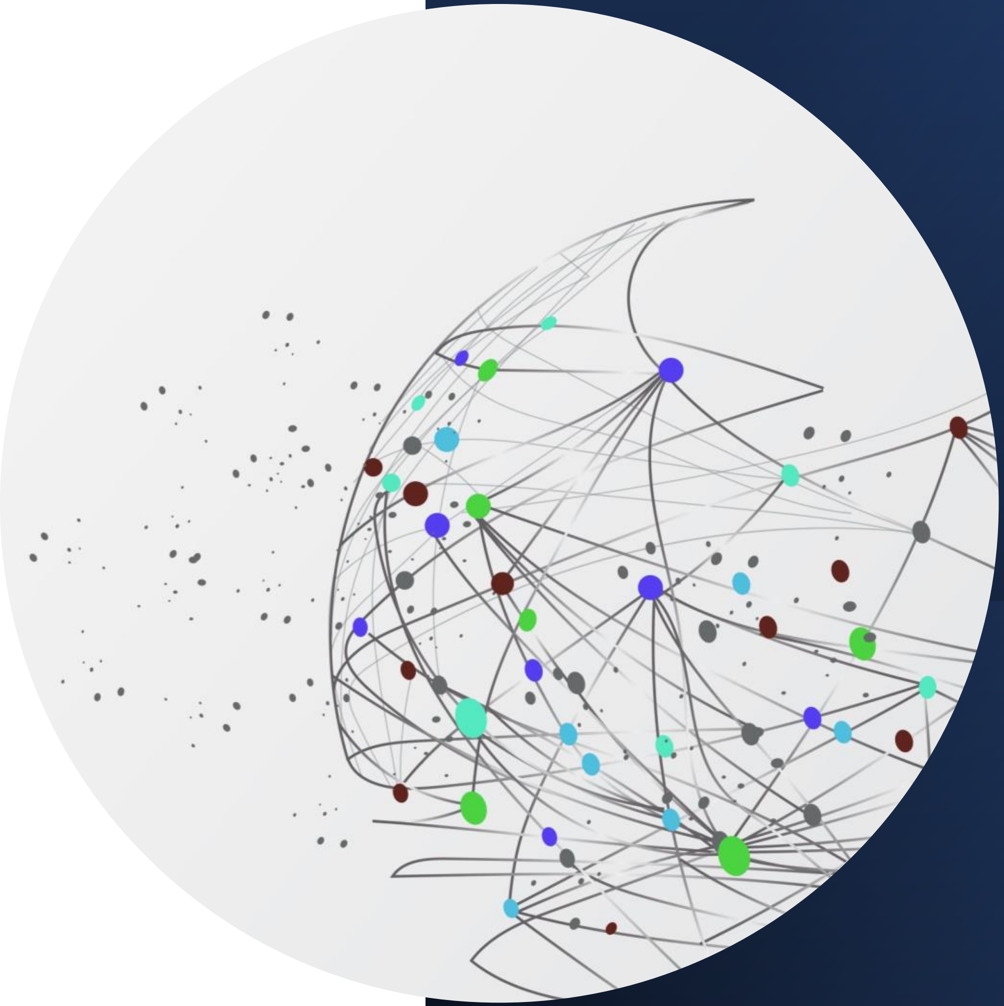
Basic Electronics Engineering:

Unit 5: Sensors

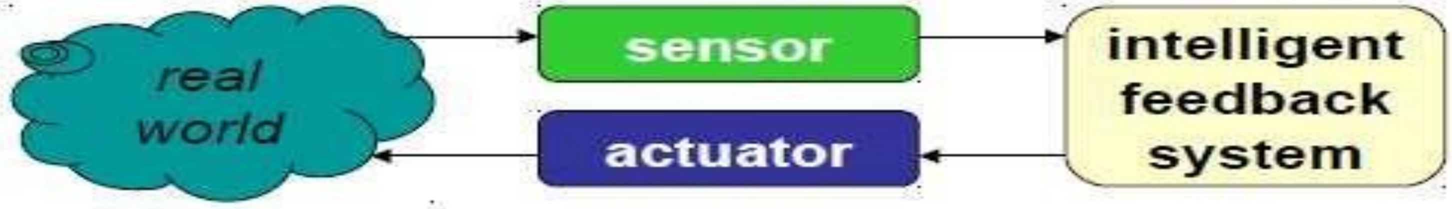


Sensors: Topics

- Classification of Sensors
  - Active and Passive
  - Analog and Digital
- Motion Sensors
  - LVDT
  - Accelerometer
- Temperature Sensors
  - Thermocouple
  - Thermistor
  - RTD
- Semiconductor
  - Gas Sensor
  - Optical Sensors
  - LDR
- Mechanical Sensors
  - Strain Gauge, Load Cell, Pressure
- Bio Sensors

Transducer

- Transducer
  - a device that converts a primary form of energy into a corresponding signal with a different energy form
    - Primary Energy Forms: mechanical, thermal, electromagnetic, optical, chemical, etc.
  - take form of a **sensor** or an **actuator**
- Sensor (e.g., thermometer)
  - a device that detects/measures a signal or stimulus
  - acquires information from the "real world"
- Actuator (e.g., heater)
  - a device that generates a signal or stimulus



What makes a machine a robot?

Sensing → Planning → Acting

Sensing
sensor

Planning

Acting
Actuator

information
about the
environment

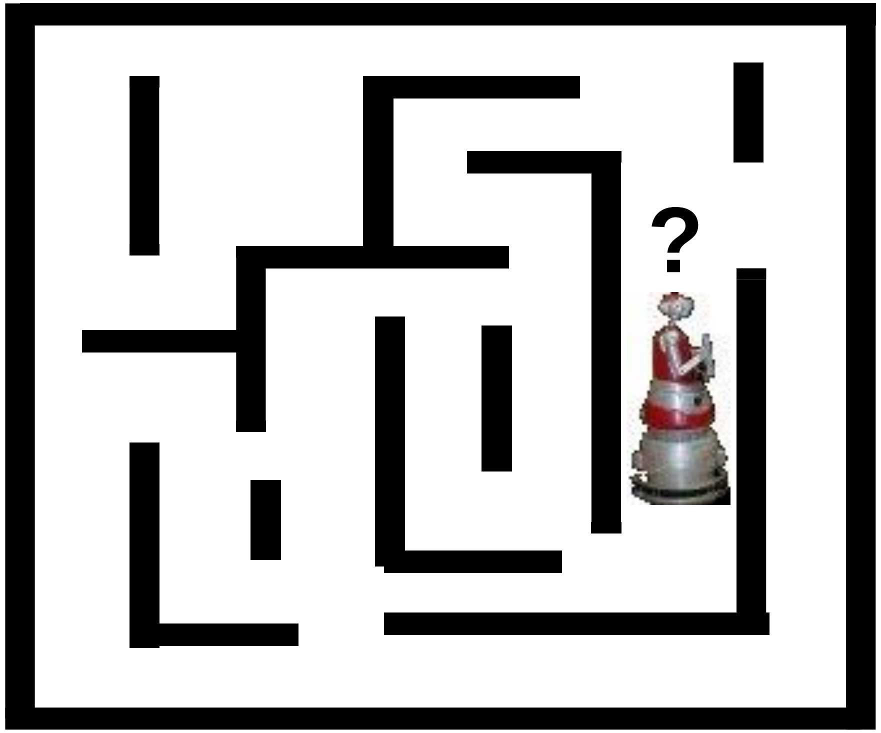
action
on the
environment

Sensors

- Sensors are as an electrical device that consists of components that are used to measure physical quantities (temperature, light, pressure, etc.) and produce electrical signals - usually voltage or current signals, that can be used to determine the values for appropriate physical quantity.

Why do robots need sensors?

Where am I?



localization

Why do robots need sensors?

Will I hit anything?

obstacle detection

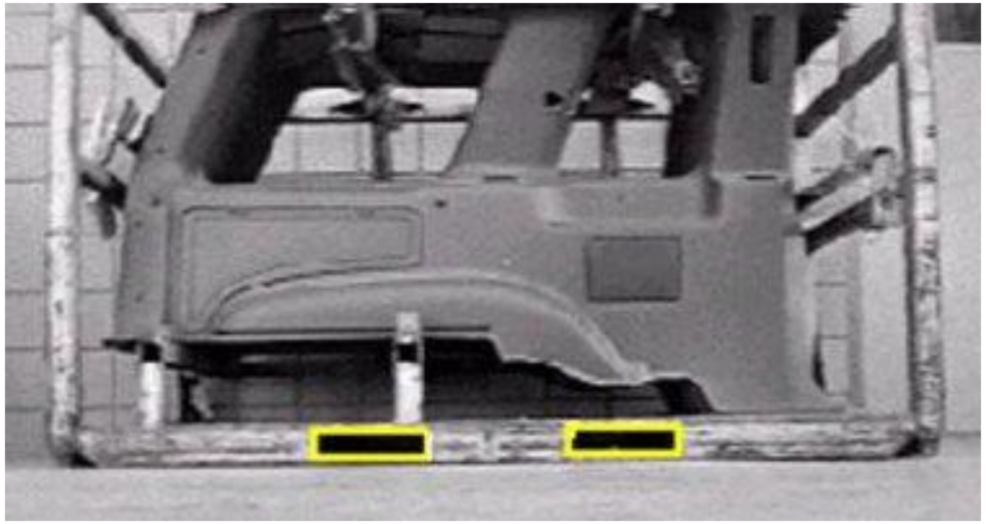
Sensing for specific tasks

Where is the cropline?

Autonomous harvesting

Sensing for specific tasks

Where are the forkholes?



Autonomous material handling

Sensing for specific tasks

Where is the face?

Face detection & tracking

Transducer

A device which converts one form of energy to another.

When input is a physical quantity and output electrical → Sensor

When input is electrical and output a physical quantity → Actuator

Sensors

Physical parameter

↓

Electrical Output

Actuators

Electrical Input

↓

Physical Output

e.g. Piezoelectric:

Force -> voltage

Voltage-> Force

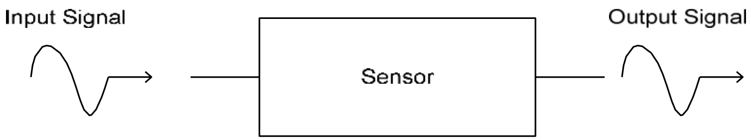
=>Ultrasound!

Microphone, Loud Speaker

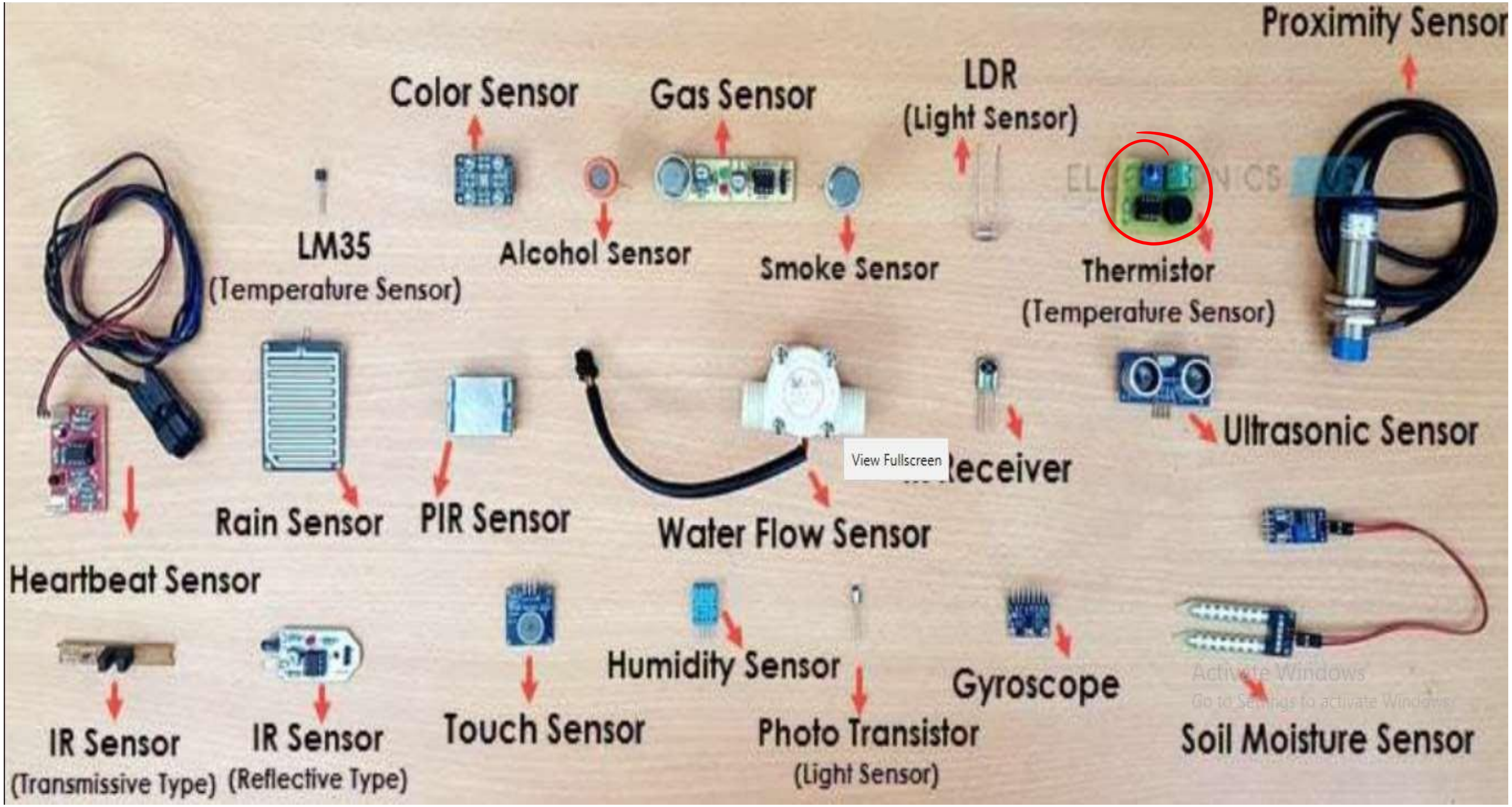
Sensors

- American National Standards Institute

  A device which provides a usable output in response to a specified measurand.



- A sensor acquires a physical quantity and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical).
- Nowadays common sensors convert measurement of physical phenomena into an electrical signal.


Proximity Sensor
Color Sensor
Gas Sensor
LDR
(Light Sensor)
LM35
(Temperature Sensor)
Alcohol Sensor
Smoke Sensor
Thermistor
(Temperature Sensor)
Ultrasonic Sensor
View Fullscreen
Rain Sensor
PIR Sensor
Water Flow Sensor
Heartbeat Sensor
Humidity Sensor
Gyroscope
Activate Windows
Go to Settings to activate Windows.
IR Sensor
(Transmissive Type)
IR Sensor
(Reflective Type)
Touch Sensor
Photo Transistor
(Light Sensor)
Soil Moisture Sensor

Commonly Detectable Phenomena

- Biological
- Chemical
- Electric
- Electromagnetic
- Heat/Temperature
- Magnetic
- Mechanical motion (displacement, velocity, acceleration, etc.)
- Optical
- Radioactivity

Common Conversion Methods

- Physical
  - thermo-electric, thermo-elastic, thermo-magnetic, thermo-optic
  - photo-electric, photo-elastic, photo-magnetic,
  - electro-elastic, electro-magnetic
  - magneto-electric
- Chemical
  - chemical transport, physical transformation, electro-chemical
- Biological
  - biological transformation, physical transformation

Commonly Measured Quantities

Stimulus	Quantity
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity
Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

Measurable Quantities

Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Light Level	Light Dependant Resistor (LDR) Photodiode Photo-transistor Solar Cell	Lights & Lamps LED's & Displays Fibre Optics
Temperature	Thermocouple Thermistor Thermostat Resistive temperature detectors (RTD)	Heater Fan
Force/Pressure	Strain Gauge Pressure Switch Load Cells	Lifts & Jacks Electromagnet Vibration
Position	Potentiometer Encoders Reflective/Slotted Opto-switch LVDT	Motor Solenoid Panel Meters
Speed	Tacho-generator Reflective/Slotted Opto-coupler Doppler Effect Sensors	AC and DC Motors Stepper Motor Brake
Sound	Carbon Microphone Piezo-electric Crystal	Bell Buzzer Loudspeaker

Need for Sensors

- Sensors are pervasive. They are embedded in our bodies, automobiles, airplanes, cellular telephones, radios, chemical plants, industrial plants and countless other applications.
- Without the use of sensors, there would be no automation !!

Classification of Transducers

- Active or Passive Transducer
- According to Transduction principle
- Analog or Digital Transducer
- Primary or Secondary Transducer
- Inverse Transducer
- According to measurement of Physical parameter.

Active Transducers

- These transducers do not need any external source of power for their operation. Therefore they are also called as self generating type transducers.
- The active transducer can be further classified as :
  - Photo voltaic
  - Thermo electric → Thermocouple
  - Piezo electric
  - Electromagnetic.
- The active transducers are self generating devices which operate under the energy conversion principle.

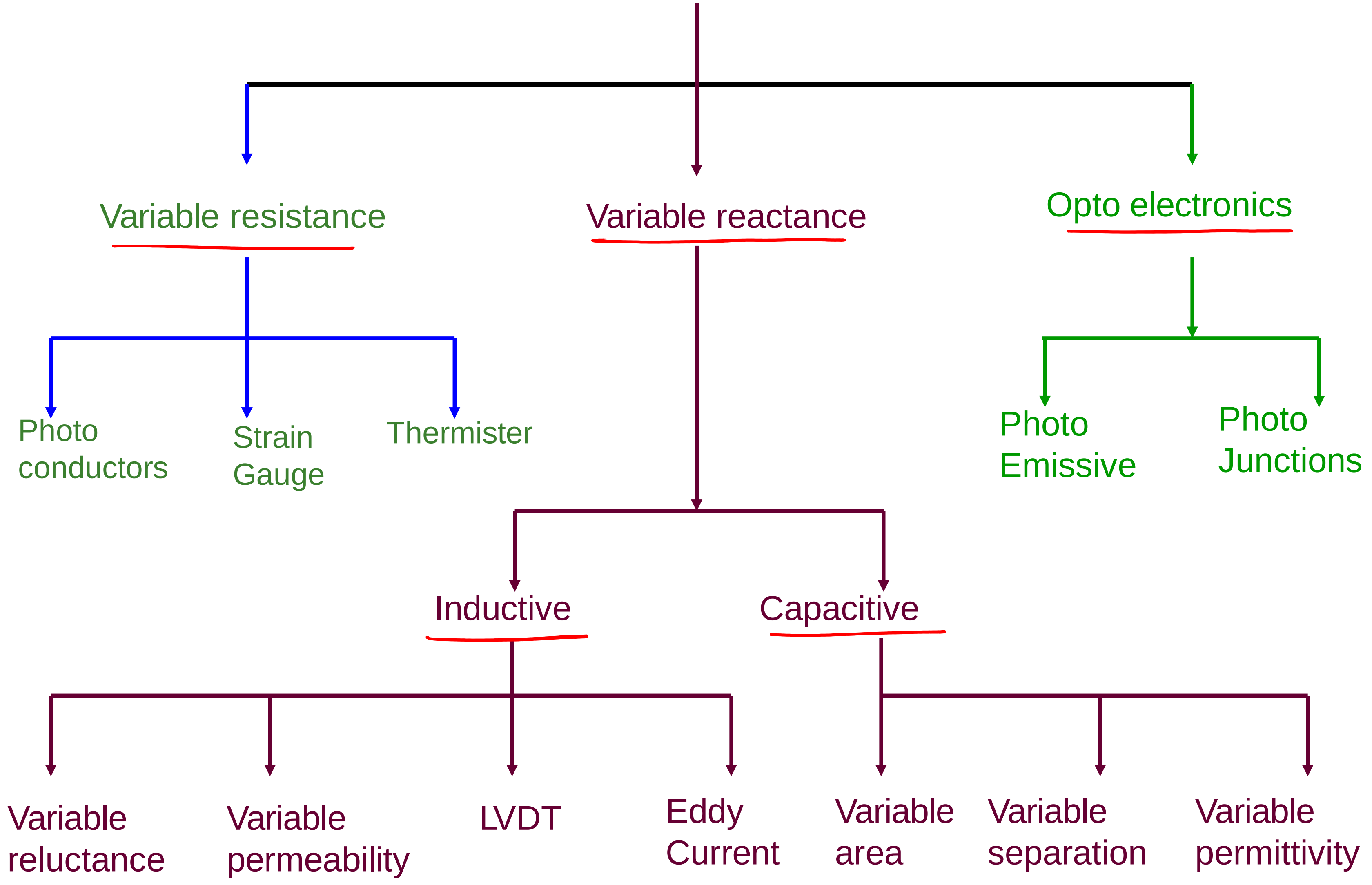
voltage and current

- At the output of active transducers we get an equivalent electrical output signal e.g. temperature to electrical potential, without any electrical source of energy being used.

Passive Transducers

- These transducers need external power supply for their operation. So, they are "not self generating" transducers.
- Passive transducers depends upon the change in an electrical parameter.
- They are also known as externally power driven transducers.
- Passive transducers are further subdivided into following:

Passive Transducers



Comparison..

Sr. No.	Active transducers	Passive transducers
1	They do not require any external source or power for their operation	They require an external source of power for their operation.
2	They are self generating type transducers.	They are not self generating type transducers.
3	They produce electrical parameter such as voltage or current proportional to the physical parameter under measurement.	They produce change in the electrical parameter such as inductance, resistance or capacitance in response to the physical parameter under measurement.
4	Examples : Thermocouple, Photocell, piezoelectric transducers.	Examples : Thermister, LDR, LVDT, Phototransistor.

