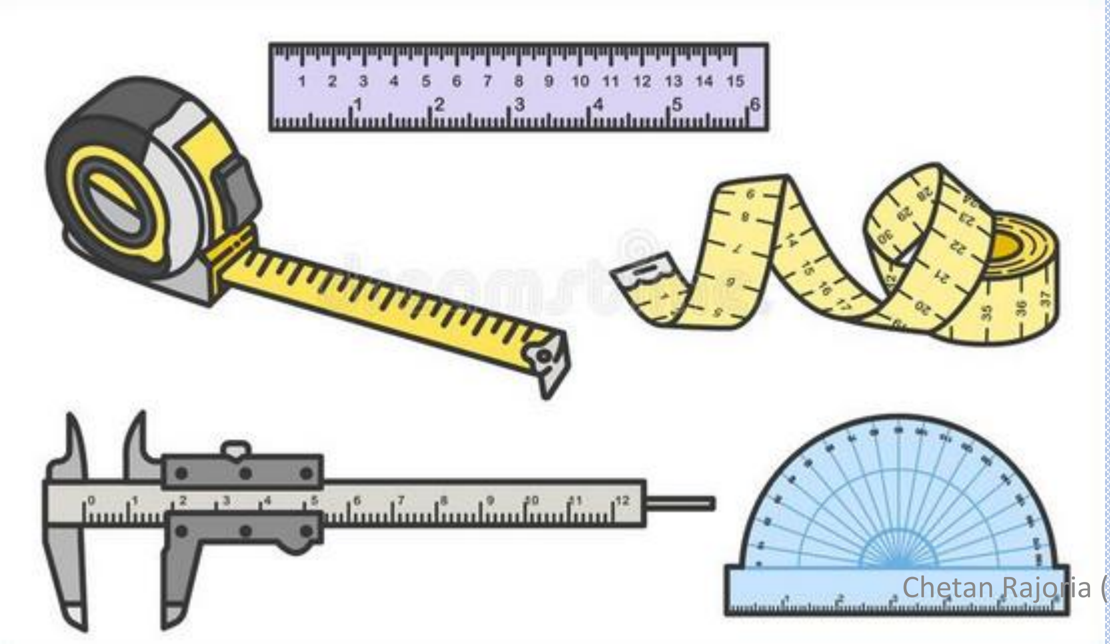
Measurement (part of Unit – 5)

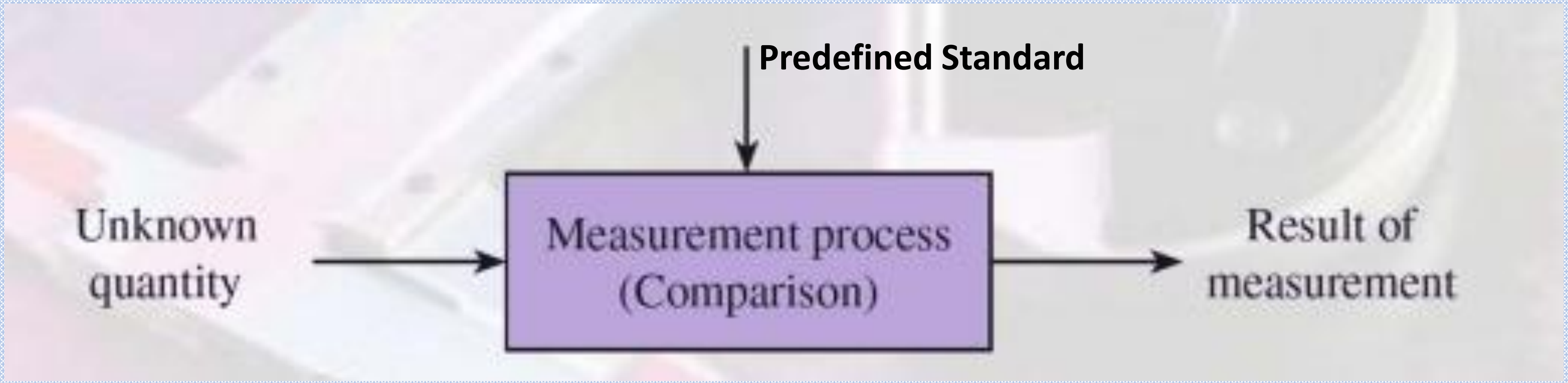


Contents of UNIT-5 (Measurement part)

Introduction to Measurement: Concept of Measurement, Error in measurements, Calibration, measurements of pressure(Bourdon Tube Pressure and U-Tube Manometer), temperature(Thermocouple and Optical Pyrometer), mass flow rate(Venturi Meter and Orifice Meter), strain(Bonded and Unbonded Strain Gauge), force (Proving Ring) and torques(Prony Brake Dynamometer); Concepts of accuracy, precision and resolution.

Introduction : Concept of measurement

- **The science of measurement is known as metrology.** Measurement is done to know whether the component which has been manufactured is as per the requirements or not. Measurements will be of mainly length, mass, time, angle, temperature, squareness, roundness, roughness, parallelism etc. For measuring any quantity there must be some unit to measure and express.
- **Measurement is defined as the process or the act of measuring some physical quantity. It consists of obtaining a quantitative comparison between a predefined standard and a measurand or unknown magnitude.**



Direct and indirect measurements (Primary, secondary and tertiary measurements)

- Direct measurement : When the value of the physical quantity is determined by comparing it directly with reference standards (e.g. measurement of mass, length, time) it is also called **primary** measurement. (comparing colours to identify darker one, matching lengths, comparing bearable temperatures by touching, etc.

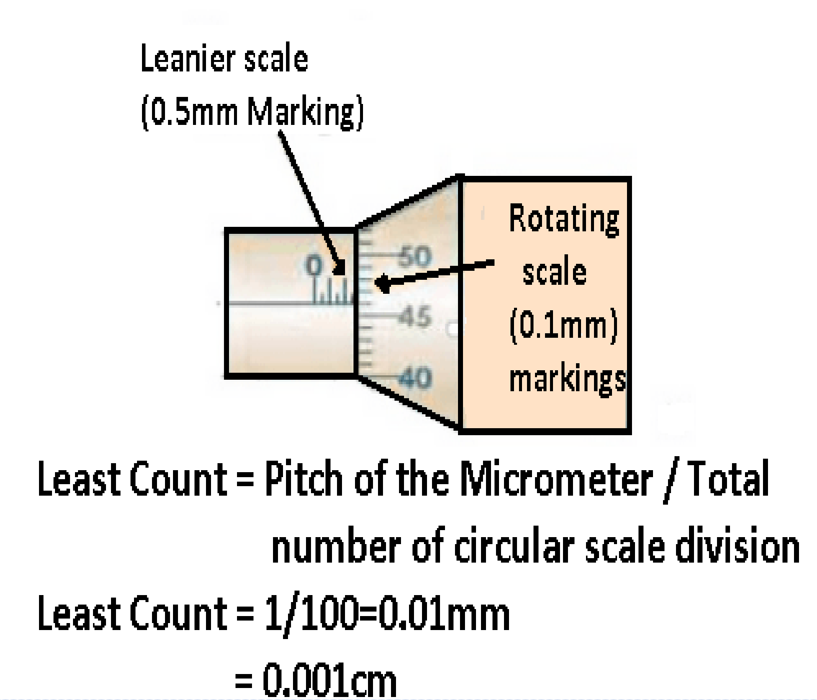
- Indirect Measurement : When the value of the physical quantity is determined by indirect comparison with secondary standards through **calibration**. The measurand value is converted into a proportional secondary signal, or if needed into a tertiary signal, and then this last signal is measured to get the desired value of the measurand. Accordingly, I may be called as **secondary** or **tertiary** measurements.

Primary, secondary and tertiary measurements

- **In primary measurements**, the value of a physical quantity is found by comparing it directly with the reference standards. E.g. matching of two lengths, time measurements, matching of colours, measurement of mass.
- In **secondary measurements**, the physical value is converted into some other signal or effect, and then this second signal or effect is measured directly. E.g. Bellows – it convert the pressure in a pipe into displacement, and this displacement is measured for the measurement of pressure. Other examples are – liquid in glass thermometer, venturimeter, etc.
- In **Tertery measurements**, the main first signal is transformed into second and the second signal is transformed into third signal. At last this third signal is measured directly for the measurement of the first signal. E.g. Bourdon tube – converts pressure into expansion of the c-shaped tube, and this expansion is converted into rotation of the central pinion rotation, which is used for the measurements.

- **Readability:**
- This term indicates the closeness with which the scale of the instrument may be read. For example, an instrument with 30 cm scale will have a higher readability than an instrument with a 15 cm scale. Closeness of graduated scale also changes the readability of scale.

- **Least Count:**
- **It is the smallest difference between two indications that can be detected on the instrument scale**. or in other words, it is the least value that can be measured with that particular device.



- **Resolution:**
- Resolution is also called as **discrimination** and defined as the smallest increment of the input signal that a measuring system is capable of displaying. (smallest change in non-zero input value, shown by an instrument).
- **Threshold:**
- If the instrument input is increased very gradually from zero, there will be some minimum value below which no output change can be detected. This minimum detectable value above zero is defined the threshold of the instrument. The main difference between threshold and resolution are :
- Resolution defines the smallest measurable input-change. While threshold defines the smallest measurable input (from zero value).
- **The threshold is measured when the input is varied from zero while the resolution is measured when the input is varied from any arbitrary non-zero value.**

- **Calibration:**

- Any measuring system must be provable, i.e., it must prove its ability to measure reliably. The procedure adopted for this is called ‘calibration’. Calibration is the periodic assessment of the outputs of an instrument by comparing its output (readings) with standard or true values, and tuning them if required.
- Calibration is the procedure used to establish a relationship between the values of the quantities indicated by the measuring instrument and the corresponding values realized by standards under specified condition.
- In other words **it is the act of marking units of measurement on an instrument so that it can be used for measuring something accurately.**
- It is the process of configuring the instrument to provide a correct measurement result, within an acceptable range.
- It is a fundamental aspect of instrumentation design, to eliminate or minimize the factors that cause inaccurate measurement.

Accuracy And Precision

Accuracy and Precision

- **Accuracy** refers to the degree of conformity and correctness of something when compared to a true or absolute value
- **Precision** refers to a state of strict exactness — how consistently something is strictly exact.

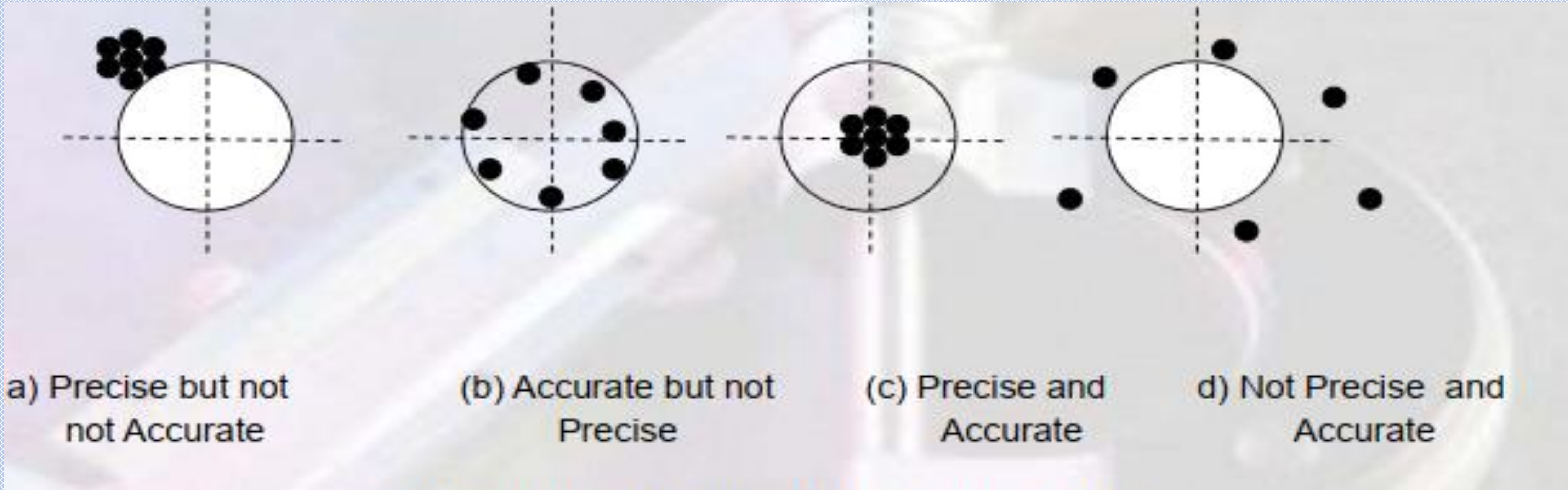


Figure 1.1: Accuracy and Precision.

Accuracy and Precision (continued)

- **Accuracy** indicates how close is the measured or obtained value, to the true value. When the measured value is closer to the true value, that means error is smaller, subsequently accuracy is more. And vice-versa.
- **Precision** indicates the closeness of repeated measurement outputs. When a measuring device is used repeatedly for measurements under same circumstances and for same inputs, and it gives you very close outputs (very less variations in readings), that means it has very high precision. So, precision indicates the closeness of repeated measurement readings for same input.

Errors in measurement

- Errors accompany any measurement, however well it has been conducted. The error may be inherent in the measurement process or it may be induced due to variations in the way the experiment is conducted. Mathematically it Can be described as the difference between the standard/true value (V_s) and the observed/measured value (V_m).

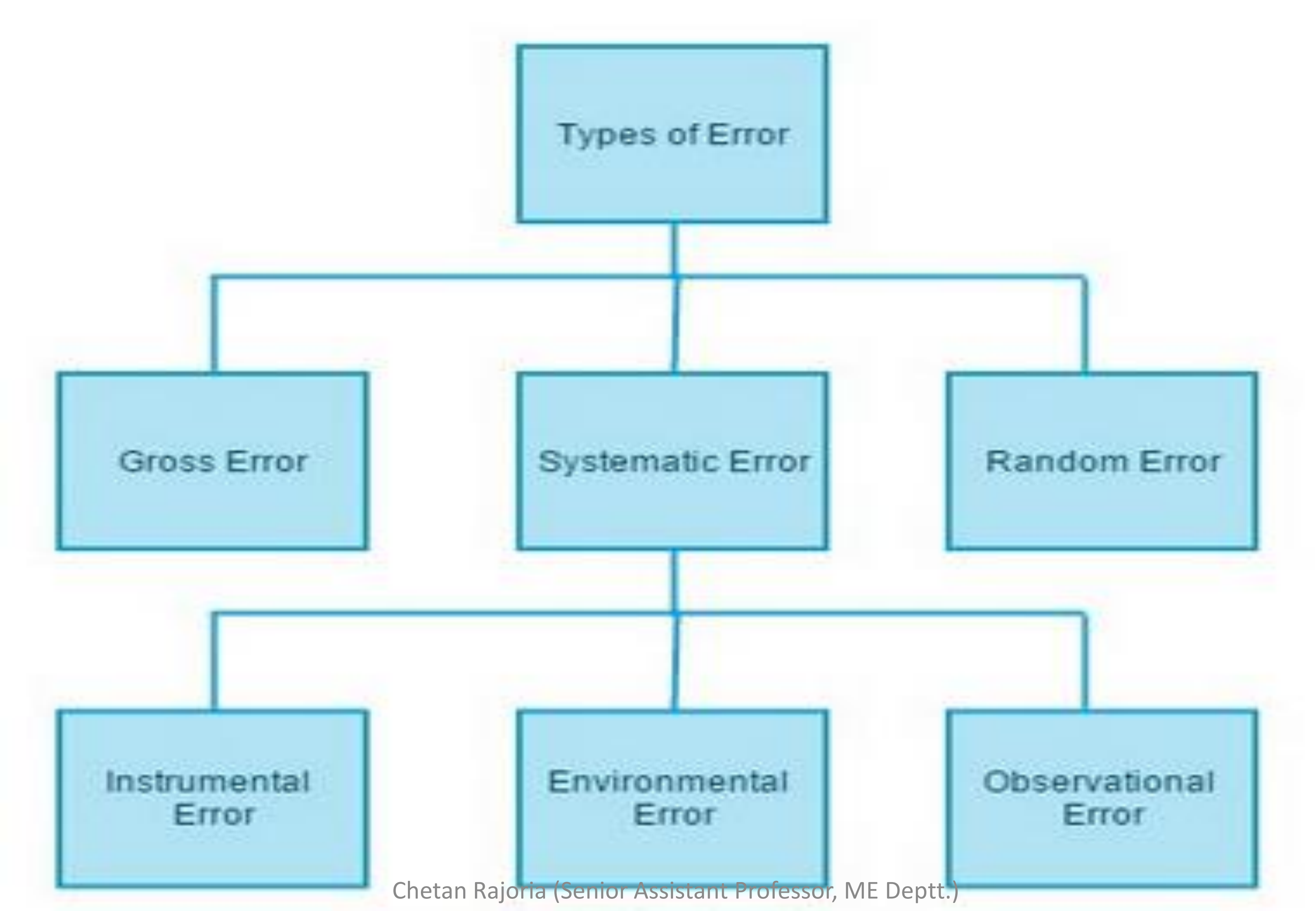
$$\text{error} = V_s - V_m$$

- Preferably, error is given as %error :

$$\%\ \text{error} = ((V_s - V_m)/V_s)*100$$

- Errors are studied under three categories :
  - 1) Systematic errors, 2) Random errors, 3) Gross errors

Errors in measurement



(1) Systematic errors (or Bias) :

- A systematic error is a type of error that deviates by a fixed amount from the true value of measurement. These types of errors are controllable in both their magnitude and their direction. Systematic error or bias is due to faulty or improperly calibrated instruments. These may be reduced or eliminated by careful choice and calibration of instruments. Sometimes bias may be linked to a specific cause and estimated by analysis. In such a case a correction may be applied to eliminate or reduce bias. Bias is an indication of the accuracy of the measurement. Smaller the bias more accurate the data.
- The following are the reasons for their occurrence-

  1) Calibration errors (i.e. instrumental errors),

  2) Ambient/environmental errors,

  3) Deformation of the work piece itself, while measurements.

  4) Other avoidable observational errors which include-
     - datum error or zero error,
     - error due to parallax effect,
     - errors due to different sensing capabilities of different observers,
     - misalignment error, etc.

