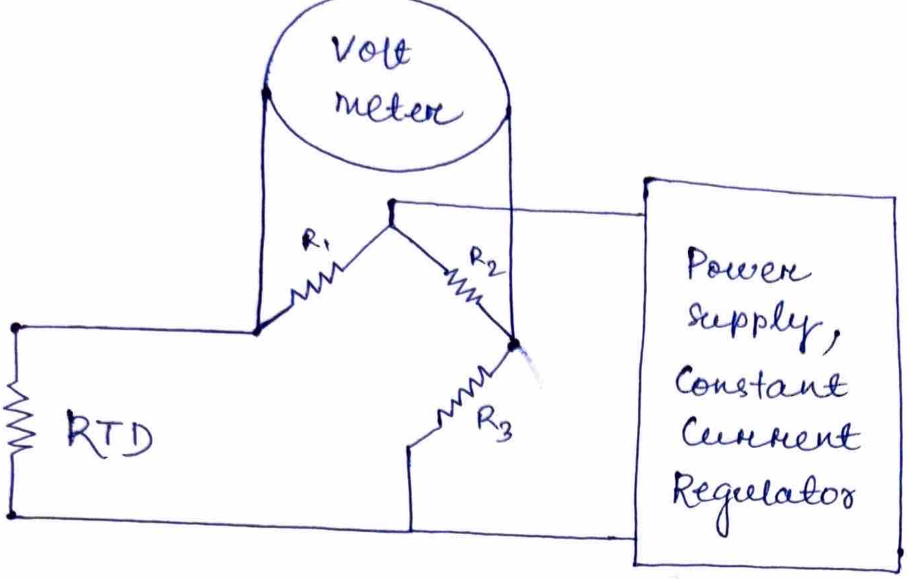
α = experimentally determined constants

In a narrow range of operation,

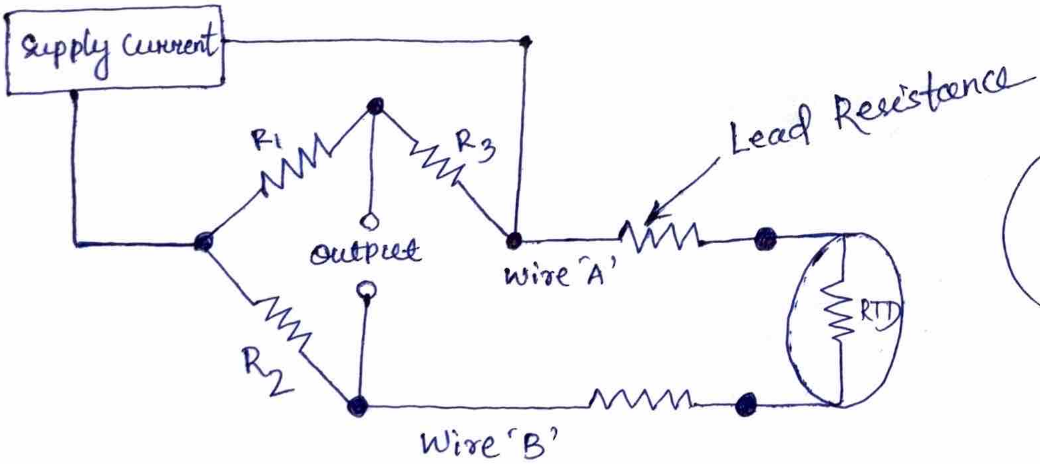
$$R = R_0(1+\alpha T) \quad \text{or} \quad R = R_0(1+\alpha T + \beta T^2)$$

$\alpha \rightarrow$ Temp. coeff. of resistance, $\Omega/\Omega\,^\circ C$.

α is +ve for metallic resistance.



By measuring the resistance of the RTD element one can determine the process temperature if the change in total resistance measured is affected only by the process temperature. But in actual practice, the RTD element is connected by wires to the readout instrument (Volt meter) and the resistance of the leads introduces error in measurement.



