1702ME402 – MEASUREMENTS AND METROLOGY

UNIT II
MEASUREMENT OF MECHANICAL PARAMETERS

Lecture by

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Syllabus

UNIT II MEASUREMENT OF MECHANICAL PARAMETERS (6 Hrs)

- **Measurement of Force** - Principle, analytical balance, platform balance, proving ring.
- **Measurement of Torque** - Prony brake, hydraulic dynamometer.
- **Measurement of Power** - Linear and Rotational
- **Pressure Measurement** - Principle, use of elastic members, Bridgeman gauge, Mcleod gauge, Pirani gauge
- **Temperature Measurement** - bimetallic strip, thermocouples, metal resistance thermometer, pyrometers.

MEASUREMENT OF FORCE

Force:

- Force is a physical quantity fundamental to engineering.

- Force represents the **mechanical quantity** which changes or tends to **change the relative motion** or shape of the body on which it acts.

METHODS OF FORCE MEASUREMENT

1. Direct Method: This involves a direct comparison with a known **gravitational force** on a standard mass.

Force = Mass x Gravity

2. Indirect Method: Force is calculated from **acceleration** due to gravity and the mass of the component.

Force = Mass x Acceleration

DEVICES USED TO MEASURE FORCE

I. DIRECT FORCE MEASUREMENT

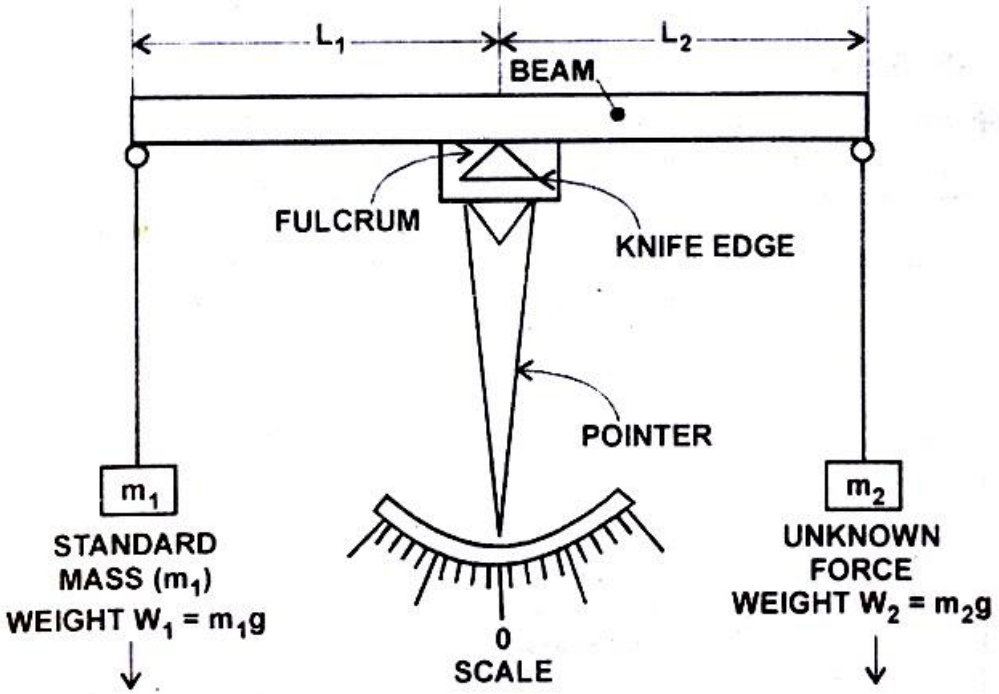
- **(a) Equal Arm Balance**
- **(b) Unequal Arm Balance**
- **(c) Pendulum Type**

II. INDIRECT FORCE MEASUREMENT

- ***a. Accelerometers***
- ***b. Load Cells***
  - **i. Strain Gauge Load Cell**
  - **ii. Hydraulic Load Cell**
  - **iii. Pneumatic Load Cell**
- ***c. Elastic Loaded Members***
  - ***Proving ring***

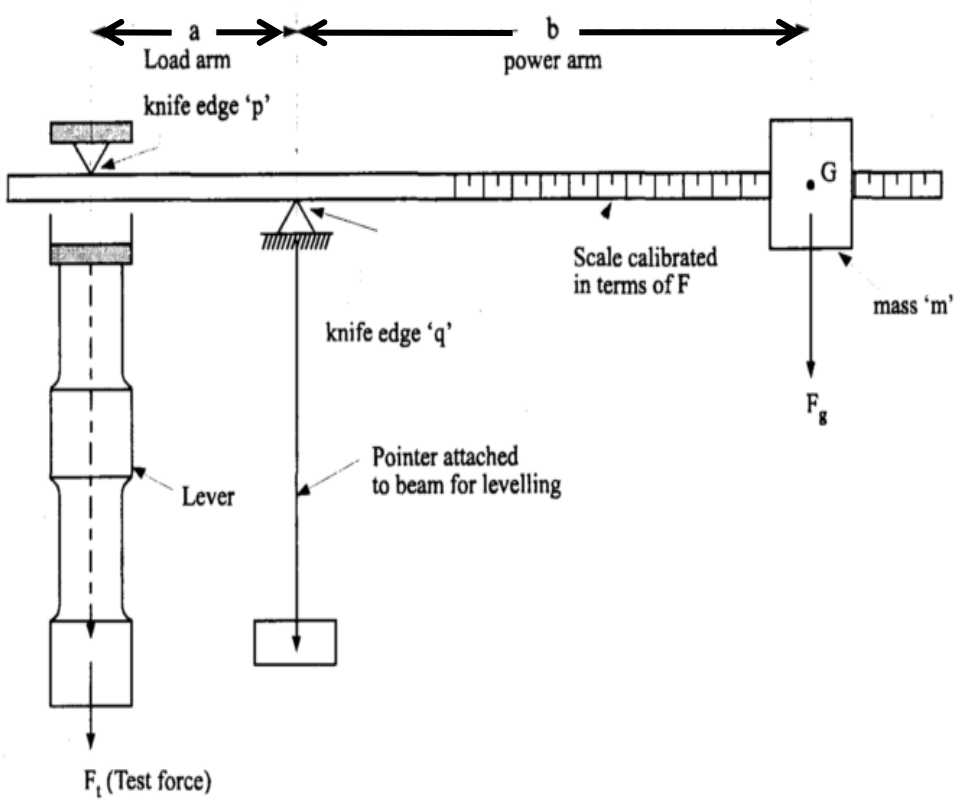
I. DIRECT FORCE MEASUREMENT

(a) Equal Arm Balance



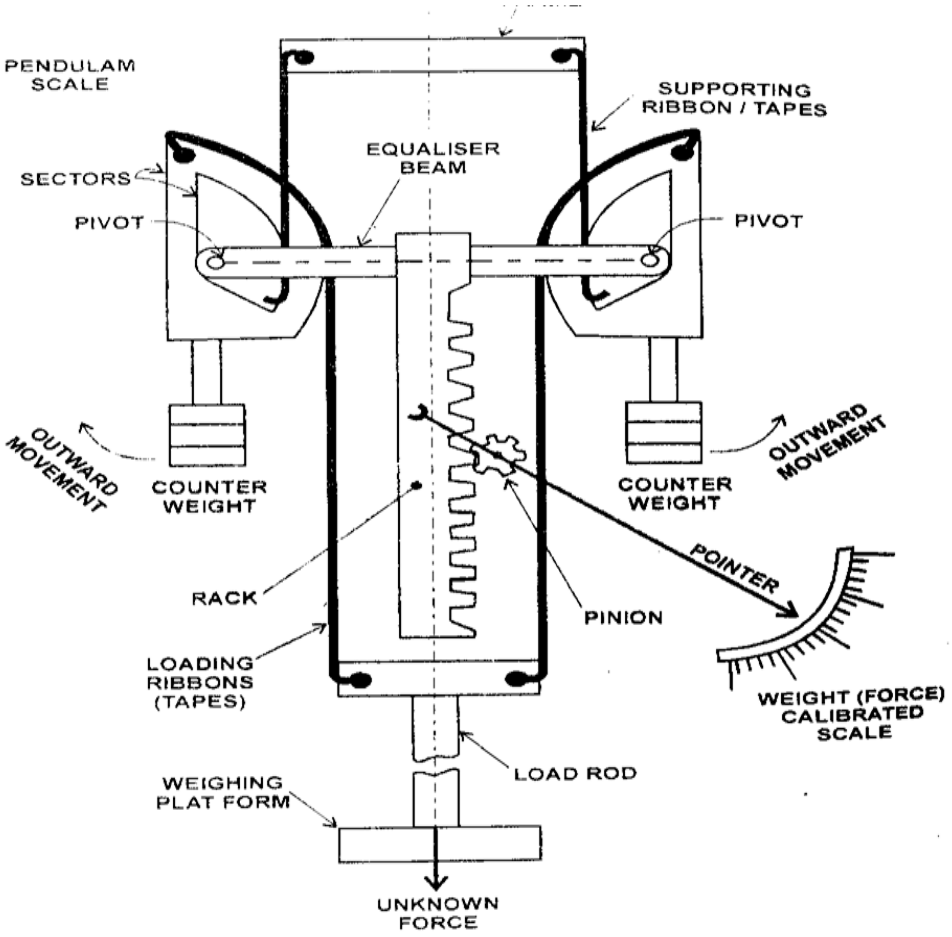
I. DIRECT FORCE MEASUREMENT

(b) Unequal Arm Balance



I. DIRECT FORCE MEASUREMENT

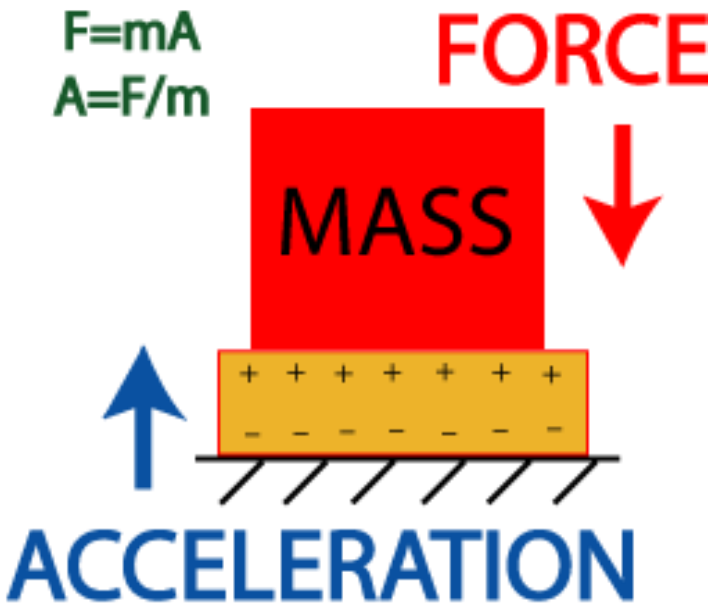
(c) Pendulum Type Balance



II. INDIRECT FORCE MEASUREMENT

a. Accelerometers

A force will make a body to accelerate. By measuring the acceleration, the force may be determined, from the equation **F=ma**. To measure acceleration, accelerometers are used.

