Transducers

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TRANSDUCERS

A **Transducer** is a device that converts one form of energy to another. Energy types include (but are not limited to): electrical, mechanical, electromagnetic, chemical, acoustic, and thermal energy. Usually a transducer converts a signal in one form of energy to a signal in another

Different types of Transducers

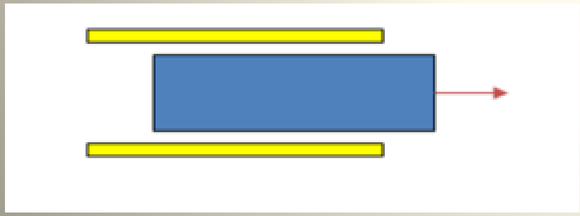
- Active Transducers - These do not need any external power source, for example Piezoelectric Transducer, etc.
- Passive Transducers - These need an external power source, for example Potentiometer, Strain Gauge, etc.

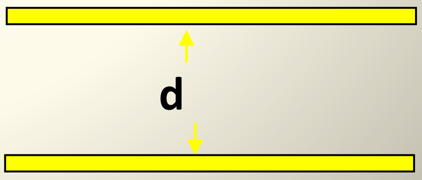
Transducers According to Transduction Principle

- Capacitive Transducers
- Electromagnetic Transducers
- Inductive Transducers
- Piezoelectric Transducers
- Photovoltaic Transducers

Capacitive Transducers

- Here, the measured is converted into a change in capacitance.
- A change in capacitance occurs either by changing the distance between the two plates or by changing the dielectric.

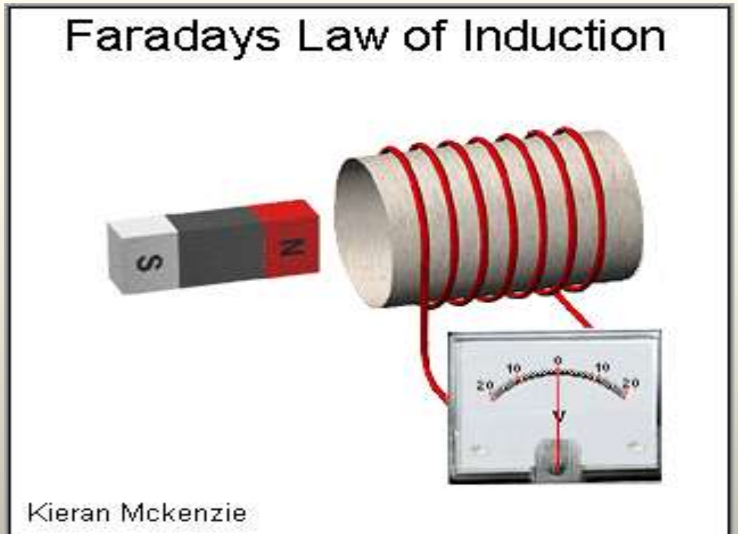




Area=A

Electromagnetic Transducers

- In electromagnetic transduction, the measurand is converted to voltage induced in conductor by change in the magnetic flux, in absence of excitation.
- The electromagnetic transducer are self generating active transducers
- The motion between a piece of magnet and an electromagnet is responsible for the change in flux



Inductance Transducers:

- In inductive transduction, the measurand is converted into a change in the self inductance of a single coil. It is achieved by displacing the core of the coil that is attached to a mechanical sensing element

Piezoelectric Transducers:

- In piezoelectric induction the measurand is converted into a change in electrostatic charge q or voltage V generated by crystals when it is mechanically stressed.

Photovoltaic Transducers:

- In photovoltaic transduction the measured is converted to voltage generated when the junction between dissimilar material is illuminated.

Analog and Digital Transducers

Analog transducers:

- These transducers convert the input quantity into an analog output which is a continuous function of time.
- Thus a **strain gauge, an L.V.D.T., a thermocouple or a thermistor** may be called as Analog Transducers as they give an output which is a continuous function of time.

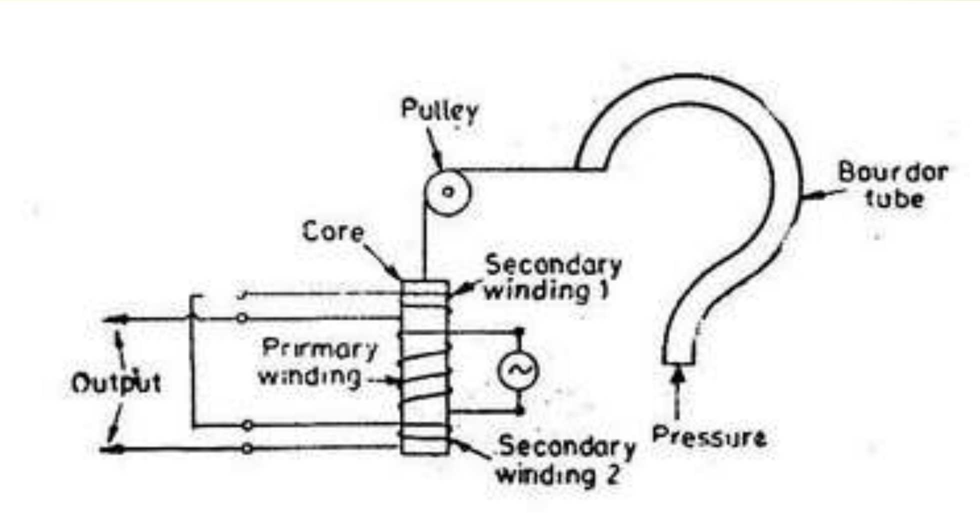
Digital Transducers:

- These transducers convert the input quantity into an electrical output which is in the form of pulses and its output is represented by 0 and 1.

Primary or Secondary Transducers

- Some transducers contain the mechanical as well as electrical device. The mechanical device converts the physical quantity to be measured into a mechanical signal. Such mechanical device are called as the primary transducers, because they deal with the physical quantity to be measured.

- The electrical device then convert this mechanical signal into a corresponding electrical signal. Such electrical device are known as secondary transducers



Transducers and Inverse Transducers

Transducer:

- Transducers convert non electrical quantity to electrical quantity.

Inverse Transducer:

- Inverse transducers convert electrical quantity to a non electrical quantity. A piezoelectric crystal acts as an inverse transducer because when a voltage is applied across its surfaces, it changes its dimensions causing a mechanical displacement.

Characteristics of Transducers

- **Accuracy**: It is defined as the closeness with which the reading approaches an accepted standard value or ideal value or true value of the variable being measured
- **Repeatability**: The o/p of the transducers must be exactly the same, under same environmental condition, when the same quantity is applied at the i/p repeatedly
- **Sensitivity**: The transducer must be sensitive enough to produce detectable output
- **Size**: The transducers should have smallest possible size and shape with minimal weight and volume. This will make the measurement system very compact
- **Dynamic Range**: For a transducer the operating range should be wide so that it can be used over a wide range of measurement conditions

Transducers Selection Factors

- **Loading Effects:** The transducer should have a high input impedance and low output impedance to avoid loading effects.
- **Environmental Compatibility:** It should be assured that the transducer selected to work under specified environmental conditions maintains its input- output relationship and does not break down.
- **Insensitivity to unwanted signals:** The transducer should be minimally sensitive to unwanted signals and highly sensitive to desired signals.
- **Operating Principle:** The transducer are many times selected on the basis of operating principle used by them. The operating principle used may be resistive, inductive, capacitive , optoelectronic, piezo electric etc.

Measurement of Displacement

There are mainly two types of Displacement:

- Translational Displacement: It is the motion of a body in a straight line between two points

- Rotational Displacement: It is motion of angular type, about some rotation axis

Fiber Optic Displacement

- The basic principle employed in the Fiber Optic Displacement Transducer comes down to the use of an adjacent pair of fiber optic elements, one to carry light from a remote source to an object or target whose displacement or motion is to be measured and the other to receive the light reflected from the object and carry it back to a remote photo sensitive detector.
- A fiber optic element is a flexible strand of glass or plastic capable of transmitting light along its length by maintaining near total internal reflection of the light accepted at its input end

