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Affiliated to MSBTE Mumbai, Approved by AICTE New Delhi, DTE Mumbai & Govt. of Maharashtra, Mumbai.

# MECHANICAL ENGINEERING MEASUREMENTS

## UNIT 3: MEASUREMENT OF PRESSURE & TEMPERATURE

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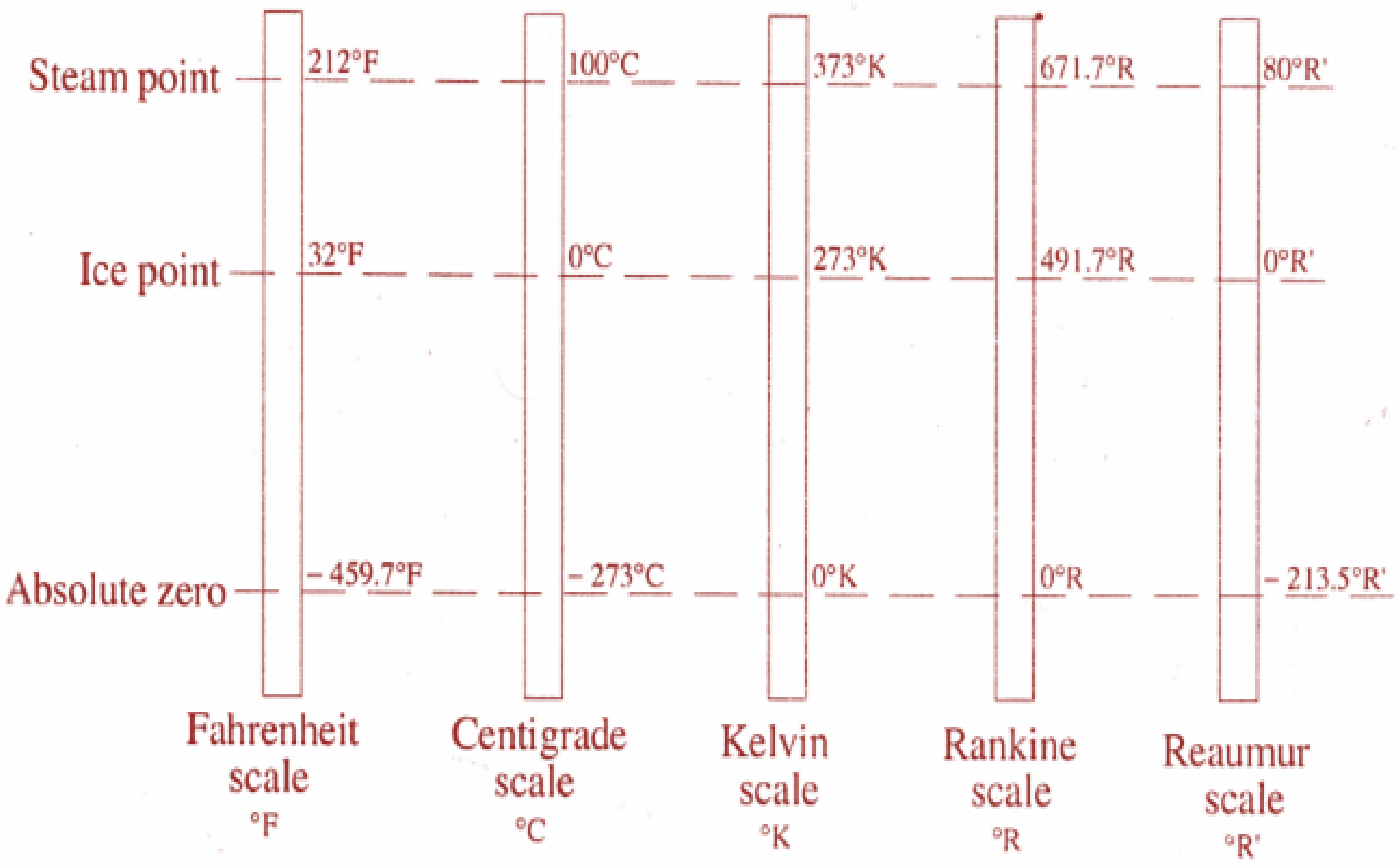
# INTRODUCTION

- Temperature: A measure proportional to the average translational kinetic energy associated with the disordered microscopic motion of atoms and molecules.

- The flow of heat is from a high temperature region toward a lower temperature region.

- When a high temperature object is placed in contact with a low temperature object, then energy will flow from the high temperature object to the lower temperature object, and they will approach an equilibrium temperature.

# Temperature Scales



# Temperature Scales

| | |
|---|---|
| To convert from Kelvin to Rankine | $R = \frac{9}{5} K$ |
| To convert from Fahrenheit to Rankine: | $R = °F + 459.69$ |
| To convert from Celsius to Rankine: | $R = \frac{9}{5} °C + 491.69$ |
| To convert from Fahrenheit to Kelvin: | $K = \frac{5}{9} (°F - 32) - 273.15$ |
| To convert from Celsius to Kelvin: | $K = °C - 273.15$ |
| To convert from Rankine to Kelvin | $K = \frac{5}{9} R$ |
| To convert from Rankine to Fahrenheit: | $°F = R - 459.69$ |
| To convert from Kelvin to Fahrenheit: | $°F = \frac{9}{5} (K - 273.15) + 32$ |
| To convert from Kelvin to Celsius: | $°C = K + 273.15$ |
| To convert from Rankine to Celsius: | $°C = \frac{5}{9} (R - 491.69)$ |

# Methods or classification of Temperature Measurement

classified according to the nature the change produced in the testing body with change of temperature.

**(1) Changes in physical dimensions -** expansion thermometers

Changes in temperature → Solid/liquid/gas → Changes in dimensions

(a) Expansion of solids - Bimetallic thermometers
(b) Expansion of liquids - Liquid in glass or metal bulb thermometers
(c) Expansion of gases - Gas thermometers.

**(2) Changes in liquid, gas or vapour pressure -** Filled system thermometers

Changes in temperature → Filled system → Changes in pressure

(a) Gas filled thermometers
(b) Liquid filled thermometers
(c) Vapour-pressure thermometers

**(3) Changes in electrical properties**

Changes in temperature → Metals/alloys/conductors/ semiconductors → Change in resistance/voltage

(a) Resistance Temperature Defectors (RTD)
(b) Thermistors
(c) Thermocouples

**(4) Change in emitted thermal radiation**

Change in temperature → Pyrometer → changes in radiation intensity

(a) Radiation pyrometers
(b) Optical pyrometers

# Expansion thermometers- **Bimetallic Thermometer**
## Solid expansion

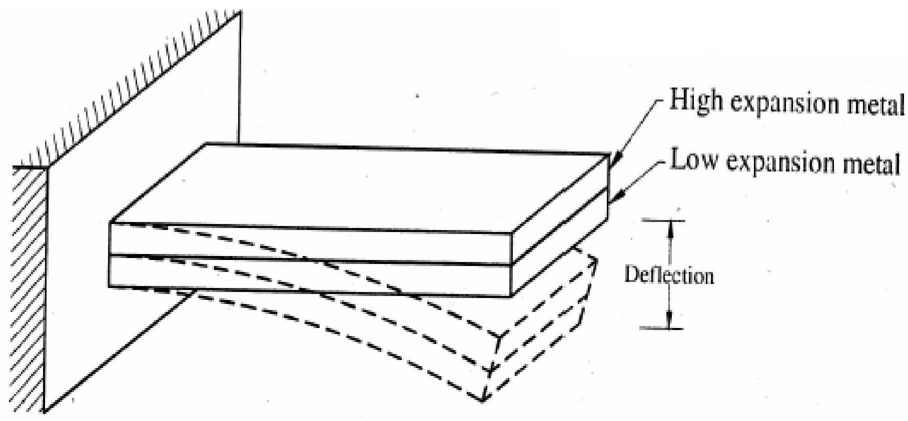
Matter (solid, liquid or gas) expands or contracts with change in temperature.

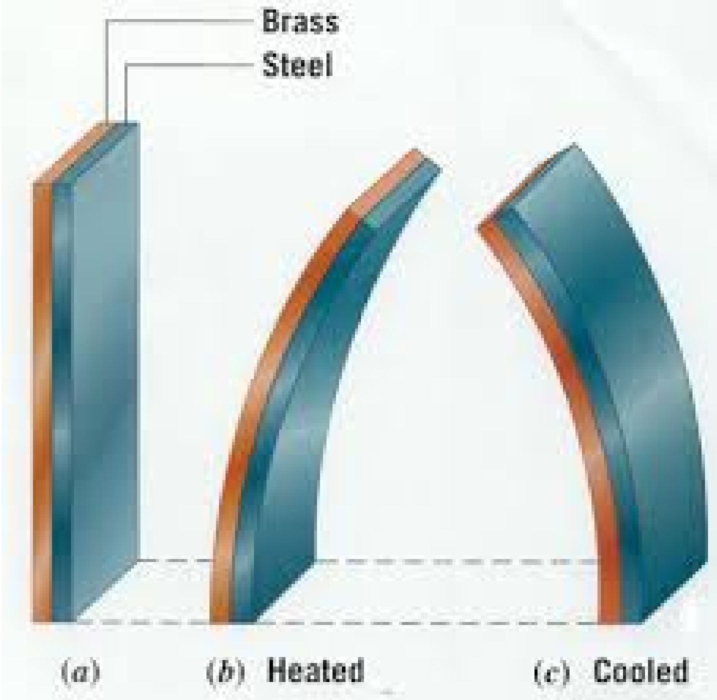
- If two strips of metals (with different thermal expansion co-efficients) at the same temperature are firmly bonded together, a temperature change causes a differential expansion. Hence, any change in temperature around the bimetal strip can be measured in terms of the free end deflection.
- A bimetallic strip as shown in Fig., consists of two metal strips welded together, each strip made from a metal having different co-efficient of thermal expansion. The bimetallic strips may be in form of simple straight , helical or spiral. In simple straight form, bimetallic strip is fixed at one end in form of cantilever beam, while its other end is free to move. The metal having high co-efficient of thermal expansion expands more in length than the metal having relatively low co-efficient of thermal expansion. Since these two metals are bonded in cantilever form, as temperature around the strip increases, the strip bends towards the metal having low thermal expansion co-efficient. Thus free end of the strip gets deflected and this free end deflection is nearly proportional to the change in temperature.
- Material of bimetal strip : Invar (an alloy of nickel and iron is most commonly used for low expansion material. Brass, Nickel or Ni-Mo alloy are used for high expansion material.