Classification based on Quantity to be measured

Transducer

- Temperature Transducers
- Pressure Transducers
- Displacement Transducers
- Flow Transducers
- Others

Analog and Digital Transducers

- Depending on the nature of output obtained from a transducer, it is classified into two categories namely analog transducers and digital transducer.
- Analog Transducers:
  - The output of these transducers is in analog form that means it is a function of time.
  - The examples of analog transducers are thermocouple, LVDT, strain gauge etc.
- Digital Transducers:
  - The output of these transducers is in the digital form that means it is in the form of digital pulses discrete in time.
  - Digital output

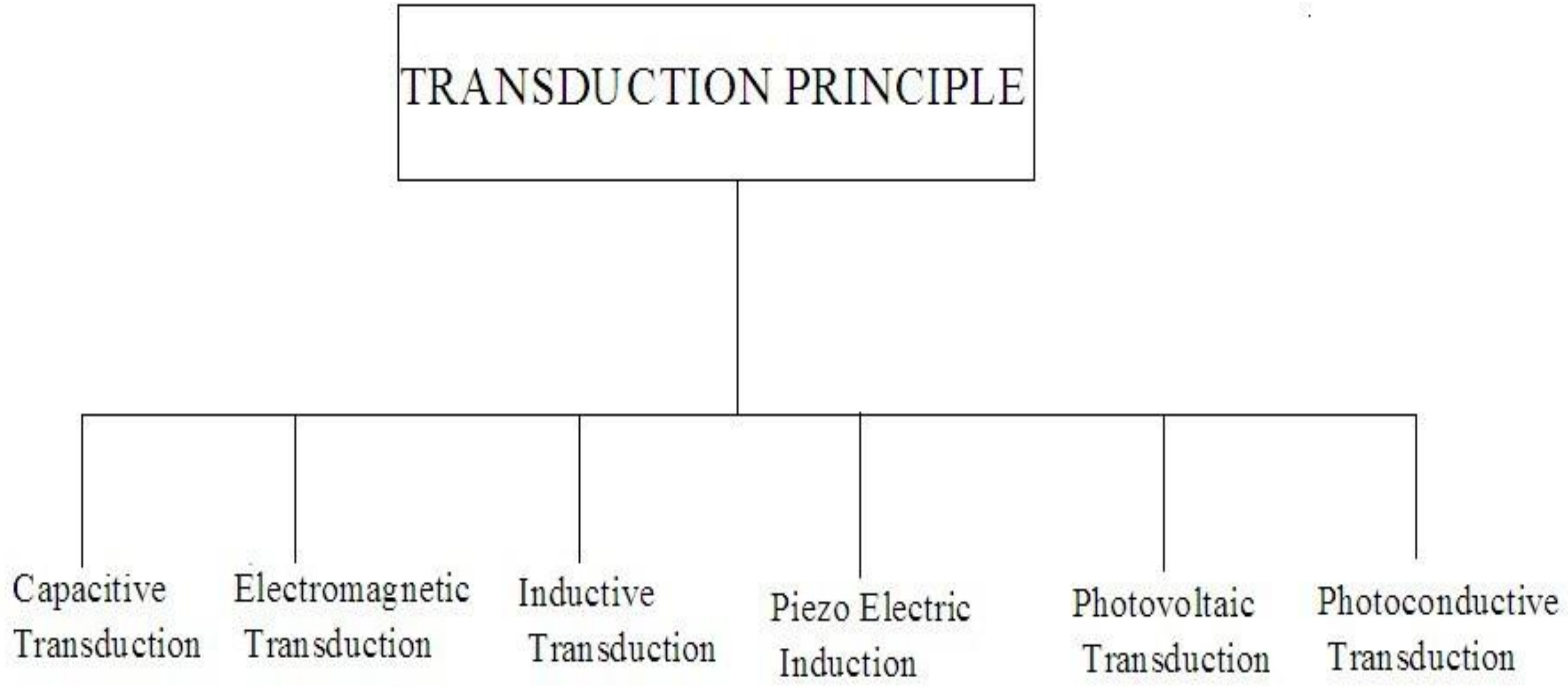
Primary and Secondary Transducers

- Some transducers contain the mechanical as well as electrical devices. The mechanical device converts the physical quantity to be measured into a mechanical signal. Such mechanical devices are called as the primary transducers.
- The electrical device then converts this mechanical signal into a corresponding electrical signal. Such electrical devices are known as the secondary transducers.

1) Primary Transducer
   - LVDT for displacement measurement
   - strain gauge for pressure measurement

2) Secondary Transducer
   - LVDT for pressure measurement

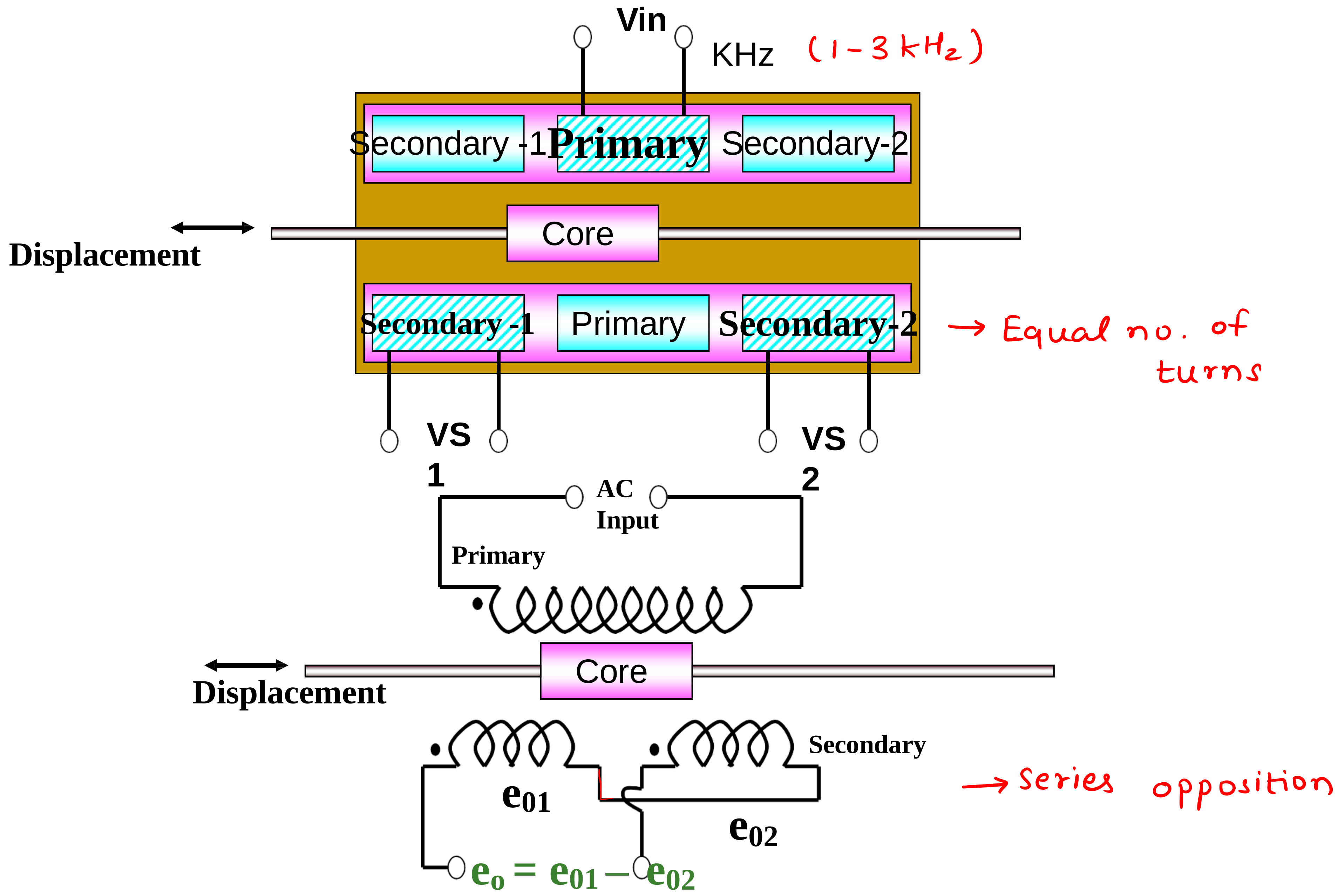
Classification according to Transduction Principle



Linear Variable Differential Transformer (LVDT)

- LVDT is widely used for measurement of linear displacement.
- It is transformer with one primary winding and two secondary windings.
- It works on the principle of mutual induction.
- Passive sensor

Object whose displacement has to be measured is connected to core



Working of LVDT

- The primary of LVDT is fed by a.c. excitation. Then, voltage is transformed to secondaries due to mutual inductance between primary and secondary windings.
- The voltage induced in S1 and S2 are,
  - Vs1=m1(di/dt)
  - Vs2=m2(di/dt)

If core is at centre position,

$m_1 = m_2$

$V_o = 0$

↓

Null position

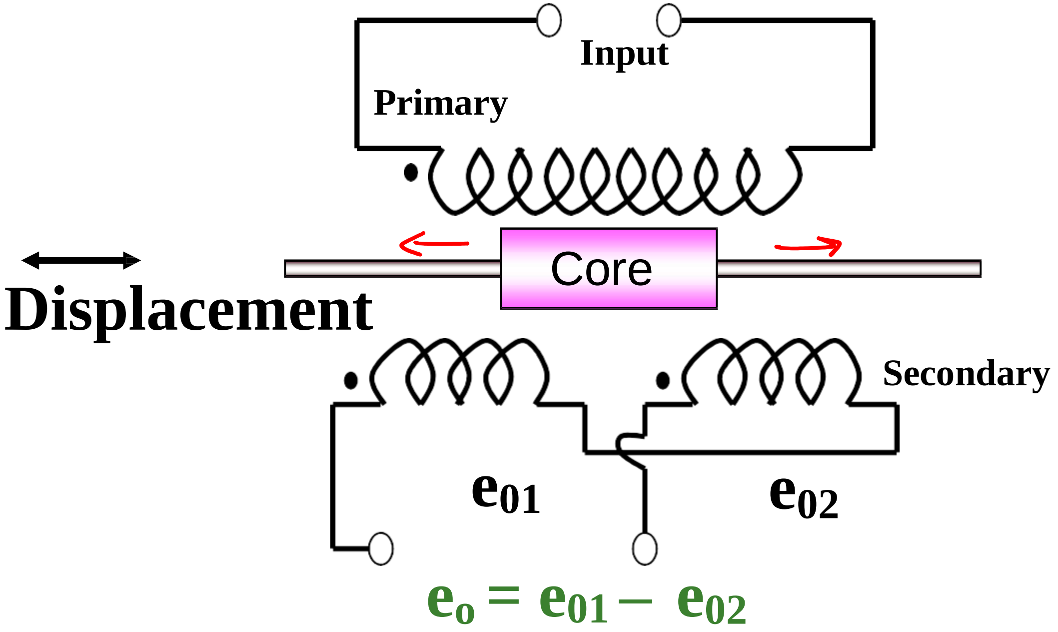
- m1 and m2 are core mutual inductance depends on core position.
- As the two secondaries are connected in series opposition, the output voltage is,
  - Vo=Vs1 - Vs2=(m1-m2) di/dt
  - Vo α (m1-m2)

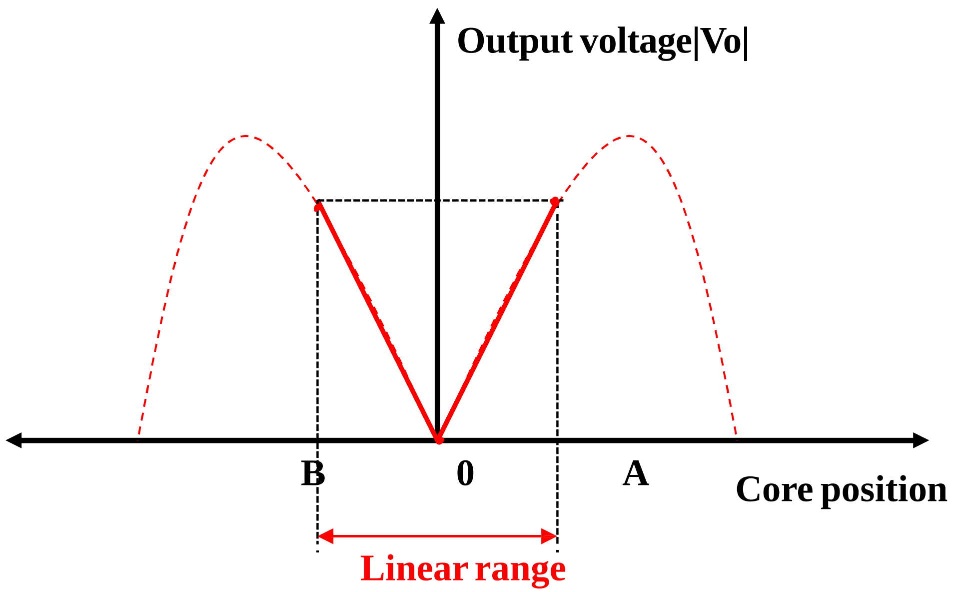
↳ Net mutual inductance

$$V_o = V_{s1} - V_{s2}$$
$$= m_1\frac{di}{dt} - m_2\frac{di}{dt}$$
$$= (m_1 - m_2)\,di/dt$$

$$\boxed{V_o \propto (m_1 - m_2)}$$

Working of LVDT





$$vo = \frac{Vs \times d}{Total\ travel}$$

Vs : Secondary voltage

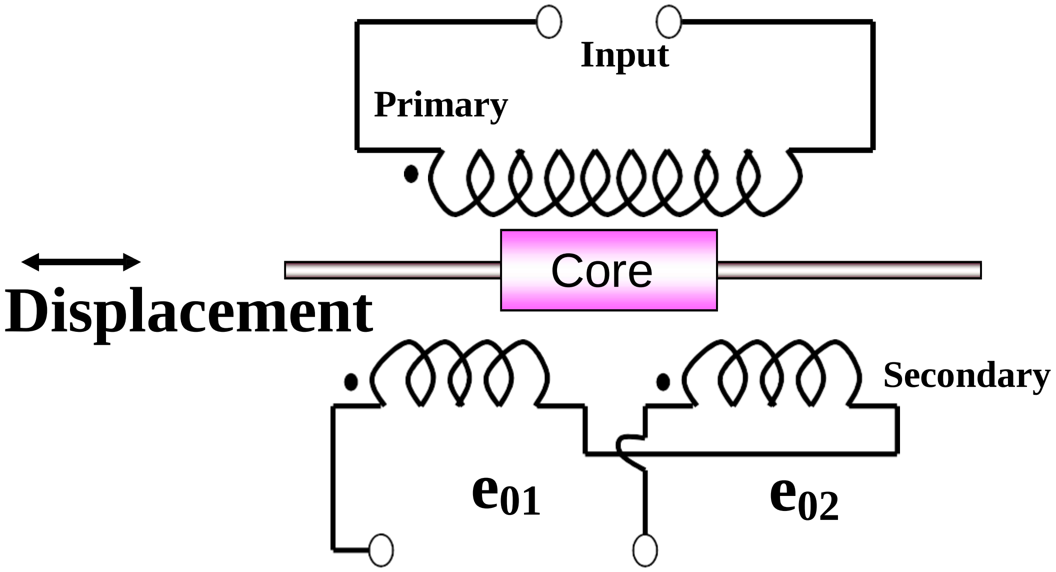
Vo : Output Voltage

d : Displacement of core from center.

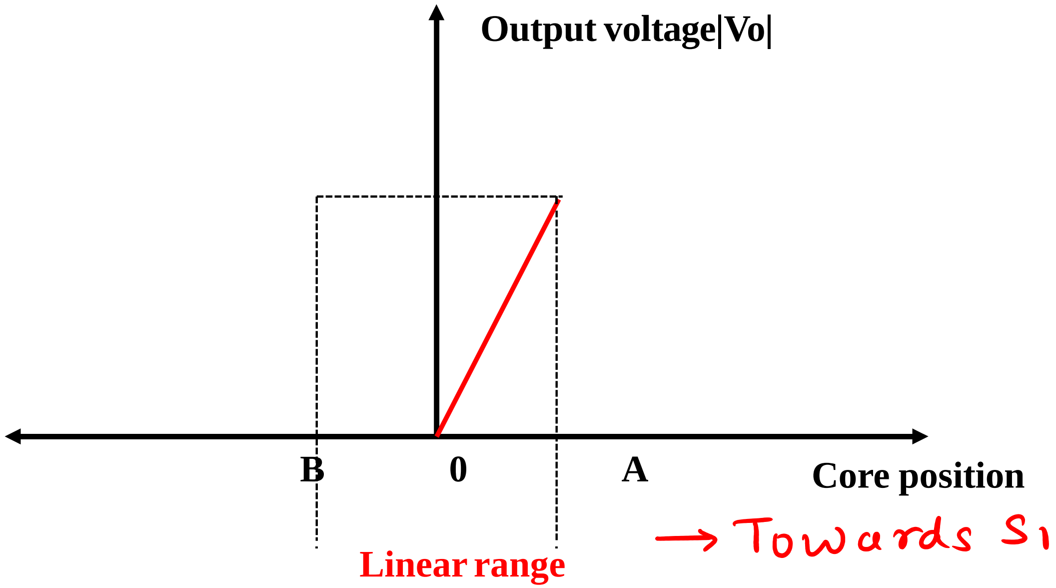
It is –ve towards s2 and +ve towards s1.

Total Travel : Maximum possible displacement from center.

Working of LVDT



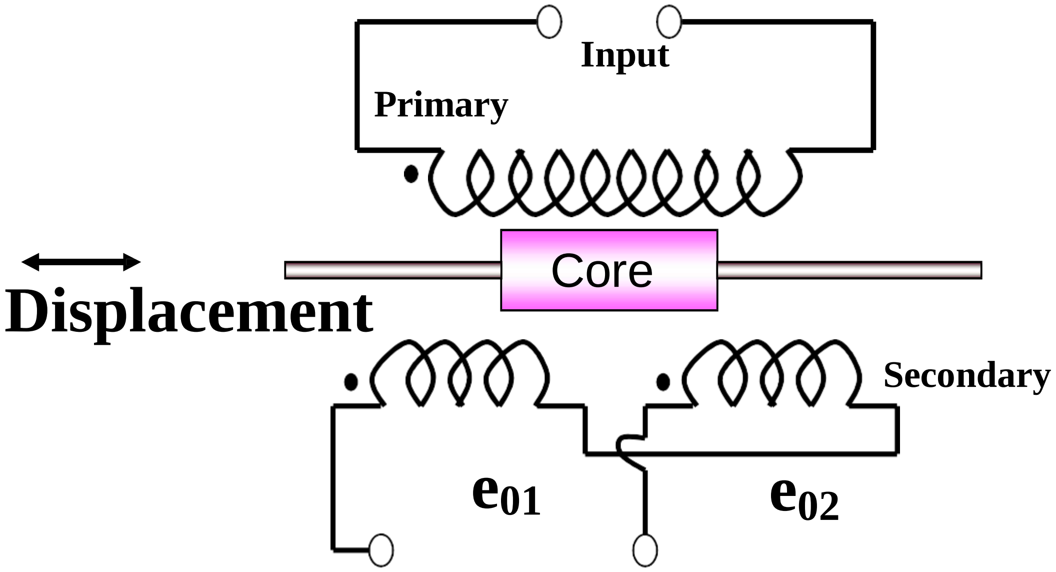
$e_o = e_{01} - e_{02}$



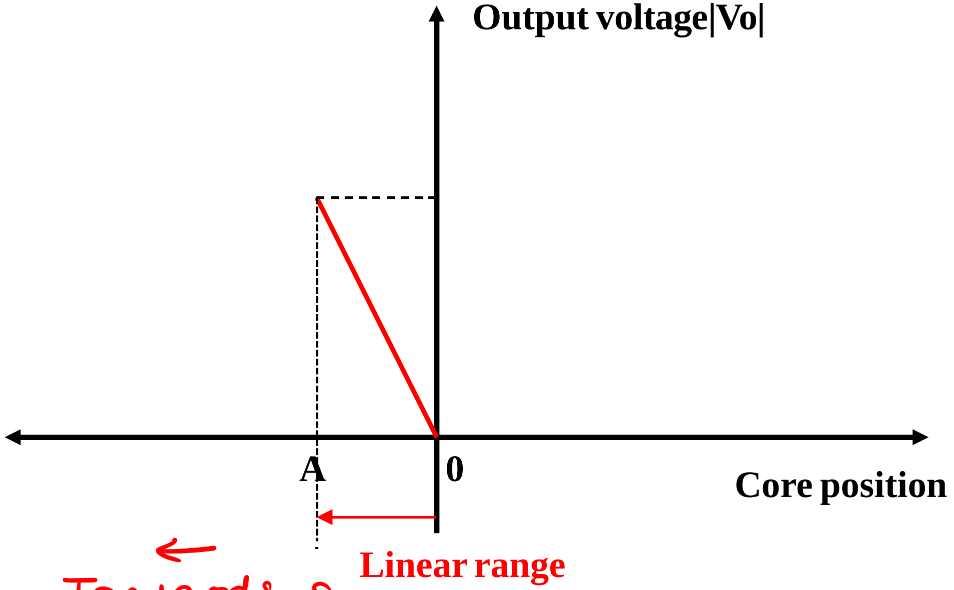
When core moves towards s1,
$e_{01} > e_{02}$

$e_o = e_{01} - e_{02} \rightarrow$ positive

Working of LVDT



$e_o = e_{01} - e_{02}$



Towards S_2

When the core moves towards S_2,

$e_{01} < e_{02} \Rightarrow e_{02} > e_{01}$

$e_0 = e_{01} - e_{02} \Rightarrow$ Negative

Advantages of LVDT:

- Very fine resolution, High accuracy, Very good stability
- Linearity of transfer characteristics
- Ease of fabrication and installation
- Ability to operate at high temperature
- High sensitivity.