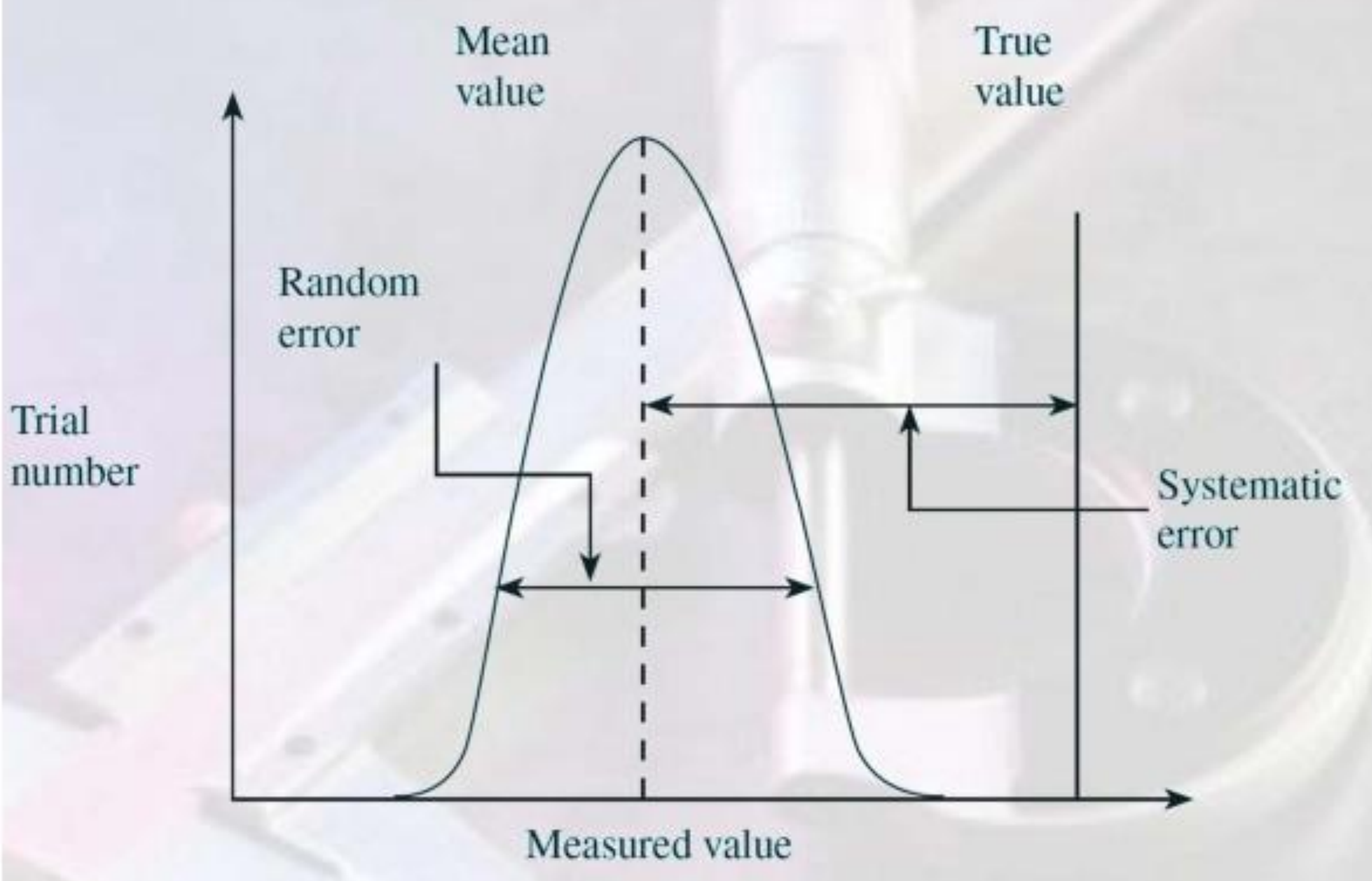
(2) Random errors :

- Random errors provide a measure of random deviations when measurements of a physical quantity are carried out repeatedly.
- Random errors are due to non-specific causes like natural disturbances that may occur during the measurement process.
- These cannot be eliminated completely, but can only be minimized. The magnitude of the spread in the data due to the presence of random errors is a measure of the precision of the data.
- **Smaller the random error more precise is the data**. When random error increases, precision decreases, and vice versa.
- Random errors are statistical in nature. These may be characterized by statistical analysis. The values lie around a central mean value.
- They are of variable magnitude and may be either positive or negative.
- Probable reasons are : Presence of friction in the movable parts, difference in operators' judgement, looseness/play in linkages, fluctuations in input, small variations in settings.

(3) Gross Errors :

- These are the human errors, due to lack of care taken by the observer, or due to his/her lack of attention. These can be minimized by careful observation.

Systematic error and Random error



[redacted] Relationship between systematic and random errors with measured value

Temperature Measurement

- The temperature is a thermal state of a body which distinguishes a hot body from a cold body.
- Temperature can be defined as a condition of a body by virtue of which heat is transferred from one system to another system.
- Temperature can be sensed using many devices, which can broadly be classified into two categories: **contact types and non-contact types**.
- Instruments for measuring ordinary temperatures are known as **thermometers** and those for measuring high temperatures without contact are known as **pyrometers**.

Devices for Temperature Measurement

- Thermal Expansion thermometers (liquid in glass thermometers, bimetallic strip)
- **<u>Thermocouples</u>**
- RTDs (Resistance Temperature Detectors)
- Thermistors
- **Pyrometers**
  - Infrared type
  - Total radiation type
  - **<u>Optical</u>**

Thermometers and thermometric properties

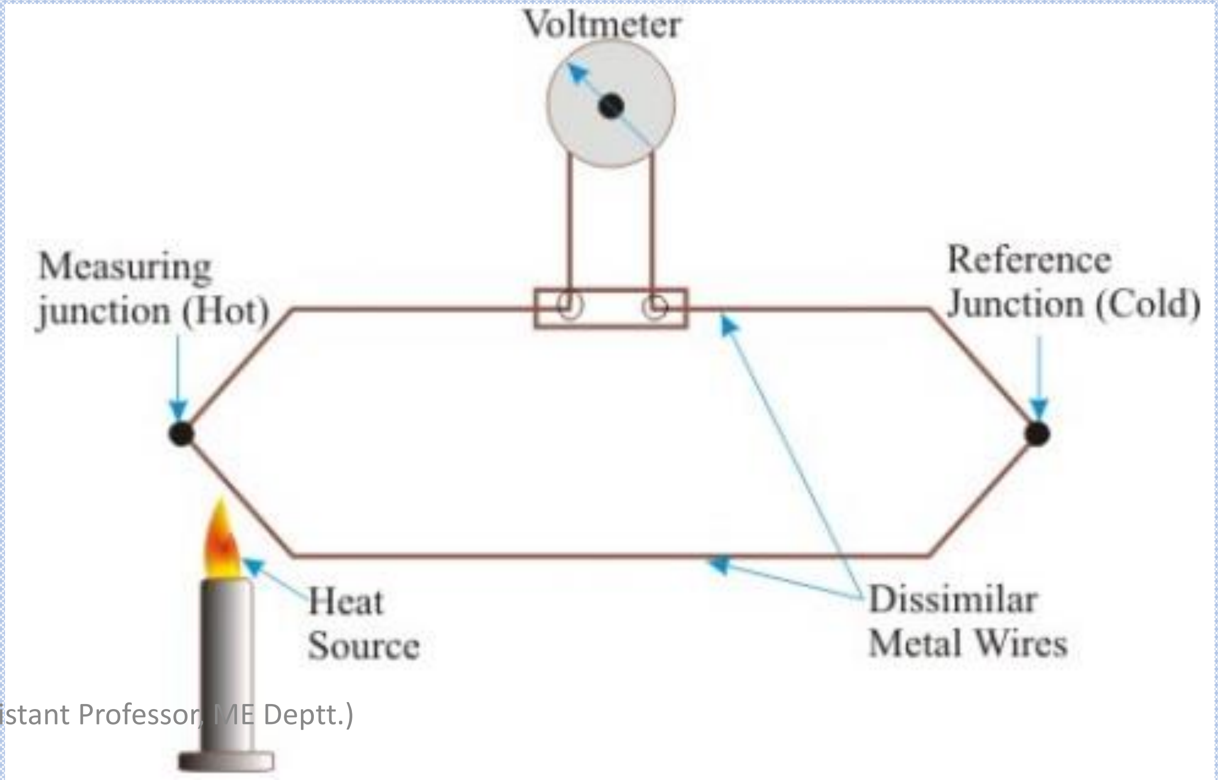
Thermometer	Thermometric property	Symbol
Gas at constant volume	Pressure	P
Electric resistance under constant tension	Electrical resistance	R
Thermocouple	Thermal electromotive force	E
Saturated vapor of a pure substance	Pressure	P
Black body radiation	Spectral emissive power	$E_{b\lambda}$
Acoustic thermometer	Speed of sound	a

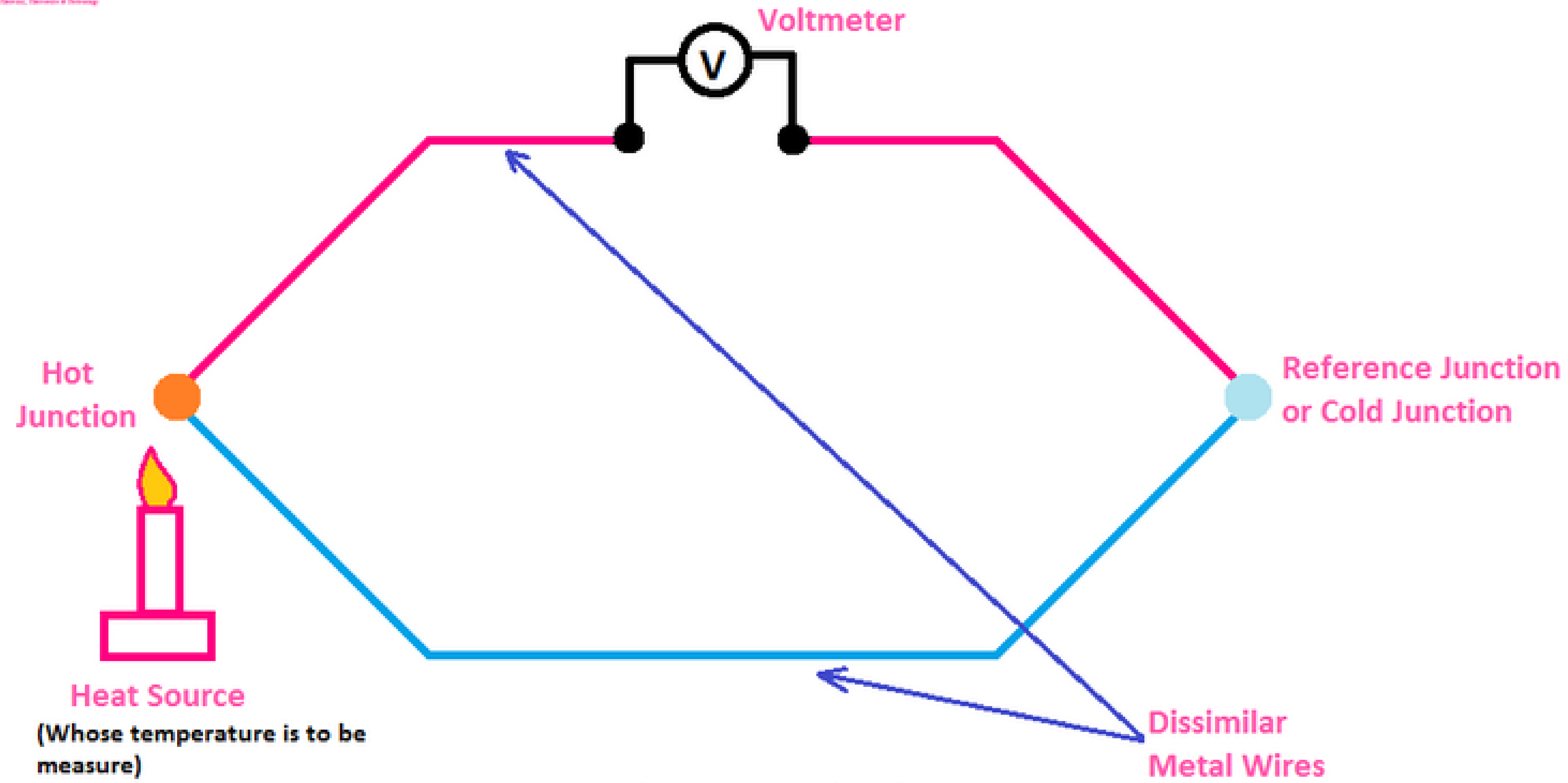
Thermocouples

- **Principle of Thermocouples**

When two dissimilar metals such a iron and copper are connected to form a closed circuit, current flow when one junction is at higher temperature and the other one is at lower temperature as shown in the figure.

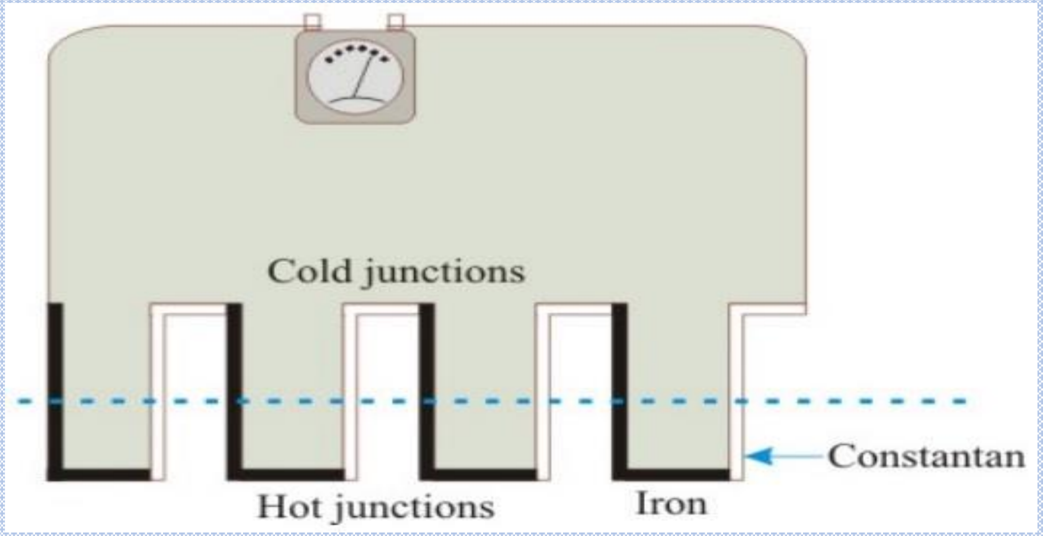
- The emf driving the current is called a thermoelectric emf and the phenomenon is known as **thermoelectric effect** or **SEEBACK'S effect**.





Thermocouple Diagram

Usually a thermoelectric emf is very small. When several thermocouples are arranged in series, the emf is added together to give an appreciable output, this arrangement is called **thermopile** as shown in the figure.

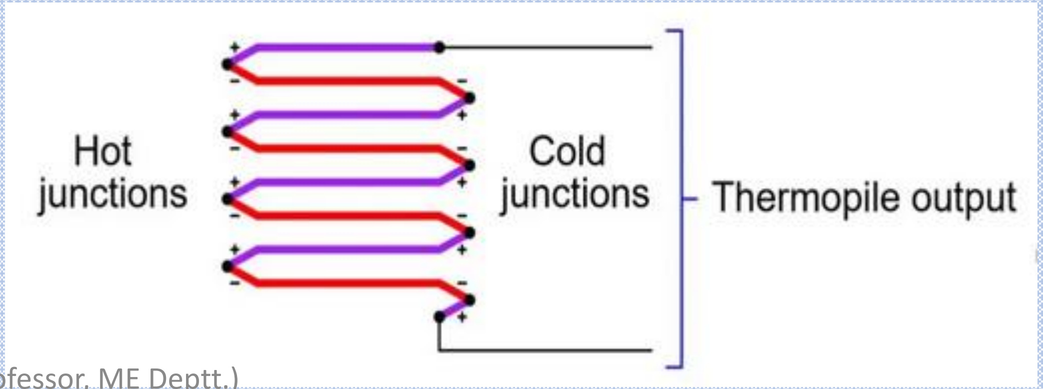


Advantages

- Better response
- High range of temperature measurements
- Cheaper than resistance thermometers

Disadvantages

- Lower accuracy
- Complex electrical circuits.



Suitable material for thermocouple : Platinum (Pt) with Constantan (40% Ni + 60% Cu) (There are many other suitable combinations also, e.g. different Pt-Rh alloy combinations, Cu/Constantan etc)

Radiation Pyrometers

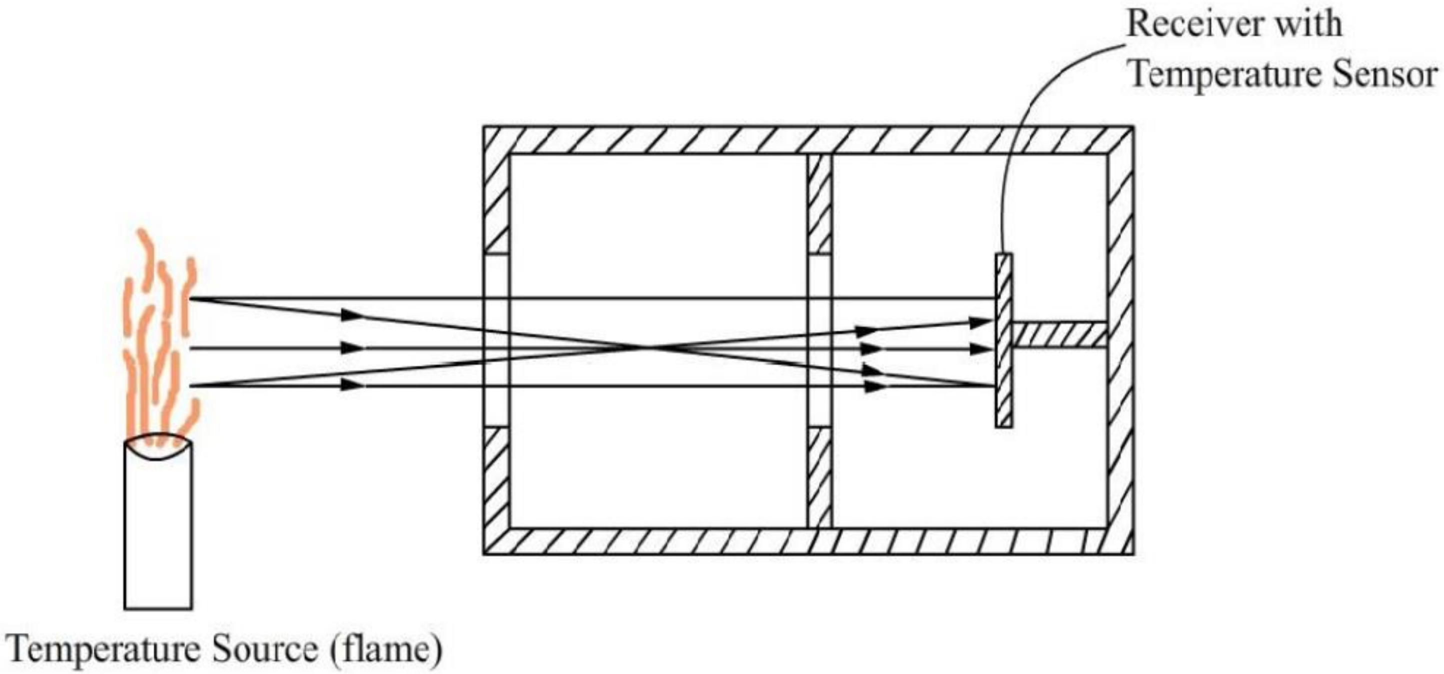
- The principle, that the radiant energy emitted from a body increases with temperature, is used in measuring temperatures particularly in higher ranges.
- Following two principles (i.e., types) are used for the construction of radiation temperature measurement devices
    - Total radiation pyrometers
    - Infrared type
    - Optical pyrometers