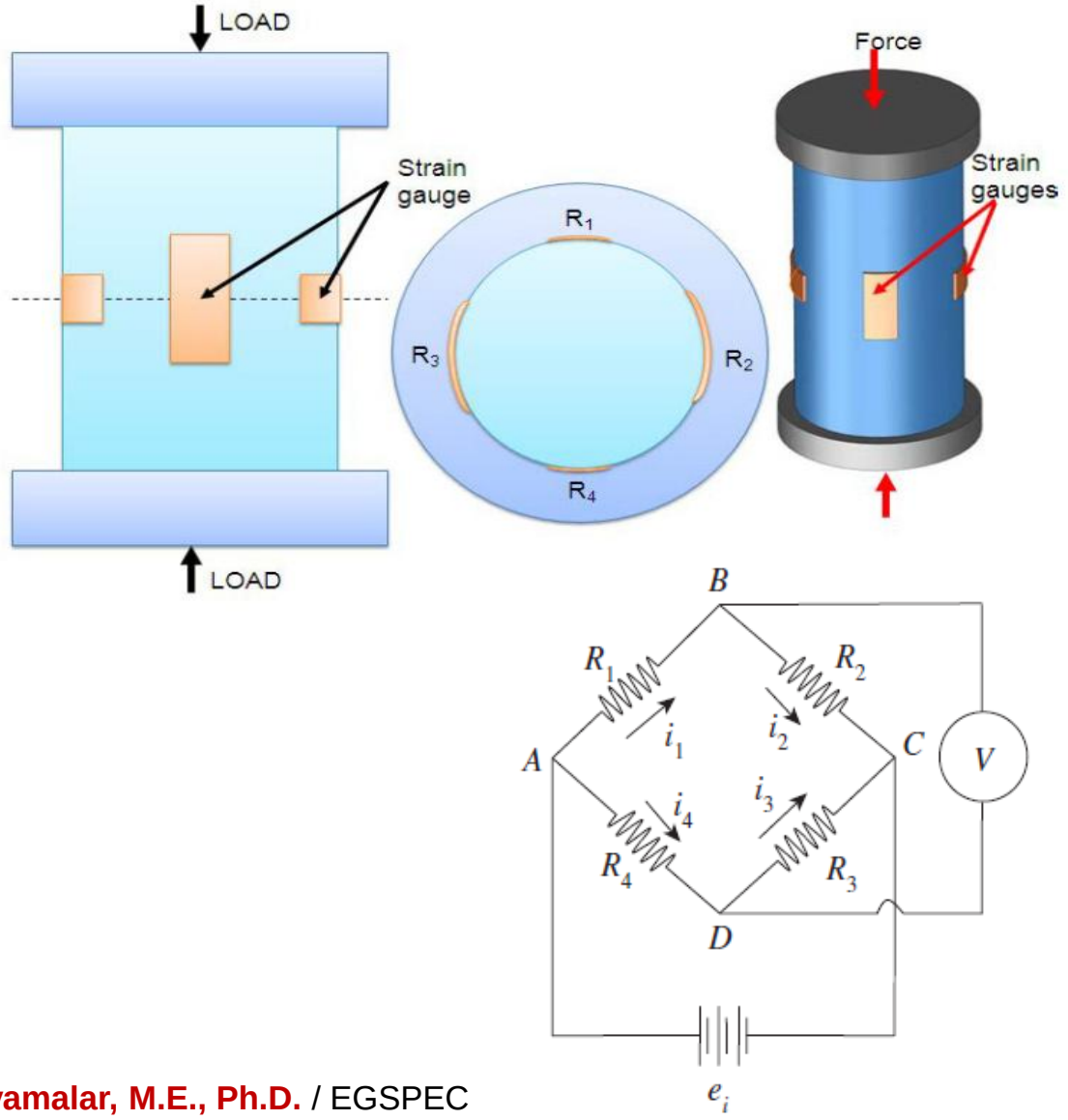


II. INDIRECT FORCE MEASUREMENT

b. Load Cells

i. Strain Gauge Load Cell

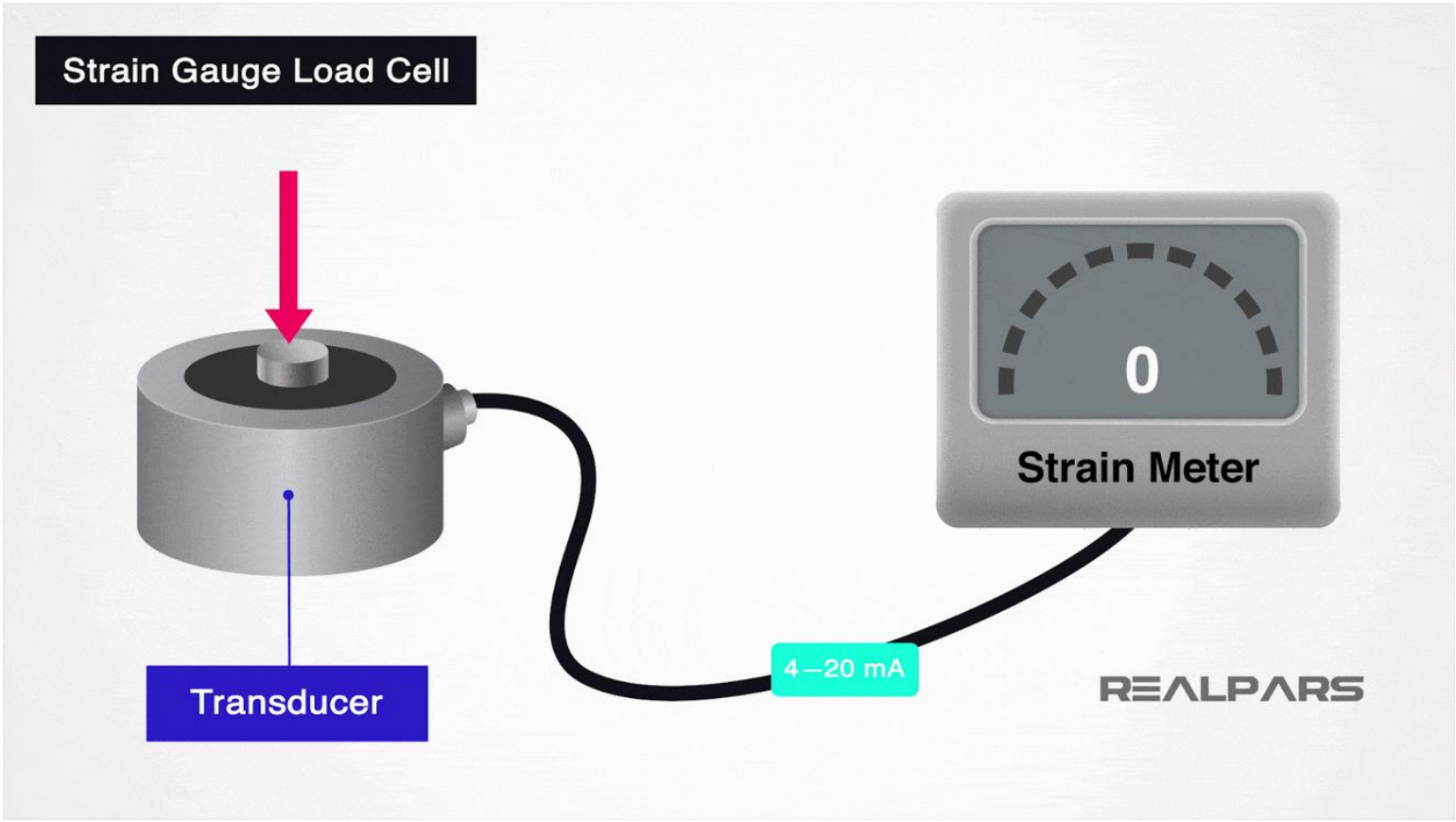
- Load cells are extensively used for measurement of force.
- Strain gauge transducer converts force into electrical signal.
- The strain gauge is bonded to a beam or structural member that deforms when a force is applied.
- Deflection induces a stress that changes its resistance.
- A wheatstone bridge converts the resistance change into a calibrated output signal.
- The sensor's output is a function of force and distance.