Disadvantages of LVDT:

- LVDT is sensitivity to the external fields. To minimize this effect magnetic shielding is necessary.
- Complicated circuitry is needed.
- Larger displacements are required to get differential output.

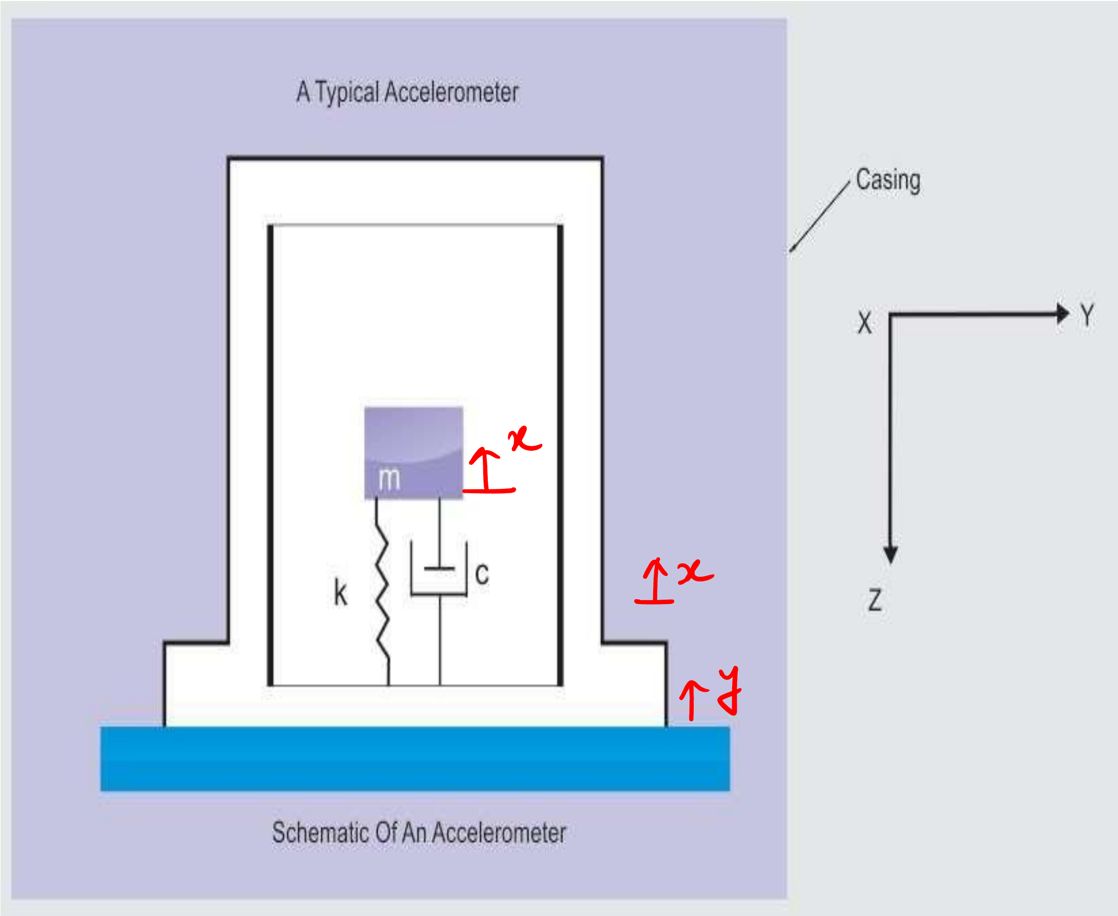
Application of LVDT:

- In addition to displacement the LVDT is used in measurement of pressure, load, acceleration, force, weight etc.

Accelerometer

- An accelerometer is a sensor that measures the physical acceleration experienced by an object due to inertial forces or due to mechanical excitation.
- Acceleration is defined as rate of change of velocity with respect to time.
- It is a sensor used to measure acceleration.
- An accelerometer is an electro-mechanical device that is used to measure the specific force of an object, a force obtained due to the phenomenon of weight exerted by an object that is kept in the frame of reference of the accelerometer.
- It is also used for measurement of vibration, shock.

Accelerometer



Mass – damper – spring

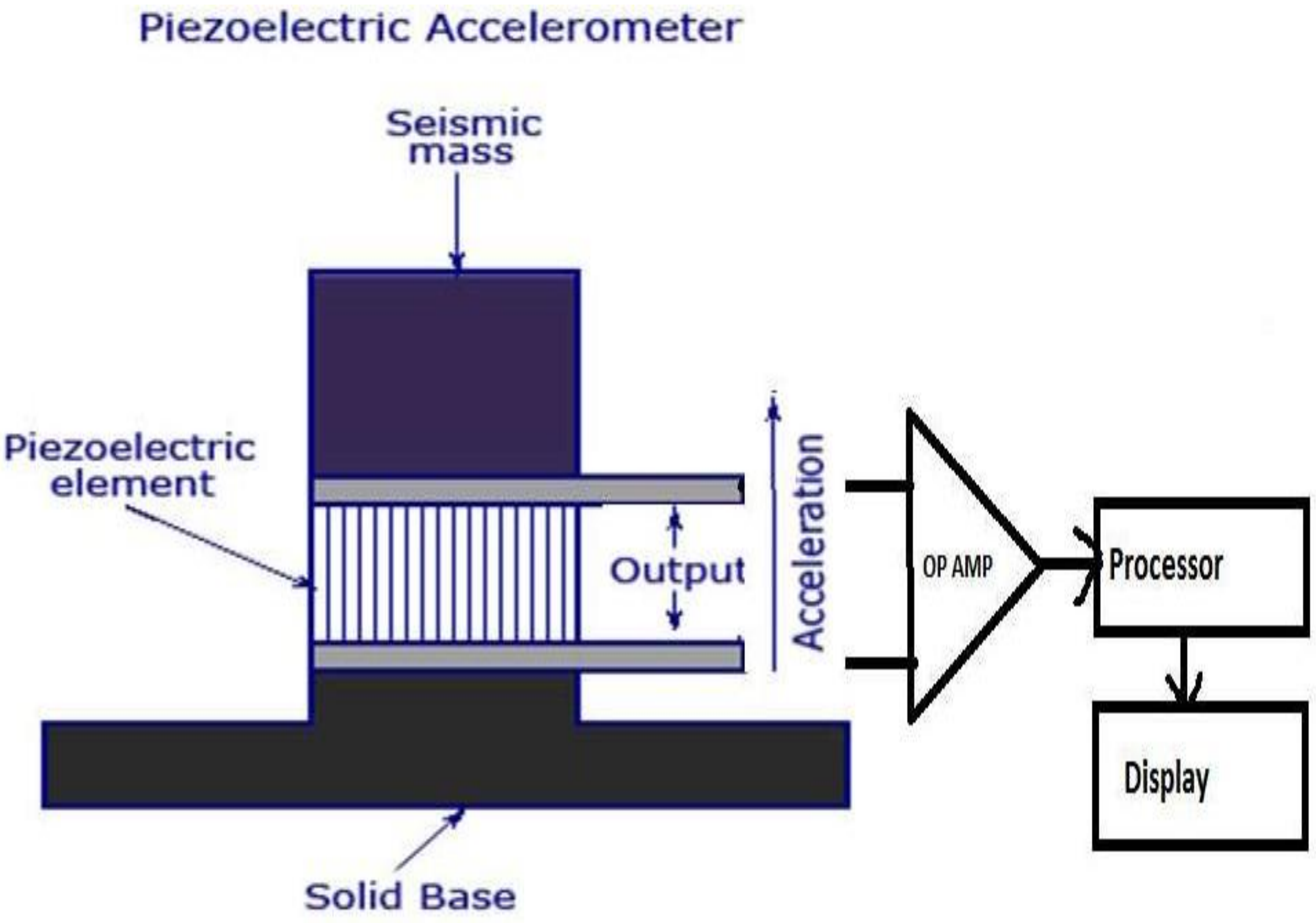
$\underbrace{\text{– damper –}}$

↓

seismic instrument

Relative displacement $(\underline{x-y})$

Construction of Accelerometer



Working of Accelerometer

- The most common device is the piezoelectric accelerometer. As the name suggests, it uses the principle of piezoelectric effect.
- The device consists of a piezoelectric quartz crystal on which an accelerative force, whose value is to be measured, is applied.
- Due to the special self-generating property, the crystal produces a voltage that is proportional to the accelerative force. The working and the basic arrangement is shown in the figure.
- The basic underlying working principle of an accelerometer is such as a dumped mass on a spring. When acceleration is experienced by this device, the mass gets displaced till the spring can easily move the mass, with the same rate equal to the acceleration it sensed. Then this displacement value is used to measure the give the acceleration.

Applications

- Used to measure earthquake activity
- Used in Internal Navigation system (INS) for measuring the position, orientation and velocity of an object.
- Machine monitoring i.e. mostly in industrial application

Temperature Sensors

- The Sensor which change their output with change in temperature is called as temperature sensor.
- Ex: thermocouple, thermistor,
- When body is heated or cooled, various effects of heating or cooling can be observed these effects include:
  - Change in the physical or chemical state.
  - Change in the physical dimensions.
  - Change in the electrical properties.
  - Change in the intensity of total radiation emitted.
- The electrical method are by far the best methods for temperature measurement.
  - Method based on change in resistance → Thermistor, RTDs
  - Method based on generation of thermo emf. → Thermocouple

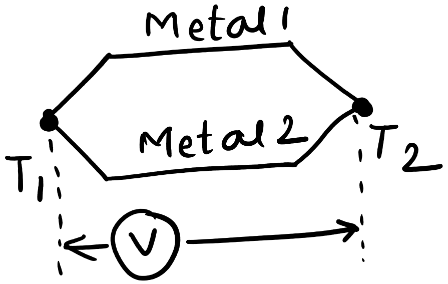
Examples - 1) LM35
2) DHT11/DHT22

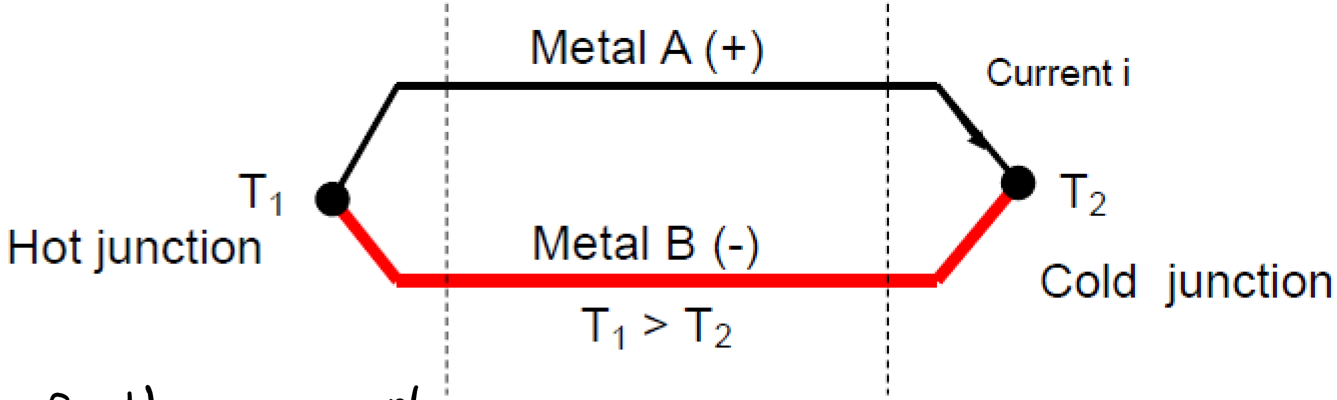
Temperature Sensors

- **Resistance Temperature Detectors (Passive)(RTDs)**
  - Platinum, Nickel, Copper metals are typically used
  - positive temperature coefficients, connected in a Wheatstones bridge circuit.
- **Thermistors (Passive) (“thermally sensitive resistor”)**
  - Formed from semiconductor materials, non-metals
  - Often composite of a ceramic and a metallic oxide (Mn, Co, Cu or Fe)
  - Typically have negative temperature coefficients
- **Thermocouples (Active)**
  - Based on the Seebeck effect
  - Dissimilar metals at different temperature signal

Thermocouple (Active)

- The operation of thermocouple is based on a phenomenon called as seeback effect.
- It states that a current flows in a closed circuit made of two dissimilar metals if the junction of two metals are kept at different temperatures.
- Due to this current flow, an emf proportional to the temperature difference is produced.





$V_o \propto (T_1 - T_2)$

$V_o = c(T_1 - T_2)$

c = sensitivity of thermocouple.
mV/°C µV/°C

Thermocouple

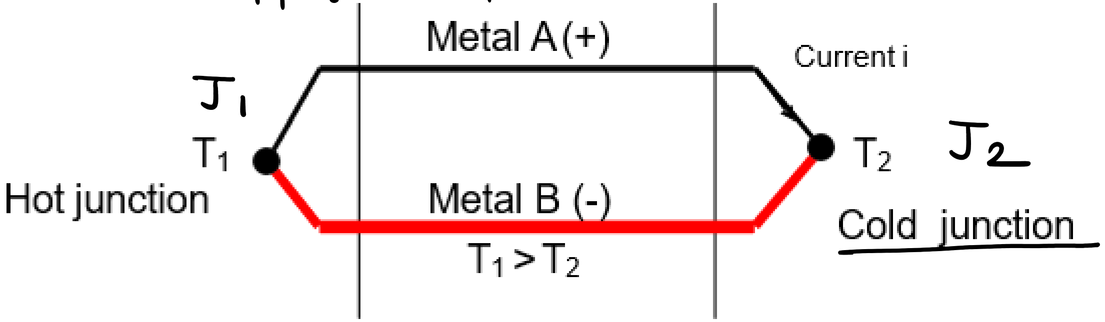
- The thermocouple is one of the simplest and most commonly used methods of measuring process temperature.
- A thermocouple consist of a pair of dissimilar metal wires joined together at one end forming a hot junction and terminated at the other end known as reference or cold junction.

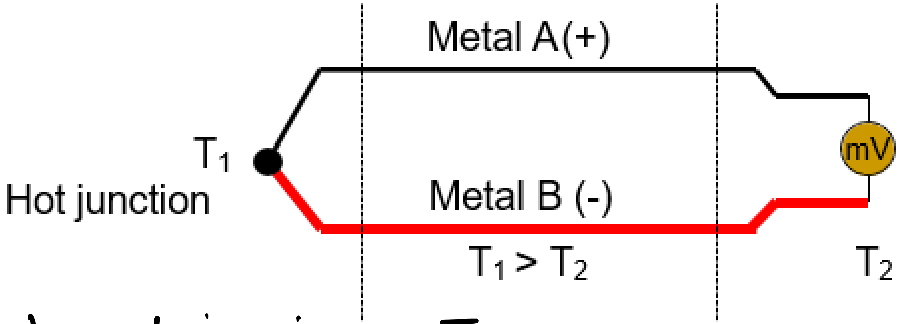
J_2 : Reference Junction (cold)

T_2 : Reference temp.

J_1 : Measuring Junction

T_1 : Temp. to be measured





$$V_o = c(T_1 - T_2)$$

$$T_1 - T_2 = V_o / c$$

$$\boxed{T_1 = \frac{V_o}{c} + T_2}$$

If J_2 is placed in ice, $T_2 = 0$

$$T_1 = \frac{V_o}{c}$$

Materials used for Thermocouples

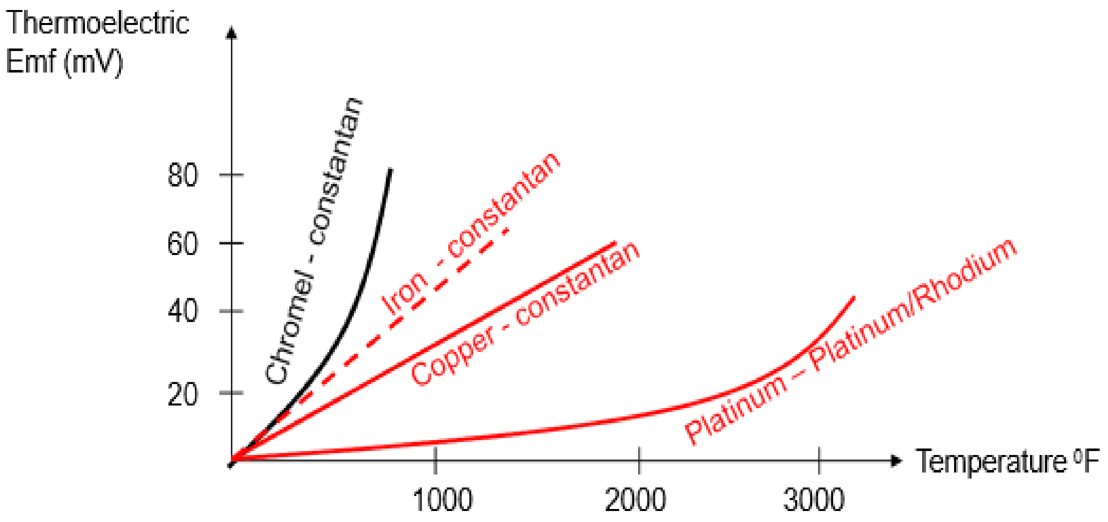
- Different metals used for manufacturing the thermocouple are as follows:

  1. Copper-constantan : 0 – 2000°F

  2. Iron – constantan : 0 – 1200°F

  3. Platinum – Platinum/ rhodium alloy : 0 – 3000°F

  4. Chromel – Alumel alloy : 0 – 900°F



Advantages

- Wide temperature range (-200°C to 1100°C)
- External DC source is not required → Active
- Good sensitivity i.e. small changes in temperature can be sensed.
- Fast dynamic response i.e. it responds quickly to any temperature changes.
- Less expensive and small in size.

Limitations

- The temperature characteristics of thermocouple is slightly nonlinear.
- Thermally generated emf is small. Hence amplification is required.
- Cold junction compensation needs to be done for accurate measurement of temperature.

Applications

They are used in applications where:

1. Wide operating temperature range is required.

2. Temperature at remote places are to be measured.

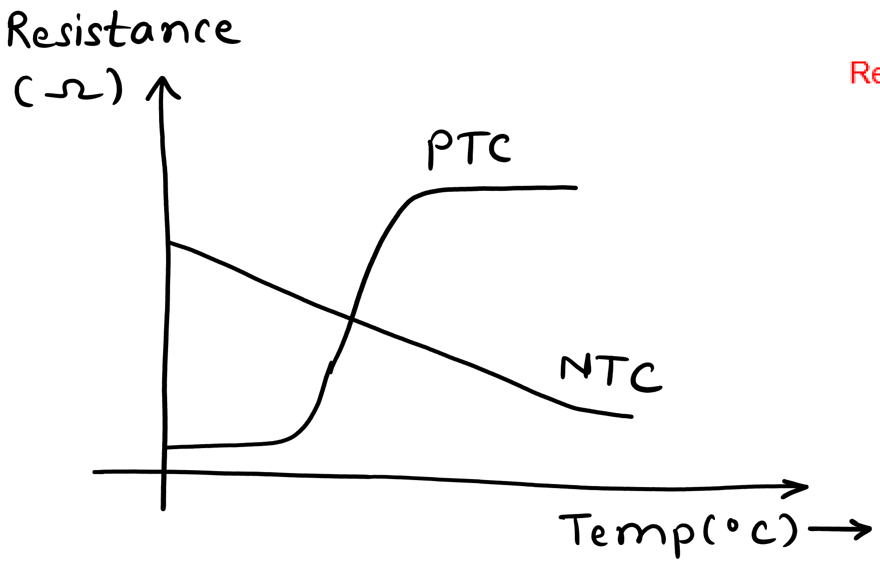
3. High response is required.

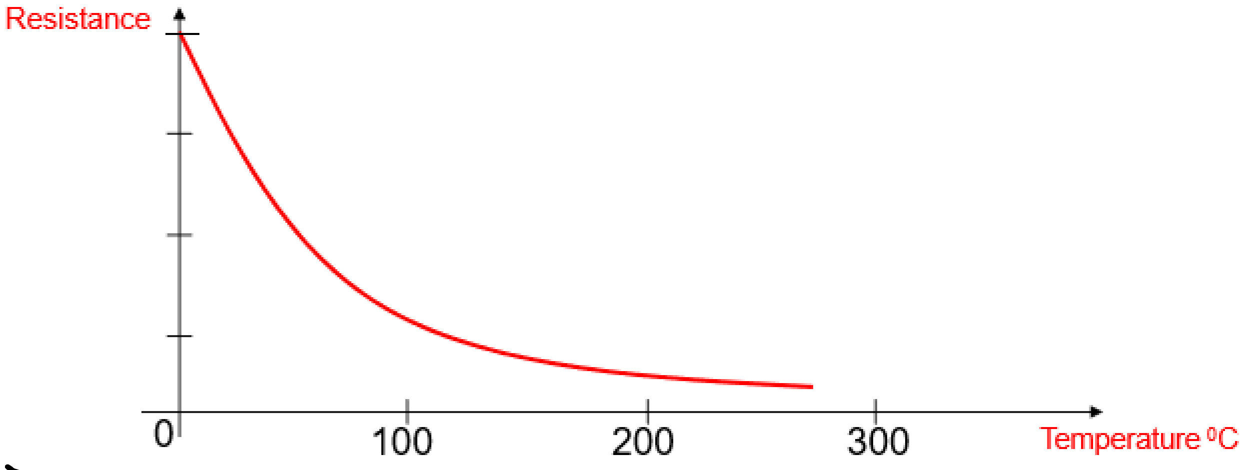
Thermistor

- Thermistor is a contraction of a term “thermal resistor”.
- Thermistor are temperature dependent resistors. They are made of semiconductor material.
- Thermistor are widely used in application which involve measurement in the range of 0-60°.