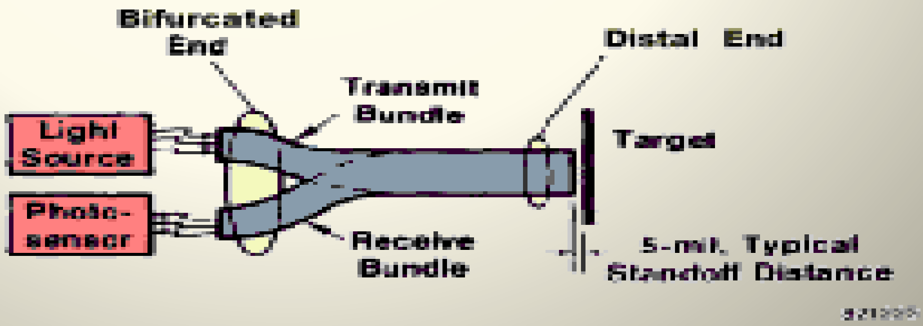


Fig. 4 Fiber Optic Probe

Linear Variable Differential Transducer

- The **linear variable differential transducer** (LVDT) is a type of electrical transformer used for measuring linear displacement. The transformer has three solenoidal coils placed end-to-end around a tube. The center coil is the primary, and the two outer coils are the secondary. A cylindrical ferromagnetic core, attached to the object whose position is to be measured, slides along the axis of the tube.
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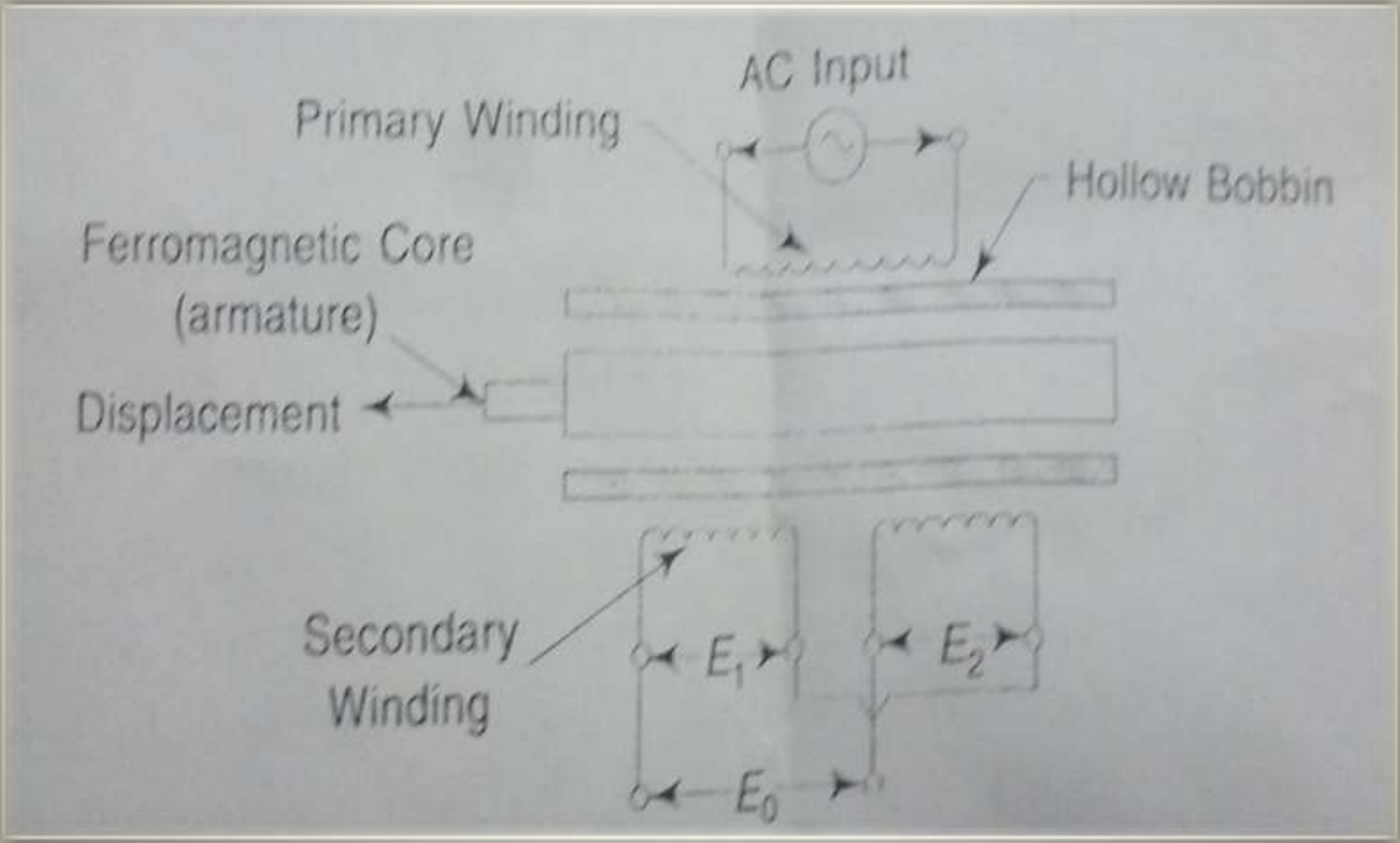
Construction



- A differential transformer consists of a primary winding and two secondary windings. The windings are arranged concentrically and next to each other.
- A ferro-magnetic core(armature) in the shape of a rod or cylinder is attached to the transducer sensing shaft.
- The core slides freely within the hollow portion of the bobbin.

- An a.c. excitation is applied across the primary winding and the movable core varies the coupling between it and the two secondary windings.
- As the core moves away from the centre position, the coupling to one secondary becomes more and hence its output voltage increases, while the coupling and the output voltage of the other secondary decreases

Principle

- Any physical displacement of the core causes the voltage of one secondary winding to increase while simultaneously, reducing the voltage in the other secondary winding.
- The difference of the two voltages appears across the output terminals of the transducers and gives a measure of the physical position of the core and hence the displacement.

Operation

- When the core is in the neutral or zero position, voltages induced in the secondary windings are equal and opposite and the net output is negligible.
- By comparing the magnitude and phase of output with input source, the amount and direction of movement of core and hence displacement may be determined.

Advantages and Disadvantages

Advantages of LVDT

- The transducers possess a high sensitivity.
- The transducers have low hysteresis and hence repeatability is excellent under all conditions.
- They have infinite resolution.
- They are simple, light in weight and easy to maintain.

Disadvantages of LVDT

- They are sensitive to stray magnetic fields but shielding is possible.
- They are inherently low in power output.
- Temperature affects the perfomance of transducer.

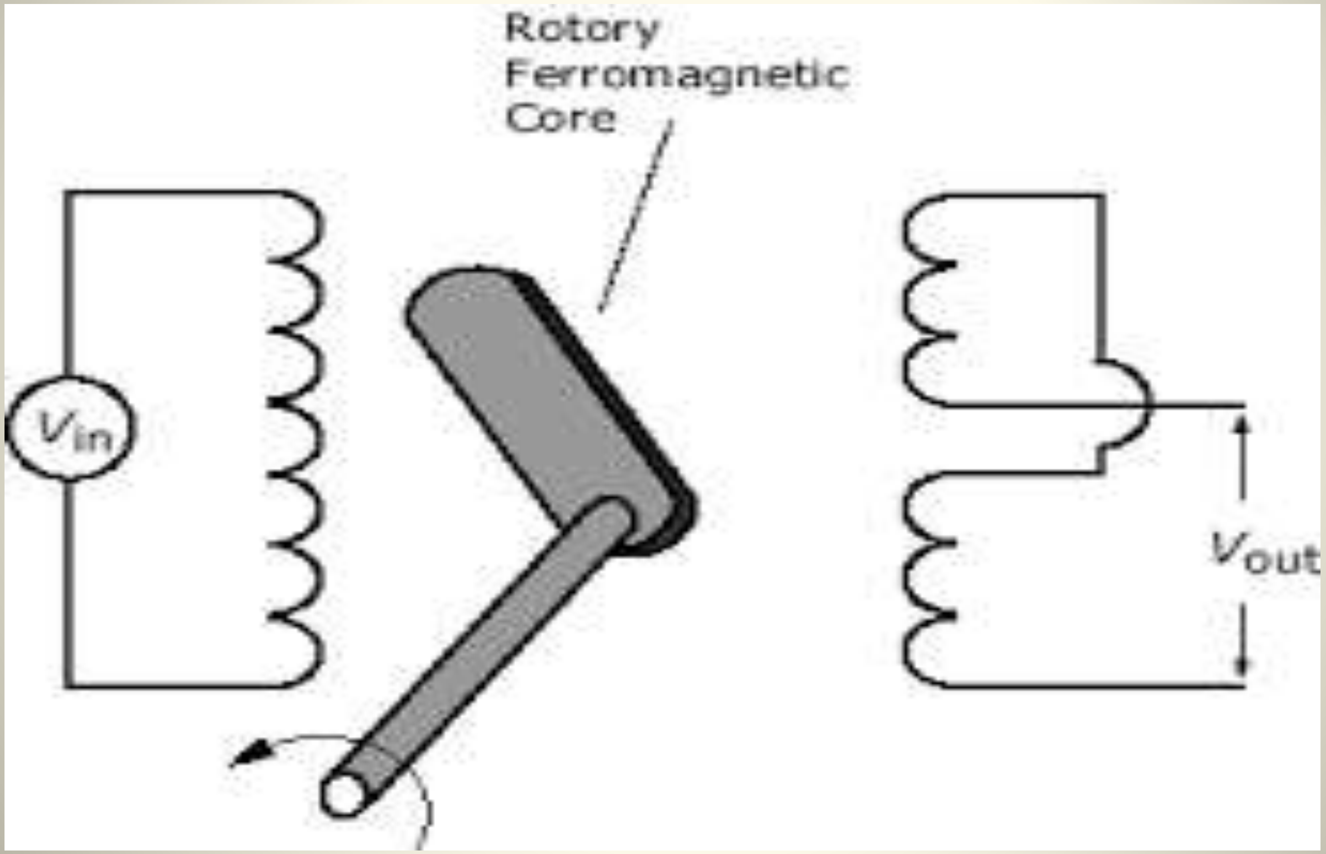
Applications

- The LVDT can be used in all applications where displacements ranging from fraction of a mm to a few cm have to be measured.
- Acting as a secondary transducer it can be used as a device to measure force, weight and pressure.