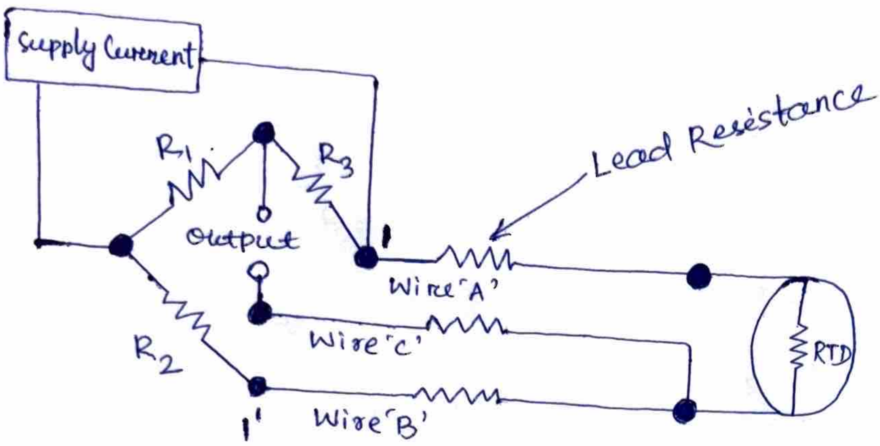
(Two wire connection)

The length of the wire from the RTD to the wheatstone bridge circuit can be significant.

Since, the device has relatively low resistance, the lead resistance of RTD assembly can add a significant error to the measured resistance.

RTD : Lead wire Error → Compensation

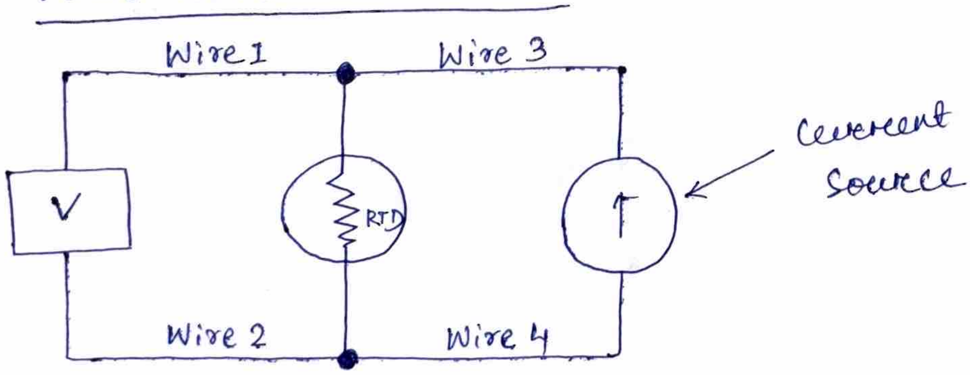
↳ Three wire Connection



Two leads (1 & 1') to the sensor are on the adjoining arms. (Direct contact to sensor)

If wire A and B are of equal length (have same resistance), their impedance effect will cancel each other. The third wire, C acts as a sense lead and also has same resistance as A, B.

Four wire Connection



The four wire technique does not use the Wheatstone bridge method of measuring the resistance of an RTD. Four wire technique uses a current source along with a remotely located Digital Volt Meter (DVM). The output voltage read by the DVM is directly proportional to RTD resistance.

The three bridge resistors are replaced by one RTD. The digital voltmeter measures only the voltage dropped across the RTD and is insensitive to the length of the lead wires.

Construction of RTD

Two common methods

1) Winding of platinum wire on glass or ceramic bobbin followed by sealing with molten glass
2) Depositing a platinum or metal-glass slurry on a ceramic substrate. The film is then etched and sealed to form the resistance element. This is called thin film sensor.

Selection of RTD Materials

- ✓ High temp. coeff. – for larger sensitivity
- ✓ High resistivity of the material – for larger output
- ✓ Linearity of resistance – temp. relationship
  ↳ Convenient calibration
- ✓ Stability of electrical characteristics – for repeatability
- ✓ Good mechanical strength.
- ✓ Resistance to contamination.