Thermistors

- Thermistors are also temperature dependent resistors (RTD).
- They are made of semiconductor materials which have a negative temperature coefficient of resistivity.
- The variation of resistance with changes in temperature is nonlinear.
- Thermistors can be used to measure temperatures in the range of -100°C to 300°C.





Resistance of Thermistor

Measurement system:

The resistance of a thermistor expressed as :

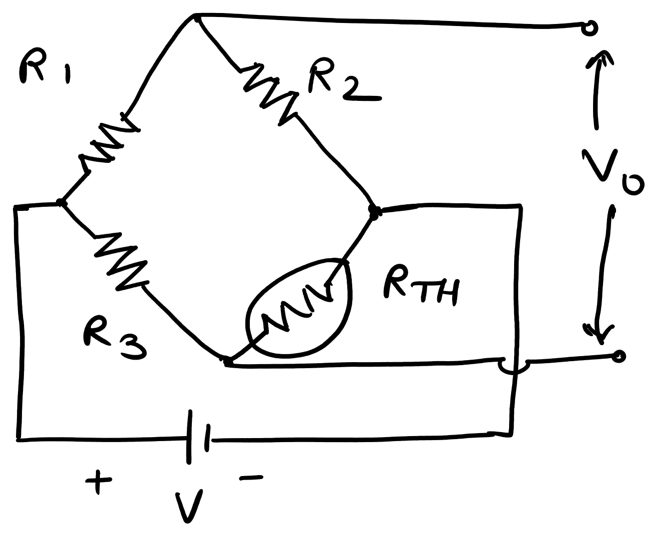
$$R_T = R_o \ \mathrm{Exp}\left[\beta\left[\frac{1}{T} - \frac{1}{T_o}\right]\right]$$

R_T = Resistance at T ^{0} K

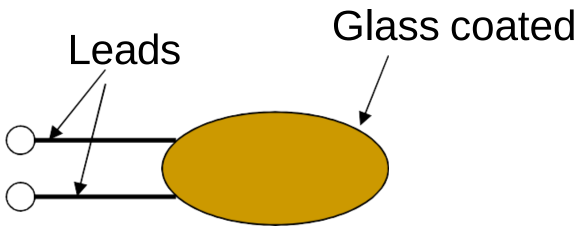
R_0 = Resistance at $T_0{}^0$ K

β = characteristics temperature / Material constant

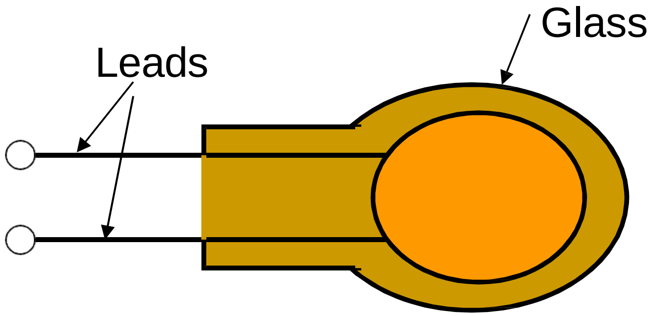
$$R_T = R_0 e^{\beta\left(1/T - 1/T_0\right)}$$



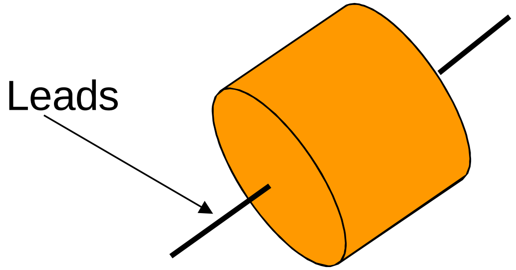
Construction of Thermistors



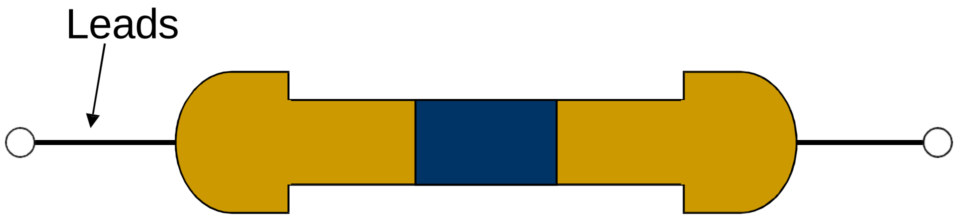
1. Bead



2. Probe



3. Disc



4. Rod

- **Advantages of Thermistors:**
- Small size and low cost.
- Comparatively large change in resistance foe a given change in temperature.
- Fast response over a narrow temperature range.

- **Disadvantages of Thermistors:**
- Temperature Vs resistance characteristics is nonlinear.
- Needs external DC power supply for its operation. (Passive)
- Not suitable for wide range operation. (range -100°C to 300°C)

- **Applications of Thermistors:**
- As a temperature sensor with or without compensation.
- In biomedical instrumentation.
- In measuring the temperature distribution or temperature gradient.

Resistance type Temperature sensor (RTD) (Passive)

- It has been observed that the resistance of metal increases with increase in temperature. Therefore, metals are said to have a positive temperature coefficient of resistivity.
- However , some semiconductor materials have a negative temperature coefficient of resistivity, that means their resistance decreases with increase in temperature.
- Thus, it is possible to convert the temperature variation into equivalent changes in resistance.
- This is the principle of operation of resistance type temperature sensors. These transducers are called as resistance temperature detector (RTD).

The relation is given as,

$$\boxed{R_T = R_0(1 + \alpha_0 \Delta T)}$$

Where, R_T = Resistance at T °C

R_0 = Resistance at 0 °C

α_0 = Resistance - temp. coeff at 0 °C

ΔT = Temperature difference
($T - 0 = T$)

Resistance type Temperature sensor (RTD)

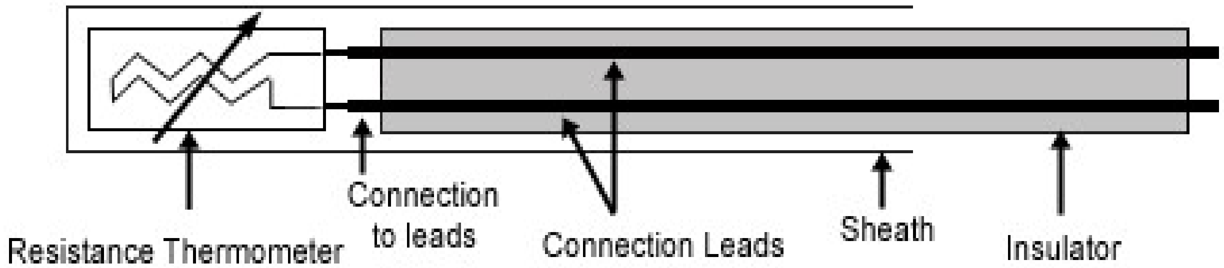
- The resistance type temperature sensors are of two types:

  1. Platinum Resistance Thermometer (PRT) and

  2. Thermister

Resistance Thermometer

- Resistance of metal increase with increases in temperature. Therefore metals are said to have a positive temperature coefficient of resistivity.
- The Figure shows the simplest type of open wire construction of platinum resistance thermometer.
- The platinum wire is wound in the form of spirals on an insulating material such as mica or ceramic.
- This assembly is then placed at the tip of probe.
- This wire is in direct contact with the gas or liquid whose temperature is to be measured.

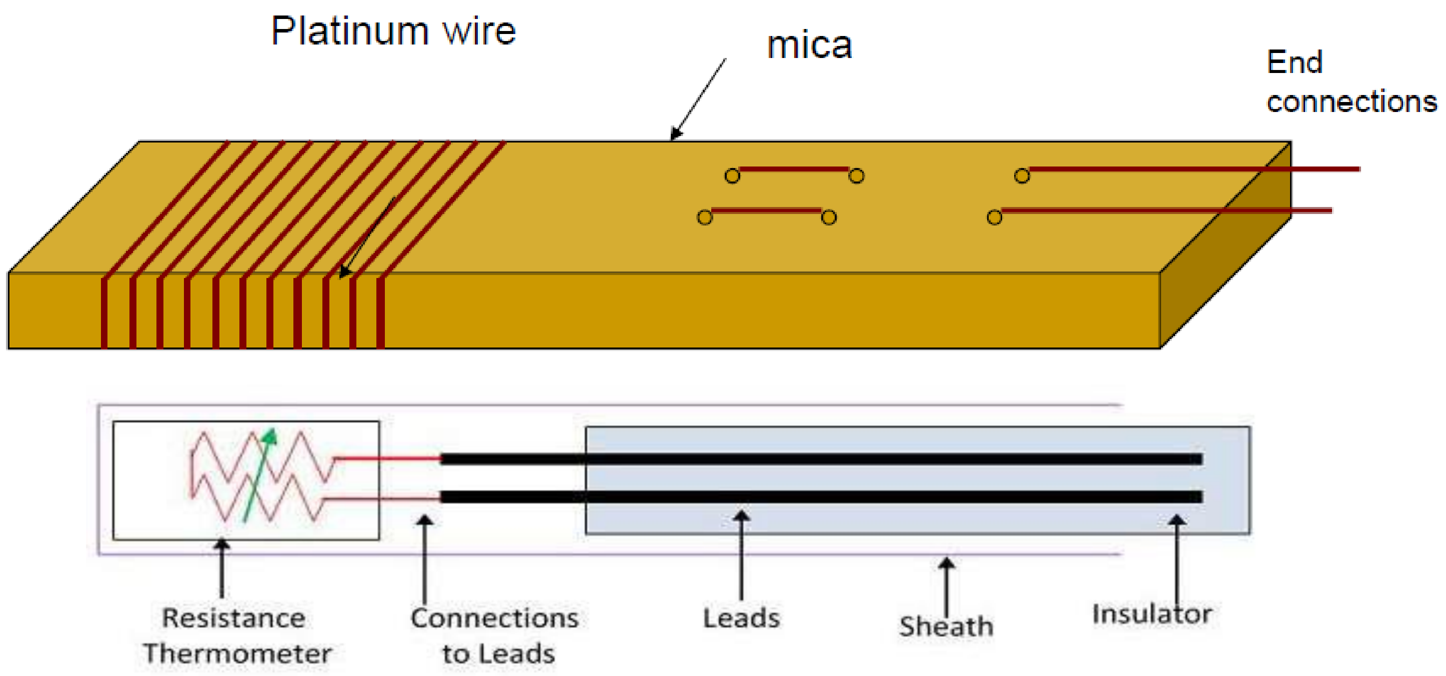


Resistance Thermometer

- The resistance of the platinum wire changes with the change in temperature of the gas or liquid.
- This type of sensor have a positive temperature coefficient of resistivity as they are made from metals they are also known as resistance temperature detector.
- Resistance thermometer are generally of probe type for immersion in medium whose temperature is to be measured or controlled.

Construction of PRT

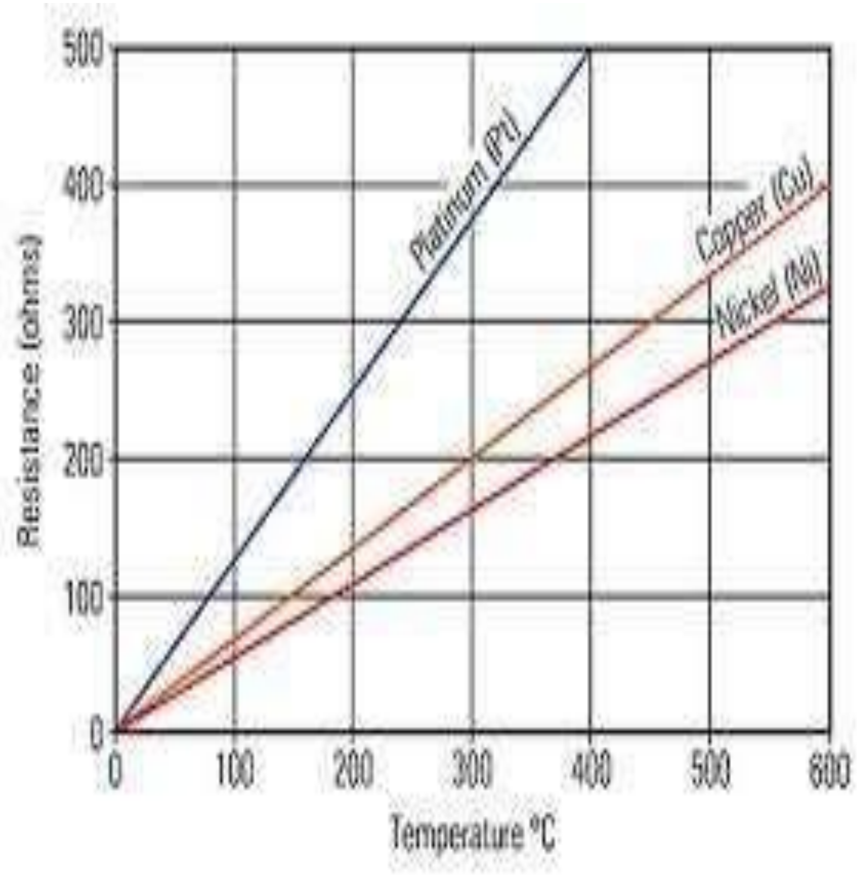
- As shown in figure, the resistance temperature detector is composed of resistance element , internal conductors, insulated tube reinforcing tube or sheath.



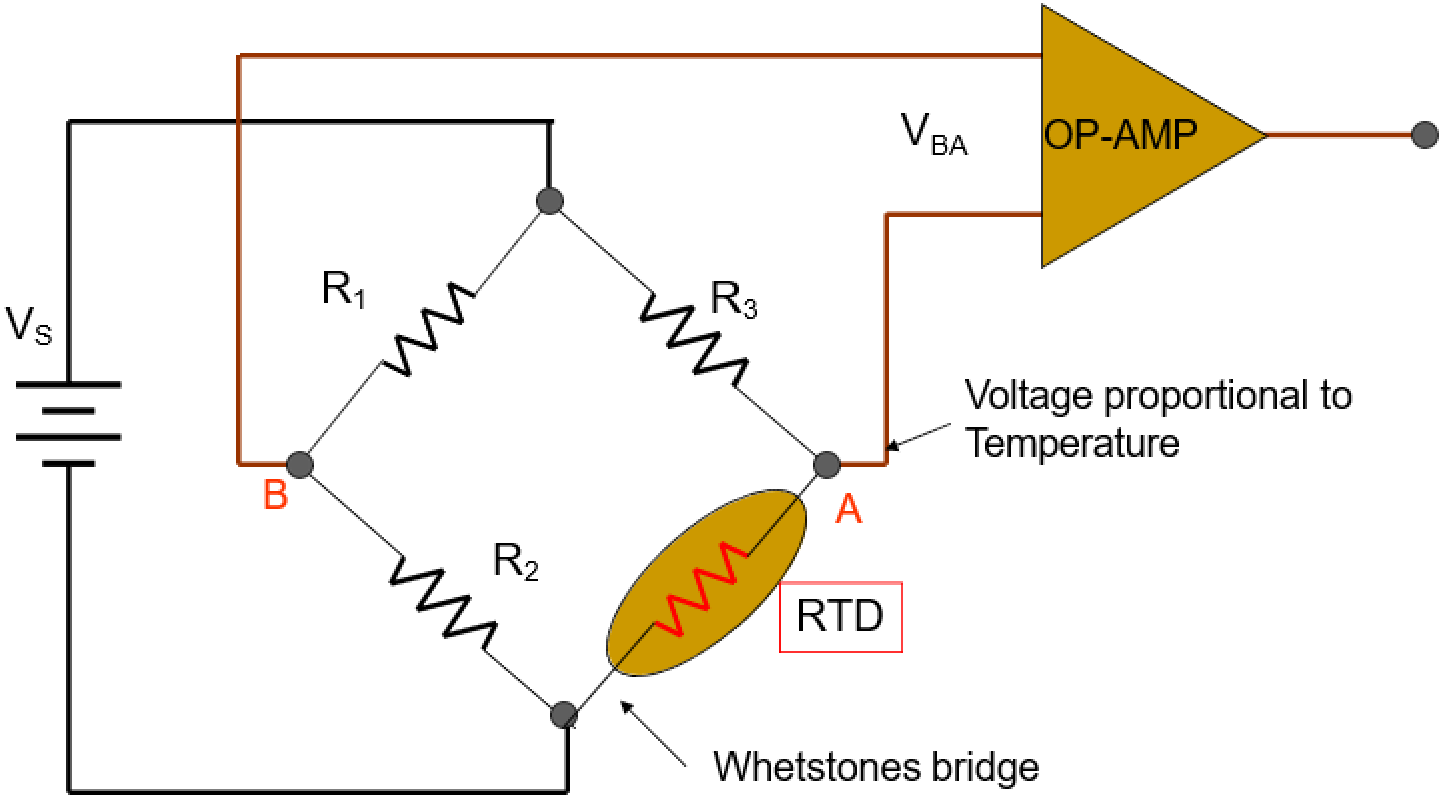
Resistance Thermometer

Construction of PRT

- **Resistance element:** RTD uses Platinum, nickel or copper as a resistance element. It is placed in a protective tube to provide excellent resistance against vibration
- **Internal lead wire/connection lead:** It is used to connect the resistance element to the terminal. A standard nickel lead wire is generally used for this purpose.
- **Insulate Tube:** It is for insulating the internal lead wire .It gives protection against a short circuit. for high temperature ,a ceramic insulator is used and for medium temperature a fiber glass is used
- **Protection tube/sheath:** It protects resistance element, internal lead wires etc. when operated in external ambient conditions. So the material used for it must be selected properly


Resistance (ohms)
500
400
300
200
100
0
0
100
200
300
400
500
600
Temperature °C
Platinum (Pt)
Copper (Cu)
Nickel (Ni)

RTD Resistance Measurement



RTD Resistance Measurement

- The temperature measurement can be carried out by using Wheatstone bridge. As shown in figure bridge is formed by resistor R1, R2, R3 and the RTD (R4) whose resistance varies with change in temperature.
- As the temperature changes ,resistance of the RTD changes, therefore the bridge gets unbalanced and produces change in the output voltage .Thus we get a change in output voltage for corresponding change in the input temperature.

Resistance Temperature Detector(RTD)

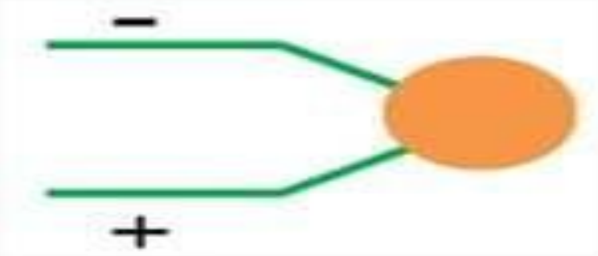
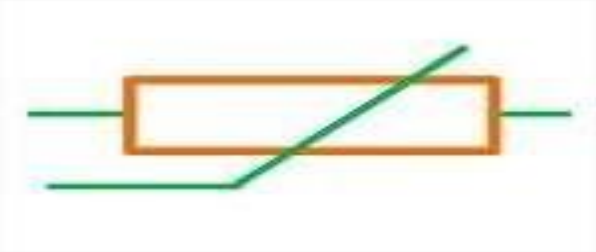
- Based on the temperature dependence of resistivity of all metals and alloys.
- Although virtually all metals can be employed, platinum is used almost exclusively: predictable response, long-term stability and durability, ultimate in accuracy . Other RTDs are Nickel, Copper etc.
- All RTD's have positive temperature coefficients (Carbon & Germanium have NTC). RTDs are not suitable fast response or small area sensing.

Advantages of RTD:

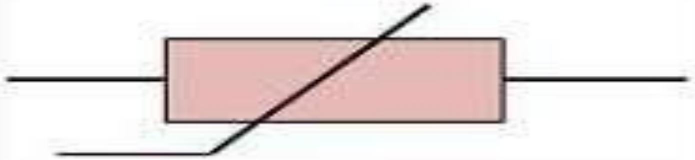
- They can be used for measurement of small as well as large temperature difference.
- High accuracy.
- High reproducibility i.e. characteristics remain unaltered.
- Good dynamic response i.e. it responds very quickly to the changes in temperature.
- Wide temperature range (- 200°C to 650°C)

Disadvantages of RTD:

- Large size
- Sophisticated instrumentation is necessary for protection of resistance wire.
- External DC power source is required (Passive)
- High cost.

Basis For Comparison	Thermocouple	Thermistor
Definition	The thermocouple is a type of device used for measuring the temperature	Thermistor is the thermal resistor whose resistance changes with the temperature.
Symbol		
Sensing Parameter	Voltage generate at the junction.	Resistance
Material	Copper, iron, Constantan, Chromel, Alloys of metals like Chrome, chromium and nickel, platinum and rhodium, tungsten and rhenium, rhodium and iridium.	Manganese, nickel or cobalt oxides, semiconductor material.

Basis For Comparison	Thermocouple	Thermistor
Characteristic Curve	Non-linear for negative temperature coefficient.	Linear
Cost	Expensive (because of external power source and devices on circuit.)	Cheap
Uses	In home appliances like ovens, refrigerators, fire alarm etc.	In Industries.
Applications	For controlling temperature, Measurement of temperature, thermal conductivity, temperature compensation etc.	Measuring and controlling temperature.

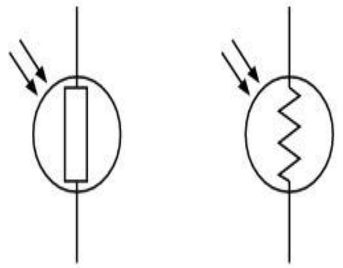
Basis For Comparison	RTD (Resistance Temperature Detector)	Thermistor
Definition	The device use for measuring the change in temperature is known as the RTD or Resistance Temperature Detector.	It is a thermal resistor whose resistance changes with the temperature.
Symbol		
Material	Metals (platinum, nickel, copper, etc.)	Semiconductor
Accuracy	Less accurate.	Their accuracy is high. It can detect even small changes in temperature because of negative temperature coefficient.