Rotary Variable Differential Transformer

- A Rotary Variable Differential Transformer (RVDT) is an electromechanical transducer that provides a variable alternating current (AC) output voltage that is linearly proportional to the angular displacement of its input shaft. When energized with a fixed AC source, the output signal is linear within a specified range over the angular displacement

CONSTRUCTION



- Basic RVDT construction and operation is provided by rotating an iron-core bearing supported within a housed stator assembly. The housing is passivated stainless steel. The stator consists of a primary excitation coil and a pair of secondary output coils.
- A fixed alternating current excitation is applied to the primary stator coil that is electromagnetically coupled to the secondary coils. This coupling is proportional to the angle of the input shaft. The output pair is structured so that one coil is in-phase with the excitation coil, and the second is 180 degrees out-of-phase with the excitation coil.

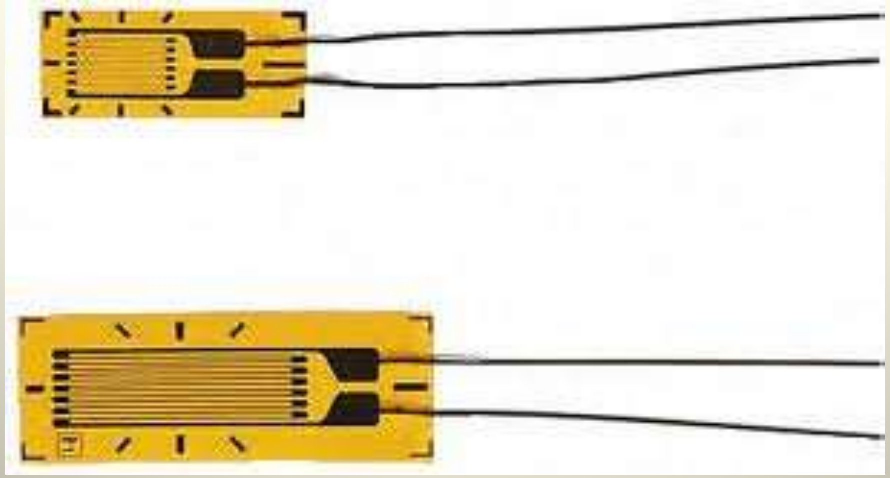
- When the rotor is in a position that directs the available flux equally in both the in-phase and out-of-phase coils, the output voltages cancel and result in a zero value signal. This is referred to as the electrical zero position or E.Z. When the rotor shaft is displaced from E.Z., the resulting output signals have a magnitude and phase relationship proportional to the direction of rotation.
- Because RVDT’s perform essentially like a transformer, excitation voltages changes will cause directly proportional changes to the output (transformation ratio). However, the voltage out to excitation voltage ratio will remain constant.

Advantages

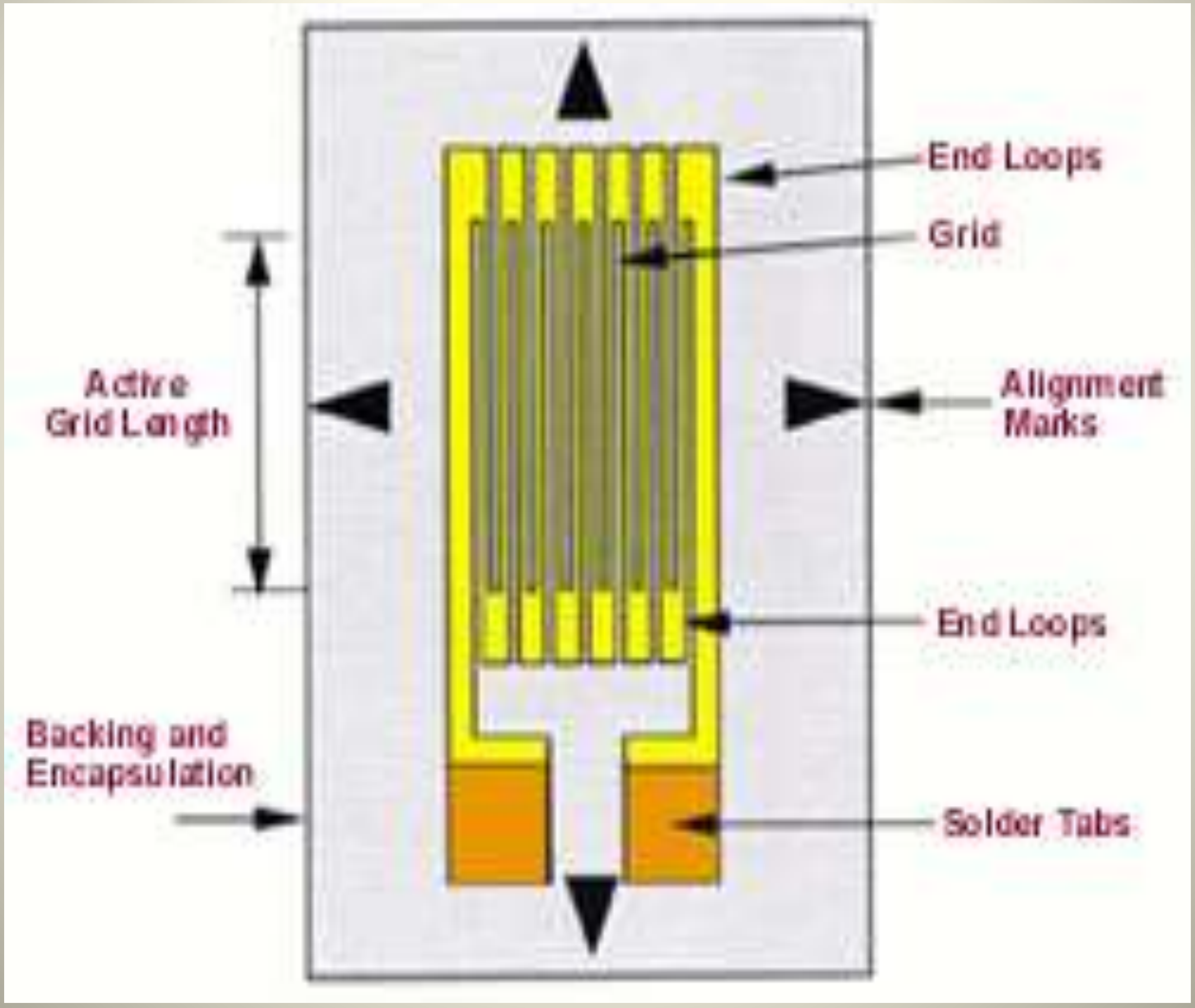
- Low sensitivity to temperature, primary voltage & frequency variations
- Sturdiness
- Low cost
- Simple control electronics
- Small size

Strain Gauge

- A strain gauge is an example of passive transducer that converts a mechanical displacement into a change of resistance.
- A strain gauge is a thin, wafer-like device that can be attached to a variety of materials to measure applied strain.



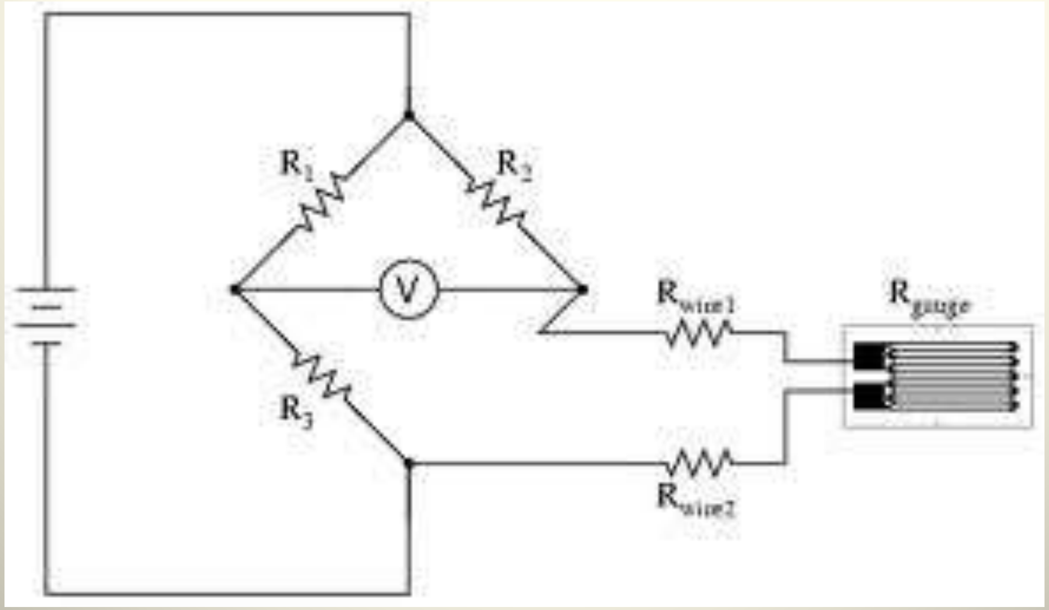
Construction



- The majority of strain gauges are foil types, available in a wide choice of shapes and sizes to suit a variety of applications. They consist of a pattern of resistive foil which is mounted on a backing material.
- They operate on the principle that as the foil is subjected to stress, the resistance of the foil changes in a defined way.