Total radiation pyrometers

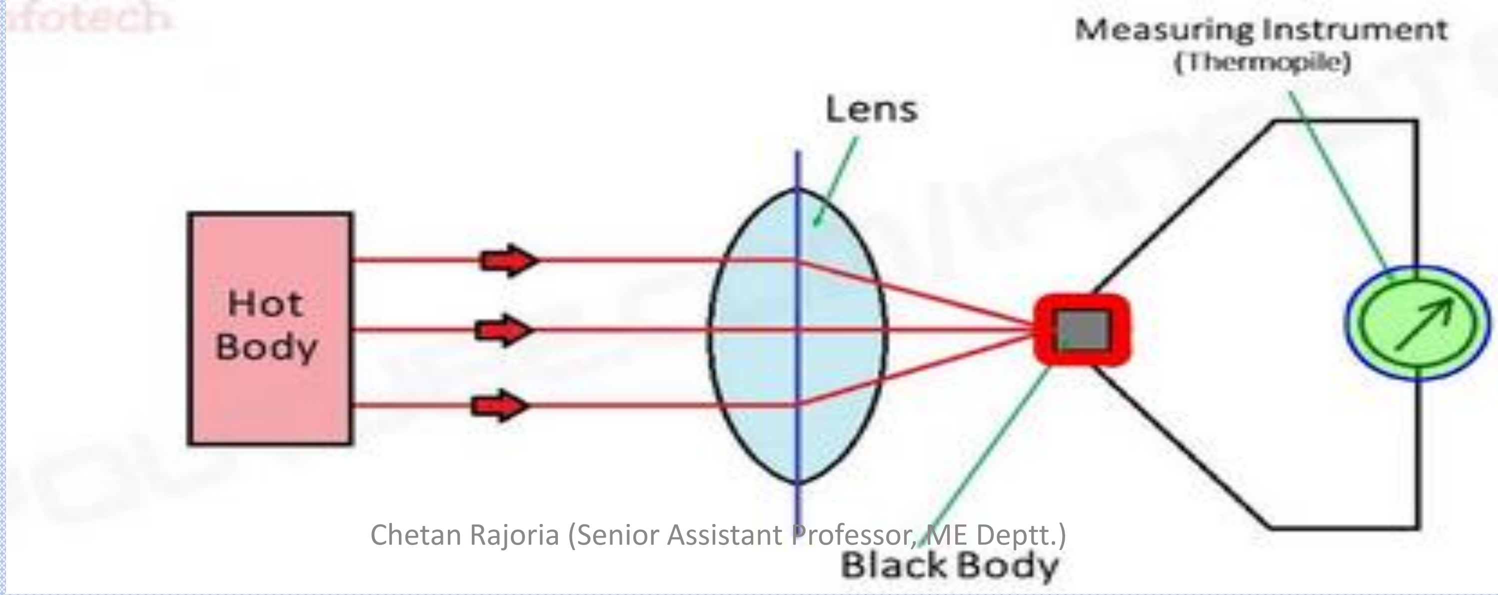
- Total radiation pyrometer accepts a controlled sample of total radiation and through determination of the heating effect of the sample obtains a measure of temperature. All bodies above absolute zero temperature radiate energy, not only do they radiate or emit energy, but they also receive and absorb from other sources. It is known that all substances emit and absorb radiant energy at a rate depending on the absolute temperature and physical properties of the substance.
- **Stefan-Boltzmann law**
- According to Stefan – Boltzmann law the net rate of exchange of radiation energy between two ideal radiators A and B is,

$$q = \sigma \left({T_A}^4 - {T_B}^4 \right)$$

- q = Radiative heat transfer
- σ = Stefan-Boltzman Constant (5.6703 x 10^-8 W/(m^2.K^4))
- , T_A = Unknown temperature, T_B= Known (atmospheric) temperature.



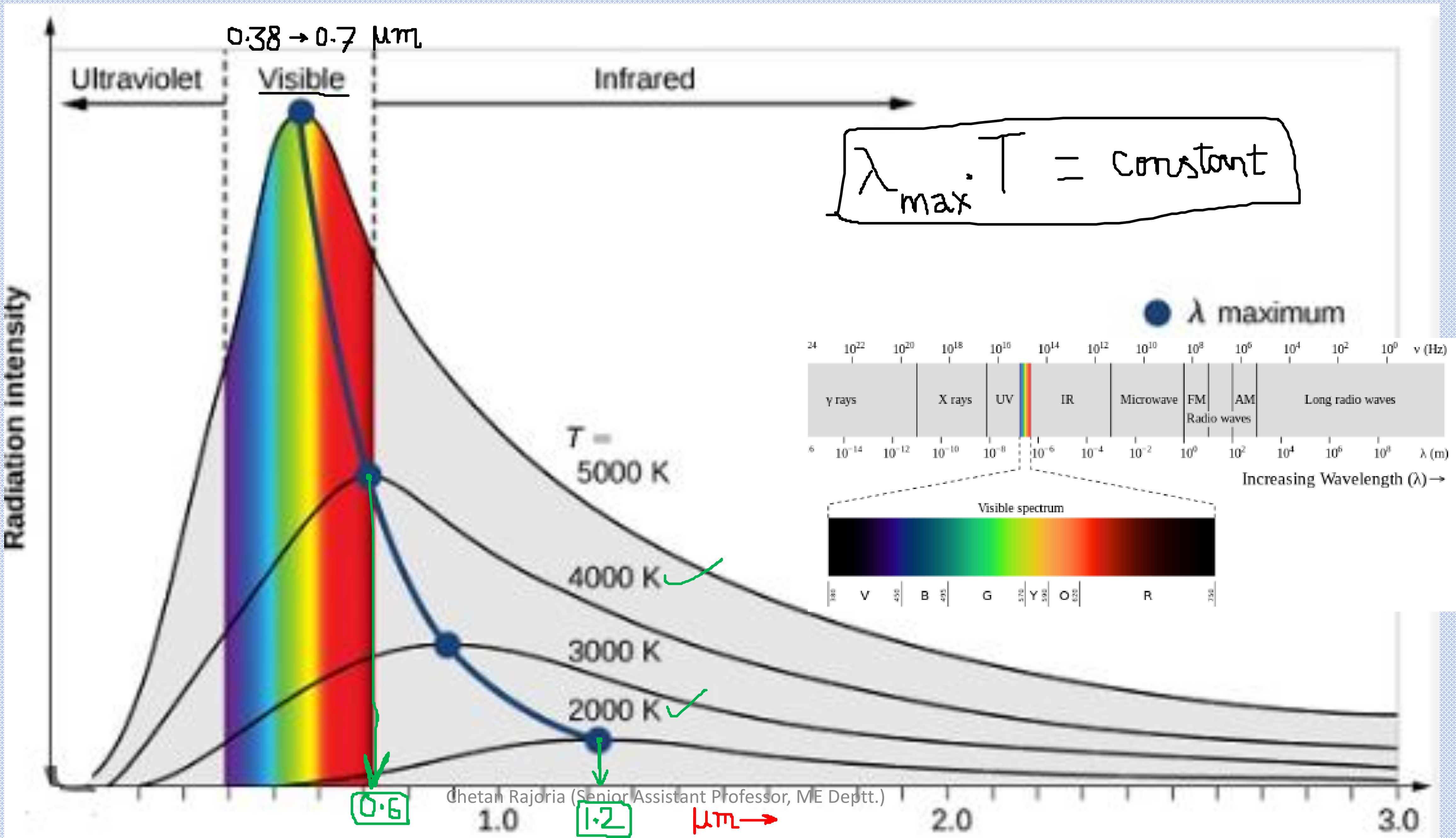
Total radiation pyrometer



- In total radiation pyrometers, the radiation from the measured body is focused on some sort of black body (radiation detector) which produces an electric signal.
- Detectors may be classified as thermal detectors or photon detectors.
- Thermal detectors are blackened elements designed to absorb a maximum of the incoming radiation at all wavelengths (ideally, a black body).
- The absorbed radiation causes the temperature of the detector to rise until equilibrium is reached with heat losses to the surroundings.
- The thermal detectors measure this temperature using a resistance thermometer, thermistor, thermocouple or a thermopile.

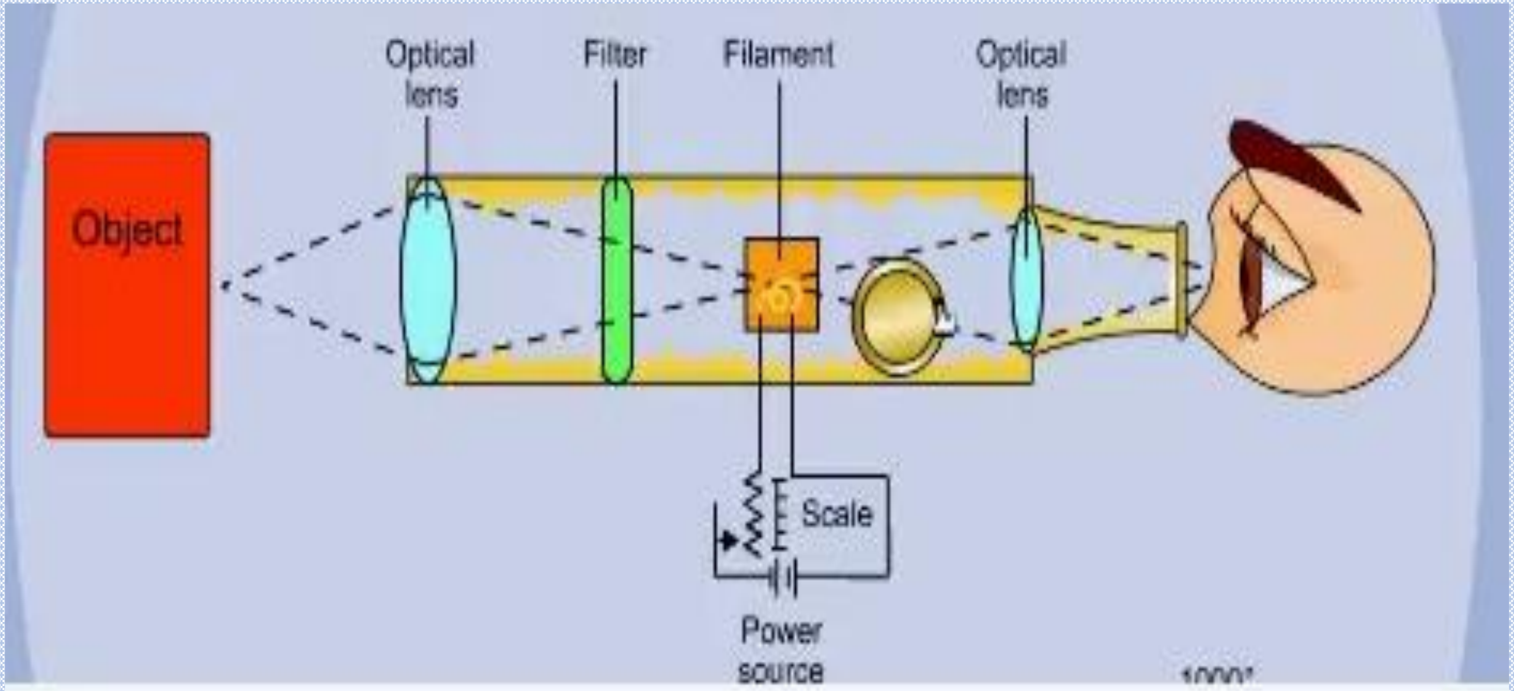
Optical Pyrometer

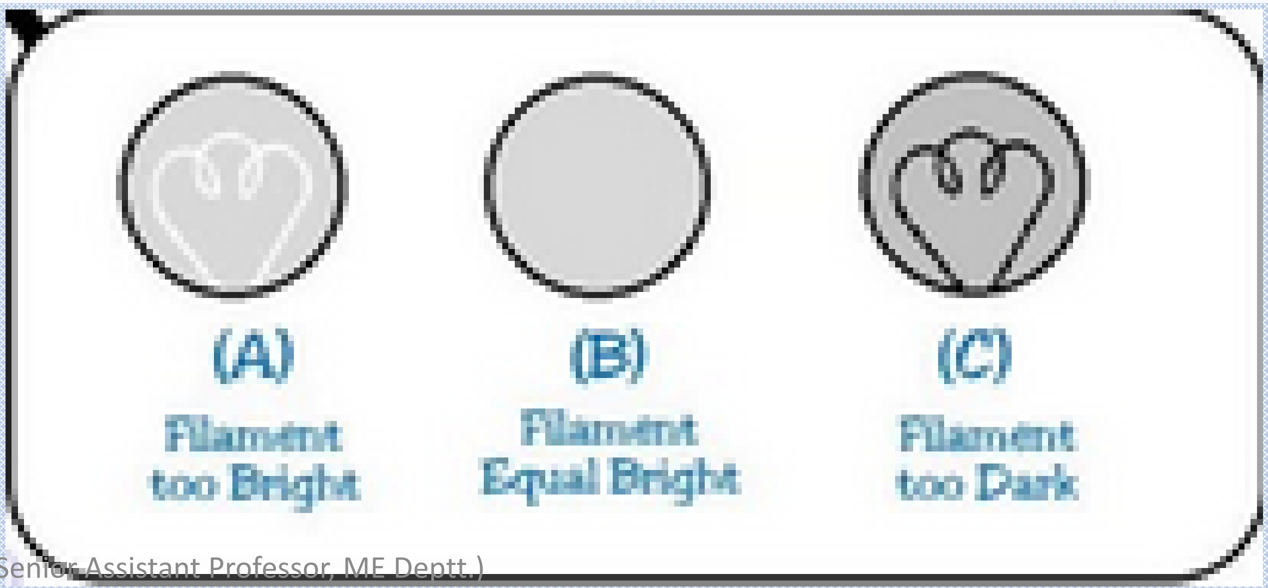
- Optical pyrometer employs an optical means for estimating the change in average wavelength of visual radiation with temperature. The instrument works on the principle of **Wien's displacement law.**
- **Wien's displacement law** provides a relationship between the temperature of a blackbody and the wavelength at which it emits the most radiation (i.e. maximum intensity of radiation). It states that *the blackbody radiation curve for different temperatures will peak at different wavelengths that are inversely proportional to the temperature*. i.e., $\lambda_{max} = b/T$ (here b = 2.898x10^-3 m.K)



$$\lambda_{max} \cdot T = \text{constant}$$

In the operation of the optical pyrometer, method of matching is used. Reference temperature is obtained by an electrically heated filament lamp which is controllable through a variable resistance (rheostat). A measure of temperature is obtained by optically comparing the visual radiation from filament with that from the unknown source. Current in the circuit is adjusted until the filament brightness exactly matches with that of the external object. At this moment the filament disappears (figure B) and temperature can be found on variable resistance reading using calibration techniques.





Filament of an Optical Pyrometer

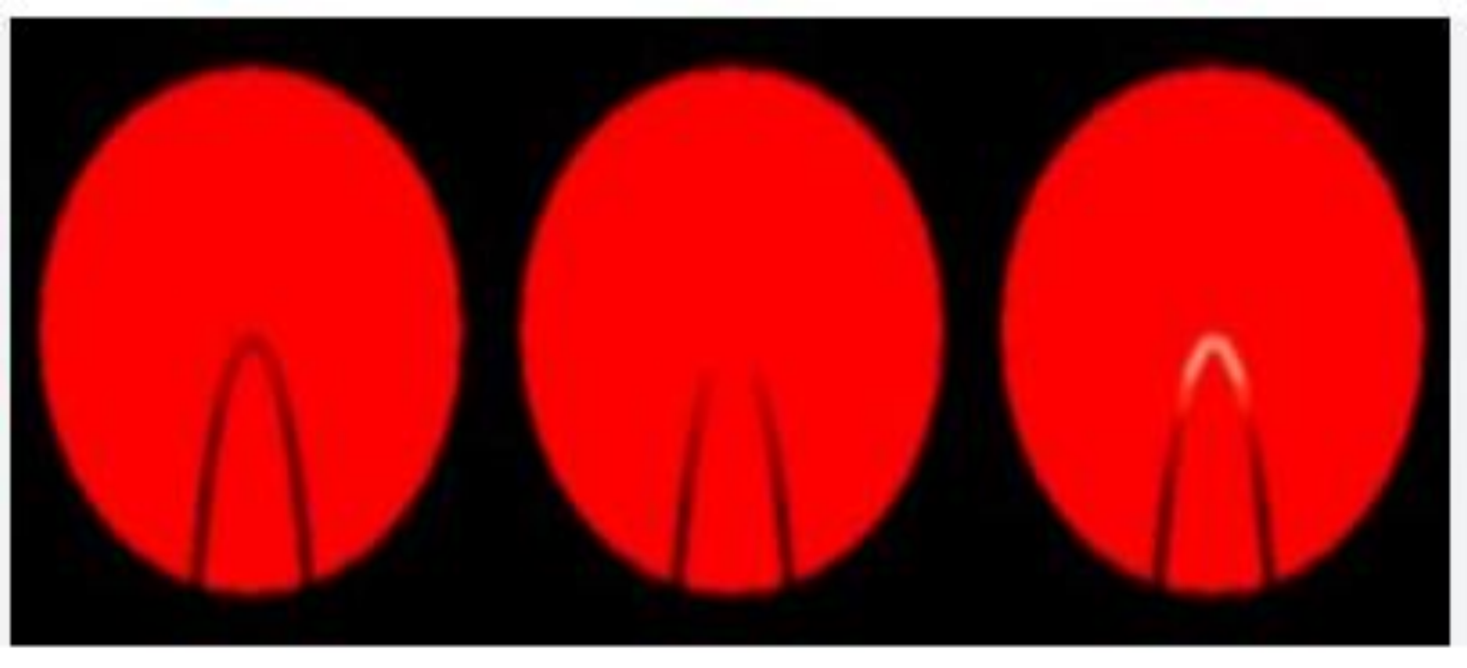


Fig (1) Fig (2) Fig (3)

- Fig (1) : Temperature of filament < temperature of Object
- Fig (2) : Temperature of filament = temperature of Object ***(filament disappeared.*** *Condition used for temperature measurement****)***
- Fig (3) : Temperature of filament > temperature of Object

Advantages of Optical Pyrometer

- The optical pyrometer has high accuracy.
- The temperature is measured without contacting the heated body. Because of this property, the pyrometer is used for the number of applications.

Disadvantages of Optical Pyrometer

The working of the pyrometer depends on the intensity of light emitted by the heated body. Thereby, the pyrometer is used for measuring the temperature having a temperature more than 700-degree Celsius. The accuracy of the pyrometer depends on the adjustment of the filament current. Also, the pyrometer is not used for measuring the temperature of clean gases.

Strain Measurement

MEASURING STRAIN

When a force is applied to a structure, the components of the structure change slightly in their dimensions and are said to be strained. Devices to measure these small changes in dimensions are called strain gauges.