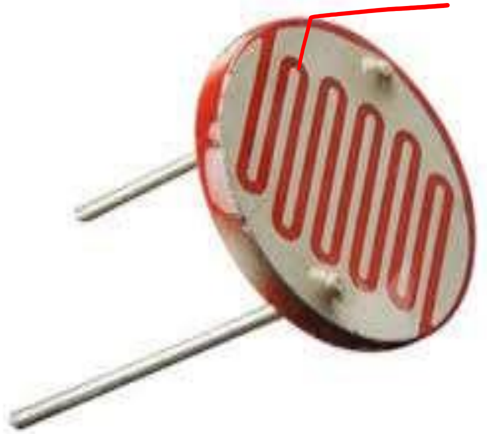
Optical Sensors

- Optical sensors are sensitive to light.
- The electrical properties of these sensors change with the intensity of light falling on them.
- Following optical sensors are commonly used
  - Photo diode (Photoconductive device)
  - Photo transistor (Photoconductive device)
  - Photo voltaic cell
  - Photo multiplier tube
  - Light dependent resistor(LDR)

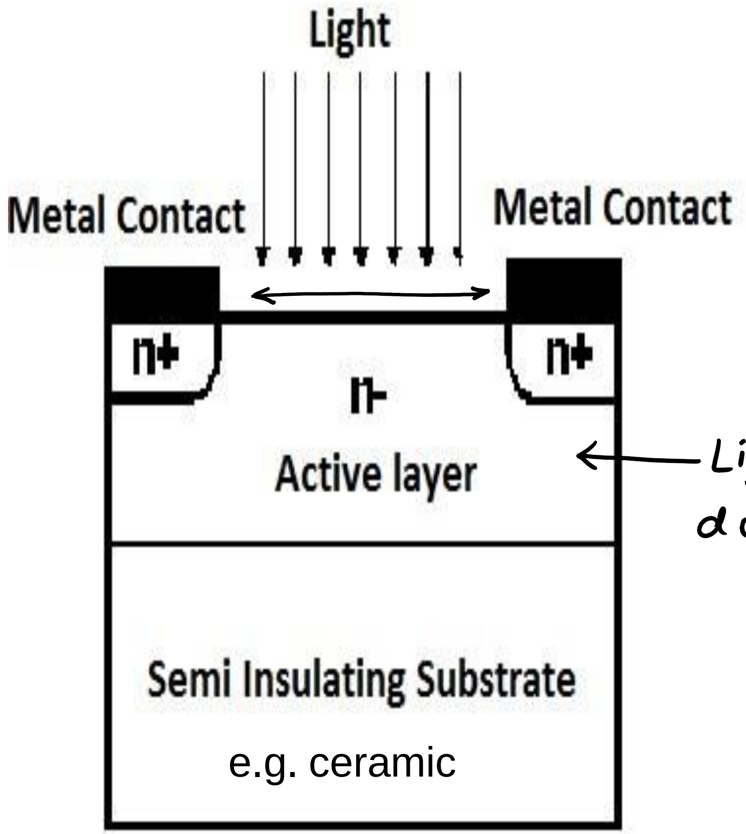
LDR (Light Dependent Resistors)

- It is a device whose resistance depends on the intensity of light falling on it.
- It is also called as photo resistor or photocell.
- Principle: Resistivity of LDR decreases with increases in light intensity, it exhibits photoconductivity



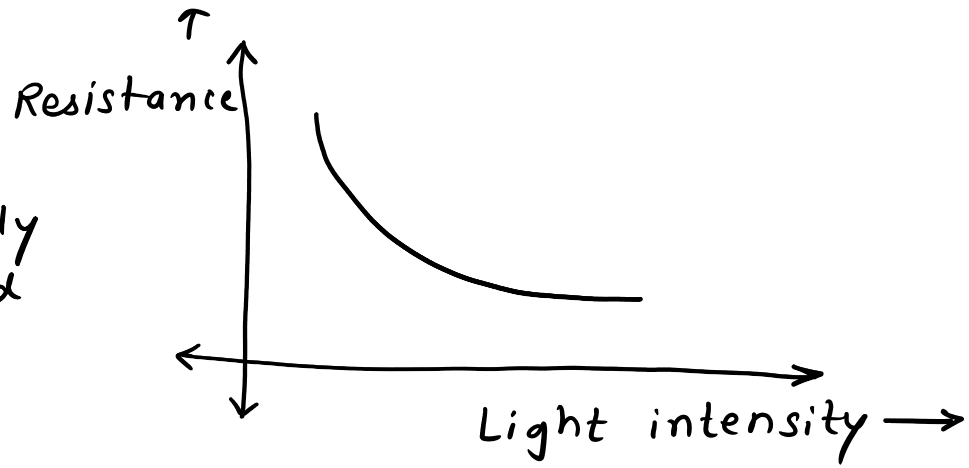


Construction of LDR



Lightly doped

* High resistance
* Less no. of free $e^{\ominus}$
* When light falls on it, resistance decreases as $e^{\ominus}$ absorbs (gains) energy from photons.

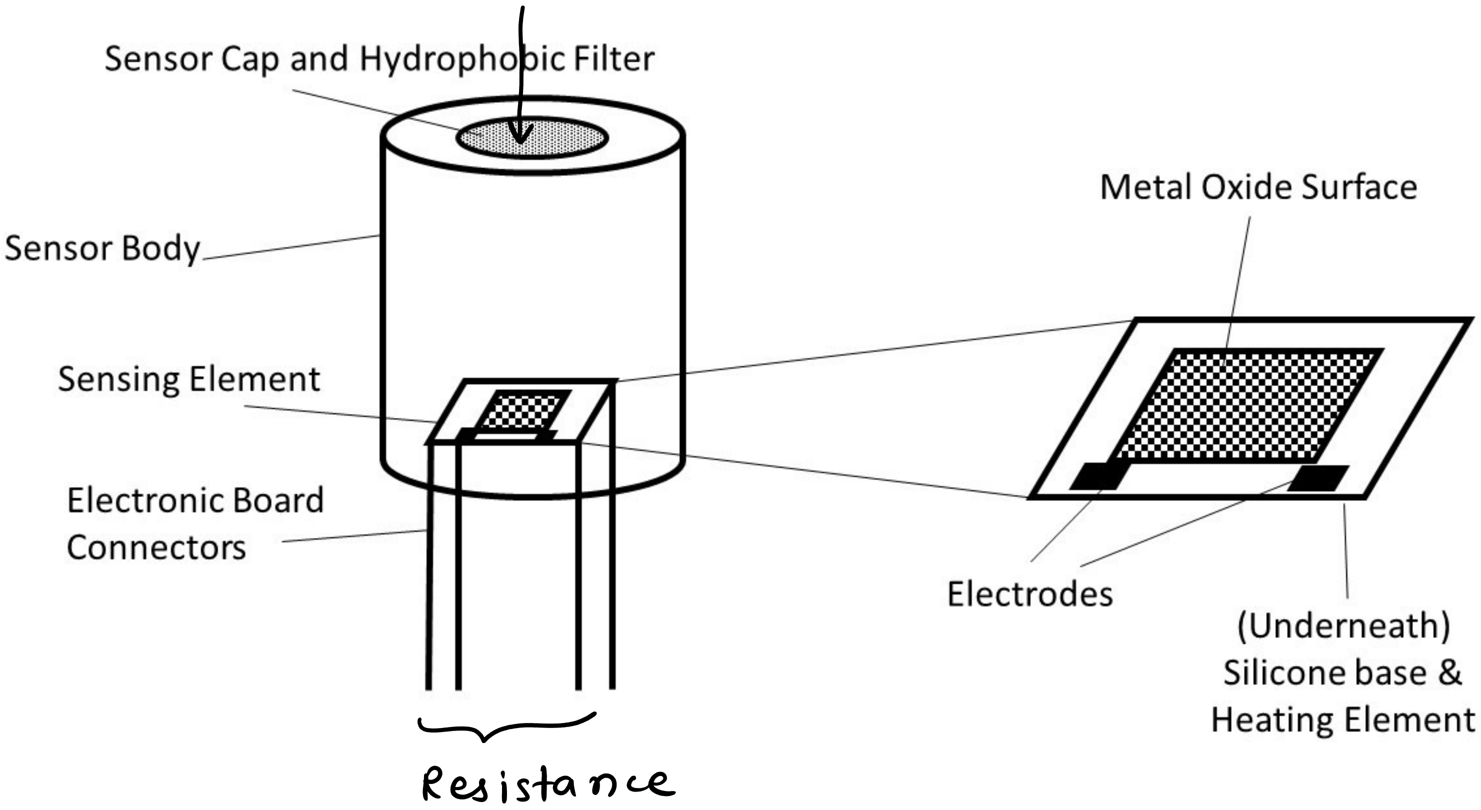


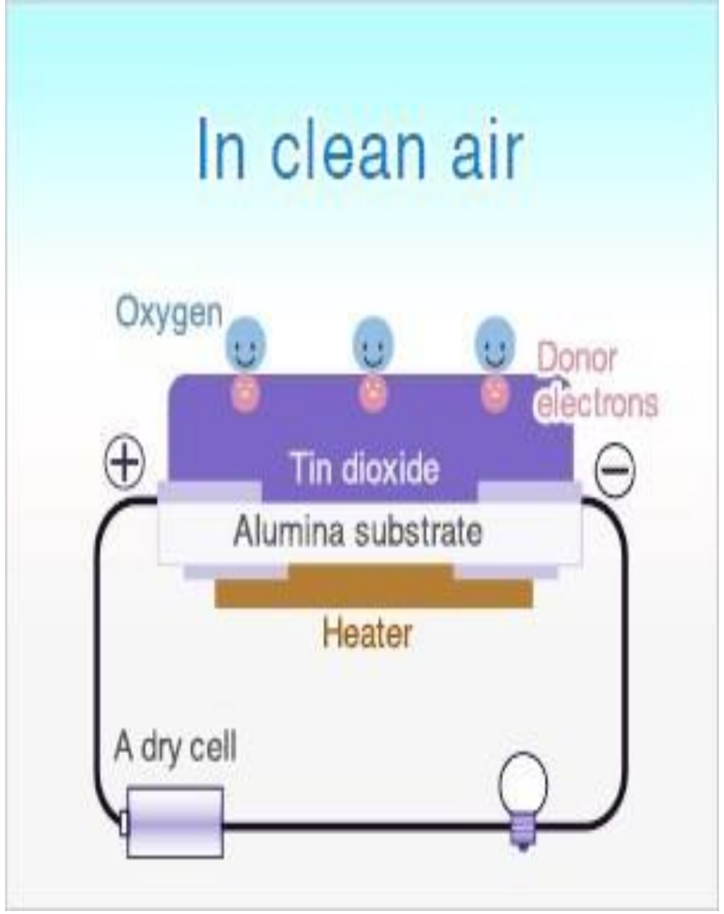
* Dark Resistance : Resistance of LDR when no light falls on it. (MΩ)
  20 MΩ
* Daylight Resistance of LDR = 5k Ω

Construction of LDR

- The structure of a **light dependent resistor** consists of a light sensitive material which is deposited on an insulating substrate such as ceramic.
- The material is deposited in zigzag pattern in order to obtain the desired resistance and power rating.
- This zigzag area separates the metal deposited areas into two regions. Then the ohmic contacts are made on the either sides of the area.
- The resistances of these contacts should be as less as possible to make sure that the resistance mainly changes due to the effect of light only. Materials normally used are cadmium sulphide, cadmium selenide, indium antimonide and cadmium sulphonide.
- The use of lead and cadmium is avoided as they are harmful to the environment.

Semiconductor Sensors : Gas Sensor





Gas Sensor : Working Principle

- Semiconductor sensors, also known as metal-oxide- semiconductor sensors (MOS sensors), detect gases by a chemical reaction that takes place when the gas comes in direct contact with the sensor
- Tin dioxide is the most common material used in semiconductor sensors, and the electrical resistance in the sensor is decreased when it comes in contact with the monitored gas.
- The resistance of the tin dioxide is typically around 50 kΩ in air but can drop to around 3.5 kΩ in the presence of 1% methane.

* The change in resistance is proportional to concentration of gas to be measured.

Gas Sensor : Working Principle

- This change in resistance is used to calculate the gas concentration.
- Semiconductor sensors are commonly used to detect hydrogen, oxygen, alcohol vapor, and harmful gases such as carbon monoxide.
- One of the most common uses for semiconductor sensors is in carbon monoxide sensors.
- They are also used in breathalyzers.

Gas Sensor : Working Principle

- Because the sensor must come in contact with the gas to detect it, semiconductor sensors work over a smaller distance than infrared point or ultrasonic detectors.
- MOS sensors can detect different gases, such as carbon monoxide, sulfur dioxide, hydrogen sulfide, and ammonia.
- Since the 1990s, MOS sensors have become important environmental gas detectors.

Strain Gauge

- The strain gauge is a passive, elastic resistive transducer which converts the mechanical elongation and compression(strain) into a resistance change.
- It is used to measure pressure, force and weight.
- This change in resistance takes place due to variation in length and cross sectional area of the gauge wire, when an external force acts on it.
- The Characteristics of strain gauge are described in terms of its sensitivity called gauge factor. (GF)
- GF= (dR/R) / (dL/L)
- The resistance of any conductor can be given by,

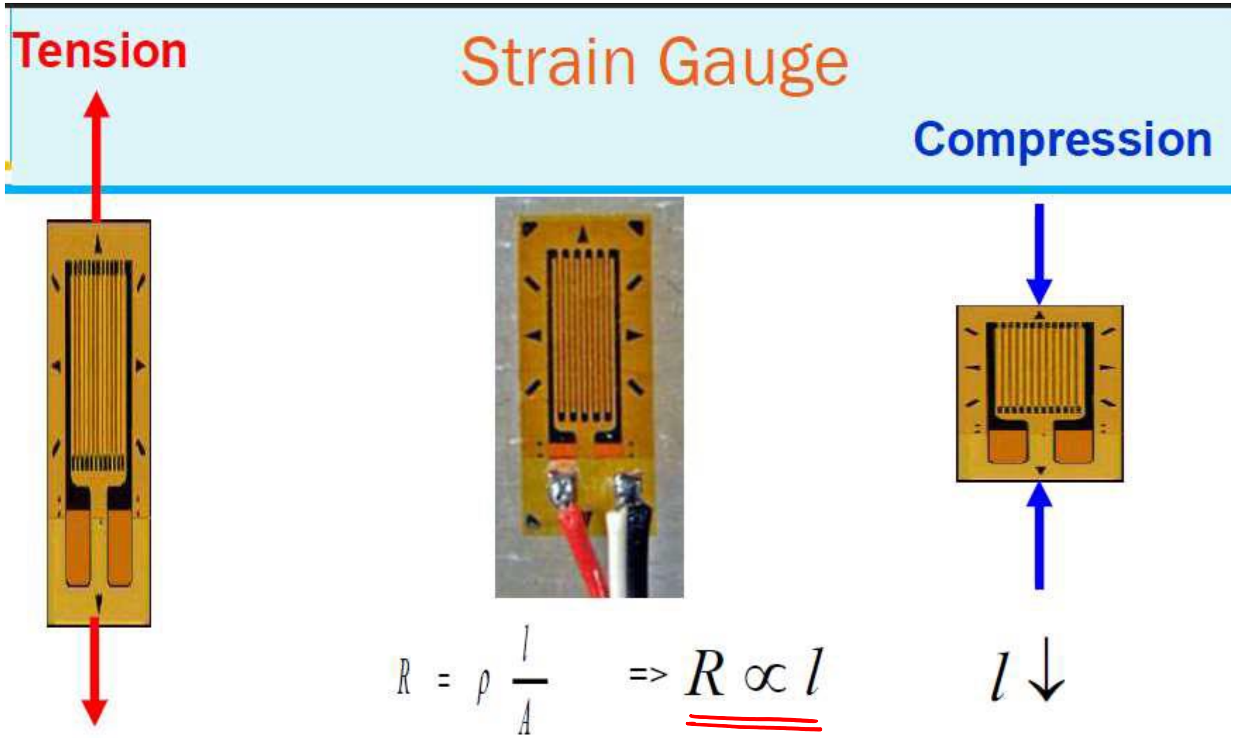
$$R = \rho \frac{L}{A}$$

ρ = Resistivity
L = Length
A = Cross-sectional area

$$\boxed{GF = \frac{(dR/R)}{(dL/L)}}$$

Strain Gauge

Elongation →



$$R = \rho \frac{l}{A} \quad \Rightarrow \underline{R \propto l}$$

$l \uparrow$ $R \uparrow$ (Tension)

$l \downarrow$ $R \downarrow$ (Compression)

R = Resistance

ρ = Property of material

l = Length of wire

A = Effective cross sectional area of wire

Principle of Strain Gauge

- When the strain gauge is under tension, its resistance goes up.
- When the strain gauge is under compression, its resistance goes down.

* $Gauge\ factor = GF = \dfrac{dR/R}{dL/L} = 1 + 2v$

GF = 1 + 2V

V = Poisson's Ratio

$= \dfrac{\varepsilon L}{\varepsilon a}$

- $v = possions\ ratio = \dfrac{\varepsilon L}{\varepsilon a}$

$$\varepsilon a = \frac{dl}{l} = Axial\ strain$$

$$\varepsilon L = \frac{-dD}{D} = Lateral\ strain$$

* Pressure measurement using strain gauge:

$$P = \frac{k}{GF} \cdot \frac{dR}{R}$$

k = constant of proportionality between pressure and strain

Types of Strain Gauge

- The following type of strain gauge are the most important:

1. Wire strain gauge: Unbonded & Bonded
2. Foil strain gauge
3. Semiconductor strain gauge

Foil Strain Gauge

- Formed by rolling out a thin foil of the resistive material and then cutting away parts of the foil by a photo etching process to create the required grid pattern.
- Material used: Nickel, Platinum Nichrome, Constantan(Ni+cu), Isoelastic (Ni+Cr+Mo).

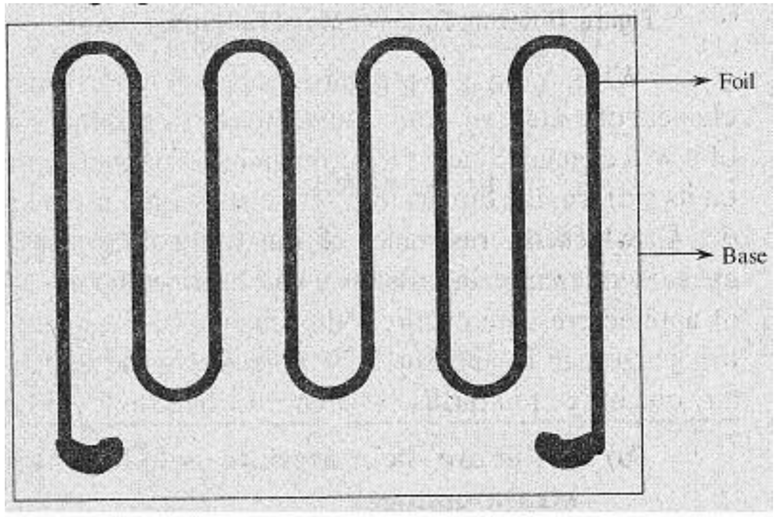


fig 10.1 Foil type Strain Gauge

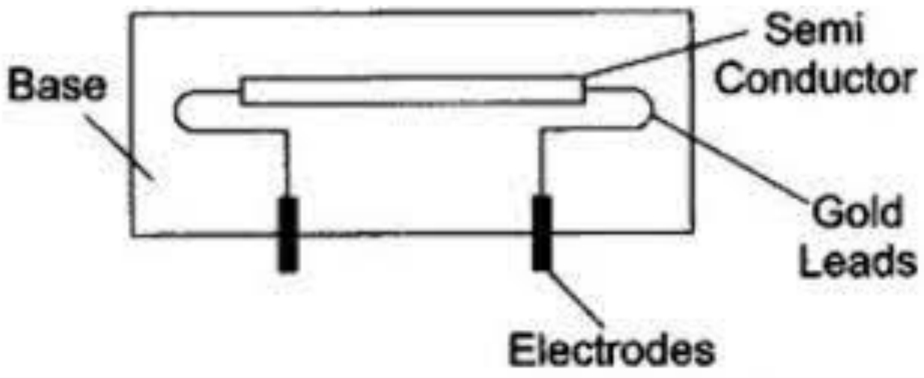
Foil Strain Gauge

Advantages:

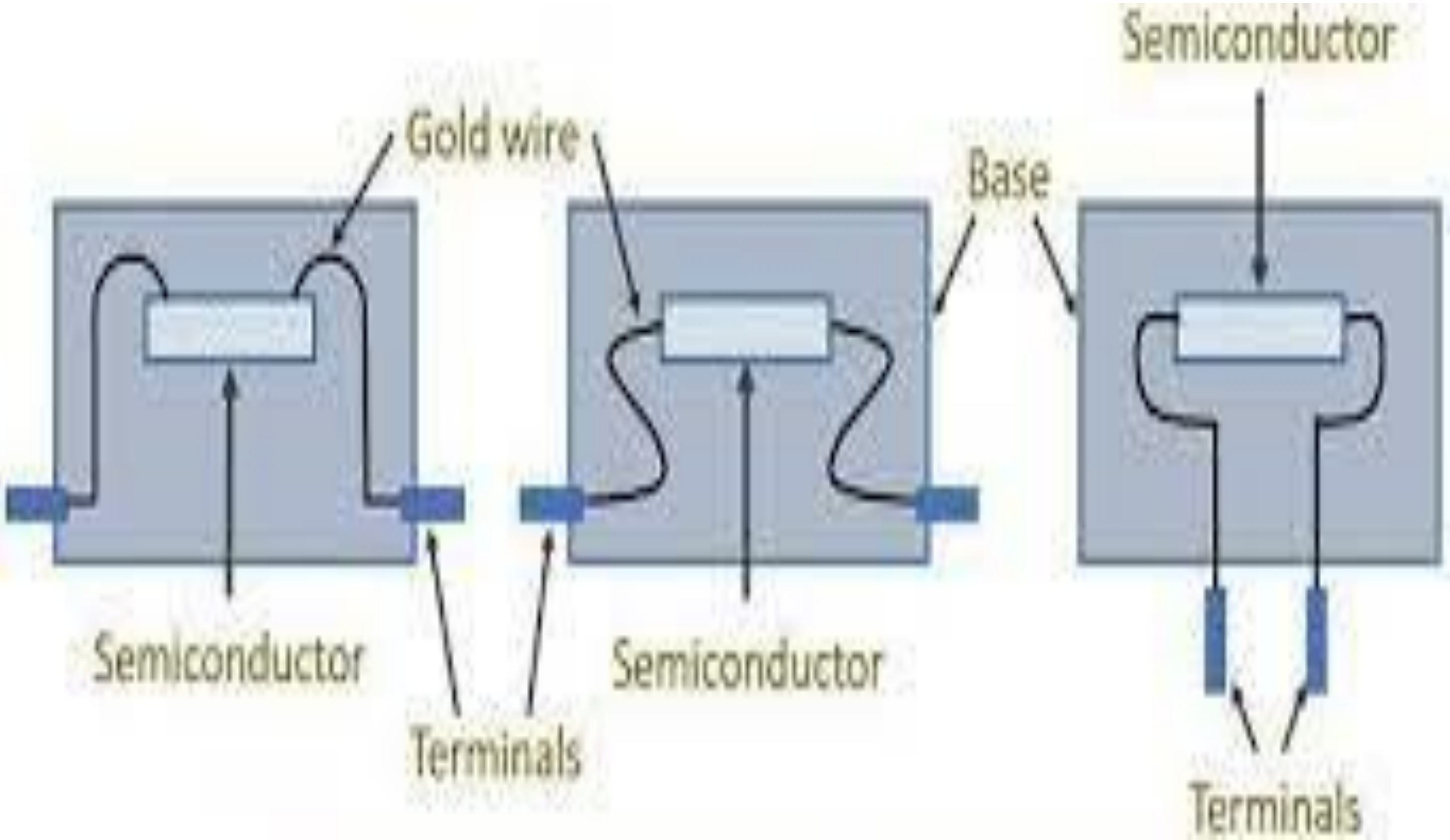
- More thin than wire hence it is more flexible.
- Greater dissipation capability due to large surface area. Hence in can be operated in higher temperature range.
- Better bonding & fabricated in any shape and etched on the carrier.
- Resistance in between 50-1000 ohms & thickness of the film is about 0.2mm.