II. INDIRECT FORCE MEASUREMENT

b. Load Cells

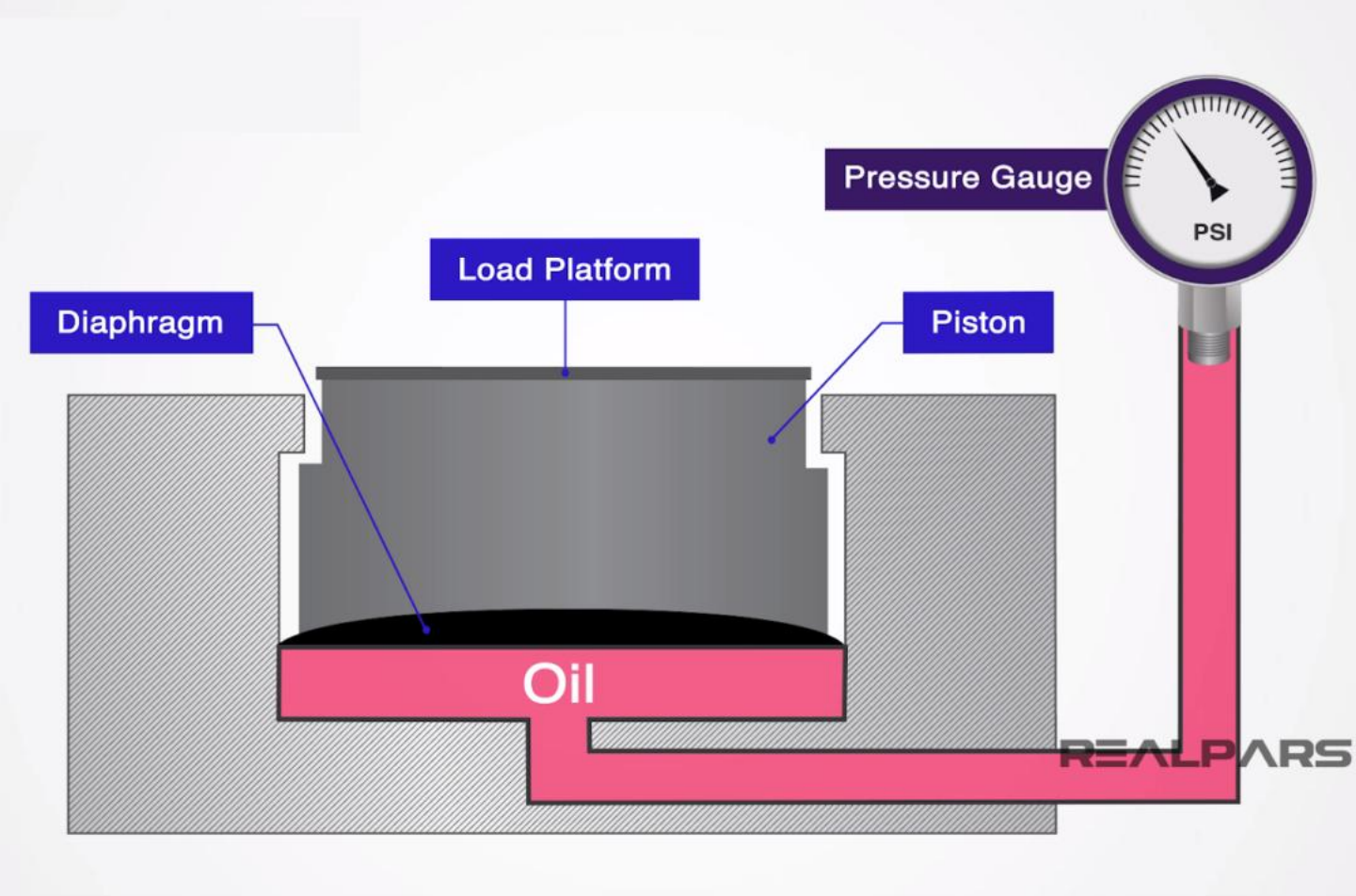
i. Strain Gauge Load Cell



II. INDIRECT FORCE MEASUREMENT

b. Load Cells

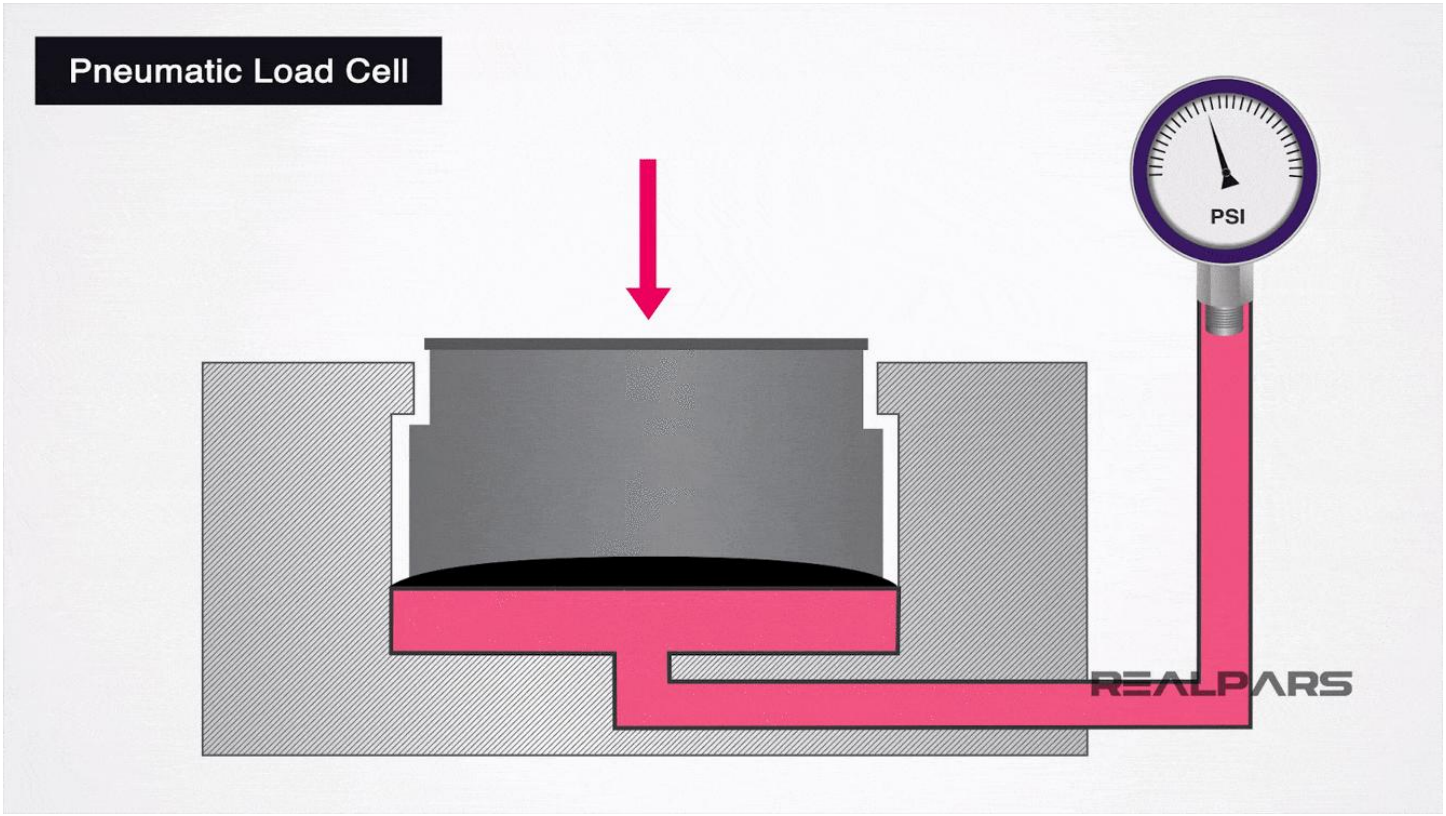
ii. Hydraulic Load Cell



II. INDIRECT FORCE MEASUREMENT

b. Load Cells

iii. Pneumatic Load Cell



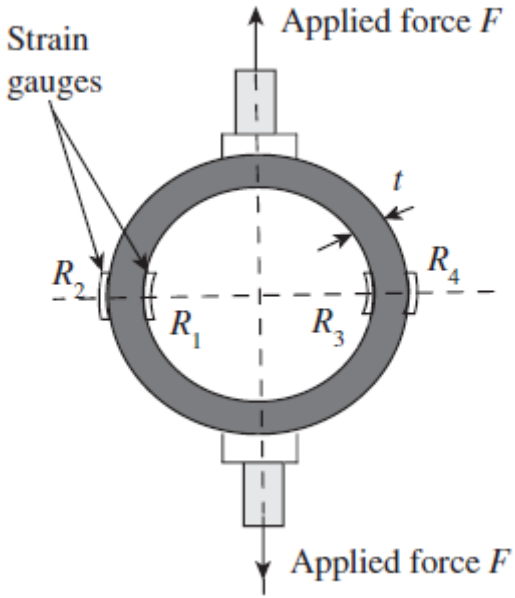
II. INDIRECT FORCE MEASUREMENT

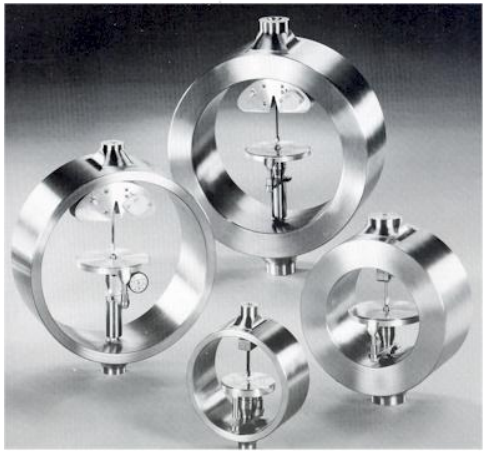
c. Elastic Loaded Members

Proving Ring

- Proving Rings can be used for measurement of both compressive and tensile forces.
- It consists of a hollow cylindrical beam of radius R, thickness t and axial width b.
- The two ends of the ring are fixed with the structures between which force is measured.
- Four strain gages are mounted on the walls of the proving ring, two on the inner wall, and two on the outer wall.
- When force is applied, gages 2 and 4 will experience strain –ε (compression), while gages 1 and 3 will experience strain + ε (tension).
- The magnitude of the strain is given by the expression:

$$\varepsilon = \frac{1.08FR}{Ebt^2}$$





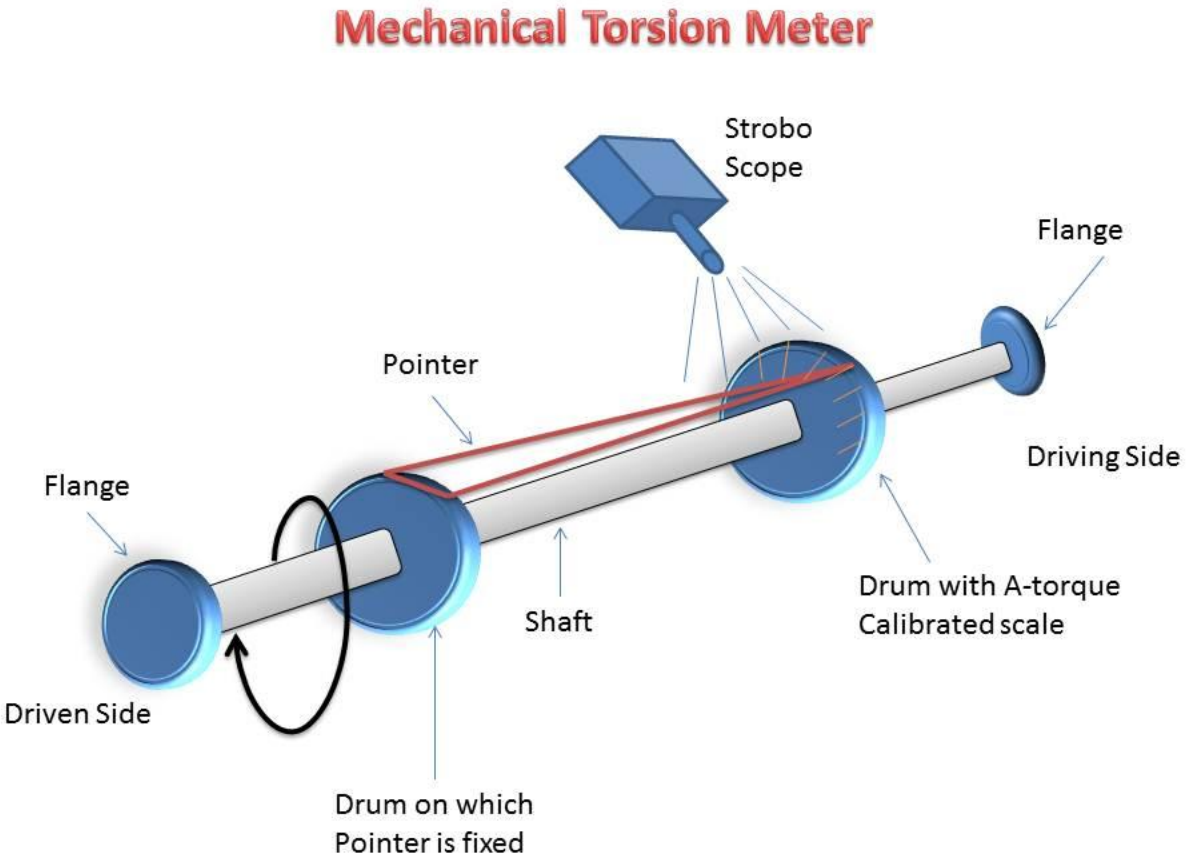
MEASUREMENT OF TORQUE

- Force that causes **twisting or turning moment**.
- The main purpose of torque measurement is to determine the mechanical power required or developed by a machine.
- Torque measurement also helps in obtaining load information necessary for **stress or strain** analysis.
- **T = F x r, *N-m***

INSTRUMENTS FOR MEASURMENT OF TORQUE

1. Mechanical Torsion Meter (Stroboscopic Method)
2. Optical Torsion Meter
3. Electrical Torsion Meter (Using Slotted Discs)
4. Strain Gauge Torsion Meter (Strain Gauges / Rotating Shafts)

1. MECHANICAL TORSION METER (STROBOSCOPIC METHOD)



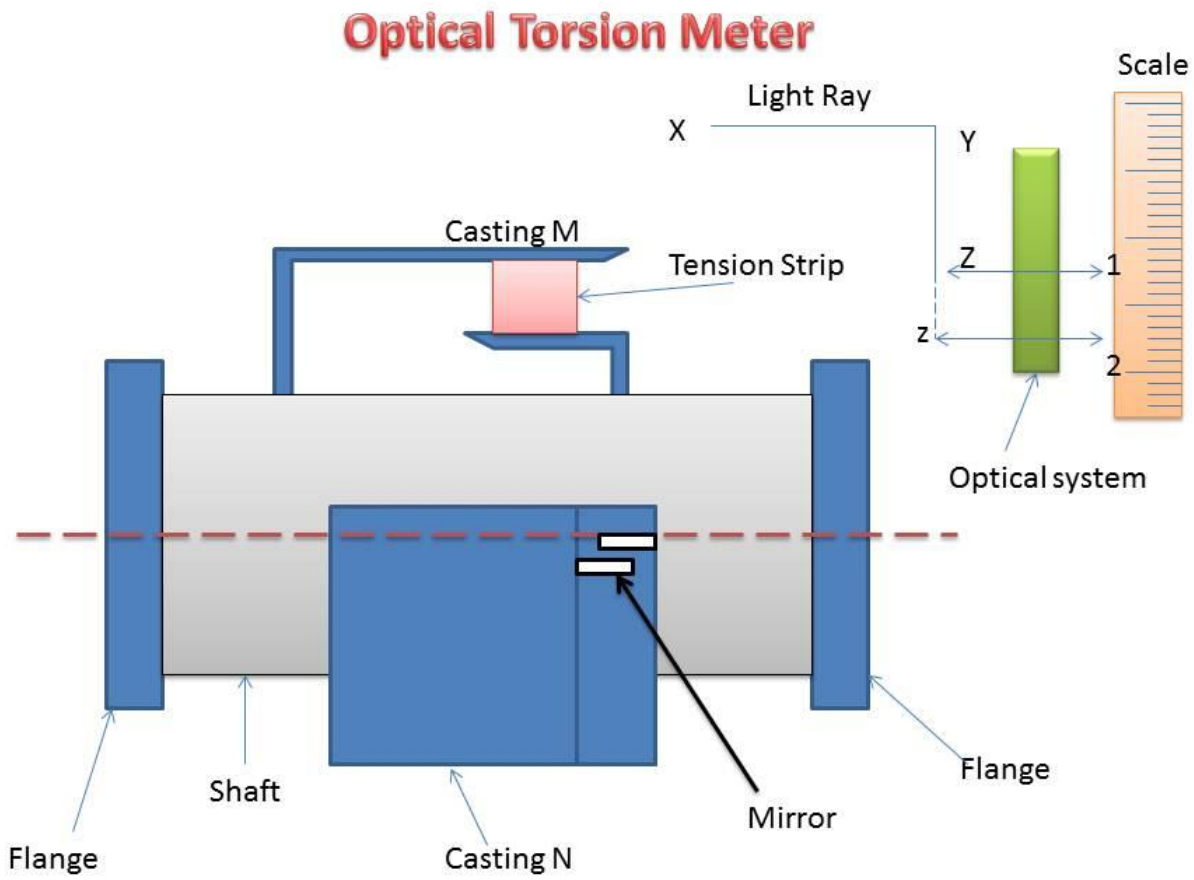
Application:

- Simple and inexpensive method.
- Power of shaft also can be calculated (flashing frequency gives information about speed).

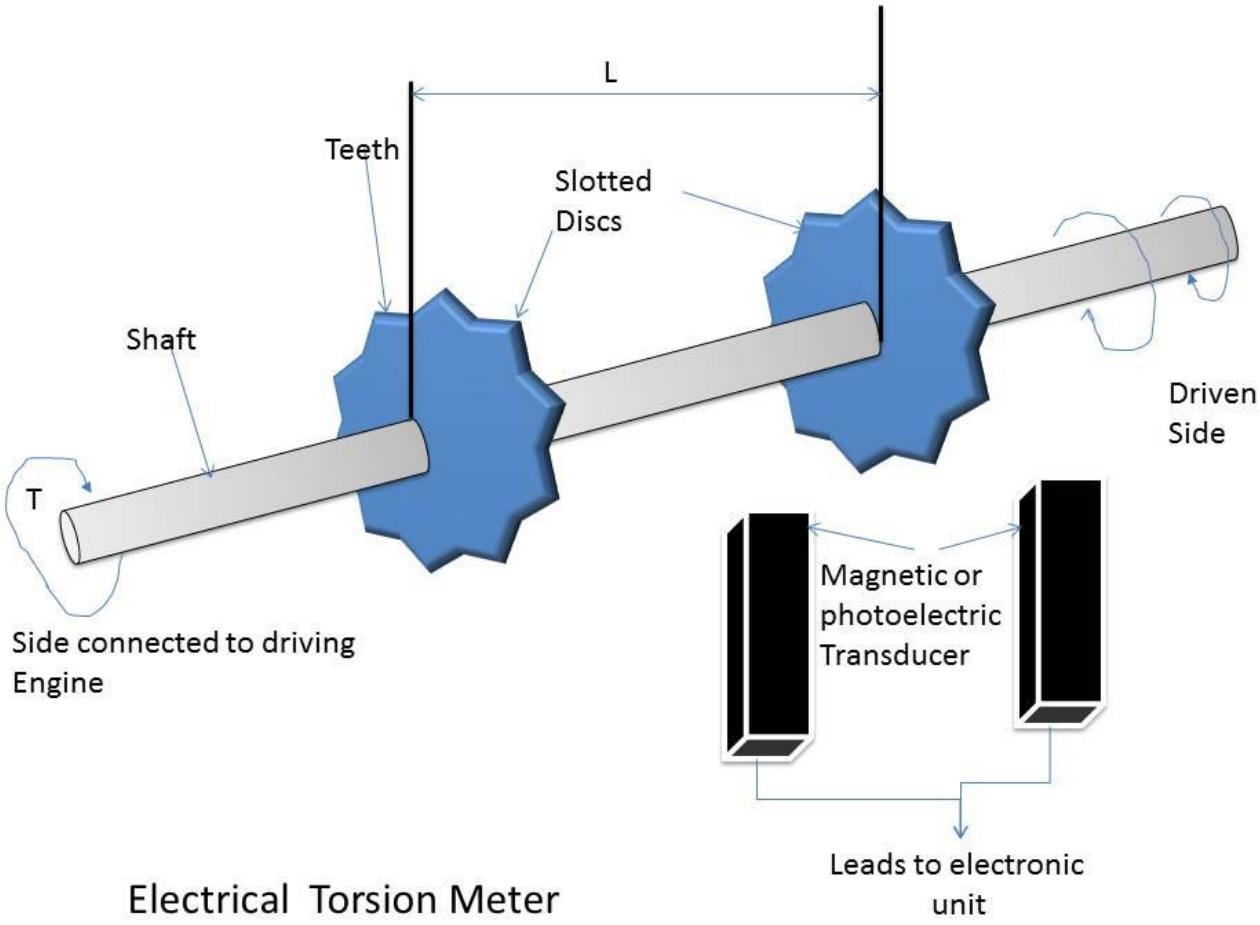
Limitations:

- Poor accuracy due to small displacement of the pointer.
- Sensitivity is reduced even due to small variations in speed.
- Can be used only on shafts rotating at a constant speed.

2. OPTICAL TORSION METER

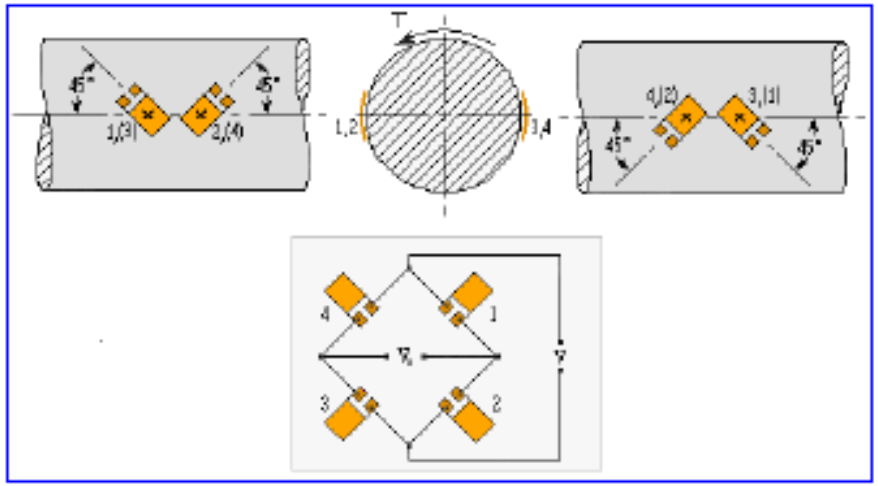


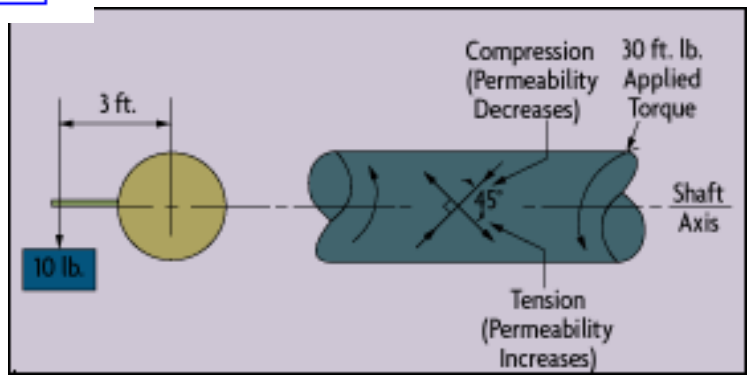
3. ELECTRICAL TORSION METER (USING SLOTTED DISCS)



Electrical Torsion Meter

4. STRAIN GAUGE TORSION METER (STRAIN GAUGES / ROTATING SHAFTS)





APPLICATION:

- Used to measure torque on rotating shafts

ADVANTAGES:

- Fully temperature compensated
- Sensitivity is high

LIMITATIONS:

- Difficult to connect the bridge circuit to the power source
- Difficult to connect the display to the bridge circuit.

MEASUREMENT OF POWER

- Dynamometer is a machine or a setup which is used for power measurement.

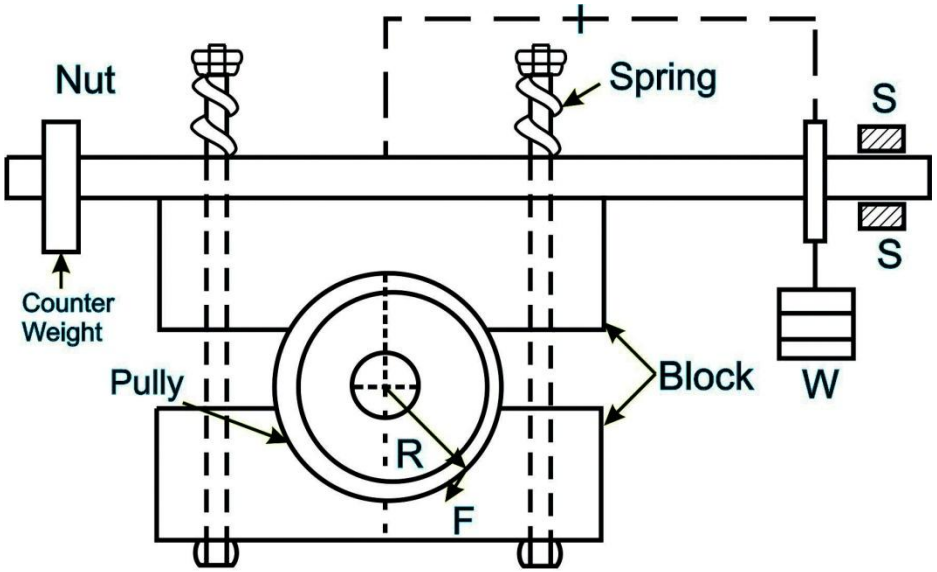
Types of Dynamometers:

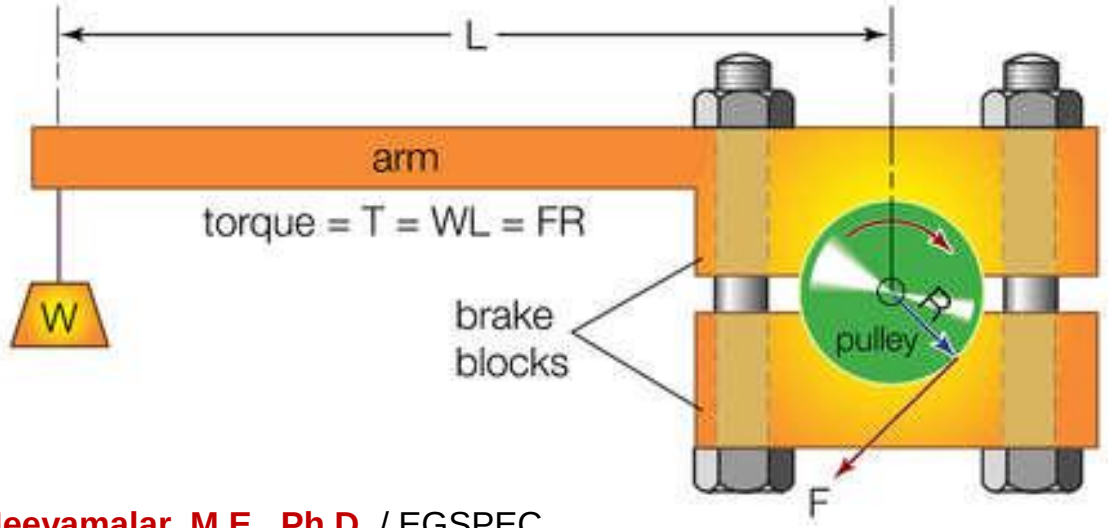
1. **Absorption type** – shaft whose power is to be measured is **stopped** (engines or electric motors).
2. **Transmission type** – shaft whose power is to be measured is **rotating continuously** (drives and pully).
3. **Driving type** – shaft whose power is to be measured acts as a **driving member** (pumps, compressors).

1. MECHANICAL DYNAMOMETERS (Absorption type)
(PRONY BRAKE DYNAMOMETER)

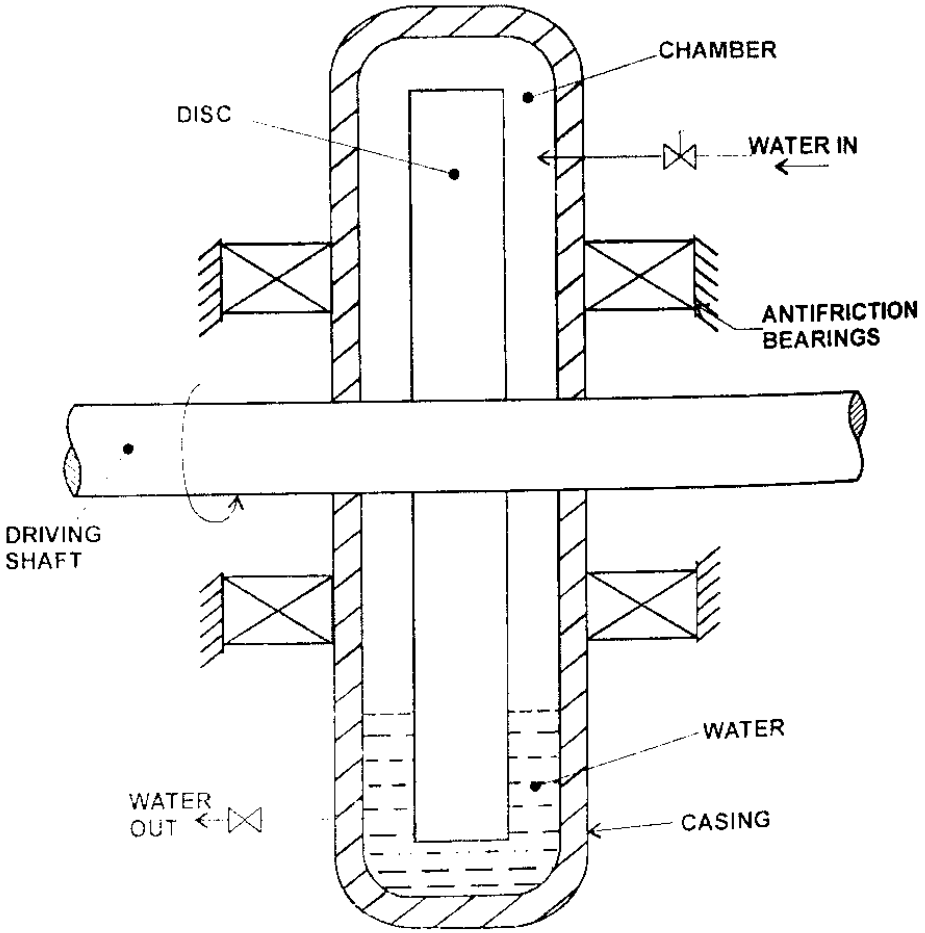
- A Prony brake dynamometer is one of the simplest, inexpensive, and the most popular absorption dynamometers.
- It is a mechanical type of device that depends on dry friction wherein mechanical energy is converted into heat.
- Prony brake dynamometer comprises two wooden blocks that are mounted on either side of the fly wheel in diagrammatically opposite directions.
- The fly wheel is attached to the shaft whose power needs to be determined.
- A lever arm is fixed to one block and the other arm is connected to an arrangement provided to tighten the rope.
- Tightening of the rope is performed in order to enhance the frictional resistance between the blocks and the flywheel.