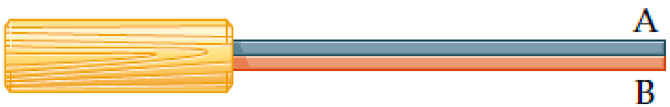
# Expansion thermometers- Bimetallic Thermometer

Solid expansion

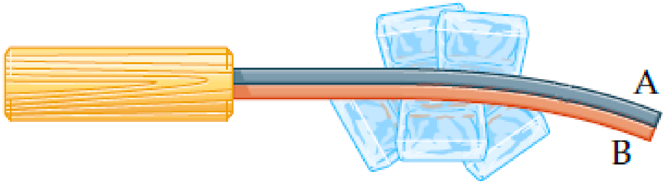
**Bimetal strip**



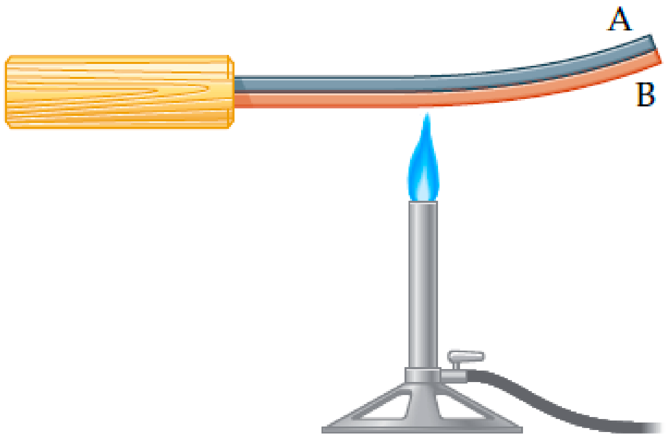



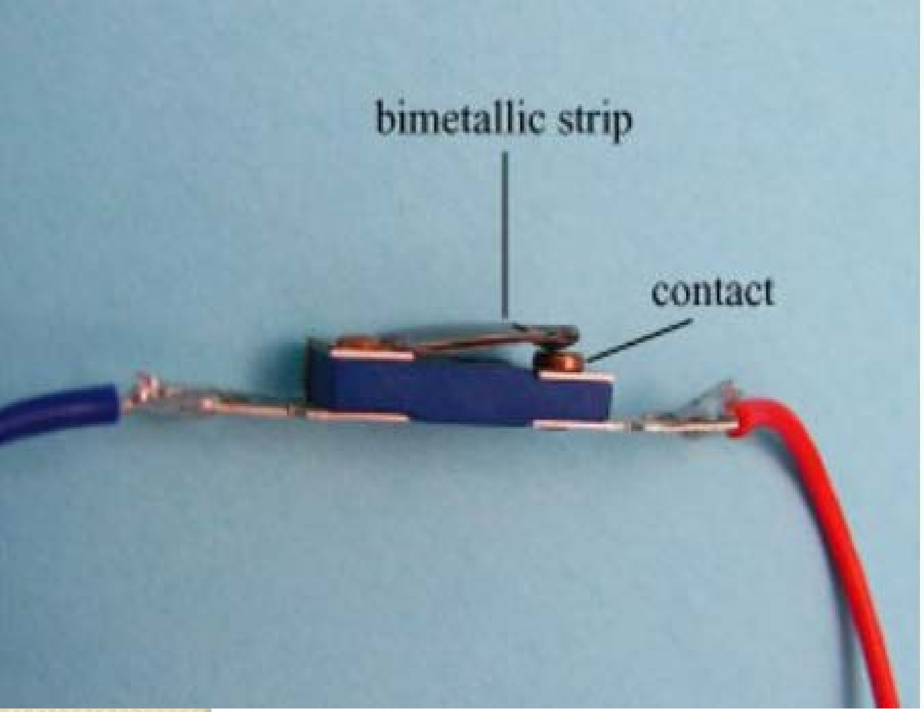

(a) A bimetallic strip

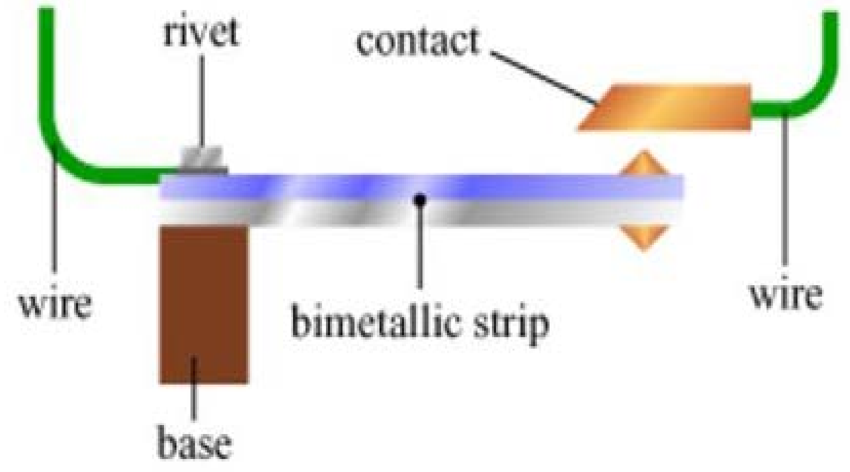


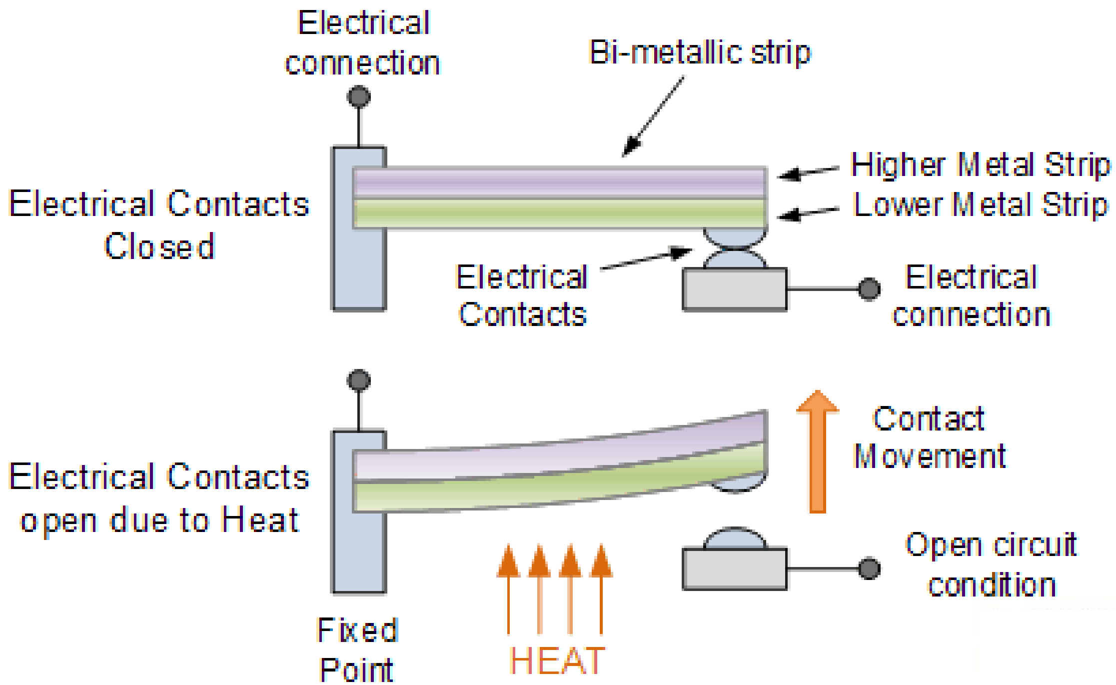

(b) Chilling the strip

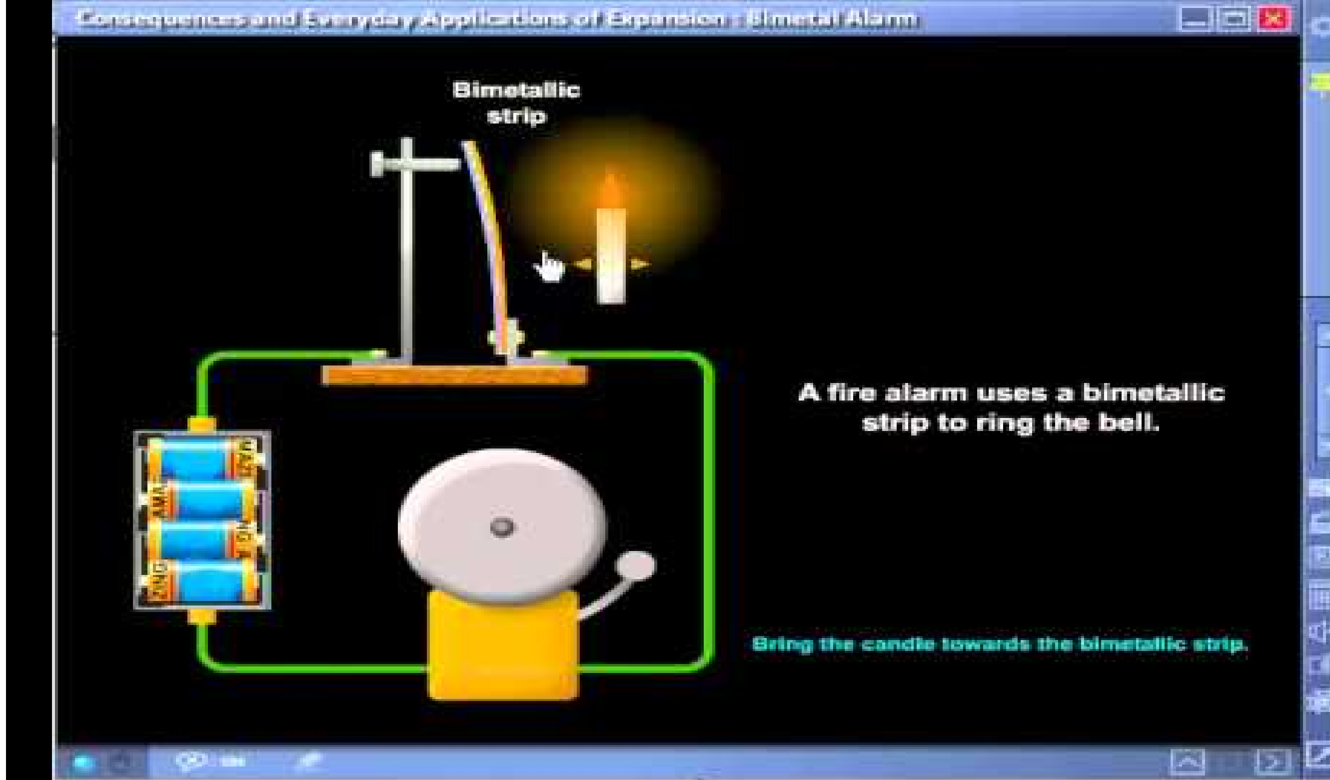



(c) Heating the strip


bimetallic strip
contact


rivet
contact
wire
bimetallic strip
wire
base

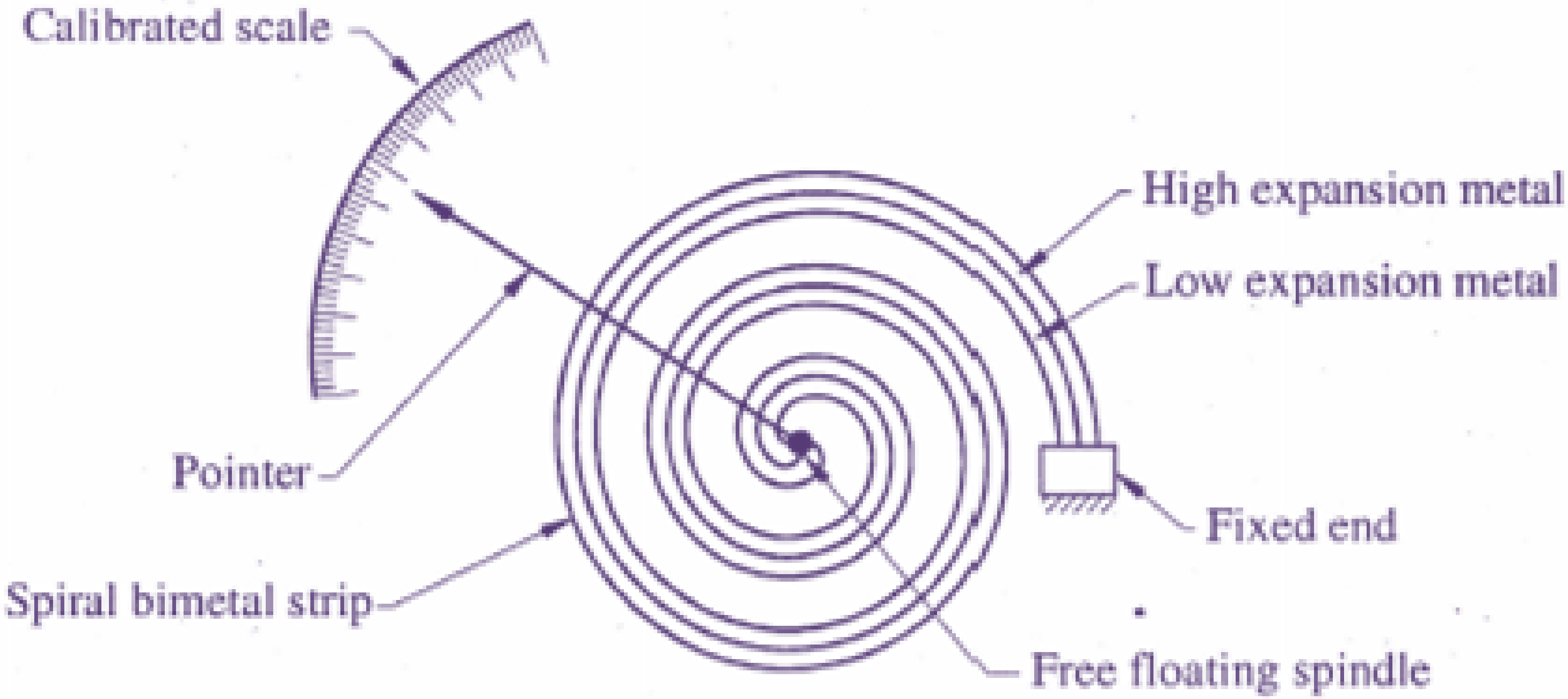

Electrical connection
Bi-metallic strip
Higher Metal Strip
Lower Metal Strip
Electrical Contacts Closed
Electrical Contacts
Electrical connection
Contact Movement