Working

- The strain gauge is connected into a Wheatstone Bridge circuit. The change in resistance is proportional to applied strain and is measured with Wheatstone bridge.



- The sensitivity of a strain gauge is described in terms of a characteristic called the gauge factor, defined as unit change in resistance per unit change in length, or

$$K = \frac{\Delta R/R}{\Delta l/l}$$

- Gauge factor is related to Poisson's ratio μ by,

$$K=1+2\mu$$

K=Gauge factor

R=Gauge wire resistance

ΔR=change in wire resistance

L= length of gauge wire in unstressed condition

Δl=change in length in stressed condition

Types

Based on principle of working :

- Mechanical
- Electrical
- Piezoelectric

Based on mounting :

- Bonded strain gauge
- Unbounded strain gauge

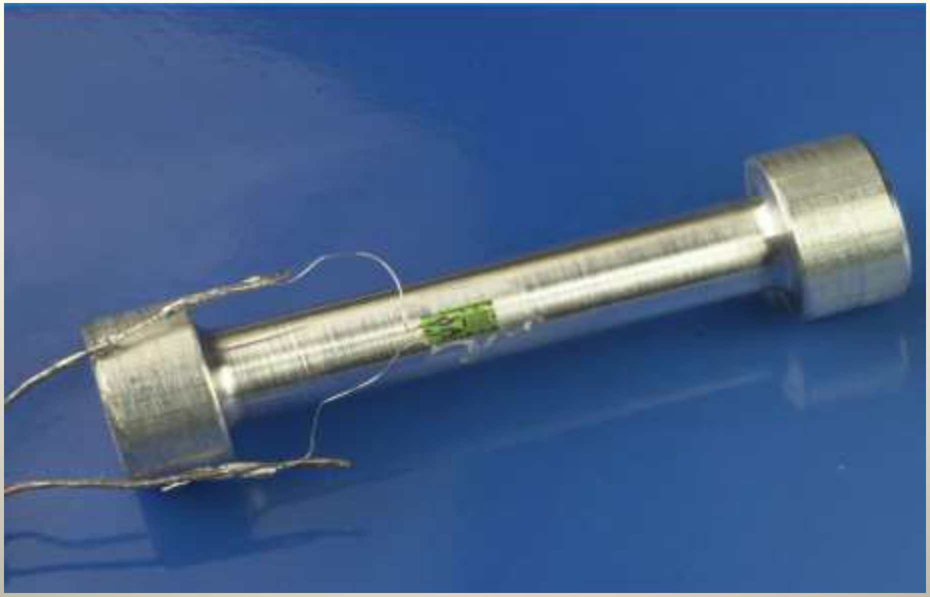
MECHANICAL STRAIN GAUGE

- It is made up of two separate plastic layers. The bottom layer has a ruled scale on it and the top layer has a red arrow or pointer. One layer is glued to one side of the crack and one layer to the other. As the crack opens, the layers slide very slowly past one another and the pointer moves over the scale.

  The red crosshairs move on the scale as the crack widens**.**

ELECTRICAL STRAIN GAUGE

- When an electrical wire is stretched within the limits of its elasticity such that it does not break or permanently deform, it will become narrower and longer, changes that increase its electrical resistance end-to-end.
- Strain can be inferred by measuring change in resistance.

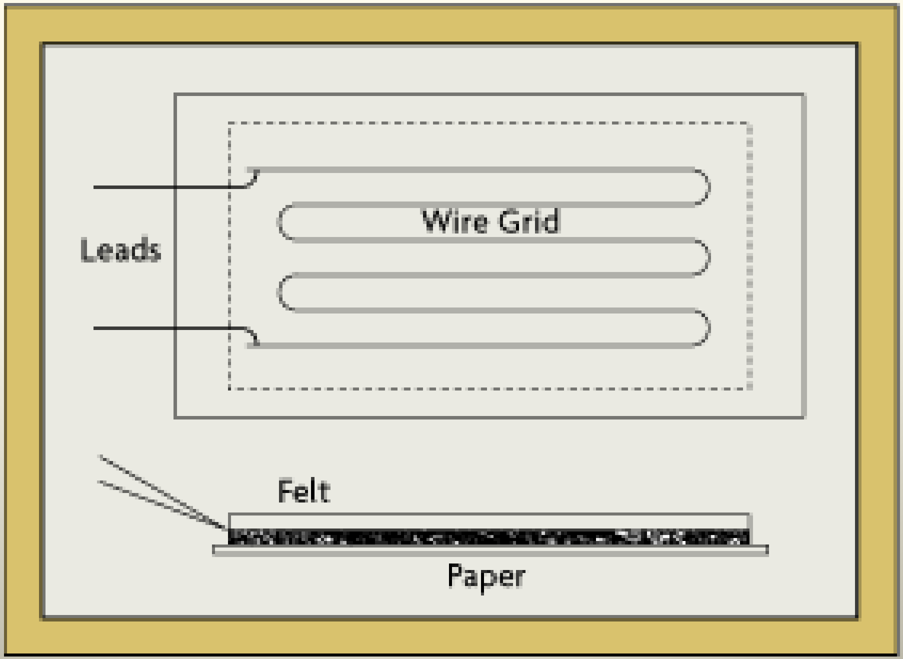


PIEZOELECTRIC STRAIN GAUGE

- Piezoelectric generate electric voltage when strain is applied over it. Strain can be calculated from voltage. Piezoelectric strain gauges are the most sensitive and reliable devices.

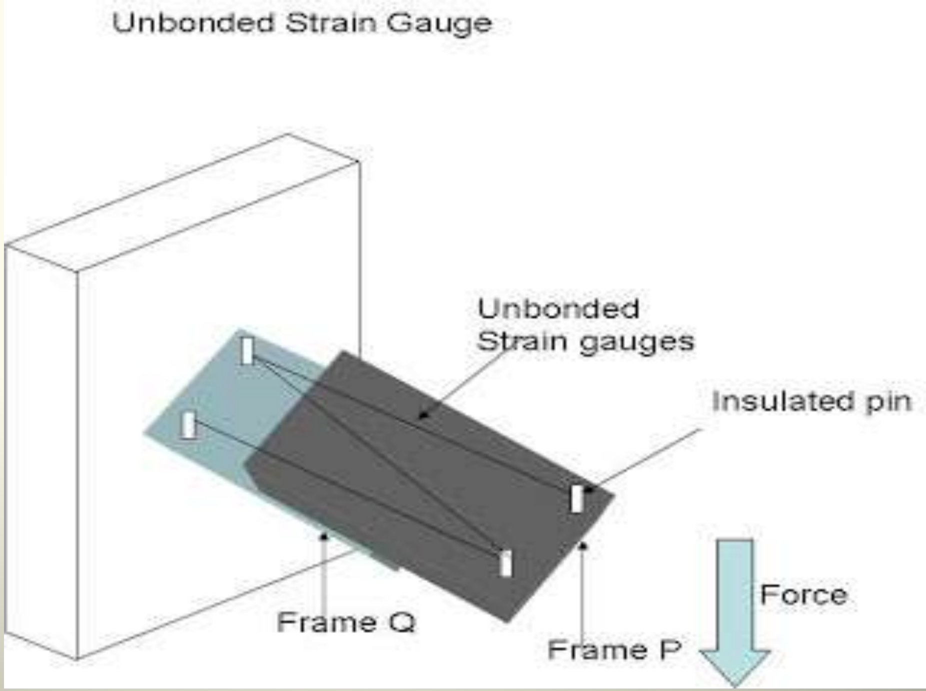
BONDED STRAIN GAUGE

- A bonded strain-gage element, consisting of a metallic wire, etched foil, vacuum-deposited film, or semiconductor bar, is cemented to the strained surface.