PRONY BRAKE DYNANOMETERS

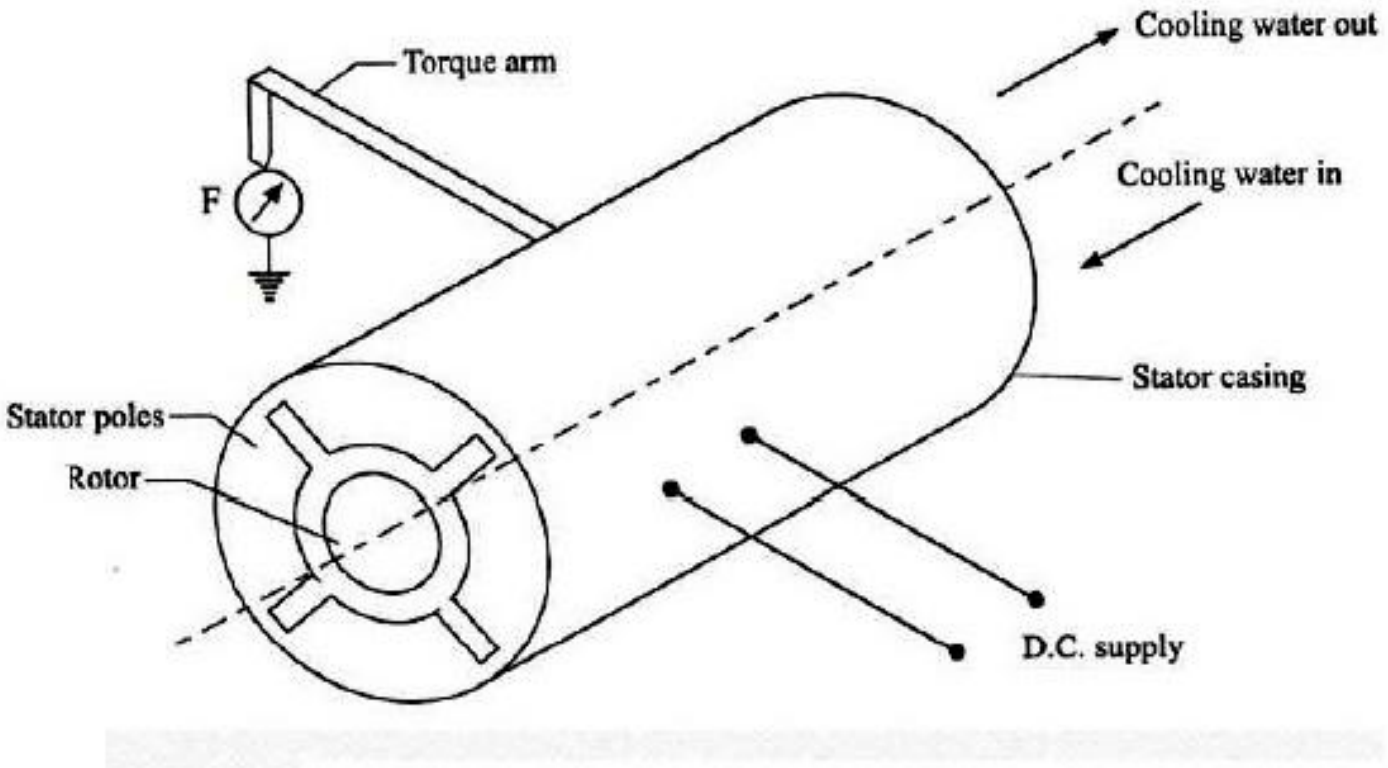




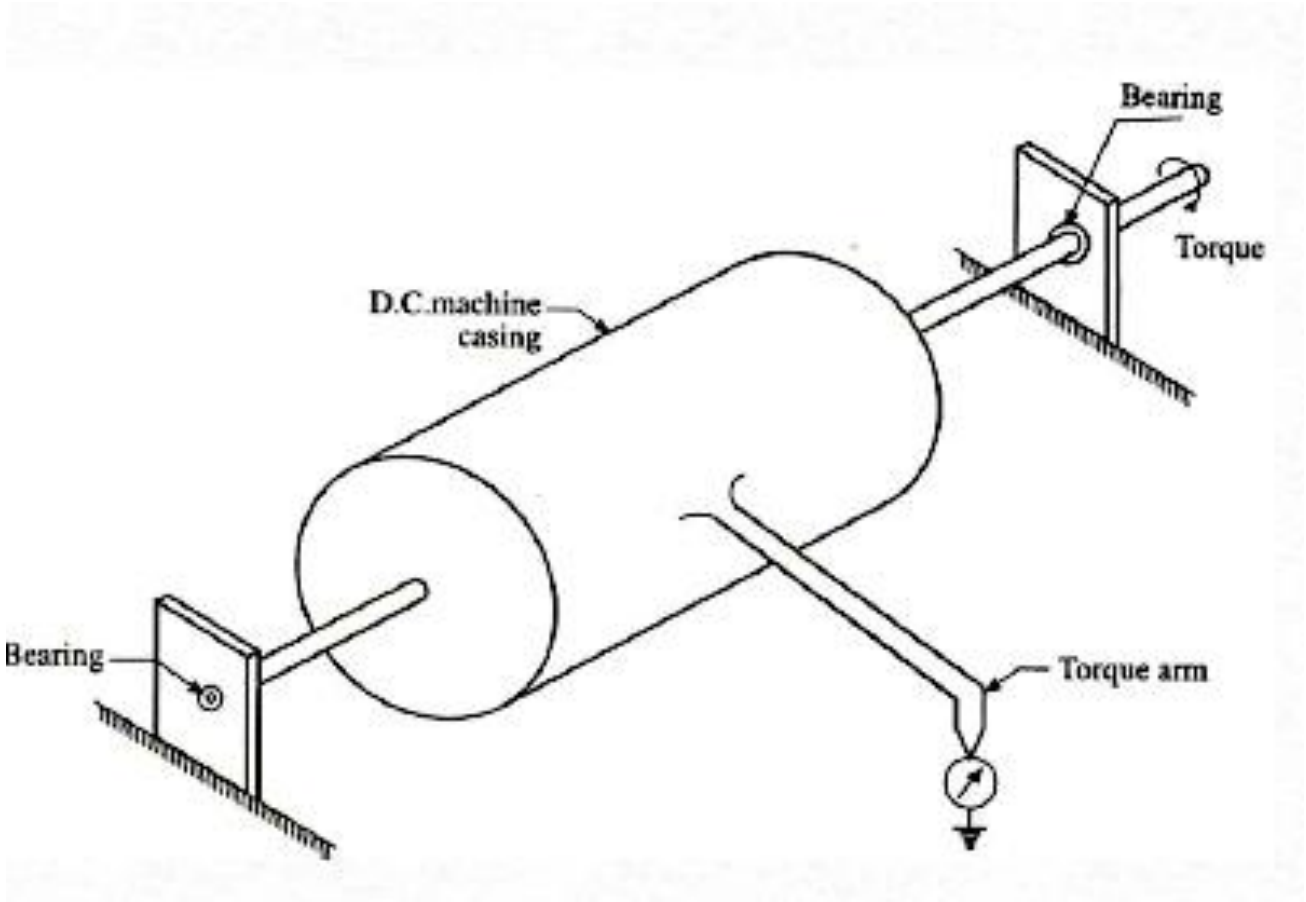
2. HYDRUALIC DYNANOMETERS (Absorption type)



3. EDDY CURRENT DYNAMOMETERS (Absorption type)
(ELECTRIC DYNAMOMETER)



4. DC DYNAMOMETERS (Driving type)



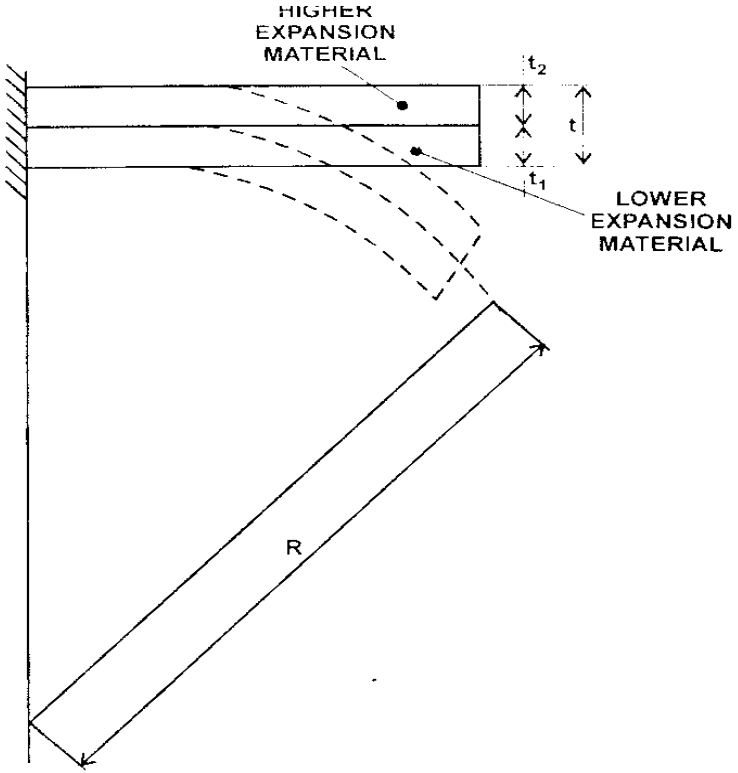
TEMPERATURE MEASUREMENTS

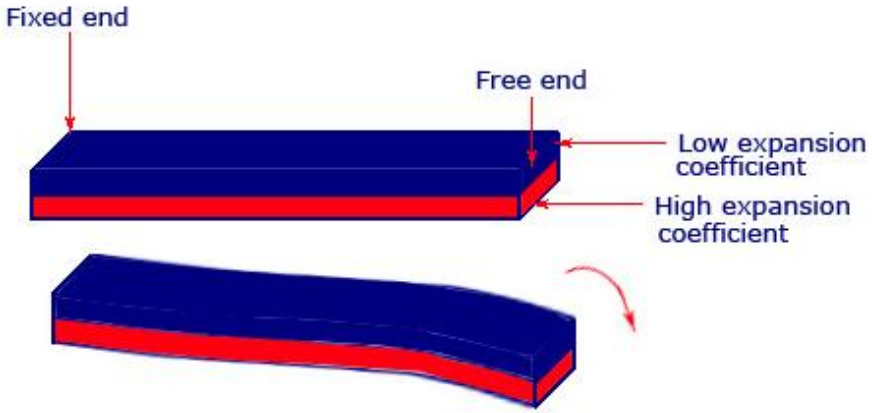
- Temperature is a quantity independent of the size of the system.
- Temperature is an indication of intensity of molecular activity.
- A condition of a body by virtue of which heat is transferred to or from other bodies
- A quantity whose difference is proportional to the work from a Carnot engine operating between a hot source and a cold reservoir.

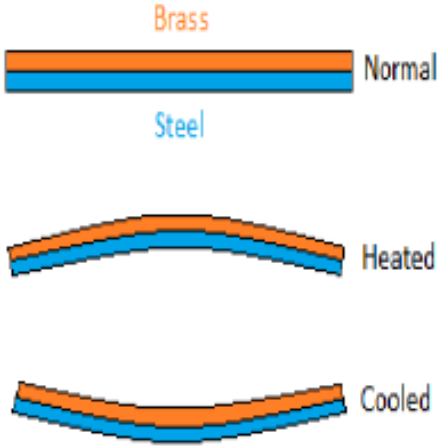
INSTRUMENTS TO MEASURE TEMPERATURE

1. Bimetallic Thermometers
2. Fluid Expansion Type
3. Pressure Thermometer
4. Resistance Thermometer
5. Thermistors
6. Thermocouples
7. Pyrometers
    a. Total Radiation Pyrometer
    b. Optical Pyrometer (Disappearing Filament Type)
    c. Infra Red Pyrometer

1. BIMETALLIC THERMOMETERS



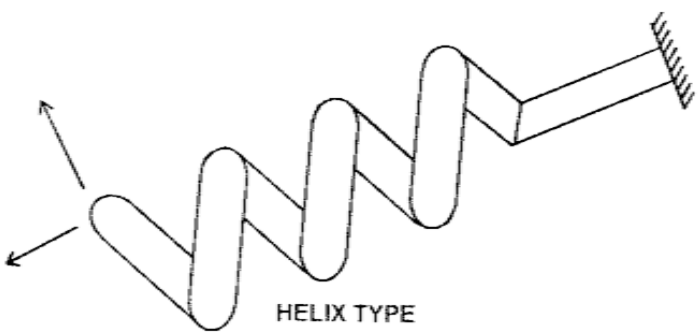


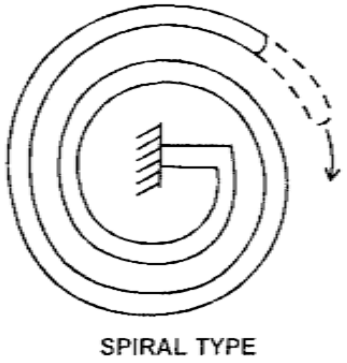


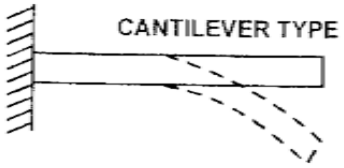
Important properties of material for selection of bimetallic thermometers. (these properties should be high)

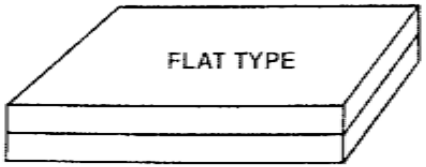
- **Coefficient of expansion**
- **Modulus of elasticity**
- **Elastic limit after cold rolling**
- **Electrical conductivity**
- **Ductility**
- **Metallurgical ability**

