Unit 2 : Transducers

- Definition
- Types of transducer
- Classification of transducer
- resistive, inductive, capacitive, piezoelectric, photoelectric transducers
- Temperature transducers
- pressure transducers
- displacement transducers
- strain guages
- optical transducers
- detectors
- biomedical ~~transducers~~ electrode & transducers.

Questions -

1. Draw and explain pressure and displacement transducers. A19
2. Define a transducer. Give classification of transducer and explain each of them. A-19 A-18
3. Draw & explain resistive and inductive transducers. A-19 N-18
4. with well labelled diagrams, explain temp. transducers. A-19
5. Describe resistive and ~~and~~ capacitive transducers with neat diagrams. A18
6. Explain inductive and capacitive transducer. A18

7. ~~Explain~~ Draw and explain piezoelectric and photoelectric transducers. A18

8. With well labelled diagrams explain temperature transducers. N-18

9. Draw and explain pressure and displacement transducers. N-18

10. Draw and explain in detail optical transducer. N-18

Transducers -

A device which converts one form of energy into another form of energy is called as transducer.

An electric heater and loud speakers are the simplest examples of transducer.

An electric heater converts electrical energy into heat energy while loudspeakers converts electrical energy into sound energy.

But, the definition of transducer in electrical instrumentation can be defined as a device which converts a physical quantity into an electrical signal.

- The input quantity for most instrumentation system is a non-electrical quantity. In order to use electrical methods and techniques for measurement, manipulation or control, the nonelectrical quantity is converted into electrical quantity.

The transducers may be classified according to their application, method of energy conversion, nature of output signal and so on.

Transducers

- on the basis of principle used
  - Resistive
  - capacitive
  - inductive
- active / passive
  - based on power type
- primary / secondary
  - based on physical phenomenon
- analog / digital
  - based upon type of output
- transducers / inverse transducers
  - based on transduction phenomenon.

Advantages of electrical transducers -

There are a no. of transducers which transform a variety of physical quantities and phenomenon into electrical signals.

The advantages of converting physical quantities into electrical quantities are -

(1) electrical amplification and attenuation can be done easily

(2) The mass - inertia effects are minimised.

(3) The effects of friction are minimised.

(4) The electrical or electronic systems can be controlled with a very small power.

(5) The electrical output can be easily used, transmitted and processed for the purpose of measurement.

Classification -

(1) The transducers can be classified on the basis of principle of transduction as resistive, inductive and capacitive depending upon how they convert input quantity into resistance, inductance and capitance respectively. They can be classified as piezoelectric, thermoelectric, magetoresistive, electrokinetic and optical.

② Analog and digital transducer -

- Electrical transducers can also be classified on the basis of output.

- The output may be continuous function of time or may be discrete in steps.

- Analog transducer convert the input physical phenomenon or quantity into analogous output which is continuous function of time.

  Ex. Thermocouple or thermister etc.

- Digital transducers converts input physical phenomenon into an electrical output which is in the form of pulses.

③ Primary and secondary transducers -

- Primary transducers are detectors which sense a physical phenomenon or quantity.

  Example of primary transducer is a thermocouple which senses the radiant energy and directly converts it into analogues electrical output which is a voltage.

- secondary transducers converts the analogous output into an electrical signal.

input signal → primary transducer → intermediate stage → secondary transducer → output signal

④ Active and passive transducers –

- The transducers can be active i.e. self generating type or passive that is externally powered.
- Active transducers develop their own voltage or current. The energy required for production of an output signal is achieved from the physical phenomenon being measured.
- piezoelectric transducers are active transducers
- Passive transducer derive the power required for energy conversion from an external power source.
- Potentiometers are the examples of passive transducers.

⑤ Transducer and inverse transducers –

Transducer – A transducer can be broadly defined as a device which converts a non-electrical quantity into an electrical quantity.

Inverse transducer – A inverse transducer is defined as a device which converts an electrical quantity into a non-electrical quantity.

A piezoelectric crystal acts as an inverse transducer because when a voltage is applied accross its surfaces, it changes its dimensions causing a mechanical displacement.

Resistive Transducers

A transducer which works on the concept of change in resistance due to any phenomenon is known as resistive transducer.

We know that, the resistance of a transducer is given by,

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

where ρ is the resistivity in Ωm

l length of the conductor in meter

A area of the conductor

Thus, ~~to form~~ Electrical resistive transducer works on the principle of varying any of the above mentioned variables. There are several methods by which resistance can be changed by a physical phenomenon.

The translational and rotational potentiometers which work on the basis of change in value of resistance with change in length of the conductor can be used for measurement of translational or rotational displacements.

Strain guages works on the principle of that the resistance of a conductor or semiconductor changes when strained.

Potentiometric resistive type transducer -

A wire wound on potentiometers, is used as a transducer for converting mechanical displacements into corresponding electrical output. such transducers are suitable for -
① linear displacement ② angular displacement
③ combination of linear and angular displacement.

Linear displacement – (translational resistive transducer).
Linear displacement caused by the linear motion of the object moves arm attached to the slider of linear potentiometers as shown. which causes the resistance change. This in turn produces voltage change, which gives the indication of amount and direction of displacement, which is caused by increase or decrease of resistance.

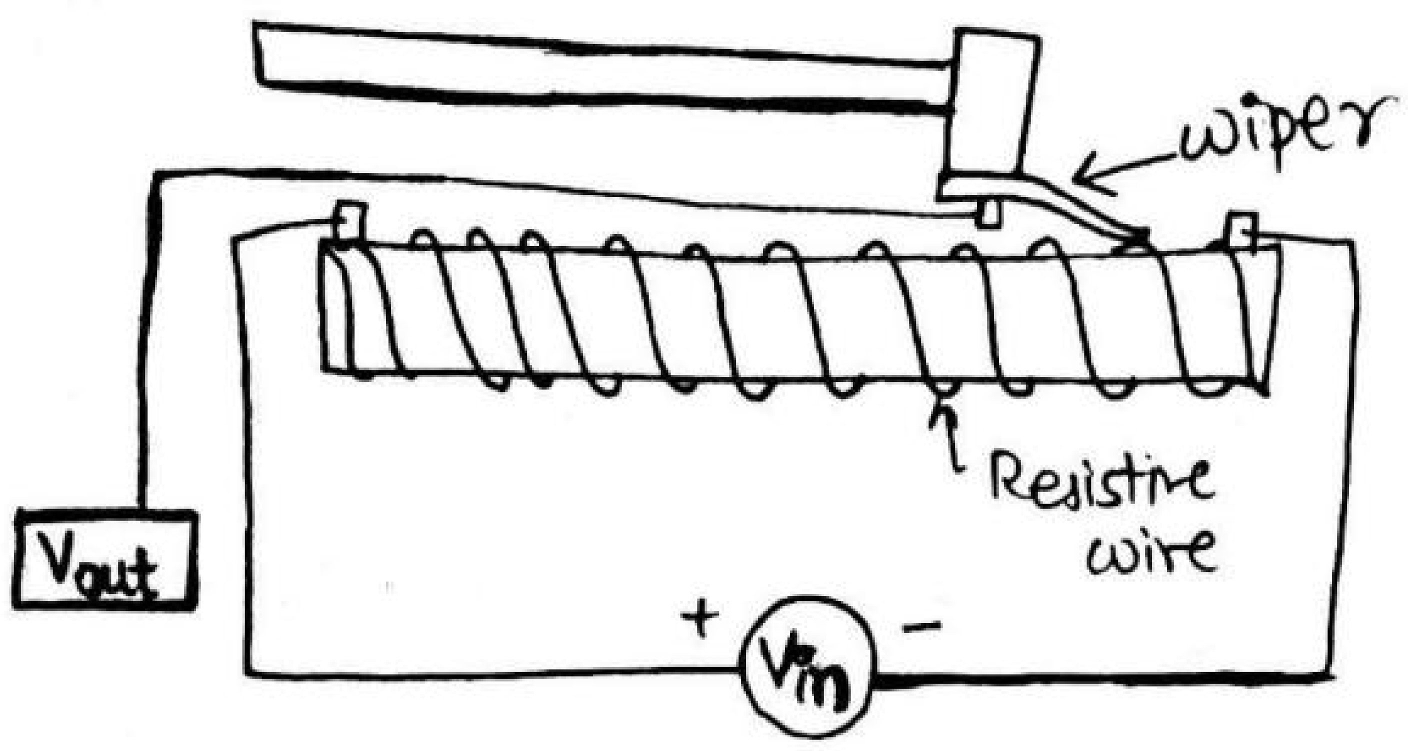
If the distribution of resistance with respect to translational movement is linear, the resistance per unit length is R_p/l_t.

The output voltage under ideal condition will be,

$$V_{out} = \left(\frac{\text{resistance at output terminals}}{\text{resistance at input terminals}}\right) \times V_{in}$$

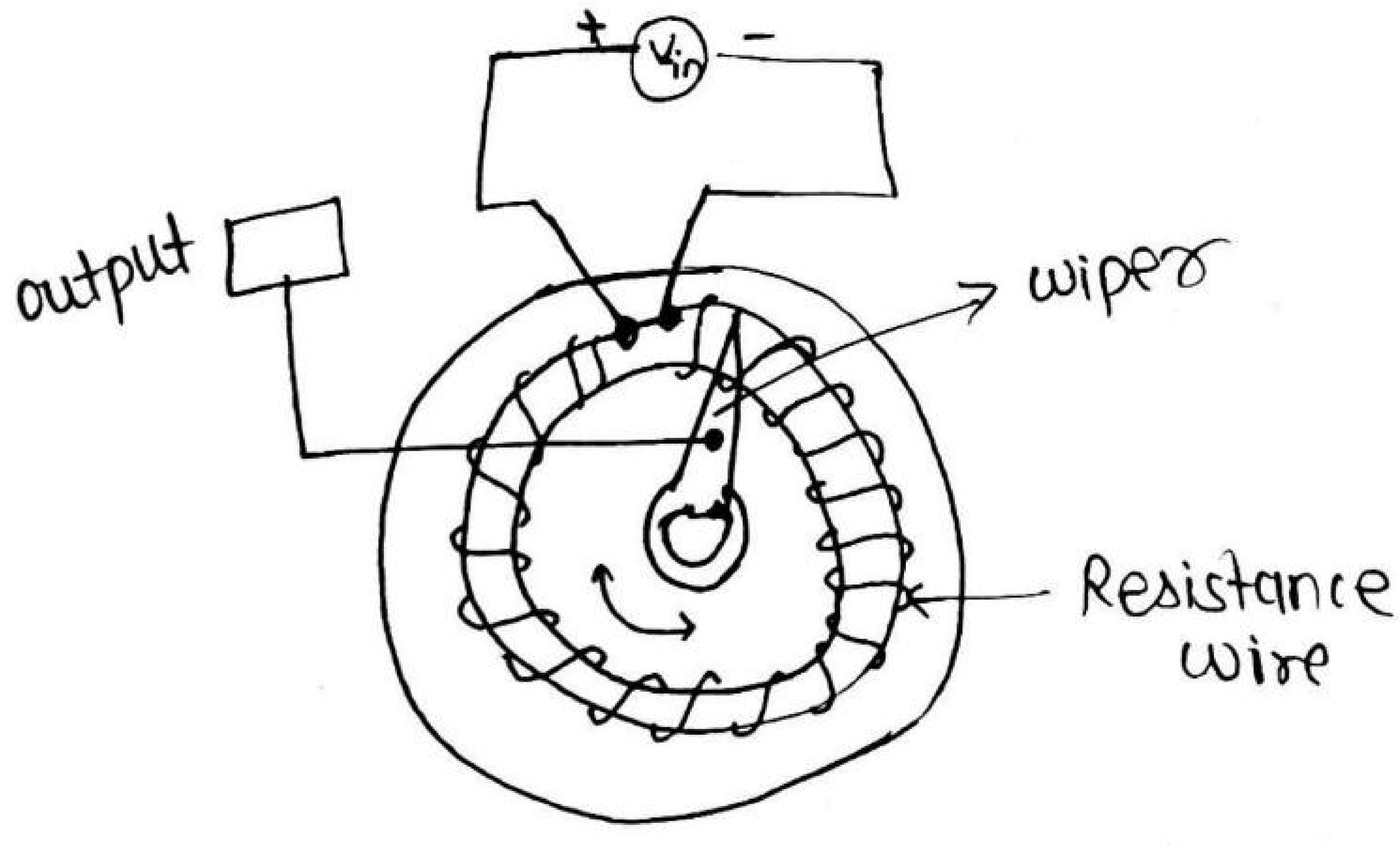
$$= \left(\frac{\frac{R_p \cdot l_i}{l_t}}{R_p}\right) \times V_{in}$$

R_p - total resistance of potentiometer in ohms.
l_t - total length of translational potentiometer in metre.
l_i - displacement of wiper from its zero position (in metre).



Angular displacement (rotational resistive transducer).

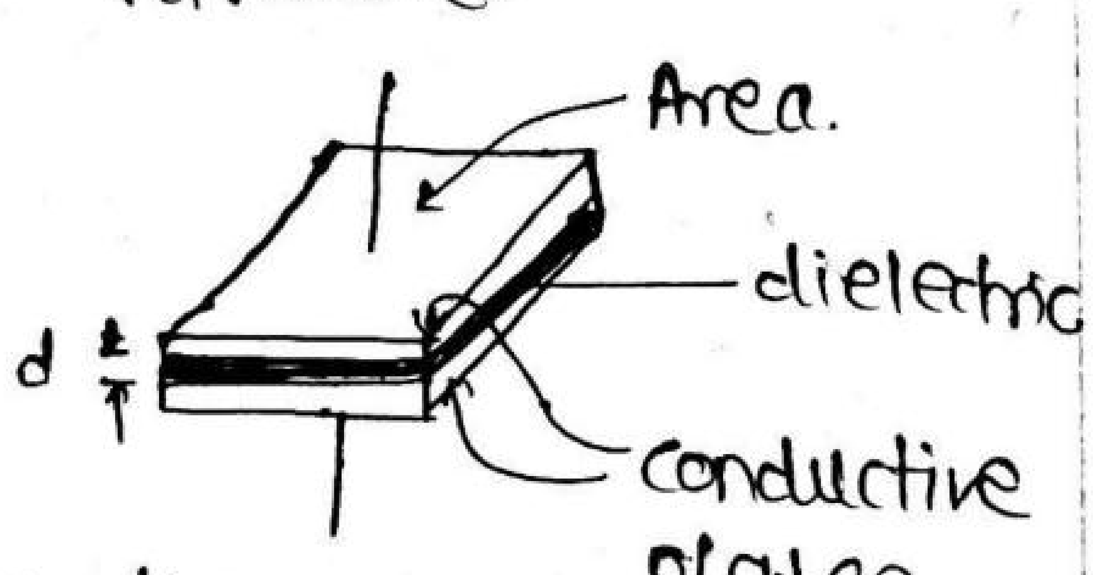
Angular displacement caused by rotary motion of the object, which is fed to the central shaft of rotary motion potentiometer. The wiper contact attached to the radial arm of the central shaft produces the output in the form of proportional potential change.



Capacitive Transducers

The capacitive transducer is a capacitor with variable capacitance. The capacitive transducer comprises of two parallel metal plates that are separated by material such as air which is dielectric material. In the parallel plate capacitor the distance between is fixed but in variable capacitive transducers the distance between the two plates is variable.

The capacitance is given by



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

where $\varepsilon = \varepsilon_r \varepsilon_0$ = permitivity of the medium

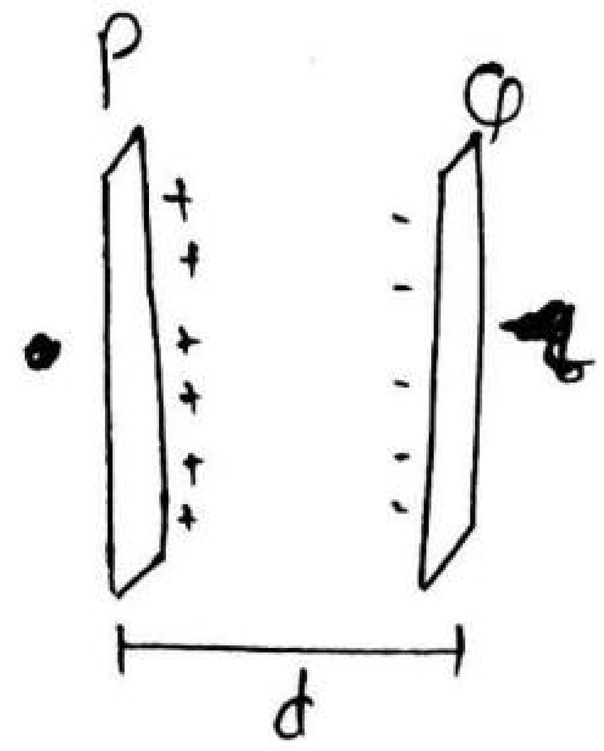
A = overlapping area of plate

d = distance between two plates.

The capacitive transducer works on the principle of change of capacitance which may be caused by -

1. change in overlapping area A
2. change in the distance d between the plates.
3. change in dielectric constant.

In the instruments using capacitive transducer the value of capacitance changes due to change in value of the input quantity that is to be measured. The capacitive transducer is used extensively for the measurement of displacement, pressure etc.



area of plates $= A$

distance betn two parallel plates $= d$

surface charge density $= \sigma = q/A$

$\therefore q = \sigma A$. — (1)

Electric field betn two plates

ie electric field at any point

$$E = \sigma/\varepsilon_0$$

$$V = -\int_d^0 E.dr = -\frac{\sigma}{\varepsilon_0}.\int dr = -\frac{\sigma}{\varepsilon_0}[r]_d^0 = \frac{\sigma d}{\varepsilon_0}.$$

capacitance $C = q/V = \frac{q}{\sigma d/\varepsilon_0} = \frac{q\varepsilon_0}{\sigma d} = \frac{\varepsilon_0 \sigma A}{\sigma d}$

$$\boxed{C = \frac{A\varepsilon_0}{d}.}$$

$C = q/V$ $\quad$ $V = E.d$ = electric fied x distance

$= \frac{q}{E.d}.$ $\quad$ $E = \sigma/\varepsilon_0$ ← surface charge density, ← permitivity of medium.