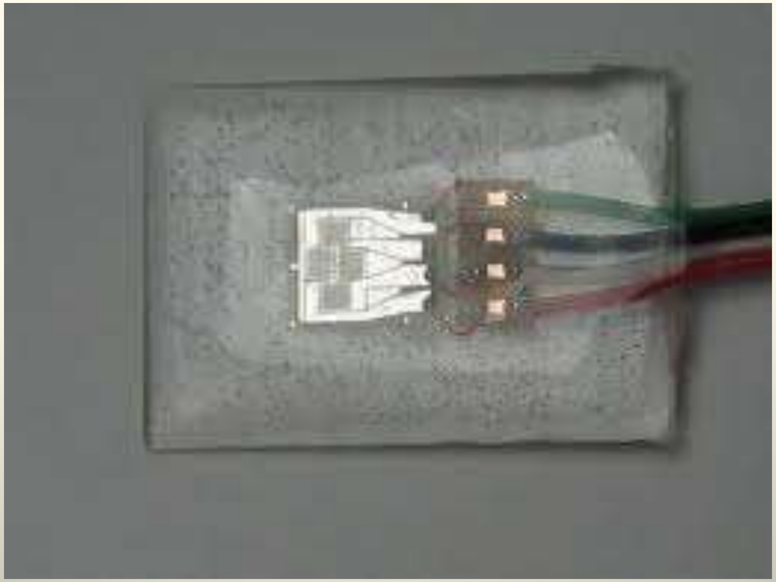
UNBONDED STRAIN GAUGE

- The unbonded strain gage consists of a wire stretched between two points in an insulating medium such as air. One end of the wire is fixed and the other end is attached to a movable element.



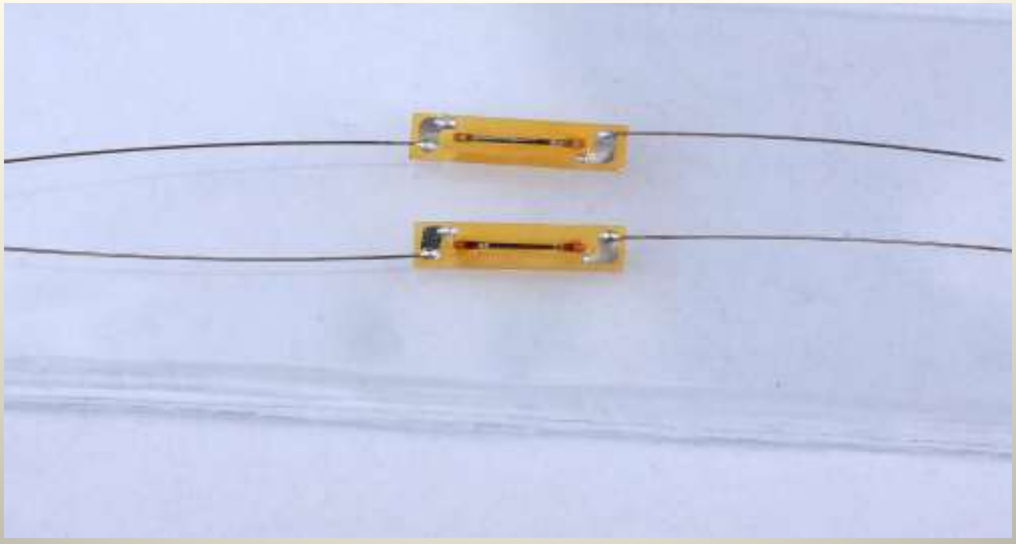
FOIL STRAIN GAUGE

- The foil strain gage has metal foil photo-etched in a grid pattern on the electric insulator of the thin resin and gage leads attached,



SEMICONDUCTOR STRAIN GAUGE

- For measurements of small strain, semiconductor strain gauges, so called piezoresistors, are often preferred over foil gauges. Semiconductor strain gauges depend on the piezoresistive effects of silicon or germanium and measure the change in resistance with stress as opposed to strain.

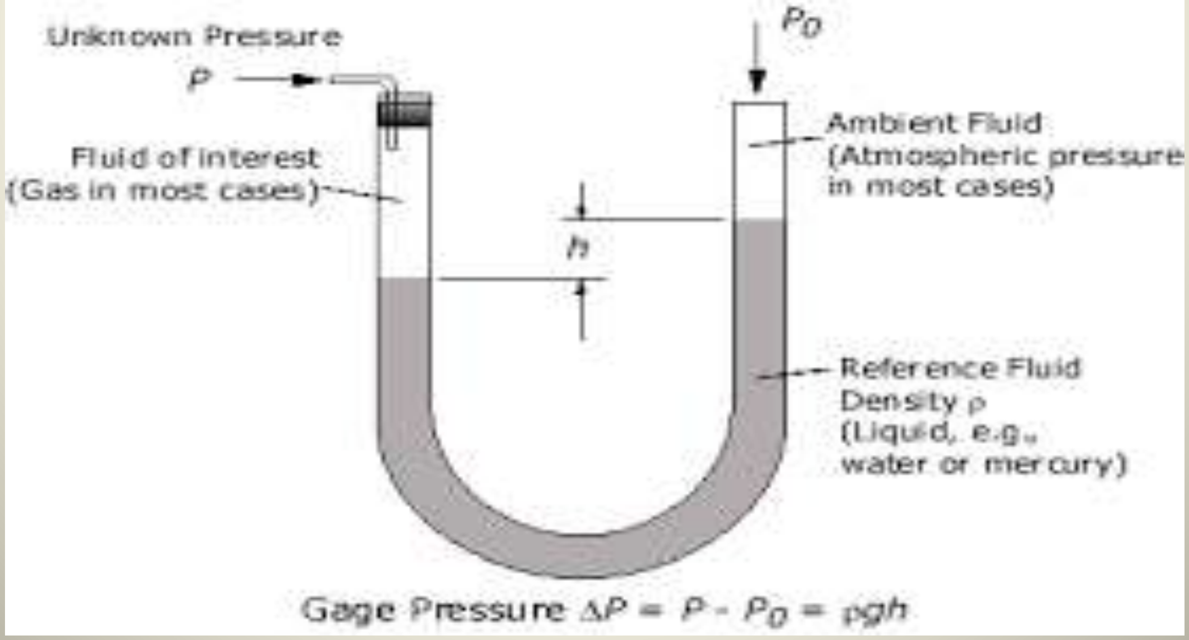


APPLICATIONS

- Residual stress
- Vibration measurement
- Torque measurement
- Bending and deflection measurement
- Compression and tension measurement
- Strain measurement

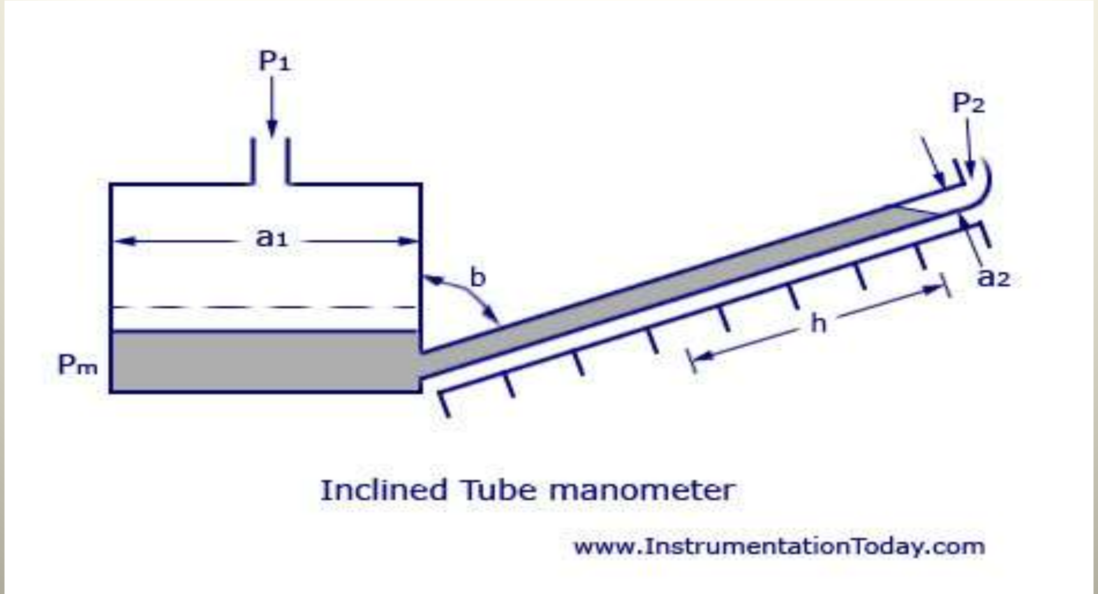
Manometer

- Instruments used to measure pressure are called **pressure gauges** or **vacuum gauges**.
- A **manometer** is an instrument that uses a column of liquid to measure pressure, although the term is currently often used to mean any pressure measuring instrument.