Electrical Contacts open due to Heat
Open circuit condition
Fixed Point
HEAT


Consequences and Everyday Applications of Expansion : Bimetal Alarm
Bimetallic strip
A fire alarm uses a bimetallic strip to ring the bell.
Bring the candle towards the bimetallic strip.

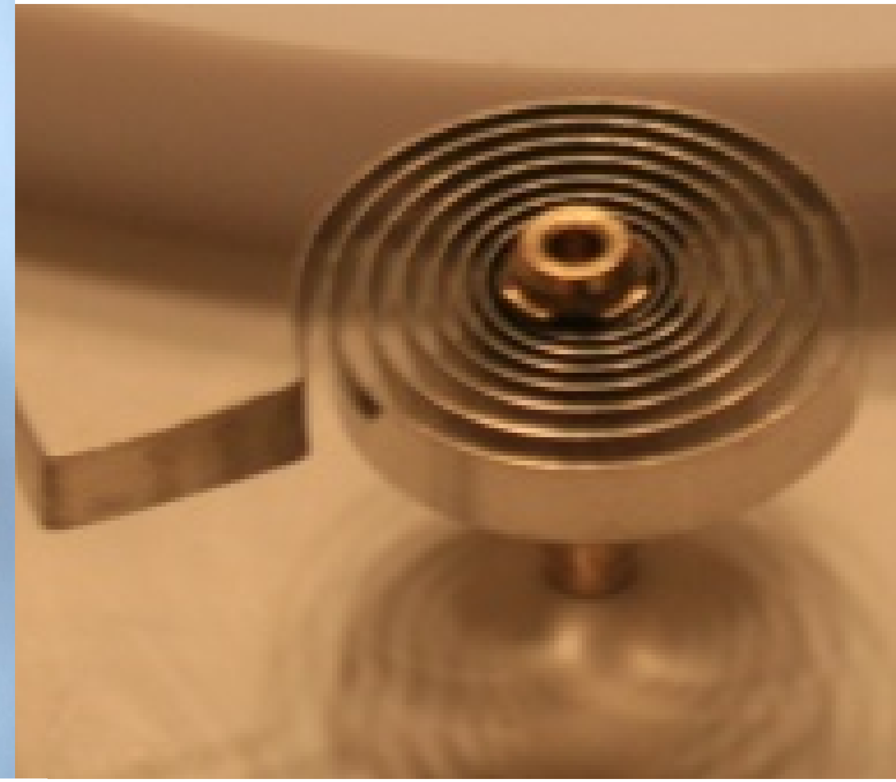
# Expansion thermometers- **Bimetallic Thermometer**

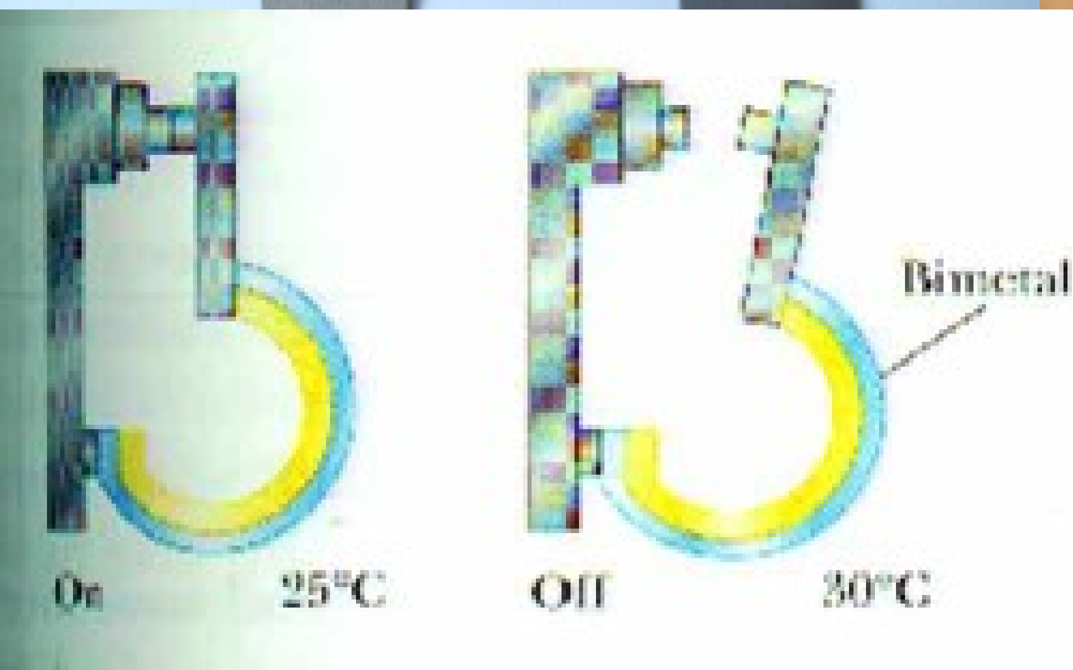
Solid expansion

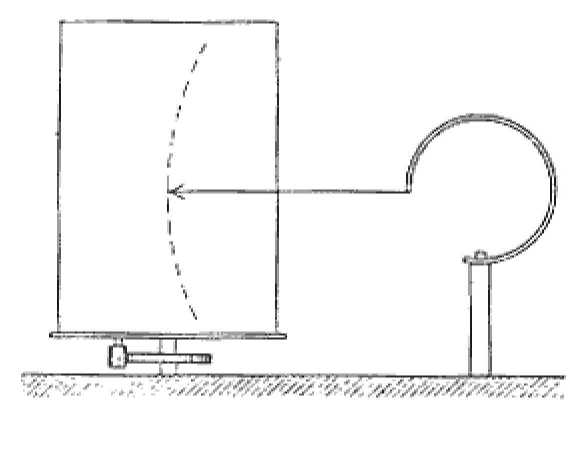
Fig. shows spiral bimetal strip thermometer, in which one end of spiral strip fixed at one end and is wound such that turn diameter goes on increasing. The other end is connected to pointer. The temperature variation causes rotation of pointer on calibrated scale.