Temperature Measuring Instruments

Lecture-25

Radiation Methods (Non-Contacting type)

Basic Principle → Measurement of temperature by measuring the energy radiated by a hot body.

It has the following advantages

1. No direct contact is necessary
2. The body may be stationary or moving
3. Temp. variation over the surface can be measured
4. High upper limit - practically no upper limit.

Radiation principle

- Thermal radiation is an electromagnetic radⁿ emitted by a hot body as a result of its temperature.
- This radiation is different from other electromagnetic radiations such as radio waves and X-rays, which don't propagate as a result of temperature.
- Thermal radiation lies in the wavelength region: 0.1 micron to 100 micron. Radiation transfer of heat takes place in the ultraviolet, visible and infrared regions.

Radiation Principle: Black Body

- A black body is an idealized body that absorbs all radiation falling on it without transmitting or reflecting any.
- A black body radiates energy at all spectral wavelengths at a maximum rate corresponding to its temperature.
- A blackbody is an ideal absorber and ideal emitter. (Emissivity = 1)
- Kirchoff's Law:

Any body in thermal equilibrium emits as much heat radiation as it receives at any given wavelength & temperature.

Stefan Boltzmann Law

The thermal radiation emitted by a blackbody is given by

$$E_b = \sigma T^4$$

σ = Stefan-Boltzmann Constant $= 5.669 \times 10^{-8}\ W/m^2K^4$

E_b = Emissive Power (W/m^2)

T = Absolute temp(K)

Betn two black-bodies with temperature T_1 & T_2:

$$E_b = \sigma\left(T_1^4 - T_2^4\right)$$

Planck's Law

The emissive power of a black body varies with wavelength. The emissive power of a blackbody at a given wavelength is given by Planck's law.

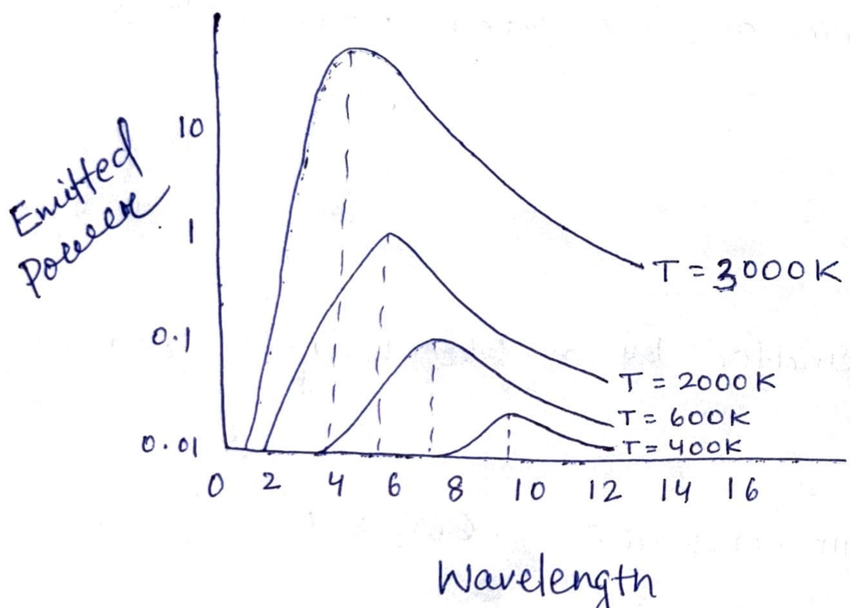
$$W_\lambda = \frac{C_1}{\lambda^5\left[e^{C_2/(\lambda T)} - 1\right]}$$ W_λ = radiant intensity, $W/(cm^2 \cdot \mu m)$

$C_1 = 37413$, $W \cdot \mu m^4 / cm^2$

$C_2 = 14388$, $\mu m \cdot K$

λ = Wavelength of radn, μm

T = Absolute temp. of blackbody, K



$$\boxed{\begin{array}{l} T\uparrow\ \lambda\downarrow\ EP\uparrow \\ T\downarrow\ \lambda\uparrow\ EP\downarrow \end{array}}$$

- Intensity of radn varies appreciably with wavelength
- Point of maxm radn intensity shifts to the shorter wavelengths as the temp. increases.
- Point of maxm intensity is given by Wein's displacement law : $\lambda_m T \approx 2898\ \mu m K$

λ_m is in micron

T is in Kelvin.