Inclined Type Manometer

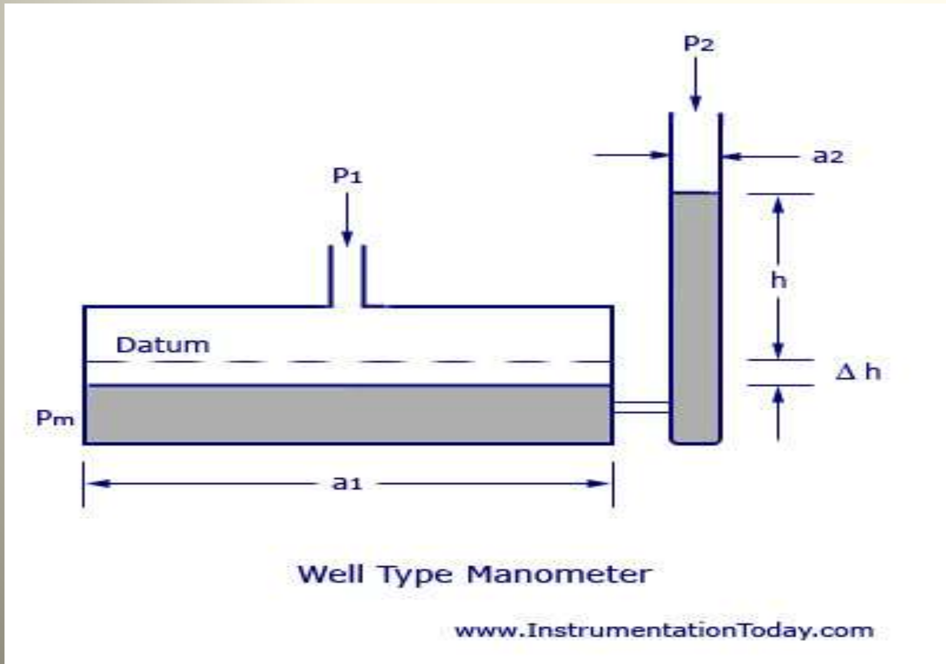
- The inclined tube manometer is an enlarged leg manometer with its measuring leg inclined to the vertical axis by an angle b. This is done to expand the scale and thereby to increase the sensitivity. The differential pressure can be written by the equation,
- $P1-p2 = \rho.g.ds \sin \phi$



Inclined Tube manometer

Well Type Manometer

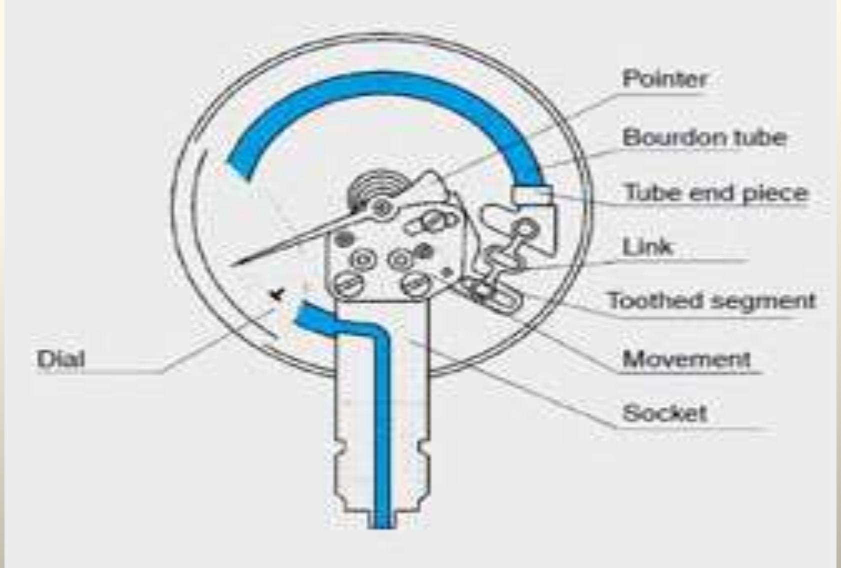
- The pressure is applied to a fluid well attached to a single indicating tube. As the fluid moves down in the well, the fluid is displaced into the smaller indicating leg of the manometer. This permits direct reading on a single scale.
- The well type manometer utilizes the principle of volume balance wherein the fluid displaced from the well is equal to the added fluid in the smaller indicating column.



Mechanical Pressure Measuring Elements

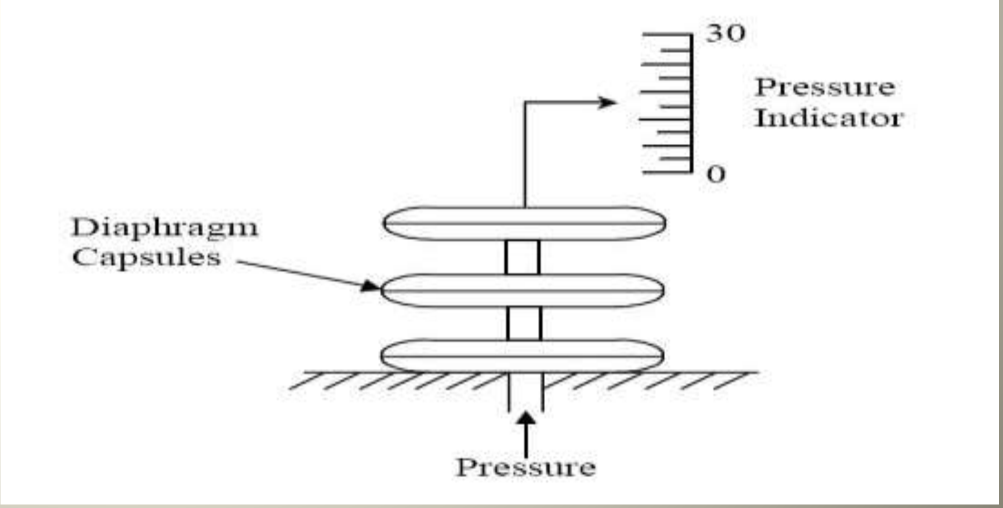
Bourdon tube pressure gauges

- The measuring element of a Bourdon tube pressure gauge is a C shaped or helical metal tube closed at one end. For pressure ranges up to 40 bar, the tube has an oval cross section and the shape of a C. For higher pressure ranges, the tube is bent into the shape of a helix. The oval cross section is obtained during bending.



Capsule pressure gauges

- Capsule pressure gauges are used in gas technology applications for low pressure ranges. Two concentrically shaped diaphragms are connected at the outer edges by means of welding or soldering. One diaphragm has an opening in the centre through which the gas to be measured can flow in. The pressure in the capsule causes it to arch to the outside. A deflection lever at the opposite side of the inlet opening transmits the linear displacement to a movement and converts it into a rotary movement.



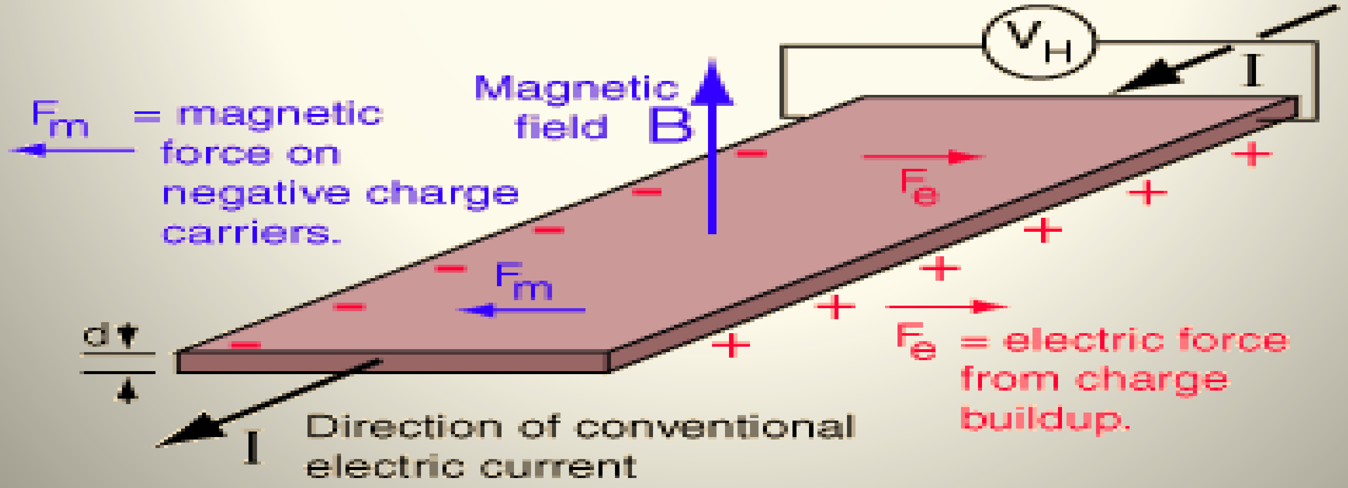
Hall Effect

- The Hall effect was discovered in 1879 by Edwin Herbert Hall while working on his doctoral degree at the Johns Hopkins University in Baltimore, Maryland, USA

- Discovered 18 years before the electron.