$C = \frac{q}{\sigma d/\varepsilon_0}$

$= \frac{q\varepsilon_0}{\sigma d} = \frac{q\varepsilon}{\sigma d}.$ $\quad$ $\sigma = q/A$

$= \frac{q\varepsilon A}{qd}$

$$\boxed{C = \frac{\varepsilon A}{d}}$$

according to Gauss law

$$\int E.dA = q/\varepsilon_0$$

$E.A = q/\varepsilon_0$ $\quad$ $E = \frac{q}{\varepsilon_0 A}$

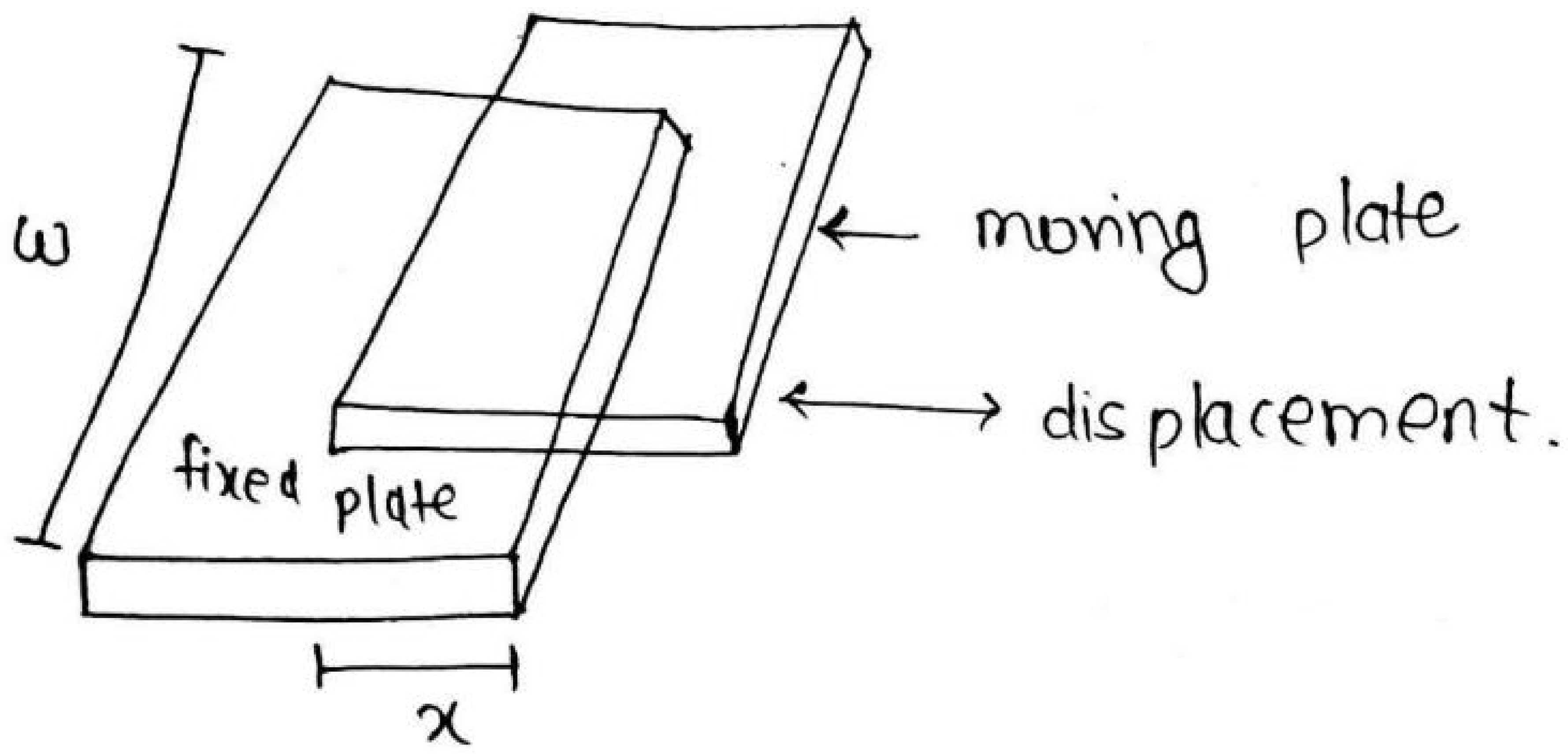
$C = q/V = \frac{q}{qd/\varepsilon_0 A} = \frac{\varepsilon_0 A}{d}$

$E = \frac{V}{d} \Rightarrow V = E.d = \frac{q}{\varepsilon_0 A}.d = \frac{qd}{\varepsilon_0 A}$

$C = A\varepsilon/d.$

(1) Transducers using change in area of plates-

from the equation $C = A\varepsilon/d$ it is found that the capacitance is directly proportional to the area A of the plates. Thus capacitance changes linearly with change in area of plates.



for parallel plate capacitor, the capacitance is

$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon x w}{d} \text{ farad.}$$

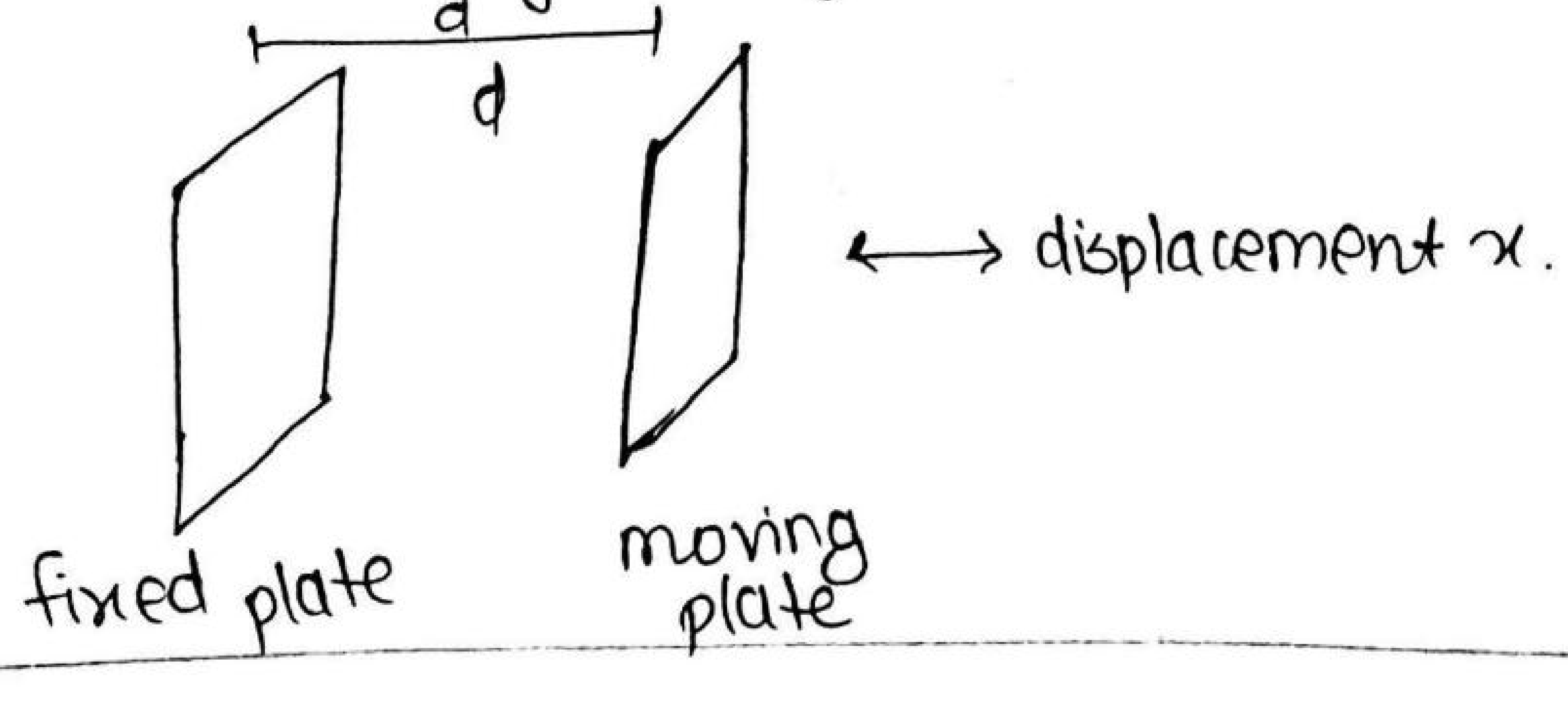
where x = length of overlapping part of plates

w = width of the overlapping part of plates.

sensitivity $S = \frac{dC}{dx} = \frac{d}{dx}\left(\frac{\varepsilon x w}{d}\right)$

$$\boxed{S = \frac{\varepsilon w}{d}}$$

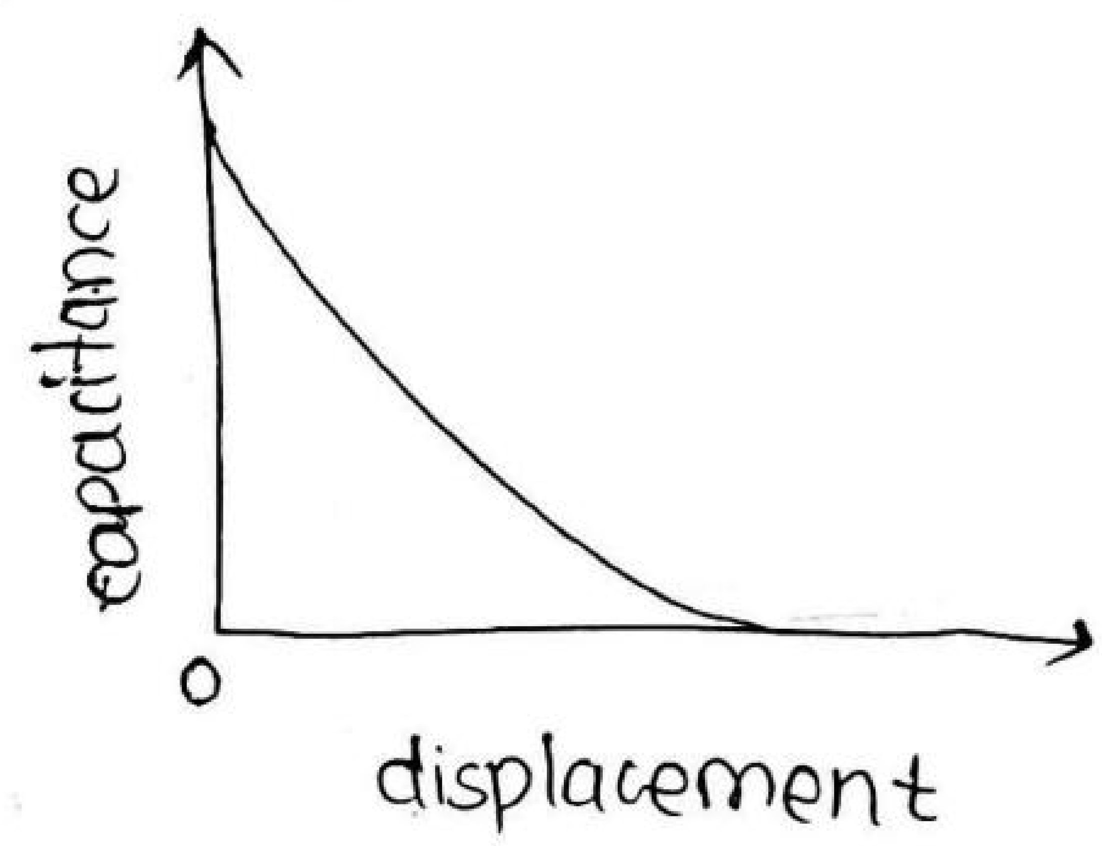
(2) Transducers using change in distance between plates.



above diagram shows the basic form of a capacitive transducer utilizing the effect of change of capacitance with change in distance between between the. two plates. one plate is fixed and displacement to be measured is applied to the other plate which is movable.

∵ the capacitance varies inversly as the distance d, the response of this transducer is not linear.

This type of transducers ~~are~~ is useful for measurement of extremly small displacements.



$$S = \frac{dC}{dx} = \frac{d}{dx}\left(\frac{A\varepsilon}{d}\right)$$

$$= \frac{d}{dx}\left(\frac{A\varepsilon}{x}\right) = \frac{-A\varepsilon}{x^2}$$

and thus it is clear that the ~~capacitance~~ sensitivity of transducer is not linear but varies over the range of transducer.

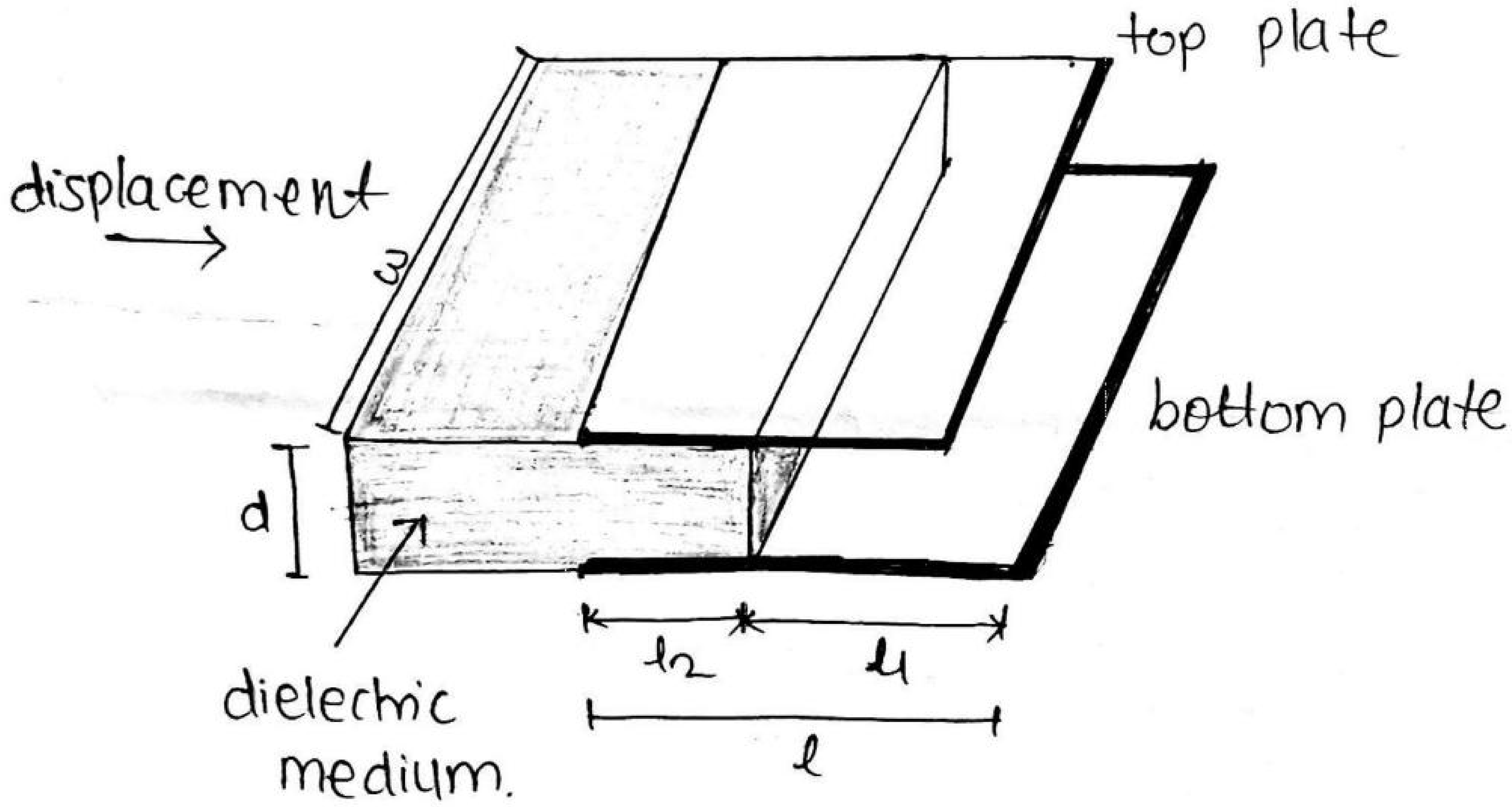
The variation of capacitance with variation of distance between plates (x) is hyperbolic and is approximately linear over a small range of displacement.

(3) variation of dielectric constant for measurement of displacement.

The third principle used in capacitive transducers is the variation of capacitance due to change in dielectric constant.

This type of transducers is used for measurement of linear displacement working on above principle.

It has a dielectric of relative permitivity ε_r.



initial capacitance of transducer

$$C = \frac{\varepsilon_0 w l_1}{d} + \varepsilon_0 \varepsilon_r \frac{w l_2}{d}$$

ε_0 = absolute

$\varepsilon = \varepsilon_0 \varepsilon_r$

$$= \frac{\varepsilon_0 w}{d}(l_1 + \varepsilon_r l_2)$$

Let, the dielectric is moved through a distance x in the x dir^n^. the capacitance change from C to $C + \Delta C$.

$$\therefore C+\Delta C = \frac{\varepsilon_0 w}{d}(l_1 - x) + \varepsilon_r \varepsilon_0 \frac{w}{d}(l_2 + x)$$

$$= \frac{\varepsilon_0 w}{d}\left[l_1 - x + \varepsilon_r (l_2 + x) \right]$$

$$= \frac{\varepsilon_0 w}{d}\left[(l_1 + \varepsilon_r l_2) + (\varepsilon_r - 1)x \right]$$

$$= \frac{\varepsilon_0 w}{d}(l_1 + \varepsilon_r l_2) + \frac{\varepsilon_0 w}{d}(\varepsilon_r - 1)x$$

$$= C + \frac{\varepsilon_0 w x}{d}(\varepsilon_r - 1)$$

$\therefore$ change in capacitance $\Delta C = \frac{\varepsilon_0 w x}{d}(\varepsilon_r - 1)$

Advantages of capacitive transducer -

- These are high sensitive
- capacitive transducers have small size and also require only a small force for their operation.

Disadvantages -

- The metallic part of capacitors need to be insulated from each other.
- change in moisture, grinding dust could cause change in dielectric and may introduce errors.

Inductive transducers -

In these type of transducers, the magnetic characteristics of an electric circuit change due to the motion of an object. These may be classified into two types.

① Self generating

In which a voltage signal is generated in the transducer, because of relative motion of conductor and a magnetic field. Electrodynamic, electromagnetic and eddy circuits types of transducers are self generating inductive transducers.

② Non-self generating or external power source type of transducer.

In which an external source is needed to energise a coil / coils, the inductance of which would change due to the motion of object.

The variable inductance transducers work, generally, upon one of the following three principles.

① change of self inductance

② change of mutual inductance

③ production of eddy currents.

① Transducers working on principle of change of self inductance.

The self inductance of a coil $L = \frac{N^2}{R}$.