Radiation Temp- Measuring Devices : Two principles

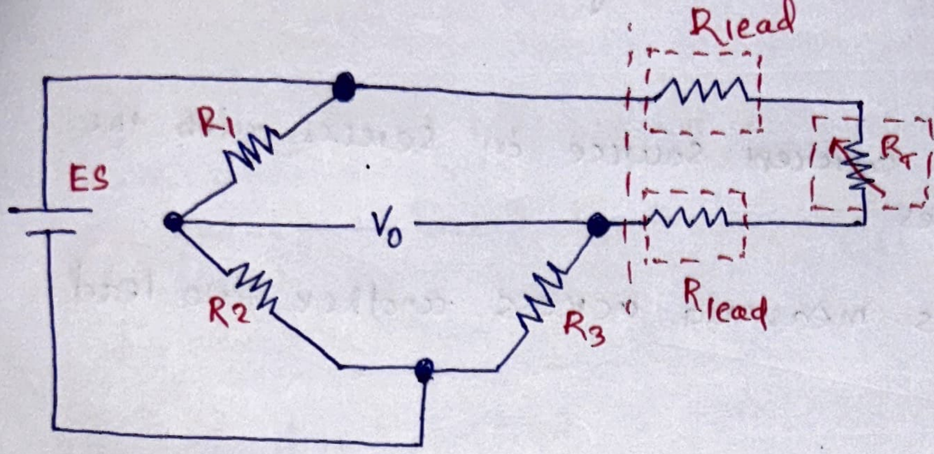
(1) Measurement of total energy of radⁿ from a heated body and relate temp with it.

Total radⁿ pyrometer works on this principle

(2) Measurement of the spectral radiant intensity of the radiated energy from a heated body at a given wavelength.

Optical pyrometer works on this principle and brightness comparison betⁿ two objects is made to measure unknown temp.

2 wire RTD



- Lead resistance gets added in the resistance of the RTD and measurement error increases.
- Bridge balance condⁿ:

$$\frac{R_1}{R_2} = \frac{R_x}{R_3} \Rightarrow R_x = \left(\frac{R_1}{R_2}\right) R_3$$

$$R_x = R_T + (2 \times R_{lead}).$$

- Lead wire resistance introduce error.

3-wire RTD

wheatstone bridge eqⁿ,

$$\frac{R_1}{R_2} = \frac{R_T + R_{lead}}{R_3 + R_{lead}}$$

→ Both numerator & denominator has Rlead
↳ So, the ratio won't get affected.

Both lead wires should have equal length to avoid lead resistance effect in the circuit.

Bridge in balance condⁿ,

$$R_T + R_{lead} = R_3 + R_{lead} \Rightarrow R_T = R_3$$

4 wire RTD

- Measures the temp. based on Voltage insted of Resistance
- 4-wire RTD

↓

Has a constant current source in series with the two lead wires

↓

The voltage drop is measured across another two lead wire

↓

Ohms law, $V = IR$

Current, I (const) ⟶ since const. current source.

⇒ Voltage change will be a f^n of change in resistance, which (resistance) depends on the measured temp.

RTD resistance will change with change in temp, and it will change the voltage drop across two lead resistors.

