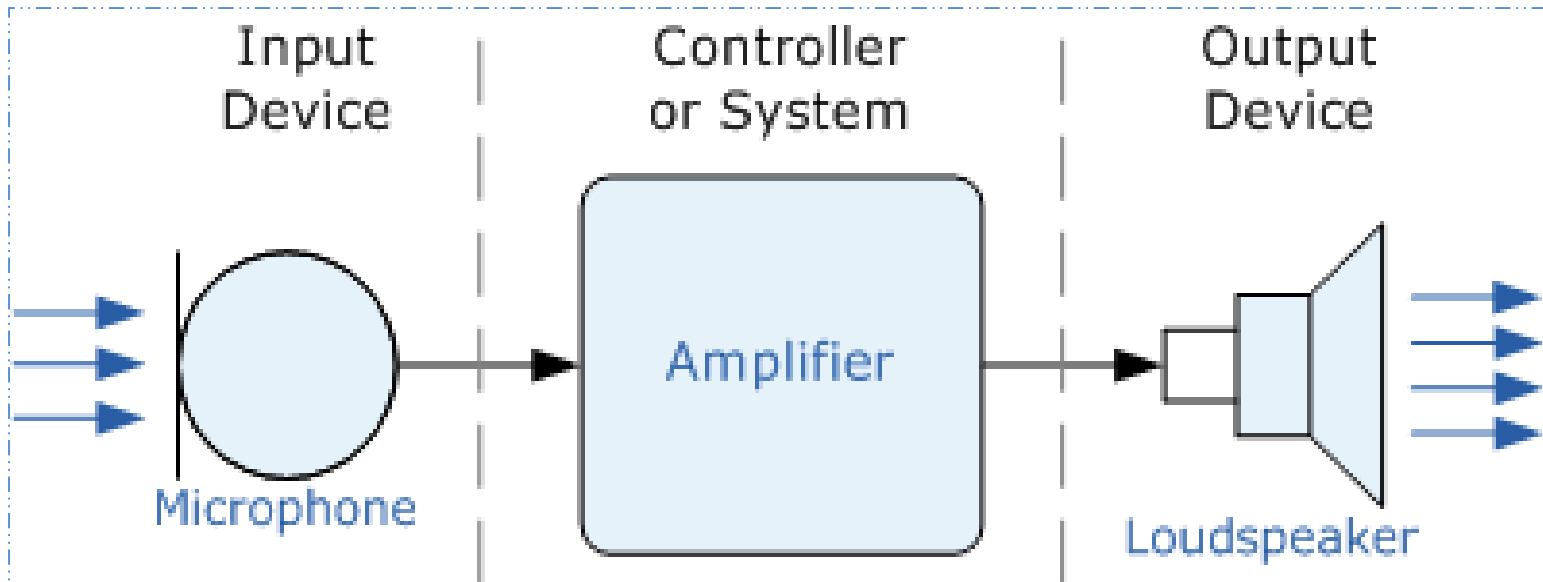


Electronic measurement and Instrumentation

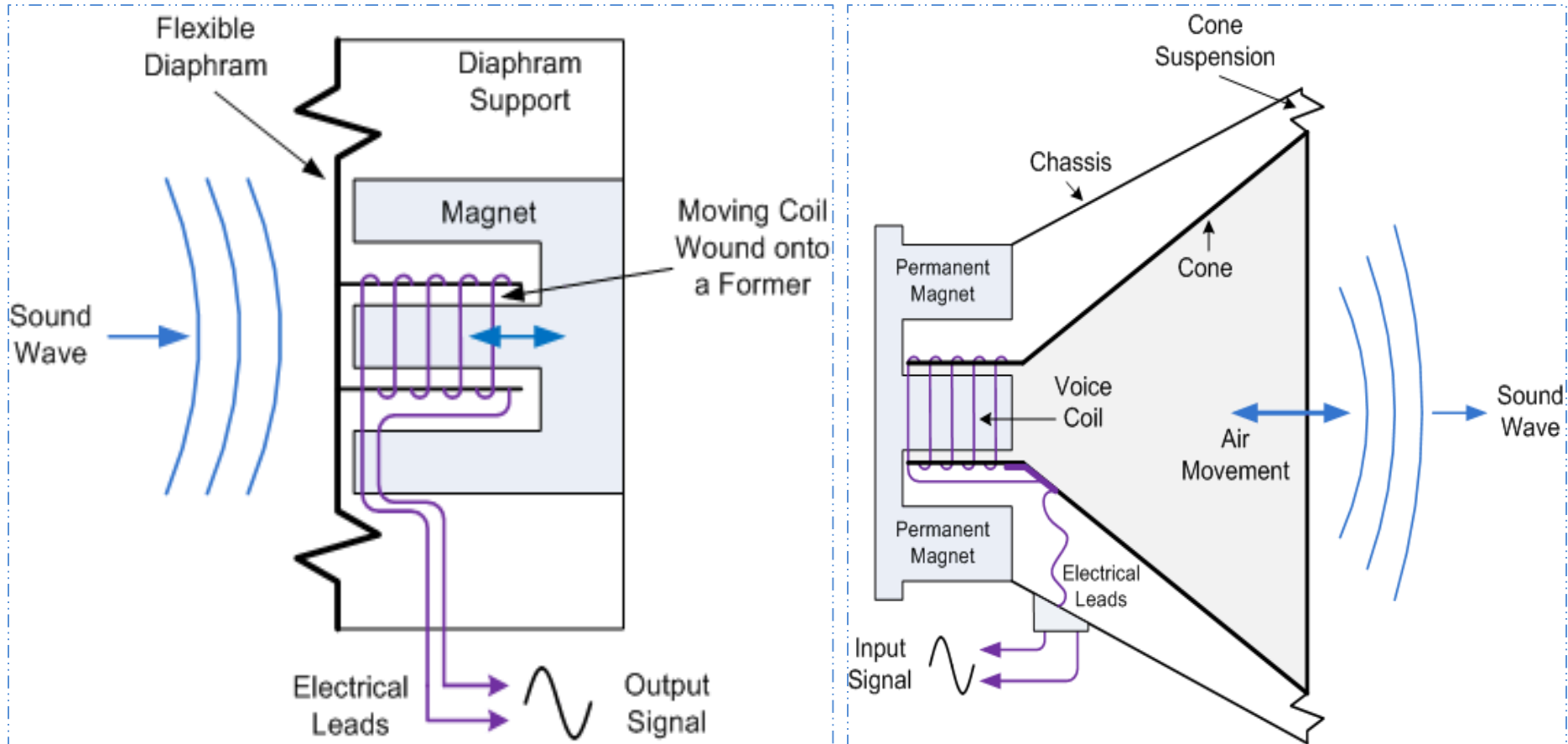
UNIT - IV

Transducer

- A transducer is a device that converts one type of energy to another.
- The input transducer is called the *sensor*.
- The output transducer is called the *actuator*.



Input and Output Transducers

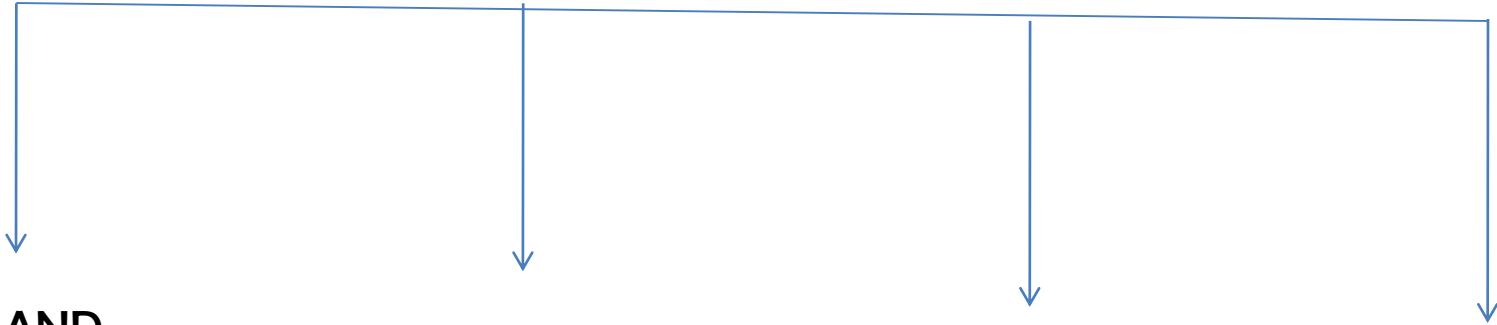


Basic requirements of a transducers

The main function of a transducer is to respond only for the measurement under specified limits for which it is designed.

- RUGGEDNESS (Capability of withstanding overload)
- LINEARITY (input – output characteristics should be linear)
- REPEATABILITY (should reproduce same output signal when the same input signal is applied again and again)
- HIGH OUTPUT SIGNAL QUALITY (quality of output signal should be good)
- HIGH RELIABILITY & STABILITY
- GOOD DYNAMIC RESPONSE (output should be faithful to input when taken as a function of time)
- NO HYSTERESIS (should not give any hysteresis during measurement)
- RESIDUAL DEFORMATION (should be no deformation on removal of load after long period of application)

CLASSIFICATION OF TRANSDUCERS



**PRIMARY AND
SECONDARY
TRANSDUCERS**

**ACTIVE AND PASSIVE
TRANSDUCERS**

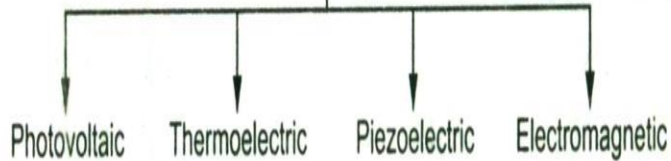
**ANALOG AND
DIGITAL
TRANSDUCERS**

**TRANSDUCERS
AND INVERSE
TRANSDUCERS**

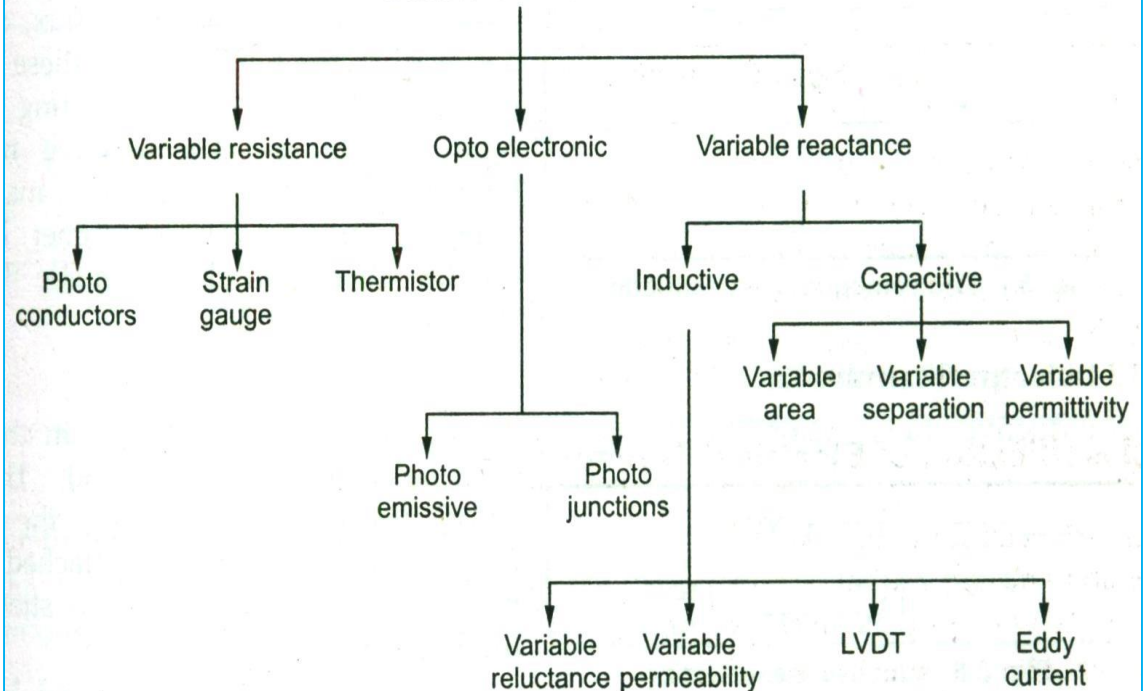
(An inverse transducer is a device which that converts an electrical quantity into a non-electrical quantity)

ACTIVE AND PASSIVE TRANSDUCERS

Active Transducers

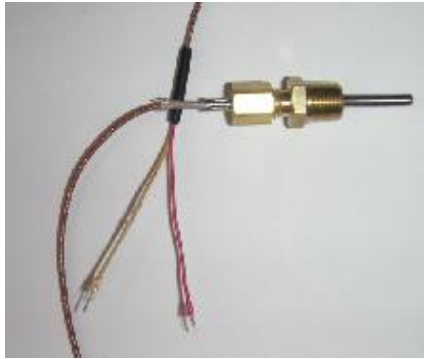


Passive Transducers



Active and Passive Transducers

- Active Transducers: The output energy of Active Transducers is supplied entirely or almost entirely by its input signal.
- Passive Transducers: Have an auxiliary source of power. This power source is necessary for the operation of passive transducers.



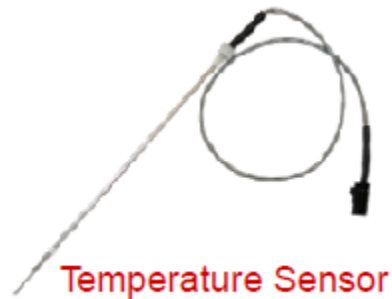
Thermocouple (Active Transducer)



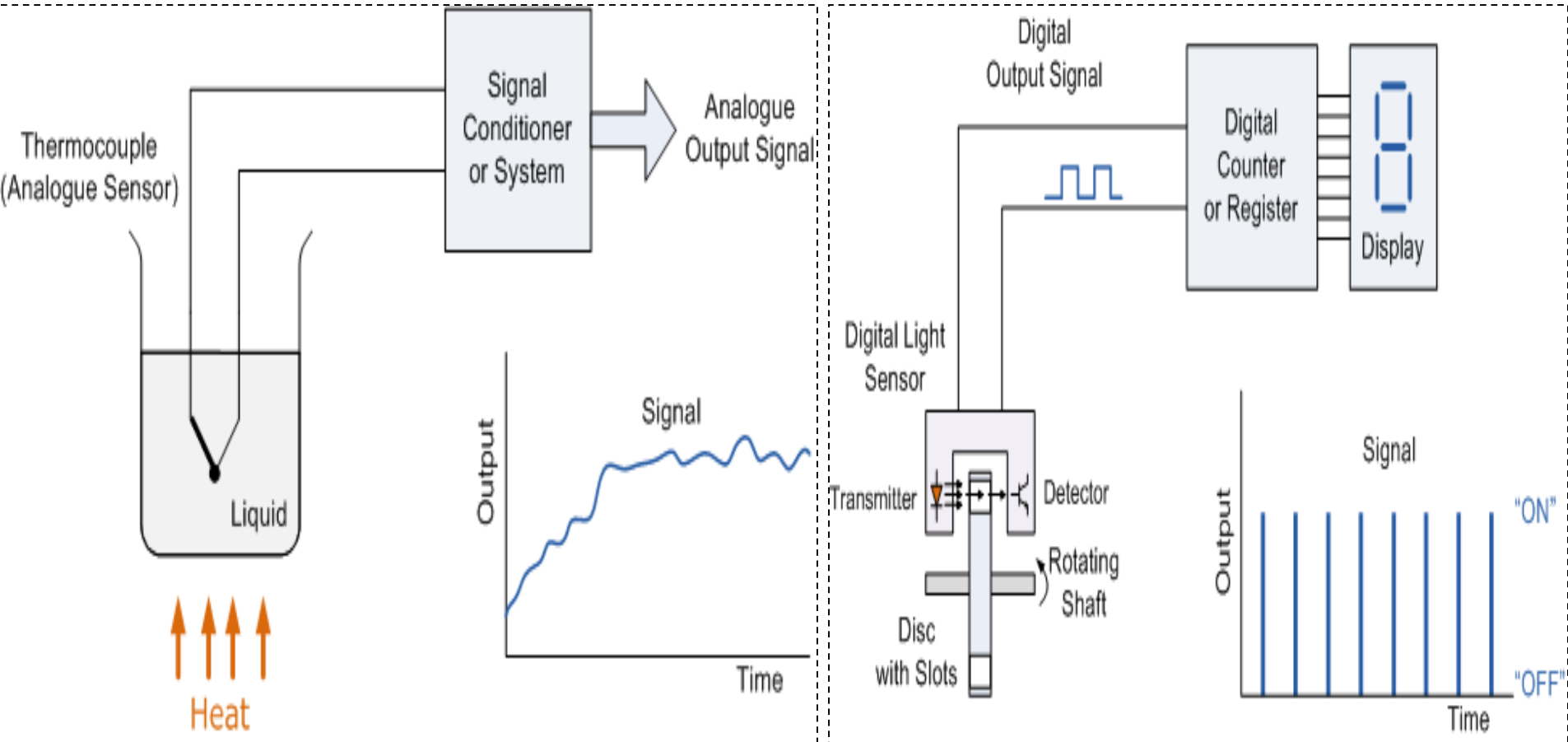
Mic (Passive Transducer)

Primary Sensing Element

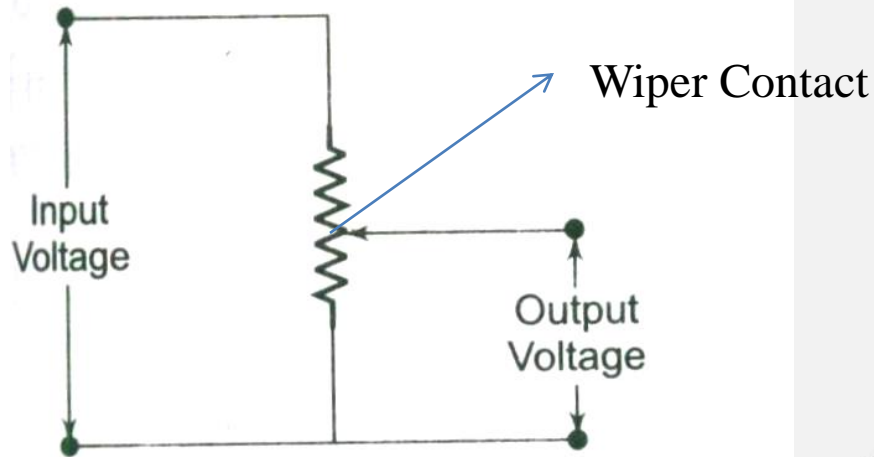
- sometimes called pickup, sensor, or transducer.
- It detects the physical variable to be measured, e.g. pressure, temperature, rate of flow, etc. and converts the signal into a more usable form.
- In practice the physical variable is usually transformed into a mechanical or an electrical signal.



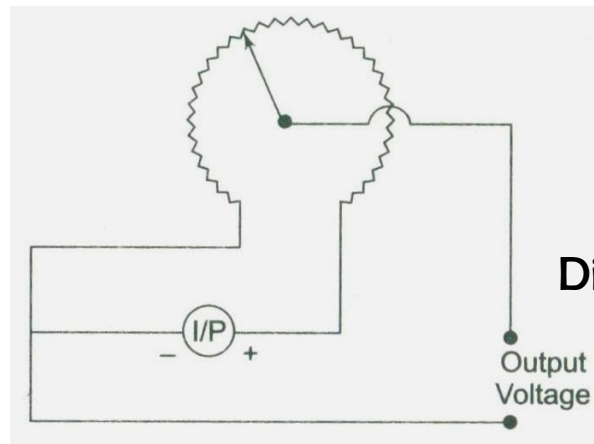
Analog and Digital



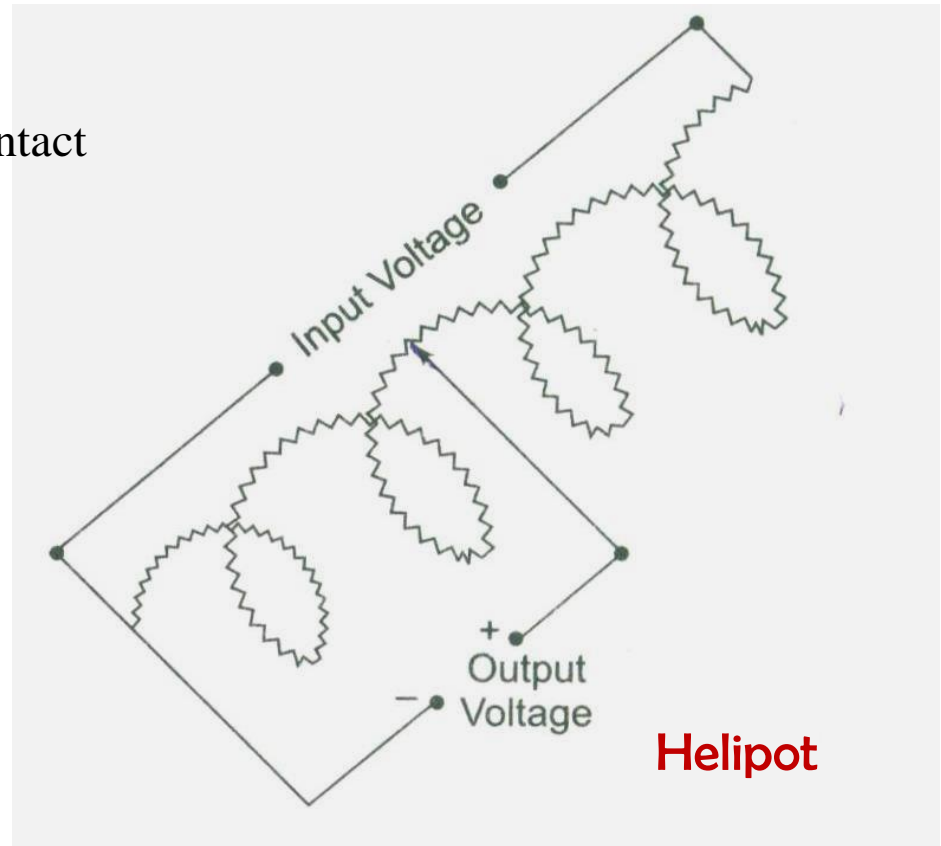
Resistive Transducer (Potentiometer)



Translatory (Displacement)