Semiconductor Strain Gauge

- Here change in value of resistivity of semiconductor when strained, this property is called piezoresistivity.
- Material :Ge,Si
- Semiconductor gauges are used in application where a high gauge factor is desired.
- The resistance of the semiconductor gauge change as strain is applied to it.



Semiconductor Strain Gauge



Gold wire
Base
Semiconductor
Semiconductor
Terminals
Semiconductor
Semiconductor
Terminals

- **Advantages:**
  - High value of Gauge Factor (50 times more than wire type) indicates higher change in resistance and hence good accuracy.
  - Better frequency response.
  - Small size.

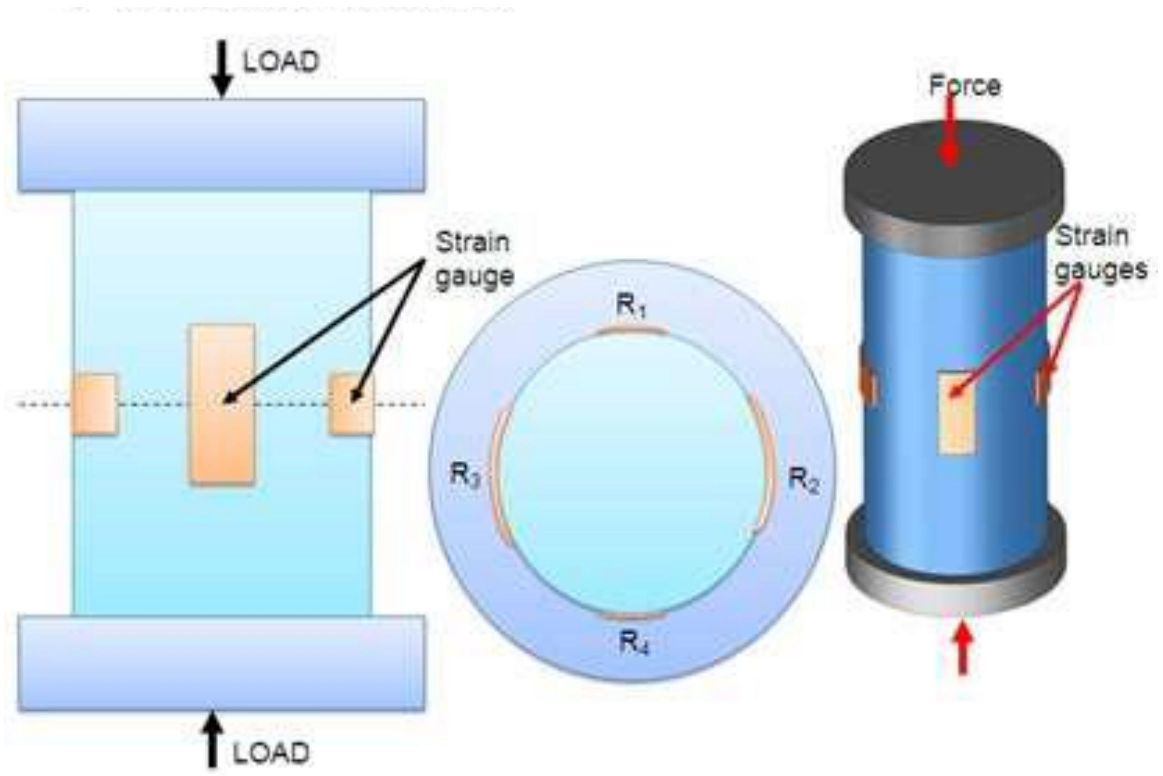
- **Disadvantages:**
  - Sensitive to temperature changes.
  - Poor Linearity.
  - Expensive.

Force Transducers: Load Cell

- Load cells are transducers that covert applied force, such as weight, into a differential electrical output voltage signal.
- The various types of load cells include
  - Strain Gauge Load Cells. → strain gauge as sensing element
    1) Column type load cell configuration
    2) Cantilever beam cell configuration
  - Hydraulic Load Cells.
  - Pneumatic Load Cells.

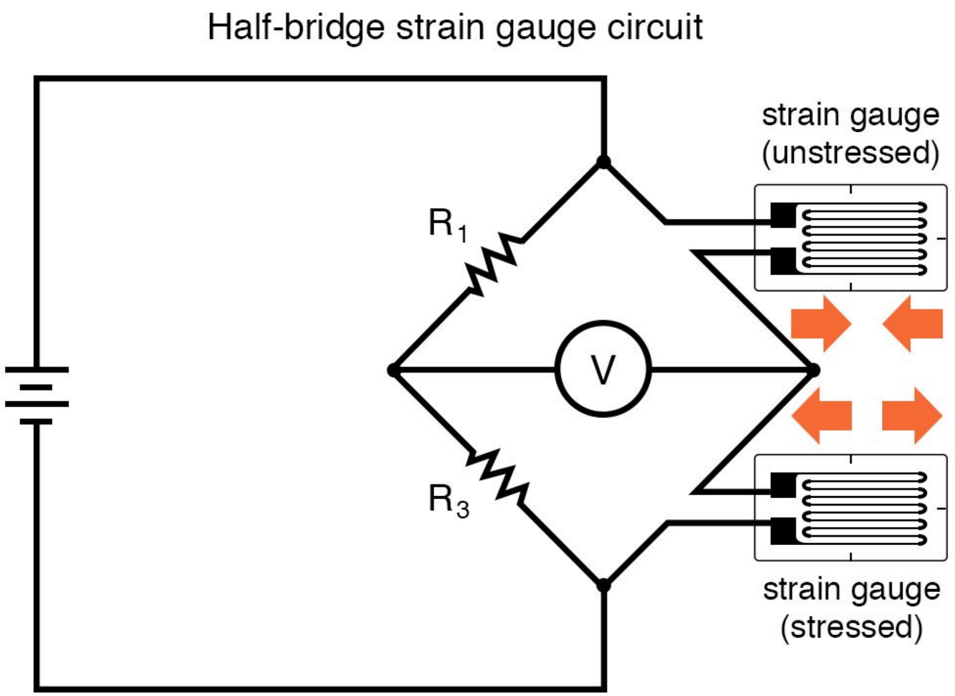
Strain Gauge Load Cell

- When weight is applied, due to stress, steel bar gets compressed along axis of load, and expand X-Y axis.
- Due to this the resistance of strain gauge A will decrease , and Stain gauge B will increase.



Strain Gauge Load Cell

- Two strain gauges are mounted on column in opposite direction.



Load Cell Types

S Type

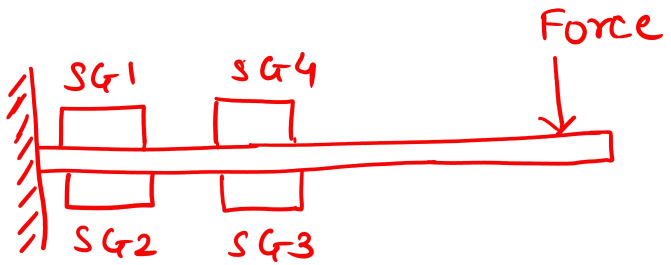
Button

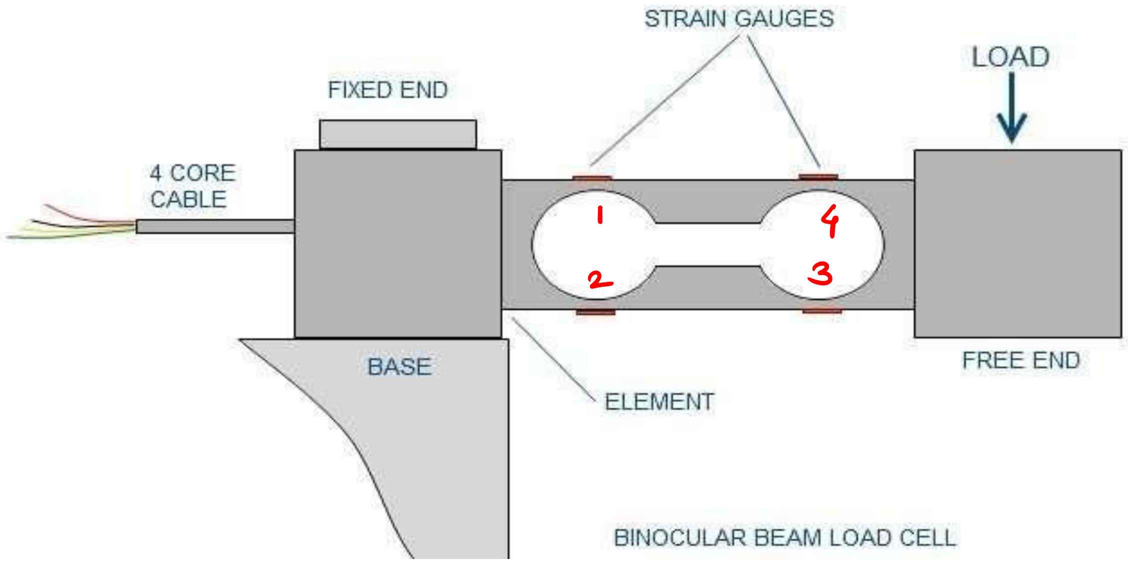
Canister

Shear

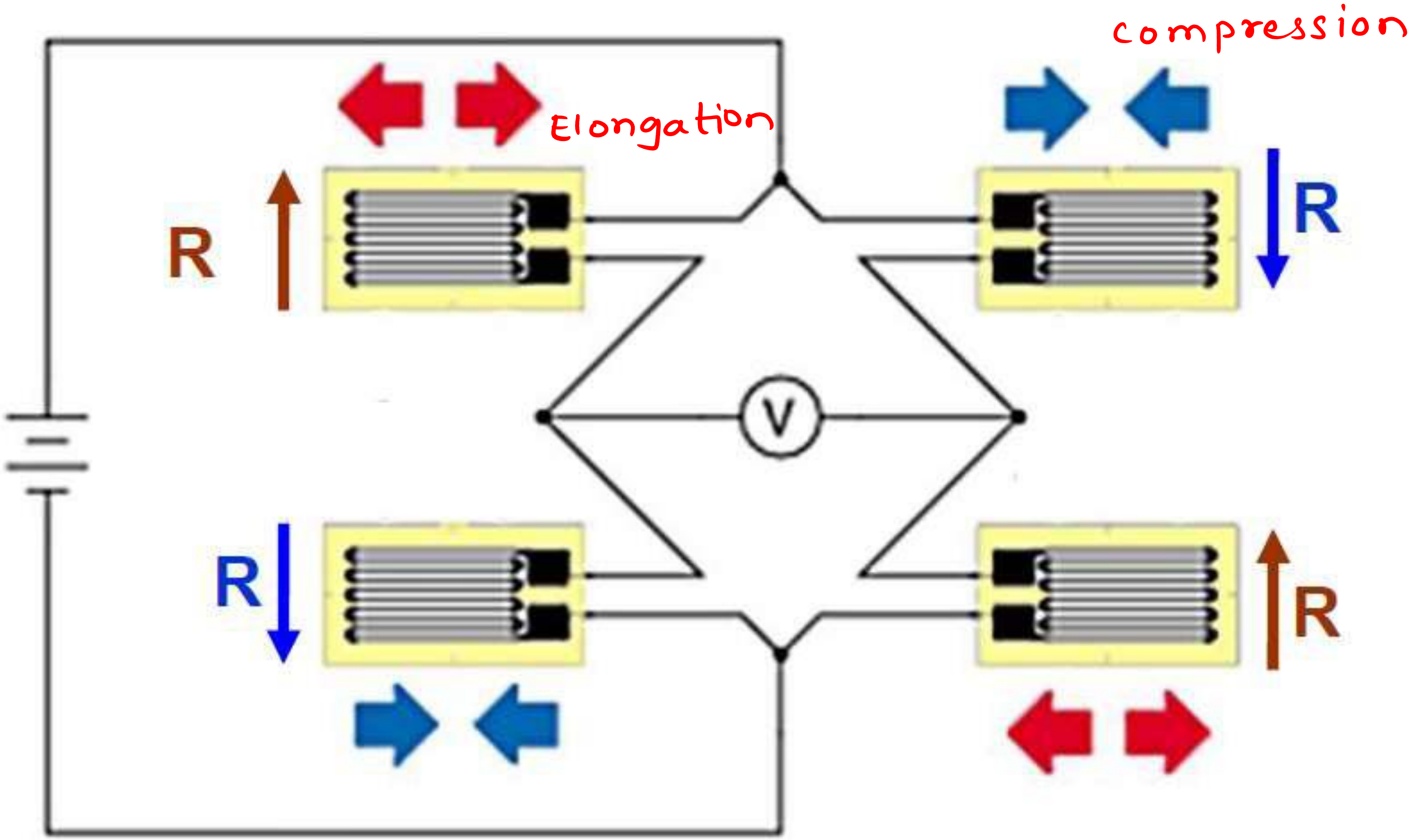
Beam

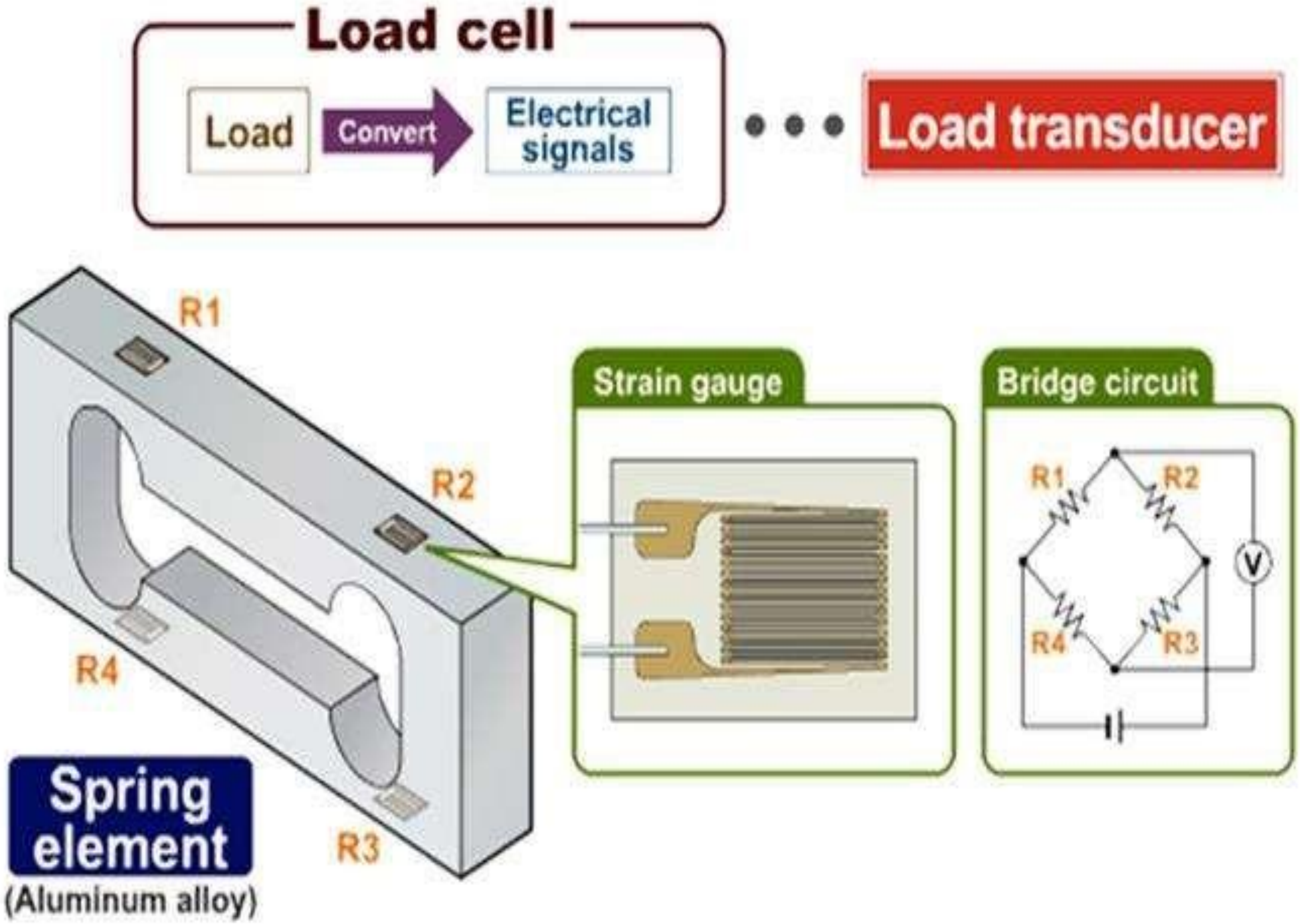
Cantilever Beam





Wheatstone Bridge configuration




Load cell
Load
Convert
Electrical signals
Load transducer
R1
R2
R3
R4
Strain gauge
Bridge circuit
R1
R2
R4
R3
V
Spring element
(Aluminum alloy)

Pressure Transducer

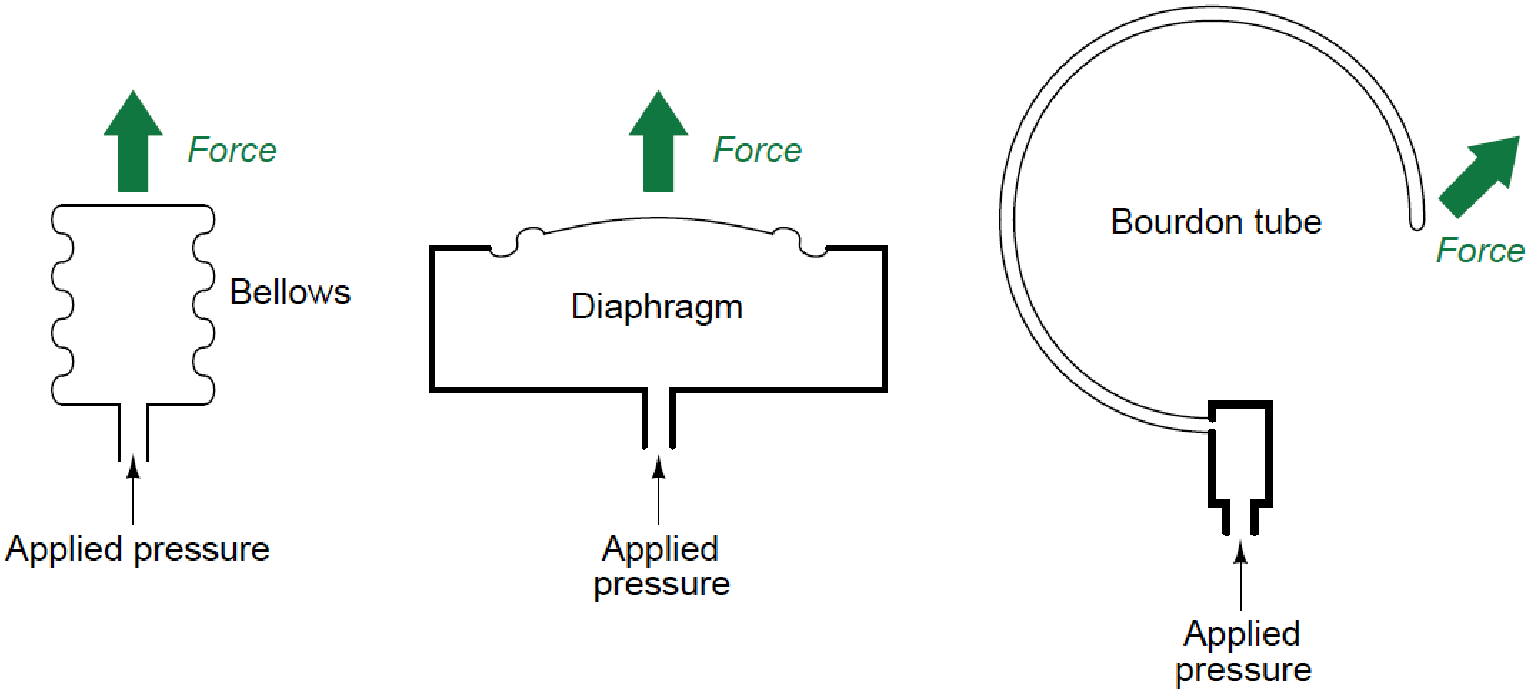
- Pressure is defined as the force acting per unit area, given at a point or over a surface.
- The SI unit of pressure is expressed in pascals i.e. N/m^2
- The pressure transducer can be classified into two categories
  - Gravitational pressure transducer
  - Elastic type pressure transducers.