*Spiral bimetal strip thermometer*

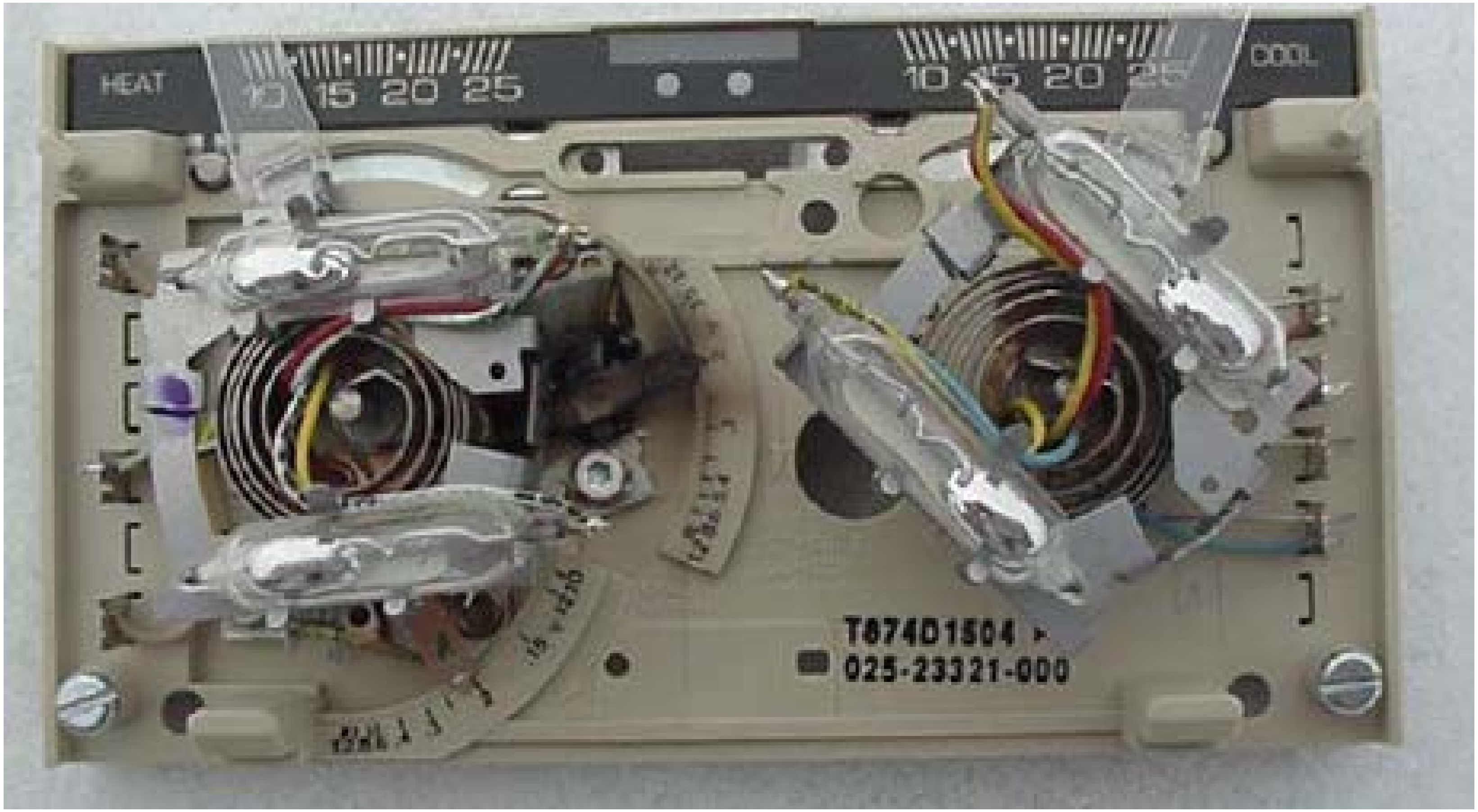


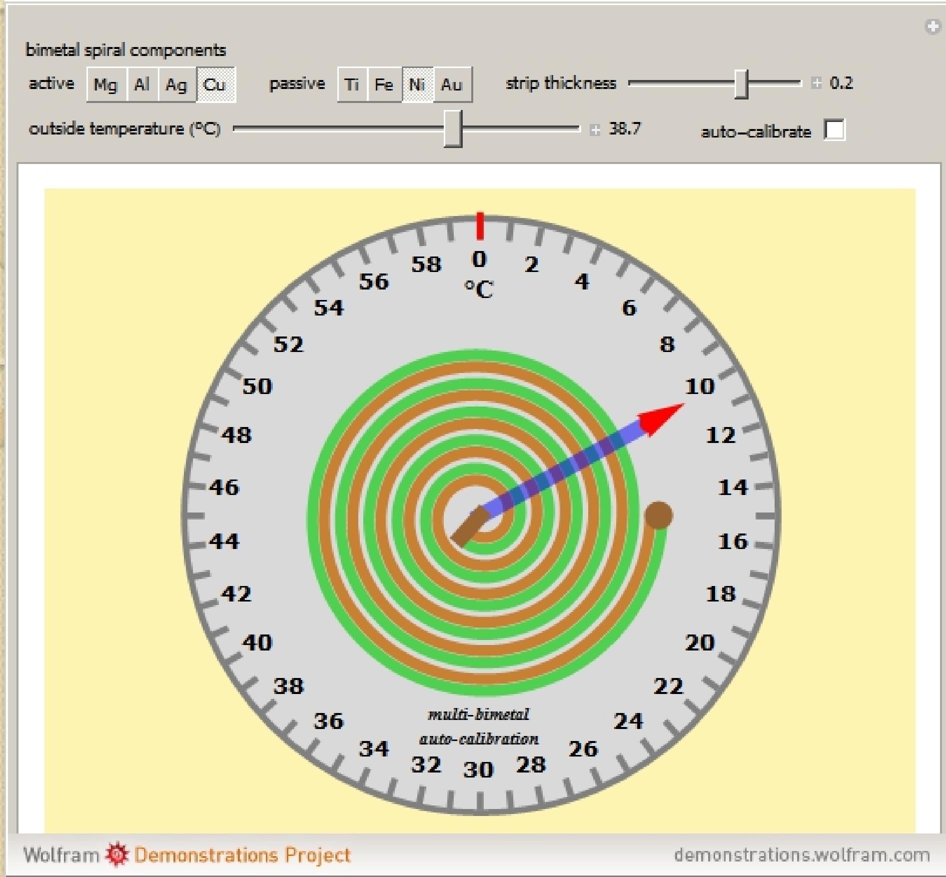

Bimetal
On
25°C
Off
30°C

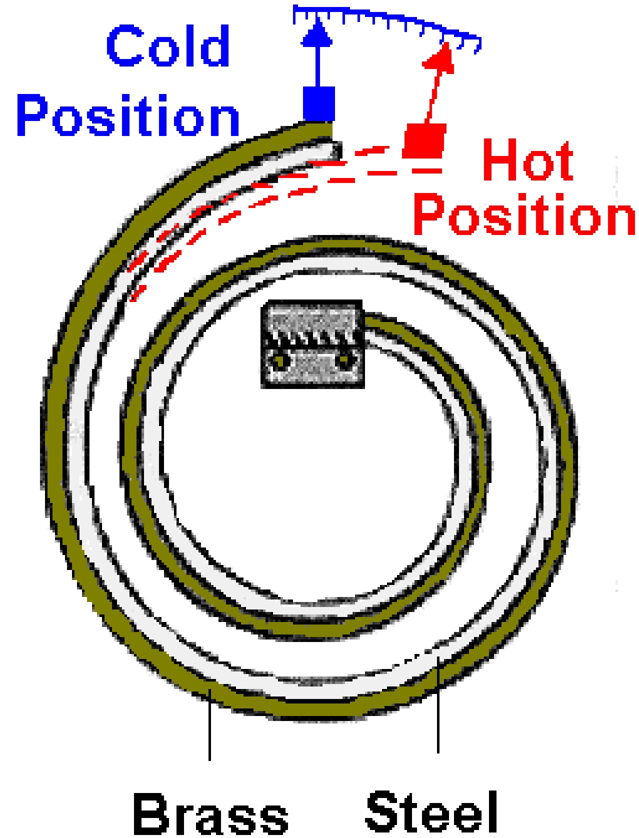


Expansion thermometers- **Bimetallic Thermometer**

Solid expansion





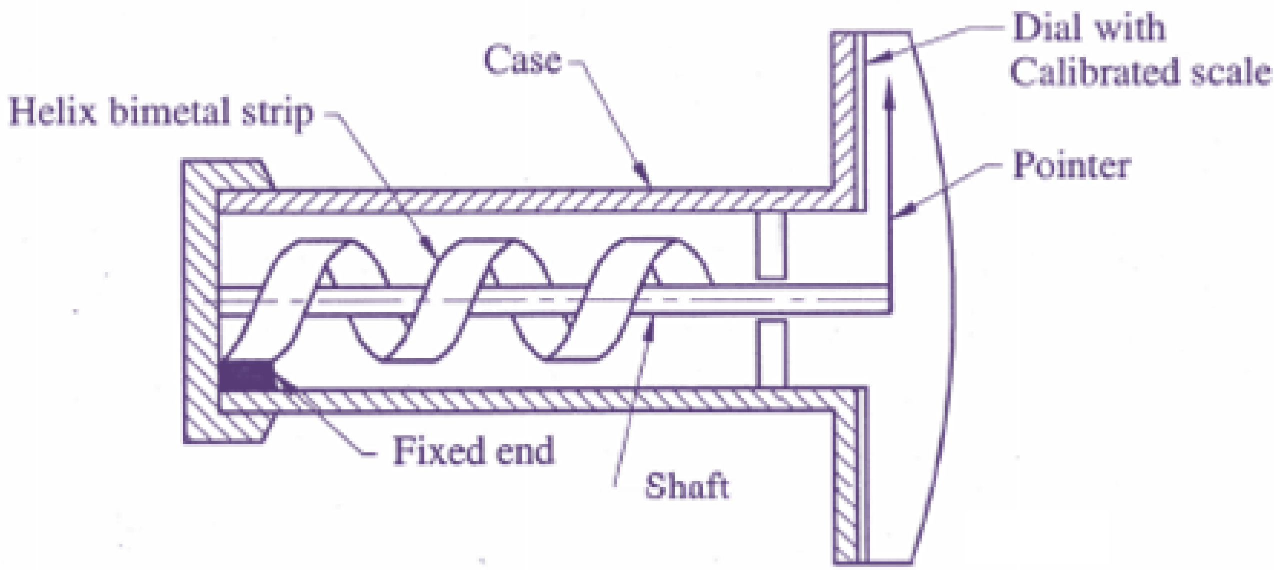

In helix bimetal strip thermometer, the strip is wound co-axially such that all turns are of same diameter as shown in Fig. 6.6. One end of strip is fastened to the case while other end is connected to the shaft. The shaft is connected to the pointer that moves on the calibrated scale.

Main **advantage** of spiral or helix metallic thermometer is compactness while providing a long length of strip necessary for adequate indicator movement.

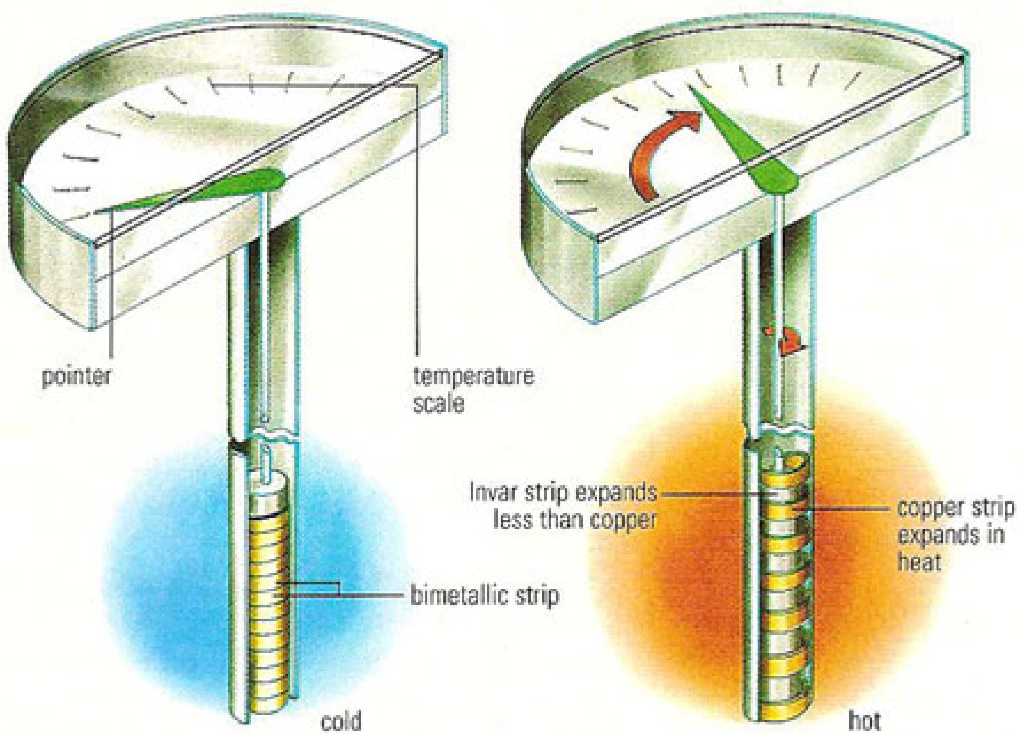
**Working temperature range accuracy of bimetallic thermometer :**

Low temperature : –30°C to 220°C, accuracy : 1% of scale range.

High temperature : 0°C to 550°C, accuracy : 2% of scale range.




*Helical bimetal strip thermometer*



# Expansion thermometers- **Bimetallic Thermometer**

# Solid expansion

**Advantages :**

(i) Simple and robust (not easily broken)
(ii) Relatively less costly.
(iii) Easily installed and maintained
(iv) Good accuracy relative to cost ( $\pm$ 2% for process type instruments and $\pm$ 0.5% for laboratory type instruments.
(v) Considerably wide temperature range.

**Disadvantages :**

(i) Accuracy is not as high as mercury in glass thermometer.
(ii) It is to be mounted at the point of temperature measurement.
(iii) Remote indication of temperature can't be obtained.
(iv) Possibility of calibration change due to rough handling.