N = no. of turns

R = Reluctance of magnetic circuit

The reluctance of magnetic circuit

$$R = \frac{l}{\mu A} \qquad \mu\text{-permeability.}$$

$$\therefore \; L = \frac{N^2}{l/\mu A} = \frac{N^2 \mu A}{l} = N^2 \mu G \; - ①$$

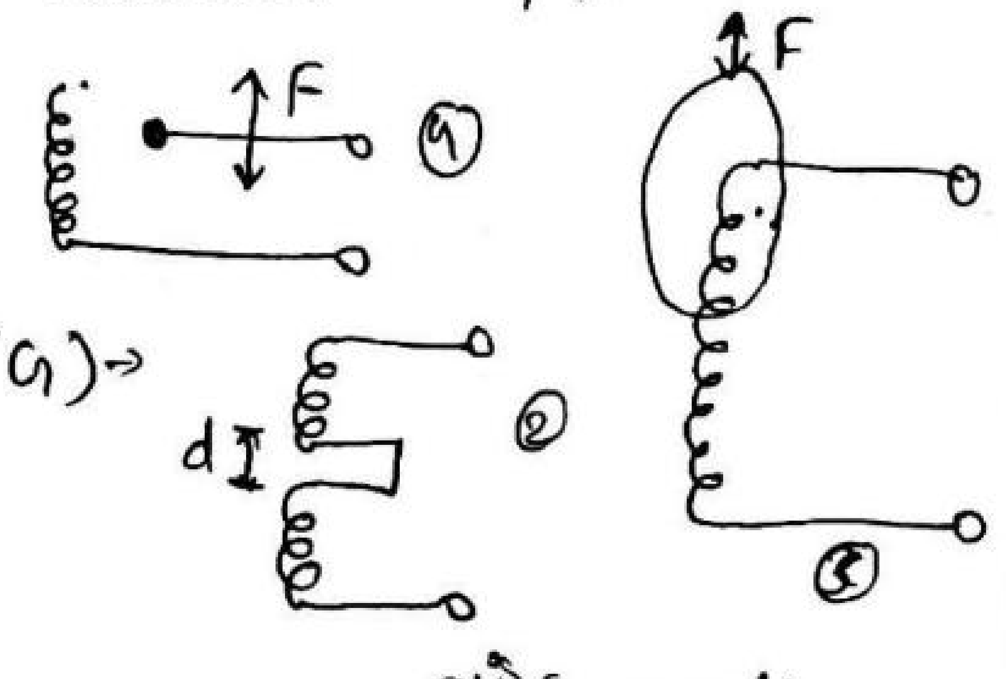
$G = \frac{A}{l}$ = geometric form factor = $\frac{\text{area of cross-section of coil}}{\text{length of coil.}}$

from the eqn ① it is clear that the inductance Variation in inductance may be caused by,

① change in no. of turns (N) →

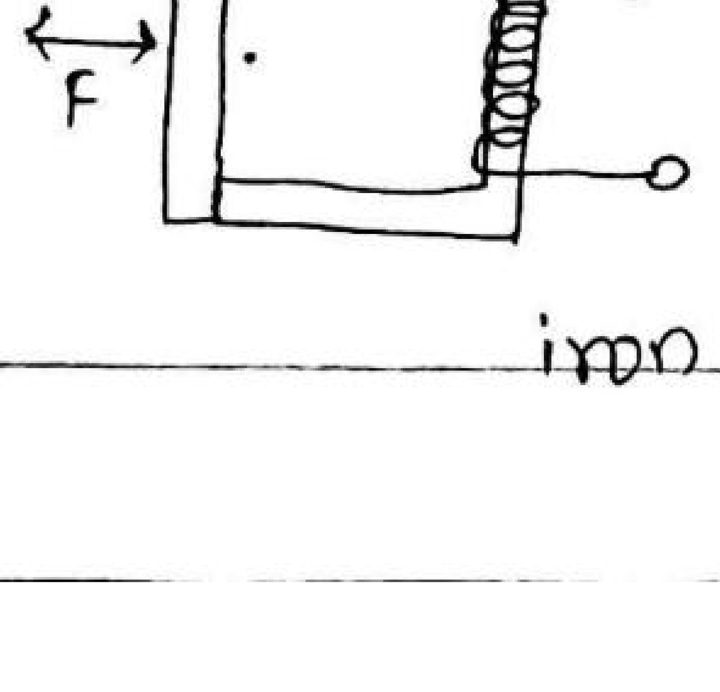
② change in geometric configuration (G) →

③ change in permeability. (μ)



air medium

Inductive transducers are mainly used for measurement of displacement. The displacement to be measured is arranged to cause variation of any of three variables in eqn ①. (ie N, G, μ).



iron

(2) Transducers working on principle of change of mutual inductance.

The inductive transducers working on the principle of variation of mutual inductance uses multiple coils.

The mutual inductance between two coils is

$$M = K\sqrt{L_1 L_2}.$$

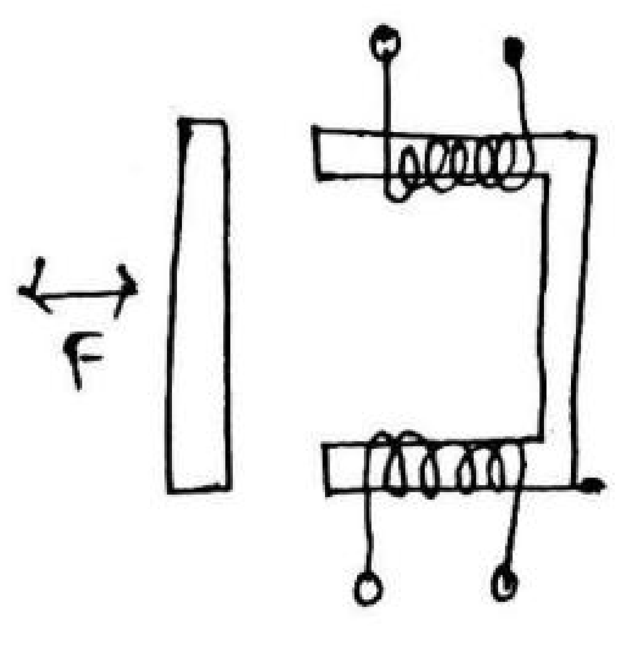
where L_1 and L_2 are self inductances of two coils.

K = coefficient of coupling.

The mutual inductance between the coils can be varied by variation of self inductances or the coefficient of coupling.

However the mutual inductances can be converted into self inductances by connecting the coils in series.

The self inductances of such an arrangement varies between $L_1 + L_2 - 2M$ to $L_1 + L_2 + 2M$. with one of the coils being stationary while other is movable. The self inductance of each coil is constant but the mutual inductance changes depending upon the displacement of movable coil.



③ Transducers working on principle of production of eddy currents -

These transducers work on the principle that if a conducting plate is placed near a coil carrying alternating current, eddy currents are produced in the conducting plate.

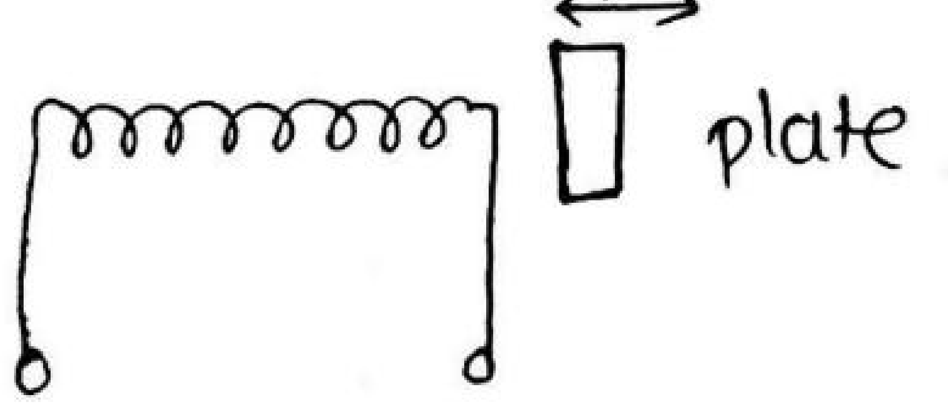
The conducting plate acts as a short circuited secondary winding of a transformer.

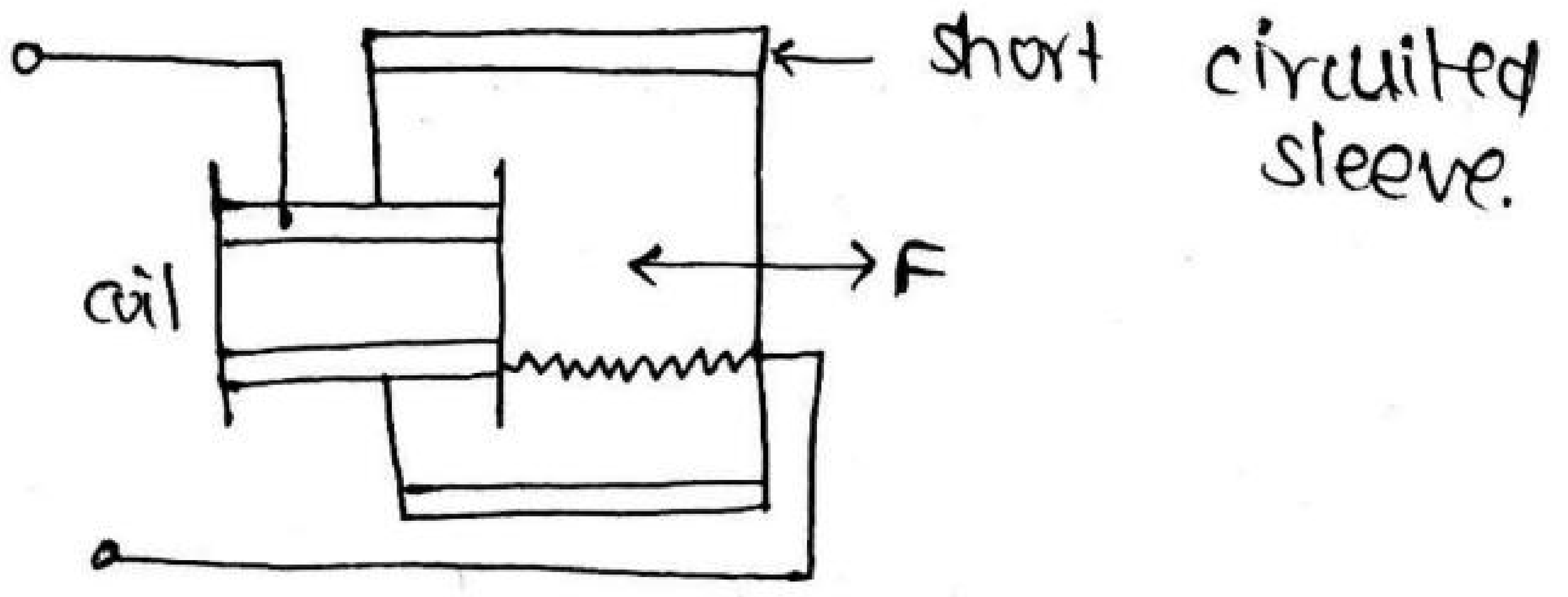
The eddy currents flowing in a plate produce a magnetic field of their own which acts against the magnetic field produced by the coil.

This ~~produce~~ results in reduction in flux and thus the inductance of coil is reduced.

The nearer is the plate to the coil, the higher are eddy currents and thus higher is the reduction in the inductance of the coil. Thus the inductance of coil alters with the variation of distance between the plate and the coil.

The two arrangents are as shown.





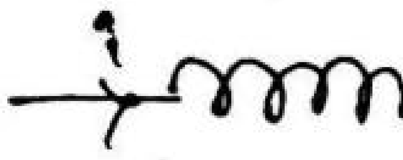
The plate may be at right angle to the axis of the coil. The displacement of plate causes a change in inductance of the coil.

In the other arrangement a conducting sleeve runs in parallel and coaxially over a coil. If the short-ciruited sleeve is away from the coil, the inductance of the coil is high and while if sleeve is covering the coil, its inductance is low.

The change in inductances is a measure of displacement.

Inductance - property of the electric conductor by which the change in current produces an electromotive force (emf)

- current i is flowing in the coil.



rate of change of current produces the emf (voltage)

$V \propto \frac{di}{dt}$ $\boxed{V = -L\frac{di}{dt}}$ L - self inductance

-ve sign because of lenz law

ie voltage that generated opposes the rate of change of current.

let, i is flowing through coil and because of flow of current there is a generation of magnetic flux (ϕ) if the current flowing through the coil is varying with time then flux is also varying wrt time. and time varying flux produces emf (voltage) in coil.

faradays law $\boxed{V = -N\frac{d\phi}{dt}}$ - ②

from ① and ②.

$Li = N\phi$

$\boxed{L = \frac{N\phi}{i}}$

Piezoelectric transducer

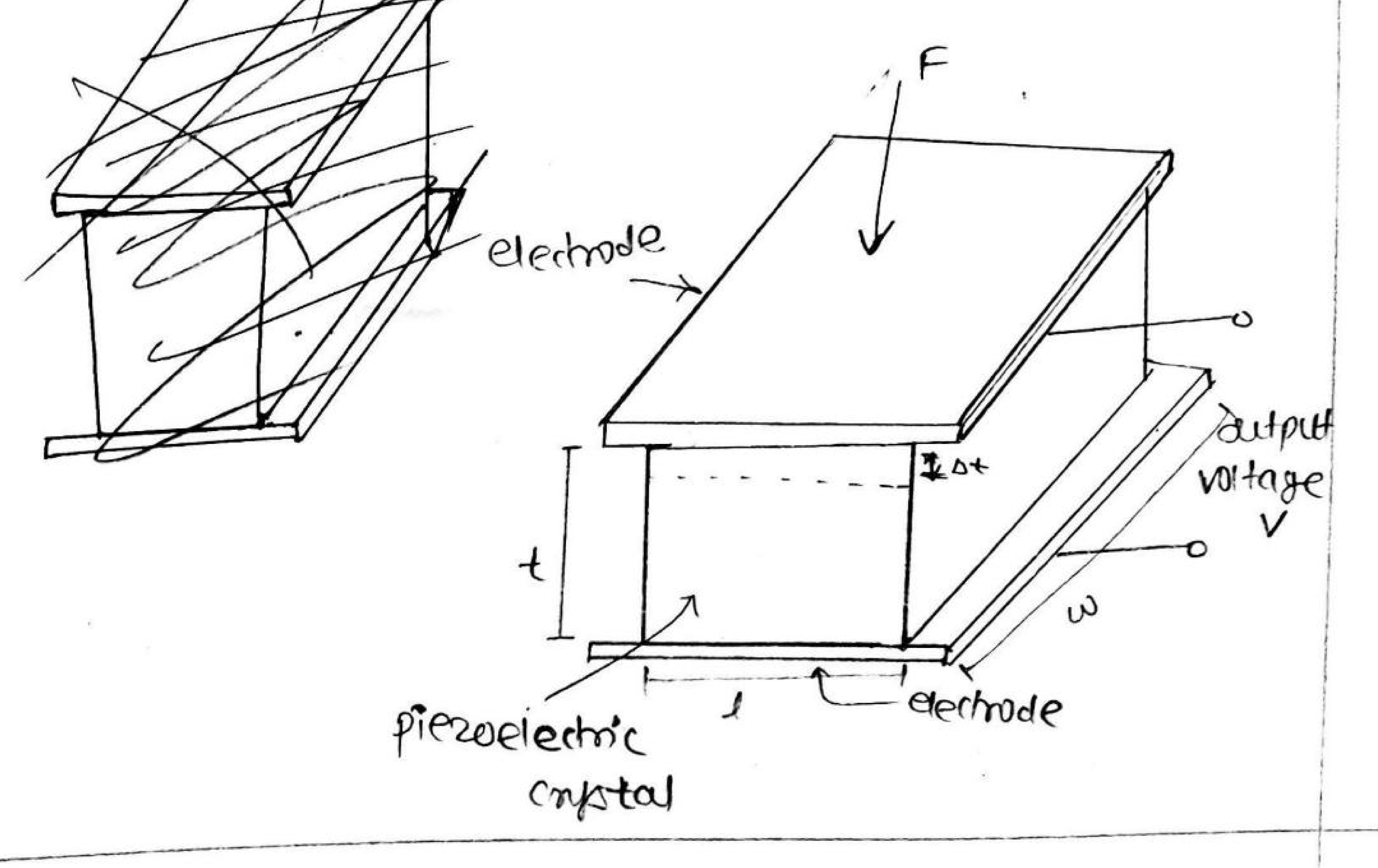
- A piezoelectric material is one in which an electrical potential appears accross certain surfaces of a crystal if the dimensions of the crystal are changed by the application of a mechanical force. This potential is produced by the displacement of charges.

The effect is reversible ie conversly if a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it.

The materials that show piezoelectric effect are known as electro-resistive elements and can be classified as natural elements and synthetic elements.

Natural elements : Quartz and Rochelle salt.

Synthetic : ethylene diamine tartarate, lithium sulphate etc



The charge Q is accumulated on the electrodes, when a force F is applied on a crystal and is given by

$Q = F \cdot d$ —① where d is charge sensitivity

also charge Q can be expressed in terms of capacitive transducer $Q = C_p V_o$.

where V_o is the voltage generated at the output of transducers.

Youngs modulus $E = \frac{stress}{strain} = \frac{F/A}{\Delta t / t}$

$$E = \frac{Ft}{\Delta t \cdot A} \Rightarrow F = \frac{\Delta t \cdot A E}{t}$$

A = area = wl

where w = width of crystal

l = length of crystal

∴ eqn ① becomes $Q = F \cdot d$

$$= \frac{AE \; \Delta t}{t} \cdot d$$

$$= \frac{AEd}{t}\left(\frac{\Delta t}{t}\right)$$

The charge at the electrodes gives rise to the output voltage.

∴ voltage $E_o = Q/C_p$.

C_p = capacitance between electrodes

$$C_p = \frac{\varepsilon_r \varepsilon_o A}{t}.$$

∴ $E_o = \frac{Q}{C_p}$ becomes.

[illegible]

$$E_0 = \frac{F \cdot d}{\varepsilon_r \varepsilon_0 A/t} = \frac{F \cdot d \cdot t}{\varepsilon_0 \varepsilon_r A}$$

$$E_0 = \left(\frac{F}{A}\right) \cdot \frac{d \cdot t}{\varepsilon_0 \varepsilon_r}$$

but $F/A = P$.

$$\therefore E_0 = \frac{P \cdot d \cdot t}{\varepsilon_0 \varepsilon_r}$$

$$= g\,t\,P.$$

$g = \frac{d}{\varepsilon_0 \varepsilon_r}$ voltage sensitivity of the crystal.

which is a constant for a given crystal.