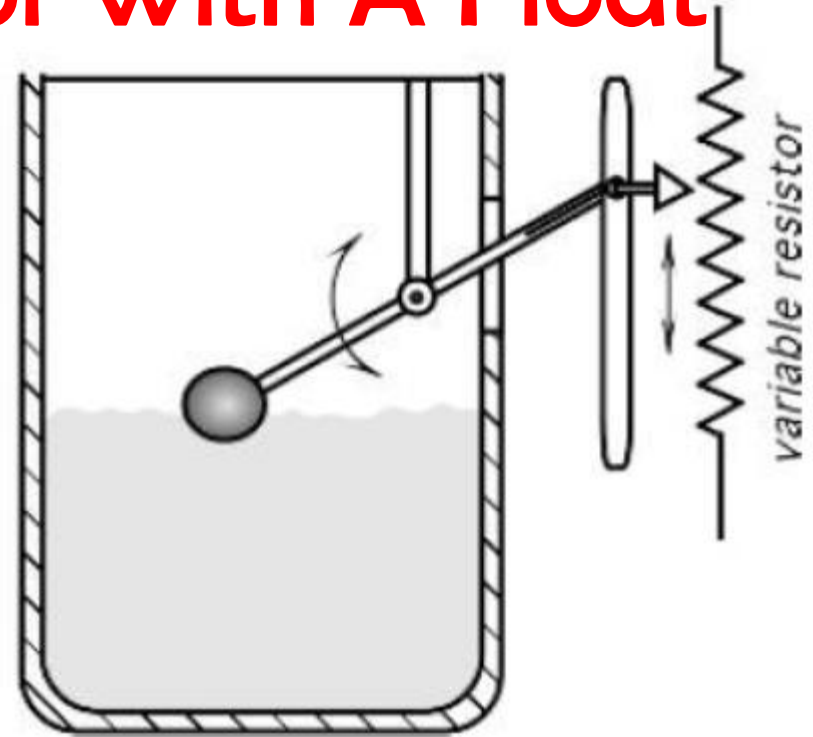
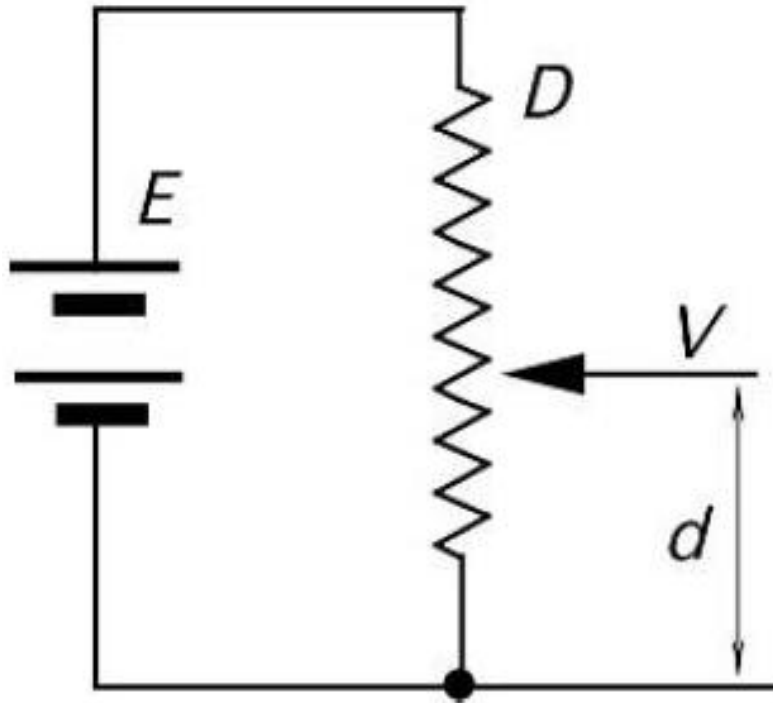
Rotational



$$V_o = \frac{R_2}{R_1 + R_2} V_T$$

Resistive Transducer

Fluid Level Sensor With A Float

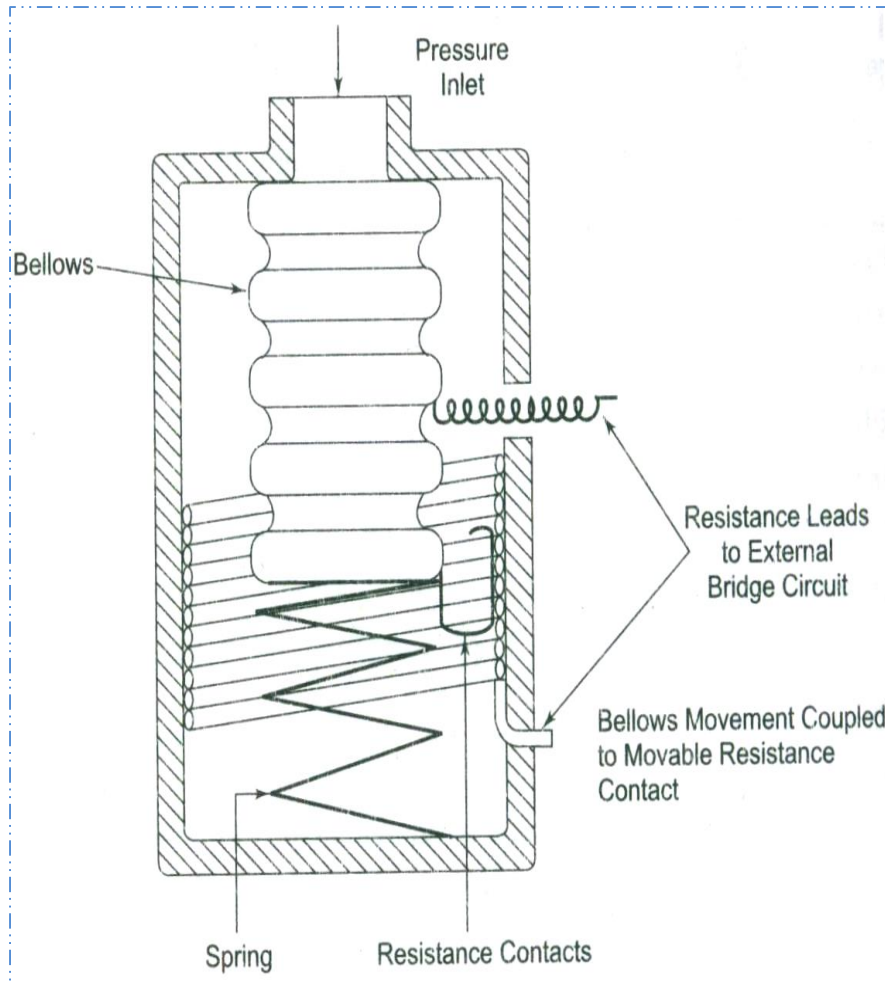


The voltage V across the wiper of a linear pot is proportional to the displacement d

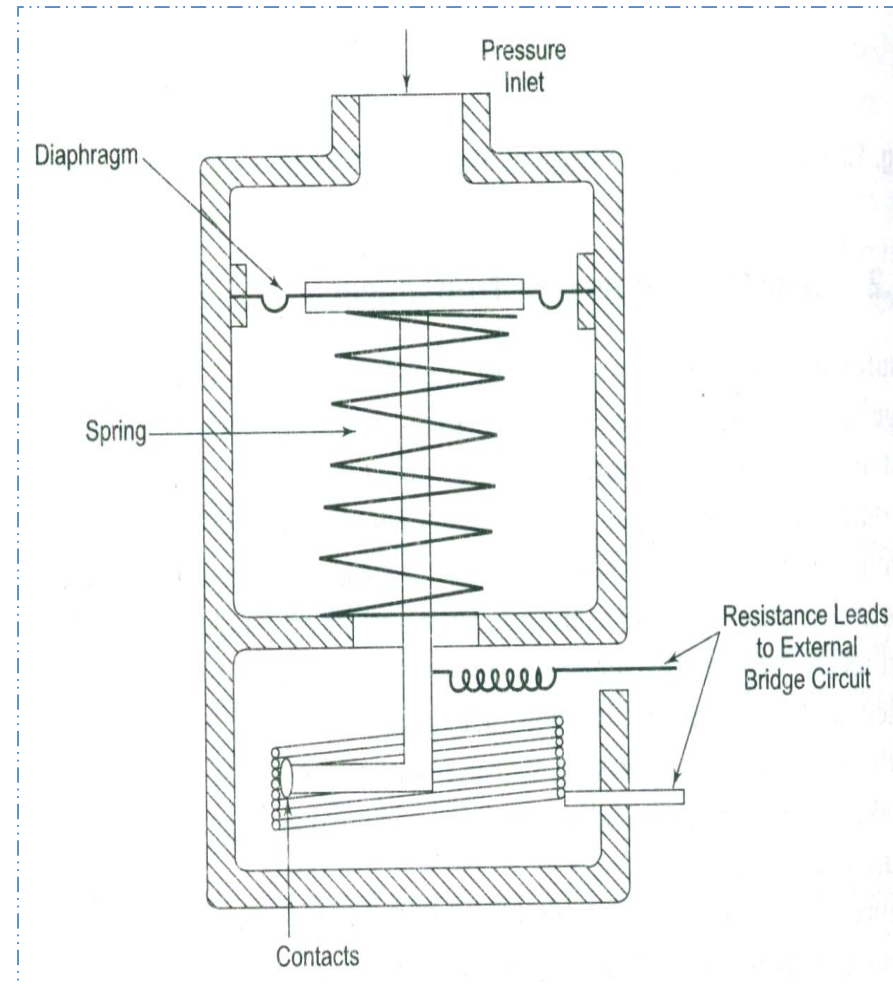
$$V = E \left(\frac{d}{D} \right)$$

Where D is the full-scale displacement and E is the voltage across the pot

Resistance Pressure Transducer



Resistance Pressure Transducer

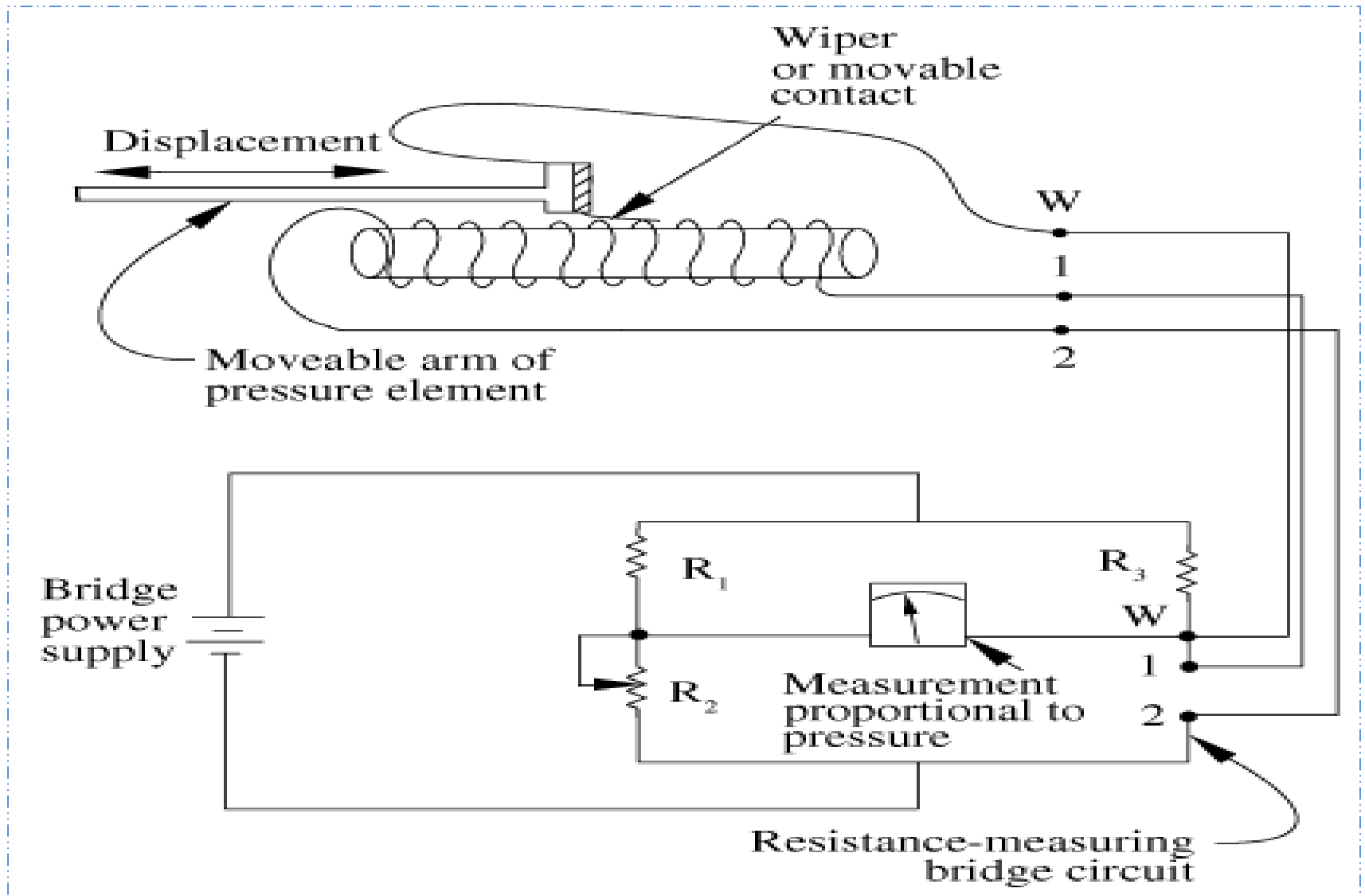


Sensitive Diaphragm Moves Resistance Contact

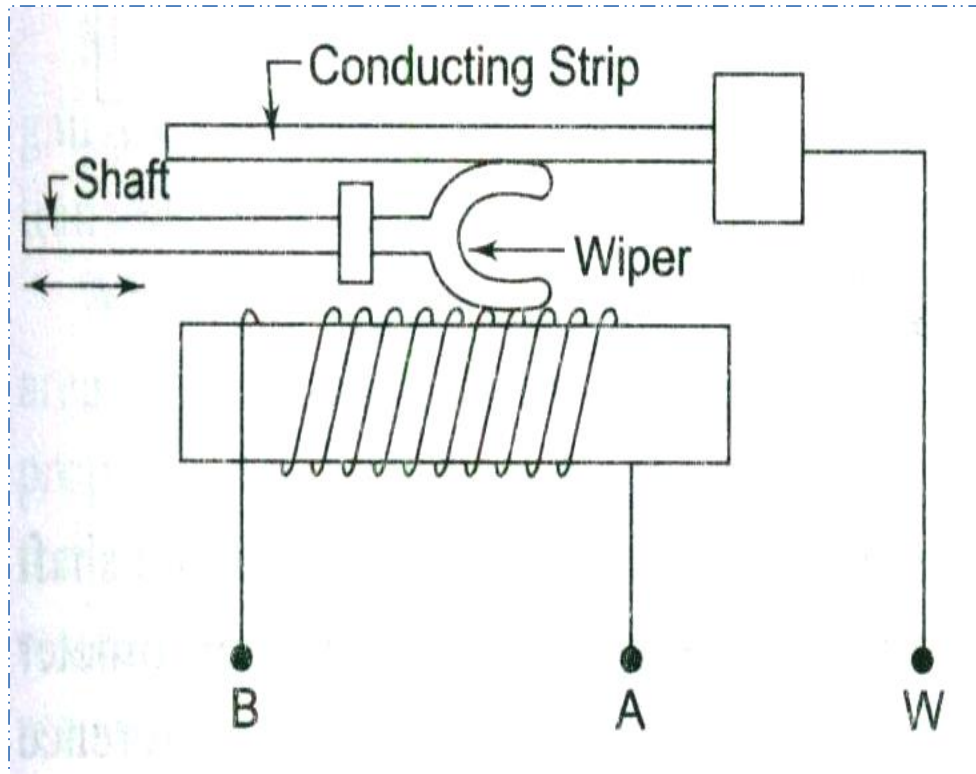
Bellows and Diaphragm



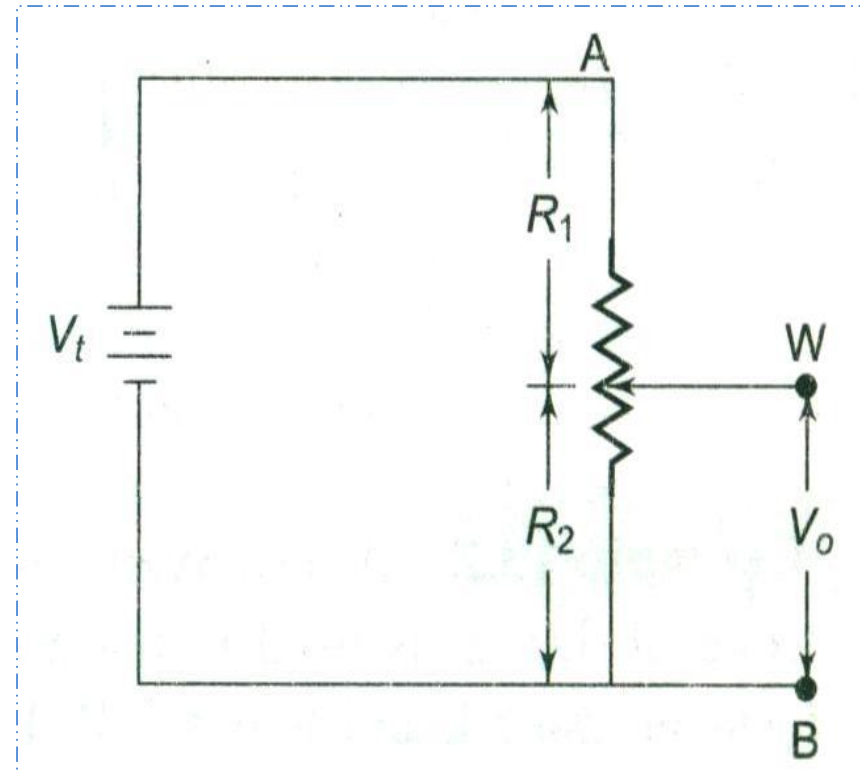
Resistive Transducer



Resistance Pressure Transducer

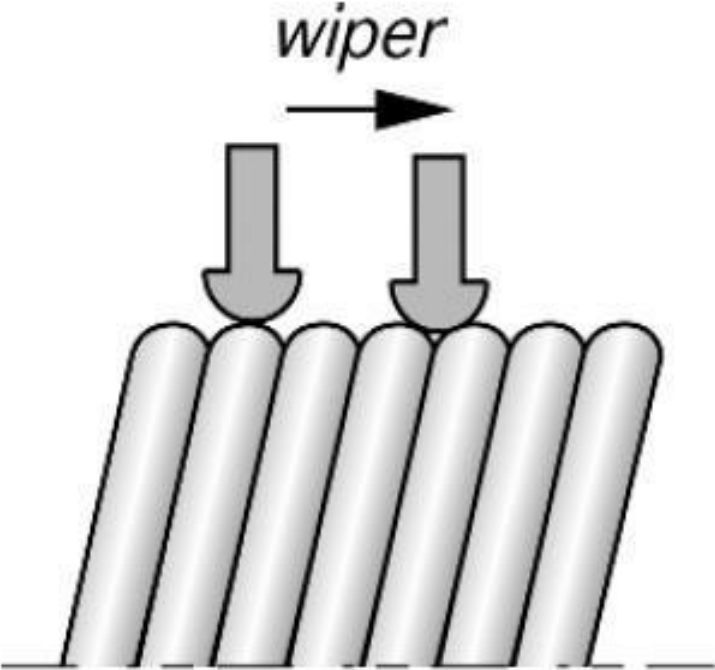


Construction

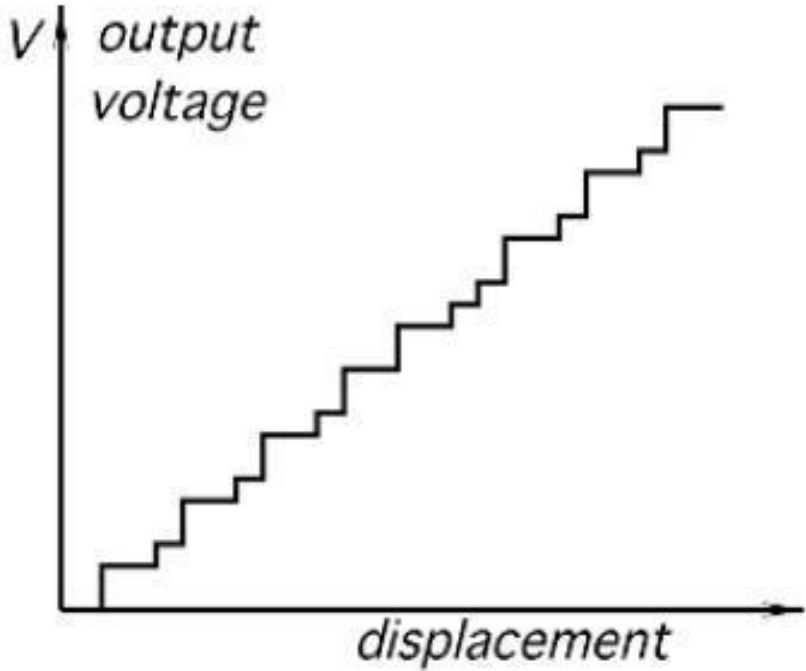


Typical Method

Wiper Contact



(A)



(B)

Strain Gauges

1. Wire Strain Gauges

➤ Resistance Wire

- i. Unbounded ii. Bounded

➤ Wire Types

- i. Grid ii. Rossette ii. Torque iv. Helical

2. Foil Strain Gauges

3. Semiconductor Strain Gauges

Stress and Strain

➤ **Stress** is a measure of the average amount of **force** exerted per unit **area**. It is a measure of the intensity of the total internal **forces** acting within a body across imaginary internal surfaces, as a reaction to external applied forces and **body forces**.

In general, stress is expressed as

$$\sigma = \frac{F}{A}$$

σ is the average stress, also called nominal **stress** and F is the force acting over the area A .