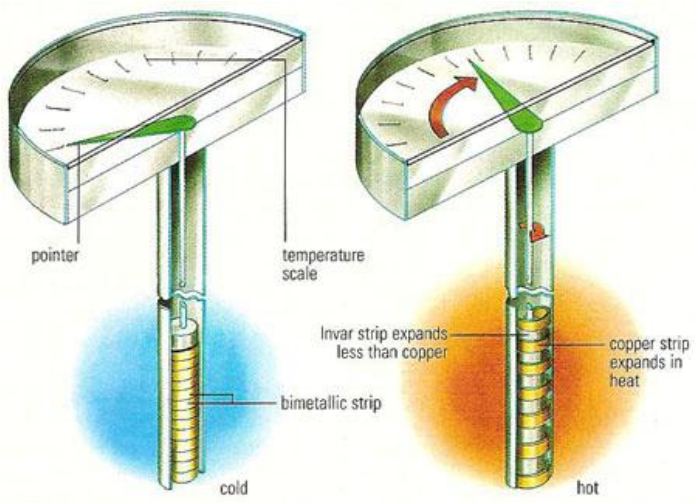
BIMETALLIC TYPES











Applications of Bimetallic strips & Thermometers

1. **The bimetallic strip is used in control devices.**

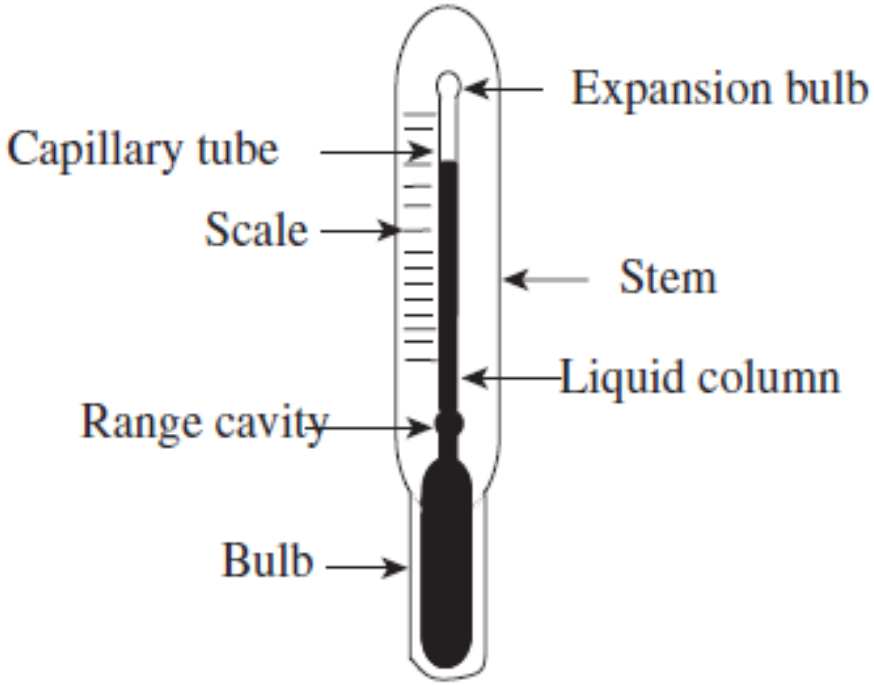
2. **The spiral strip is used in air conditioning thermostats.**

3. **The helix strip is used for process application such as refineries, oil burners, tyre vulcanizes etc.**

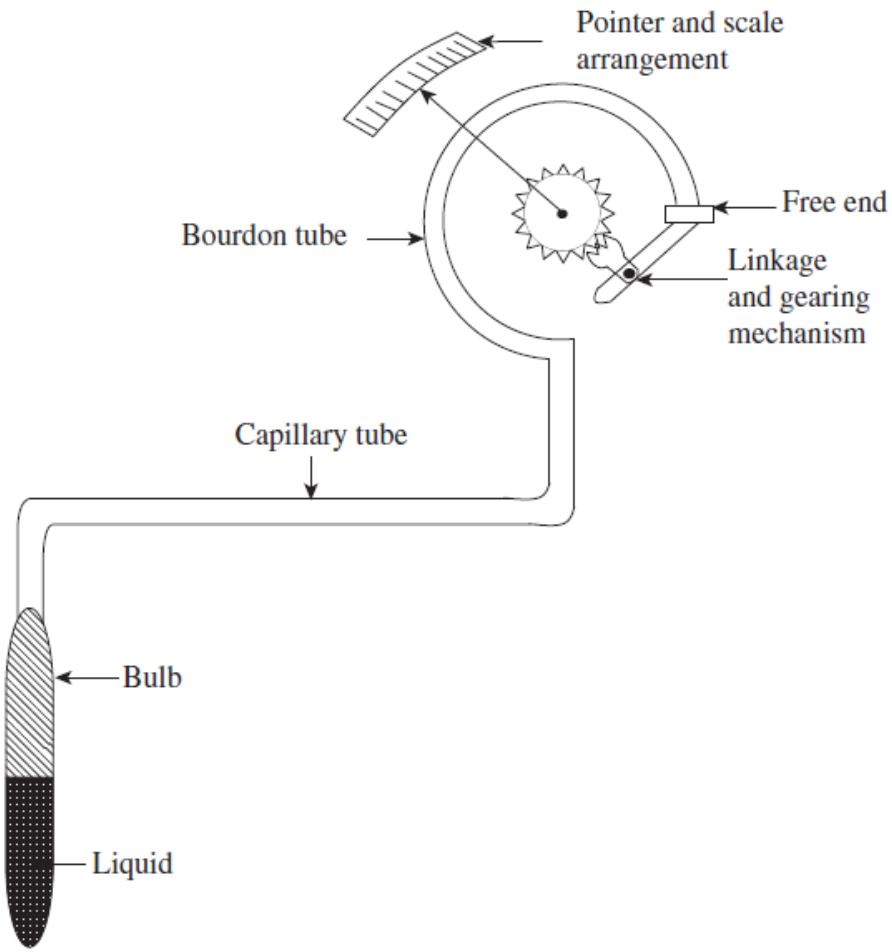
Advantages of Bimetallic Thermometer‘s

1. **They are simple, robust and inexpensive.**
2. **Their accuracy is between ± 2% to ± 5% of the scale.**
3. **They can with stand 50% over range in temperatures.**
4. **They can be used where ever a mercury-in-glass thermometer is used.**

2. FLUID EXPANSION THERMOMETER



3. PRESSURE THERMOMETERS



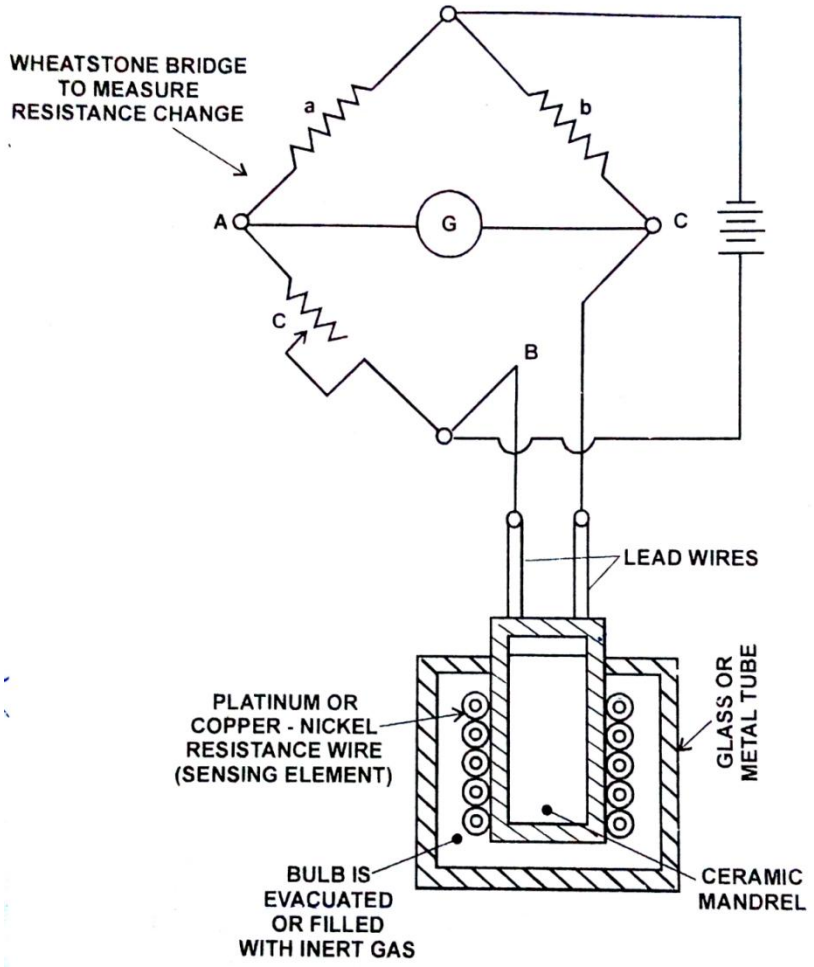
Advantages

- **These devices cost less.**
- **Speed of response and sensitivity are high.**
- **These devices are rugged.**
- **Direct driving of recording and controlling devices is possible due to the large output.**

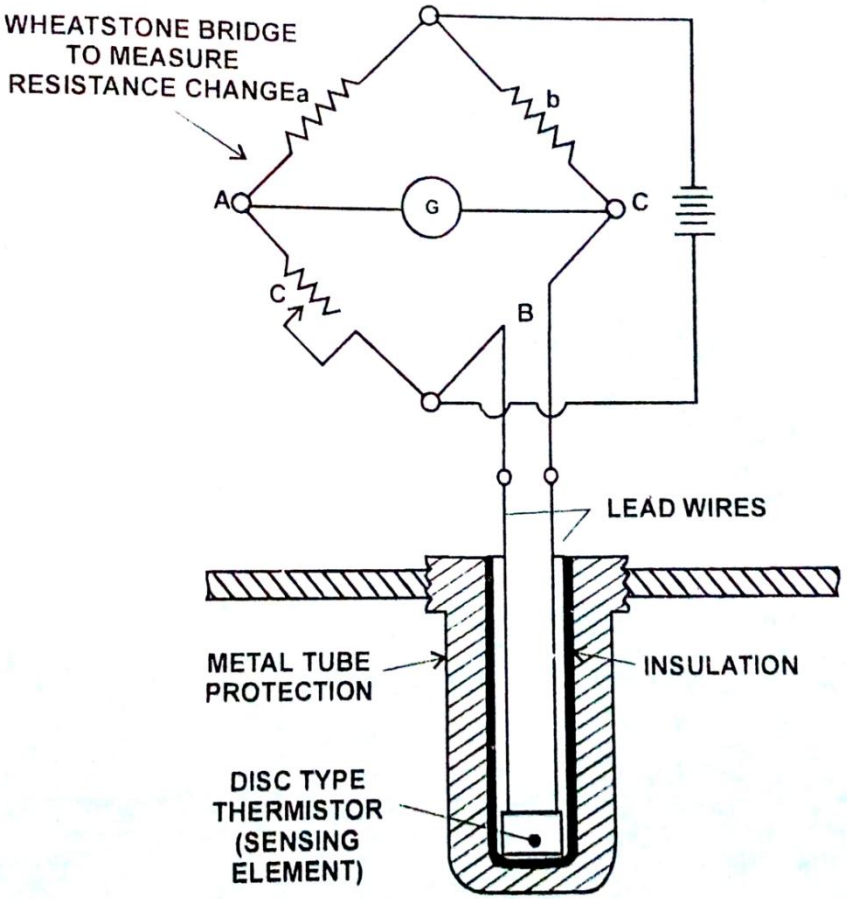
Limitations

- **If long transmitting capillary tubes are used compensation becomes a must.**
- **The filling fluid and the tube are temperature sensitive which may introduce errors.**
- **Auxiliary power source is required if it is combined with pneumatic or electric transmission systems.**
- **The filling fluid might get decomposed introducing calibration drift.**

4. RESISTANCE THERMOMETER
(Resistance Temperature Detectors- RTDS)



5. THERMISTORS (THERMAL RESISTORS)



Applications

1. **They are used for measuring varying temperatures.**
2. **Used for temperature compensation in electronic equipment.**
3. **They are used in nine delay circuits.**
4. **They are used to measure thermal conductivity.**
5. **They are used to measure pressure and Flow of liquids.**
6. **Used in precision temperature measurement**

Advantages

1. **The cost of the thermistors is low.**
2. **Accuracy is high (measurement up to 0.0l°C is attainable).**
3. **For 1°C change in temperature, the resistance changes as far as 6% in certain cases. Can measure high temperatures of the order of 800°C to 1100°C.**
4. **Ability to with stand mechanical and electrical stresses.**
5. **Thermistors can be manufactured to very small sizes as the resistivity of them are very high.**
6. **Simple electric circuits can be used to measure change in resistance.**