**Applications :**

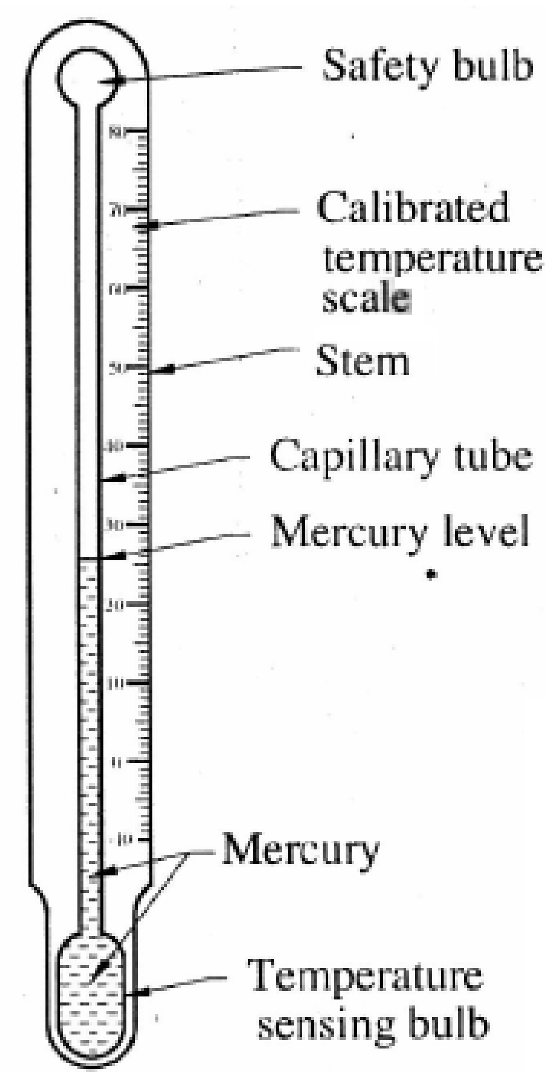
(i) The bimetallic strips find wide applications in simple thermometers in which deflection of the strip is made to open or close electrical contacts in the electrical heat supply to control a gas flow.
(ii) As switching devices used in electric irons, car winkler lamps, domestic oven and the refrigerators.
(iii) Bimetallic thermometer can be used where local temperature indication is required and point of measurement is easily accessible.

| Material | Expansion coefficient (k) |
| --- | --- |
| Aluminum | $25 \cdot 10^{-6}$°C |
| Copper | $16.6 \cdot 10^{-6}$°C |
| Steel | $6.7 \cdot 10^{-6}$°C |
| Beryllium/copper | $9.3 \cdot 10^{-6}$°C |

*Table Thermal Expansion Coefficient*

# Liquid in Glass Thermometers

- Liquid in glass thermometer works based on the principle that liquid expands as the temperature of liquid rises. The expansion causes the liquid to rise in the tube and the rise in height of liquid is used as a measure of the temperature.
- It consists of a glass stem having a fine uniform bore capillary, having a thin walled glass bulb at lower end.
- The bulb may be cylindrical or spherical in shape and has volumetric capacity very large as compared to that of the capillary. The liquid that fills the bulb and part of capillary is usually mercury.



# Liquid in Glass Thermometers

- After filling capillary open end of the capillary is sealed off under vacuum such that no air is left in the capillary. Sometime the top of capillary tube having the bulb to provide safety against accidental breakage of thermometer due to excessive expansion of mercury in case the temperature range of instrument is exceeded.

- For temperature measurement the bulb of thermometer is immersed in the system (fluid) whose temperature is to be measured. The heat from the system is transferred to mercury. Due to heating of mercury, it expands. Since the volumetric capacity of capillary smaller than that of bulb, hence expansion of mercury causes rise in mercury level inside capillary. The level of mercury in the capillary indicates the temperature of calibrated scale glass stem.

# Liquid in Glass Thermometers

- The desirable properties of liquid used in a glass thermometer:

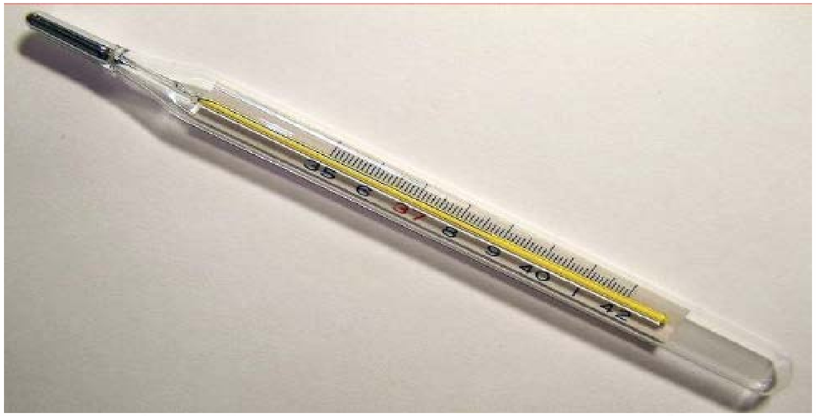
(i) Temperature - dimensional relationship should be linear. So, we can use a linear scale for dimension.

(ii) The liquid should have a greater co-efficient of expansion.

(iii) The liquid should be visible and not adhere to the glass capillary tube.

(iv) The liquid should having broad temperature span between its freezing and boiling temperatures.

# Liquid in Glass Thermometers



**Advantages of liquid in glass thermometer :**

(i) Low cost and portable
(ii) Simple to use
(iii) No auxiliary power require to use
(iv) Less space is required.

**Disadvantages :**

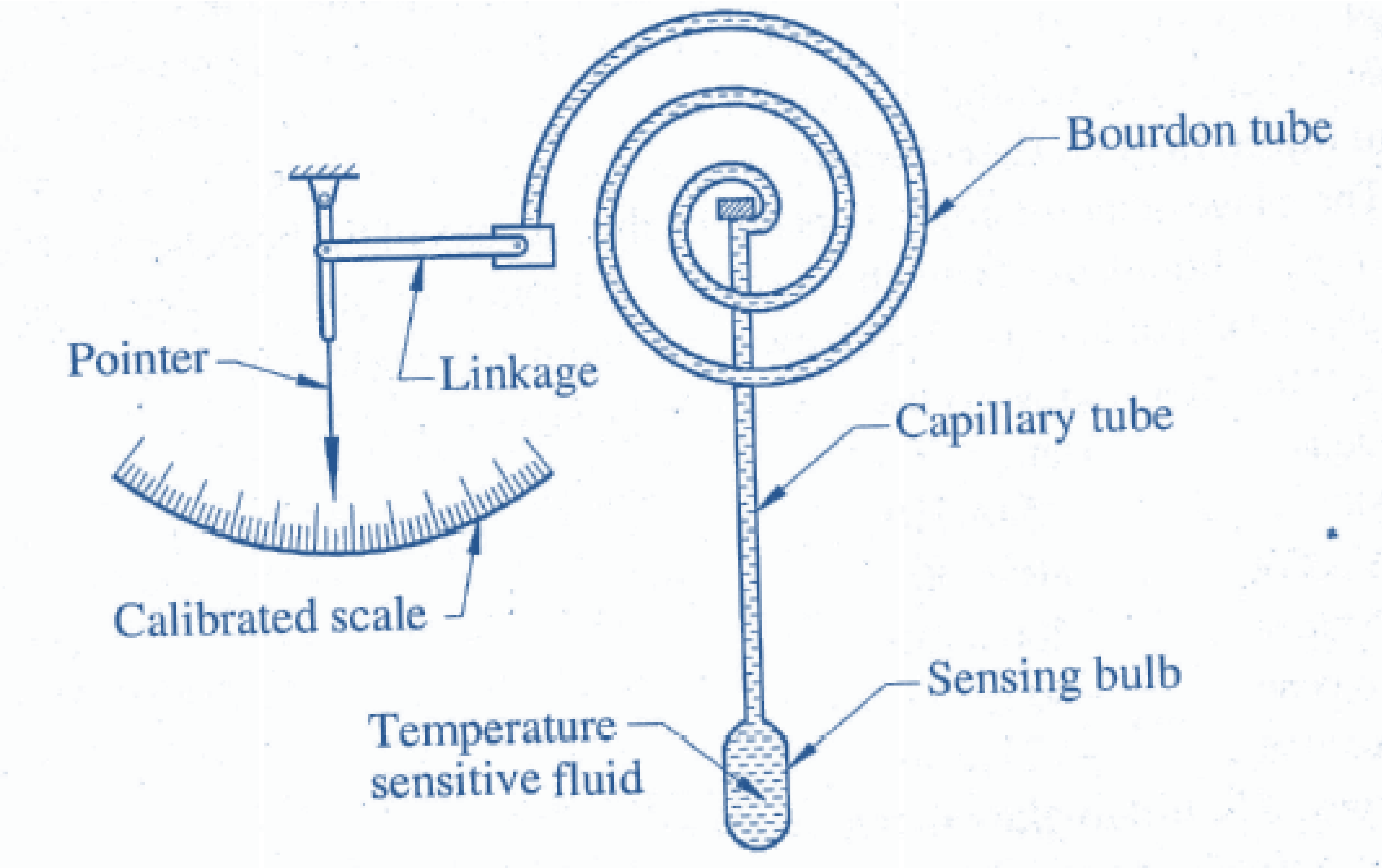
(i) Glass is very fragile (easy to break) and hence proper handling is required.
(ii) Accuracy of temperature measurement depends on position of thermometer and amount of immersion.
(iii) The scale of thermometer is not exactly linear because expansion or contraction of glass envelope, and co-efficient of expansion of mercury varies with temperature.
(iv) It is to be mounted near to the point of measurement and lack of adaptability in remote reading.
(v) Range limited to 600°C.
(vi) Difficult to read.
(vii) Poor response against variation in temperature.

**Applications :** Liquid in glass thermometer is used for temperature measurement in open tank containing liquids, molten-metal baths, steam lines, air ducts and pipe lines for fluid flow.

| *Liquid* | *Range ($^0C$)* |
|---|---|
| Mercury | -35 to 510 |
| Alcohol | -80 to 70 |
| Toluene | -80 to 100 |
| Pentane | -200 to 30 |
| Creosote | -5 to 200 |

*Table  Liquids used in Glass Thermometers*

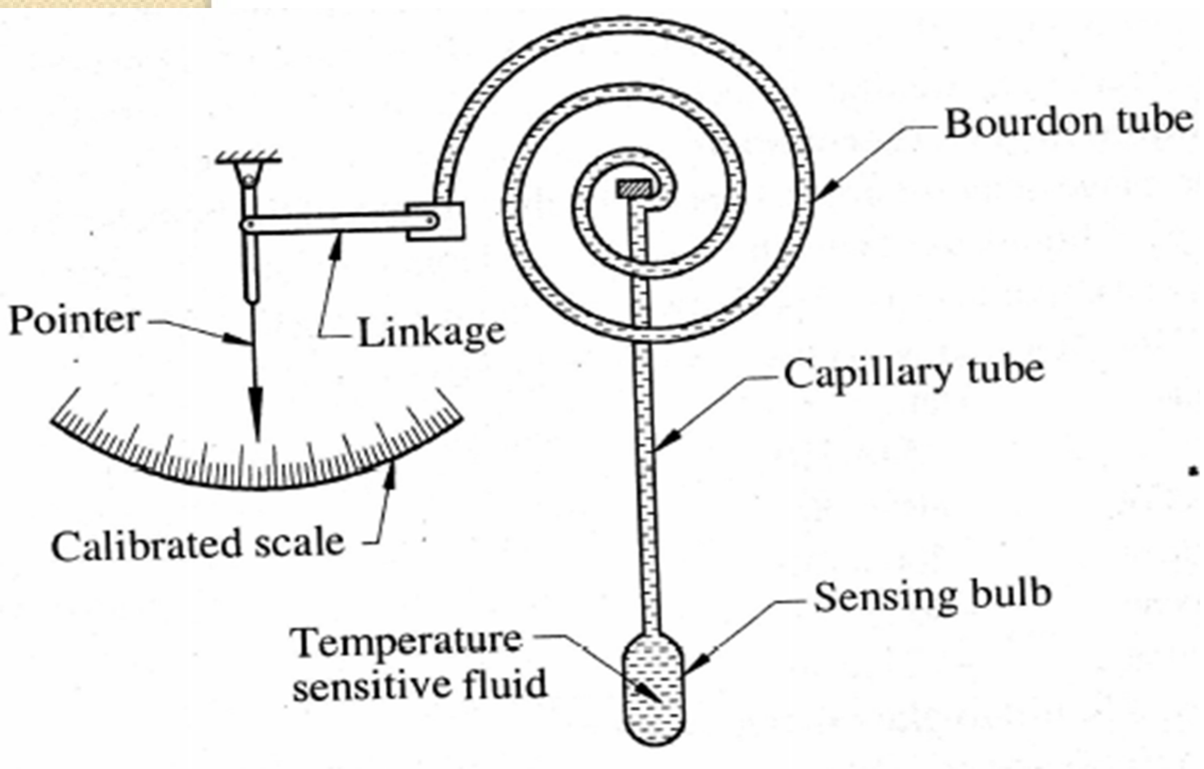
# Filled system or pressure spring thermometers