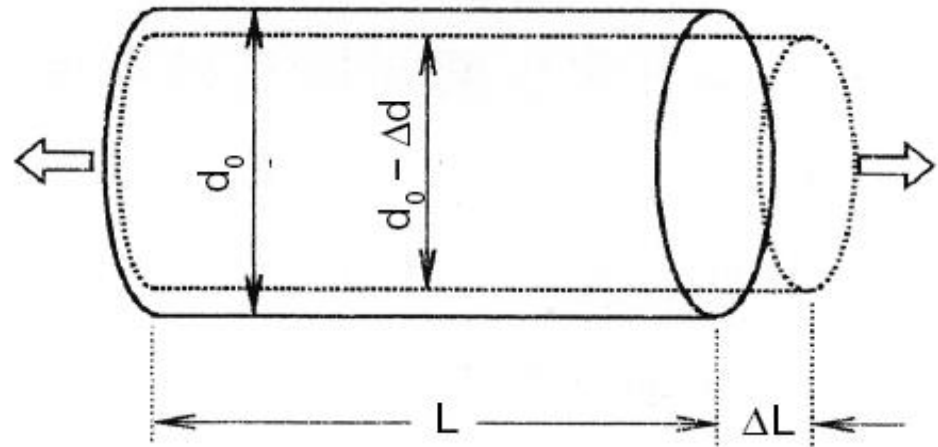
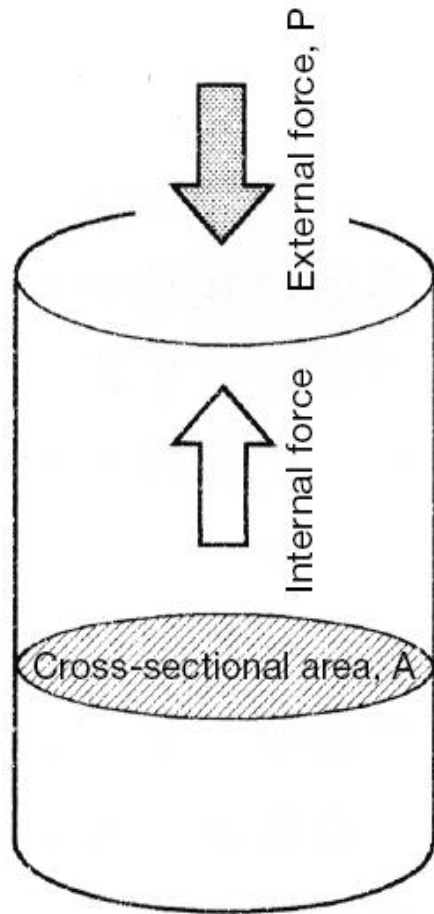
➤ **Strain** is the geometrical expression of deformation caused by the action of **stress** on a physical body. Strain is calculated by first assuming a change between two body states: the beginning state and the final state. Then the difference in placement of two points in this body in those two states expresses the numerical value of strain. Strain therefore expresses itself as a change in size and/or shape.

The strain is defined as the fractional change in length

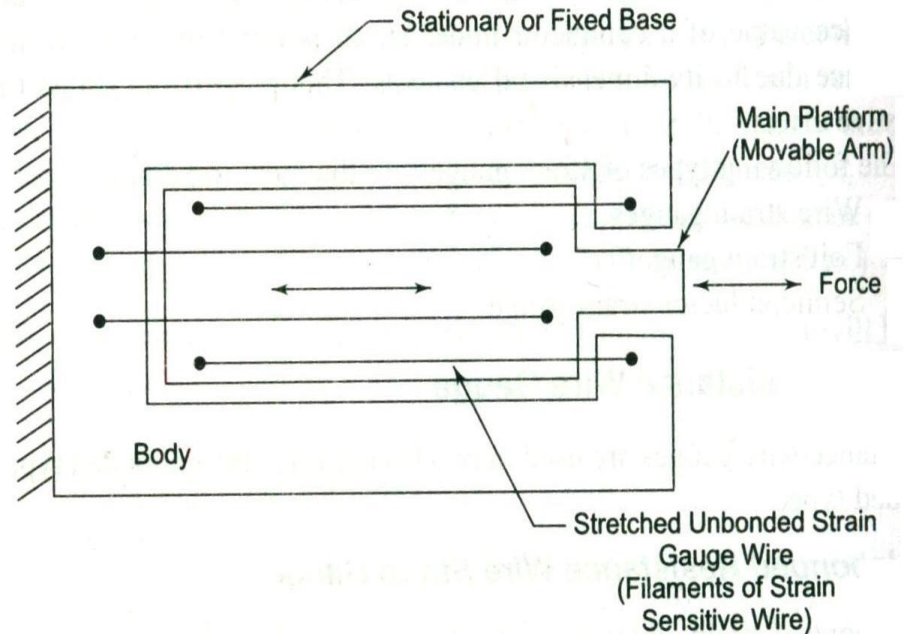
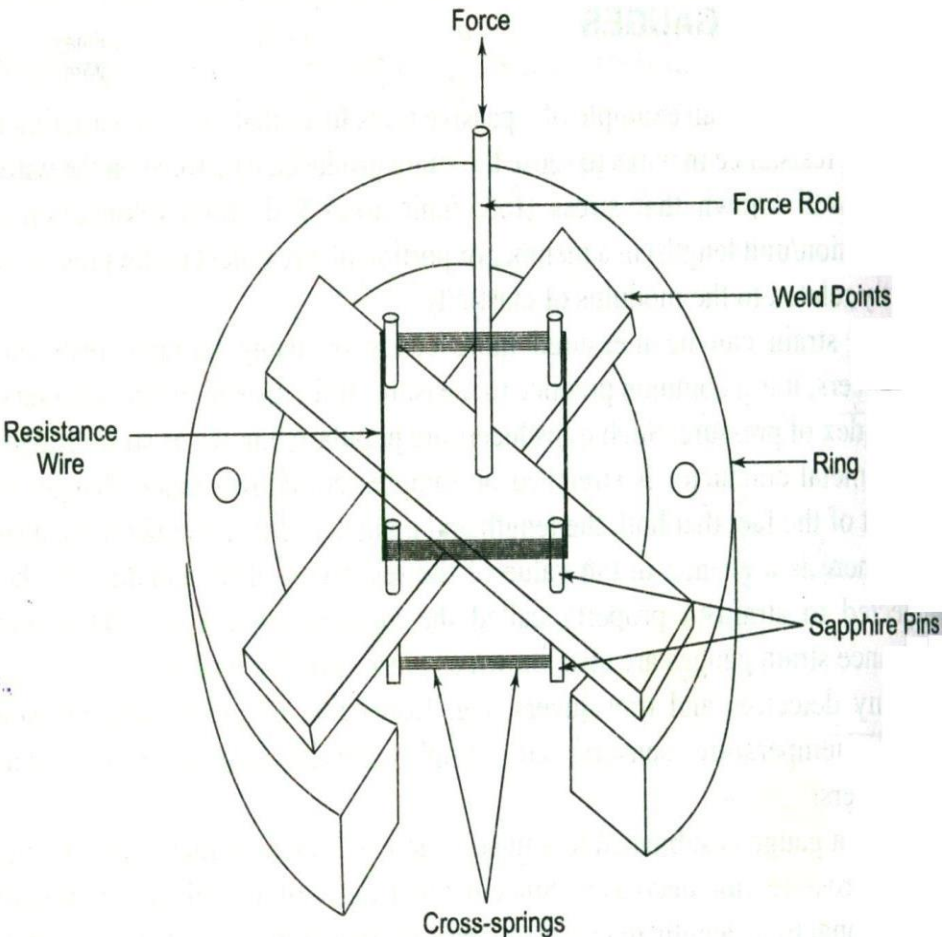
Strain is thus a unit less quantity

$$strain = \frac{\Delta l}{l}$$

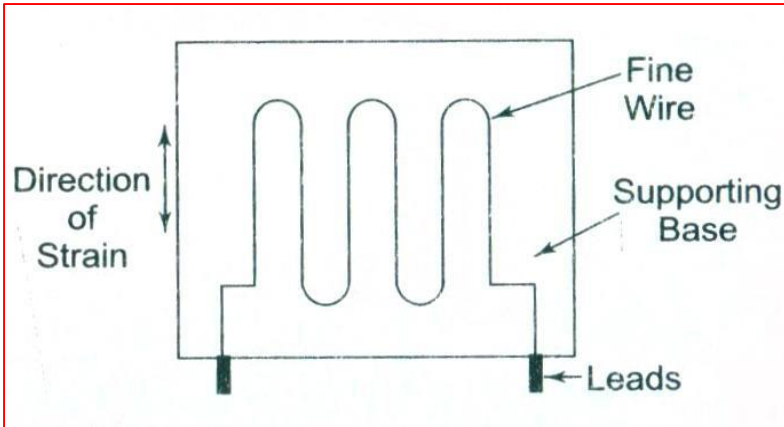
Stress and Strain



Unbonded Resistance Wire Strain Gauge

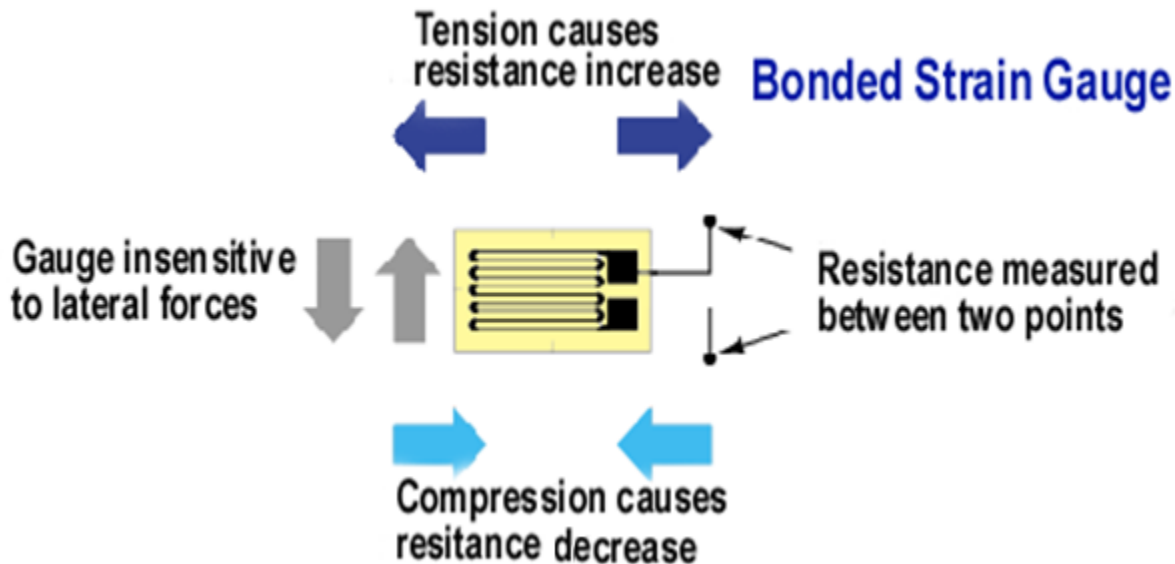


Bonded Resistance Wire Strain Gauge



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

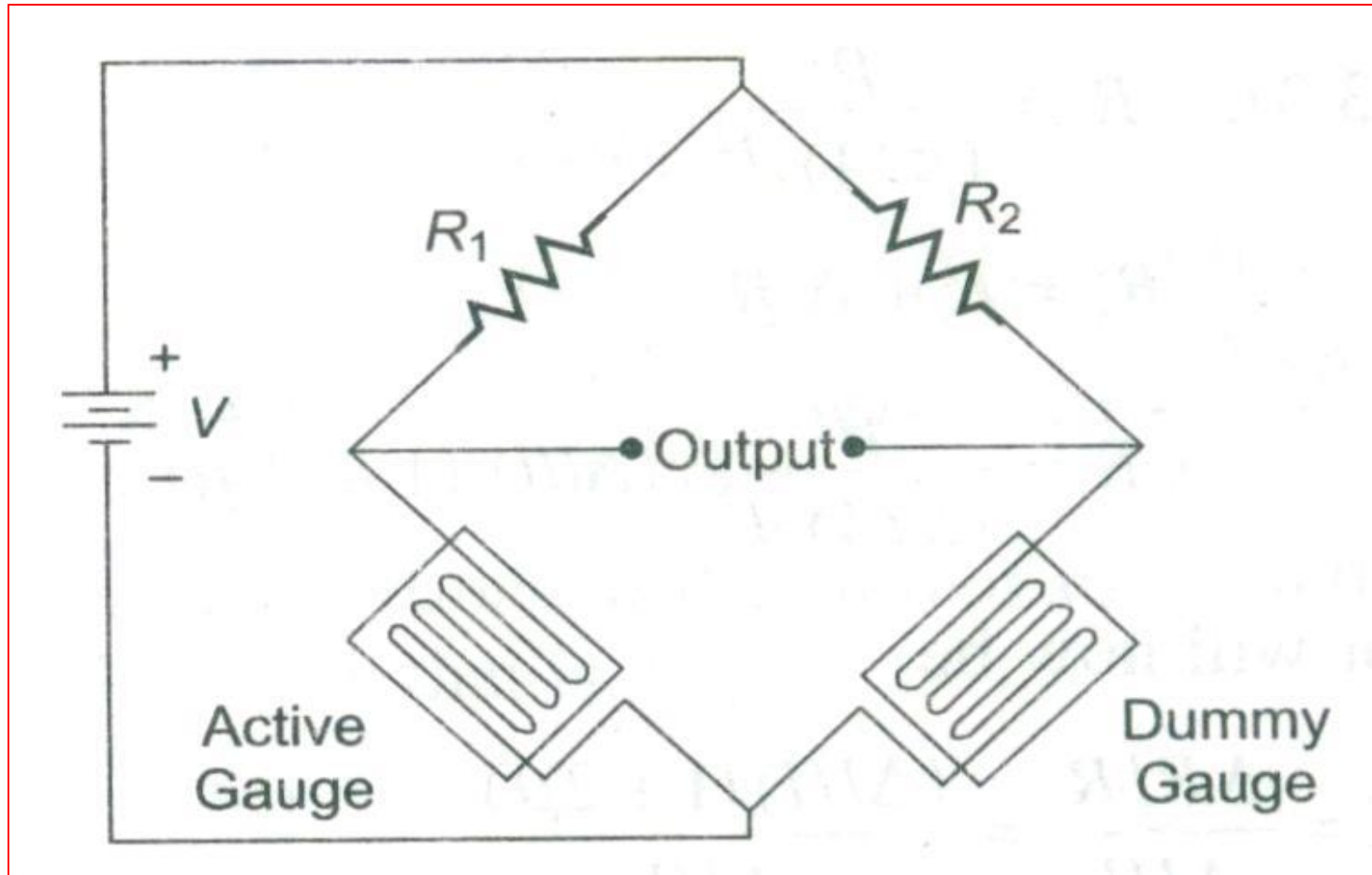
Resistance



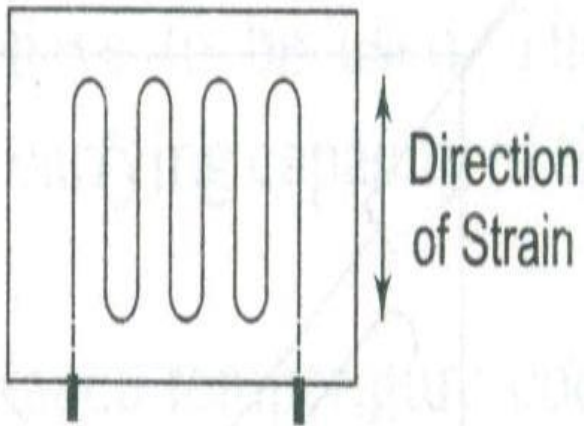
$$GF(K) = \frac{\Delta R / R}{\Delta l / l}$$

Gauge Factor (K)

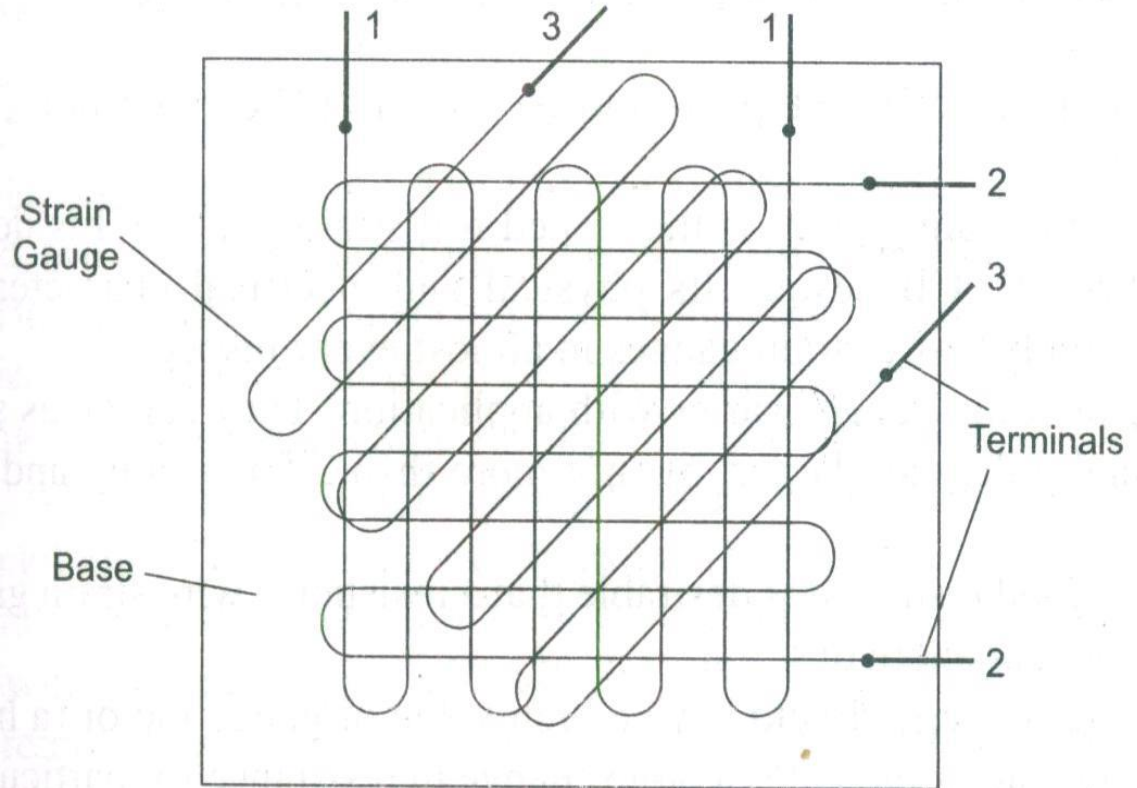
Strain Gauge In Bridge Arrangement



Types of Strain Gauges

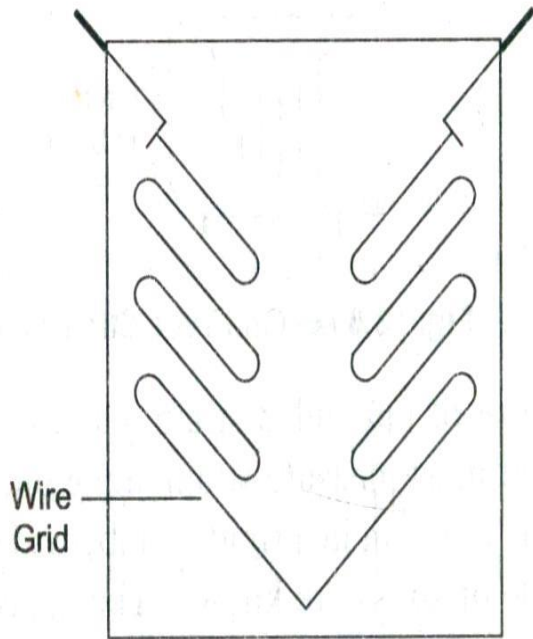


Grid Type Strain Gauge

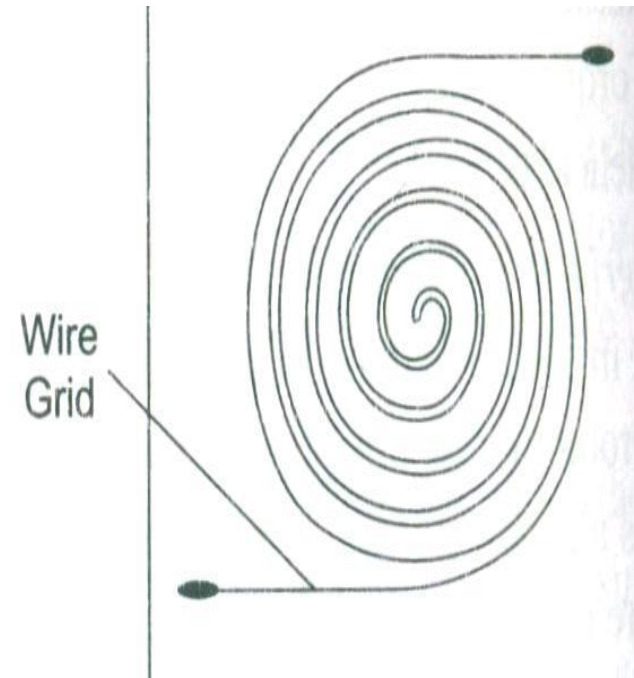
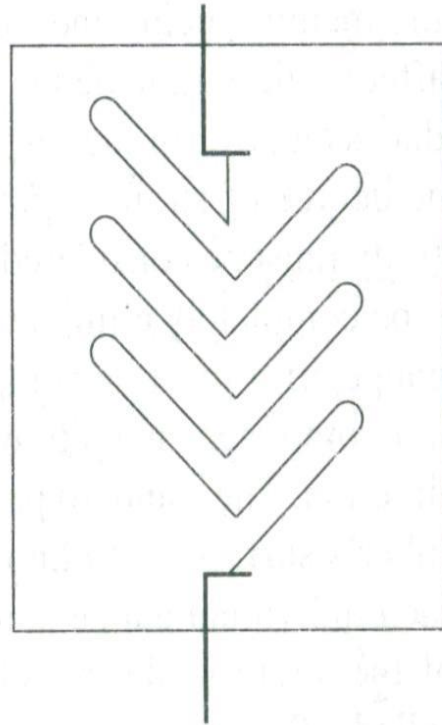