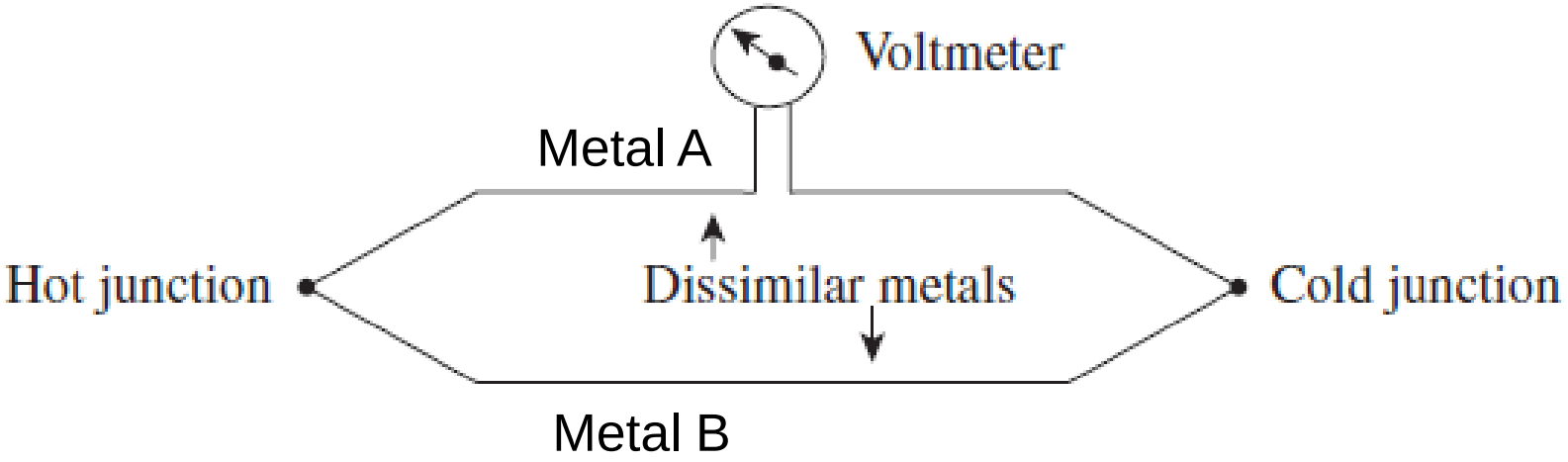
Limitations

1. **Thermistors have a non-linear scale-over its range of operation.**

2. **The resistance of the thermistor increases when time lapses. This is called as aging effect.**

3. **When current passes through the thermistor, if gets heated. This is called self heating effect.**

6. THERMOCOUPLES



LAWS OF THERMOCOUPLES

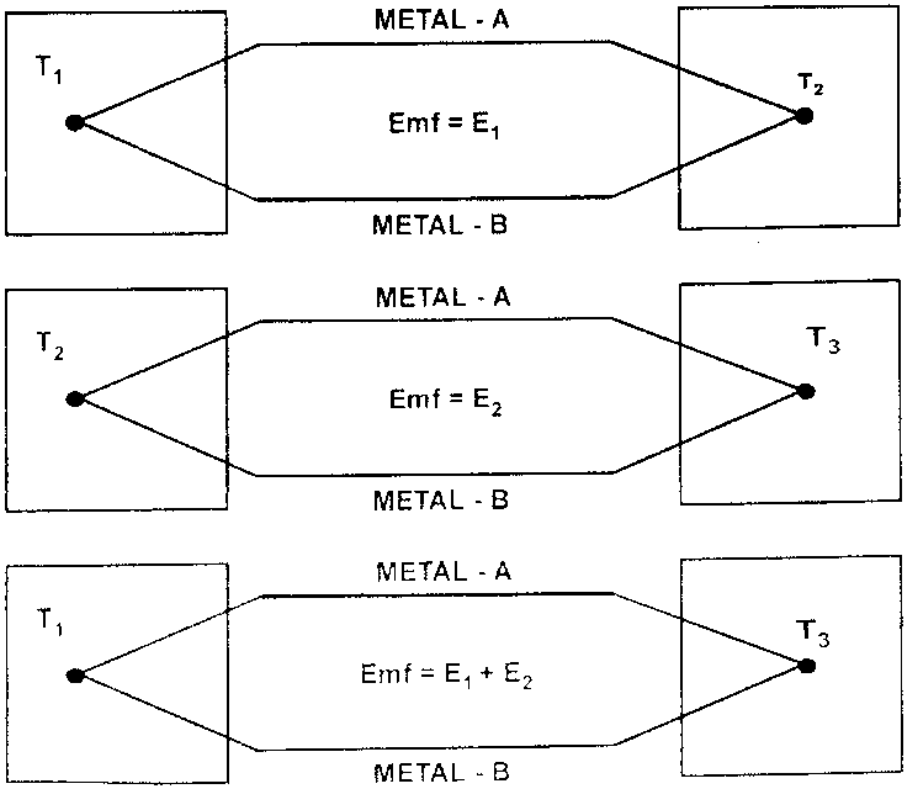
There are three laws of thermocouples namely:

1. **Law of thermoelectricity or successive or intermediate temperatures.**

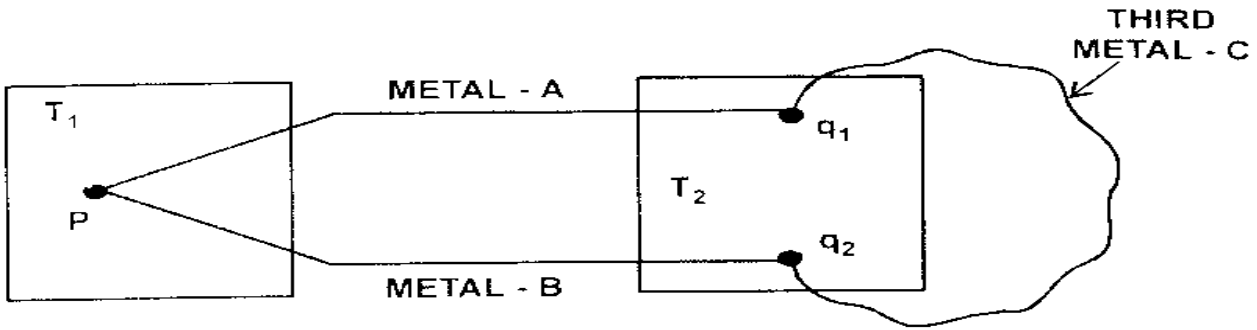
2. **Law of intermediate metals.**

3. **Law of homogenous circuit.**

(I) LAW OF INTERMEDIATE TEMPERATURE



(II) LAW OF INTERMEDIATE METALS

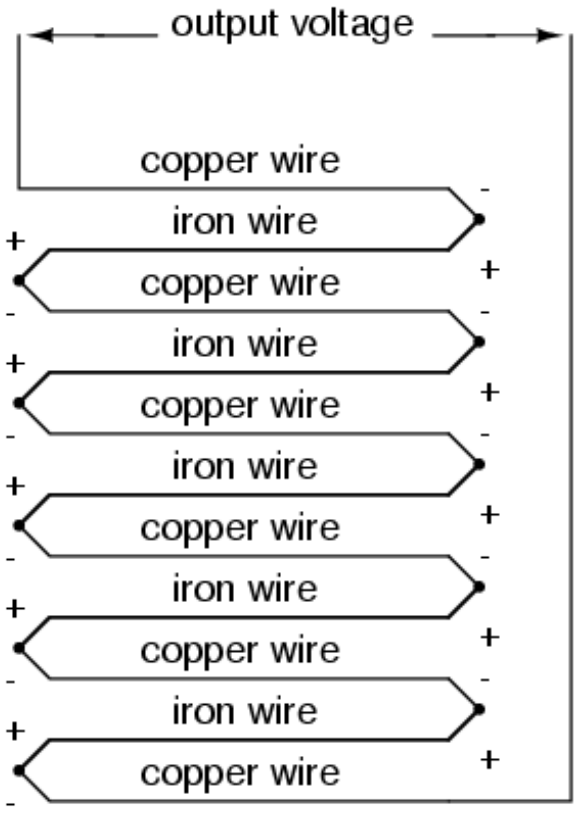


(III) LAW OF HOMOGENOUS CIRCUIT

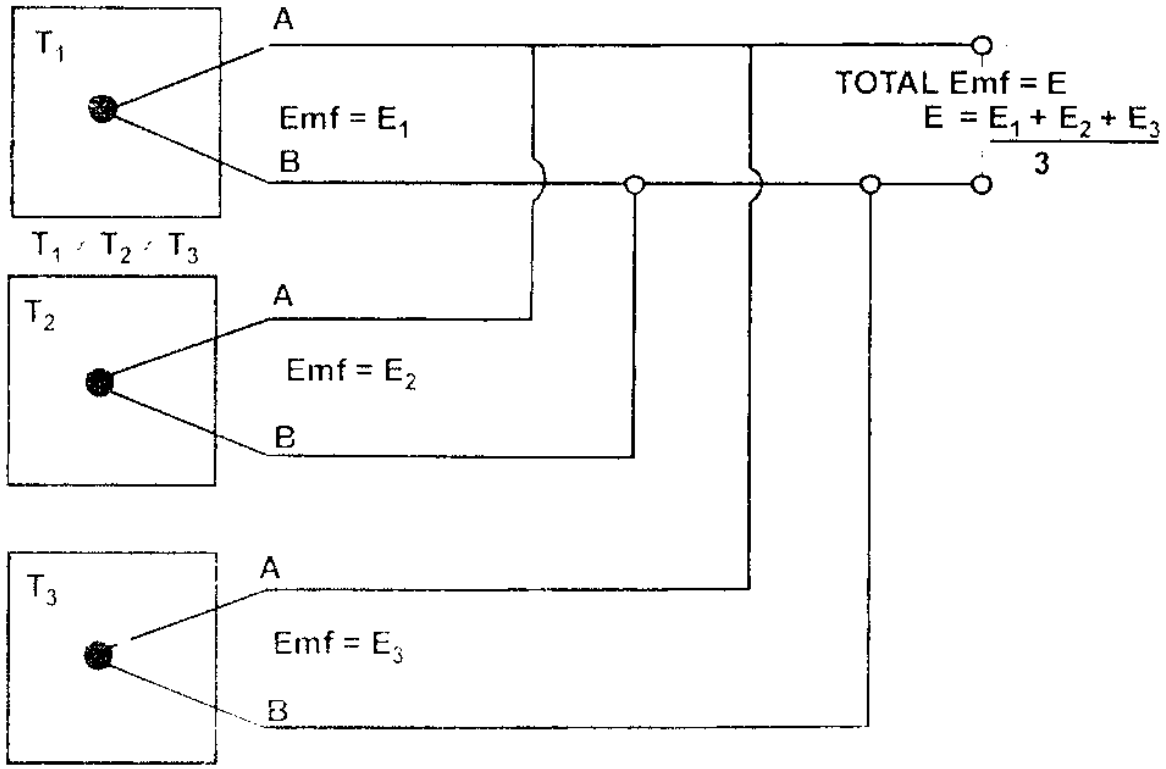
• The application of heat to a single homogenous metal is in itself not capable of producing or sustaining an electric current.

7. THERMOPILE
(THERMOCOUPLE CONNECTED IN SERIES)

- A thermopile is an electronic device that converts thermal energy into electrical energy.
- It is composed of several thermocouples connected usually in series or, less commonly, in parallel.