For a wire to function as a strain gauge, we must determine the relationship between the strain and the change in resistance. The resistance of a wire is:

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

There is term known as '**Strain Gauge factor (S)',** which is defined as " the ratio of (dR/R) to the longitudinal strain in wire. I.e., the ratio of resistive strain to the longitudinal strain is called as strain gauge factor. It indicates the relative change in electrical resistance per unit change in longitudinal strain. For manufacturing strain gauges, the metals/alloys are chosen which have **higher values of strain gauge factor**. It increases the accuracy in measurements.

$$S = \frac{dR/R}{\epsilon_a}$$

The relationship between the strain gauge factor, Poisson's ratio of the material, longitudinal strain and change in resistivity of the material is given as:

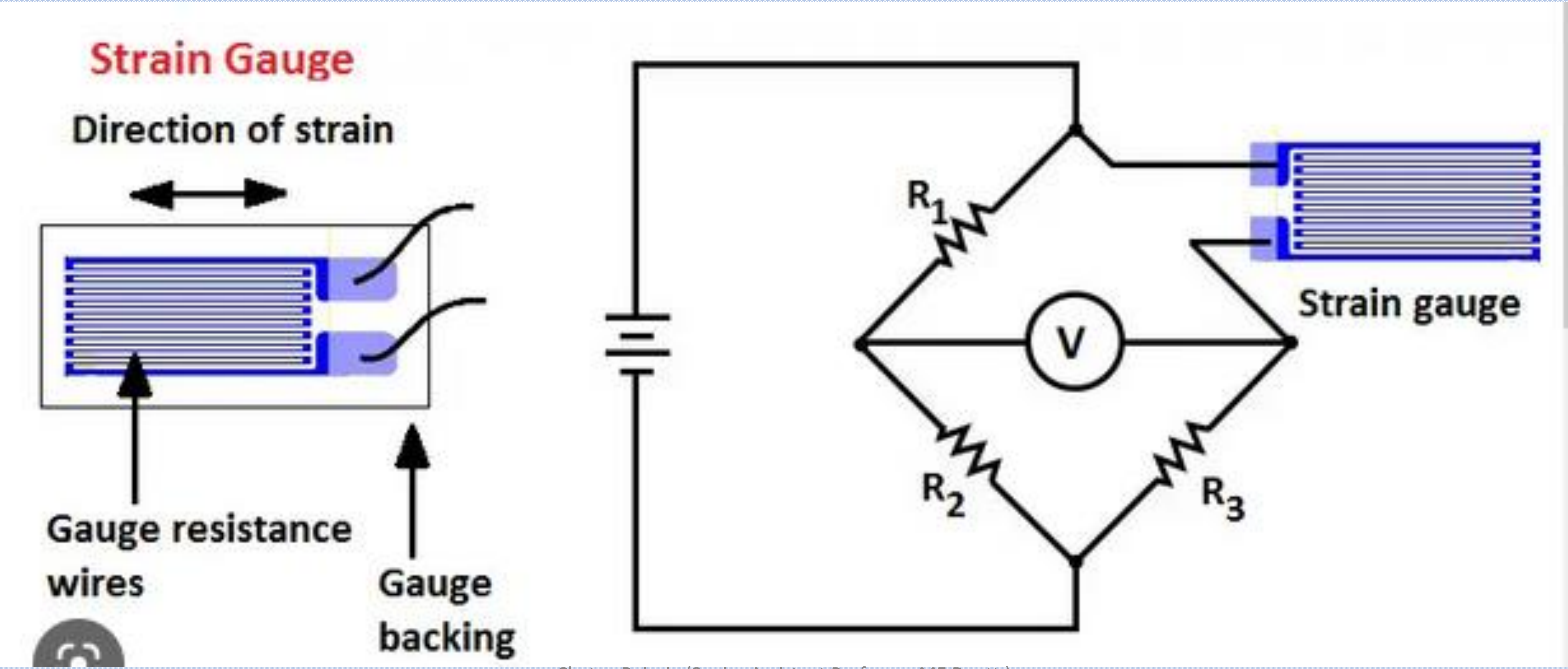
$$S = 1 + 2\mu + \frac{d\rho/\rho}{\epsilon_a}$$

If resistivity is constant for a material, means strain gauge factor is also constant for that material

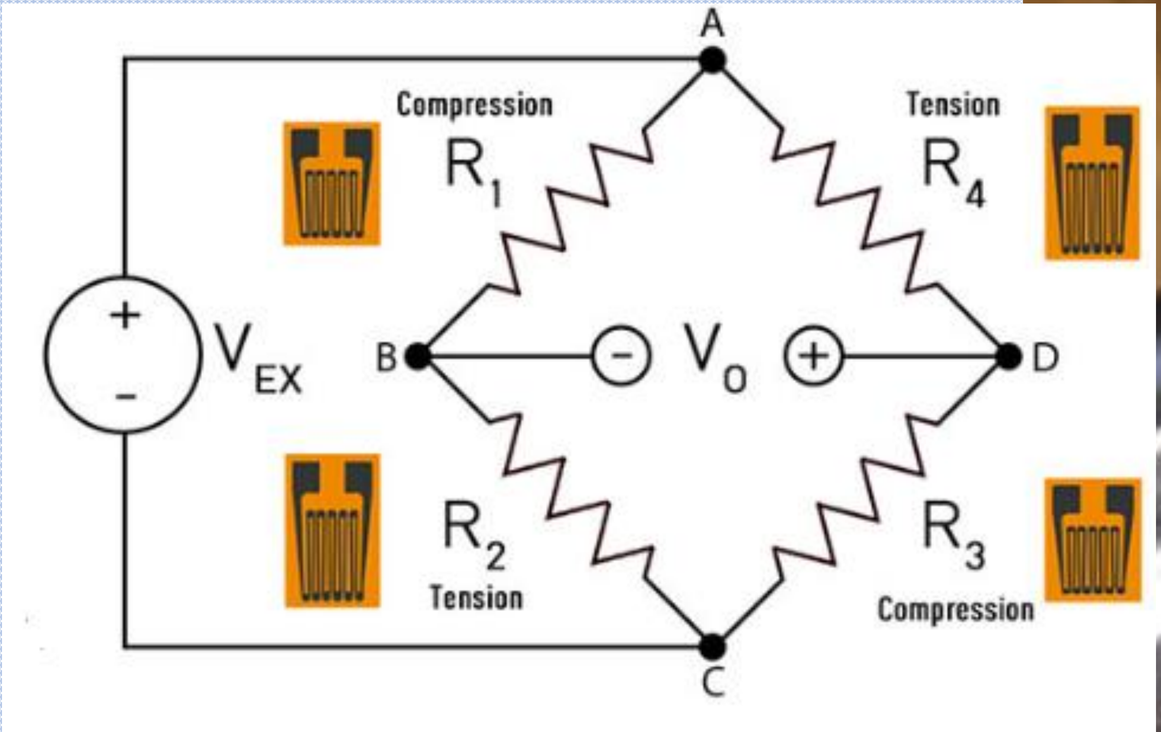
$$S = 1 + 2\mu$$

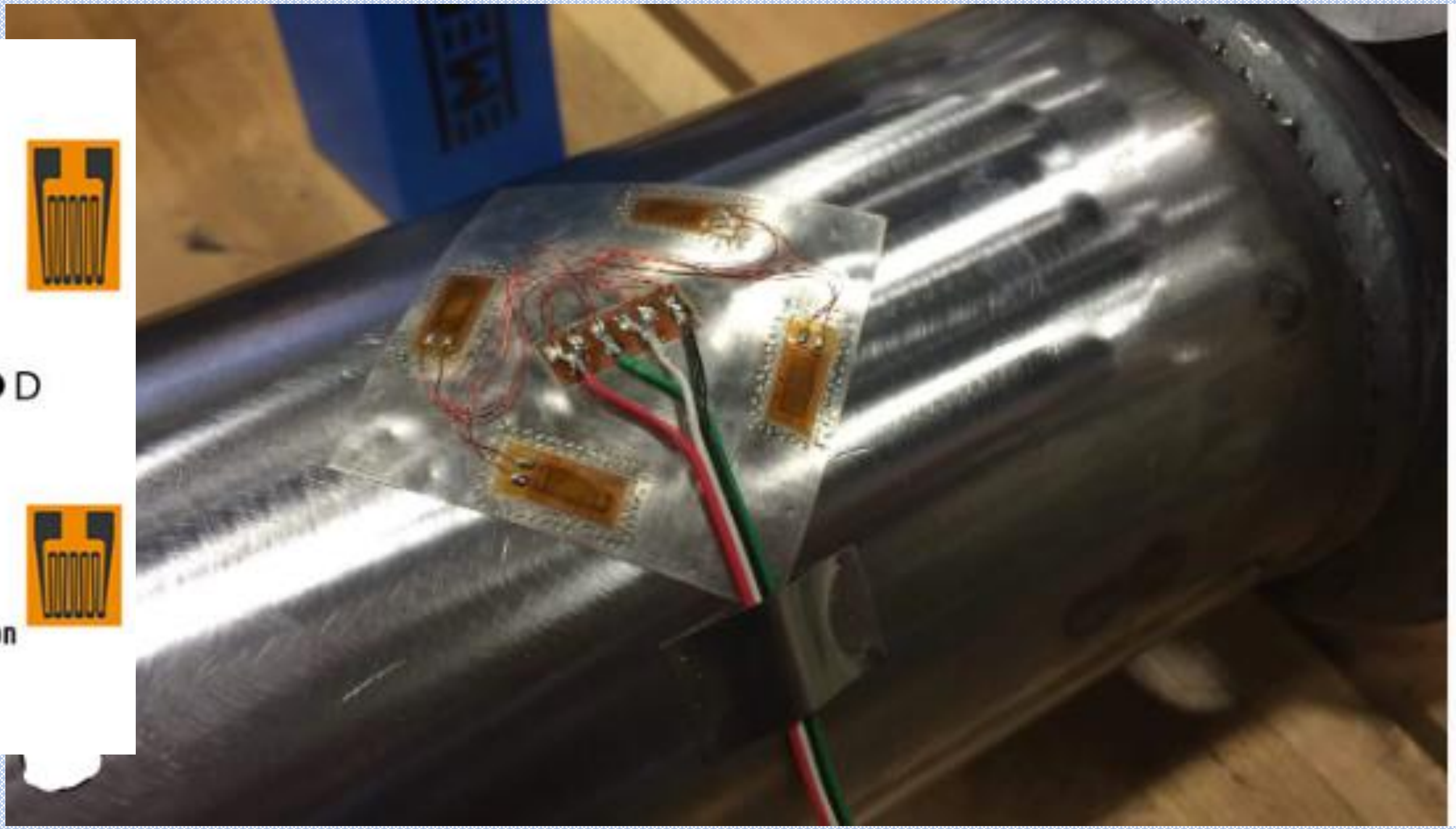
A strain gauge is a thin wire or metal foil, whose electrical resistance changes with change in its length. When dimensional changes in an object are to be found, a strain gauge is firmly GLUED on that object. Due to external forces when the dimensions change, the length of the wire of strain gauge also change with it. It causes change in its electrical resistance. The strain gauge is connected with a balanced WHEATSTONE BRIDGE circuit in which the central wire shows zero current. **Due to change in resistance, the Wheatstone bridge gets disbalanced and current in the central wire starts to flow, which can be read on a voltmeter. This deflection in voltmeter is calibrated directly to read the value of change in dimension of the object, or applied**

Working Principle of Strain Gauge (Quarter bridge)



Working Principle of Strain Gauge (full bridge)



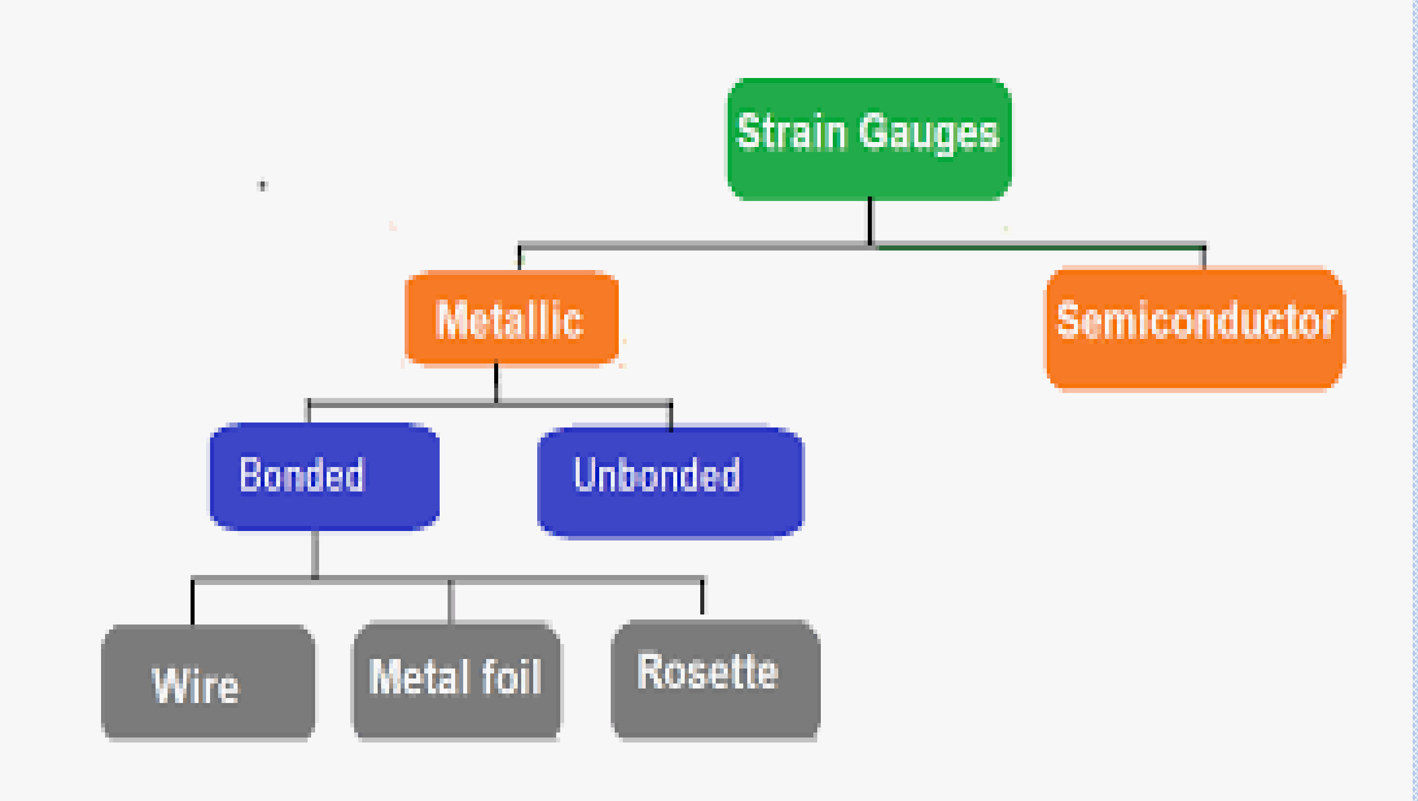


A full bridge strain gauge, <u>all four resistances are replaced by four stain gauge wires</u>. When stressed, the resistance of all four wires change. This results into better sensitiveness and readability of the electrical outputs, as comparative to half bridge or single wire strain gauge.

TYPES OF STRAIN GAUGE

- The type of strain gauge are as

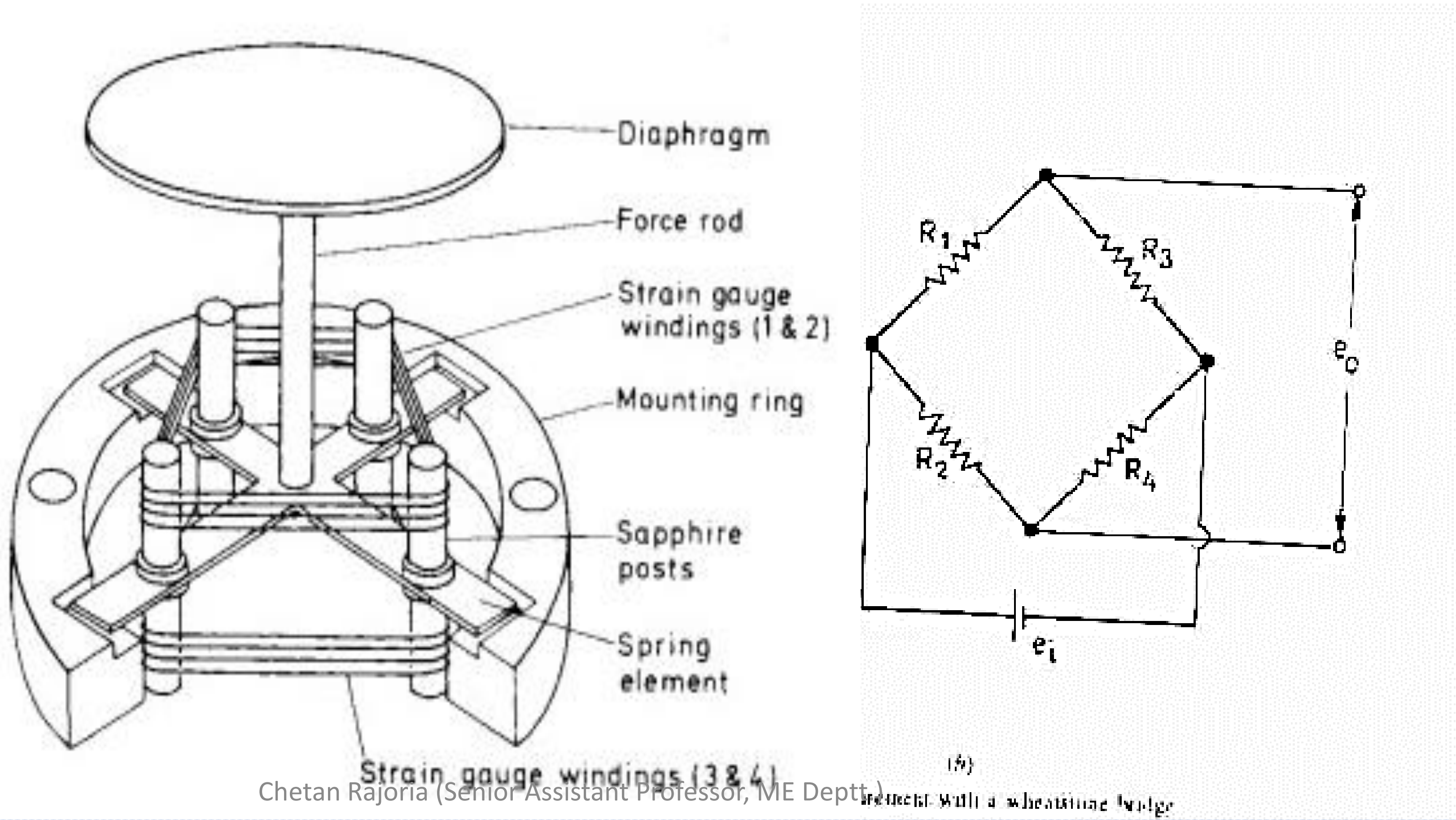
1. Wire gauge
   a) Unbonded
   b) Bonded
      (wire, metal foil and rosette types)
2. Semiconductor gauge

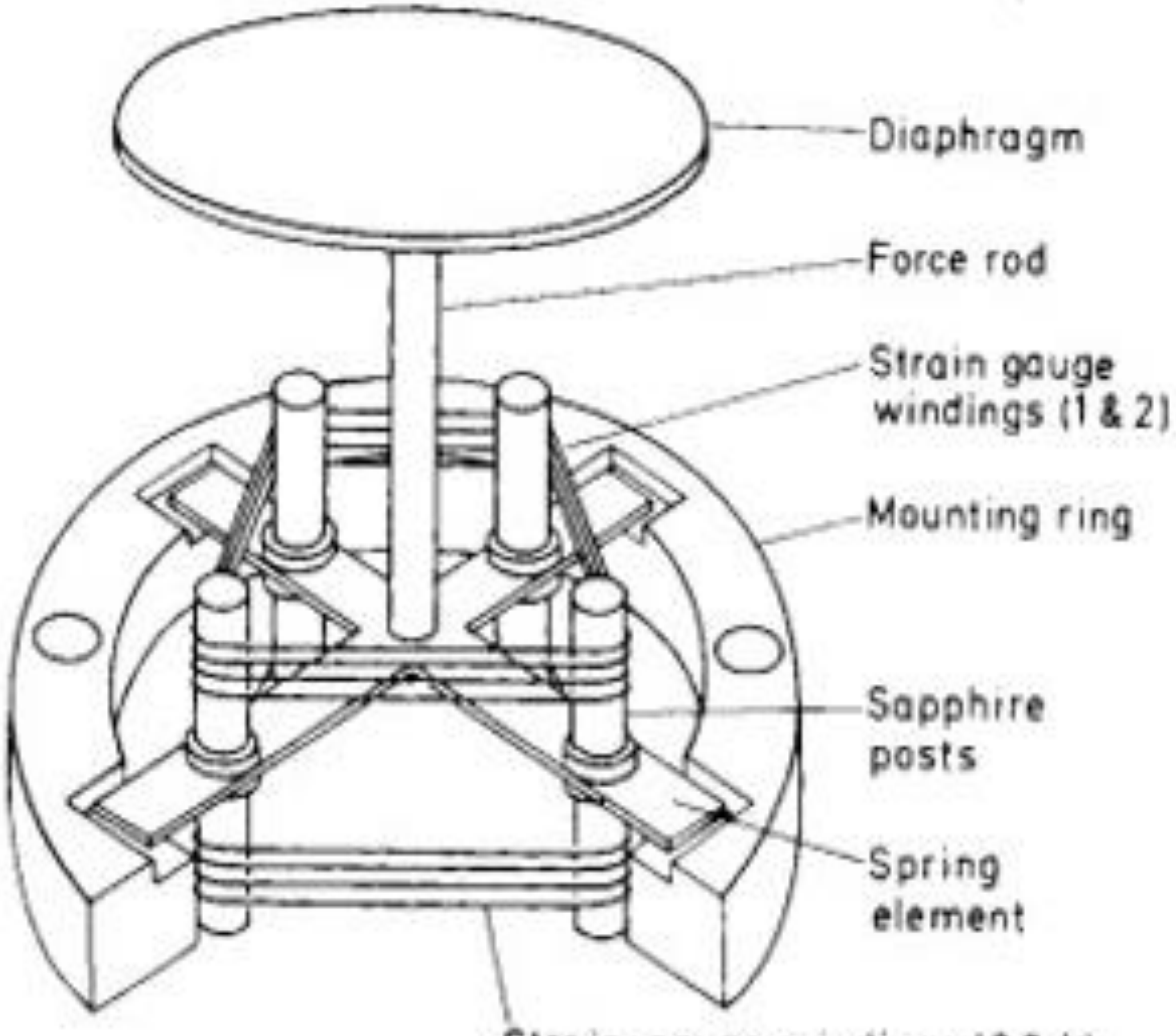


UNBONDED STRAIN GAUGE

- An unbonded meter strain gauge is shown in fig
- This gauge consist of a wire stretched between two point in an insulating medium such as air. The wires may be made of various metals or alloys like copper, nickel, crome-nickel or nickel iron alloys. The wire is not joined or bonded on any base material and it is like a free wire. That is why, it is called as unbonded type strain gauge.
- In fig the element is connected via a rod to diaphragm which is used for sensing the pressure. The wire are pre-tensioned to avoid buckling when they experience the compressive force.
- The unbounded wire gauges are used almost exclusively in transducer application which employ preloaded resistance wires connected in Wheatstone bridge as shown in fig.
- At initial preload the strain and resistance of the four arms are nominally equal with the result the output voltage of the bridge is equal to zero.