Rosette Gauge

Types of Strain Gauges



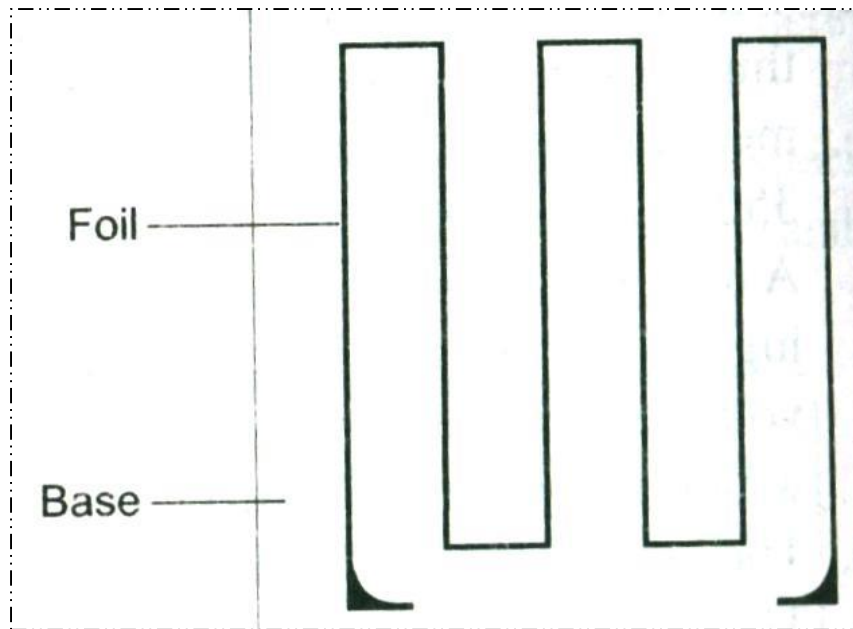
Torque Type Gauges



Helical Gauge

120 Ω , 350 Ω & 1000 Ω

Foil Strain Gauges

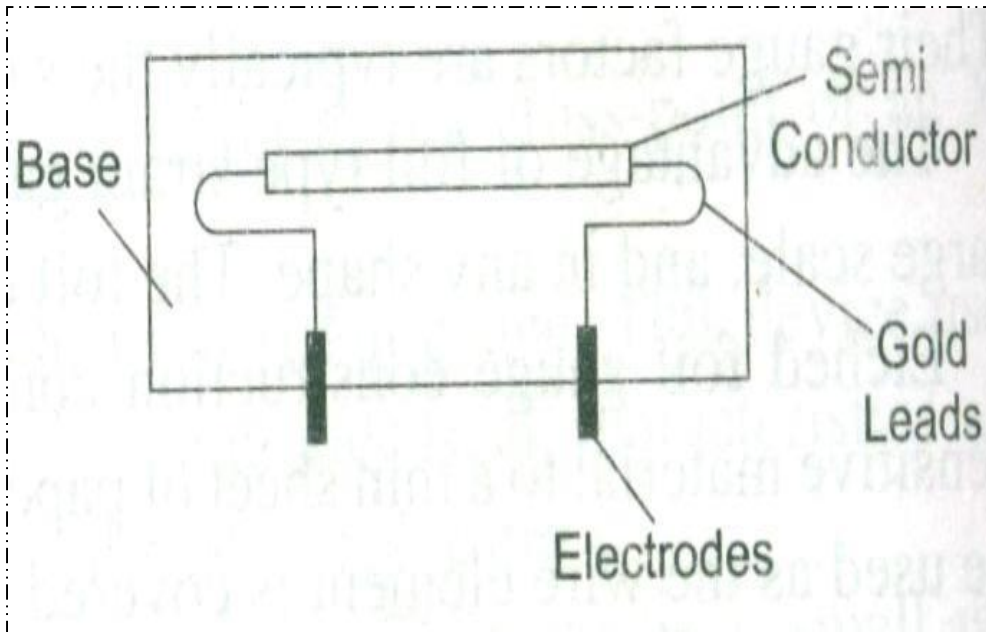


**Better for higher operating
temperature ranges**

0.2mm thick

50 & 1000 Ω

Semiconductor Strain Gauges



For Very high Gauge Factor (+130)

0.7 – 7.0 mm

Resistances as Wired Types

Temperature Measurement

The *International Practical Temperature Scale (IPTS)* defines six primary fixed points for reference temperatures in terms of:

- The triple point of equilibrium hydrogen 259.34°C
- The boiling point of oxygen 182.962°C
- The boiling point of water 100.0°C
- The freezing point of zinc 419.58°C
- The freezing point of silver 961.93°C
- The freezing point of gold 1064.43°C

(all at standard atmospheric pressure)

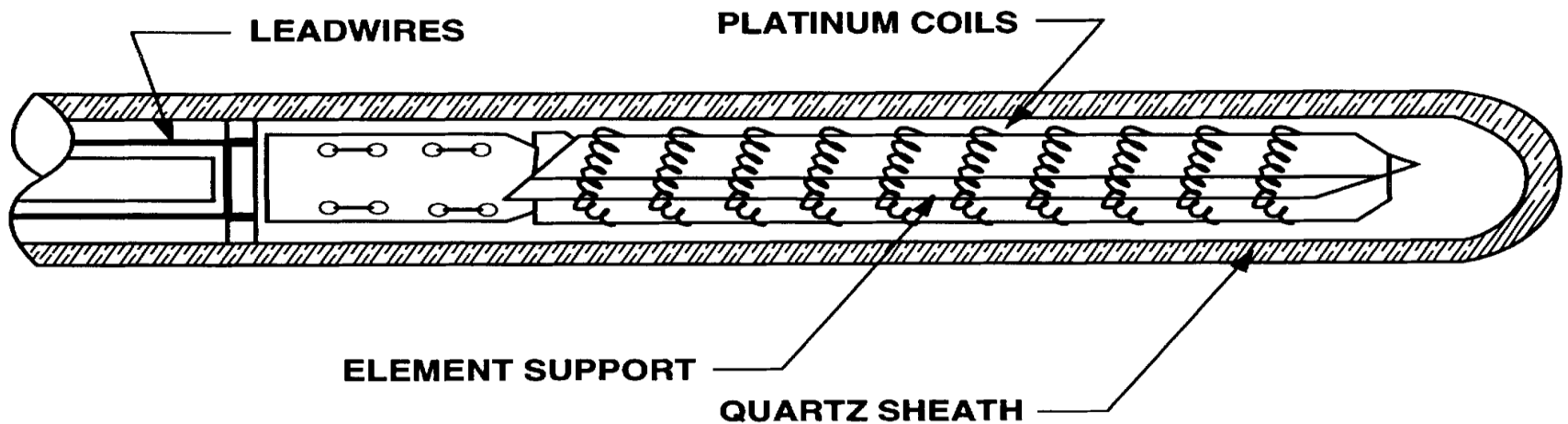
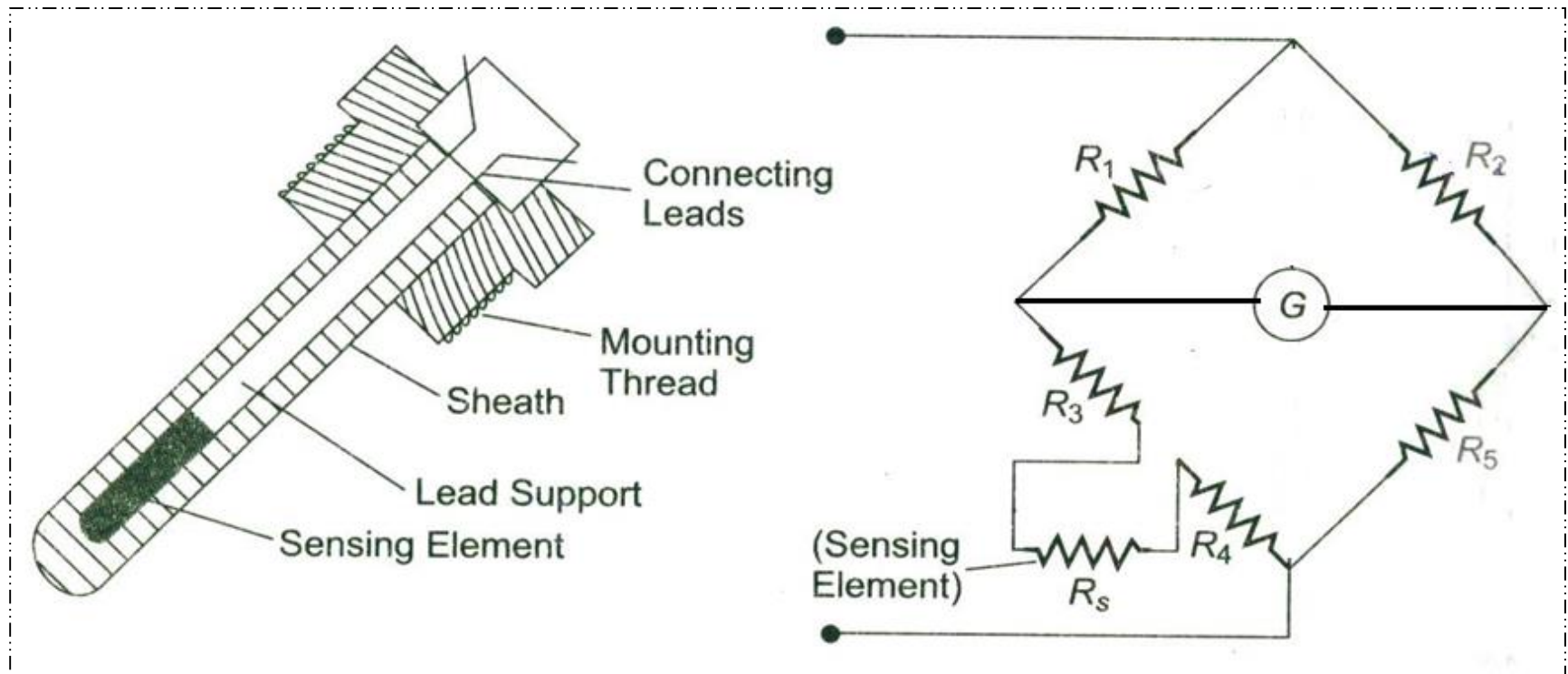
The freezing points of certain other metals are also used as *secondary fixed points* to provide additional reference points during calibration procedures.

Instruments to measure temperature can be divided into separate classes according to the physical principle on which they operate.

The main principles used are:

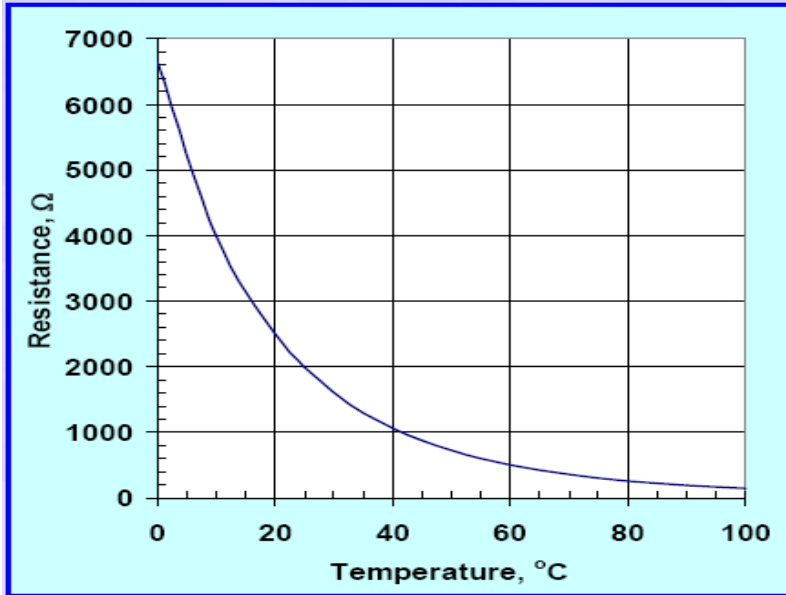
- The thermoelectric effect
- Resistance change
- Sensitivity of semiconductor device
- Radiative heat emission
- Thermography
- Thermal expansion
- Resonant frequency change
- Sensitivity of fibre optic devices
- Acoustic thermometry
- Colour change
- Change of state of material.

Resistance Thermometer



THERMISTOR

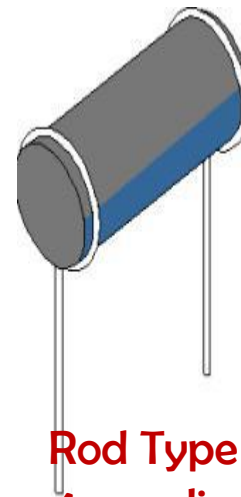
THERMally sensitive res**ISTOR**



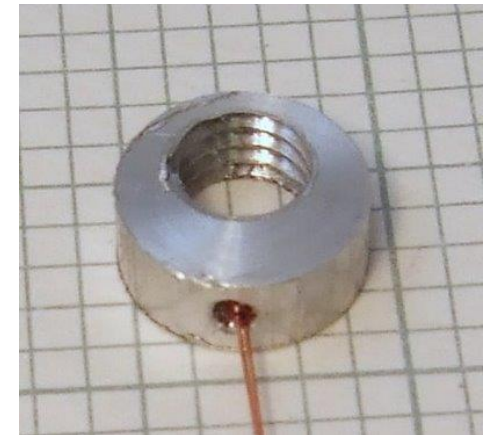
Disk Type (10mm)



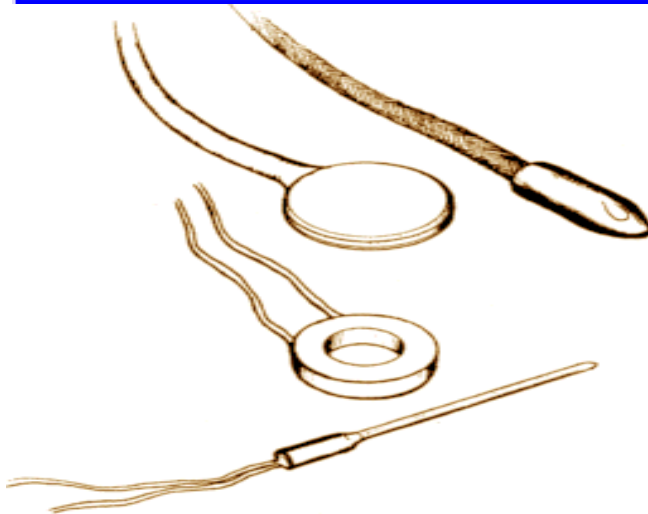
Bead Type (0.15 mm)



Rod Type
4mm dia
12.5-50mm long

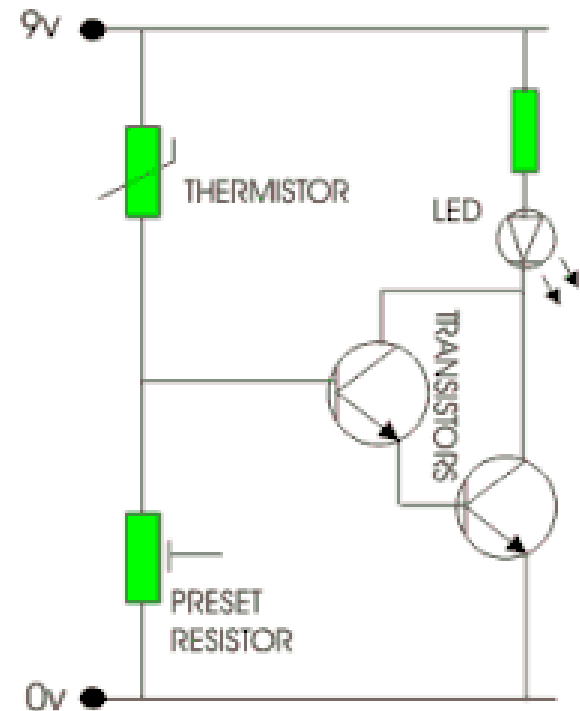
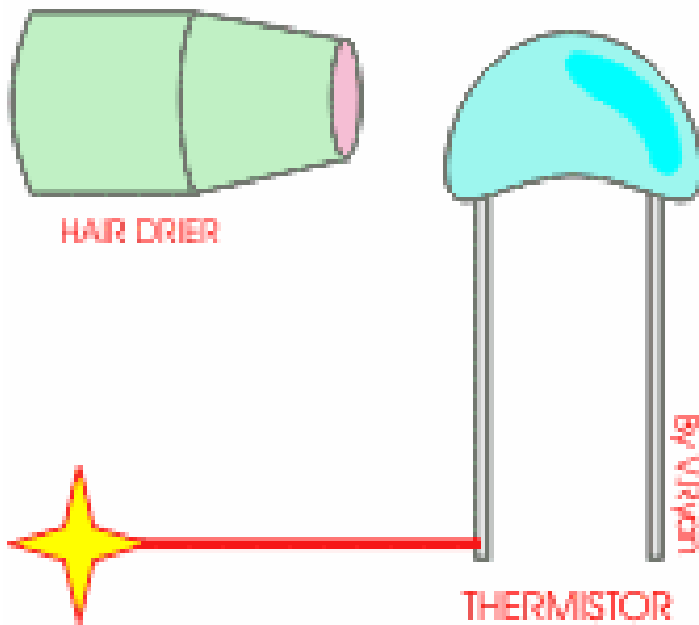