Example of elastic transducers are :

- Diaphragm, Capsule, Bellows or Bourdon Tubes.
- These transducers first convert the **pressure into displacement or strain.**
- Then this **displacement or strain is measured with an appropriate electrical sensor.**

Pressure Transducer

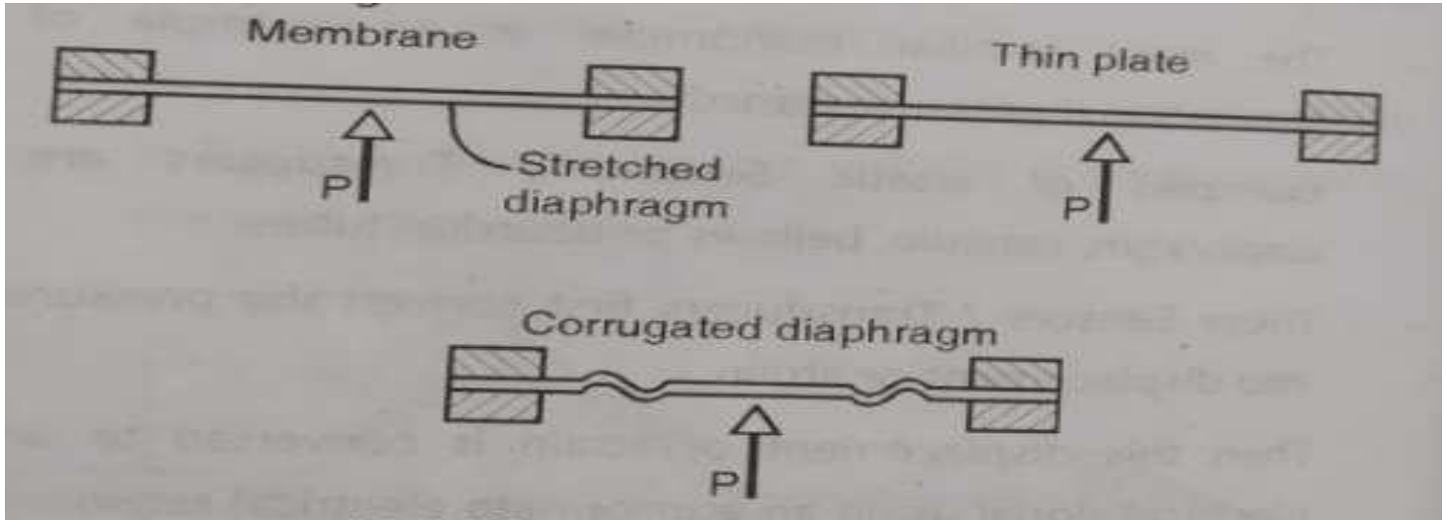
- Diaphragm
- Capsule
- Bellows
- Bourdon Tube



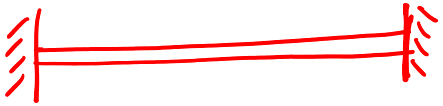
Diaphragm

→ flexible circular disks

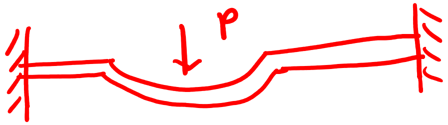
- Its structure may be flat or corrugated.
- It is used to respond to the pressures which ranges from very low value to vey high value.
- It is made up of elastic metal alloys.
- The most important consideration while selecting a diaphragm material is the chemical nature of fluid ,the pressure of which is to be measured ,temperature range, vibrations etc.



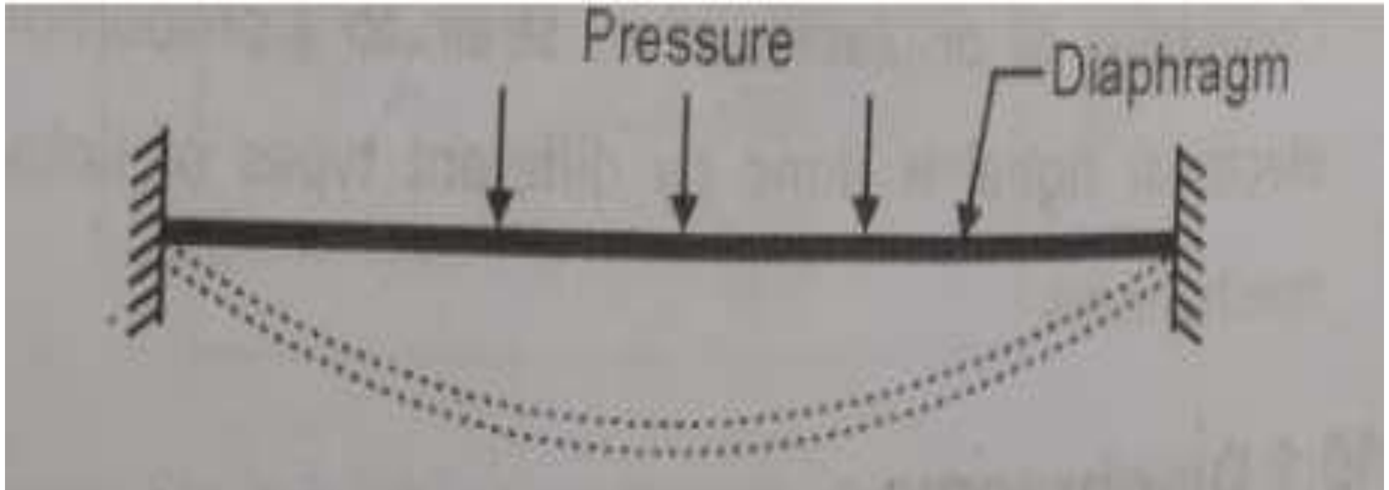
(a) Different types of diaphragms



Diaphragm without pressure

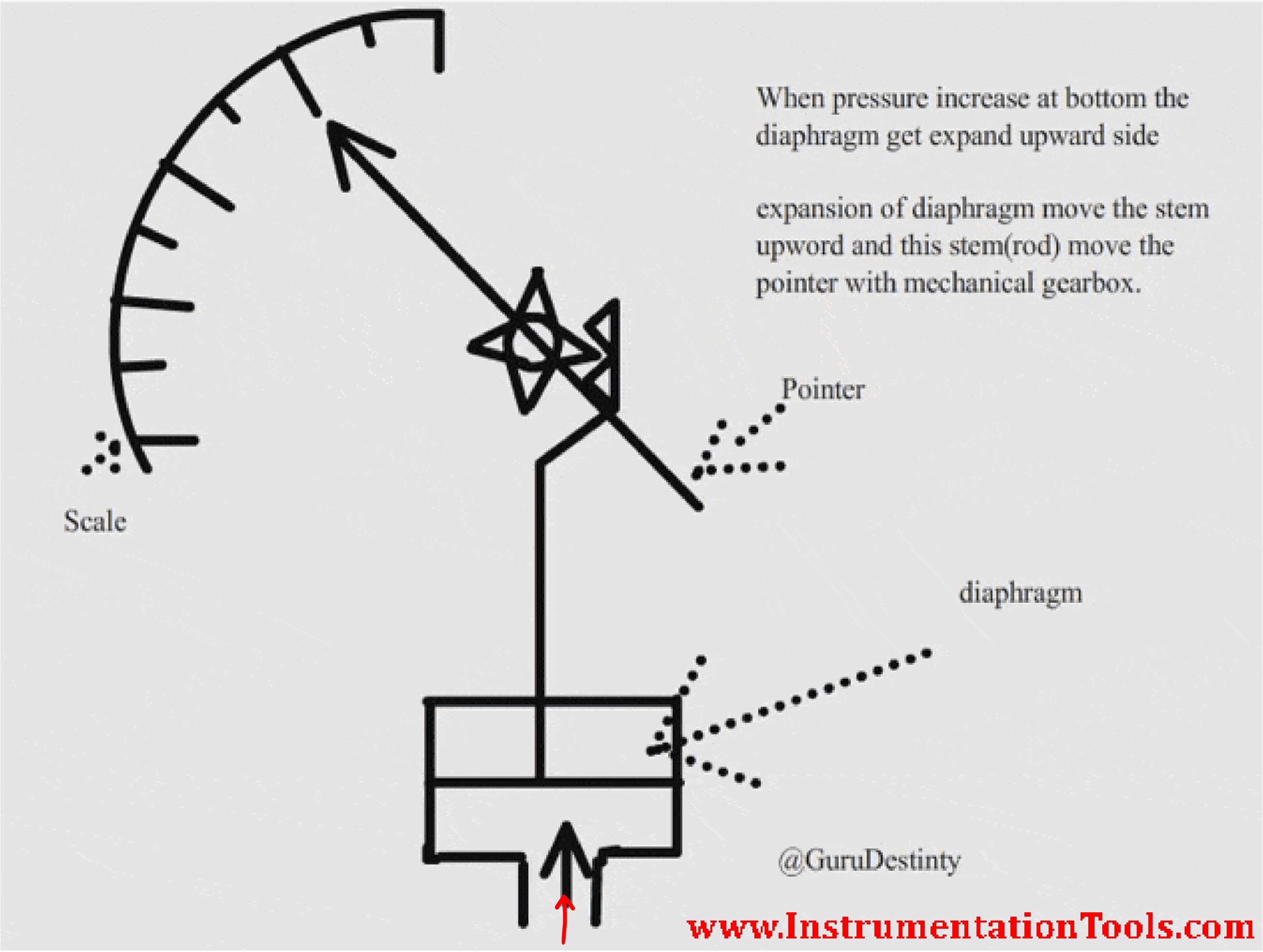


Deflection at centre



(b) Deflection in a diaphragm due to pressure

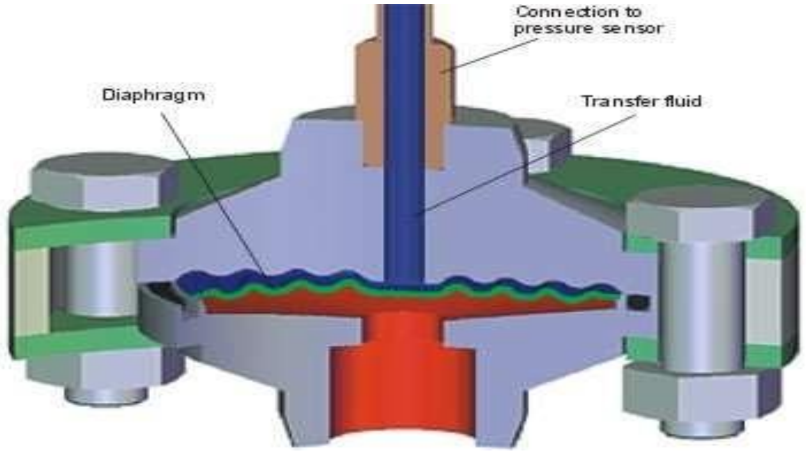
Diaphragm



Slide Credit: https://instrumentationtools.com/diaphragm-pressure-sensors/

Diaphragm

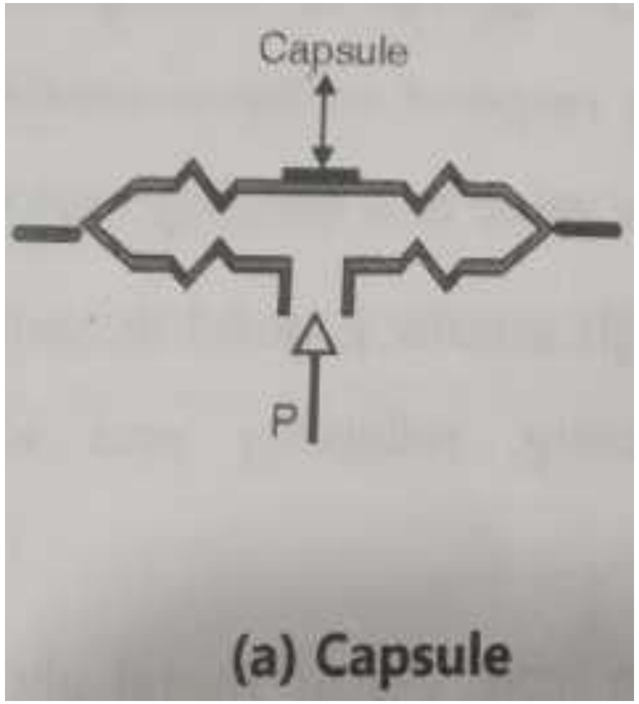
- A chemical seal consists of a chamber filled with a transfer fluid (oil-based mixture), closed on one side by a pressure sensor and closed off from the process on the other by means of a diaphragm (stainless steel or plastic).
- The pressure bends the diaphragm and is transferred from the fluid to the pressure sensor.
- Pressure transmitters are used if the process conditions no longer allow direct attachment of a pressure sensor (extreme temperatures, chemical resistance, hygiene requirements or media which form coatings or are very viscous.). A wide range of process connections also allows use in special applications.

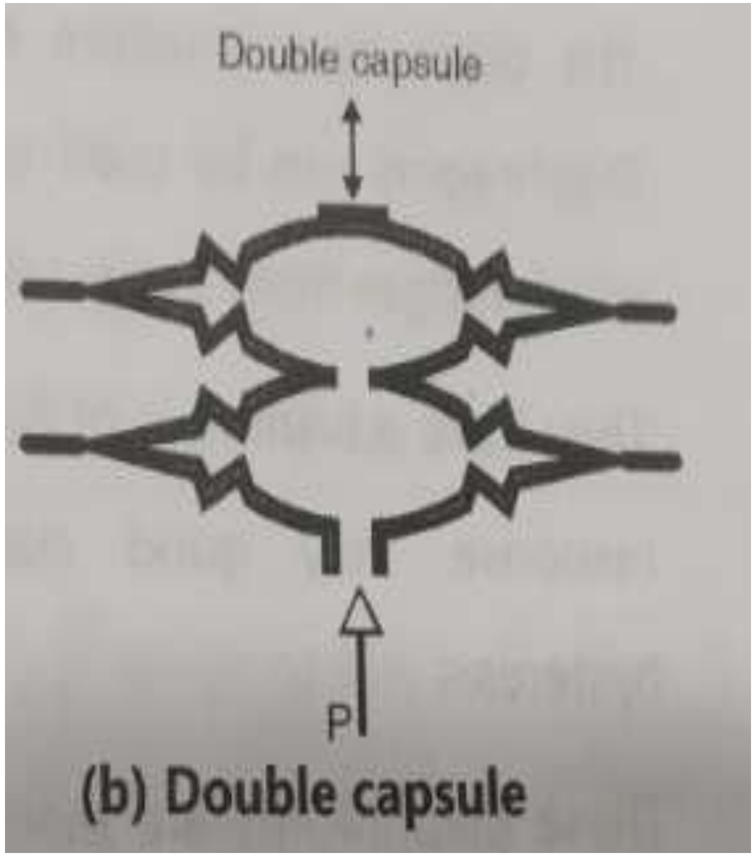


Capsule

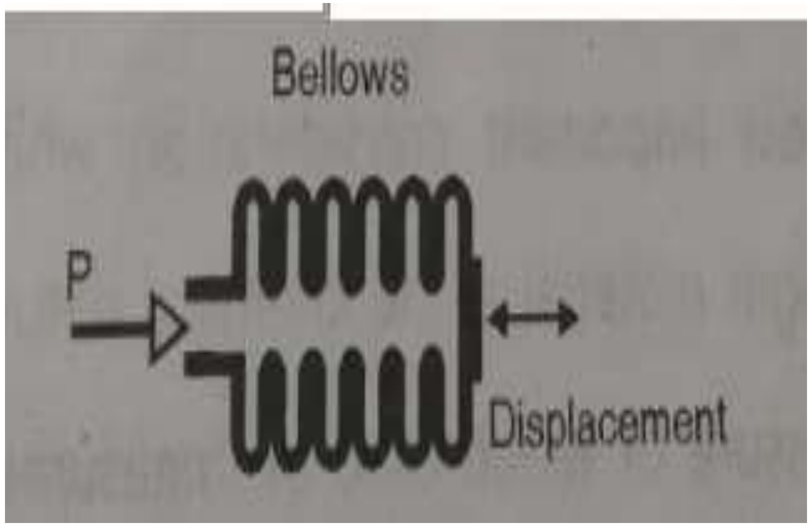
- A capsule is constructed by connecting two identical corrugated diaphragms along their flanges.
- The displacement is proportional to difference of inner and outer pressure
- The advantage is double deflection as compared to a single diaphragm.

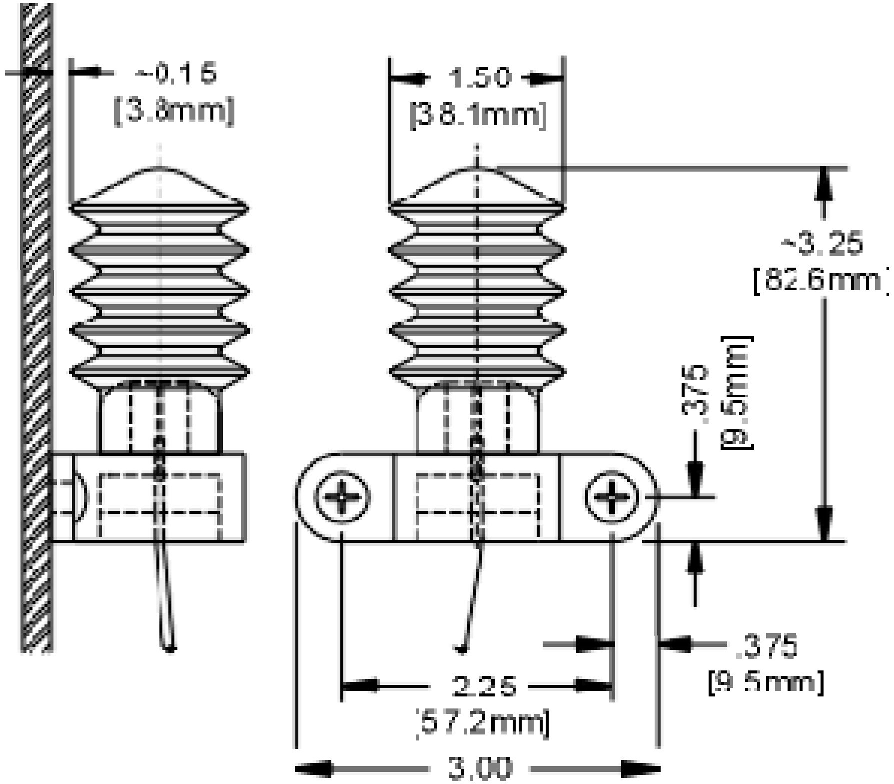
Capsule





Bellows

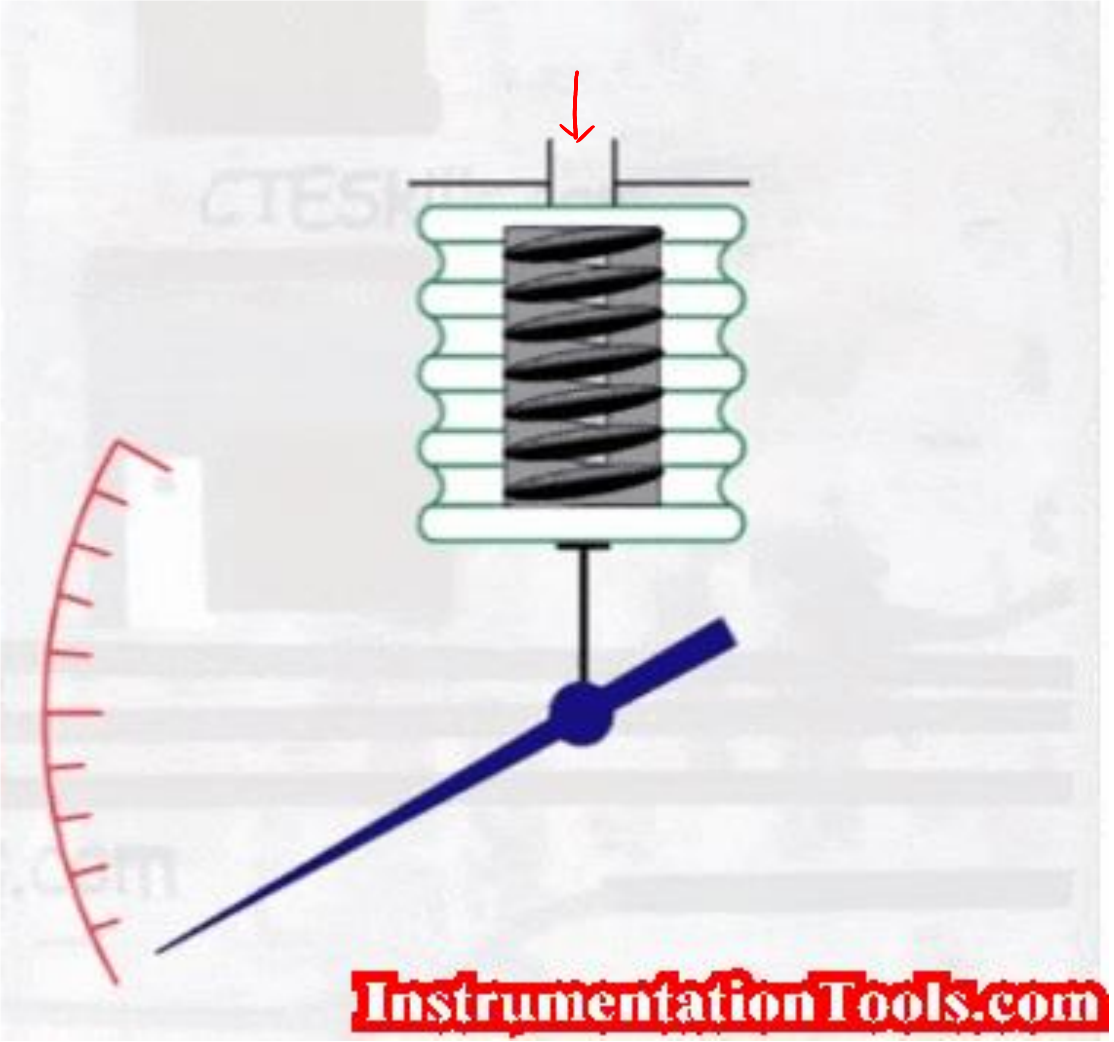

Bellows
P
Displacement


~0.15
[3.8mm]
1.50
[38.1mm]
~3.25
[82.6mm]
.375
[9.5mm]
.375
[9.5mm]
2.25
[57.2mm]
3.00