- Application of pressure produces a small displacement , the displacement increases a tension in two wire and decreases it in the other two thereby increase the resistance of two wire which are in tension and decreasing the resistance of the remaining two wire .
- This causes an unbalance of the bridge producing an output voltage which is proportional to the input displacement and hence to the applied pressure .

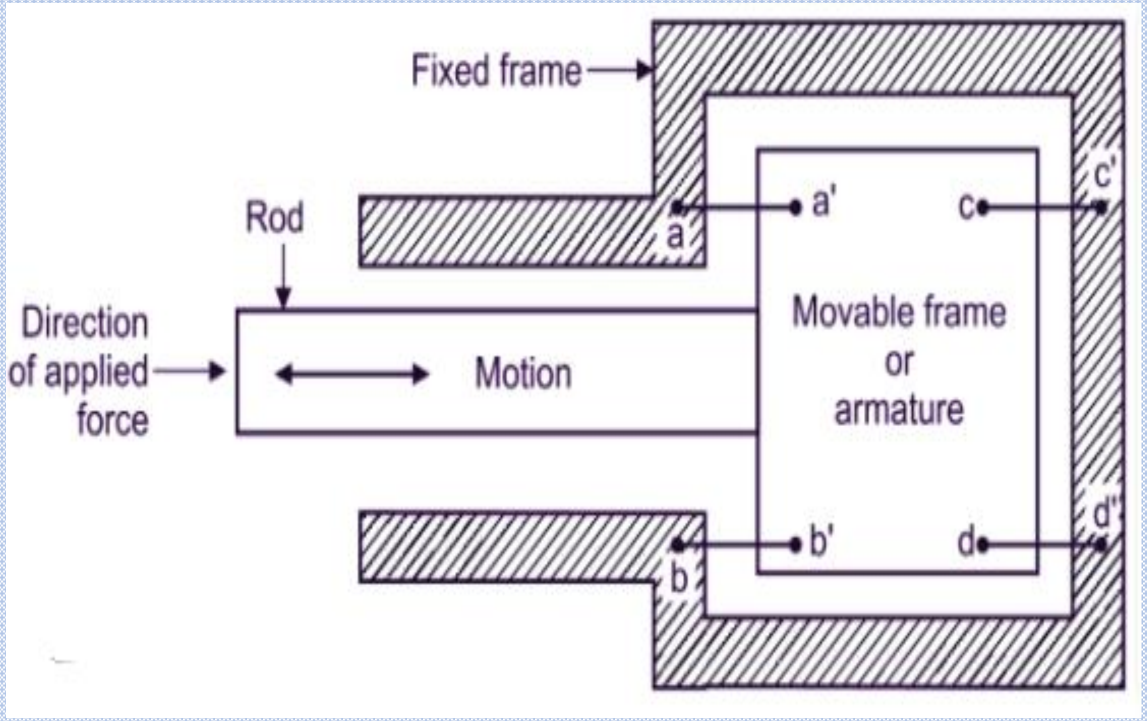



Diaphragm
Force rod
Strain gauge windings (1 & 2)
Mounting ring
Sapphire posts
Spring element
Strain gauge windings (3 & 4)

Unbonded strain gauge

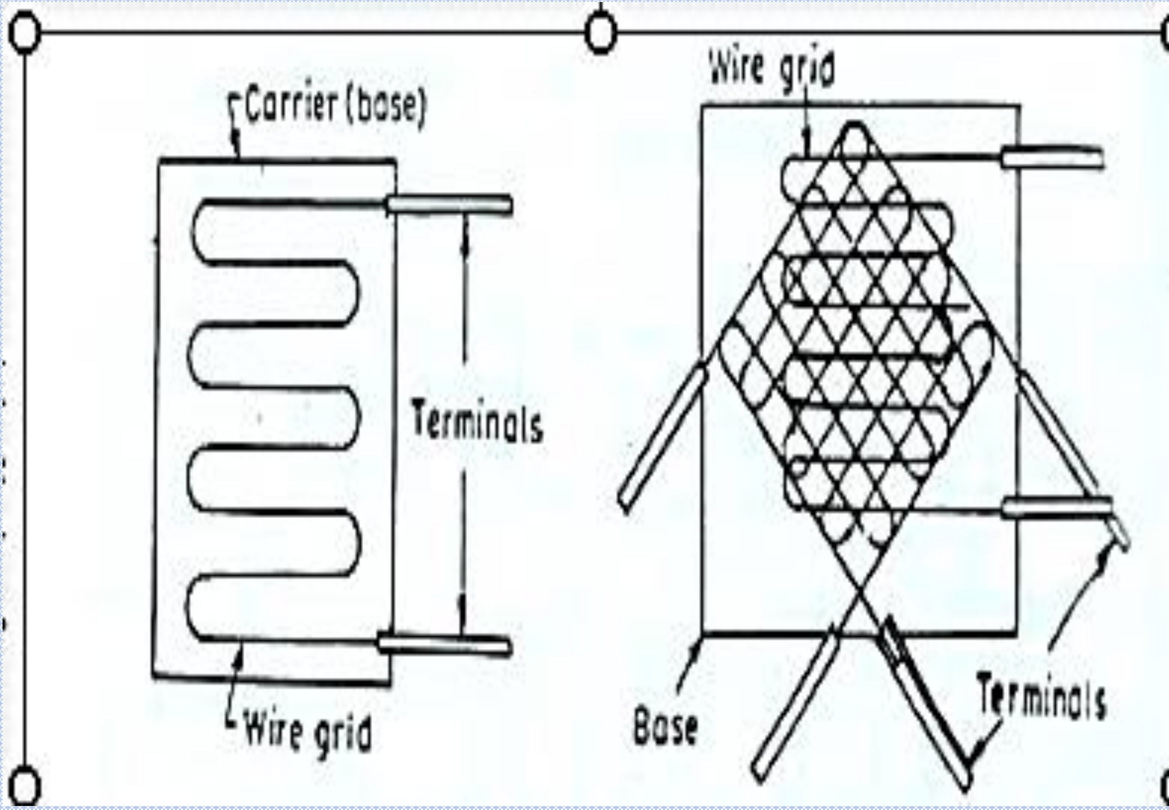
Another design is also popular in ‘unbonded type’ strain gauges. It consists of a fixed frame and a movable frame (or armature). The movable frame is connected to an arm, on which external force is applied. The fixed and the movable frames are connected via four strain gauge wires **aa’, bb’ cc’ and dd’** which **act like four resistances in a balanced Wheatstone bridge**. Two wires are connected on one side (aa’ and bb’ in the figure) and the other two are connected on the other side of the frame (cc’ and dd’ in the figure).

When the force is applied on the arm, it cause increase in tension in two wires and decrease in tension in the other two. This, in-turn, cause increase in resistance of two wires and decrease in resistance of other two, causing disbalance in the Wheatstone bridge. The voltage reading across the diagonals of Wheatstone bridge indicates the strain developed, i.e., amount of force applied externally on the arm.



BONDED STRAIN GAUGE

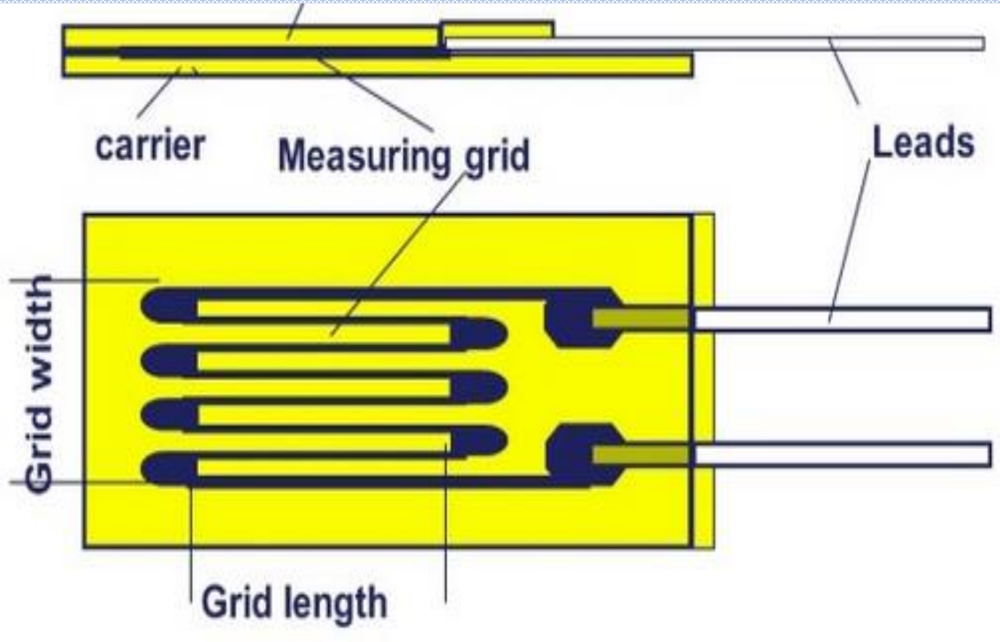
- The bonded metal wire strain gauge are used for both stress analysis and for construction of transducer.
- A resistance wire strain gauge consist of a grid of fine resistance wire. The grid is cemented firmly to a carrier or base which may be a thin sheet of paper Bakelite or Teflon.
- The wire is covered on top with a thin sheet of material so as to prevent it from any mechanical damage or oxidation.
- The carrier is bonded with an adhesive material to the specimen which permit a good transfer of strain from carrier to grid of wires.



- It consist of following parts:

1. **Base (carrier) Materials:** several types of base material are used to support the wires. Paper is used for room temp applications.
2. **Adhesive:** The adhesive acts as bonding materials. Like other bonding operation, successful strain gauge bonding depends upon careful surface preparation and use of the correct bonding agent.

In order that the strain be faithfully transferred on to the strain gauge, the bond has to be formed between the surface to be strained and the plastic backing material on which the gauge is mounted . It is important that the adhesive should be suited to this backing and adhesive material should be quick drying type and also insensitive to moisture.

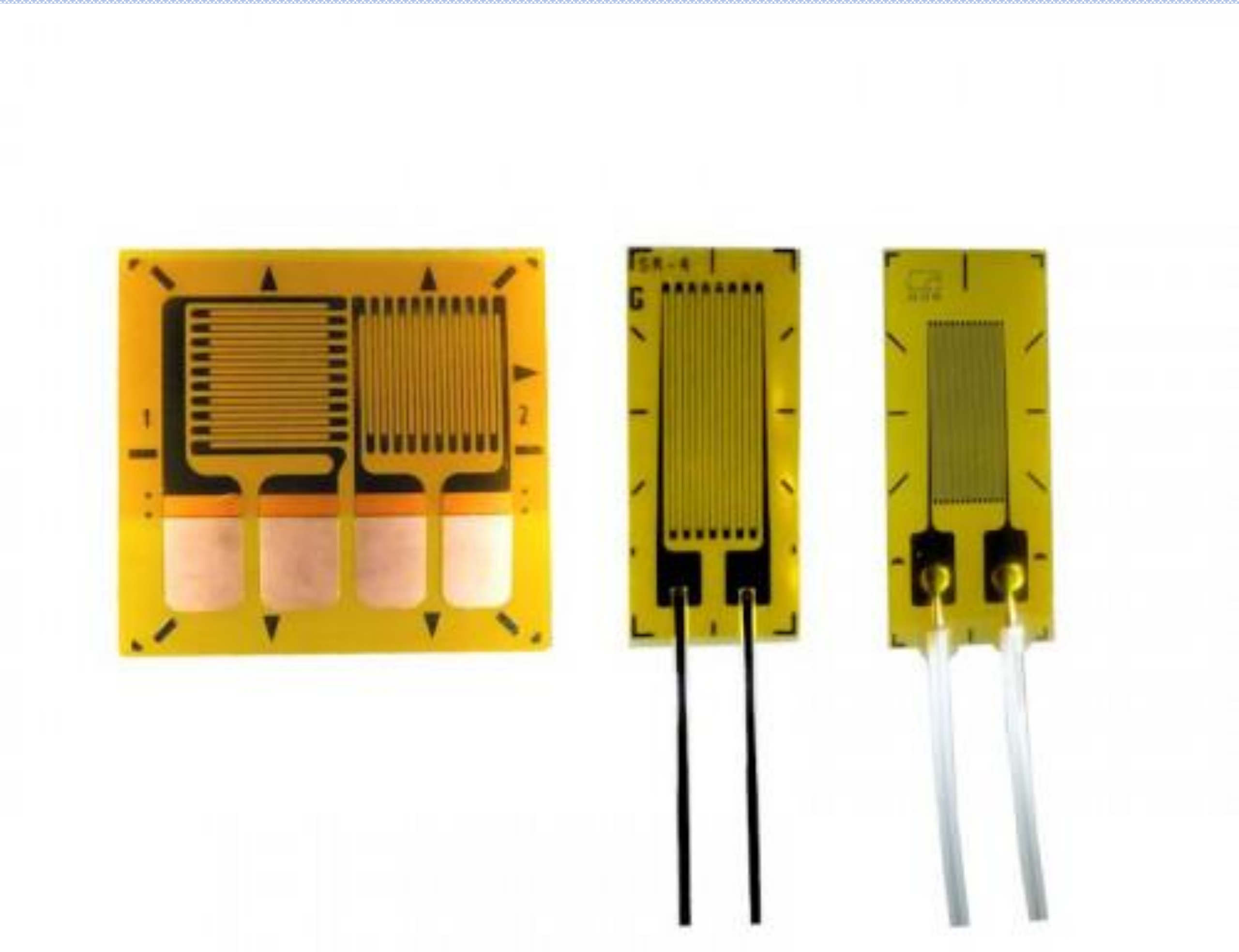


Bonded metal foil gauge.

- **Leads:** The leads should be of such materials which have low and stable resistivity and also a low resistance temperature coefficient This class of strain gauge is only an extension of the bonded metal wire strain gauges.

Metal foil strain gauge

- The bonded metal wire strain gauge have been completely superseded by bonded metal foil strain gauges. Metal foil strain gauge use identical material to wire strain gauge and are used for most general purpose stress analysis application and for many transducers.



Measurement of Force

- We all know that force is defined as the product of mass and acceleration, as per Newton's second law of motion. Force is a vector quantity whose unit of measurement is Newton (N)
- The methods for measuring force can be classified into two basic categories:
    - Direct Methods
    - Indirect Methods
- In case of **direct methods**, a direct comparison is made between an unknown force and the known gravitational force on a standard mass. For this purpose, a beam balance may be employed wherein masses are compared.
- **In indirect method,** comparison is made by a calibrated transducer that senses gravitational attraction or weight. Force is measured indirectly in terms of displacement, or electrical outputs, etc. Sometimes, the deformation due to a force applied on an elastic member is measured.

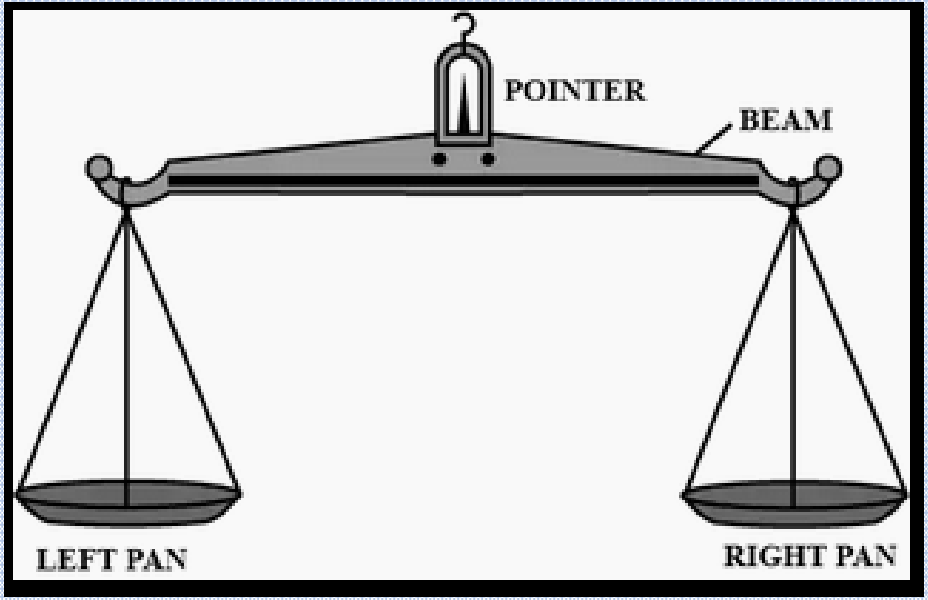
Direct Methods

- Direct methods involve the comparison of an unknown force with a known gravitational force on the standard mass. A force is exerted on a body of mass *m* due to the earth's gravitational field, which can be represented by the following equation:

$$W = mg$$

Here m is the standard mass, g is the acceleration due to gravity, and W is the weight of the body.