Washer Type



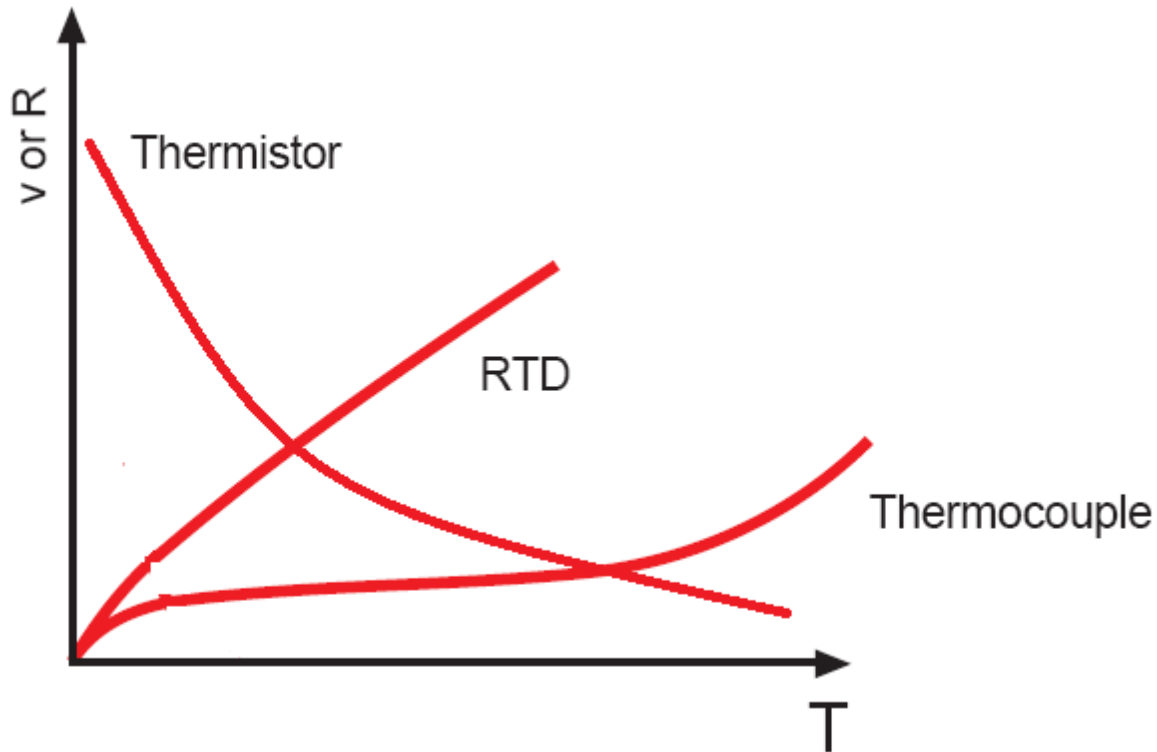
Thermistors

THERMally sensitive resISTOR

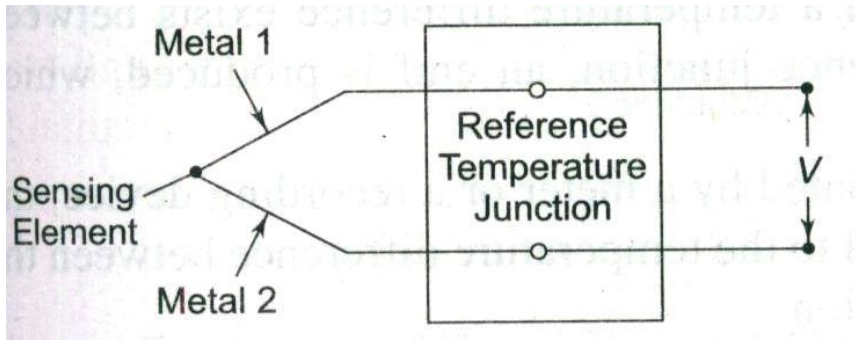


Thermistor Example

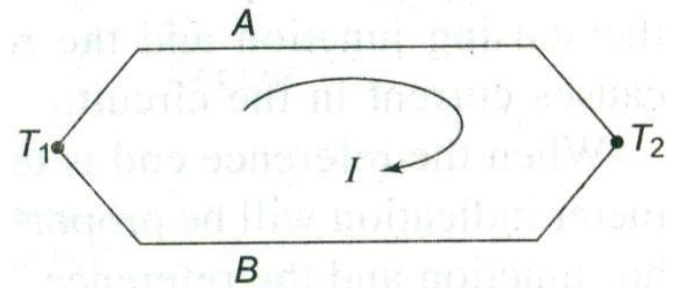
RTD , Thermistor & Thermocouple



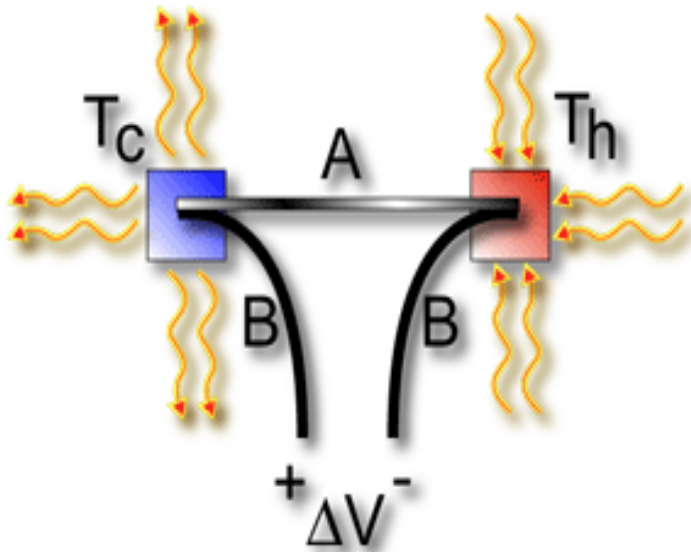
Thermocouple



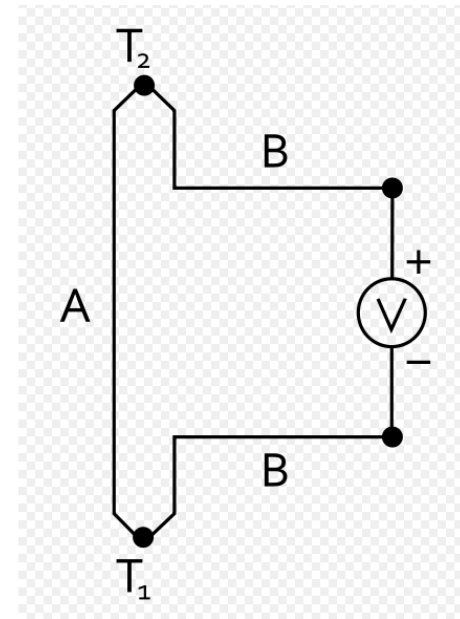
Thermocouple Connection



Current through Two Dissimilar Metals



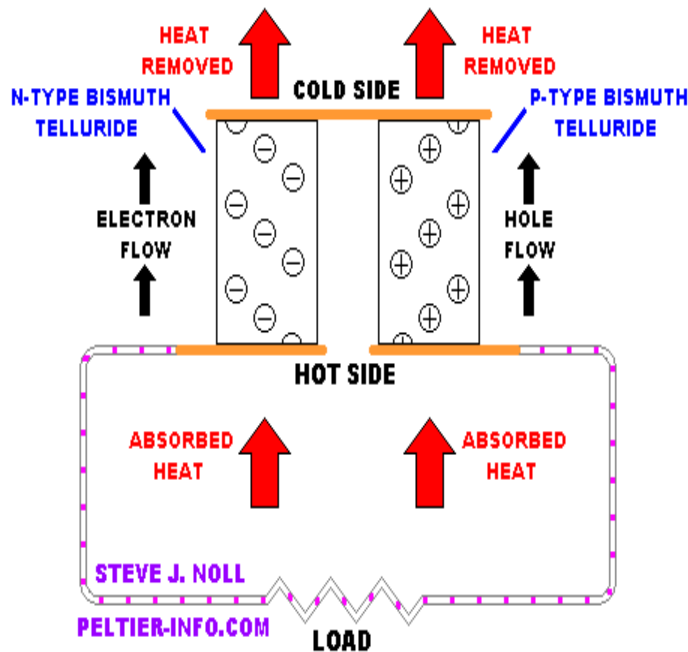
$$V = \alpha(T_h - T_c)$$



Seebeck Effect Circuit

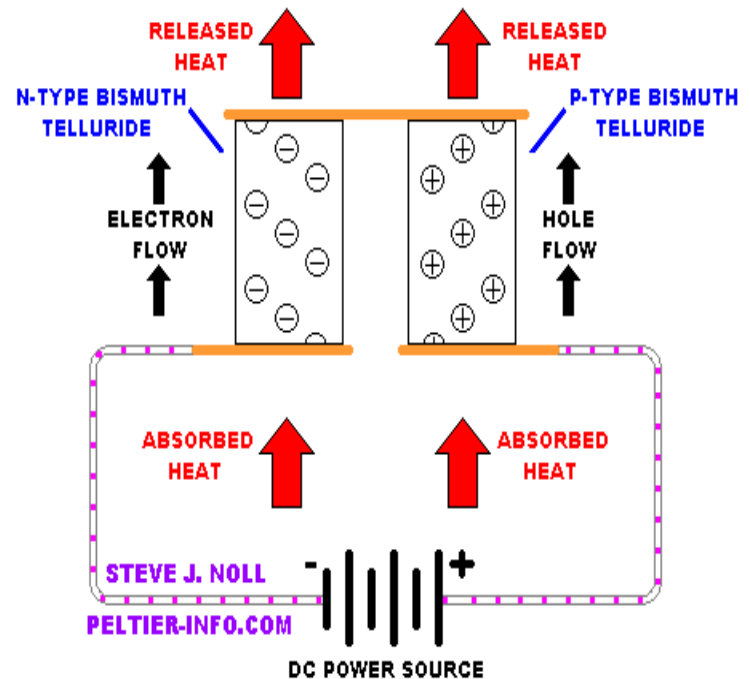
Seebeck effect & Peltier effect

ONE SEEBECK DEVICE "COUPLE" CONSISTS OF ONE N-TYPE AND ONE P-TYPE SEMICONDUCTOR PELLET



THERE MUST BE A TEMPERATURE DIFFERENCE BETWEEN THE HOT AND COLD SIDES FOR POWER TO BE GENERATED

ONE PELTIER DEVICE "COUPLE" CONSISTS OF ONE N-TYPE AND ONE P-TYPE SEMICONDUCTOR PELLET



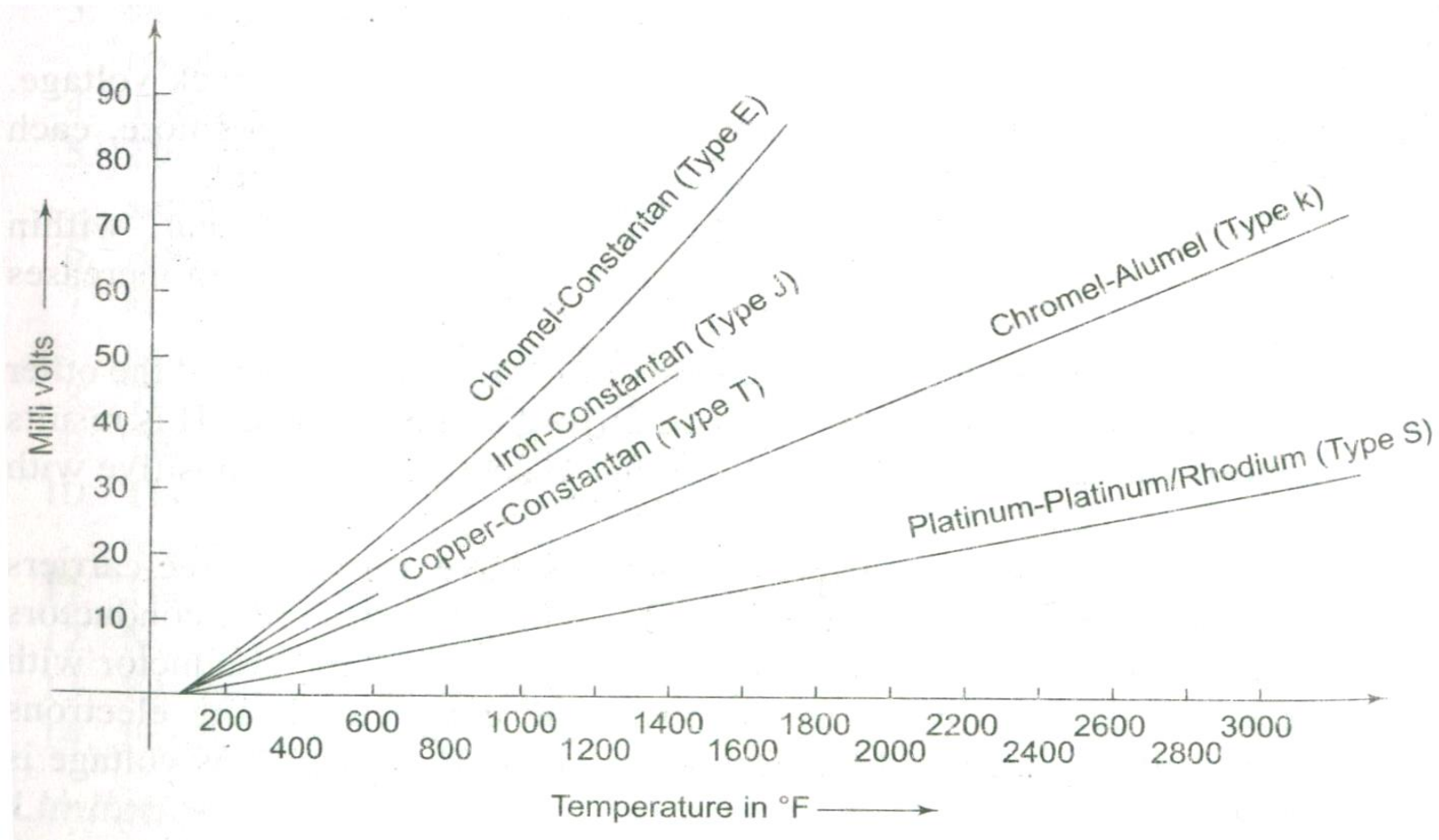
THE CHARGE CARRIERS, NEGATIVE ELECTRONS AND POSITIVE HOLES, TRANSPORT THE HEAT.

Thermocouples (Types)

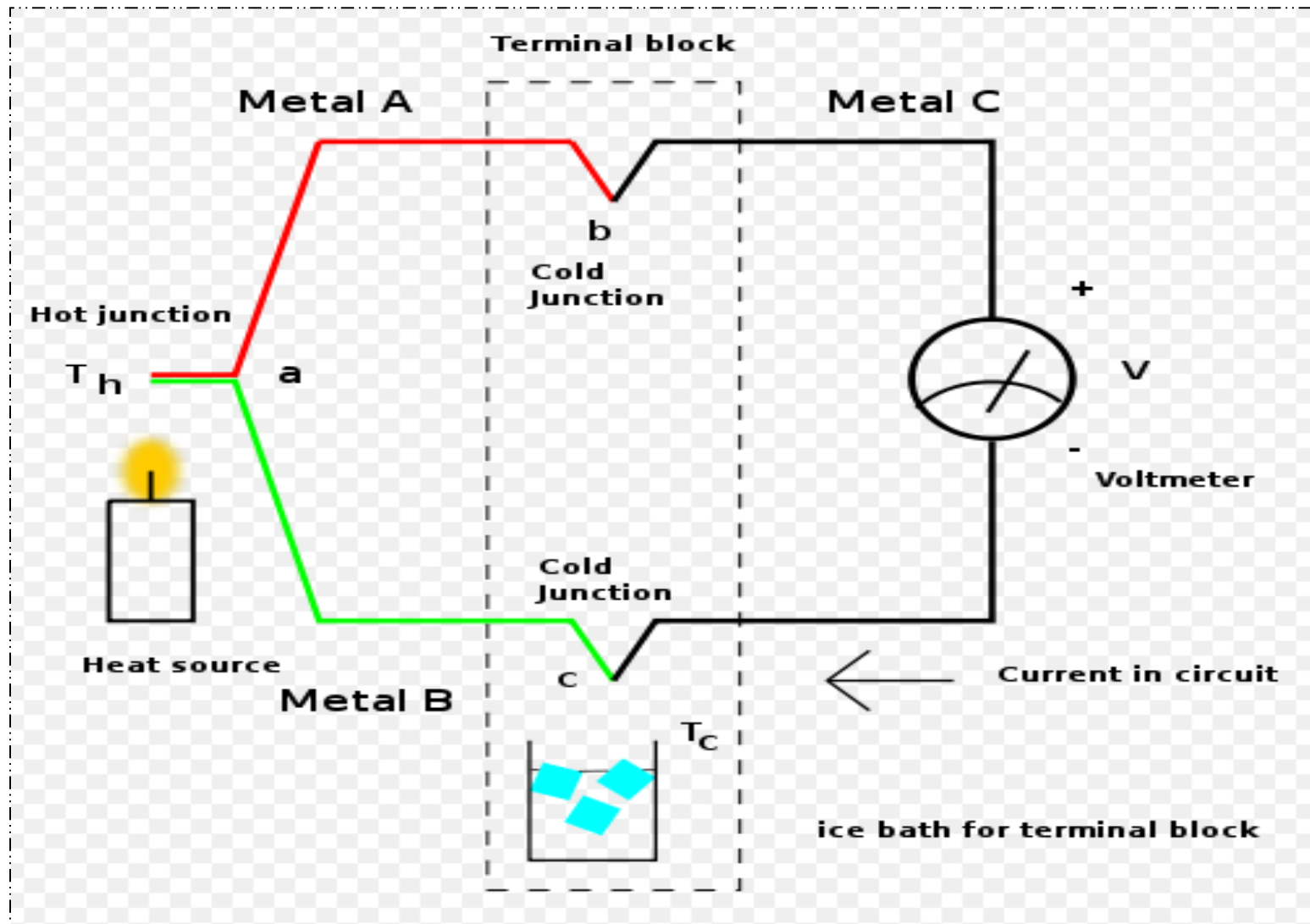
<i>Thermocouple type</i>	<i>Materials used</i>	<i>Temperature range/ °C</i>	<i>Sensitivity $\mu\text{V}/^\circ\text{C}$</i>
Type T	Copper/Constantan	-200–400	15–60
E	Chromel/Constantan	0–850	40–55
J	Iron / Constantan	-200–900	45–57
K	Chromel/Alumel	-200–1250	40–55
R	Platinum/Platinum 13% Rhodium	0–1600	5–12
S	Platinum/Platinum 10% Rhodium	0–1500	5–12
B	Platinum 6% Rhodium/ Platinum 30% Rhodium	30–1800	0.3–0.8
G	Tungsten/Tungsten 26% Rhenium	15–2800	3–20
C	Tungsten 5% Rhenium/ Tungsten 25% Rhenium	0–2750	10–20

Thermocouple

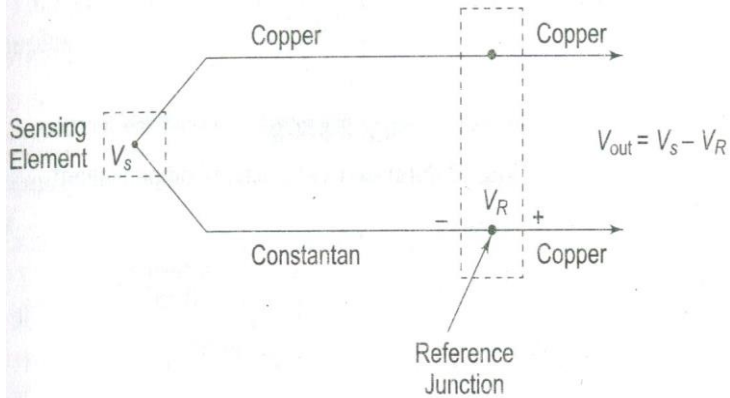
O/p Voltage Vs Temperature



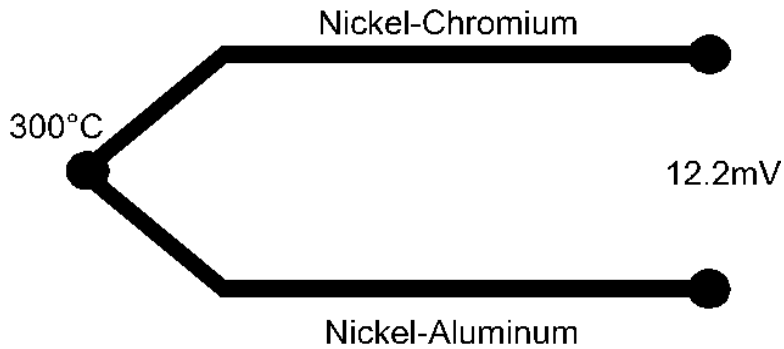
Thermocouple circuit



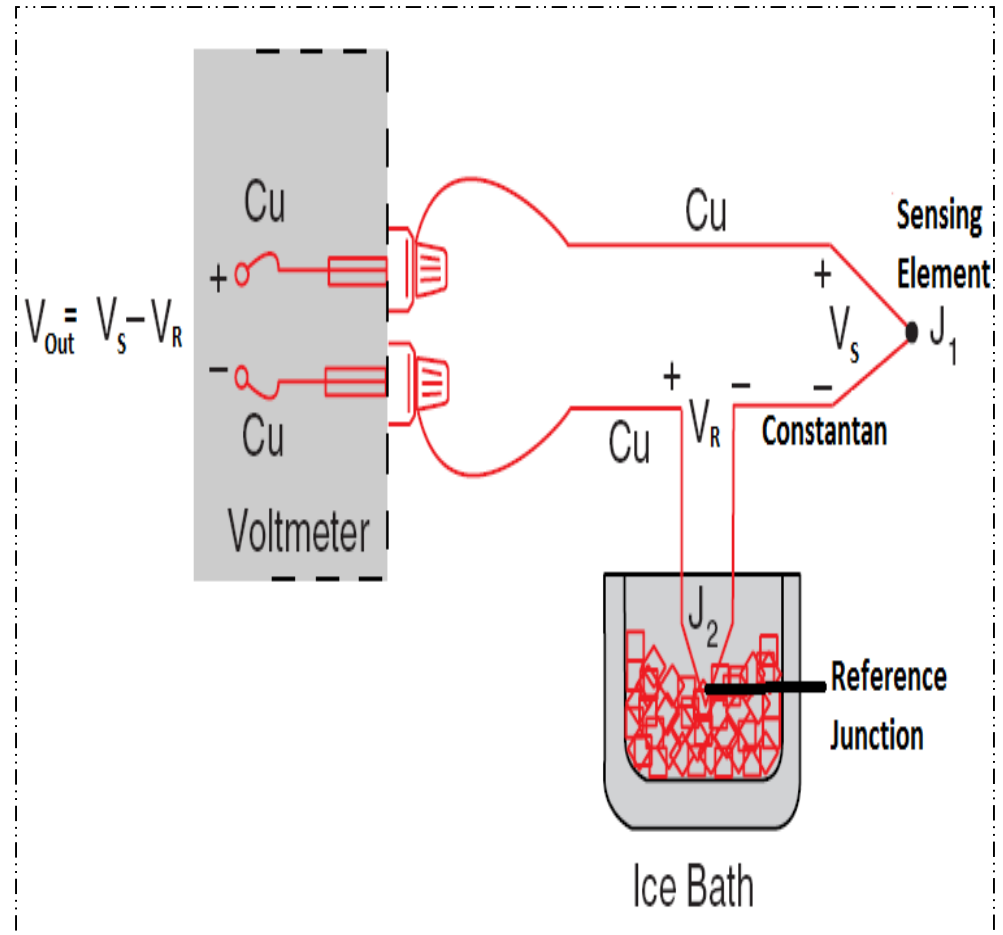
Thermocouple Compensation Circuits



Type T

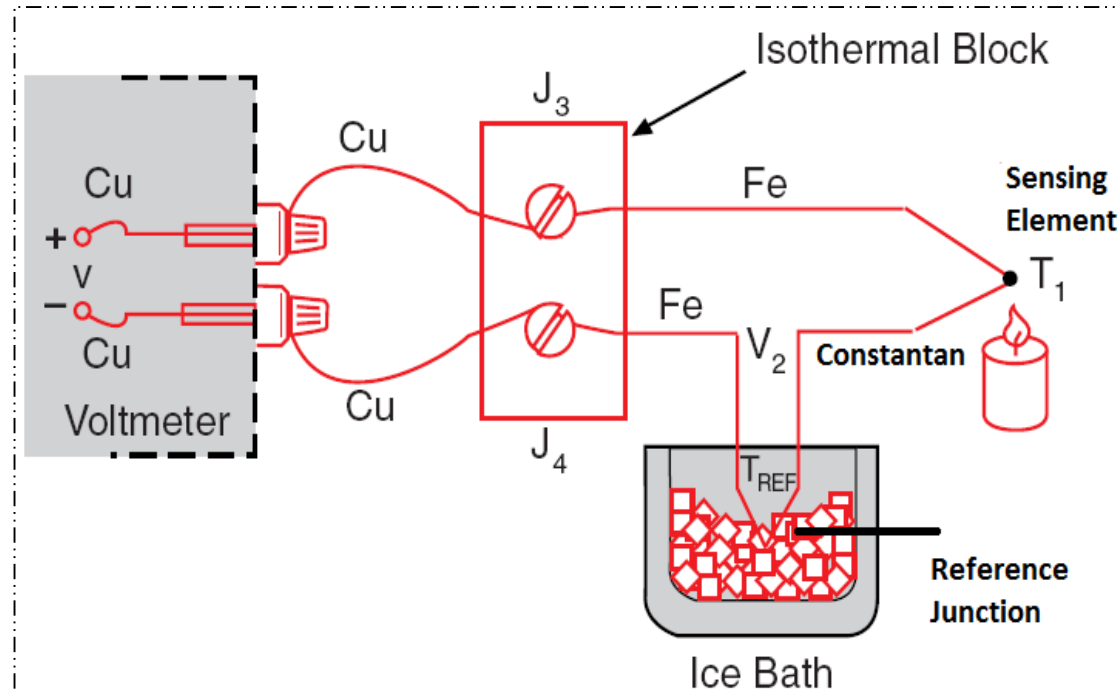
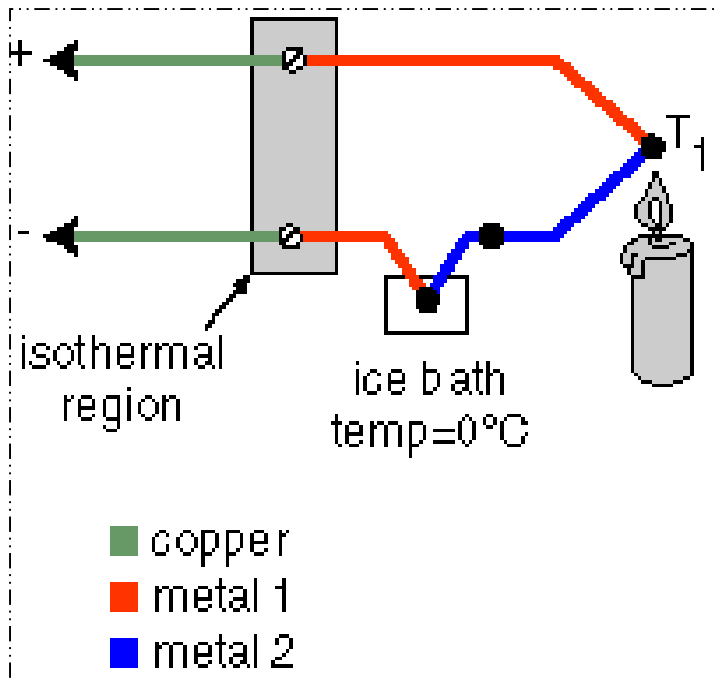