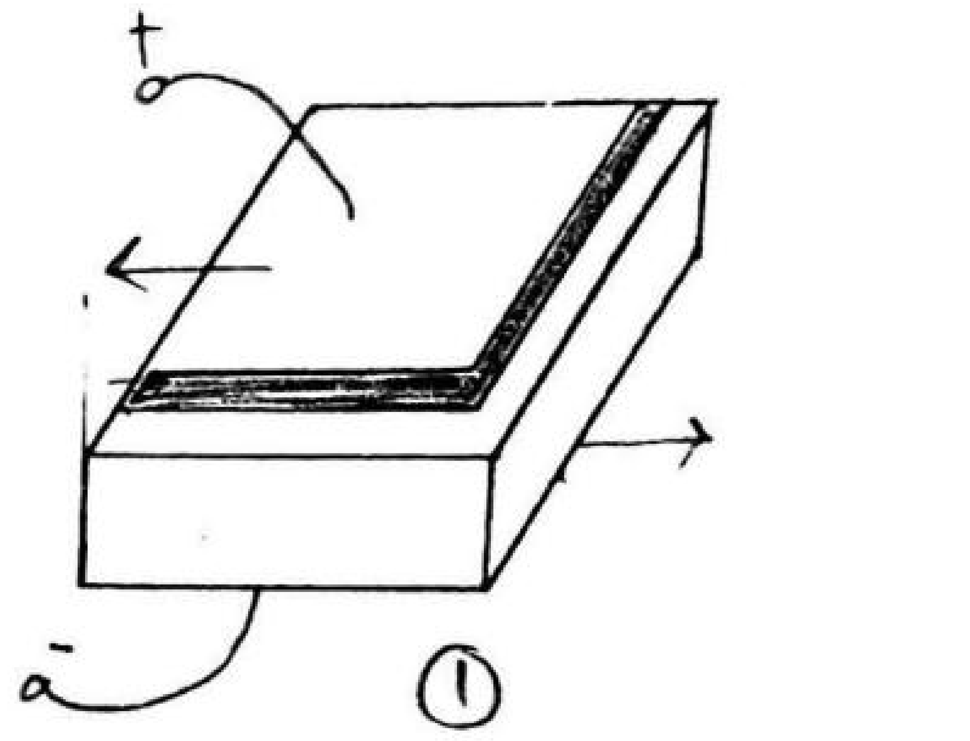
Modes of operation of piezo electric crystals.

The piezoelectric materials are used in many modes. These modes are -

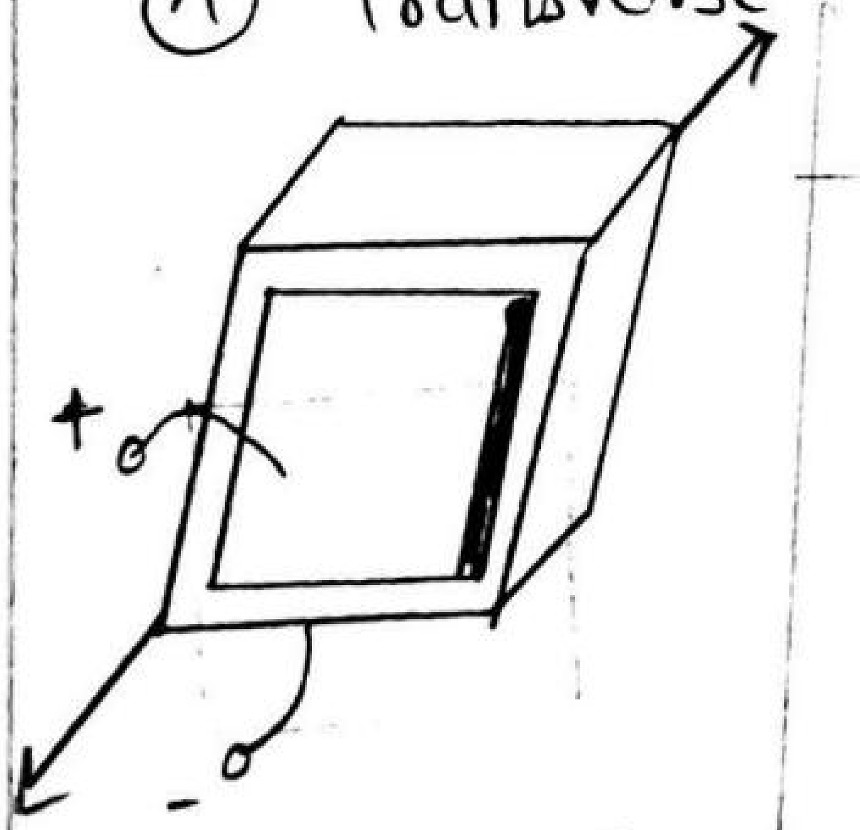
① Thickness shear ② Face shear

③ Thickness expansion

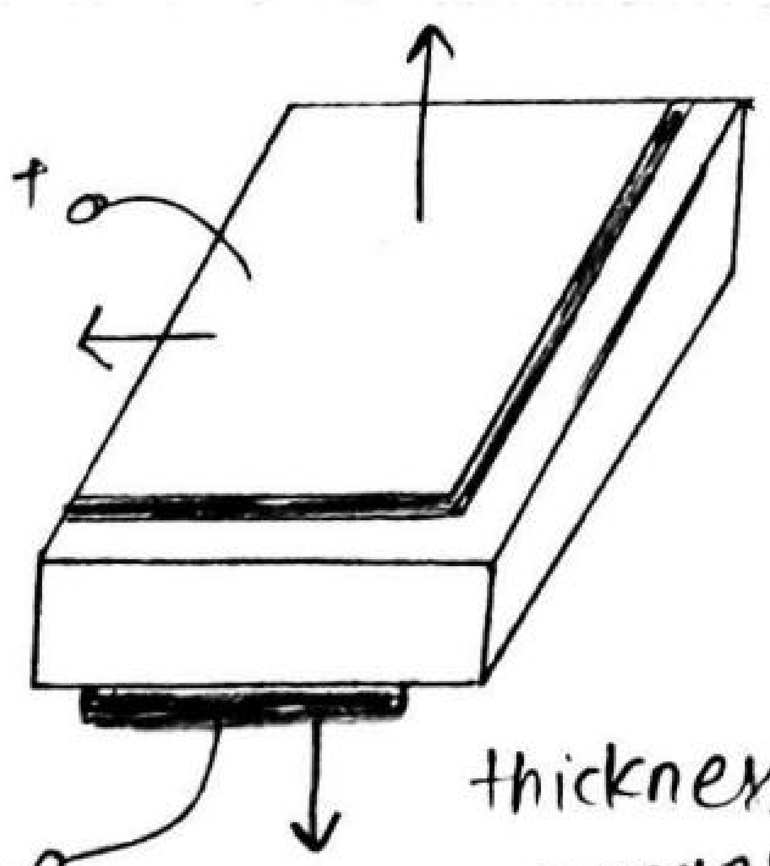
④ Transverse expansion.



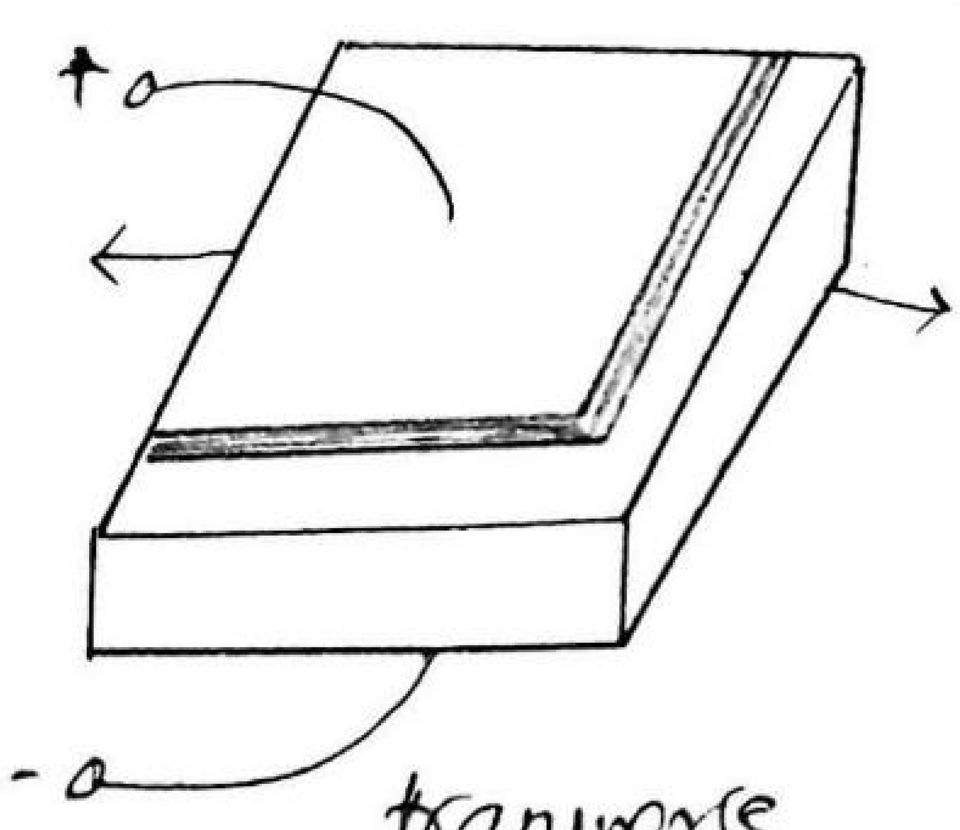
①
thickness shear



face shear



thickness expansion



transverse expansion

Advantages and disadvantages -

advantages -

① It does not require any external power source, that is it is self generating

② it is small in size and rugged

③ quartz crystal can be used over a wide range of temperatures.

disadvantages -

① The output voltage of the piezoelectric transducer varies with crystal temperature

② it cannot be used for measurement of static conditions

③ synthetic transducers cannot be used for stabilizing the frequency of oscillators.

Photoelectric Transducer

- Principle - The photoelectric transducer converts light energy into electrical energy.
- It is made up of a semiconductor material.
- The photoelectric transducer uses a photo-sensitive element, which ejects ~~the~~ electrons when the beam of light is absorbed by the photosensitive element.
- When the photoelectric transducer absorbs the radiation of light which falls on the semiconductor material, the ~~absorption of~~ light gets absorbed and the electrons flow through it.

The photoelectric devices can be categorised as

(1) photoemissive (2) photoconductive (3) photo-voltaic.

In photo emissive devices, radiations falling on a cathode causes electron to be emitted from the cathode surface.

In photo-conductive devices, the resistance of a material is changed when it is illuminated.

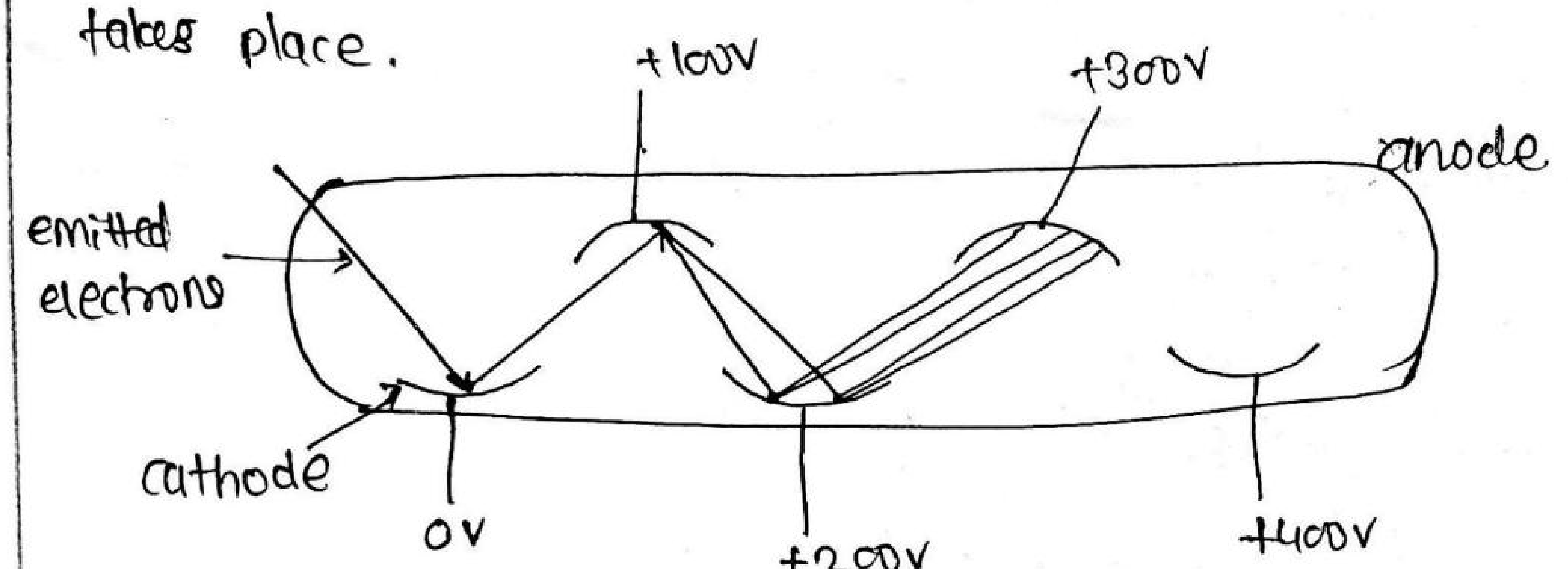
Photovoltaic cells generate an output voltage proportional to the radiation intensity.

Photoemissive

① Photomultiplier tube -

The photomulltiplier tube consists of an evacuated glass envelope containing a photo cathode, an anode and several additional electrodes. (termed dynodes) each at a higher voltage than previous dynodes.

Principle - The electrons emitted by the cathode are attracted to the first dynode. and secondary emission takes place.



When electrons moving at high velocity strike an appropriate material, the material emits a greater number of electrons than it was struck with.

In this device, the high velocity is achieved by the use of high voltage between the anode and cathode.

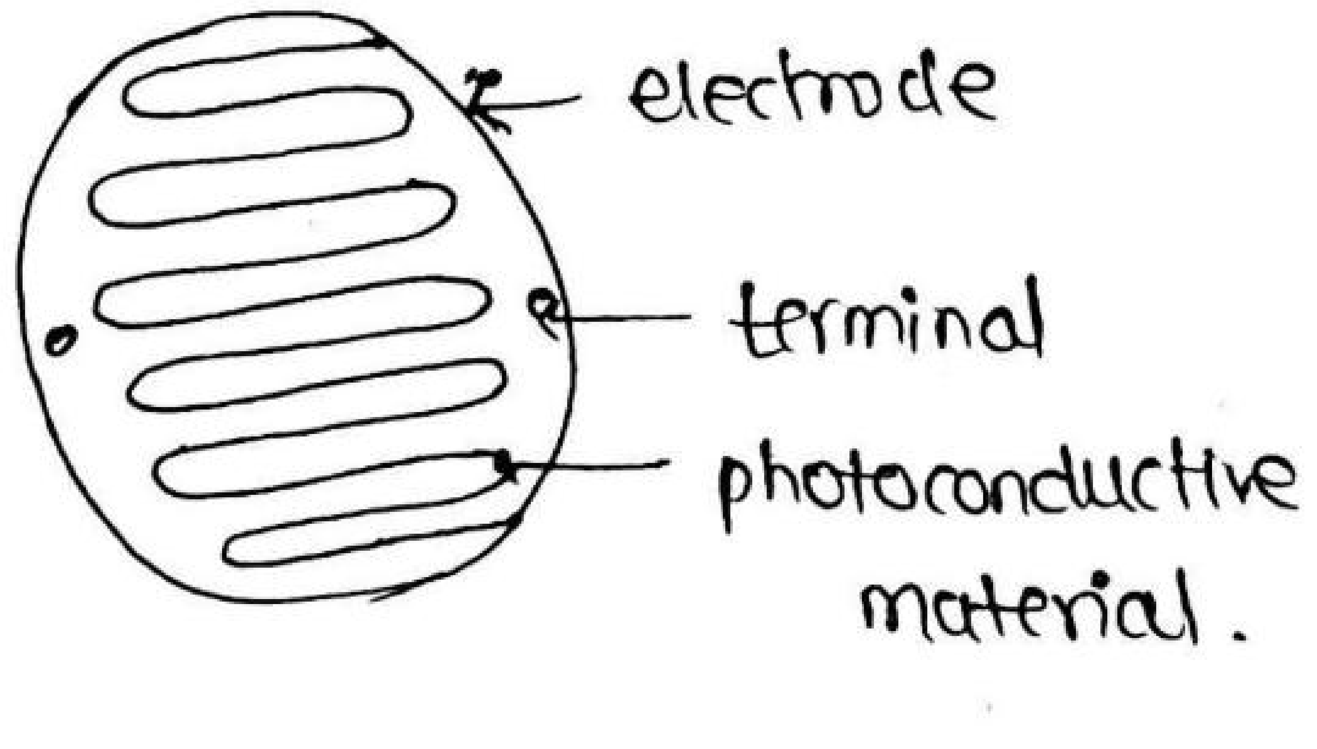
The electrons emitted by the first dynode are then attracted to the second dynode, where same action takes place again. Each dynode is at higher voltage than the previous dynode, in order to achieve requisite electron velocity each time.

Hence, secondary emission, and a resulting electron multiplication occurs at each step, with an overall increase in electron flow that may be large. Magnetic fields affect the photo multiplier because some electrons may be deflected from their normal path between stages and therefore never reach a dynode or anode. Hence gain falls.

* Photoconductive cell or photo cell

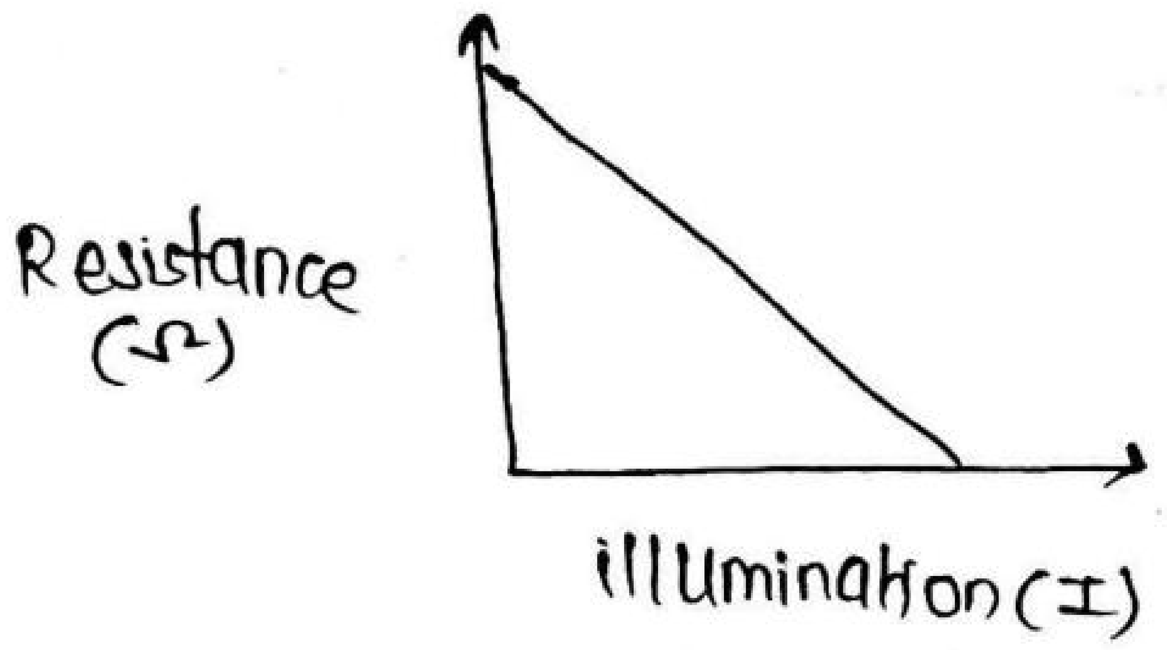
Photoconductive cells works on the principle of light that can change resistance of a material upon striking it. When the light is incident on the material (on surface), it provides some energy to it which results in the breakdown of electrons. Due to this, free electrons & holes are generated which reduce the resistance of the material.