- Direct methods are mainly of two types :
  - Equal arm balance
  - Unequal arm balance

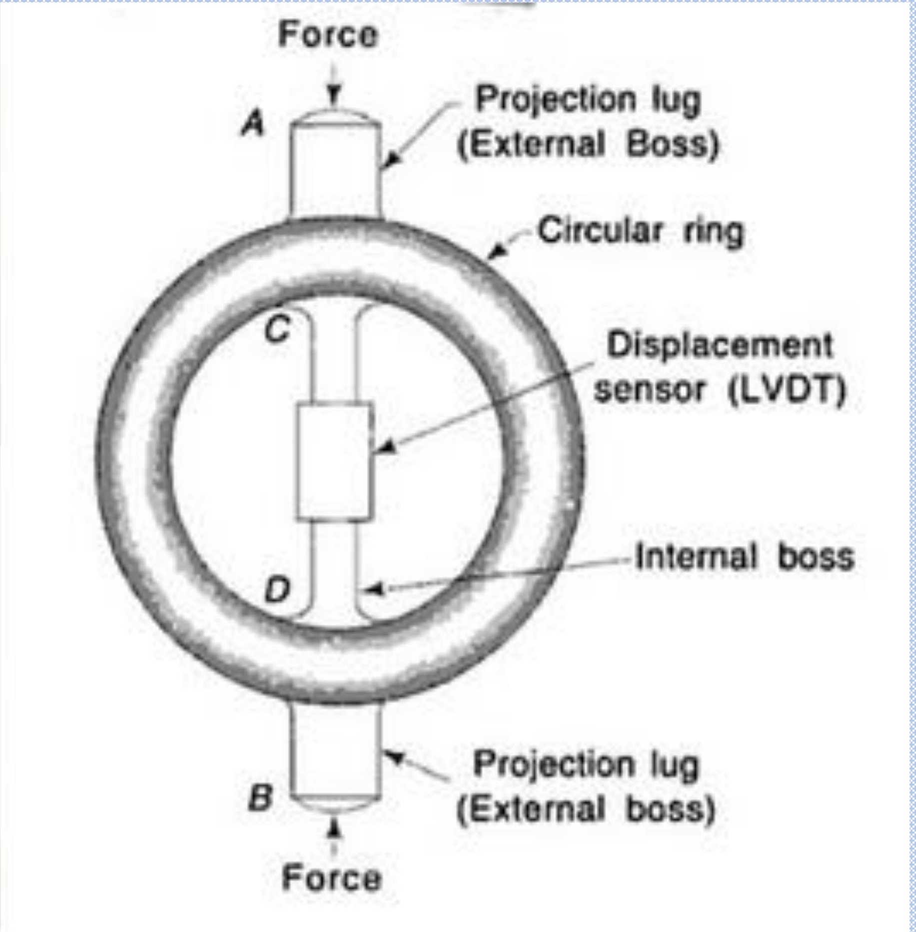


Force Measurement

Strain Gauge Load Cells

- These cells convert weight or force into electrical outputs which are provided by the strain gauges. These outputs can be connected to various measuring instruments for indicating, recording and controlling the weight or force.
- Usually the strain gauges are directly applied to the force developing device and the device is calibrated against strain gauge output.
- The load cells are used in the digital weighing machines these days.

Proving Ring



- A ring used for calibrating tensile testing machines. It works on the principle of LVDT which senses the displacement caused by the force resulting in a proportional voltage.
- It is provided with the projection lugs for loading. An LVDT is attached with the integral internal bosses C and D for sensing the displacement caused by application of force.
- When the forces are applied through the integral external bosses A and B, the diameter of ring changes depending upon the application which is known as ring deflection.

Proving Ring

The resulting deflection of the ring is measured by LVDT which converts the ring deflection or displacement in to voltage signal.

An external amplifier may be connected to provide direct current to drive the indicators or the measured value of force.

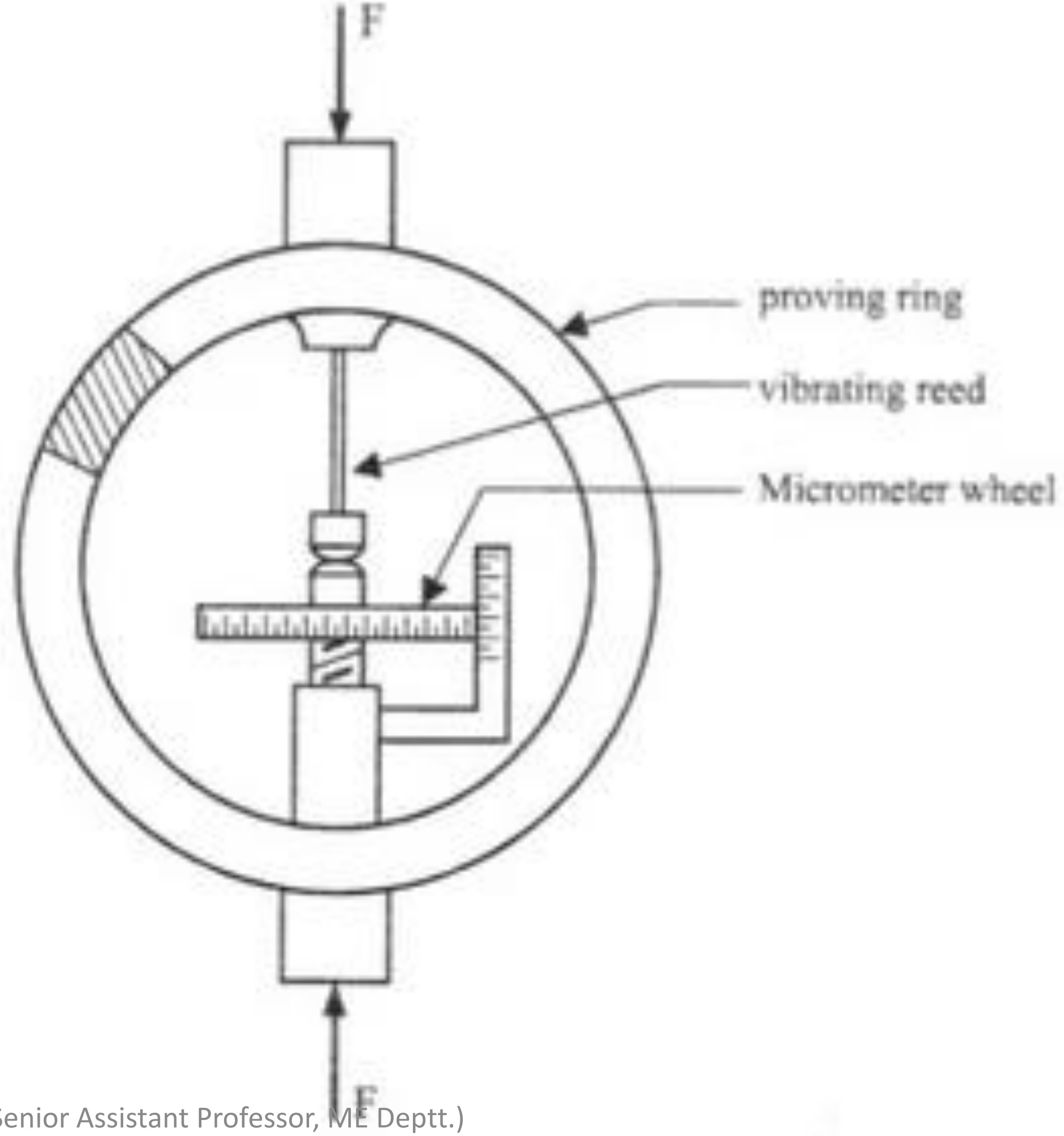
In place of LVDT micrometer can also be provided for accurate measurement of force or deflection, which is given by formula

$$F = \frac{16}{\left(\frac{\pi}{2} - \frac{4}{\pi}\right)} \frac{E.I}{D^3} y$$

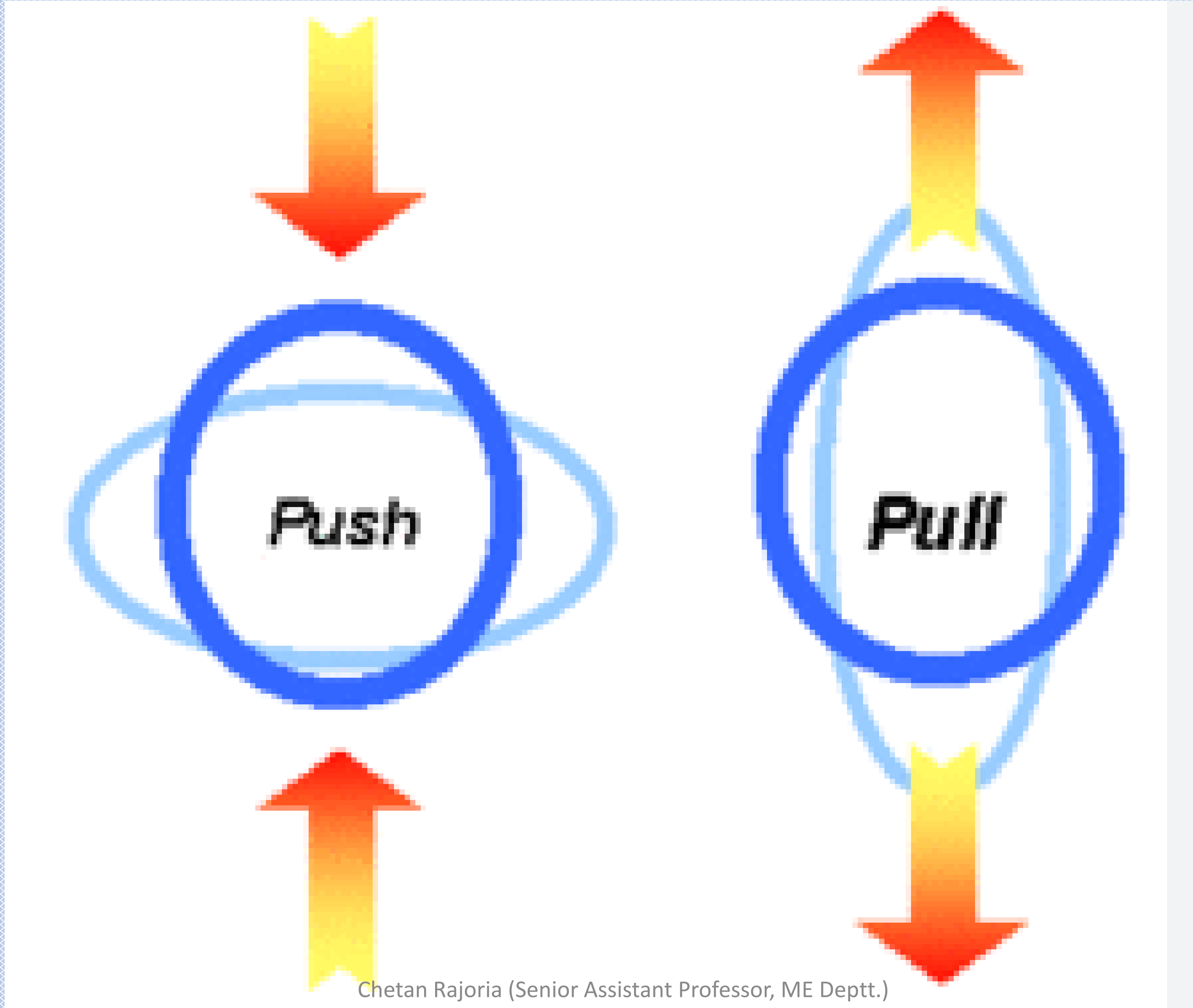
here.

F is the force, E is the young's modulus, I is the moment of inertia about the centroidal axis, D is the outer diameter of the ring and y is the deflection.

Proving Ring



$$F = \frac{16}{\left(\frac{\pi}{2} - \frac{4}{\pi}\right)} \cdot \frac{EI}{D^3} \cdot y$$


Push
Pull

Torque Measurement

- Torque is measured with the help of Dynamometers. A **dynamometer** is a brake, but in addition it has a device to measure the frictional resistance. Knowing the frictional resistance, we may obtain the **Torque** transmitted (T = F x r) and hence the **Power** of the engine (P = T x angular velocity) .

- Hence, *"A dynamometer is a device used to measure frictional torque, for finding the power of the engine."*

Types of Dynamometers

- Following are the two types of dynamometers, used for measuring the brake power of an engine-

1. **Absorption dynamometers (prony brake type, rope brake type)**

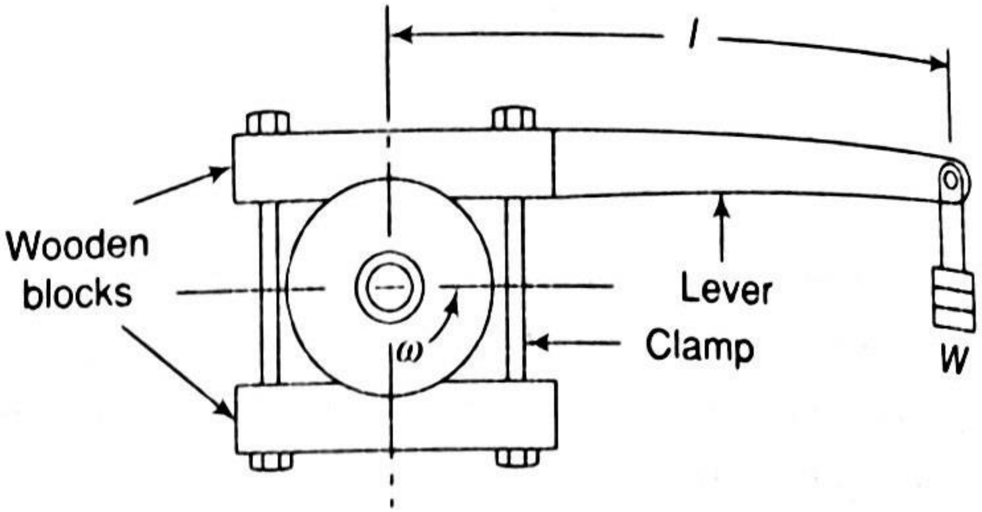
2. **Transmission dynamometers (Bewis-Gibson Torsion dynamometers, belt-transmission type dynamometers)**

Absorption Dynamometers

- In the ***absorption dynamometers,*** *the* entire energy or power produced by the engine is absorbed by the friction resistances of the brake and is transformed into heat, during the process of measurement. e.g. Prony brake dynamometer, Rope brake dynamometer.

PRONY BRAKE DYNAMOMETER

A prony brake dynamometer consists of two wooden blocks clamped together on a revolving pulley carrying a lever . The friction between the blocks and the pulley tends to rotate the blocks in the direction of rotation of the shaft. However, the weight due to suspended mass at the end of the lever prevents this tendency. The grip of the blocks over the pulley is adjusted using the bolts of the clamp until the engine runs at the required speed. The mass added to the scale pan is such that the arm remains horizontal in the equilibrium position; the power of the engine is thus absorbed by the friction.



Frictional torque = $Wl = Mgl$

Power of the machine under test = $T\omega = Mgl\,\dfrac{2\pi N}{60} = MNk$

where k is a constant for a particular brake.

Note that the expression for power is independent of the size of the pulley and the coefficient of friction.

PRONY BRAKE DYNAMOMETER

Advantages:

Simple in construction

Less cost

Suitable for measurement of small power

Disadvantages:

Not suitable for large power

Cooling system required

Shaft is not uniform, dynamometer is subjected to severe oscillations.

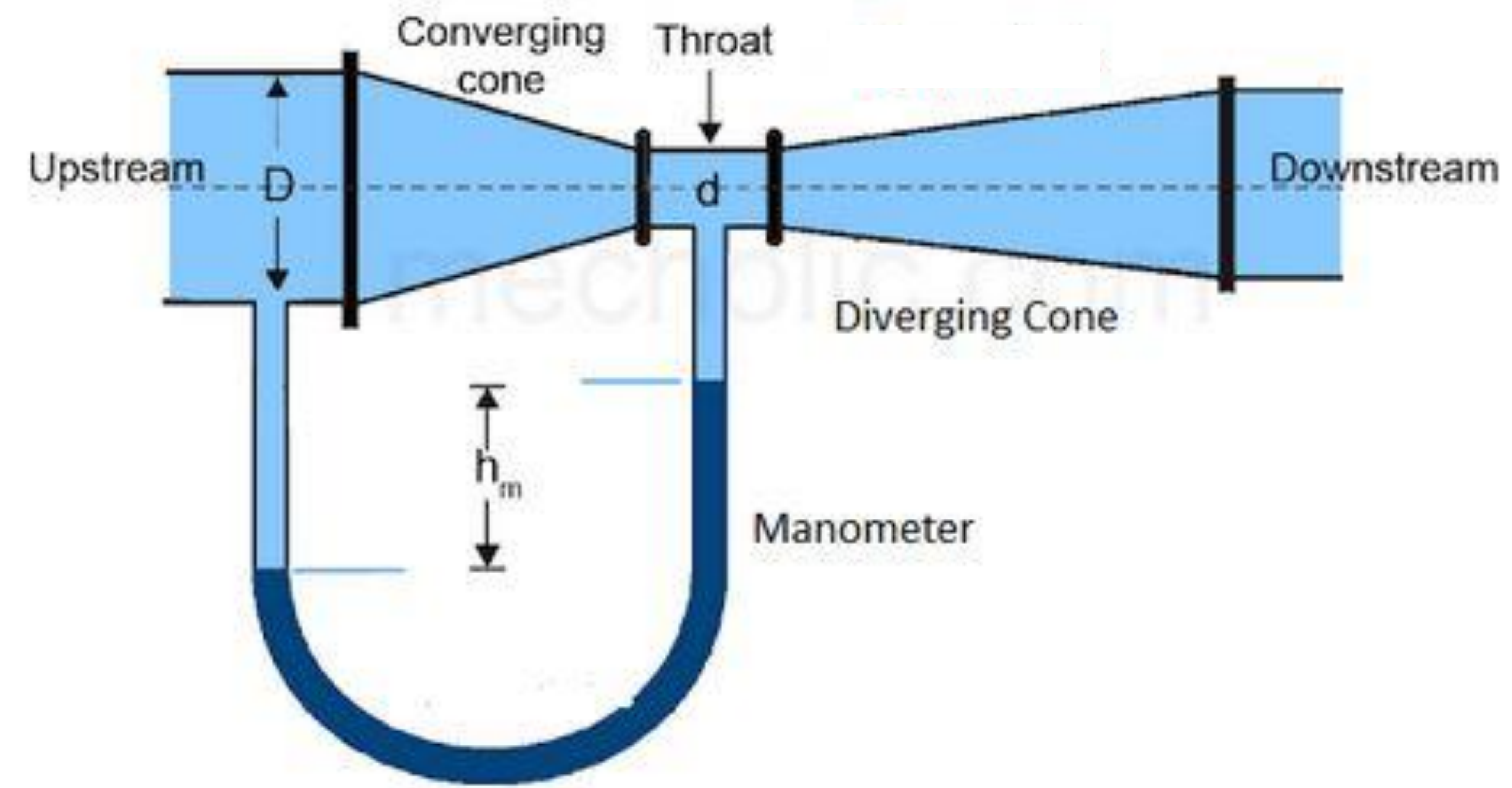
Flow Measurement

Flow measurement refers to the measurement of **discharge Q** (in “Ltrs./sec” or preferably in “m^3/sec”. in a given pipeline or channel. This can be done using various types of devices.

Different types of flow measurement

- Venturimeter
- Orificemeter
- Rotameter,
- Pitot Tube, etc.