Type K

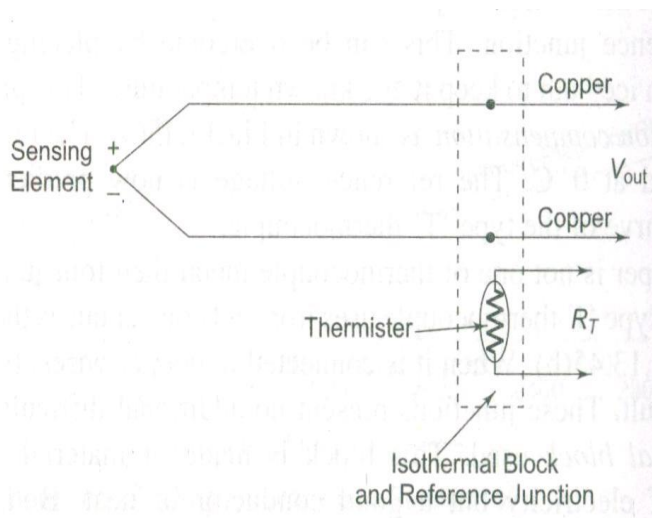


Cold Junction Compensation

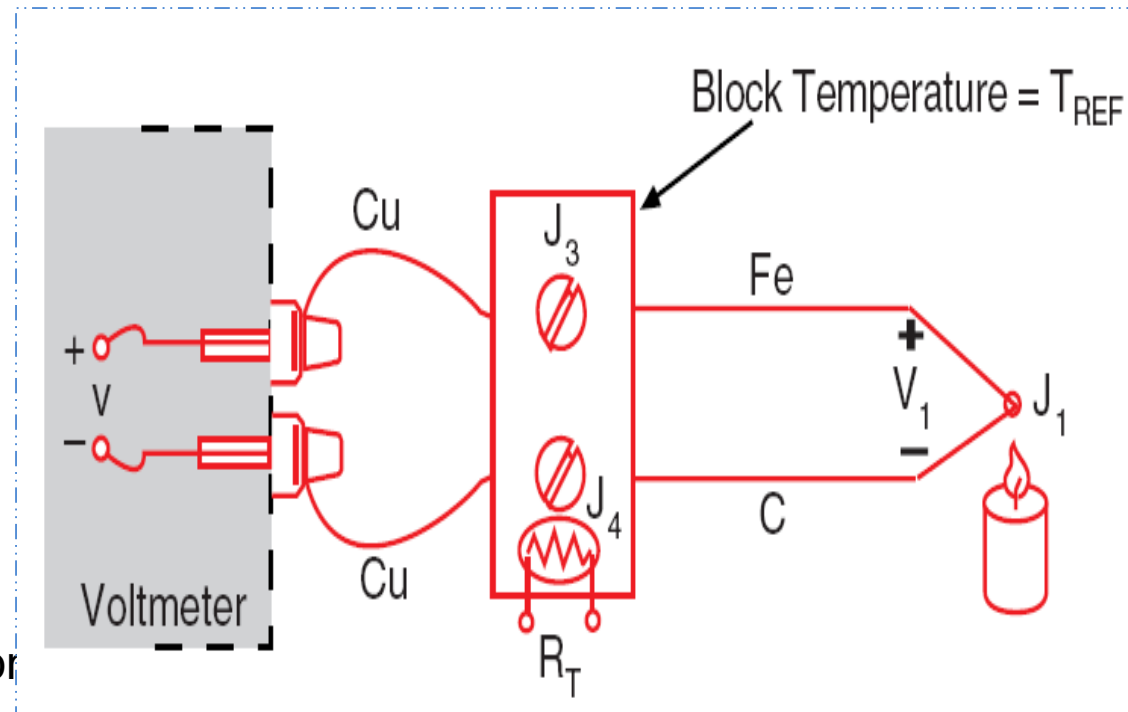
Type J Thermocouple using Isothermal Block



Reference Junction Compensation

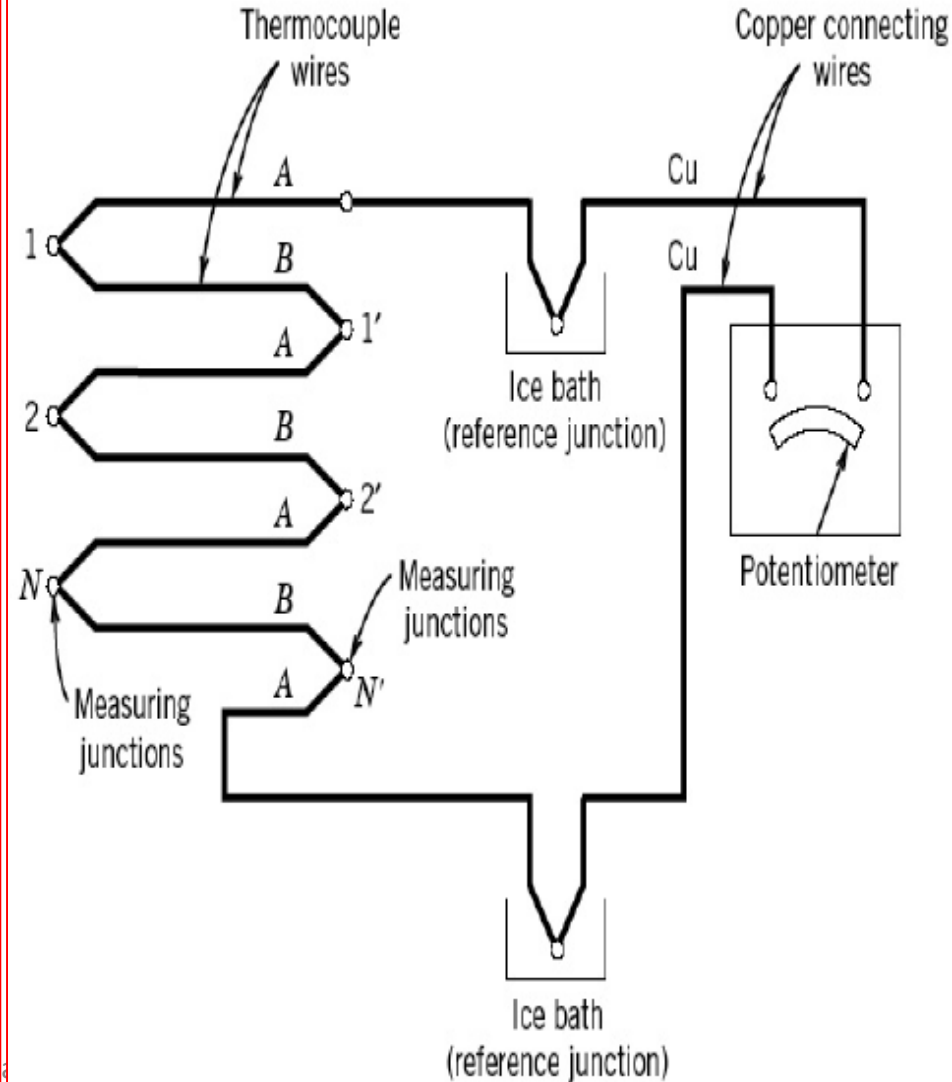
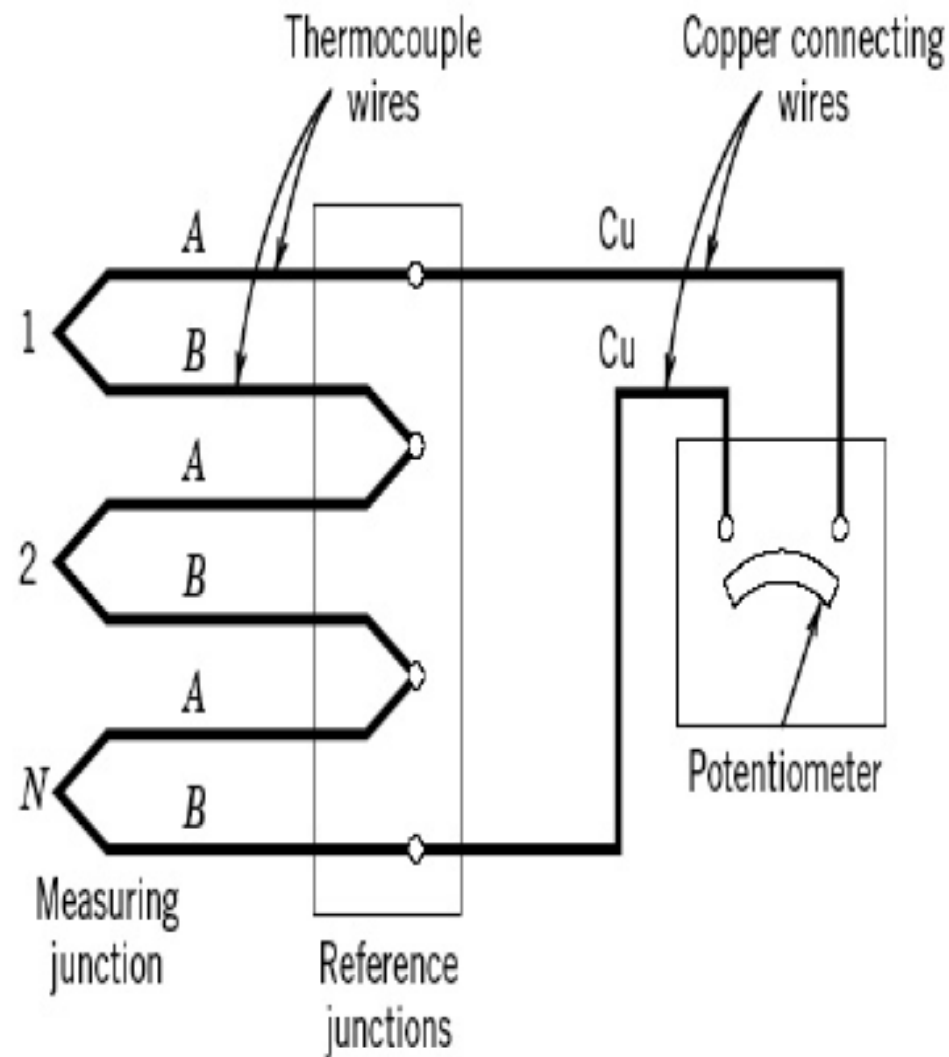


Reference Junction Compensation

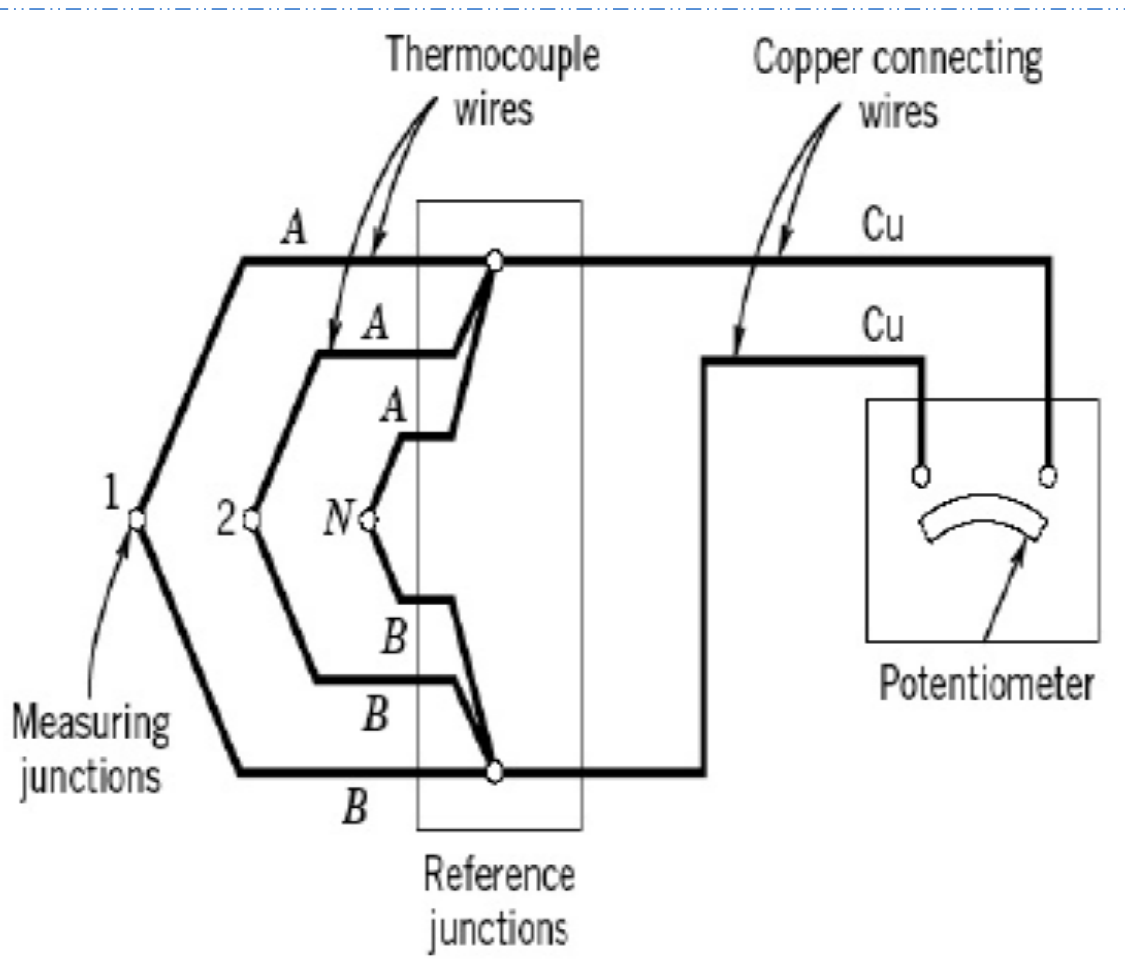


Thermopiles

Multiple-junction thermocouple circuit designed to amplify the output of the circuit



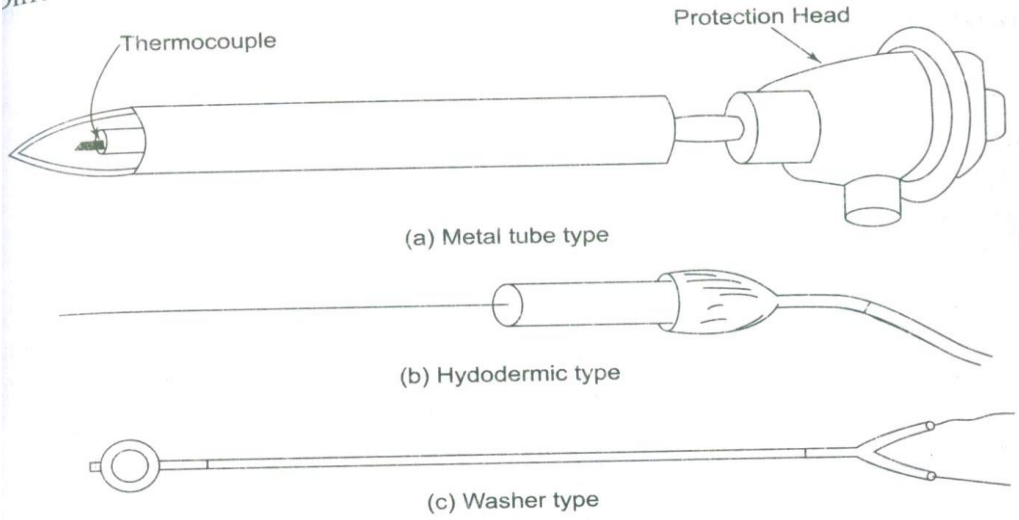
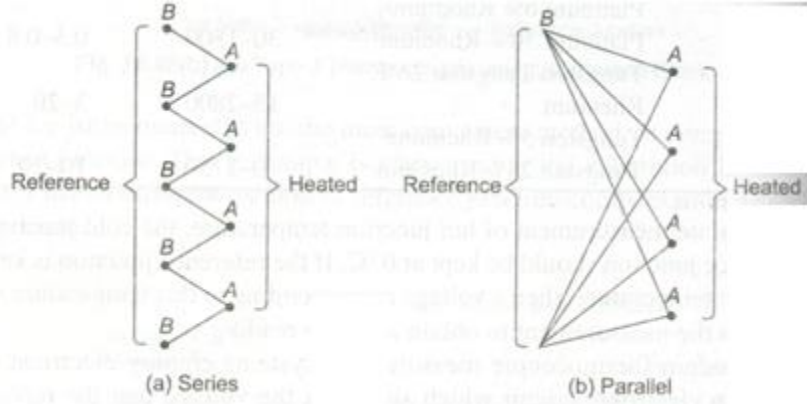
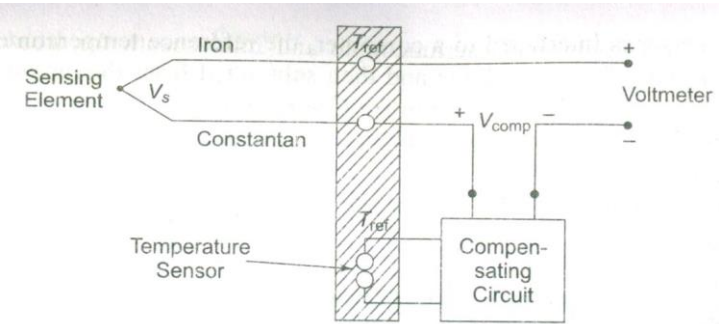
Thermocouples in Parallel



$$\overline{emf} = \frac{1}{N} \sum_{i=1}^N (emf)_i$$

$$\overline{T} = \frac{1}{N} \sum_{i=1}^N T_i$$

Different Types of Thermocouples



Advantages and Disadvantages of Thermocouples

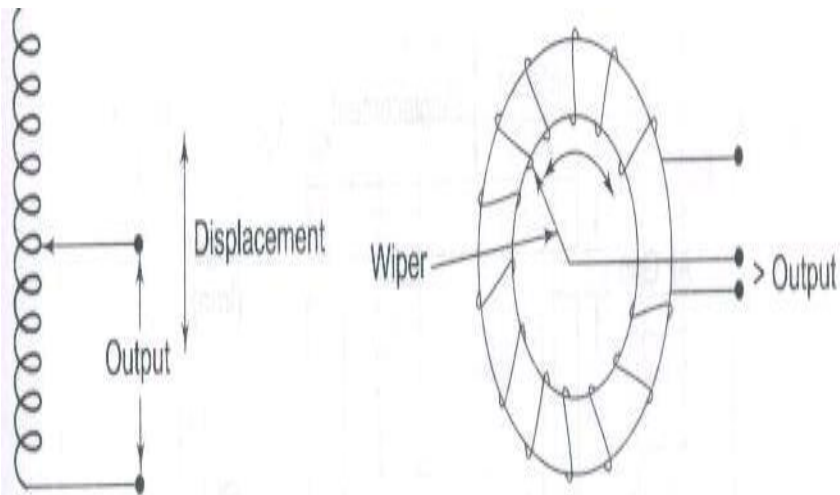
- ✓ Wide temperature range (-270°C to 2700°C)
- ✓ Rugged Construction
- ✓ Bridge Circuits not required for temperature measurement.
- ✓ Comparatively cheaper in cost
- ✓ Good reproducibility
- ✓ Speed of response is high compared to thermometer systems.
- ✓ Calibration checks can be easily performed
- ✓ Using extension leads and compensating cables, long distance transmission for temperature measurement is possible.
- ✓ Good Accuracy
- ❖ Compensation circuits is essential for accurate measurements
- ❖ They exhibit non-linearity in the emf versus temperature characteristics.
- ❖ Many applications needs signal amplifications.
- ❖ Proper separation of extension leads from thermocouple is required to avoid stray electrical signal pickup.

Variable Inductance type Transducer

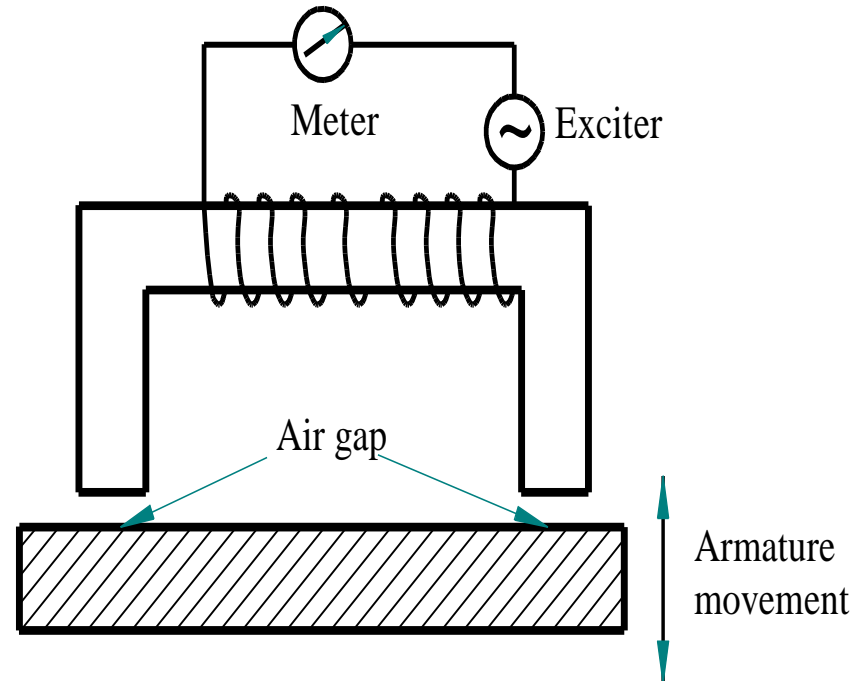
- *Inductive transducers:* **Inductance** is the property in an electrical circuit where a change in the current flowing through that circuit induces an electromotive force (EMF) that opposes the change in current.
- ✓ In electrical circuits, any electric current i produces a magnetic field and hence generates a total magnetic flux Φ acting on the circuit. This magnetic flux, according to *Lenz's law* tends to oppose changes in the flux by generating a voltage (*a counter emf*) that tends to oppose the rate of change in the current.
- The ratio of the magnetic flux to the current is called the *self-inductance* which is usually simply referred to as the *inductance* of the circuit
- *Mutual Inductance:* When the varying flux field from one coil or circuit element induces an emf in a neighboring coil or circuit element, the effect is called *Mutual Inductance*.
- ✓ *Magnetic reluctance* or magnetic resistance, is analogous to resistance in an electrical circuit. In likeness to the way an electric field causes an electric current to follow the path of least resistance, a magnetic field causes magnetic flux to follow the path of least magnetic reluctance. *Permeance is the reciprocal of reluctance*

Variation of Self Inductance

When a single coil is used as a transducer element, the mechanical input changes the permeance of the flux path generated by the coil, thereby changing its inductance. This change can be measured by a suitable circuit, indicating the value of the input. As shown in fig. below, the flux path may be changed by a change in the air gap.