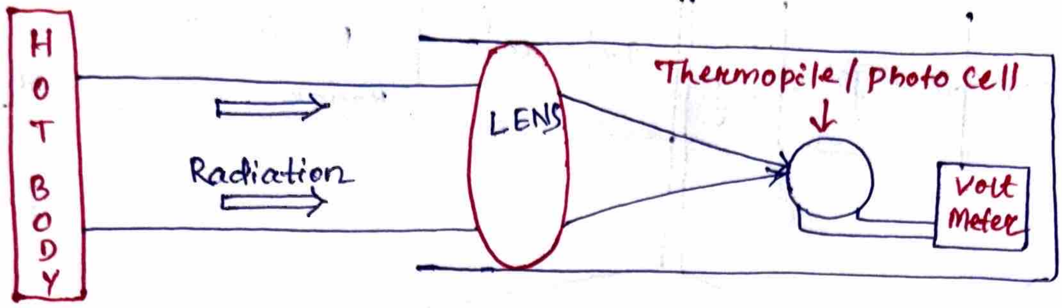
Hence, temp is measured based on voltage drop across two lead resistors

PI

Lecture - 27, 28

1

Total Radiation Pyrometer



1. Hot body ⟶ Temp. needs to be found out.
2. Radiation from hot body ⟶ Focused by the lense on the thermopile/photo cell/ thermocouple

temp. measuring device

↓

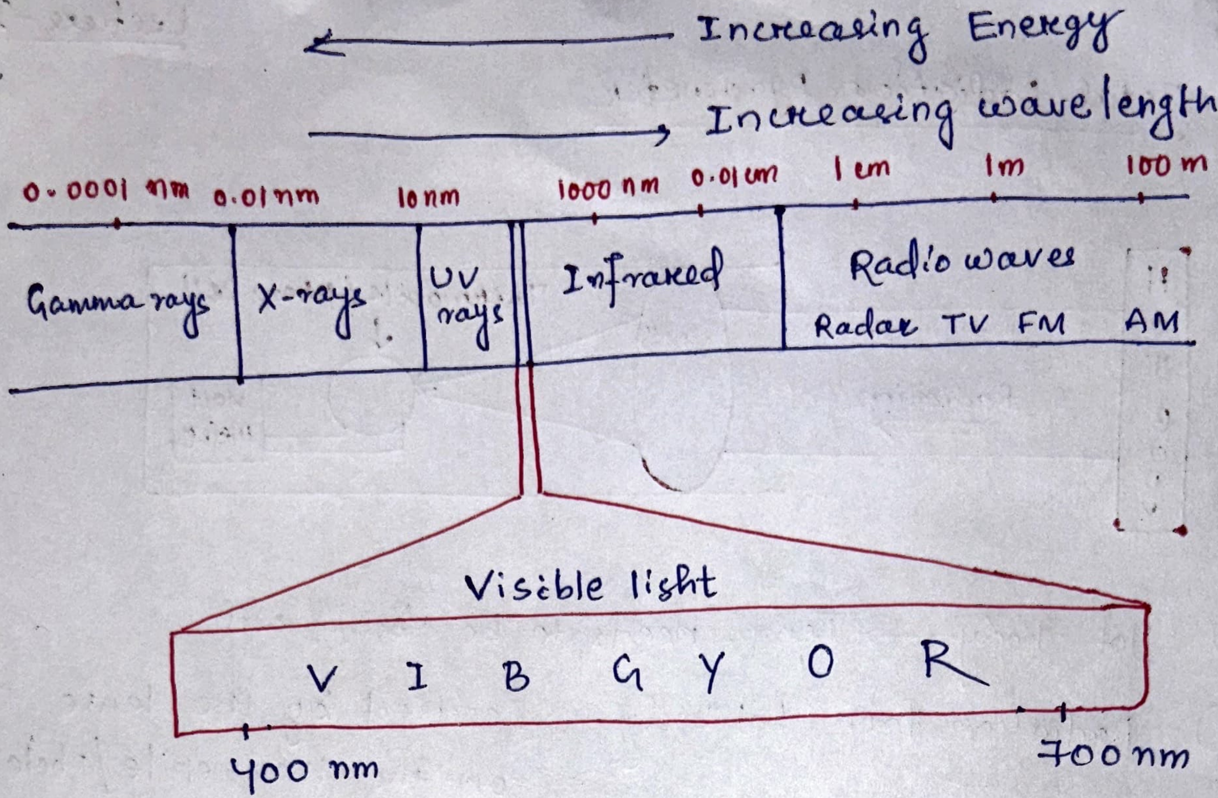
EMF will be produced corresponding to the temp.