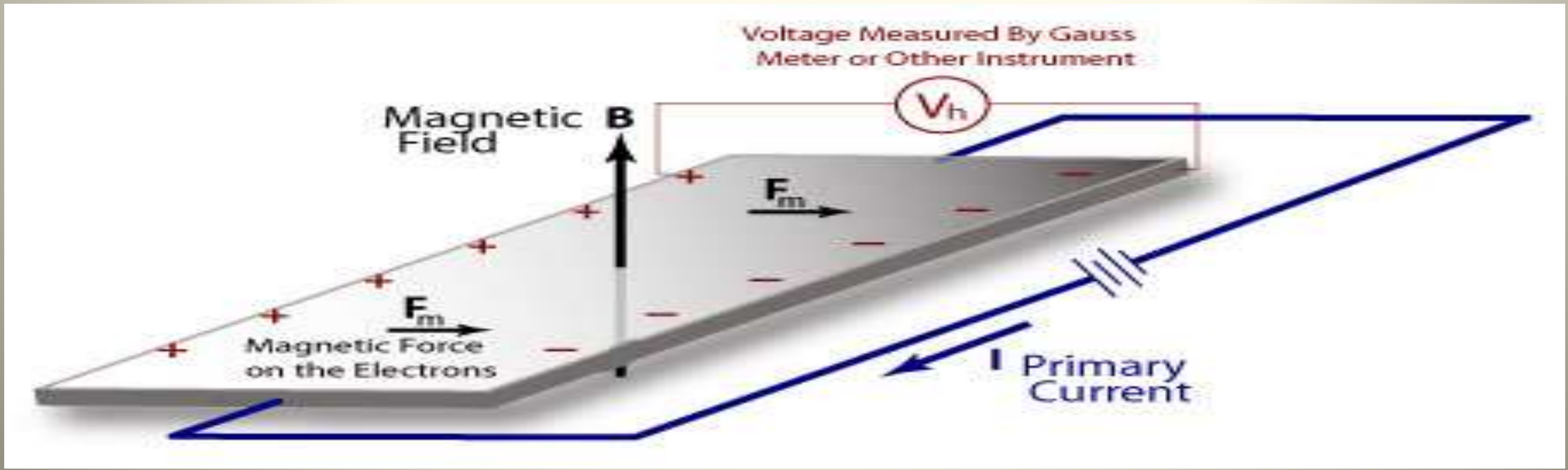
What is Hall Effect?

- The Hall effect is the production of a voltage difference (the Hall voltage) across a current carrying conductor (in presence of magnetic field), perpendicular to both current and the magnetic field.



Working

- When a current-carrying conductor is placed into a magnetic field, a voltage will be generated perpendicular to both the current and the field.
- When a perpendicular magnetic field is present. A Lorentz force is exerted on the electron. Due to which Electron moves in perpendicular direction to both current and Magnetic Field. And develop a Potential difference across the conductor or semiconductor.

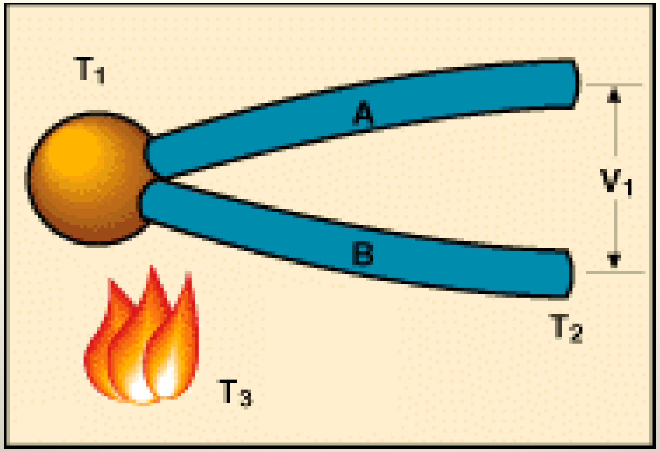


Application

- Used as Magnetometers, i.e. to measure magnetic field.
- **Hall effect sensor is also used as Current Sensor.**
- **Magnetic Position Sensing in Brushless DC Electric Motors**
- Automotive fuel level indicator.
- Spacecraft propulsion.

Thermocouple

- Thermocouples operate under the principle that a circuit made by connecting two dissimilar metals produces a measurable voltage (emf-electromotive force) when a temperature gradient is imposed between one end and the other.
- They are inexpensive, small, rugged and accurate when used with an understanding of their peculiarities.



Thermocouple Principle of Operation

- In, 1821 T. J. Seebeck observed the existence of an electromotive force (EMF) at the junction formed between two dissimilar metals (Seebeck effect).
  - Seebeck effect is actually the combined result of two other phenomena, Thomson and Peltier effects.
  - Thomson observed the existence of an EMF due to the contact of two dissimilar metals at the junction temperature.
  - Peltier discovered that temperature gradients along conductors in a circuit generate an EMF.
  - The Thomson effect is normally much smaller than the Peltier effect.

Working

- It is generally reasonable to assume that the emf is generated in the wires, not in the junction. The signal is generated when dT/dx is not zero.
- When the materials are homogeneous, ε, the thermoelectric power, is a function of temperature only.
- Two wires begin and end at the same two temperatures.

$$E = \int_{o}^{L} \varepsilon_A \frac{dT}{dx} dx + \int_{L}^{o} \varepsilon_B \frac{dT}{dx} dx \qquad \text{Equation 1}$$

If the wires are both homogeneous, then

$$E = \int_{T_{Ref}}^{T_{Jct}} \varepsilon_A \, dT + \int_{T_{Jct}}^{T_{Ref}} \varepsilon_B \, dT \qquad \text{Equation 2}$$

If both wires begin at T_{Ref} and end at T_{Jct}, then

$$E = \int_{T_{Ref}}^{T_{Jct}} (\varepsilon_A - \varepsilon_B) \, dT \qquad \text{Equation 3}$$

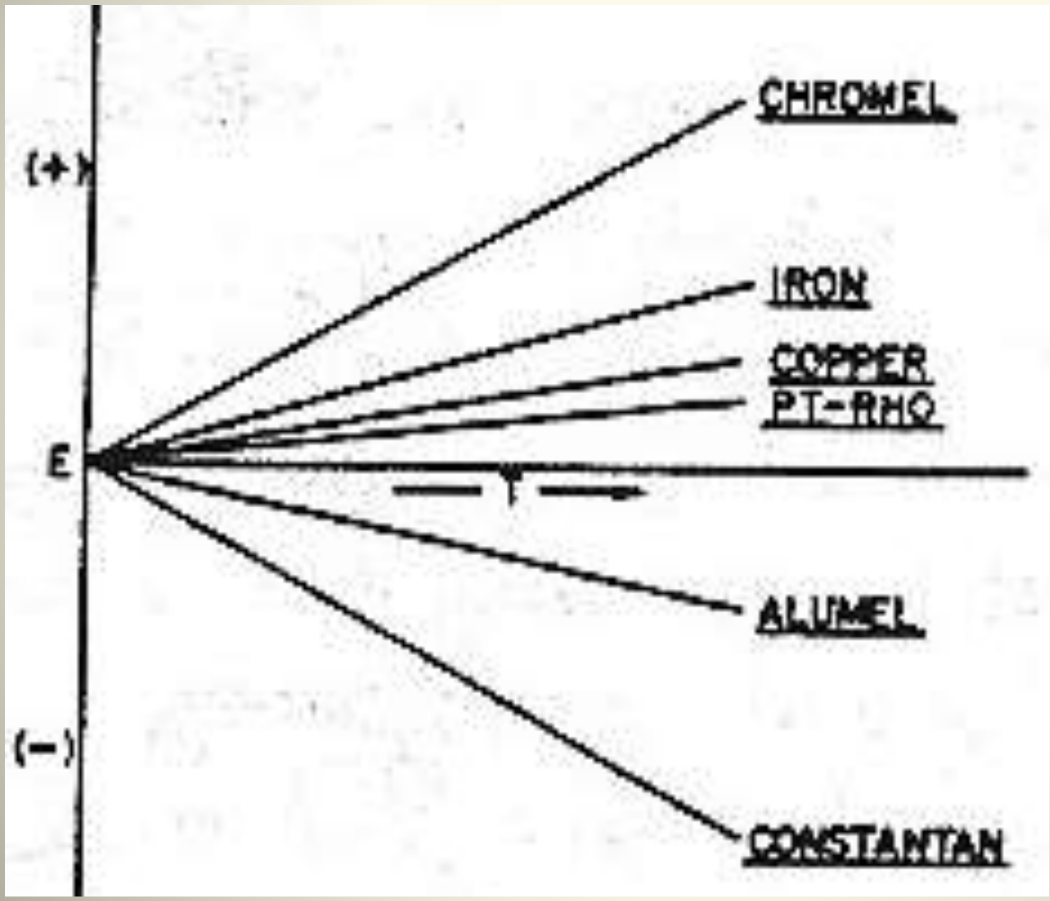
For small temperature differences, we can use the average calibrations:

$$E = (\hat{\varepsilon}_A - \hat{\varepsilon}_B)(T_{Jct} - T_{Ref}) = \hat{\varepsilon}_{AB}(T_{Jct} - T_{Ref}) \qquad \text{Equation 4}$$