Venturimeter



Converging part

It is starting section of venturimeter which attached at inlet pipe. The cross sectional area of this cone starts to decrease and the converging angle is 20 degree. Its length is 2.7(D-d). Here (D) is the diameter of inlet section and (d) is the diameter of throat. Other end of converging is attached with throat.

Throat

Throat is middle portion of venturimeter and its cross sectional area is too small. At this point pressure is decreases and velocity is increases. One end is connected with converging part and other end is attached with diverging part. Diameter of throat is ¼ to ¾ of the diameter of the inlet pipe, but mostly it is ½ of the diameter of the pipe.

Diverging part

Diverging part is last part of venturimeter and its cross sectional area is increases continually. Angle of diverging part is 5 to 15 degree. Its cross sectional area continuously increases. One end is connected to throat and other end is connected to outlet pipe.The main reason behind the low diverging angle is to avoid the formation of eddies because flow separation and eddies formation will results in large amount of loss in energy

Working:-

- Venturimeter is work on Bernoulli's equation and its simple principle is when velocity increases pressure decreases.
- Cross sectional area of throat section is smaller than inlet section due to this the velocity of flow at throat section is higher than velocity at inlet section, this happen according to continuity equation.
- The increases in velocity at the throat result in decreases in pressure at this section , due to this pressure difference is developed between inlet valve and throat of the venturimeter.
- This difference in pressure is measured by manometer by placing this between the inlet section and throat.
- Using pressure difference value we can easily calculate flow rate through the pipe.

Expression for the rate of flow through venturimeter:-

Let d1, p1, v1 & a1, are the diameter at the inlet, pressure at the inlet, velocity at the inlet and area at the cross section 1.

And d2, p2, v2 and a2 are the corresponding values at section 2.

Applying bernoulli's equation at sections 1 and 2

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

As the pipe is horizontal, so z1 = z2

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g}$$

$$\frac{p_1 - p_2}{\rho g} = \frac{v_2^2 - v_1^2}{2g} \qquad \ldots\ldots\ldots\ldots (1)$$

Therefore

(P1 – P2)/ρg is the difference of pressure heads at section 1 and 2 and it is equal to h. so

$$h = \frac{p_1 - p_2}{\rho g}$$

Substituting this value of h in equation (1), we get

$$h = \frac{v_2^2 - v_1^2}{2g} \quad \dots\dots\dots\dots\dots(2)$$

Now applying continuity equation at section 1 and 2

$$a_1 v_1 = a_2 v_2$$

$$v_1 = \frac{a_2 v_2}{a_1}$$

Substituting this value of v1 in equation (2) and solving, we get

$$v_2 = \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

Discharge

$$Q = a_2 v_2$$

Substituting value of v2 in above equation

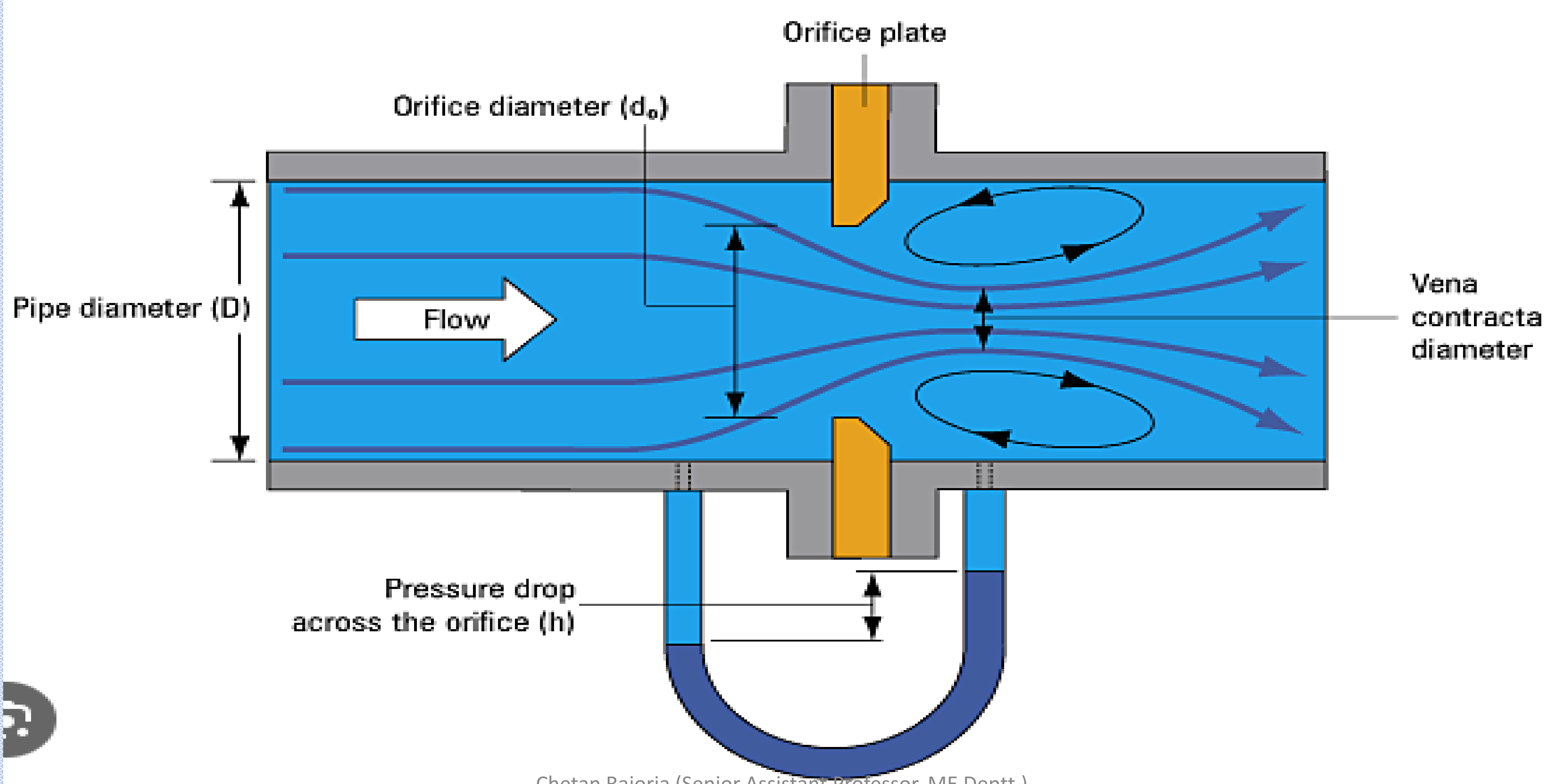
$$Q = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

Q is the theoretical discharge under ideal conditions. Actual discharge will be less than the theoretical discharge. The actual discharge is given by the formula

$$Q_{act} = C_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

Where Cd is the coefficient of venturimeter and its value is less than 1.

Orificemeter



Orificemeter

- **Orifice** : It is an abrupt or sudden hole or opening in a flowing fluid passage (pipeline).
- **Vena Contracta** : When a fluid passes through an orifice in a pipeline, the diameter of this passing stream keeps on decreasing up to a little distance after orifice. Vena contracta is the point in the fluid stream where the diameter of the stream is the least, and the fluid velocity is at its maximum.
- **Working** : By the application of Bernoulli's equation between the location of the orifice and vena contracta, we can find the rate of discharge theoretically. An additional factor for vena contracta is also taken into account. Also, there are converging and diverging streams, in place of converging and diverging nozzles. Rest all principle of working is same as Venturimeter. *(Detailed derivation is given in the PDF notes. Refer that)*

Pressure Measurement

Units: Pa(= N/m^2), psi(= pounds/in^2), bar (=10^5 Pa=100 kPa), mbar (=100 Pa),

Atm (=101.32 kPa), mmHg (or Torr), in Hg, etc. 1 bar = 14.5038 psi, 1psi = 6894.76 Pa

$$P_{abs} = P_{atm} + P_{gauge}$$

Where $P_{absolute}$: Absolute pressure

P_{atm} : Atmospheric pressure

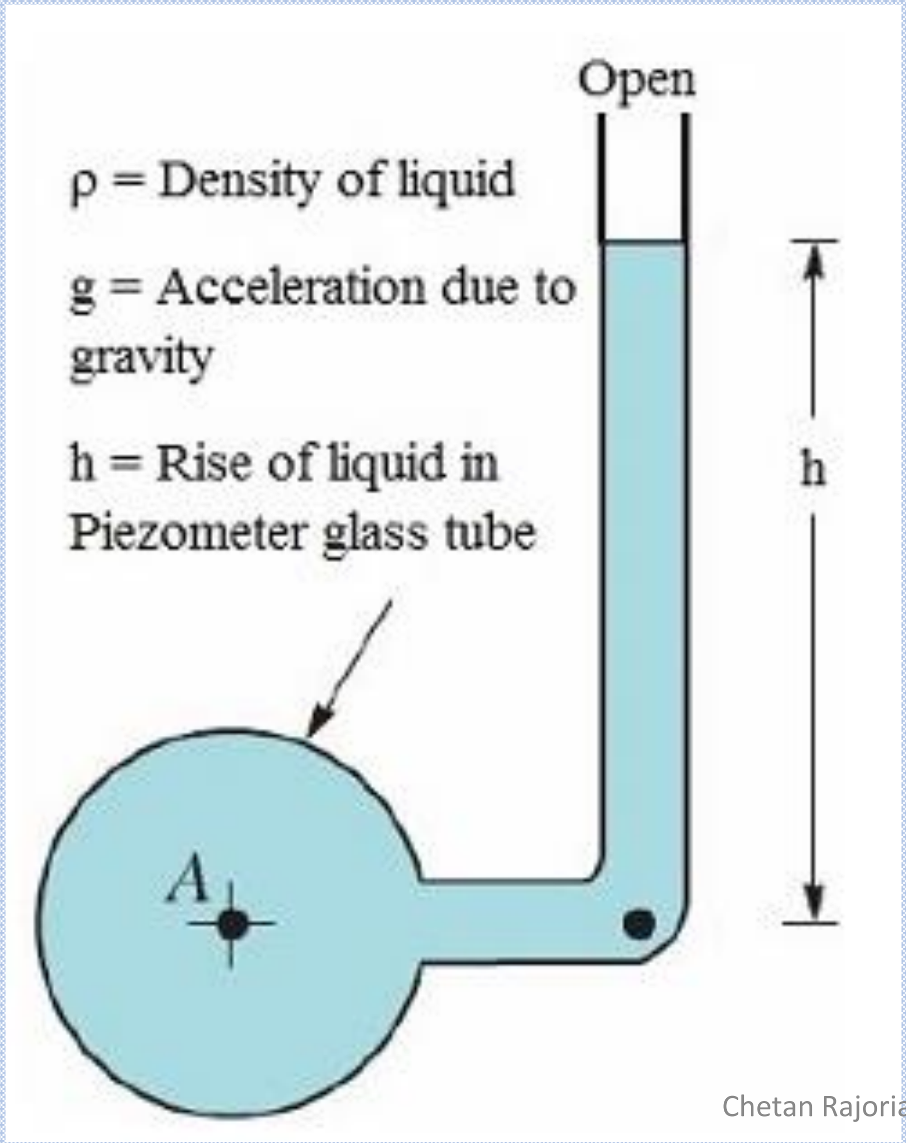
(standard is: 101.3 kPa =14.696 psi=760 mmHg)

P_{gauge} : Gauge pressure

Pressure measuring instruments

- for low pressure
  - Manometers (various types):
    - Piezometer, **U-tube manometer**, Inverted U-tube manometer, inclined tube manometer, well type manometers, inverted well manometer
- For medium and high pressure
  - **Bourdon tube**
  - Diaphragm gauge
  - Bellows
  - Potentiometers
- For measuring vacuum Pressure
  - McLeod gauge, Pirani gauge

Piezometer tube

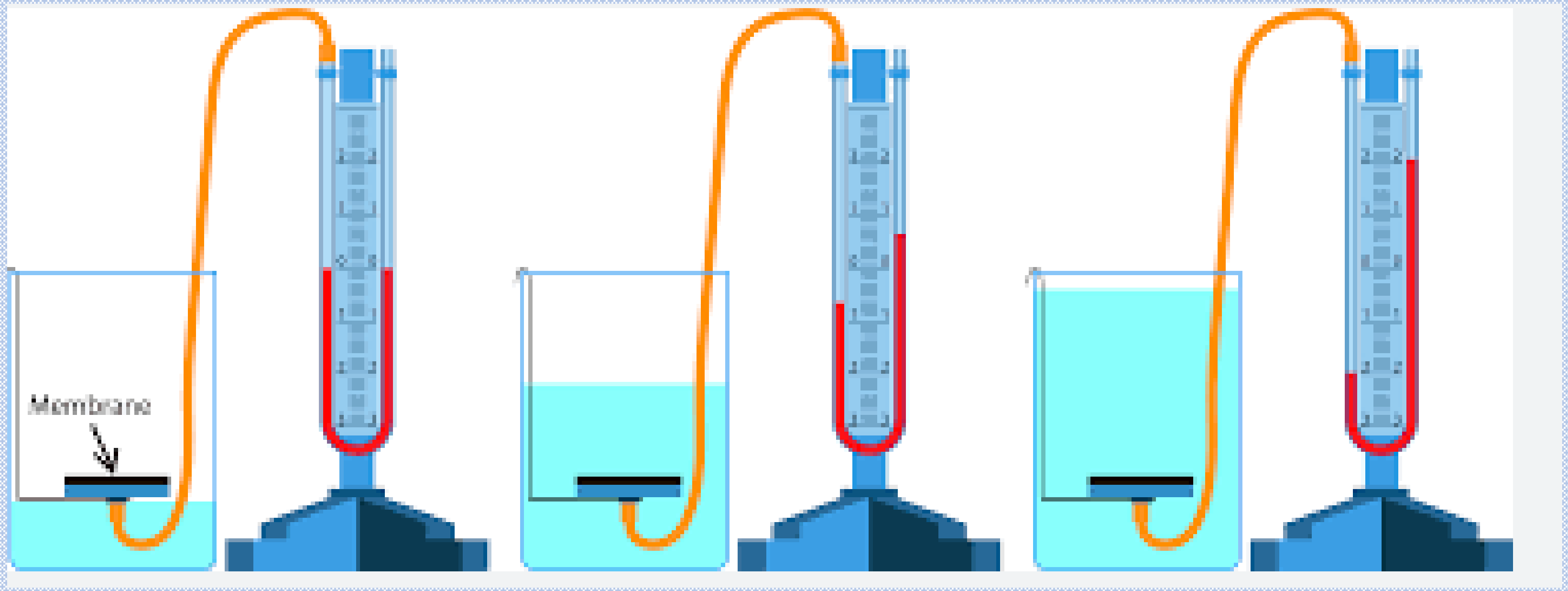


It is an open vertical tube which can be connected directly with the pipeline, in which the pressure is to be measured.

Due to the pressure of liquid in the pipeline, it climbs into the vertical glass tube until the liquid column pressure equals to the pressure inside the pipeline.

The height of the raised liquid column directly indicates the amount of pressure inside pipeline, and can be read directly in terms of pressure using correct calibration.

U tube manometer : Working principle

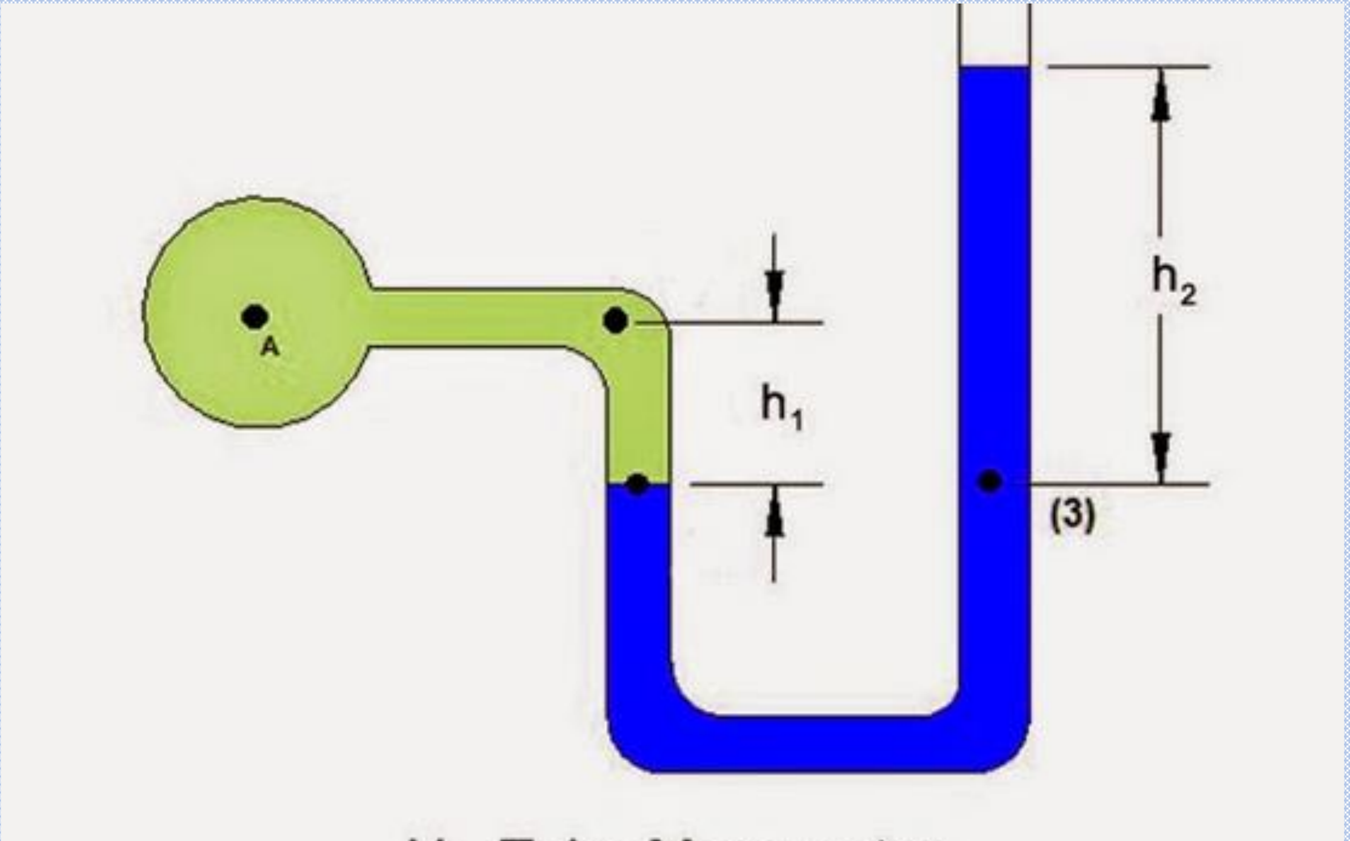


It consists of a U shaped tube, in which a suitable liquid (mostly mercury) is filled. Initially the level of the liquid is same in both the legs of manometer. But when one of the leg is connected with a pressure line (like hydrostatic pressure), it pushes the liquid down in one leg, and consequently raises the level into the other leg. The level-difference can be read directly on a scale attached there, which reflects the amount of gauge pressure in the leg. ($P = h.\rho.g$)