# Filled system or pressure spring thermometers

The fluid filled thermometers may be divided into four classes :

1. Liquid filled thermometers
2. Mercury filled thermometers
3. Gas filled thermometers
4. Vapour pressure thermometers



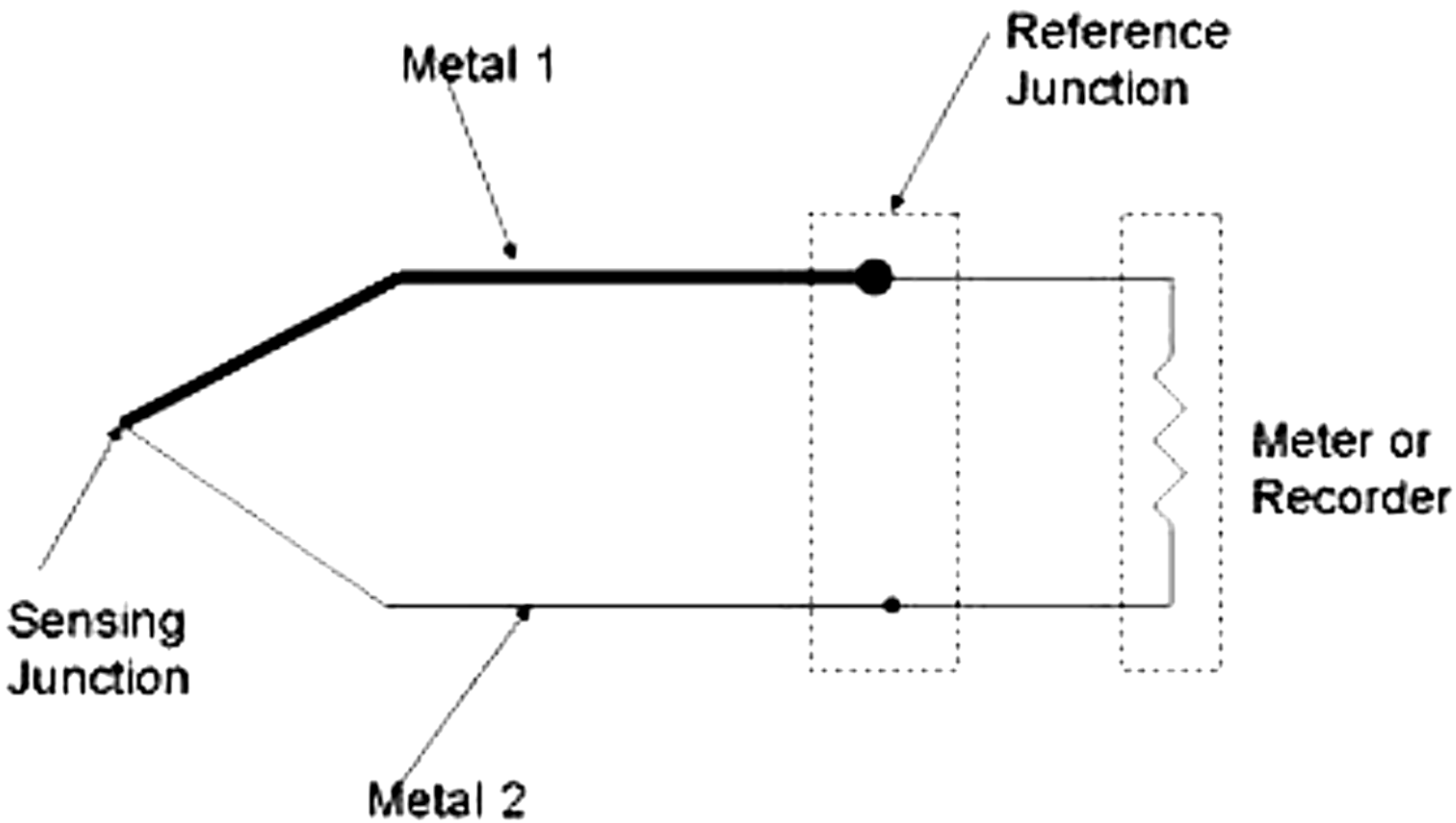
# Filled system or pressure spring thermometers


# Electrical temperature instruments

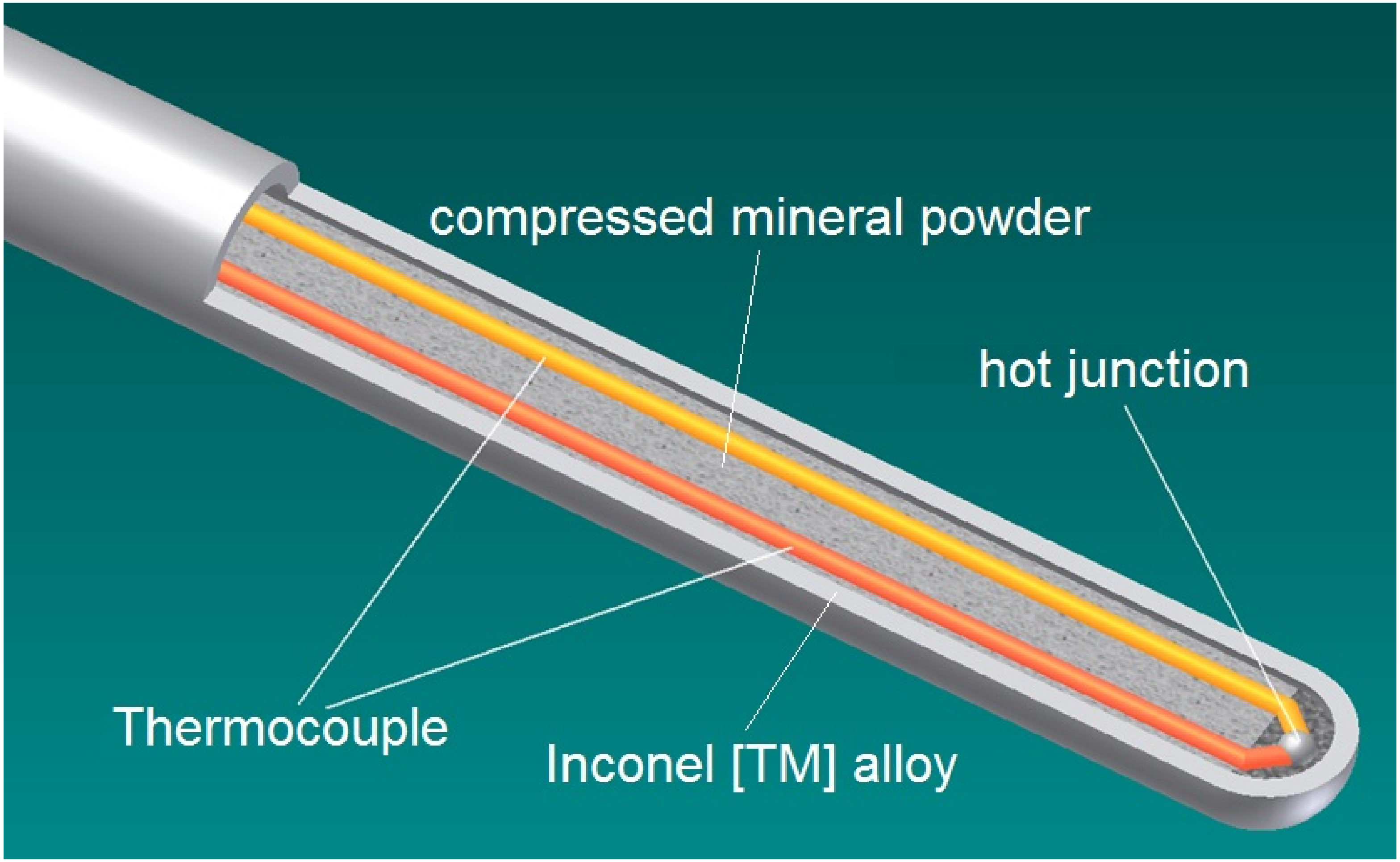
- In electrical methods of measuring temperature, the temperature signal is converted into electrical signal either through a change in resistance or voltage, leading to a change in current development of electro-motive-force (e.m.f.). The following elements are used to convert temperature into electrical signals

| |
|---|
| **Thermocouple** |
| **Thermistor** |
| **RTD** |

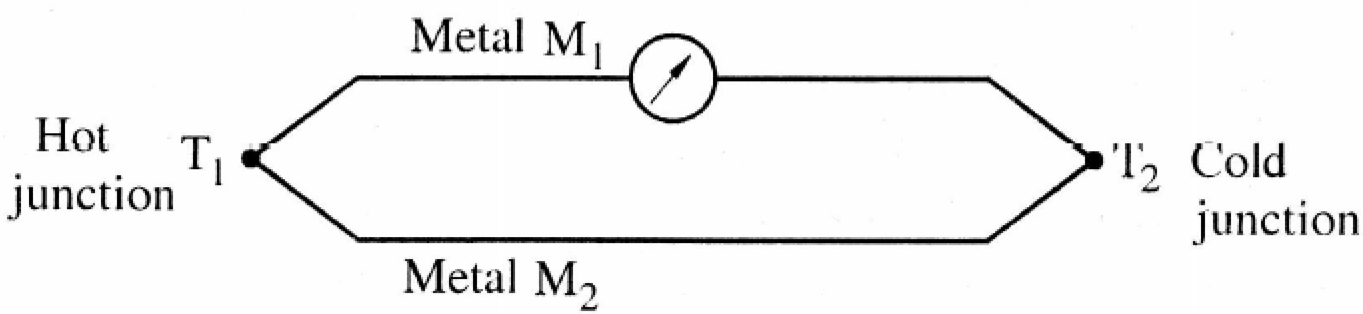
# Thermocouple



# Thermocouple



**Thermoelectric effects :** (Working principle of thermocouple) : If two wires of different metals $M_1$ and $M_2$ are joined together to form a loop (thermocouple) as shown in Fig. with one junction at temperature $T_1$ and other at temperature $T_2$, an e.m.f. is generated and if an ammeter is connected, a current flows in the circuit. This phenomenon is called the ***Seebeck effect***. The magnitude of emf generated depends on the temperatures of the junctions $T_1$ and $T_2$ and the materials of $M_1$ and $M_2$. One of the two junctions is usually maintained at some constant known temperature (reference junction). The output voltage of the circuit then indicates the temperature difference relative to the reference temperature. Normally, the ice point of water (0°C) is selected as a reference junction.