Bellows

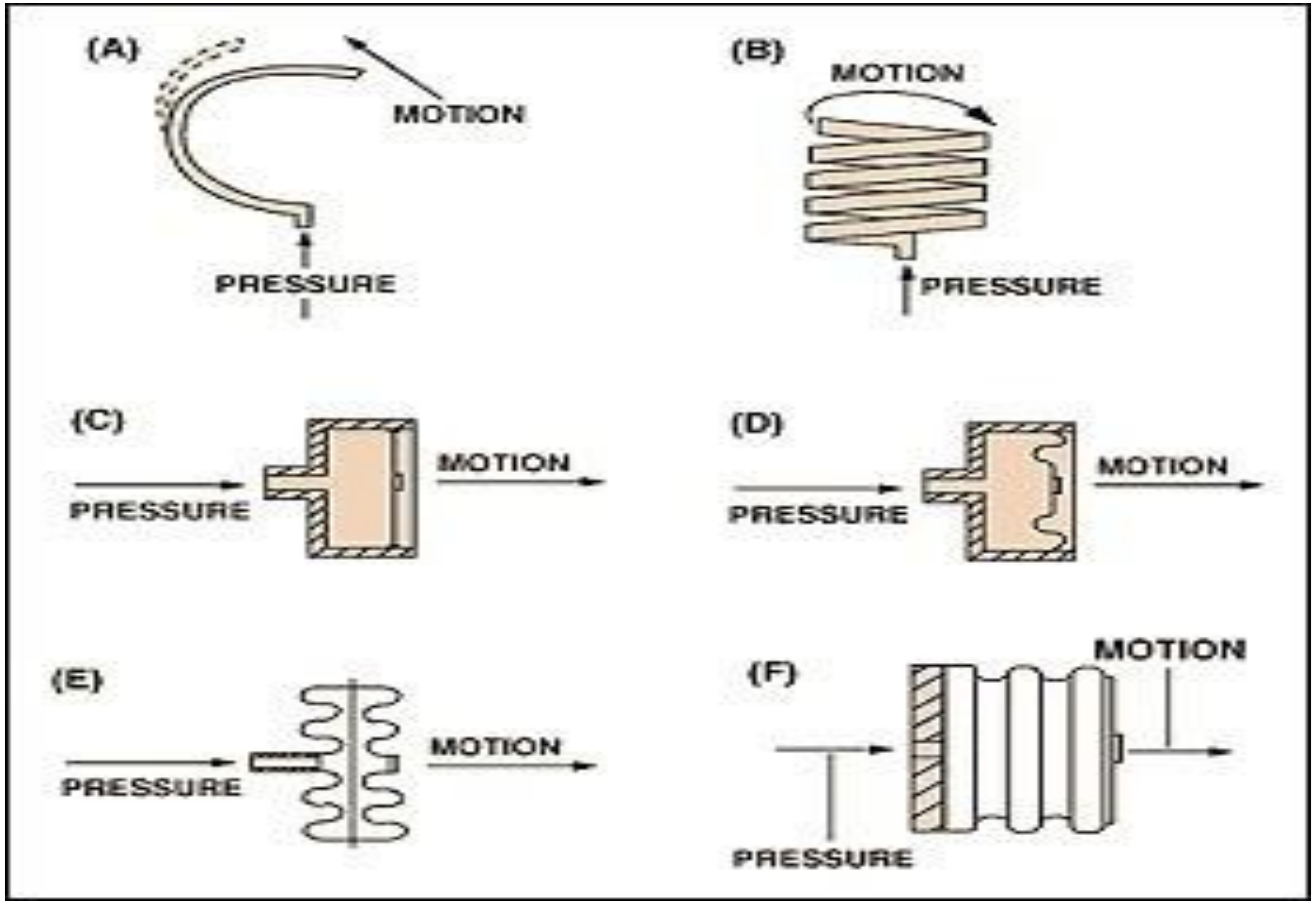
- A metallic bellow is formed from a series of circular parts resembled in folds.
- The circular parts are joined in such a way that they are expanded or contracted axially by change in applied pressure.
- Bellows are thin walled cylindrical shell with deep convolutions.
- They are sealed at one end as we apply pressure to the other end the sealed end moves axially.
- Bellows are generally suitable for low pressure measurement but they are sensitive to vibrations.
- Phosphors bronze ,stainless steel or nickel alloys are the materials used for manufacturing of bellows.
- The bellows are used in differential mode to measure differential pressure. In this case, both sides of bellows have open ends for applying pressure.

Pressure Transducer: Bellows



Slide Credit: https://instrumentationtools.com/bellows-pressure-sensors-working-principle-animation/

Bellows

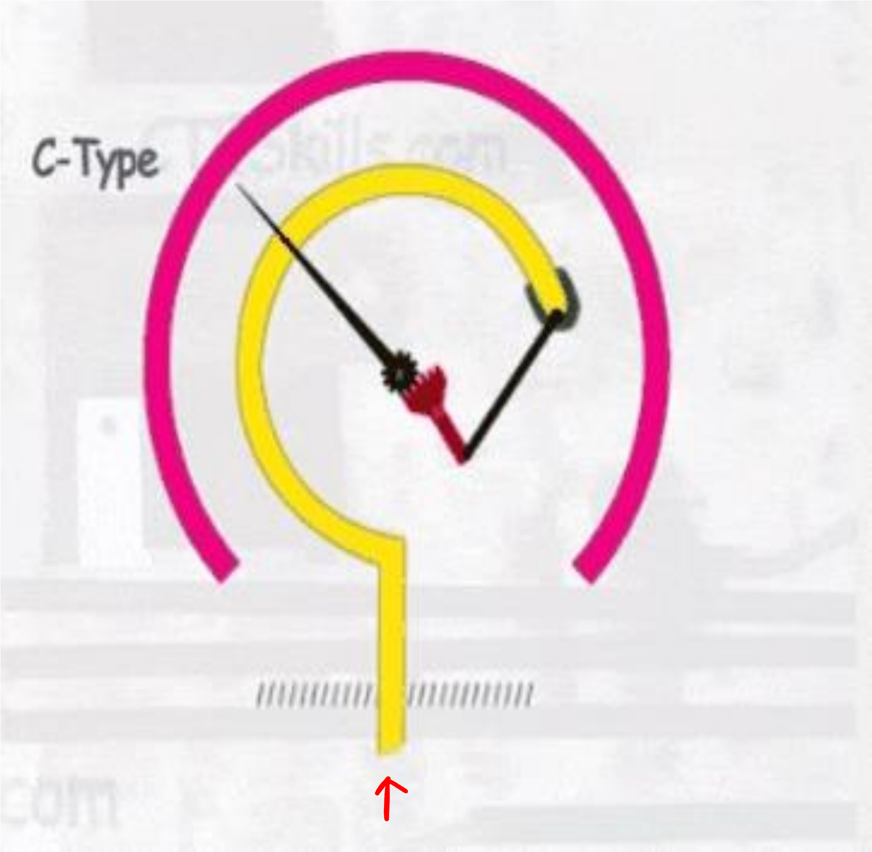


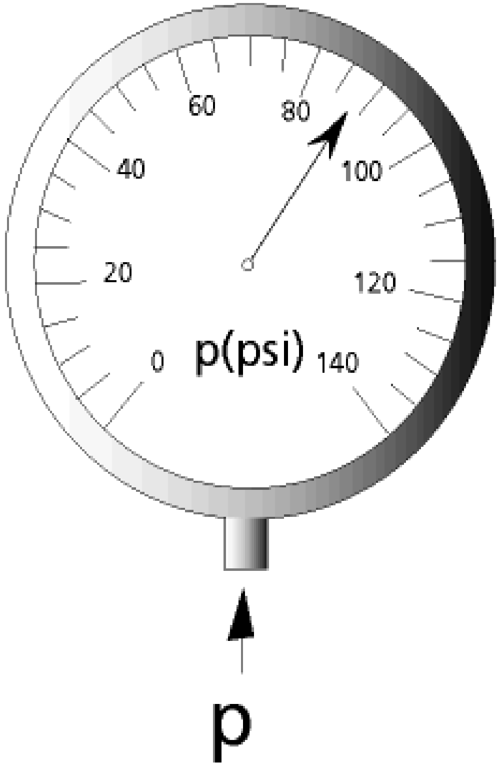
(A)
MOTION
PRESSURE
(B)
MOTION
PRESSURE
(C)
MOTION
PRESSURE
(D)
MOTION
PRESSURE
(E)
MOTION
PRESSURE
(F)
MOTION
PRESSURE

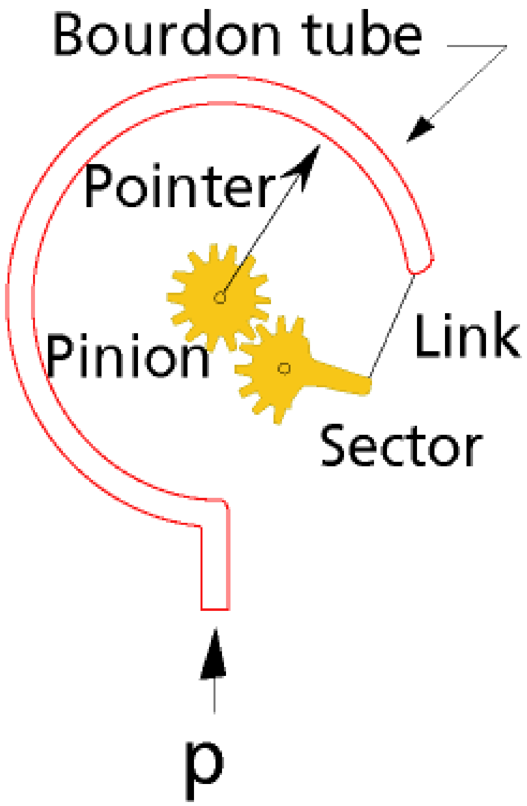
Bourdon Tube

- The bourdon tube is the most commonly used elastic pressure sensor in mechanical dial gauges.
- The bourdon tubes are available in C-type, spiral shape, twisted tube configuration and helical shape.
- C-shaped tube is used in dial gauges.
- The C-shaped bourdon tubes are made out of elliptically flattened tube bent in such a way that produces C-shape. One end of tube is sealed and the other end is exposed to pressure.

Bourdon Tube







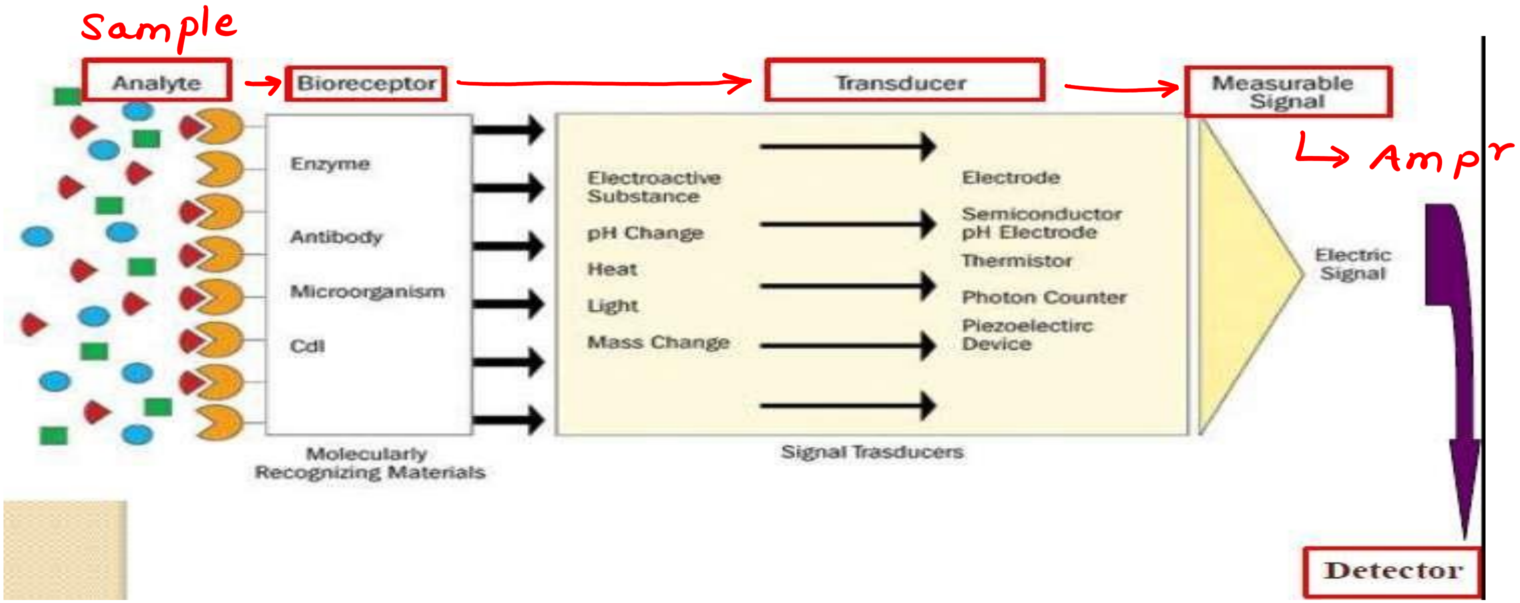
Slide Credit: https://instrumentationtools.com/bourdon-tube-pressure-gauge-working-principle-animation/

Bourdon Tube: Working Principle

- When the pressure is applied at open end of bourdon tube, the tube bends to straighten. This causes movement of sealed end of tube.
- The movement is connected to pointer through the mechanical linkage. The pointer moves and shows pressure on calibrated scale.

Bio-Sensors

- A sensor that integrates a biological element with a physiochemical transducer to produce an electronic signal proportional to single analyte which is then conveyed to a detector.
- Any device that has specific biochemical reactions to detect chemical compounds in biological samples.

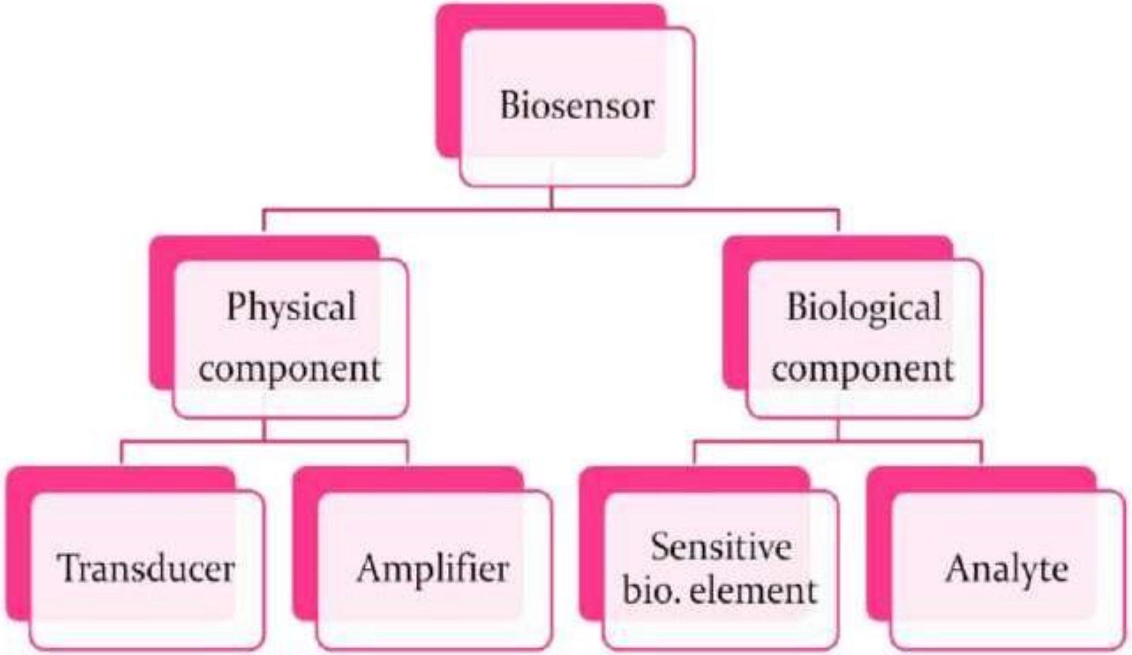


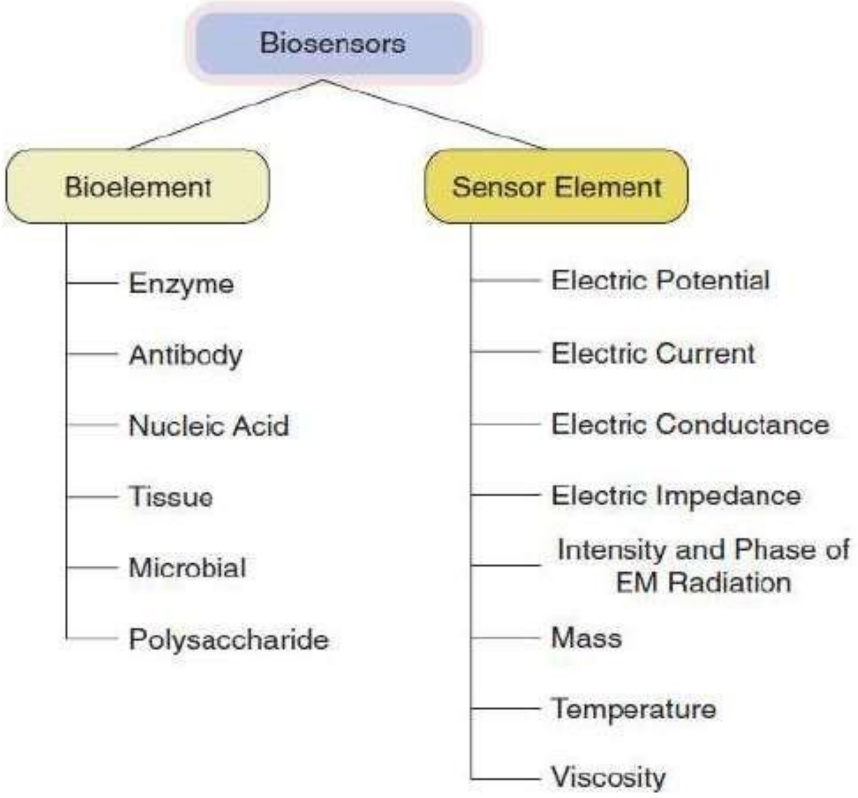
Bio-Sensors

- Analyte diffuses from the solution to the surface of the Biosensor. (Bioreceptor)
- Analyte reacts specifically & efficiently with the Biological Component of the Biosensor.
- This reaction changes the physicochmical properties of the Transducer surface.
- This leads to a change in the optical/electronic properties of the Transducer Surface.
- The change in the optical/electronic properties is measured/converted into electrical signal, which is detected.

Bio-Sensors

- Classification:





Applications of Bio-sensors

- Food processing, monitoring, food authenticity, quality and safety.
- Fermentation industry and in the saccharification process to detect precise glucose concentrations.
- Biosensors are being used pervasively in the medical field to diagnose infectious diseases.
- Glucose biosensors are widely used in clinical applications for diagnosis of diabetes mellitus.
- Fluorescent biosensors play a vital role in drug discovery and in cancer.
- Biosensors can be used for military purposes at times of biological attacks.
- Biosensors can be utilized to identify missing components pertinent to metabolism, regulation, or transport of the analyte.

References

- “Sensors and Transducers” by D. Patrnabis, 2nd Edition, PHI.
- “Sensors Handbook”, by S. Soloman, 2nd Edition.
- Web Resources

Thank you!