Semiconductor material such as cadmium sulphide, lead sulphide, selenium, thalium sulphide can be used for the construction of photoconductive cells. as their resistance decreases on irradiation.

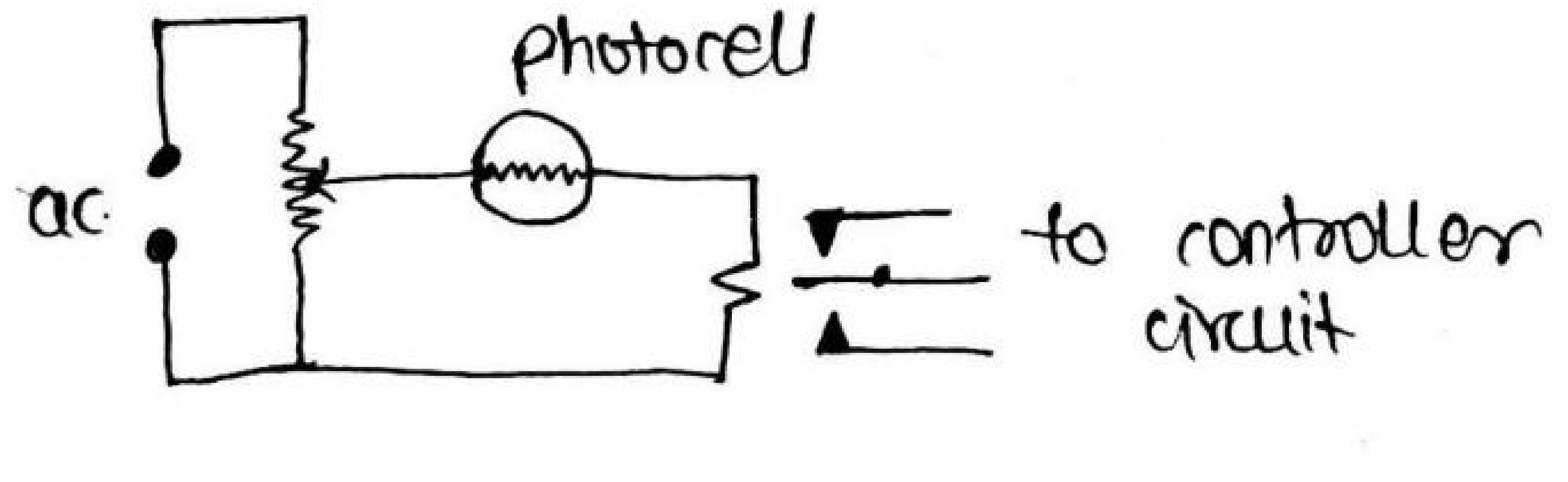


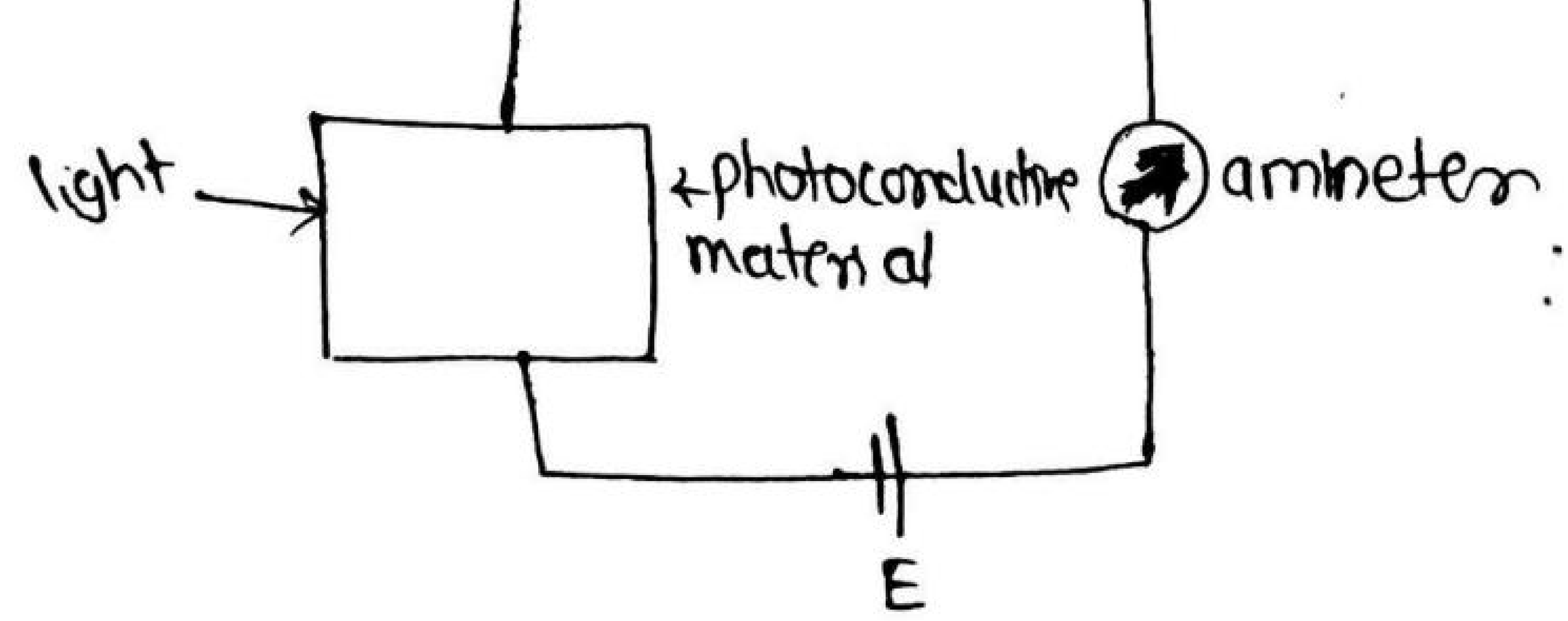
A photoconductive cell is as shown. It consists of a disc shaped base in which a long strip of a light sensitive material is placed in a zigzag pattern. On each side of the strip, connecting terminals are fitted. It is to be noted that the connecting terminals are not connected to the ends of the strip, rather they are fitted in the conductor on each side of the strip. This makes the light sensitive material appear to be a short and wide strip with conductors on both sides.

Resistance verses illumination graph of photoconductive cell representing its illumination characteristics as shown.



A typical construct circuit utilising a photoconductive cell is illustrated as shown.

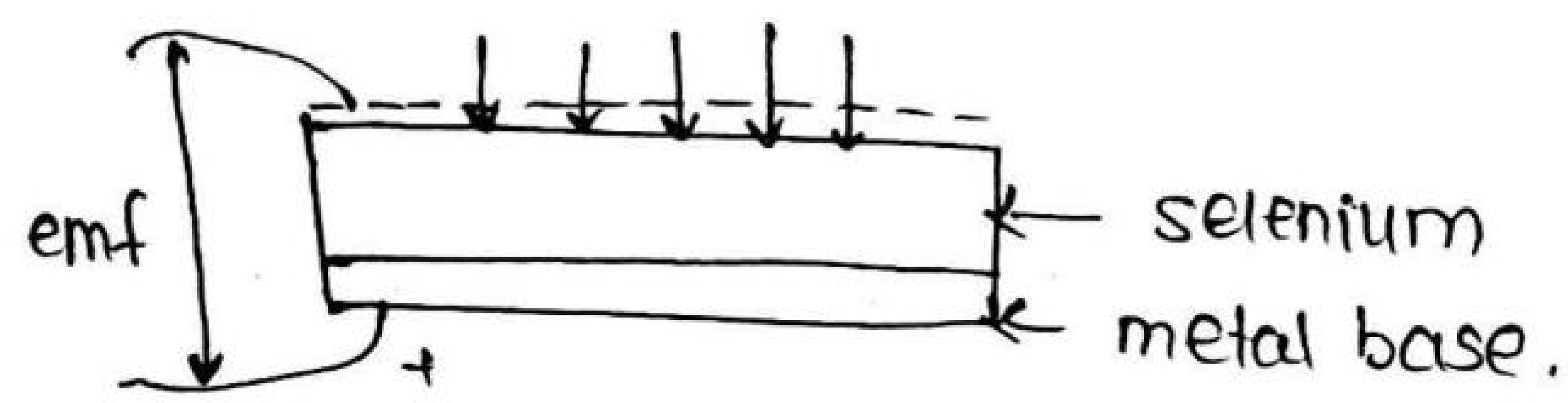




Photovoltaic cell (solar cell)

This works on the principle of generation of voltage in a material when a light is incident on it.

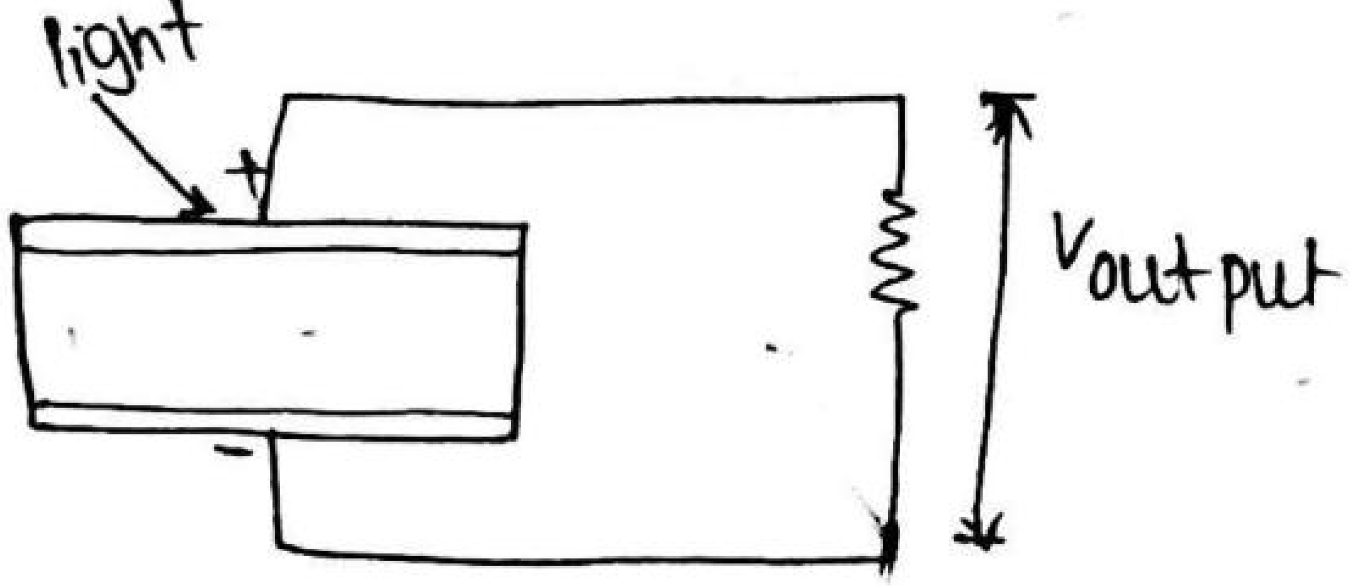
The sensitive element is used is a semiconductor including silicon and selenium.



Multiple unit silicon photo voltaic devices may be used for sensing light in applications. such ~~as~~ .

It consists of four layers - the top most layer is made of gold, followed by a barrier layer and third layer is made of selenium deposited on a metal base. ~~The~~

When the light is incident on the top layer a negative charge builds upon it and a positive charge builds on the buttom electrode. Due to this generation of charges, a voltage is generated is proportion to the incident light.



Temperature Transducer.

A voltage can be generated in a circuit by joining two dissimilar metals at the ends and keeping both the junctions at different temperatures. The voltage so generated is temperature dependent and also depends upon the material of the metal used. This is known as thermoelectric effect.

- The types of temperature transducers are resistance thermometer, thermistor and thermocouples.

(1) Resistance thermometer -

Also known as resistance temperature thermometer (RTD). uses a wire whose resistance depends upon temperature. Usually a wire of copper, platinum or nickel is used. The temperature dependence of resistance can be expressed as,

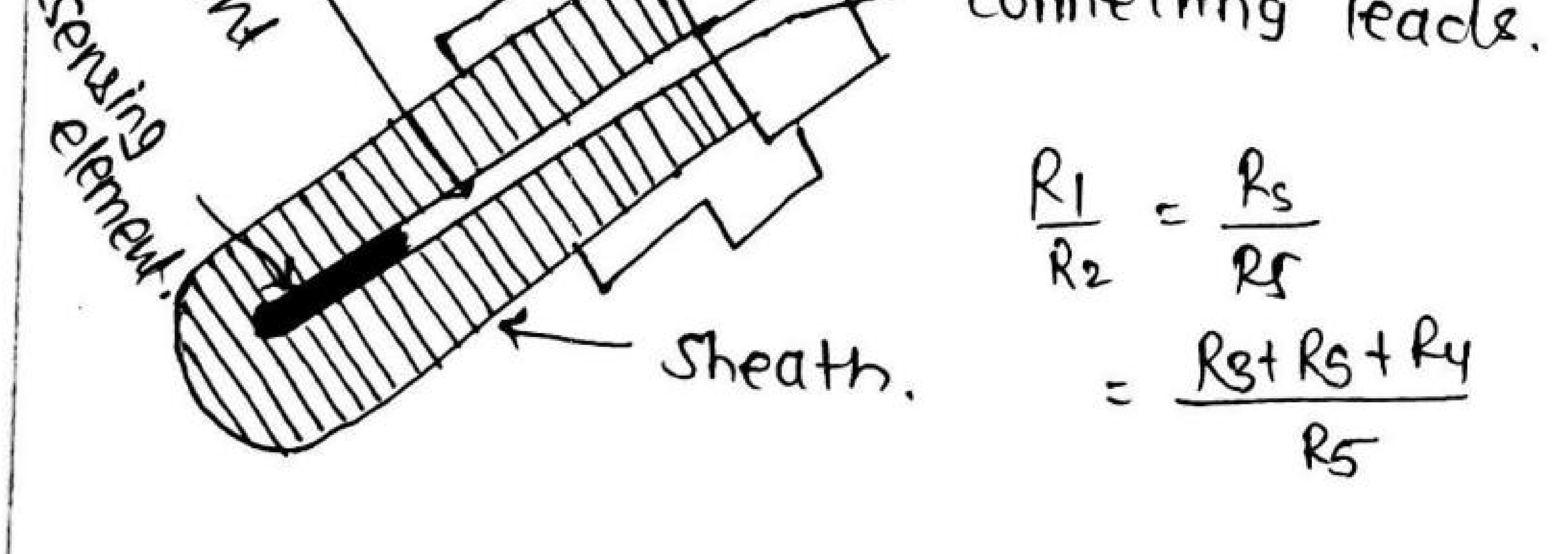
$$R_t = R_0(1+\alpha\Delta t).$$

R_t - resistance of ~~temp~~ conductor at temp at $t°c$.

R_0 - resistance of reference temperature usually $0°c$.

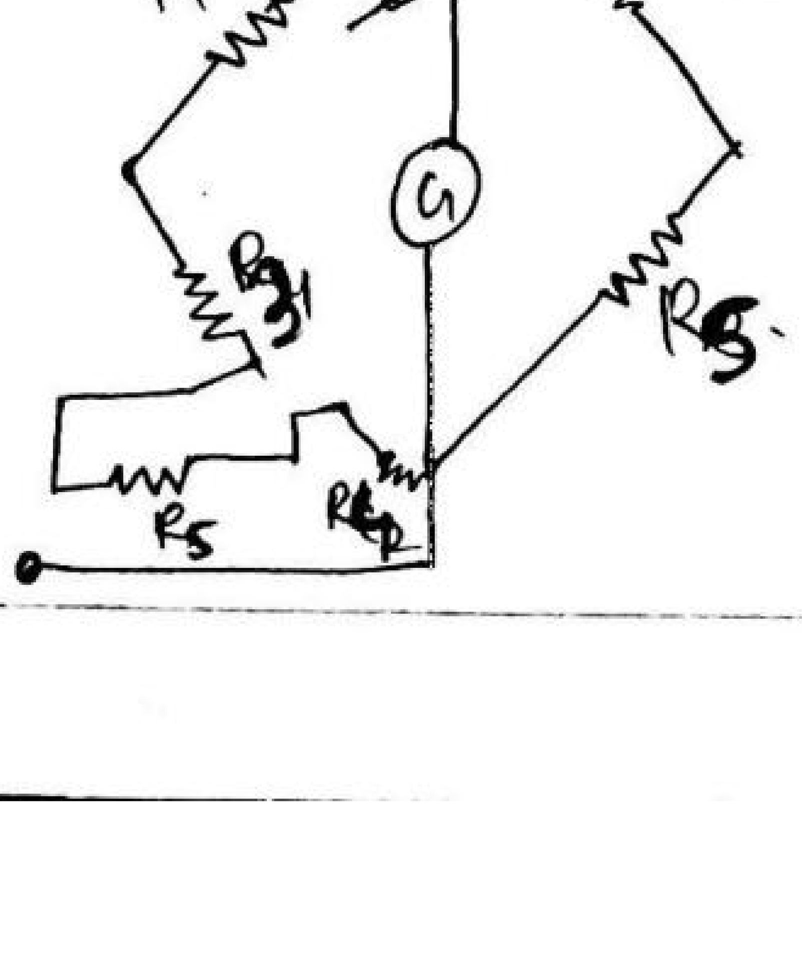
α - temperature coefficient of resistance

Δt - difference between operating and reference temperature.



$$\frac{R_1}{R_2} = \frac{R_s}{R_5}$$

$$= \frac{R_3+R_s+R_4}{R_5}$$



Almost all metals have a positive temperature coefficient (PTC) of resistance, so that their resistance increases with increase in temperature. some materials such as carbon and germanium have a negative temperature coefficient (NTC) of resistance, which means that the resistance decreases with increase in temperature.

A high value of α is desirable in a temperature sensing element so that a substantial change in resistance occurs for a relatively small change in temperature. This change in ~~temperature~~ resistance (ΔR) can be measured with the help of wheatstone's bridge, which can be callibrated to indicate the temperature that caused the resistance change, rather than resistance itself.