Generally, a second order Eqn. is used.

$$E = \alpha(T - T_o) + \beta(T - T_o)^2$$

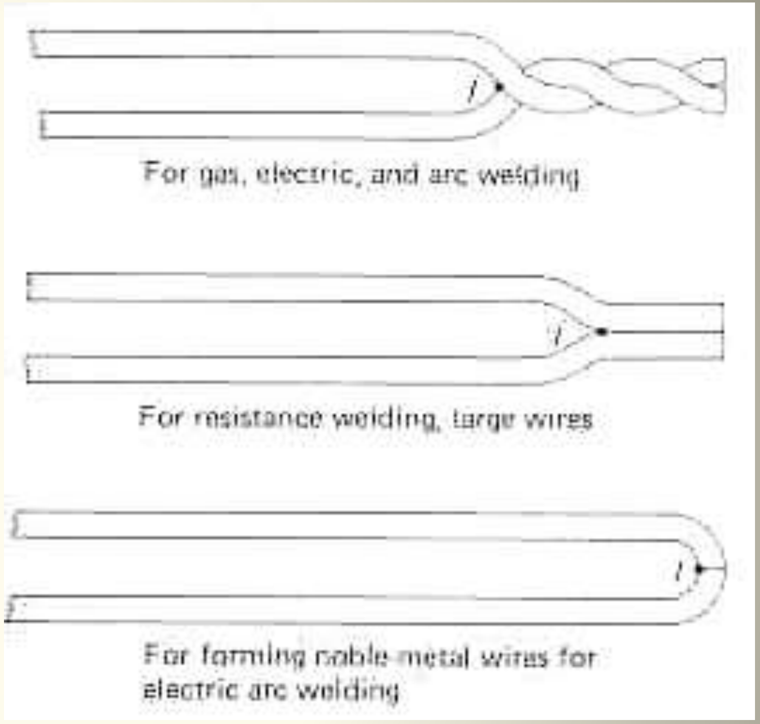
Material EMF versus Temperature

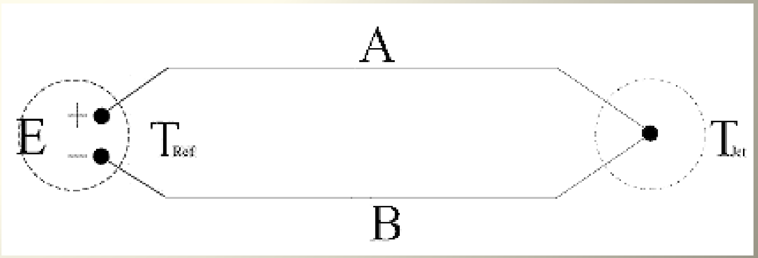


With reference to the characteristics of pure Platinum

Thermocouple Effect

- Any time a pair of dissimilar wires is joined to make a circuit and a thermal gradient is imposed, an emf voltage will be generated.
  - Twisted, soldered or welded junctions are acceptable. Welding is most common.
  - Keep weld bead or solder bead diameter within 10-15% of wire diameter
  - Welding is generally quicker than soldering but both are equally acceptable
  - Voltage or EMF produced depends on:
    - Types of materials used
    - Temperature difference between the measuring junction and the reference junction

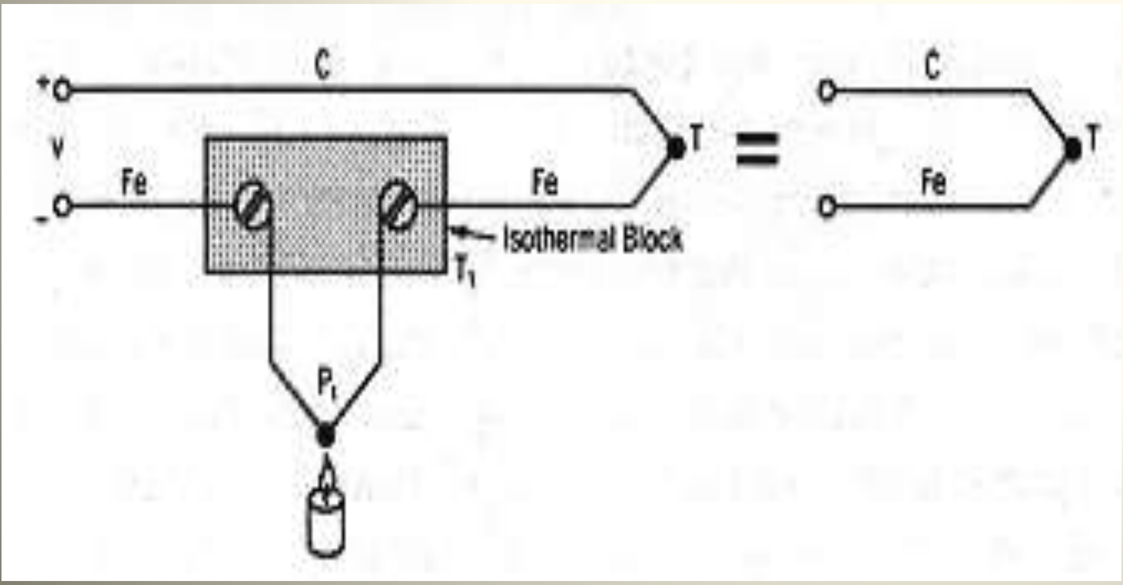


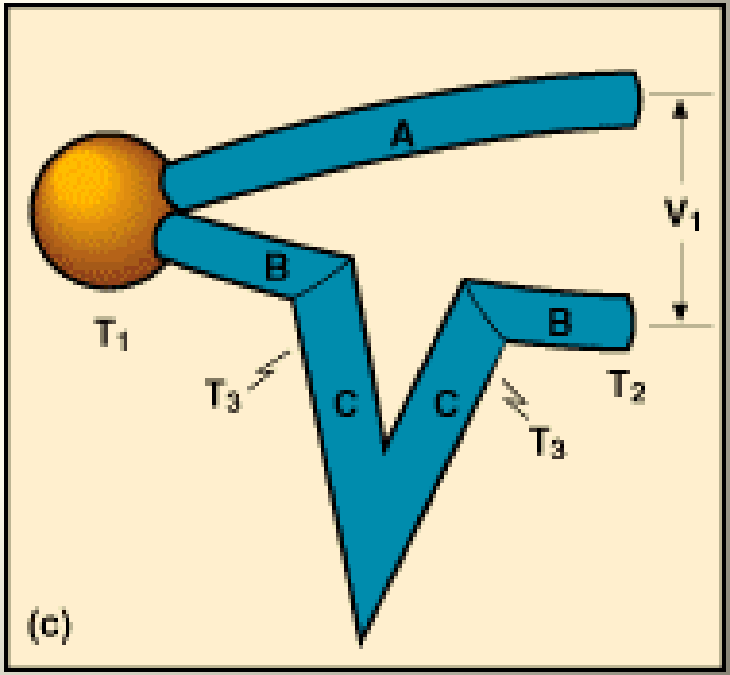


Law of Intermediate Metals

Insertion of an intermediate metal into a thermocouple circuit will not affect the emf voltage output so long as the two junctions are at the same temperature and the material is homogeneous.

- Permits soldered and welded joints.



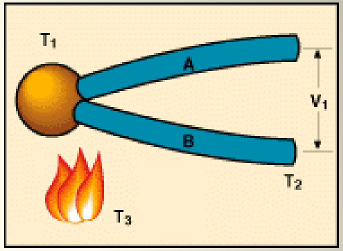


Law of Intermediate Temperatures

If a thermocouple circuit develops a net $emf_{1\text{-}2}$ for measuring junction temperatures T_1 and T_2, and a net $emf_{2\text{-}3}$ for temperatures T_2 and T_3, then it will develop a net voltage of $emf_{1\text{-}3} = emf_{1\text{-}2} + emf_{2\text{-}3}$ when the junctions are at temperatures T_1 and T_3.

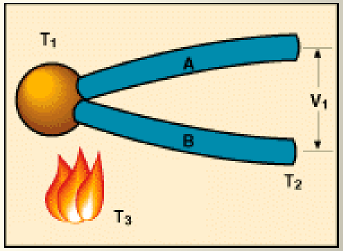
$$\mathbf{emf_{1\text{-}2} + emf_{2\text{-}3} = emf_{1\text{-}3}}$$

T2



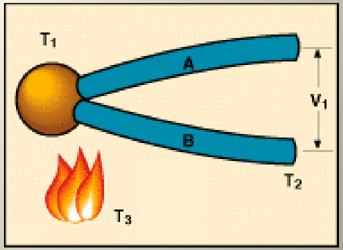
T1

T3



T2

T3



T1

Advantages

- It can measure a very large temperature range of -200 to 1500 Celsius
- It is very responsive to rapidly changing temperatures due to its low thermal capacity. the low thermal capacity is due to its low mass and metals are good conductors of electricity
- As the output is an electrical impulse it can be connected to a suitable electrical equipment for checking rapid or sudden temperature changes