U-Tube Manometer

$P(A) + \rho 1.g.h1 = \rho 2.g.h2$

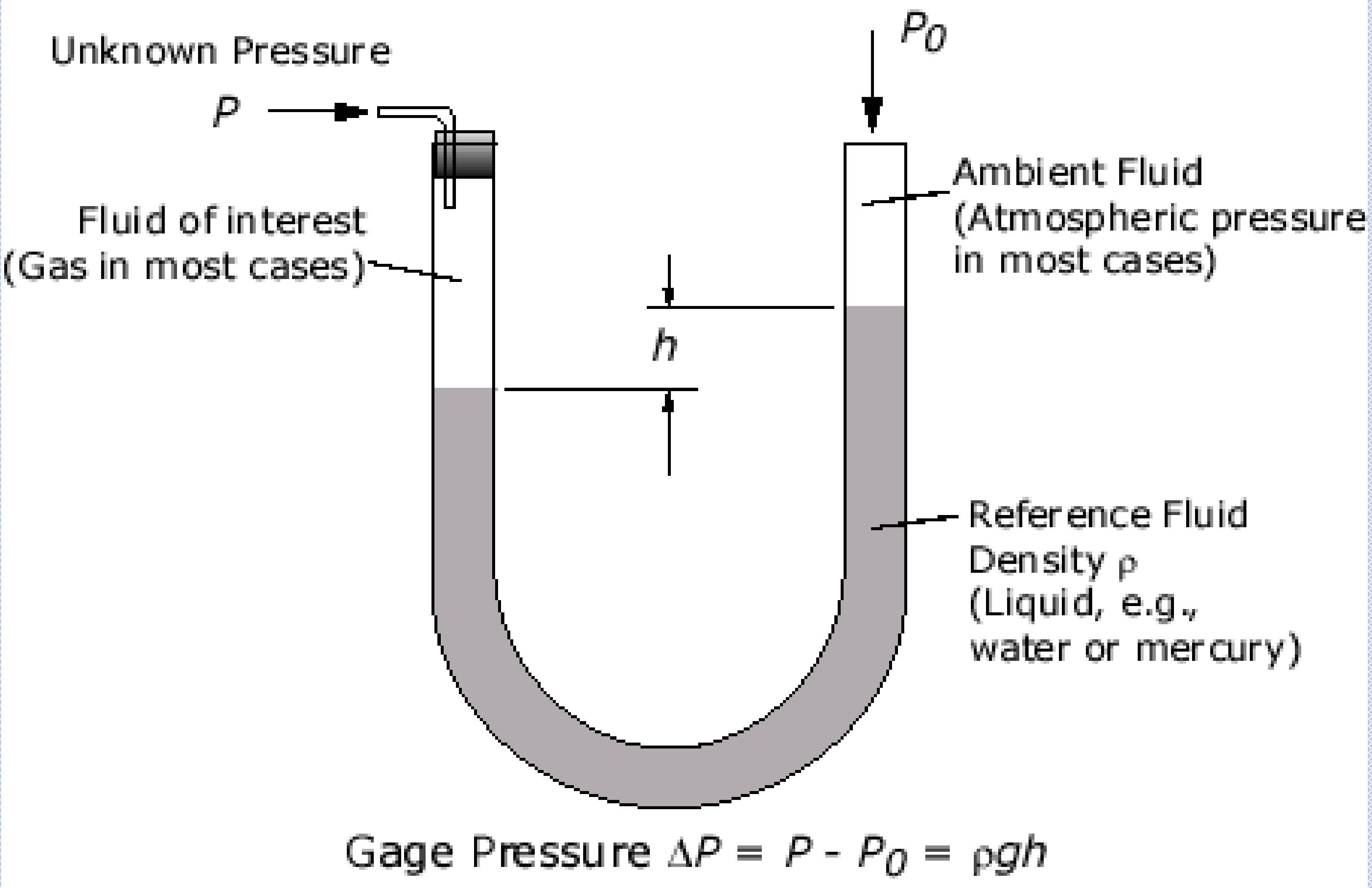
- A U tube manometer can be used for measuring gauge pressures.
- An inverted U tube manometer can be used to measure vacuum pressures.



U - Tube Manometer

Pressure Measuring Devices

U-tube Manometer



Principles: Hydrostatic Law

$$\Delta P = \rho\, g\, h$$

Some of the important and desirable properties of the manometric liquids are:

- High chemical stability
- Low viscosity
- Low capillary constant
- Low coefficient of thermal expansion
- Low volatility
- Low vapour pressure

Bourdon Tube Pressure Gauge

It consists of a elastic hollow tube. When pressure is to be measured, this tube is connected with the pressure line. Due to fluid pressure, the tube elastically deforms, i.e., its shape changes. This temporary elastic deformation is transformed into the movement of certain dial pointer which can show the amount of pressure by direct calibration.

The shape of elastic tube can be C-type, helical (spring shaped) type or spiral type. Accordingly, the names are C-type, helical type and spiral type bourdon tubes.

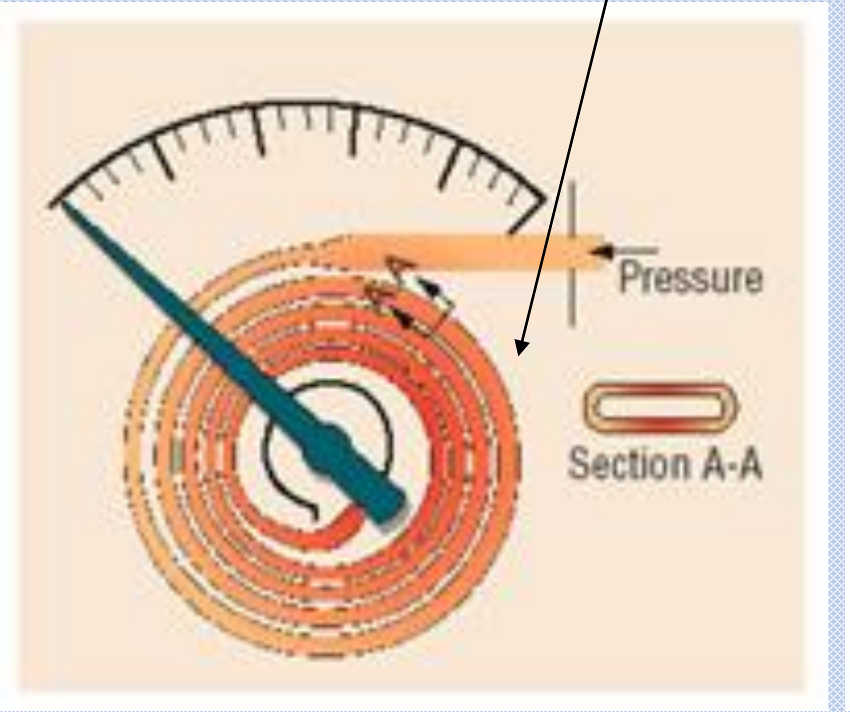
C-Type Bourdon tube :

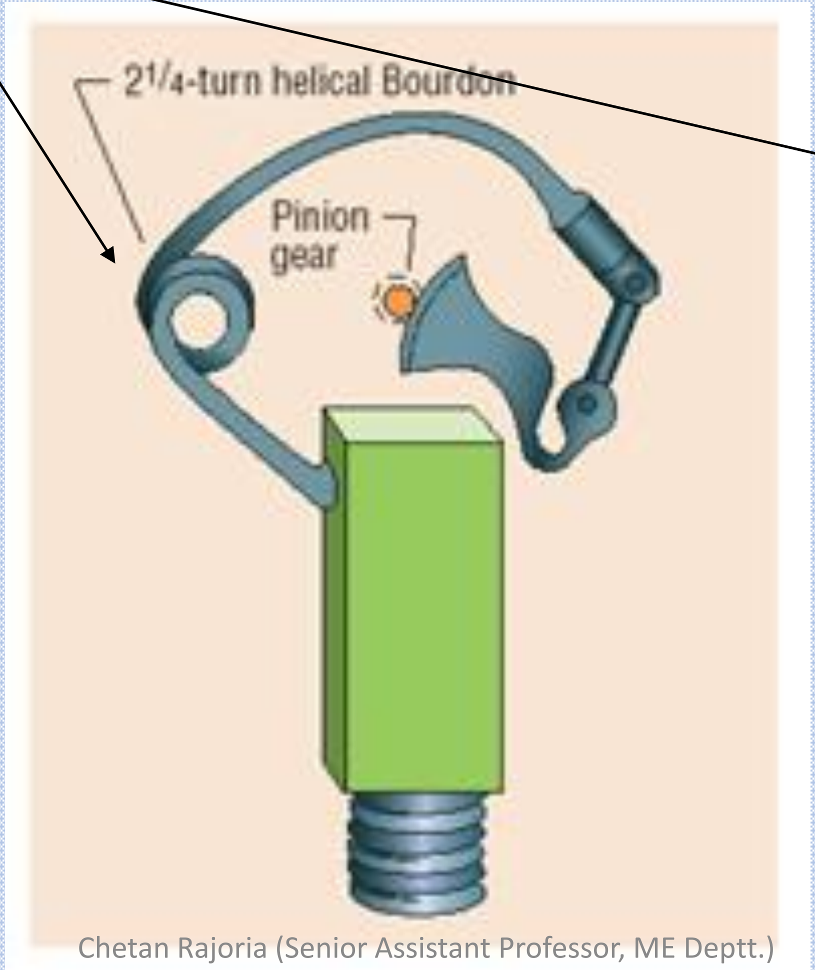
In this, the pressure line is connected with the C-shaped hollow elastic tube. Due to pressure of the fluid, the C-shaped tube expands elastically, which causes the movement of its extreme free end. This free end is connected with a connection linkage, which causes angular displacement in a 'geared sector link', causing rotation of the centrally placed pinion (small gear) and ultimately the pointer. The movement of the pointer can be calibrated to read the amount of pressure inside the tube directly on the scale.

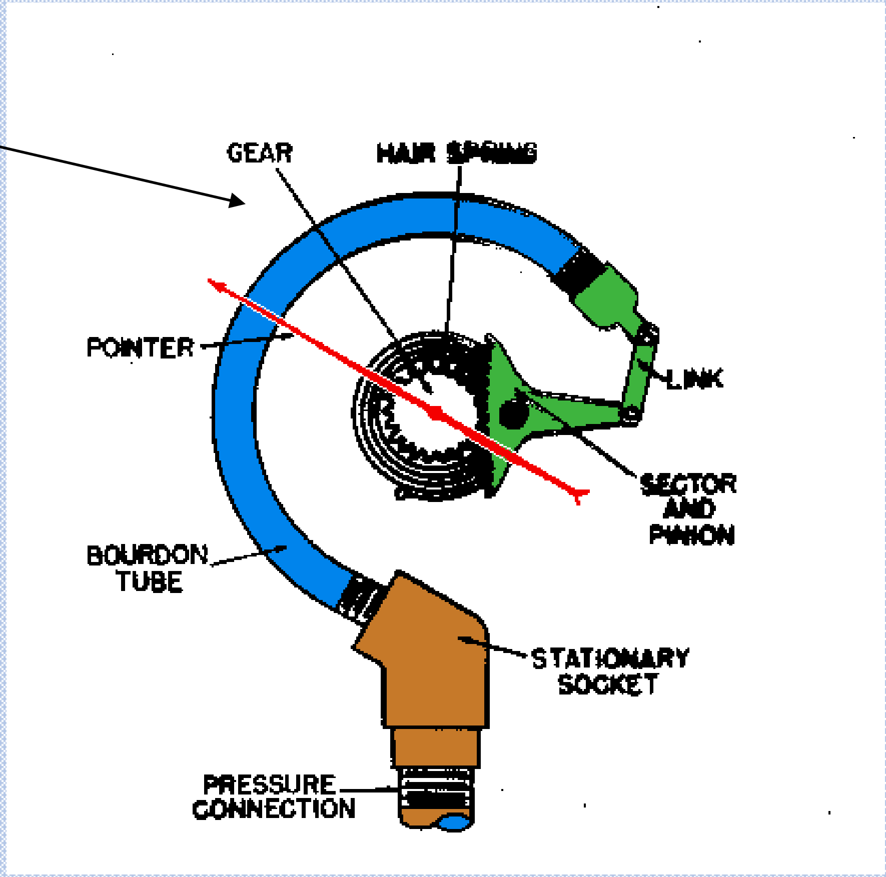
Bourdon Tube Pressure Gauge

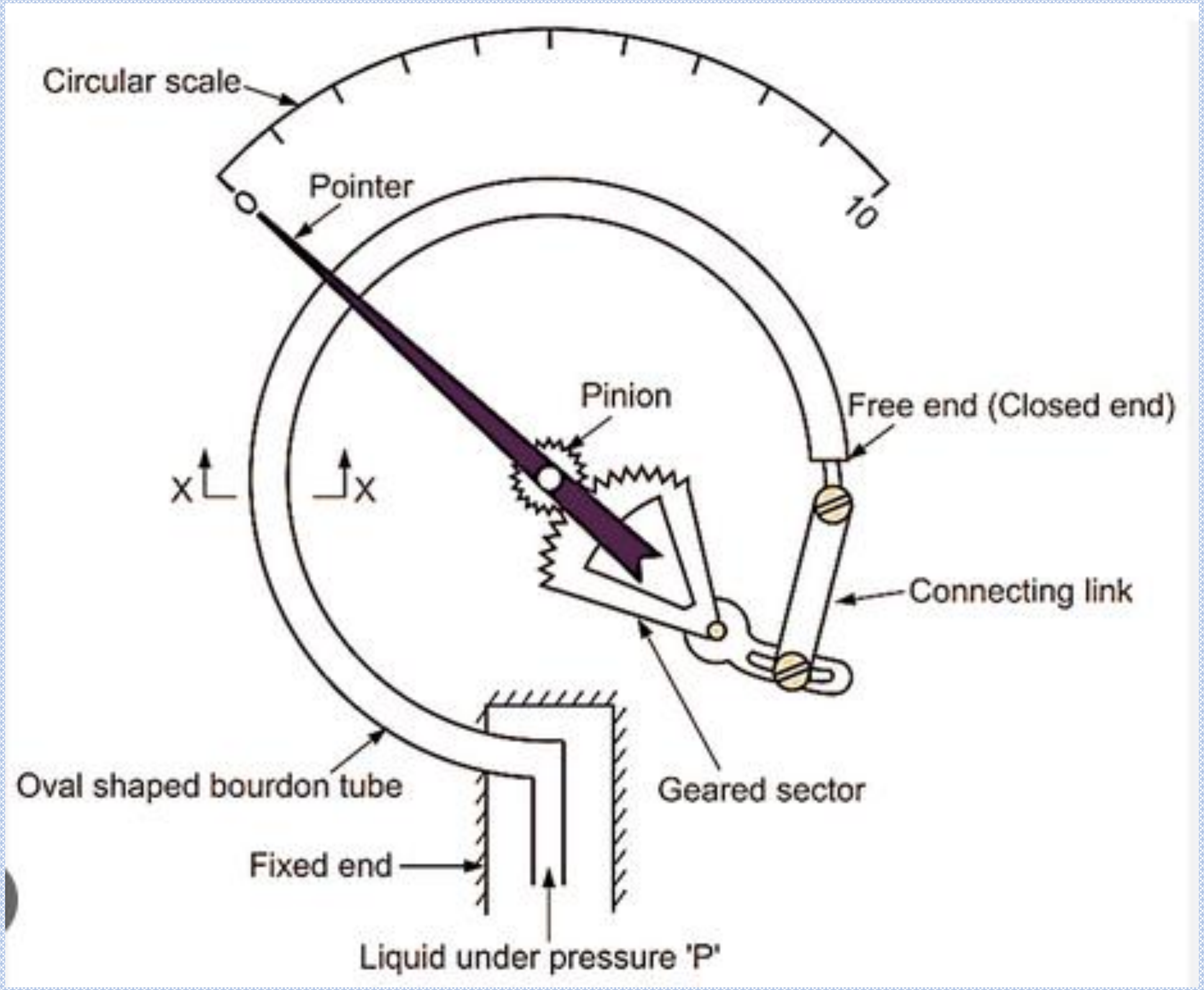
Bourdon tubes are generally are of three types;

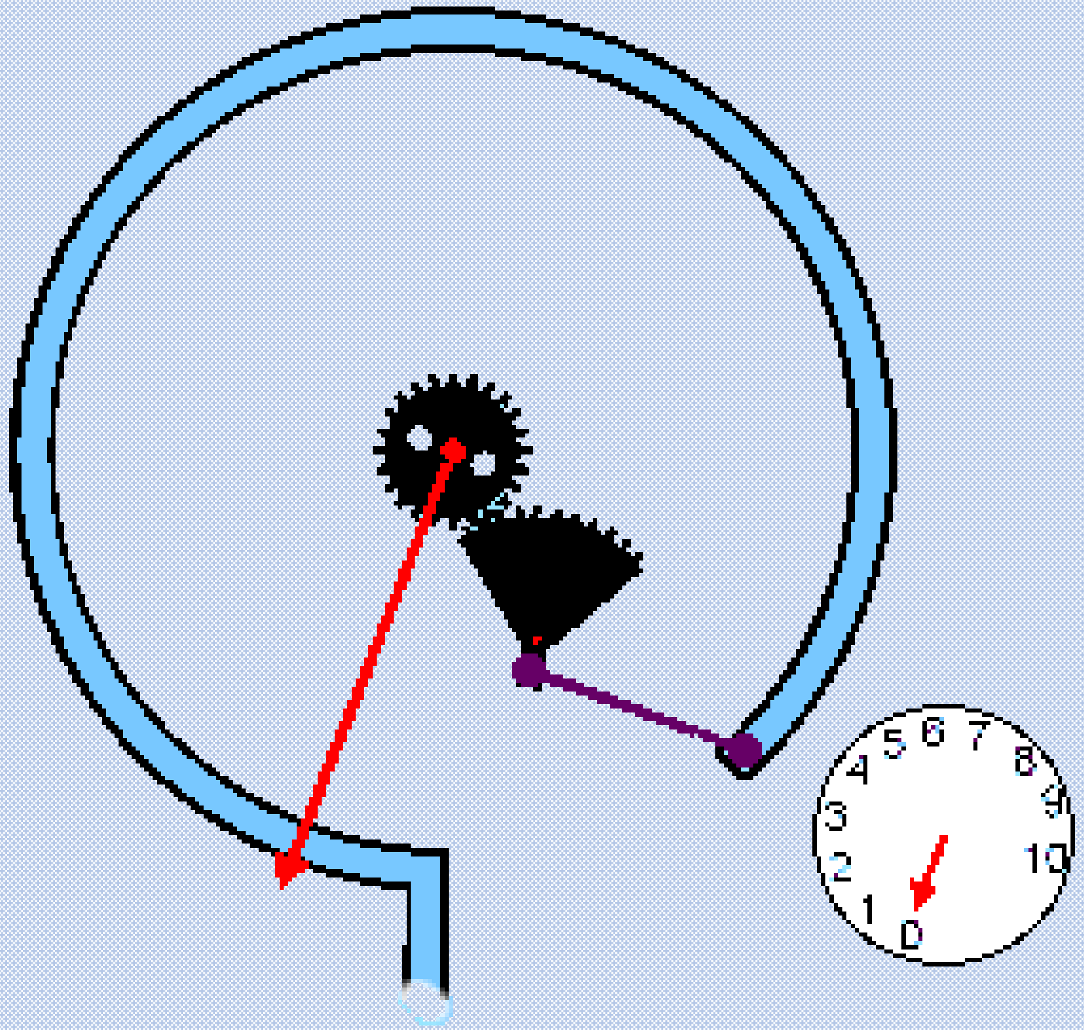
1. C-type
2. Helical type
3. Spiral type








Circular scale
10
Pointer
Pinion
Free end (Closed end)
X
X
Connecting link
Oval shaped bourdon tube
Geared sector
Fixed end
Liquid under pressure 'P'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