Platinum is the ~~most~~ widely & commonly used ~~resistance~~ wire type because of its high stability and large operating range.

Platinum RTD provides the ultimate in accuracy and stability. They have the following advantages.

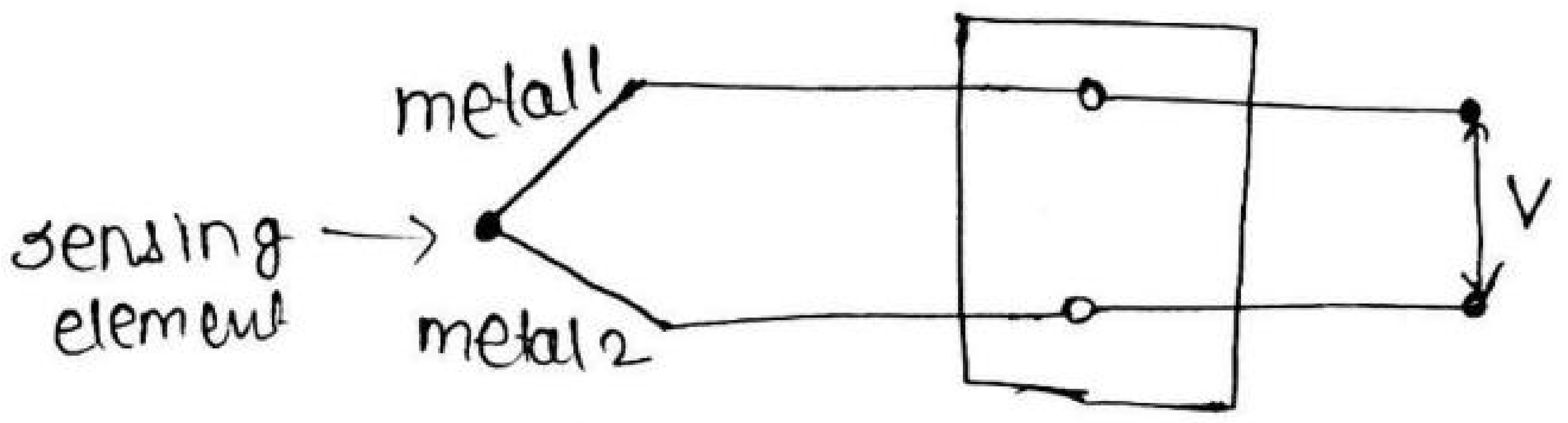
1. Linearity over a wide range
2. wide operating temperature range
3. High temperature operation
4. better stability at higher temperatures

disadvantages -

1. low sensitivity
2. Higher cost than any other temperature transducers.
3. can be affected by contact resistances, shock & accn.

② Thermocouples -

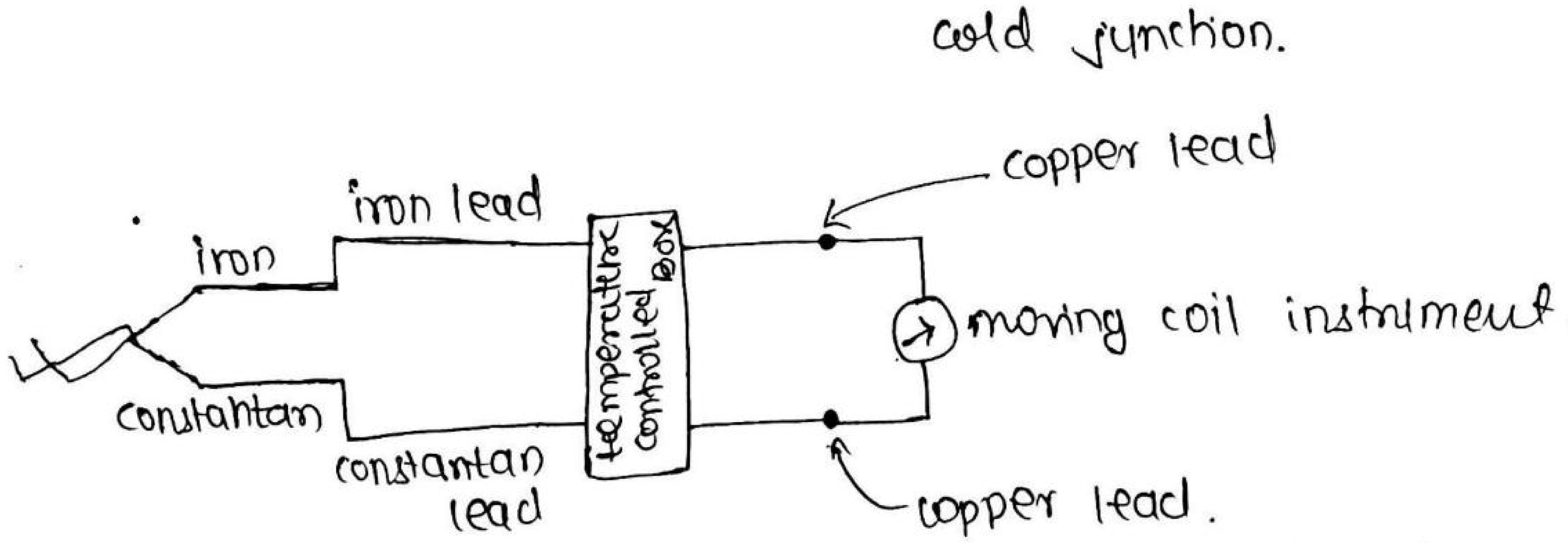
The operation of thermocouple is based on seebeck effect. When a pair of wires made of different metals is joined together at one end, a temperature difference between two ends of wires produces a voltage between the two wires.



ie.
When ~~two~~ heat is supplied to junction (hot junction) of two dissimilar metals, an emf is generated which can be measured at the other junction (cold junction). Two dissimilar metals form an electric circuit, and a current flows as a result of generated emf.

The emf produced is function of the difference in temperature of hot and cold junctions and is given by,

$E = a\Delta\theta$. $\Delta\theta$ - temp. difference betn hot & cold junction.



- Thermo couples are used to measure the temperatures in the range 1400°C.

Advantages of thermocouples -

1. thermocouples are cheaper than Resistance thermometers.
2. thermocouples offer good reproducibility
3. Bridge circuits are not required for measurements.

disadvantages -

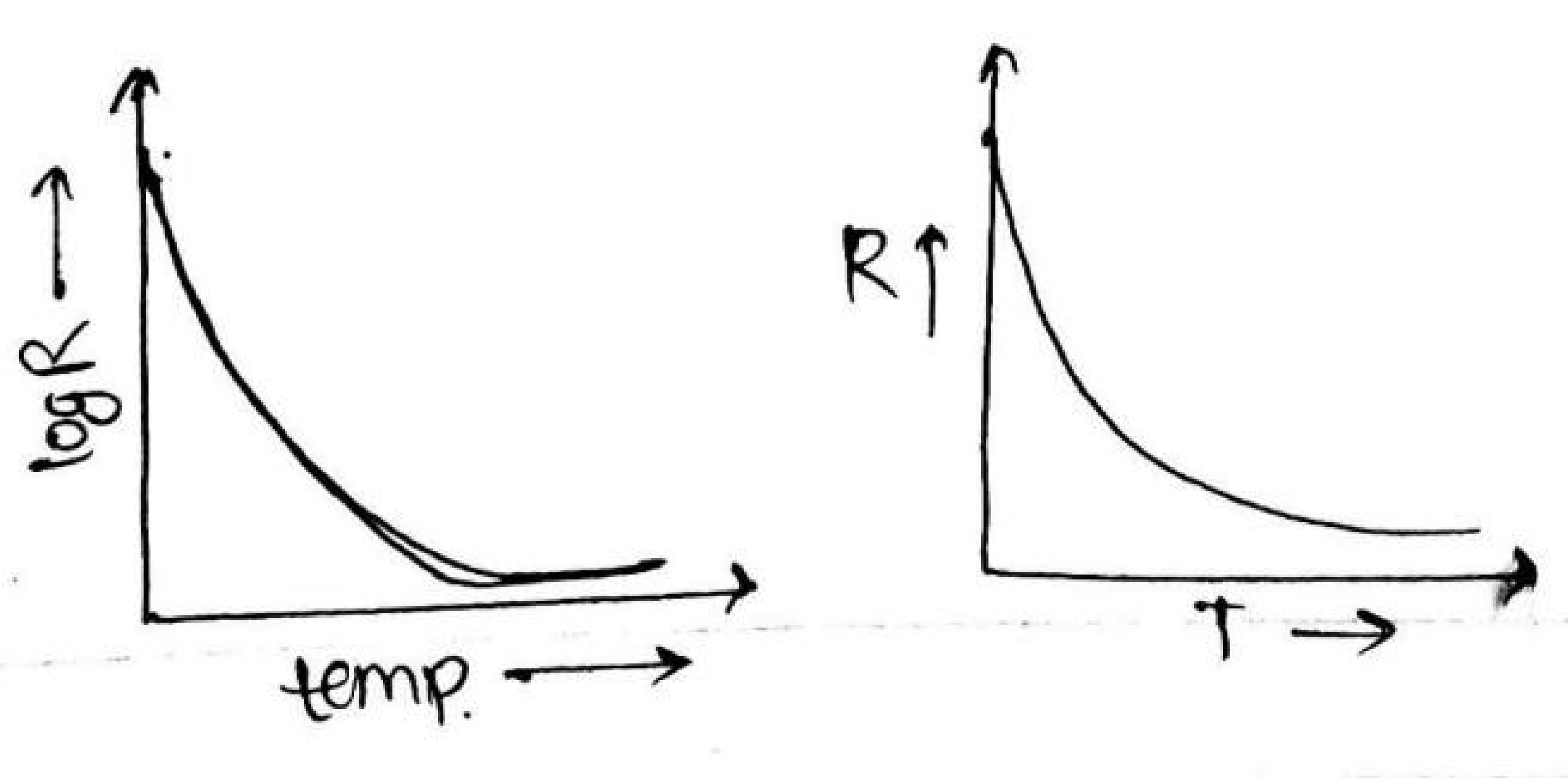
1. comparatively low acurracy.
2. cold junction and other compensation is essential for acurrate temperature measurements.

③ Thermistors - (Thermally sensitive resistors)

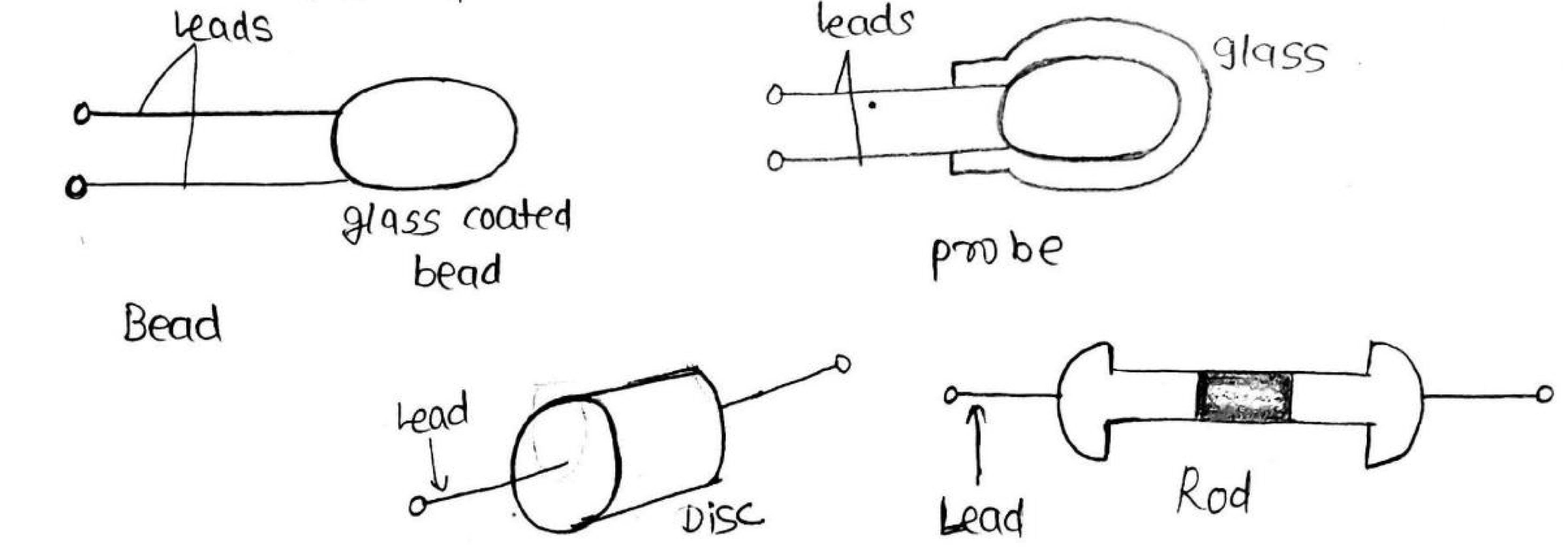
The electrical resistance of most materials changes with temperature. By selecting materials that are very sensitive to temperature, devices can be made that are useful in temperature control circuits and for temperature measurements.

Construction: Thermistor (thermally sensitive resistors) are non-metallic resistors (semiconductor materials) made by sintering mixtures of metallic oxides such as magnese, nickel, cobalt, copper and uranium.

Thermistors have a negative temperature coefficient (NTC). ie resistance decreases as temperature rises.



different forms of construction of thermistor.



Resistance temperature characteristics of thermistors.

The relationship between resistance of a thermistor and absolute temperature of thermistor is,

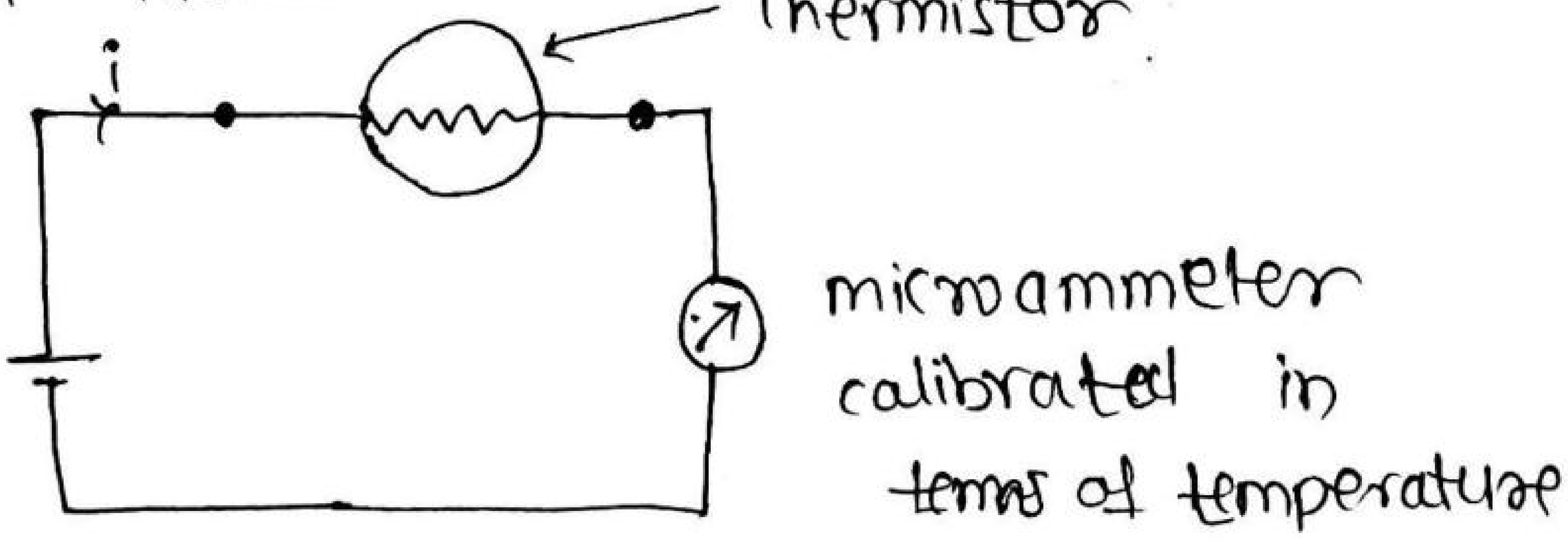
$$R_{T_1} = R_{T_2} \exp\left[\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

R_{T1} - Resistance of thermistor at absolute temperature T_1 °k

R_{T2} - Resistance of thermistor at absolute temp T_2 °k.

β - a constant depending upon material of thermistor (typically 3500 to 4500°K).

simple series circuit for measurement of temperature using a thermistor.



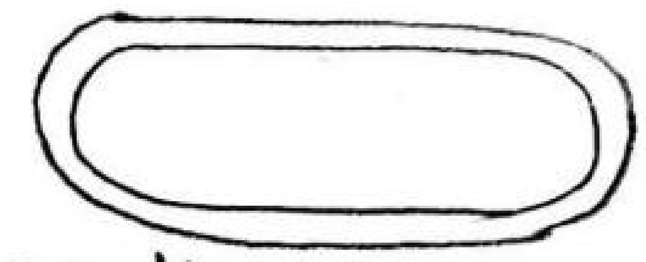
measurement of temperature - A thermistor produces a large change ~~in~~ of resistance with a small change in the temperature being measured.
This large sensitivity of thermistor ~~produces~~ provides good accuracy and resolution.
When the thermistor is connected in series circuit consisting of a battery and microammeter as shown, any change in temperature causes a change in the resistance of thermistor and corresponding change in the circuit current.