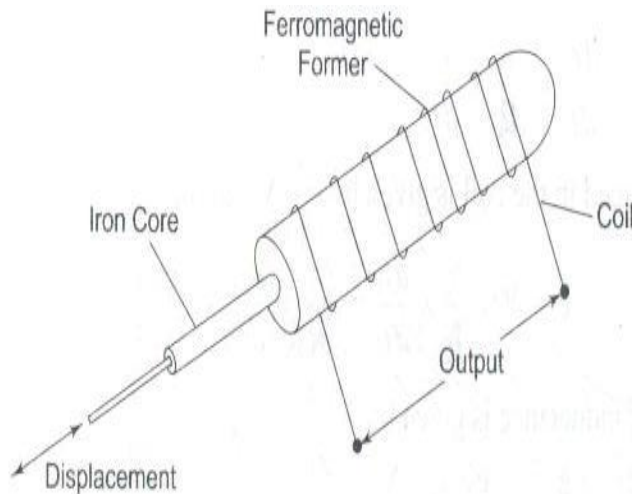
Linear and Angular Inductive Transducers



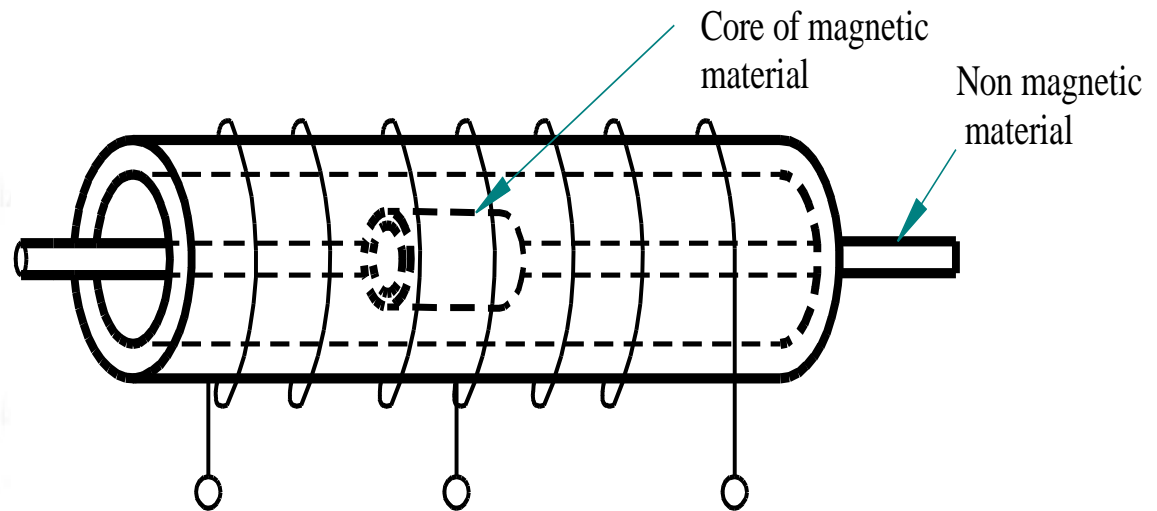
Single Coil Self inductance arrangement

Variation of Self Inductance

The Two Coil arrangement, is a single coil with a center tap. Movement of the core alters the relative inductance of the two coils. These transducers are incorporated in inductive bridge circuit in which variation in inductance ratio between the two coils provides the output. This is used as a secondary transducer for pressure measurement.



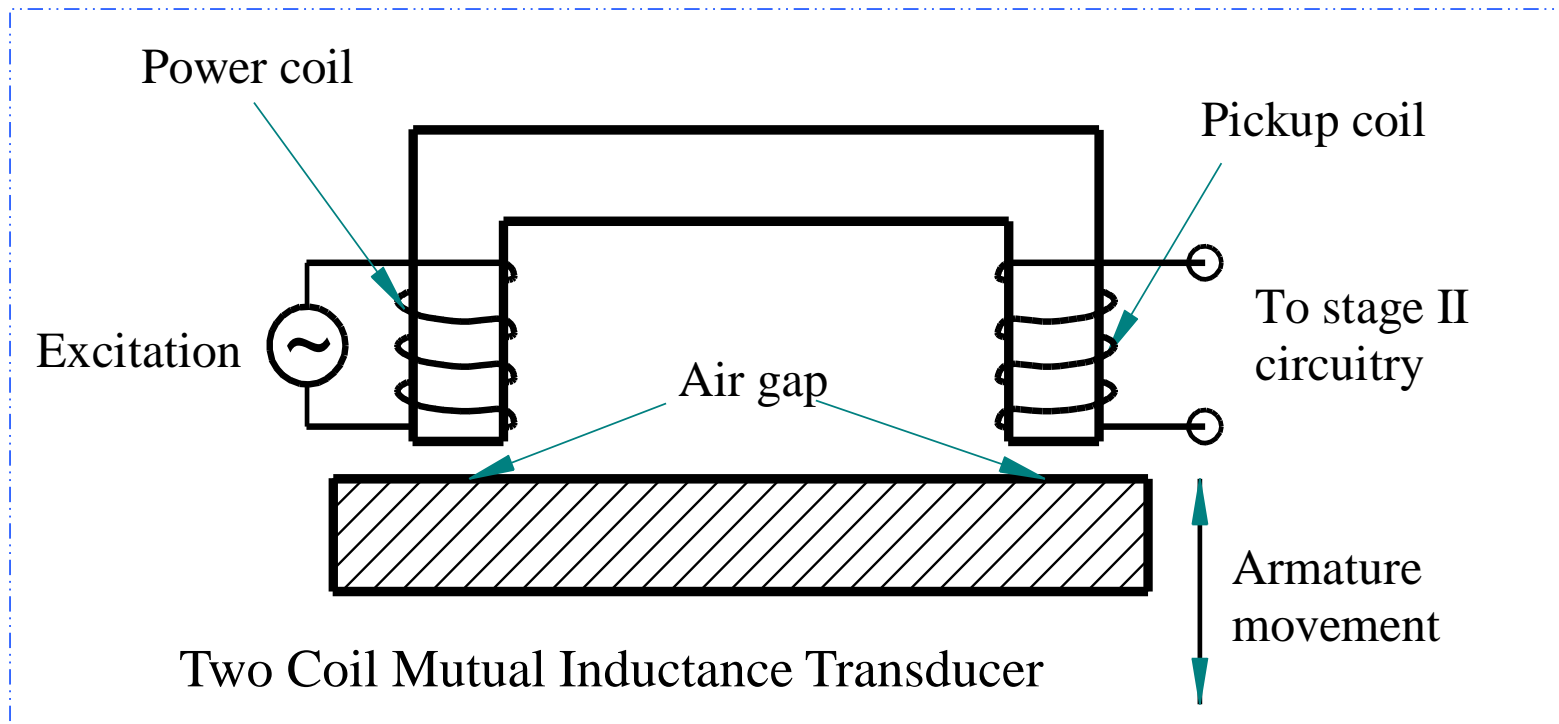
Variable Permeability
Inductive Transducers



Variable self inductance -Two Coil (Single coil with center tap)

Variation of Mutual Inductance

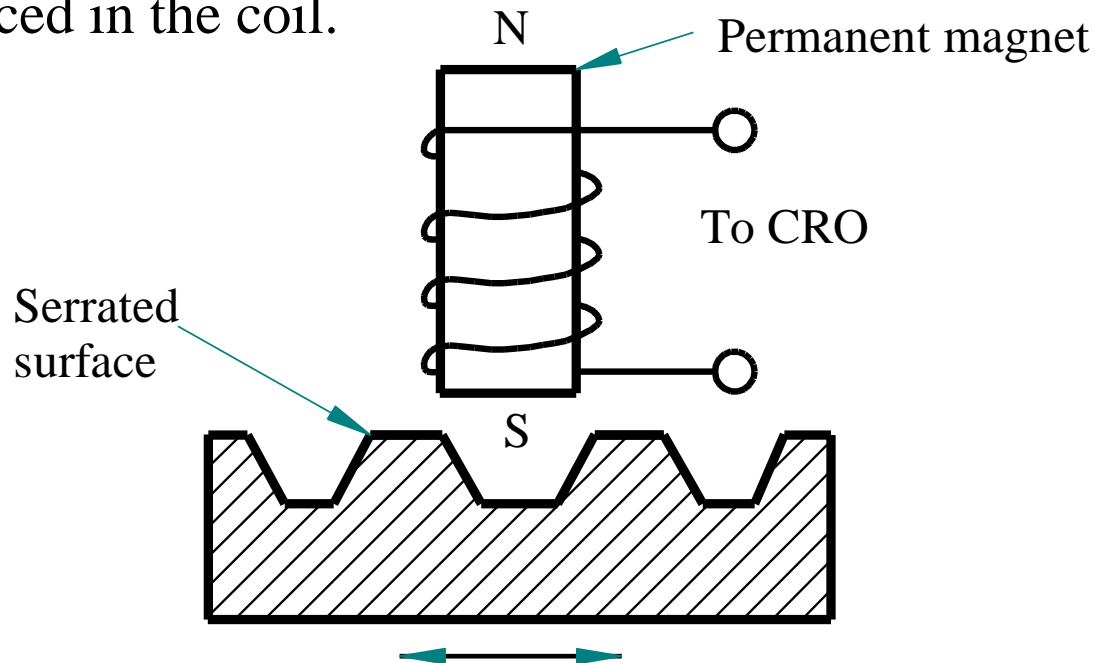
In this type, the flux from a power coil is coupled to a pickup coil, which supplies the output. Input information in the form of armature displacement, changes the coupling between the coils. The air gap between the core and the armature govern the degree of coupling.



Variable Reluctance Transducer

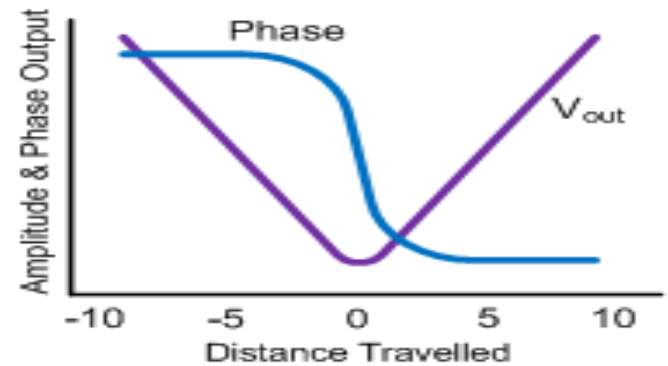
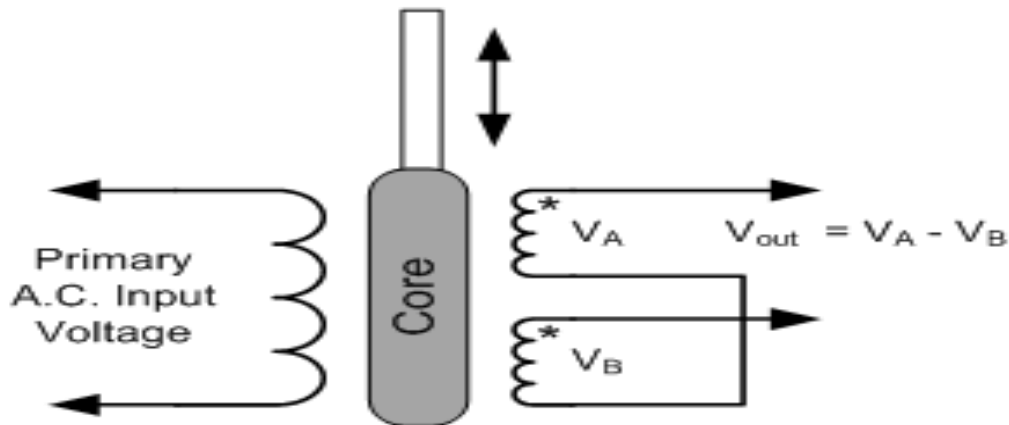
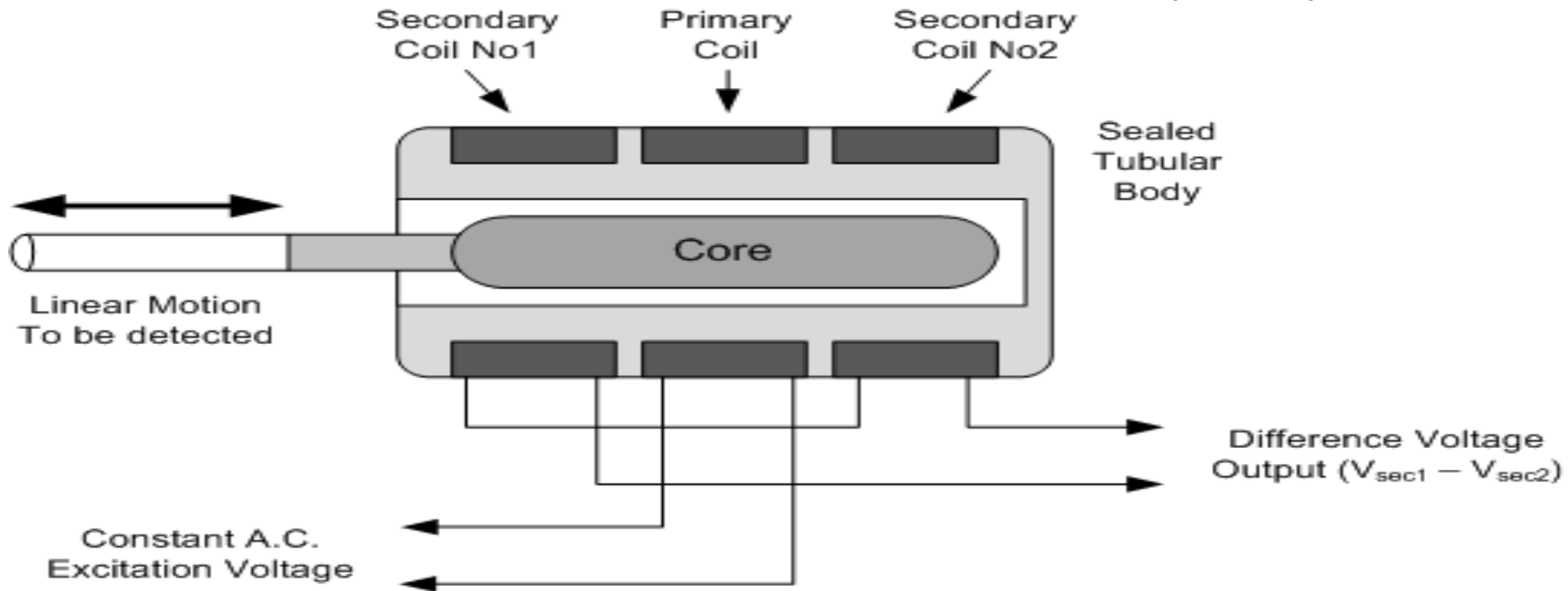
A *Variable reluctance Transducers* are used for dynamic applications, where the flux lines supplied by a permanent magnet are cut by the turns of the coil. Some means of providing relative motion is included into the device.

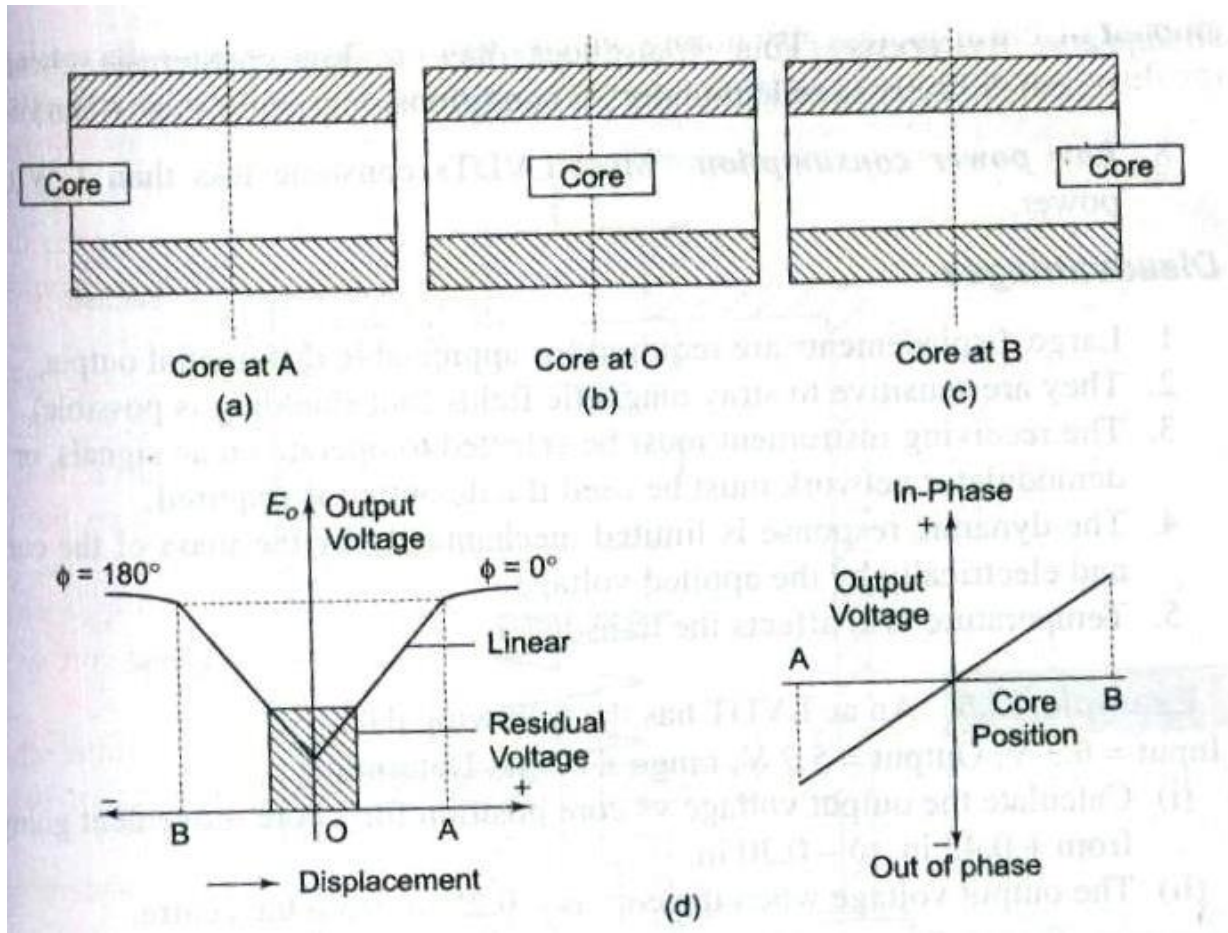
The fig shows a simple type of reluctance pickup consisting of a coil wound on a permanent magnetic core. Any variation of the permeance of the magnetic circuit causes a change in the flux, which is brought about by a serrated surface subjected to movement. As the flux field expands or collapses, a voltage is induced in the coil.



Linear Variable Differential Transformer

Three Coil mutual inductance device (LVDT)

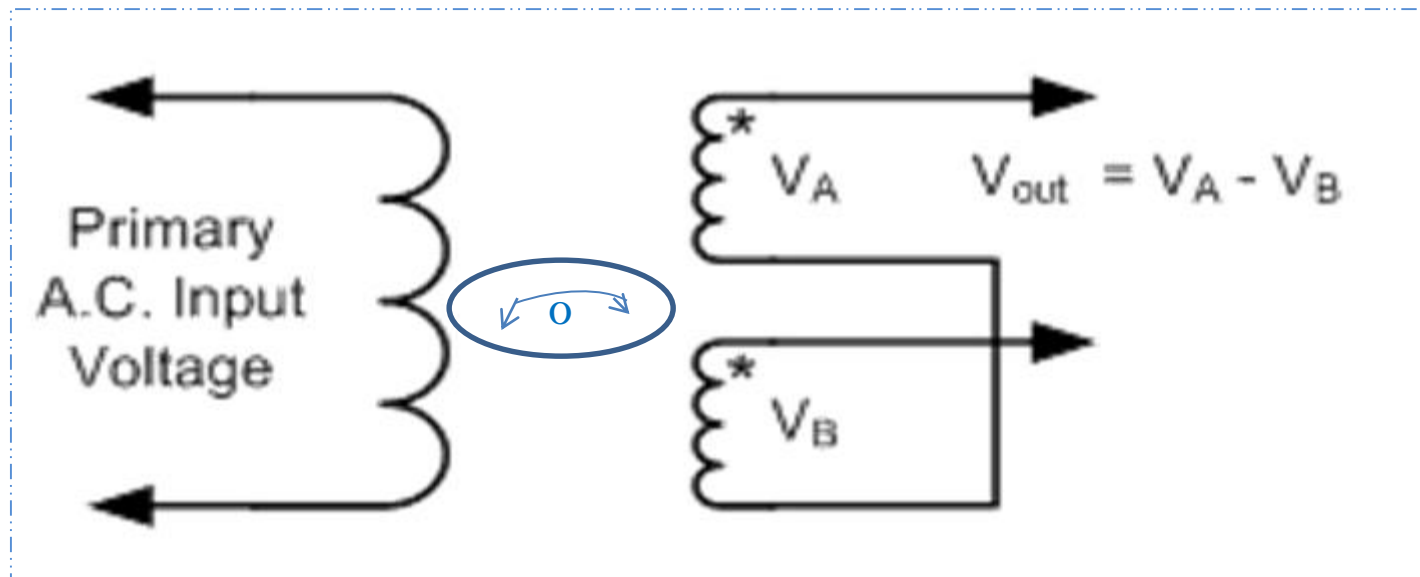




Rotary Variable Differential Transformer

A **RVDT** is a type of electrical transformer used for measuring Angular Displacement .