***Seebeck effect - basic thermocouple circuit***

changes in temperature the See beck voltage is linearly proportional to temperature:

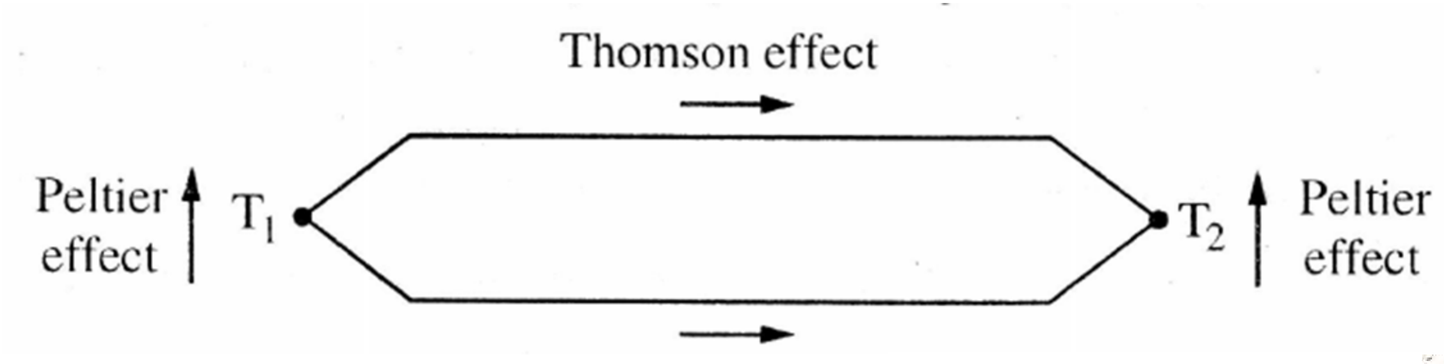
$$e^{AB} = \alpha T$$

Where α, the See beck coefficient, is the constant of proportionality.

# Thermocouple effects

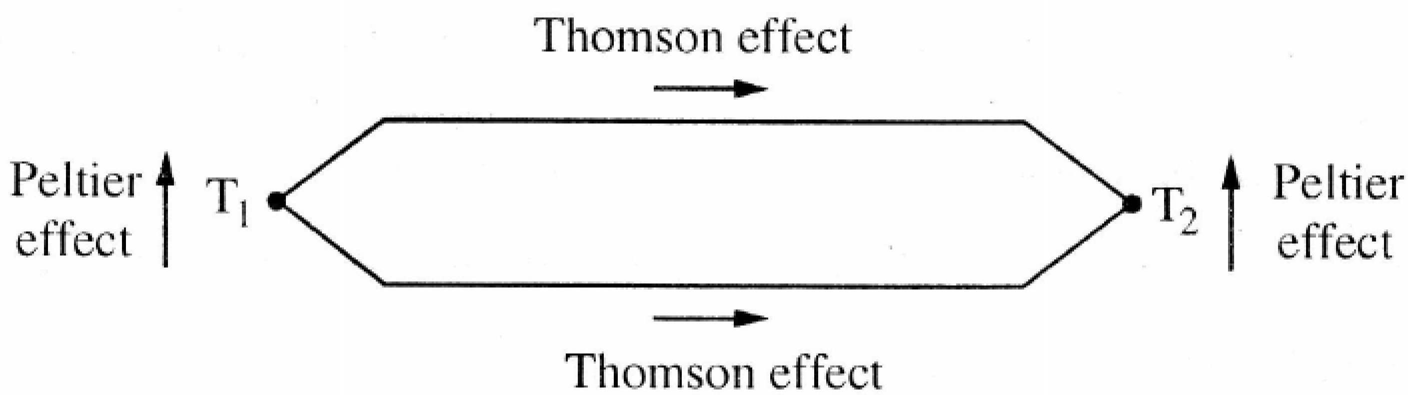
**Peltier effect:**

- The temperatures T1 and T2 of junctions slightly change if the thermoelectric current is allowed to flow in the circuit.
- Heat is generated at cold junction and is absorbed from the hot junction thereby heating the cold junction slightly and cooling the hot junction slightly.
- This phenomenon is called Peltier effect.
- This effect takes place whether the current is introduced extremely or is induced by the thermocouple itself.



# Thermocouple effects

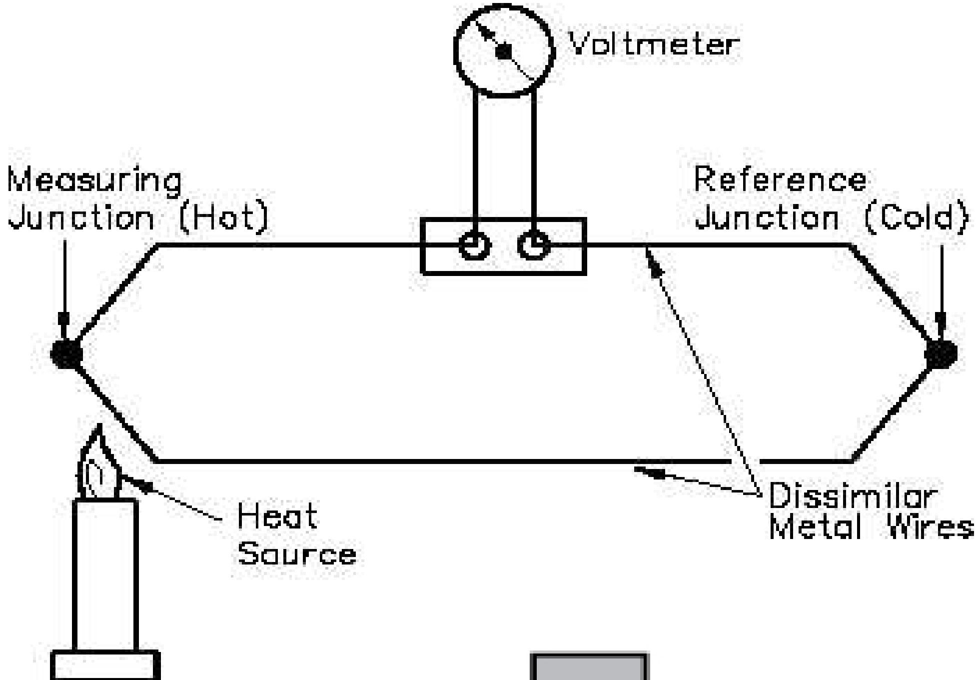
**Thomson effect :** The junction emf may be slightly changed if the temperature gradient exist along either or both the materials. This phenomenon is called Thomson effect.

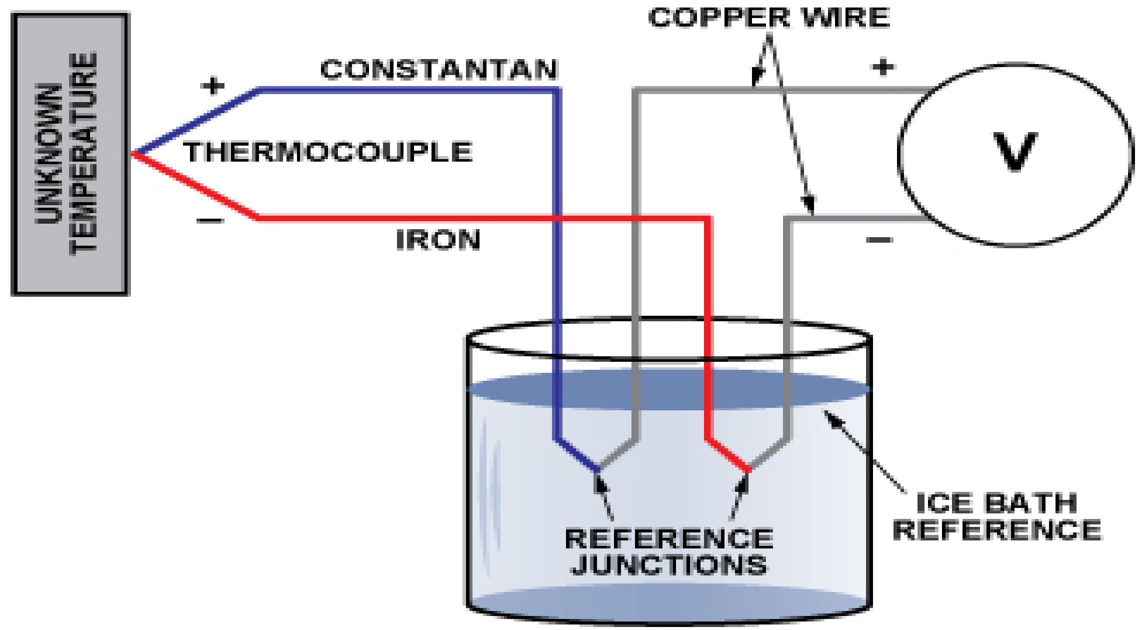



Seebeck emf causes by junction of dissimilar metals

Peltier emf causes by a current flow in circuit

Thomson emf causes by a temperature gradient in the material


Voltmeter
Measuring
Junction (Hot)
Reference
Junction (Cold)
Heat
Source
Dissimilar
Metal Wires

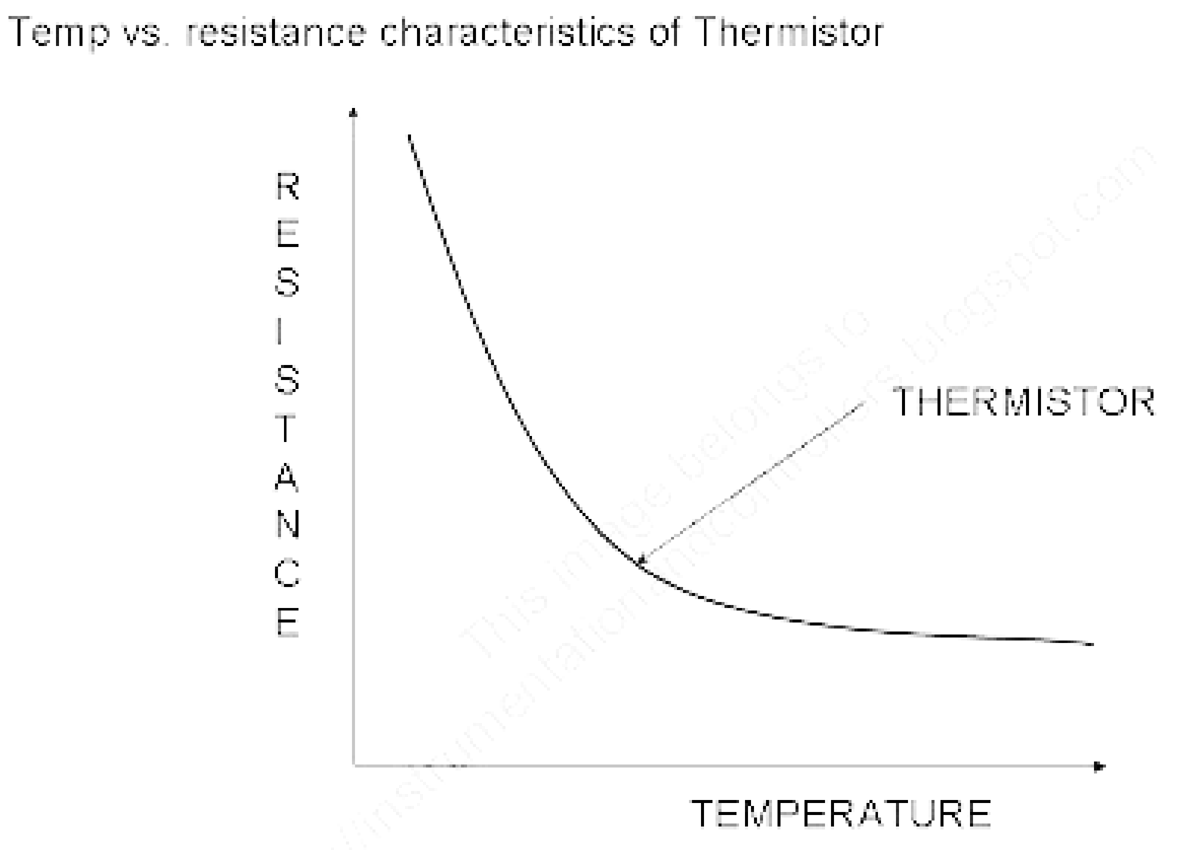

UNKNOWN
TEMPERATURE
CONSTANTAN
THERMOCOUPLE
IRON
COPPER WIRE
+
−
+
−
V
REFERENCE
JUNCTIONS
ICE BATH
REFERENCE

| Material | Maximum operating temperature(°C) |
|---|---|
| Mild steel | 900 |
| Nickel-chromium | 900 |
| Fused silica | 1000 |
| Special steel | 1100 |
| Mullite | 1700 |
| Rectrystallized alumina | 1850 |
| Beryllium | 2300 |