Pressure transducer

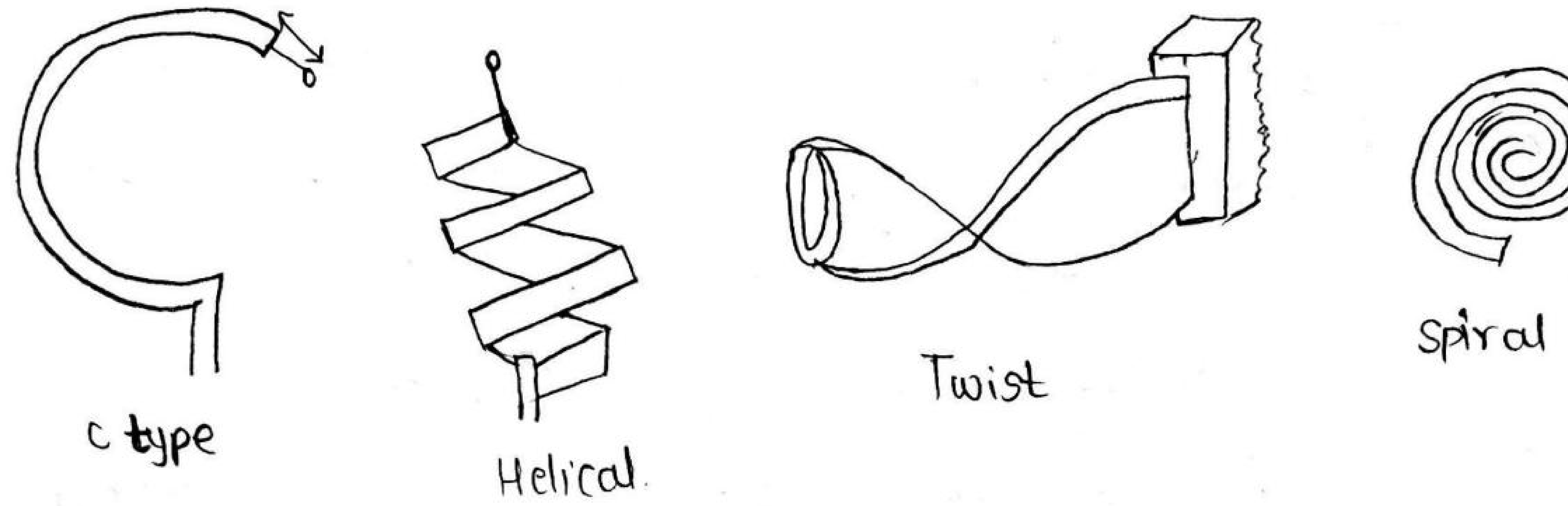
- Mechanical elements used to convert the applied pressure into displacement are known as force summing devices.
- Most of the pressure measuring devices use elastic ~~[illegible]~~ members for sensing pressure at primary stage.
- These elastic members are of many types and convert the pressure into mechanical displacement which is later converted into an electrical form using a secondary transducer.
- Diaphragrams, bellows and bourdon tubes are used as primary sensing element in pressure transducer.
- The working principle of such devices is that the pressure sensitive element is pressed by passing the fluid whose pressure is to be measured. This results in mechanical displacement to be measured by electrical transducer.
- Here, these devices acts as a primary ~~sensing~~ transducers in circuit and a secondary transducer is needed to convert the displacement into electrical form.

① Bourdon tubes -

Bourdon tubes are made from an elliptical flattened tube which is bent to produce the desired shape. They are available in four configurations namely, ctype, helical, twisted, and spiral.



tube crosssection



The one end of the tube is sealed or closed. The other end is open for the fluid to enter. when the fluid whose pressure is to be measured enters the tube, the tube tends to straighten out on account of the pressure applied. This causes a movement of the free end (closed end) and the displacement of this end is amplified through mechanical linkages. The amplified displacement of the free end may be used to move a pointer on a scale calibrated in terms of pressure or may be applied to a electrical displacement whose output may be calibrated in terms of pressure applied.

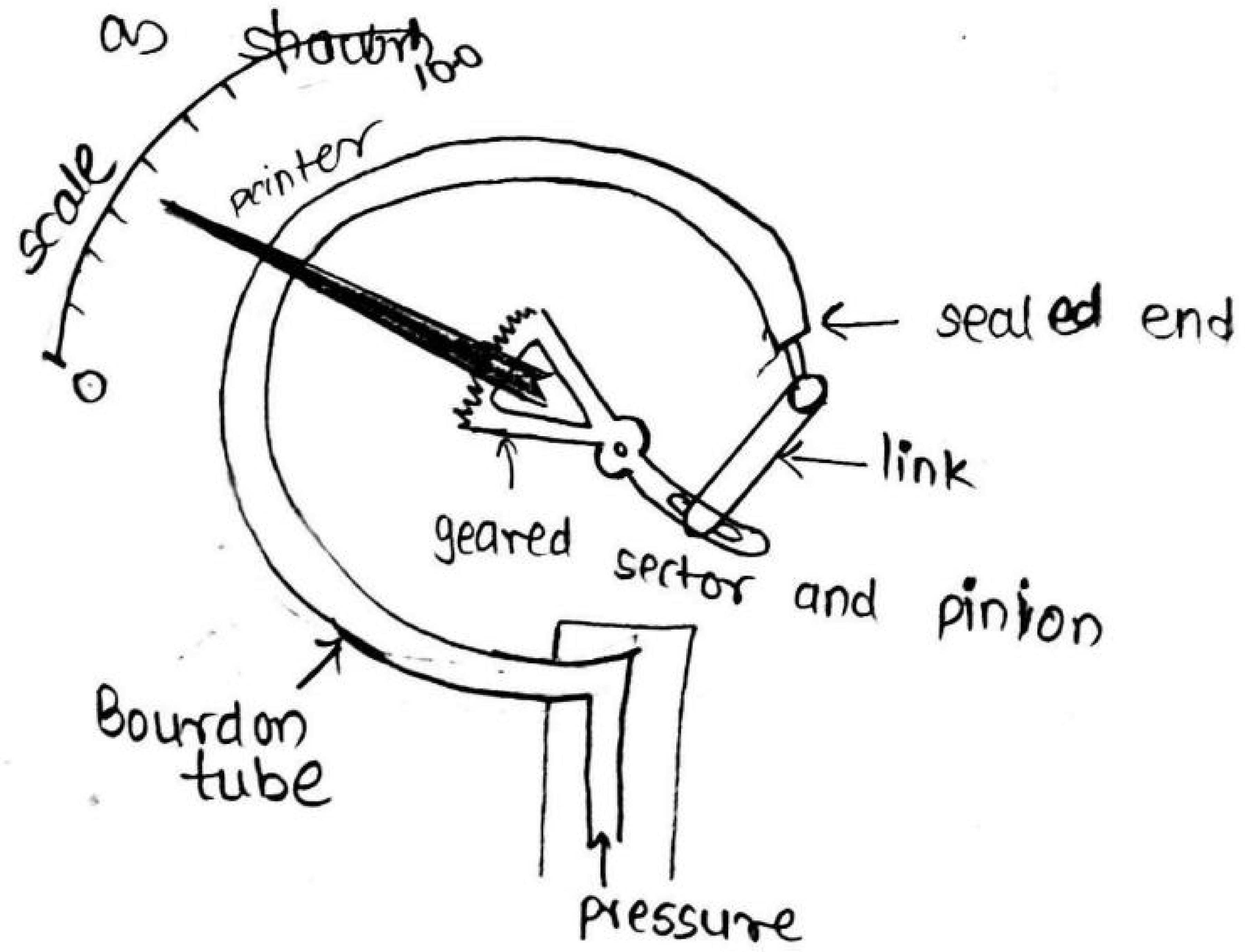
Advantages - low cost, simple construction, high pressure range, good accuracy.

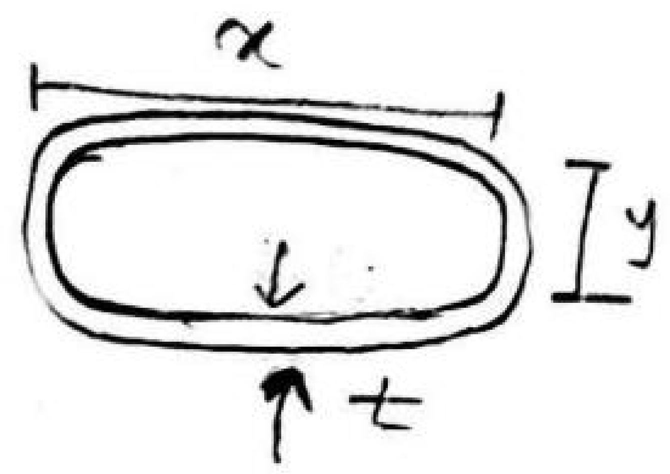
- easily adapted for obtaining electrical outputs.

disadvantages - low spring gradient

① C-type -

The c type of Bourdon tube is most commonly used for local indication but it is also used for pressure transmission and control applications. The tube which is oval in section is formed into an arc of 250° and hence the name c configuration which is as shown

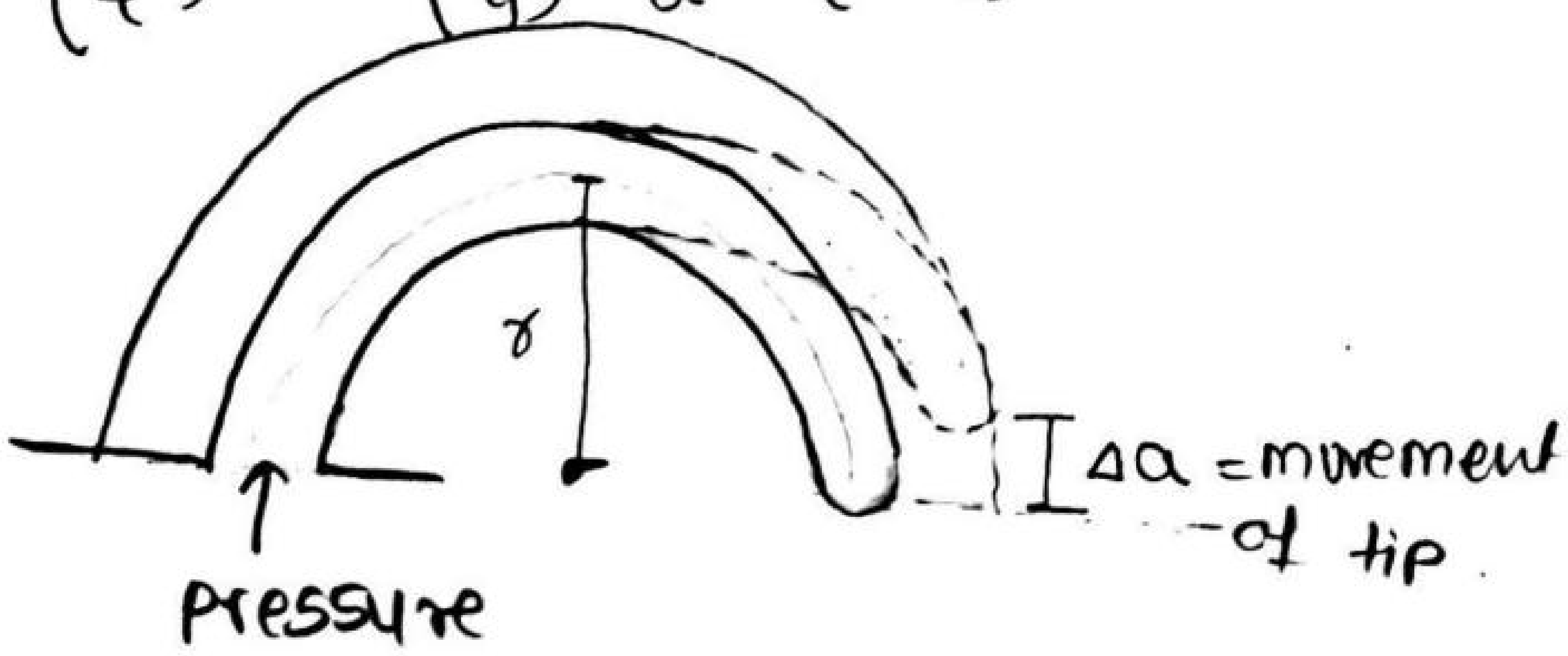




The displacement of the tip

$$\Delta a = 0.05 \frac{ap}{E} \left(\frac{r}{t}\right)^{0.2} \left(\frac{x}{y}\right)^{0.33}_{a} \left(x/t\right)^{3}.$$

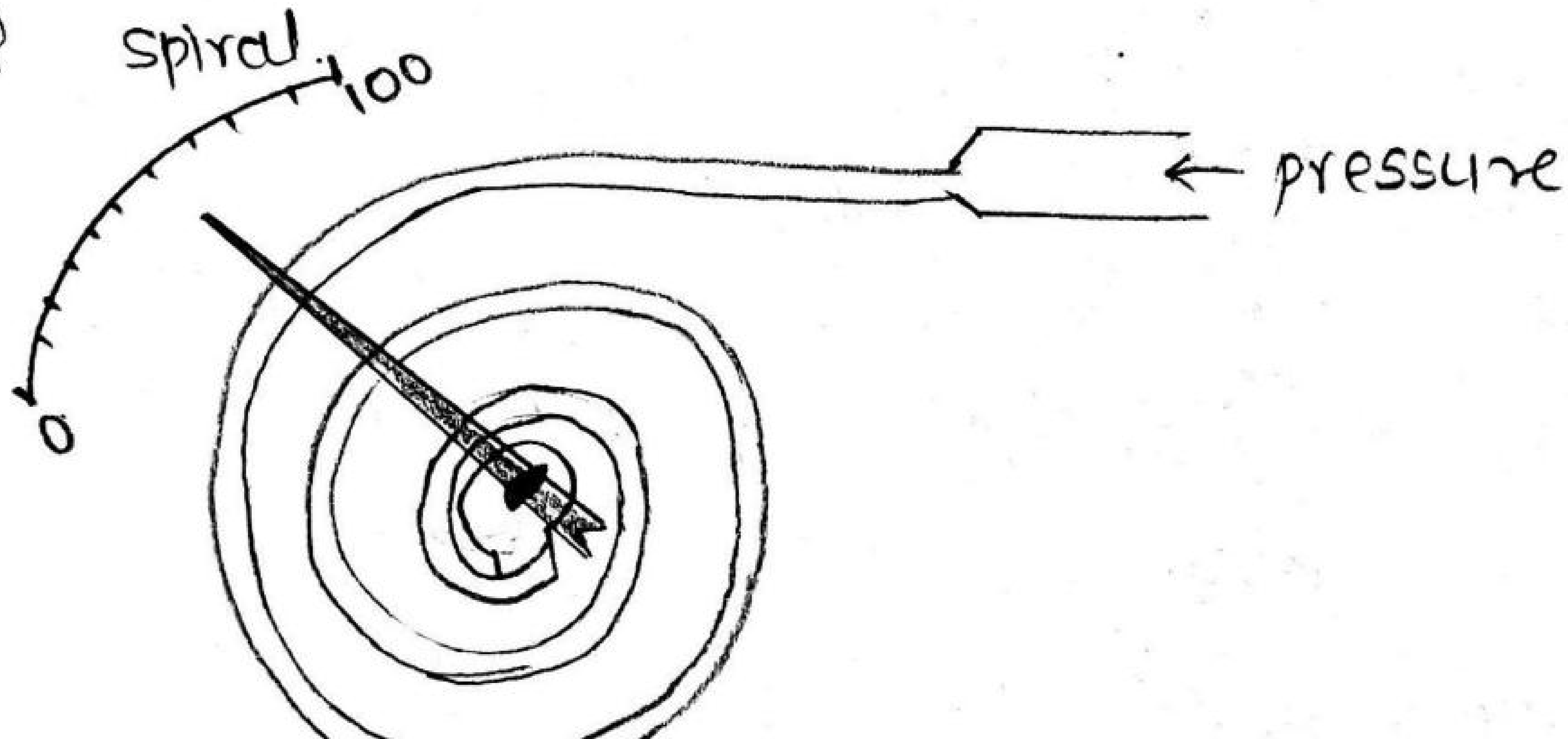
E - elastic constant
P - pressure applied.



Thus, the relationship between the displacement of tip and the applied pressure is nonlinear ie each pressure increment does not produce a corressponding tip movement.

② Spiral type - from the above equation it is clear that the displacement of the tip varies inversly as the wall thickness and depends on the cross-sectional form of the tube. It also varies as the length of ~~area~~ arc a.

A spiral type Bourdon tube is made by winding several turns of the tube with its flattend cross-section in the form of spiral.



When the pressure to be measured is applied to the spiral, it tends to uncoil producing a relatively long movement of tip whose displacement can be used for indication.

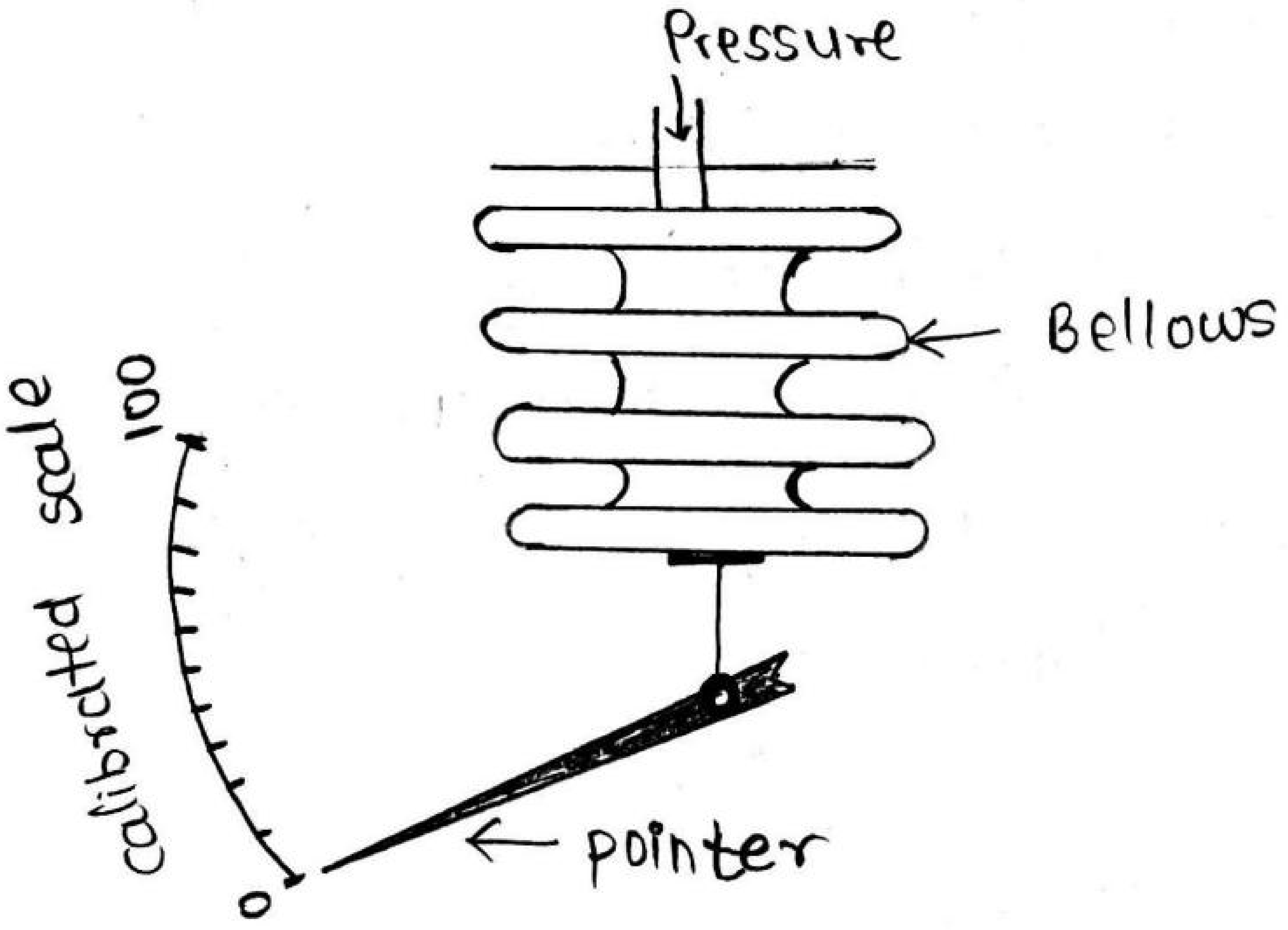
③ Helical type -

Usually a central shaft is installed within a helical element and the pointer is driven from this shaft by connecting links.