↓

EMF can be calculated by temp. units.

Optical pyrometer

1. Hot body → Temp. has to be measured
2. Filament which can be heated to a particular temp. by sending different amount of current to the filament.
3. Radⁿ from the hot body is focused on the filament through the lens.
4. So, the image of the hot body is superimposed on this filament and we can see the filament through an eye piece.



- Visible region → 0.38 μm – 0.78 μm (380 nm to 780 nm)

Thermal radⁿ happens in visible region as well as UV and infrared region.

- visible region → higher wavelength → red color

- The optical pyrometer is designed to measure temperatures where the maximum radⁿ emission is in the red part of the visible spectrum (0.65 μm). This means that the object glows a certain shade of red according to its temp.

- It requires a visual brightness match by a human operator. Thus the ~~i~~ instrument can measure temp. only above 600°C.

Send particular amount of current to the filament

↓

Depending on that the filament will assume some temp.

↓

Corresponding to this temperature, the brightness of the filament will be defined.

↓

We view the filament through the eye piece and through a red filter.

↓

Red filter improves the accuracy in the measurement because the red filter will pass a narrow wavelength light which corresponds to 0.65 micrometer.

↓

Now, when we view the filament through the eye piece, 3 things can happen

(i) The filament may look dark compared to the hot body.

↳ Brightness of the hot body may be much higher than the brightness of the filament

↓

In that case, you will see a dark filament on a white background.

(ii) If filament is too bright compared to hot body,

↓

A white filament on a dark background.

(iii) Brightness of filament = Brighness of hot body

↳ The filament can't be identified

↳ see all white.

So, the point of measurement –

① Manipulate or change the current which is being Sent through the filament.

↳ It means, we are heating up the filament at different temp. until the brightness of the filament matches with the brightness of the hot body

↓

Under this circumstance, you know that the temp. of the filament is the measure of the temp. of the hot body.

↓

The temp. of the hot body can be measured in terms of current that you are flowing through the filament

Filament → heated tungsten within optical system

↳ The filament is heated by sending current through it and the image of the hot body is superimposed on it by the objective lens

↳ The current in the filament is increased until its color is the same as that of the hot body. Under these conditions the filament apparently disappears when viewed against the background of the hot body

↳ Temp. measurement is thus obtained in terms of the current flowing in the filament

As the brightness of different materials at any particular temperature varies according to the emissivity of the material, the calibration (of the pyrometer) must be adjusted according to the emissivity of the target.

An optical filter is used that passes a narrow band of frequencies of wavelength around 0.65 μm corresponding to the red part of the visible spectrum which improves accuracy.

Considered visible spectrum so that our eye can see.

other spectrum, we can't see and there will be error in measurement.

Lecture - 17

Photoelectric Transducer

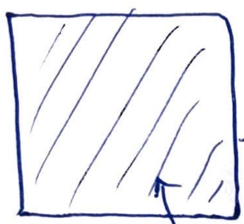
① Photoelectric effect → Converts light energy into electrical energy.

Photo → light energy

electric → electrical energy

② Material → semiconductors.

③



→ photosensitive element

Beam of light fall on the element

↓

eject electrons.

④ Photoelectric Transducer

Photoemissive Transducer	Photoconductive Transducer	Photovoltaic Transducer
✓ Photoemissive cell or Phototubes are used. ✓ Anode → +ve terminal batt. ✓ Cathode → -ve " ". ✓ Initially no light ↳ No Deflection. ✓ Light fall on cathode → Emits electrons → captured by Anode ✓ Current flow ↳ Deflection.	Light falls on the semiconductor material ↳ conductivity increases ↳ Deflection. (Relay control circuits)	Input → light energy output → electrical E. Solar cell ↳ sense the light energy. Normal metal → Cu → can't convert LE → EE