THERMOCOUPLE CONNECTED IN PARALLEL



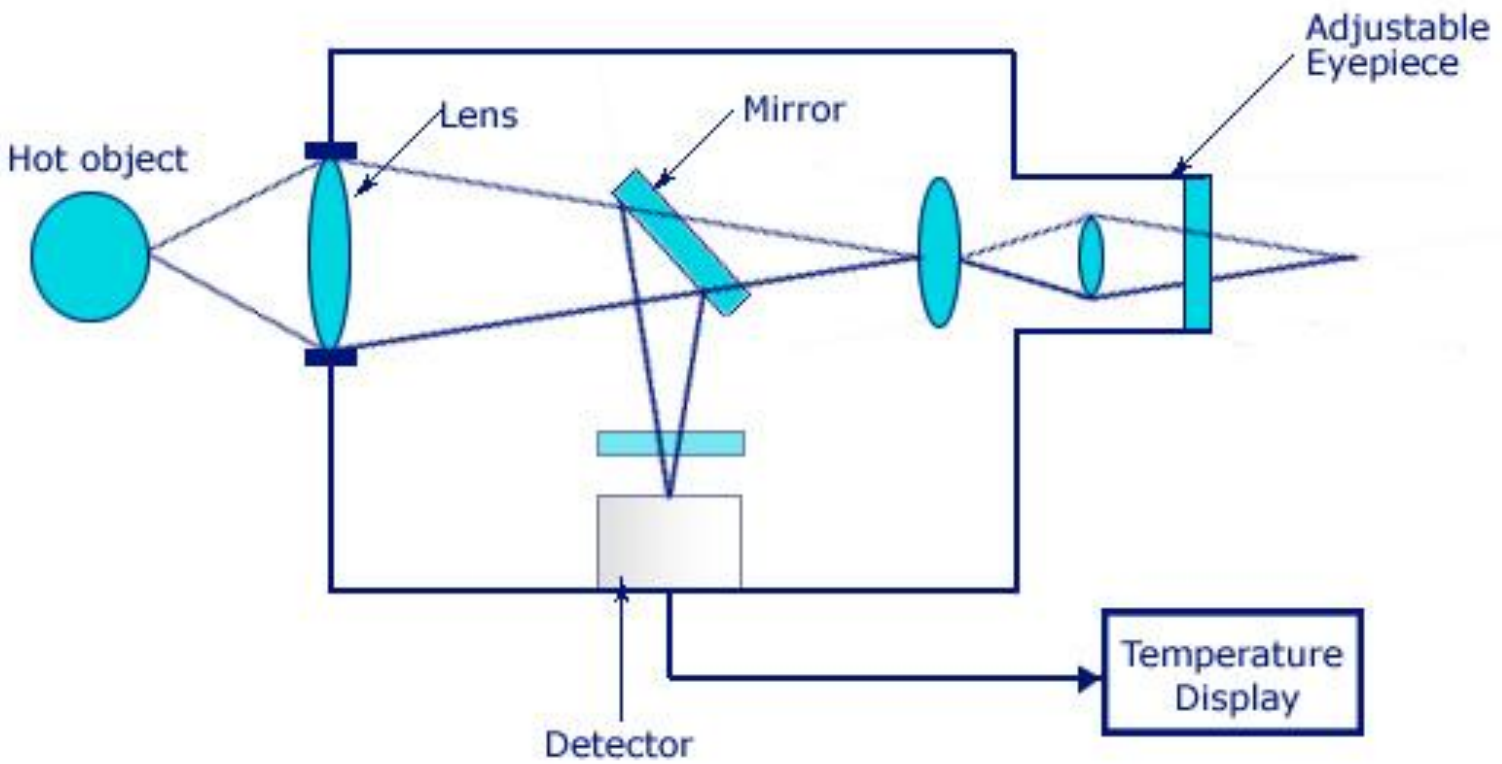
8. PYROMETERS

- Pyrometry is a technique for measuring temperature **without physical contact**.
- It depends upon the relationship between the temperature of hot body and eletronicmagnetic **radiation** emitted by the body.

The pyrometers are three types,

1. **Total radiation pyrometers**
2. **Infra red pyrometers**
3. **Optical radiation pyrometers**

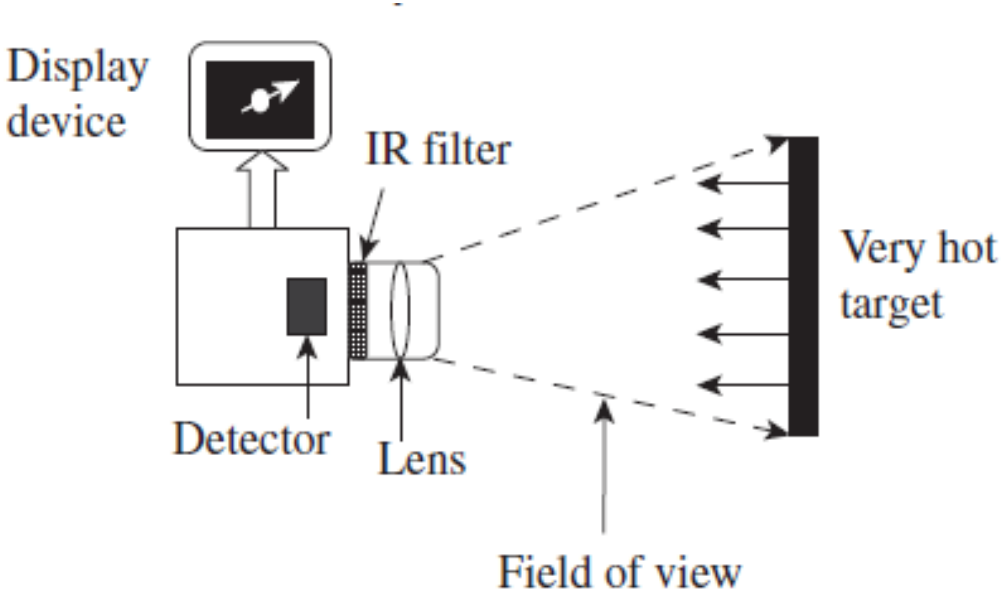
a. TOTAL RADIATION PYROMETERS



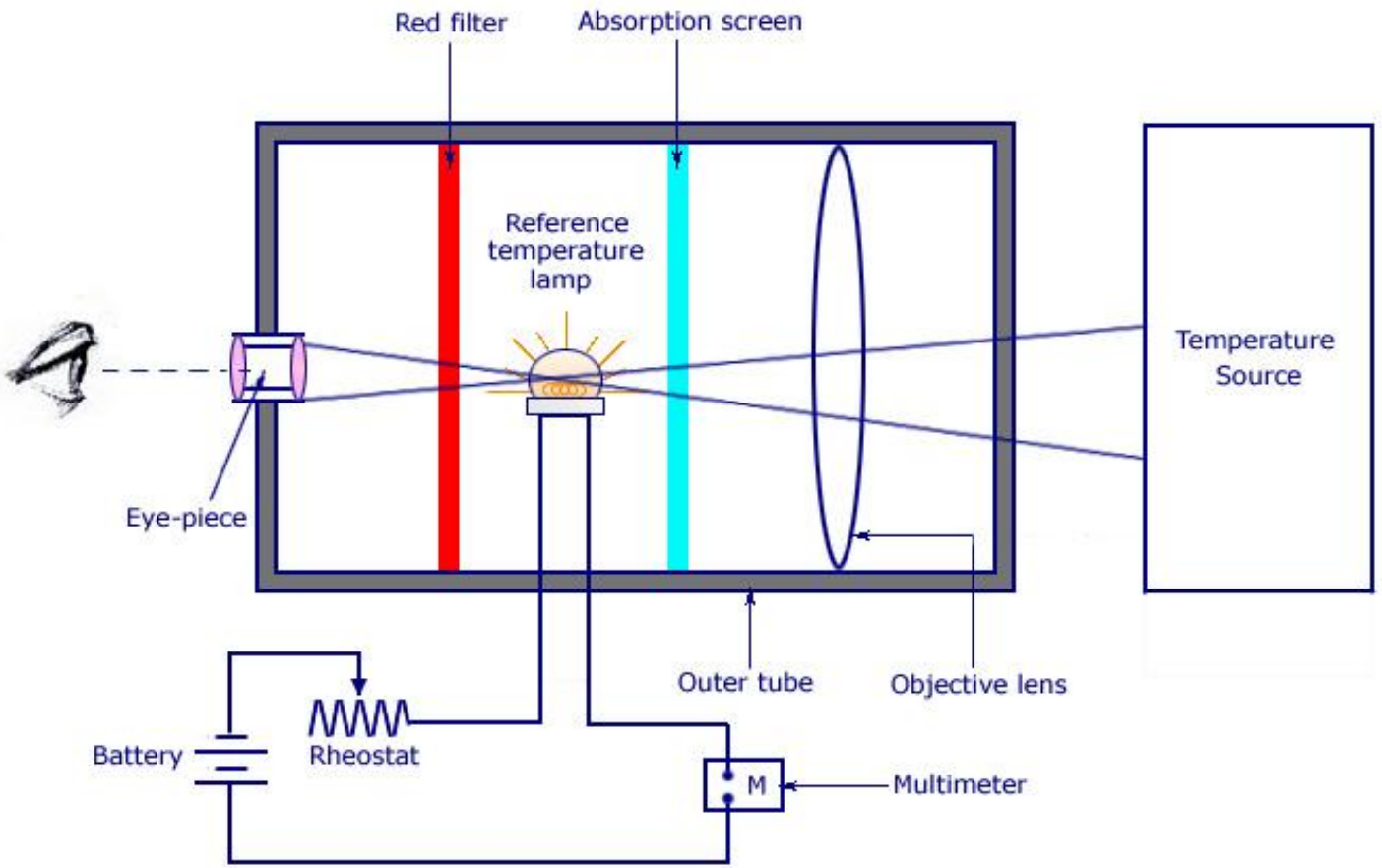
Working

- The radiation pyrometer has an optical system, including a lens, a mirror and an adjustable eye piece.
- The heat energy emitted from the hot body is passed on to the optical lens, which collects it and is focused on to the detector with the help of the mirror and eye piece arrangement.
- The detector may either be a thermister or photomultiplier tubes. Though the latter is known for faster detection of fast moving objects, the former may be used for small scale applications.
- Thus, the heat energy is converted to its corresponding electrical signal by the detector and is sent to the output temperature display device.

b. INFRA RED PYROMETERS



c. OPTICAL RADIATION PYROMETERS



Construction

- An eye piece at the left side and an optical lens on the right.
- A reference lamp, which is powered with the help of a battery.
- A rheostat to change the current and hence the brightness intensity.
- So as to increase the temperature range which is to be measured, an absorption screen is fitted between the optical lens and the reference bulb.
- A red filter placed between the eye piece and the reference bulb helps in narrowing the band of wavelength.

Working

- The radiation from the source is emitted and the optical objective lens captures it. The lens helps in focusing the thermal radiation on to the reference bulb.
- The observer watches the process through the eye piece and corrects it in such a manner that the reference lamp filament has a sharp focus and the filament is super-imposed on the temperature source image.
- The observer starts changing the rheostat values and the current in the reference lamp changes. This in turn, changes its intensity.

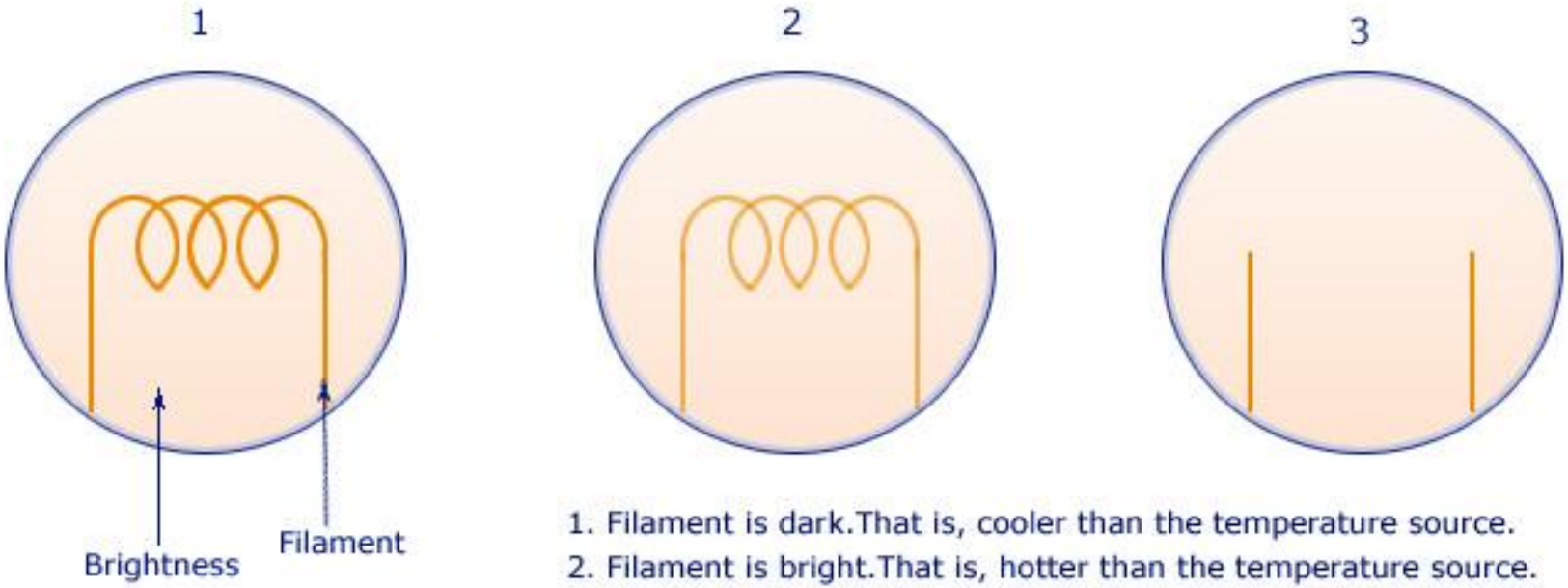
OPTICAL RADIATION PYROMETERS

•This change in current can be observed in three different ways.

1. The filament is dark. That is, cooler than the temperature source.
2. Filament is bright. That is, hotter than the temperature source.
3. Filament disappears. Thus, there is equal brightness between the filament and temperature source.

At this time, the current that flows in the reference lamp is measured, as its value is a measure of the temperature of the radiated light in the temperature source, when calibrated.

Optical Pyrometer - Temperature Measurement



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