The advantage of helix elements include the high over range capabilities which may be the ratio as high as 10:1.

(2) Bellows -

A metallic bellows is a series of circular parts, resembling the folds in an accordin as shown.



- These parts are formed or joined in such a way that they are expanded or contracted axially by changes in pressure.
- The metals used for the construction of Bellows must be thin enough to be flexible, ductile for easily ~~fabirac~~ fabrication and have good resistance to fatigue failure.
- materials that are commonly used - Bronze, brass, copper, beryllium, alloys of nickel and copper, steel.
- Soldering and welding of annular sections, rolling, spinning and turning from solid stock may used for manufacture of bellows.

The displacement of bellows element is given by,

$$d = \frac{0.453\ Pb\ n\ D^2 \sqrt{1-\nu^2}}{Et^3}.$$

where P - pressure

b - radius of each corrugation

n - no. of semicircular corrugation

t - thickness of wall

D - mean diameter

E - modulus of elasticity

ν - poisson's ratio.

Bellows has the ability to move over a greater distance than required pressure application and ∴ to give it maximum life and to have better accuracy, its movement is generally opposed by a calibrated spring so that only a part of the maximum stroke is used.

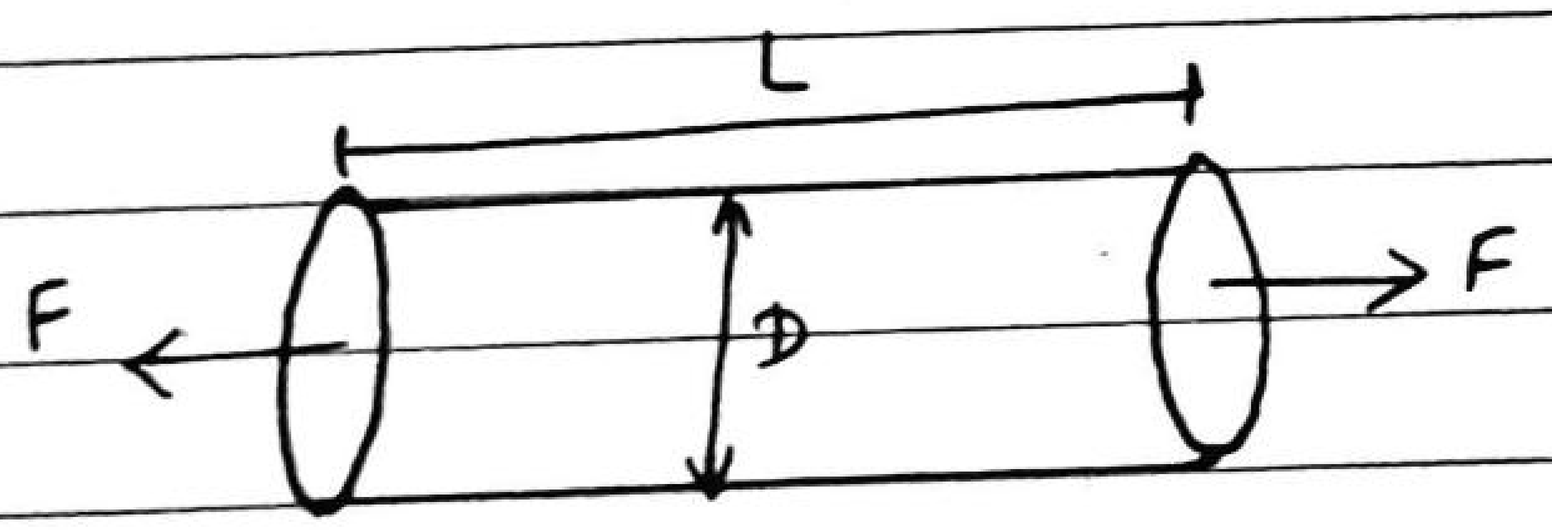
Strain Guages.

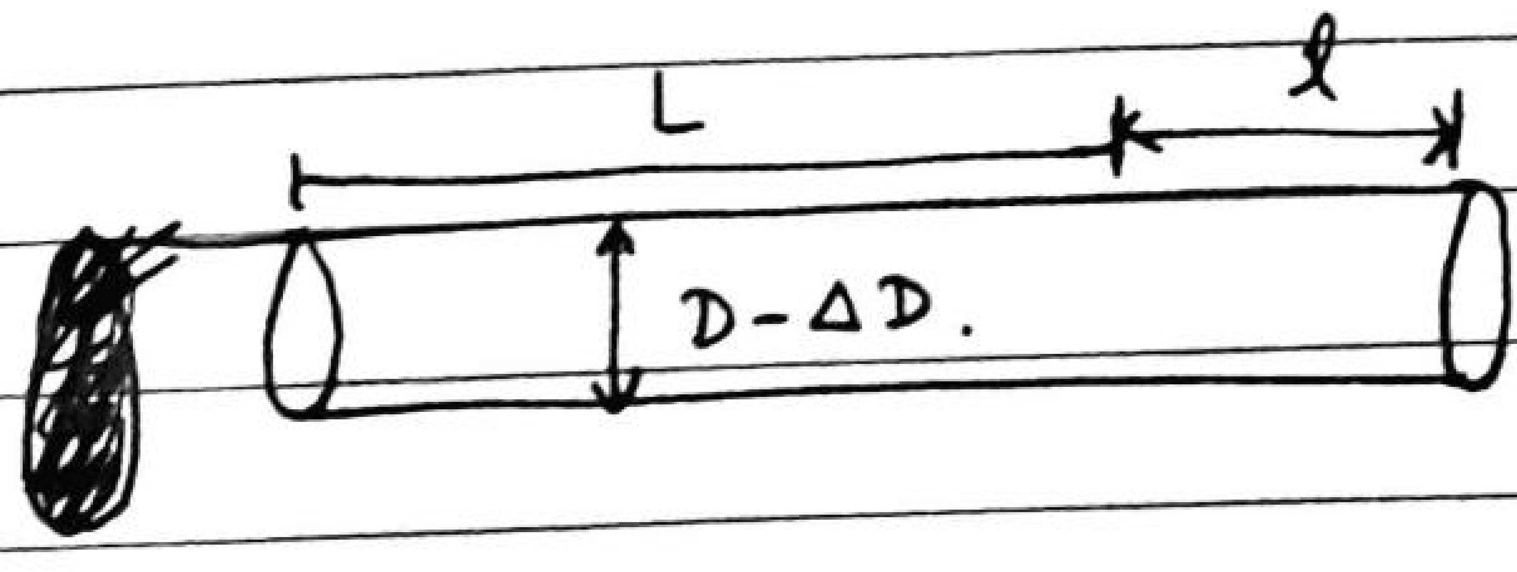
- A strain guage is a sensor whose resistance varies with applied force.
- Strain guages are used to measure strain.
- The change in resistance of the material can be explained by the change in the behaviour of elastic material.
- It is also known that stress and strain in a portion of any object under pressure is directly related to the modulus of rigidity.
- If a metal conductor is stretched or compressed, its resistance changes on account of the fact that both diameter and length of the conductor changes. also there is a change in the value of resistivity
- Mathematically strain = ~~$e = \frac{\Delta l}{l} = l - l$~~

$$e = \frac{\Delta L}{L} = \frac{L - l}{L}$$

L = original length

l = final length





- The resistance of a conductor is proportional to the length and inversely proportional to ~~the~~ l cross-section.

Let us consider a strain guage made of circular wire. The wire has resistivity ρ, then resistance of unstrained guage is given by

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

where L = length of conductor
A = area of conductor.

Let the tensile stress is applied to the wire. The length of the conductor increases and the diameter will decrease.

$$R = \rho L \frac{1}{A} \quad \text{—} (1)$$

differentiate resistance R with respect to applied stress

$$\frac{dR}{dS} = \rho L \left(\frac{-1}{A^2}\right) \frac{\partial A}{\partial S} + \frac{\rho 1}{A}\left(\frac{\partial L}{\partial S}\right) + \frac{L}{A}\left(\frac{\partial \rho}{\partial S}\right)$$

$$= \frac{\rho}{A}\left(\frac{\partial L}{\partial S}\right) - \frac{\rho L}{A^2}\left(\frac{\partial A}{\partial S}\right) + \frac{L}{A}\left(\frac{\partial \rho}{\partial S}\right) \quad \text{—} (2)$$

divide eqn (2) by eqn (1).

$$\therefore \frac{1}{R}\frac{dR}{dS} = \frac{\frac{\rho}{A}\left(\frac{\partial L}{\partial S}\right)}{\frac{\rho L}{A}} - \frac{\frac{\rho L}{A^2}\left(\frac{\partial A}{\partial S}\right)}{\frac{\rho L}{A}} + \frac{\frac{L}{A}\left(\frac{\partial \rho}{\partial S}\right)}{\frac{\rho L}{A}}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\left(\frac{\partial L}{\partial S}\right) - \frac{1}{A}\left(\frac{\partial A}{\partial S}\right) + \frac{1}{\rho}\left(\frac{\partial \rho}{\partial S}\right) \quad \text{—} (3)$$

from above equation, we can say that The per unit change in resistance is due to

1. per unit change in length $(\partial L/L)$
2. per unit change in area $(\partial A/A)$
3. per unit change in resistivity $(\partial \rho/\rho)$.

$r = D/2$

let area $A = \pi r^2$ but $r = D/2$

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

$$\frac{dA}{dS} = \frac{\pi}{4}\left[2D \cdot \frac{dD}{dS}\right]$$

$$\frac{1}{A}\frac{dA}{dS} = \frac{\frac{\pi}{4} \cdot 2D \frac{dD}{dS}}{\pi D^2/4} = \frac{2}{D}\frac{dD}{dS}$$

put this value in eqn no. ③

$$\therefore \frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\left(\frac{\partial L}{\partial S}\right) - \frac{2}{D}\left(\frac{\partial D}{\partial S}\right) + \frac{1}{\rho}\left(\frac{\partial \rho}{\partial S}\right)$$

The poisson's ratio $\gamma = \frac{\text{lateral strain}}{\text{longitudinal strain}}$

$$= \frac{-\Delta D/D}{\Delta L/L}$$

$$\therefore \frac{\partial D}{D} = -\gamma \frac{\Delta L}{L}$$

$\therefore$ [illegible]

The strain guage factor is defined as the ratio of per unit change in resistance to per unit change in length.

Gauge factor $G = \frac{\Delta R/R}{\Delta L/L}$

$$\therefore \frac{\Delta R}{R} = G \cdot \frac{\Delta L}{L}$$

$$= G \cdot \varepsilon$$

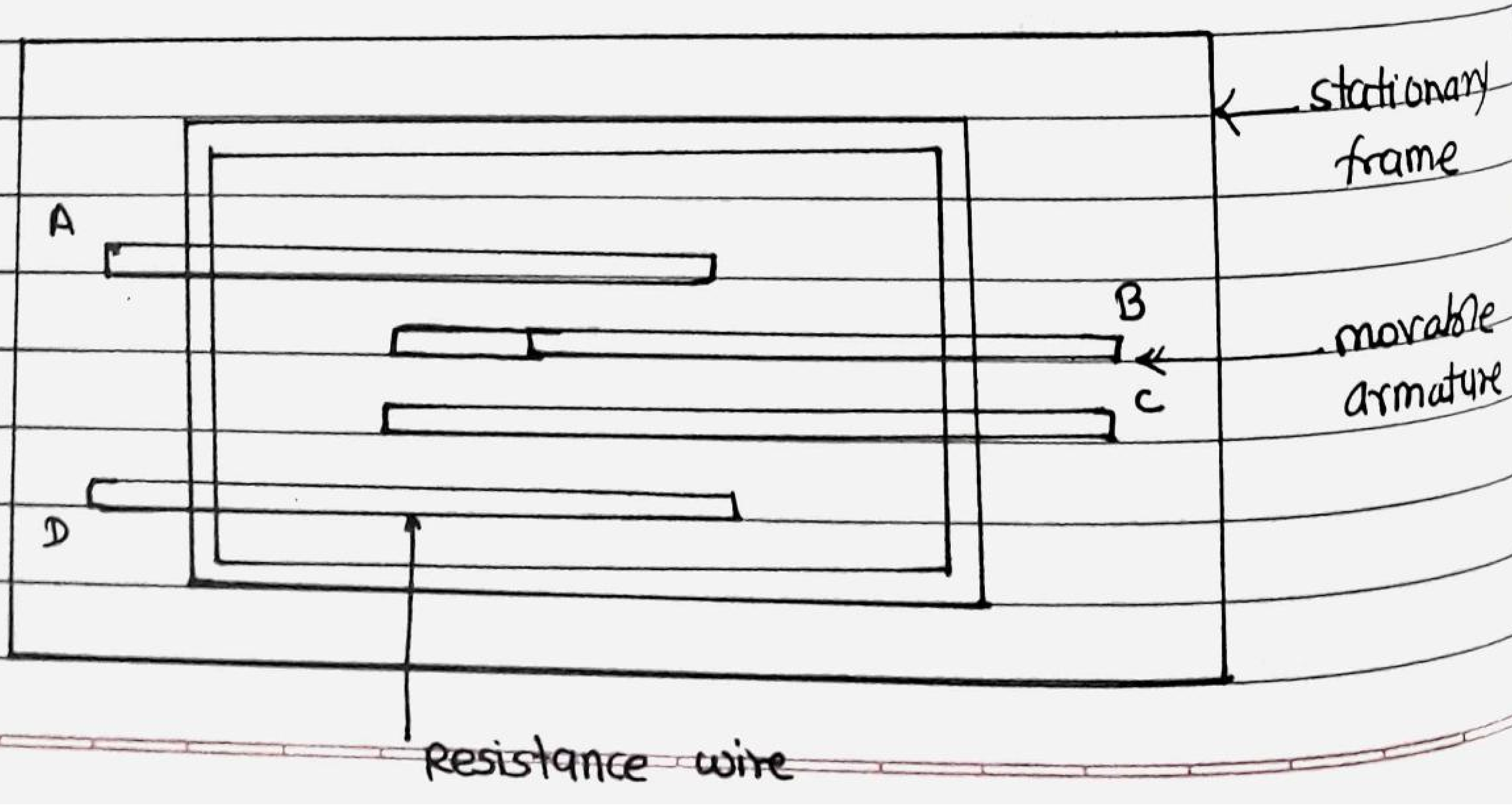
ε = strain.

The poisson's ratio for all metals is between 0 to 0.5. which gives guage factor (G) approximate 2.

The types of strain guages are -
① wire strain guage
② foil strain guage
③ semiconductor strain guage.

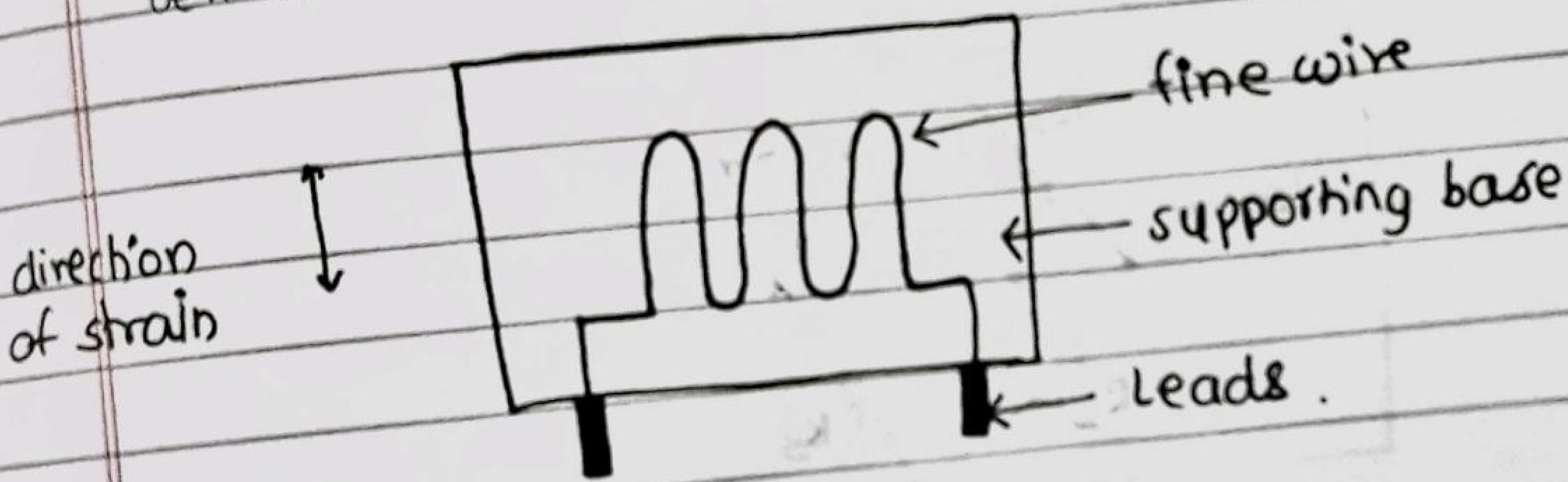
① Wire strain guage -
Resistance wire strain guages are used into two basic forms as -
ⓐ unbonded resistance wire strain guage
ⓑ bonded resistance wire strain guage.

ⓐ Unbonded resistance wire strain guage -
- The unbonded metallic strain guage is based on the principle that electrical resistance of a metallic wire changes due to the change in the tension of wire.
- This type of strain guage consists of movable platform and a stationary frame.
- Relative motion between platform and stationary frame increases the tension in two loops.
- When the external load is applied, the resistance of the strain guage changes, causing an unbalanced of the bridge circuit resulting in an output voltage.



5) Bonded Strain guage -

- Bonded strain guage is connected to a paper or a thick plastic film support. The measuring leads are soldered or welded to the guage wire.
- The bonded strain guage with the paper backing is connected to the elastic member whose strain is to be measured.
- A fine element of wire (about 25 μm) or less in diameter is looped back and forth on a carrier (base) or mounting plate, which is usually cemented to the member ~~th~~ undergoing stress.



Types of strain guages -

Some common types of strain guages are as follows -

① Grid type ② Rossette type

③ Torque type ④ Helical type.

How do ~~you~~ you measure strain with strain guage-

as mentioned, strain guages works on the principle of conductors resistance which gives the value of guage factor as

$$G = \frac{\Delta R}{R} . \varepsilon$$

In practice, the change in strain of an object is a very small quantity which can only be measured using a wheatstone Bridge.

Wheatstone Bridge circuit is as shown