The RVDT construction is similar in construction to LVDT, except that a cam-shaped core replaces the core in the LVDT as shown below.



Capacitive Transducers

The principle of these type is that variations in capacitance are used to produce measurement of many physical phenomenon such as dynamic pressure, displacement, force, humidity, etc.

An equation for capacitance is
$$C = \frac{0.088KA(N-1)}{d} \text{ Pico farads}$$

Where $K =$ dielectric constant (for air $K=1$),

$A =$ area of one side of one plate,

$N =$ Number of plates,

$d =$ Separation of plate surfaces (cm)

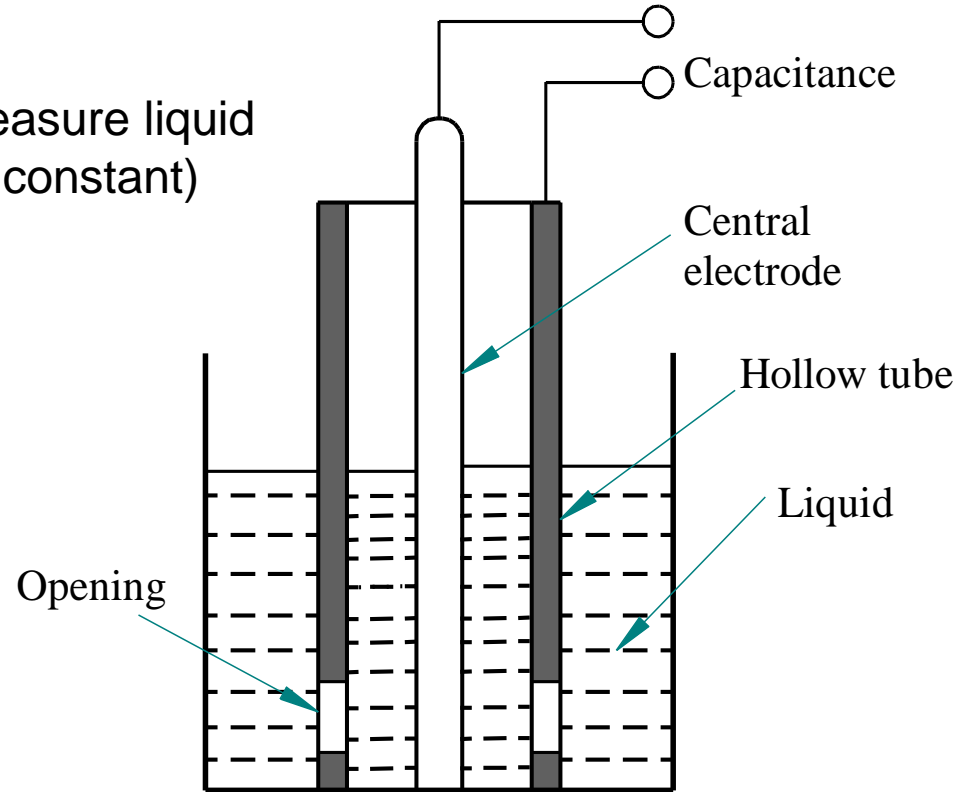
Capacitance is the ability of a body to hold an electrical charge.

Capacitance is also a measure of the amount of electric charge stored for a given electric potential. A common form of charge storage device is a two-plate capacitor. If the charges on the plates are $+Q$ and $-Q$, and V gives the voltage between the plates, then the capacitance is given by $C=(Q/V)$

The SI unit of capacitance is the **farad**; **1 farad = 1 coulomb per volt**

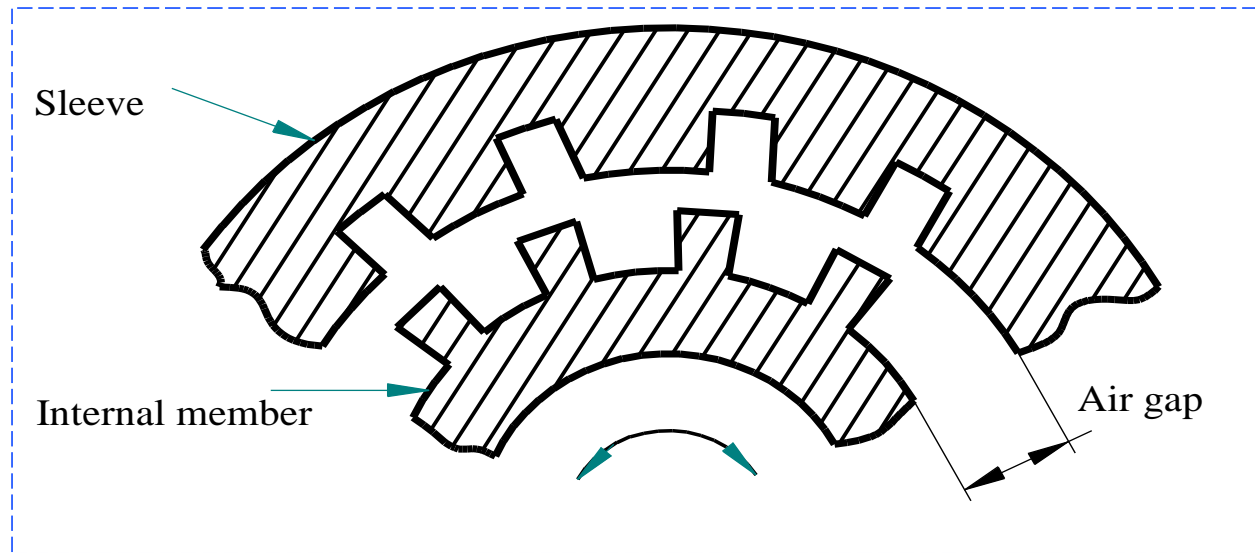
Capacitive Transducer

Capacitance Pickup to measure liquid level (Changing dielectric constant)



The above fig. shows a device used for the measurement of liquid level in a container. The capacitance between the central electrode and the surrounding hollow tube varies with changing dielectric constant brought about by changing liquid level. Thus the capacitance between the electrodes is a direct indication of the liquid level. Variation in dielectric constant can also be utilized for measurements of thickness, density, etc.

Capacitive Transducer (Torque meter)



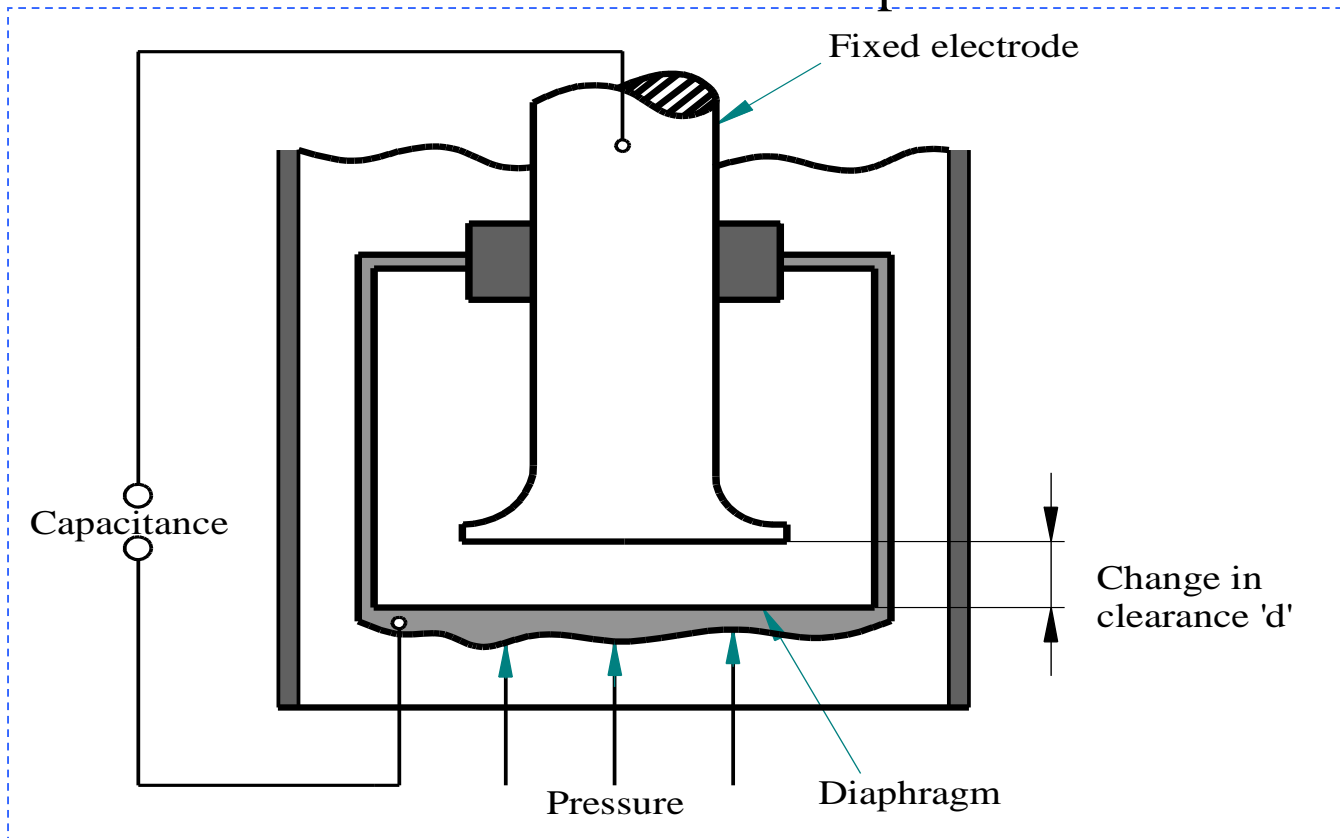
Capacitance changes depending on the change in effective area. This principle is used in the secondary transducing element of a *Torque meter*. This device uses a sleeve with serrations cut axially and a matching internal member with similar serrations as shown in the above fig.

Torque carried by an elastic member causes a shift in the relative positions of the serrations, thereby changing the effective area. The resulting capacitance change may be calibrated to read the torque directly.

Capacitive Transducer

(Capacitive Type Pressure Transducer)

The capacitance varies inversely as the distance between the plates. The fig shows a capacitive type pressure transducer where the pressure applied to the diaphragms changes the distance between the diaphragm & the fixed electrode which can be taken as a measure of pressure.



Advantages of Capacitive Transducers

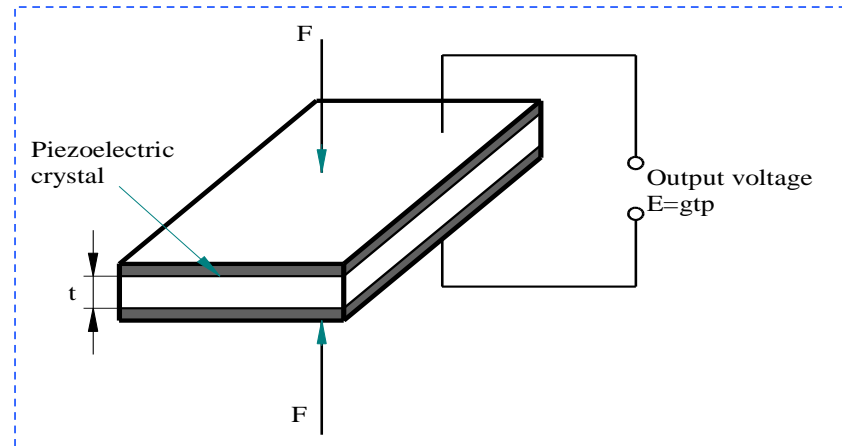
- (1) Requires extremely small forces to operate and are highly sensitive
- (2) They have good frequency response and hence useful for dynamic measurements.
- (3) High resolution can be obtained.
- (4) They have high input impedance & hence loading effects are minimum.
- (5) These transducers can be used for applications where stray magnetic fields render the inductive transducers useless.

Disadvantages of Capacitive Transducers

- (1) Metallic parts must be properly insulated and the frames must be earthed.
- (2) They show nonlinear behaviour due to edge effects and guard rings must be used to eliminate this effect.
- (3) They are sensitive to temperature affecting their performance.
- (4) The instrumentation circuitry used with these transducers are complex.
- (5) Capacitance of these transducers may change with presence of dust particles & moisture.

Piezo-Electric Transducers

Certain materials can produce an electrical potential when subjected to mechanical strain or conversely, can change dimensions when subjected to voltage. This effect is called '*Piezoelectric effect*'.



The fig shows a piezoelectric crystal placed between two plate electrodes and when a force 'F' is applied to the plates, a stress will be produced in the crystal and a corresponding deformation. The induced charge $Q = d \times F$ where 'd' is the piezoelectric constant.

The output voltage $E = g \times t \times p$ where 't' is crystal thickness, 'p' is the impressed pressure & 'g' is called voltage sensitivity given by $g = (d/e)$, e being the strain.

Piezo-Electric Materials

The common piezoelectric materials are quartz, Rochelle salt (Potassium sodium tartrate), ammonium dihydrogen phosphate and ordinary sugar. The desirable properties are stability, high output, insensitivity to temperature and humidity and ability to be formed into desired shape.

Quartz is most suitable and is used in electronic oscillators. Its output is low but stable.

Rochelle salt provides highest output, but requires protection from moisture in air & cannot be used above 45°C.

Barium titanate is polycrystalline, thus it can be formed into a variety of sizes & shapes.

Piezoelectric transducers are used to measure surface roughness, strain, force & torque, Pressure, motion & noise.

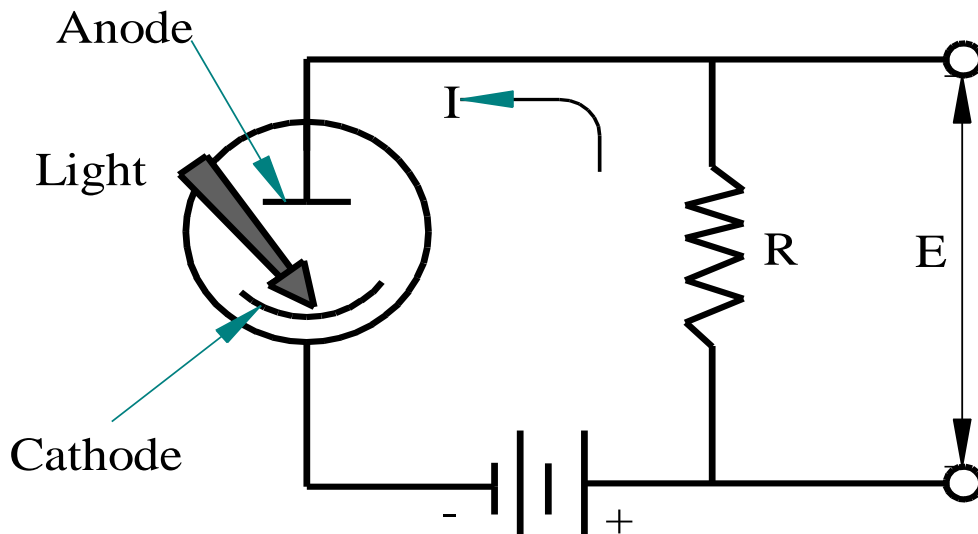
Photoelectric Transducers

A photoelectric transducer converts a light beam into a usable electric signal. As shown in the fig, light strikes the photo emissive cathode and releases electrons, which are attracted towards the anode, thereby producing an electric current in the circuit. The cathode & the anode are enclosed in a glass or quartz envelope, which is either evacuated or filled with an inert gas. The photo electric sensitivity is given by

$$I = s \times \phi$$

Where I =Photoelectric current, s =sensitivity, ϕ =illumination of the cathode. The response of the photoelectric tube to different wavelengths is influenced by

- (i) The transmission characteristics of the glass tube envelope and
- (ii) Photo emissive characteristics of the cathode material.

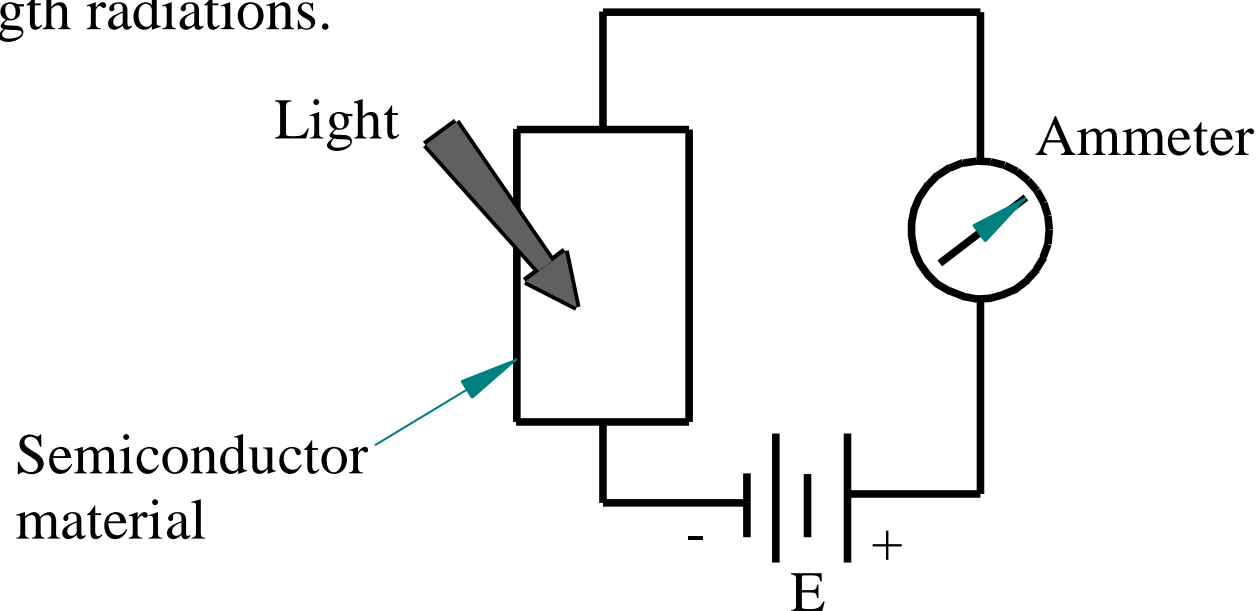


Photoelectric tubes are useful for counting purposes through periodic interruption of a light source

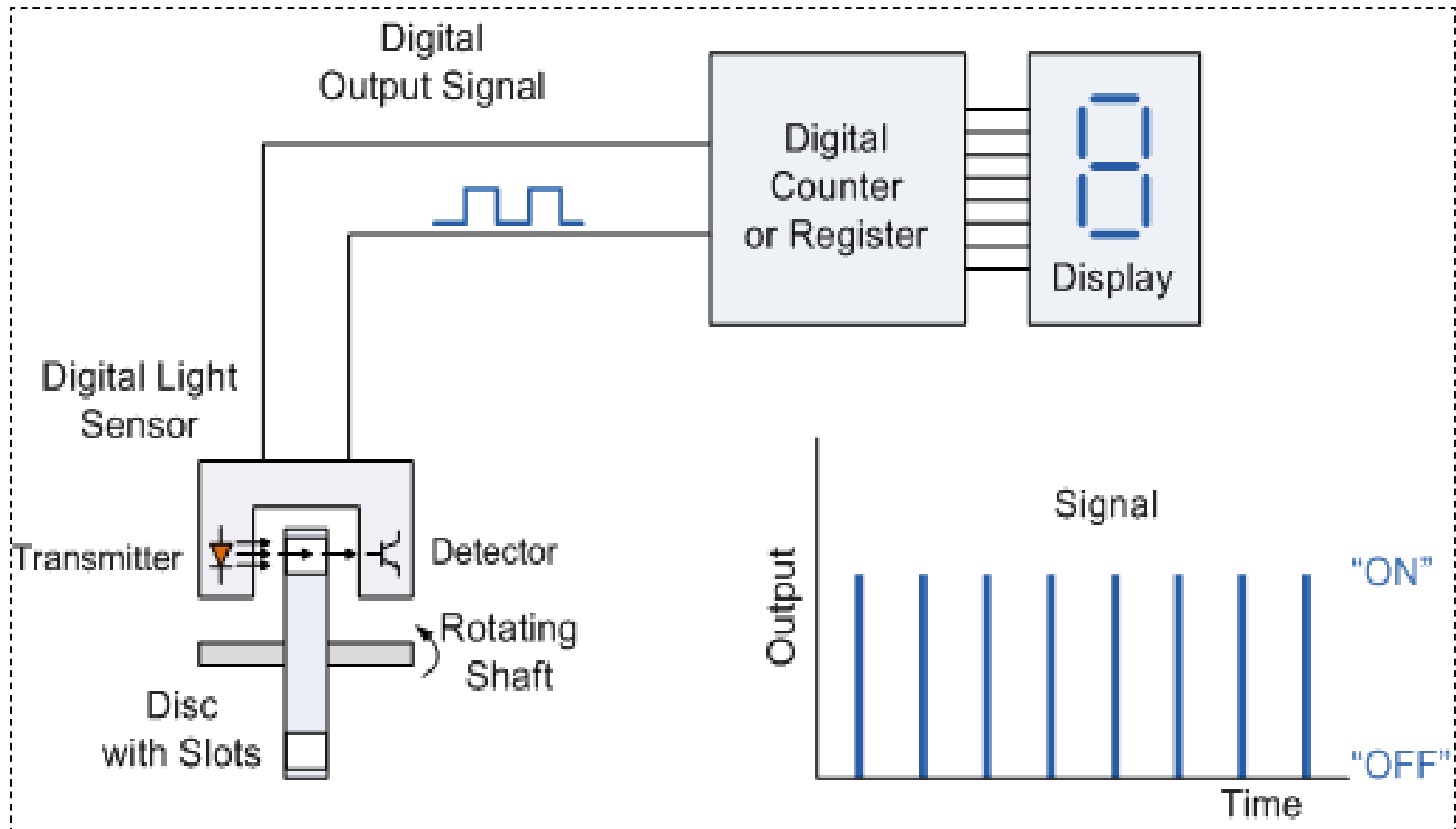
Photoconductive Transducers

The principle of these transducers is when light strikes a semiconductor material, its resistance decreases, thereby producing an increase in the current. The fig shows a cadmium sulphide semiconductor material to which a voltage is applied and when light strikes, an increase in current is indicated by the meter.

Photoconductive transducers are used to measure radiation at all wavelengths. But extreme experimental difficulties are encountered when operating with long wavelength radiations.



Digital Transducers



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