# Thermistors

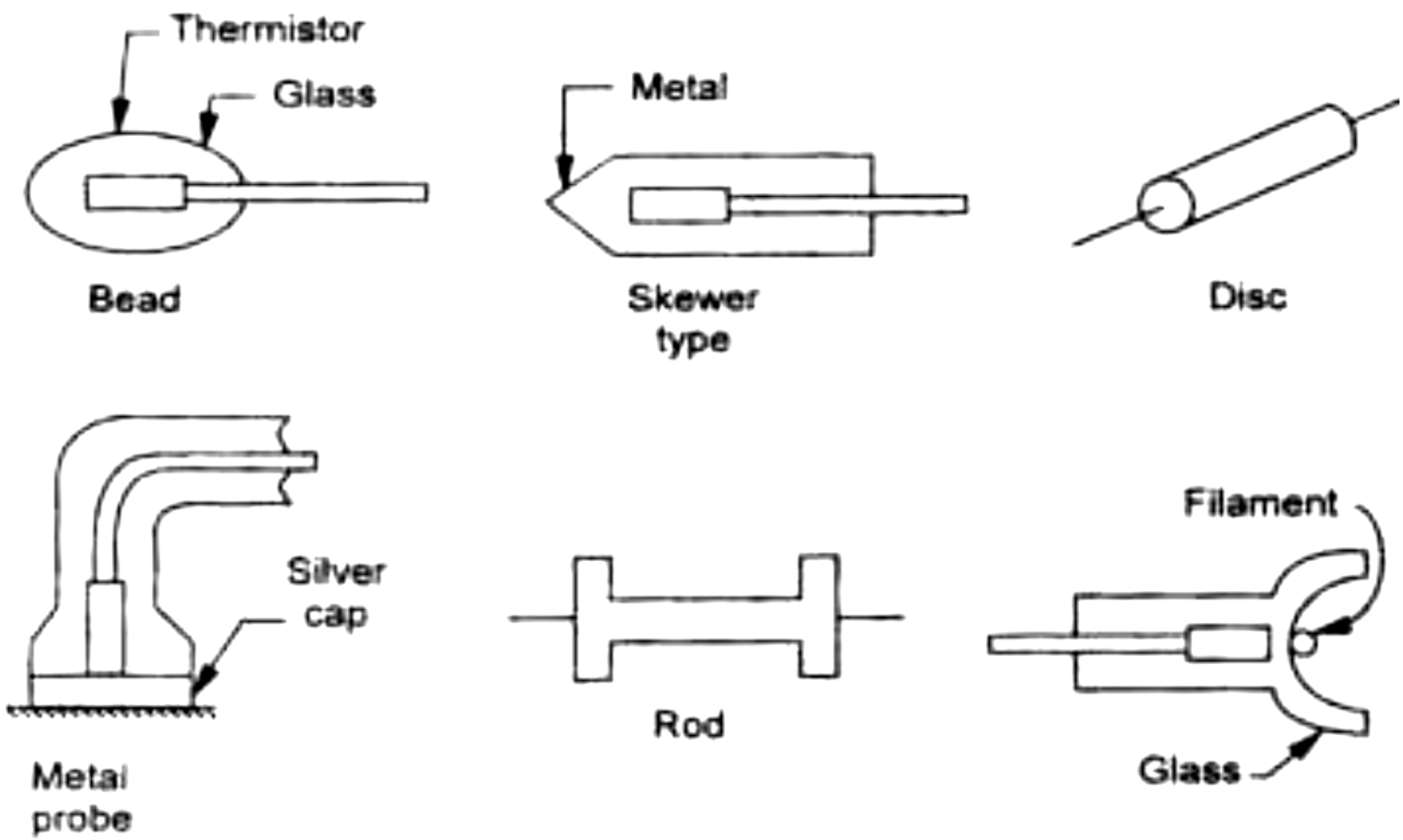
- Thermistor is a contraction of term "Thermal Resistor". They are essentially semiconductors which behave as registers with a high negative temperature coefficient.
- As the temperature increases, the resistance goes up. This is just opposite to the effect of temperature changes on metals.
- A high sensitivity to temperature changes (decrease in resistance as much as 6% for each 10C rise in temperature in some cases) makes the thermistors extremely useful for precision temperature measurement.

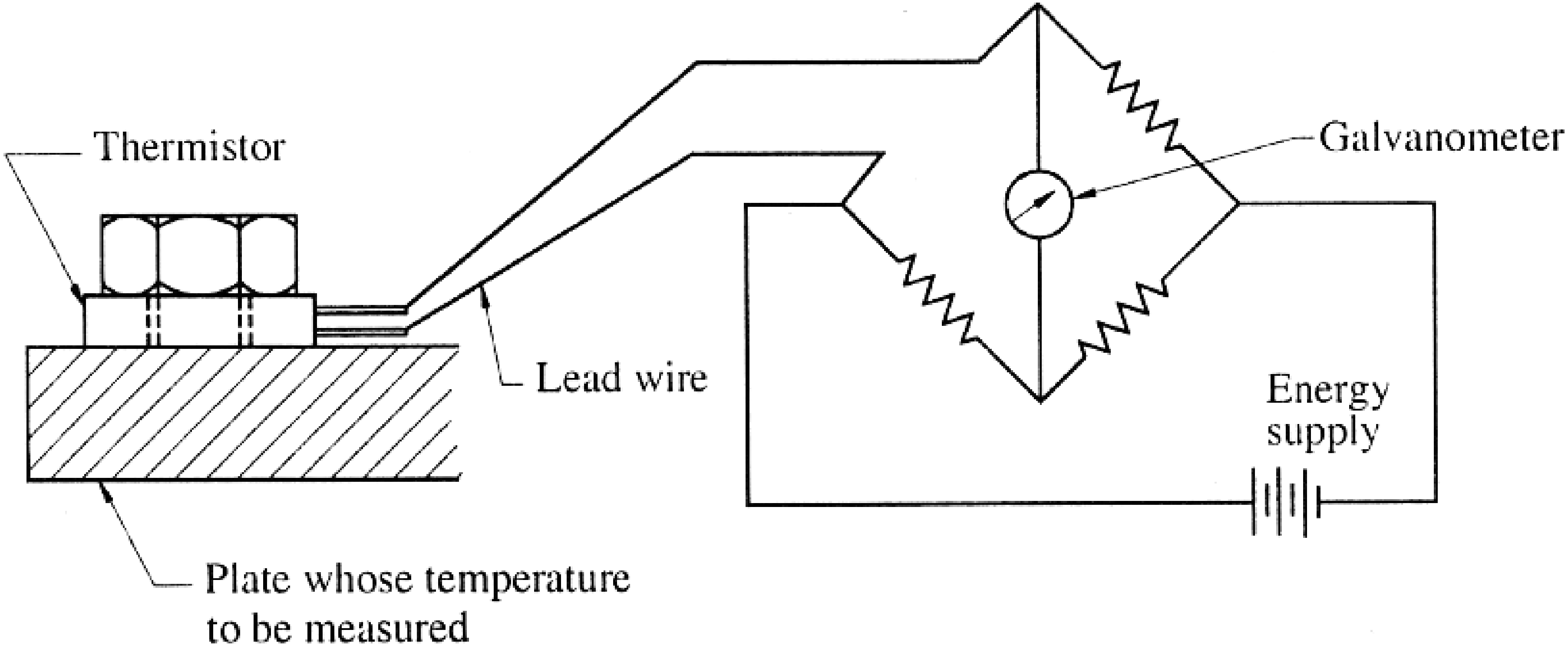
1. Positive Temperature Coefficient Thermistor. (PTC)
2. Negative Temperature Coefficient Thermistor.(NTC)




**Negative Temperature Coefficient Thermistor.(NTC)**

# Types of Thermistors






# Thermistor with Wheatstone bridge circuit

# Thermistors

- The thermistors are composed of metal oxides. The most commonly used oxides are those of manganese, nickel, cobalt, iron, copper and titanium.
- The fabrication of commercial NTC thermistors uses basic ceramics technology and continues today much as it has for decades.
- In the basic process, a mixture of two or more metal oxide powders are combined with suitable binders, are formed to a desired geometry, dried, and sintered at an elevated temperature.
- By varying the types of oxides used, their relative proportions, the sintering atmosphere, and the sintering temperature, a wide range of resistivity and temperature coefficient characteristics can be obtained.

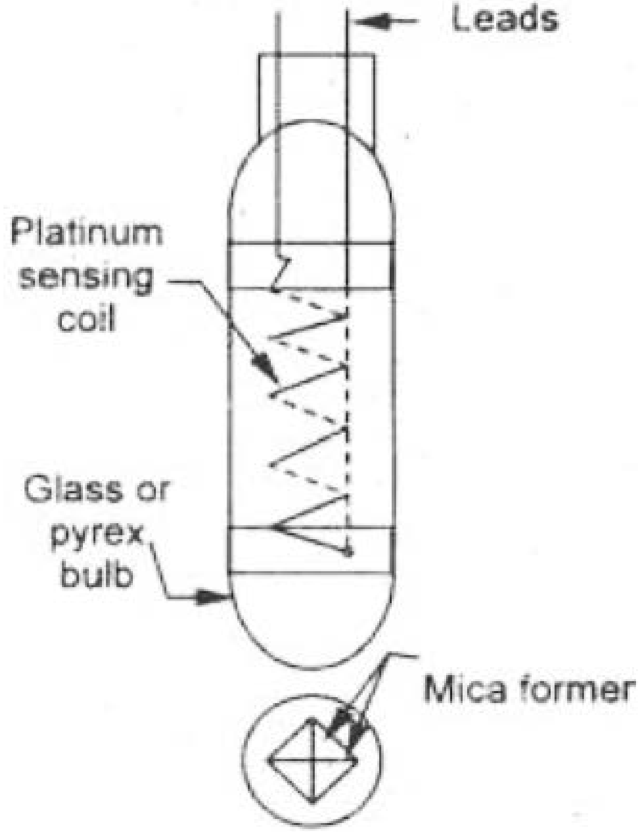
# Metal resistance thermometer

- This thermometer is an instrument used to measure the temperature variation in control room.

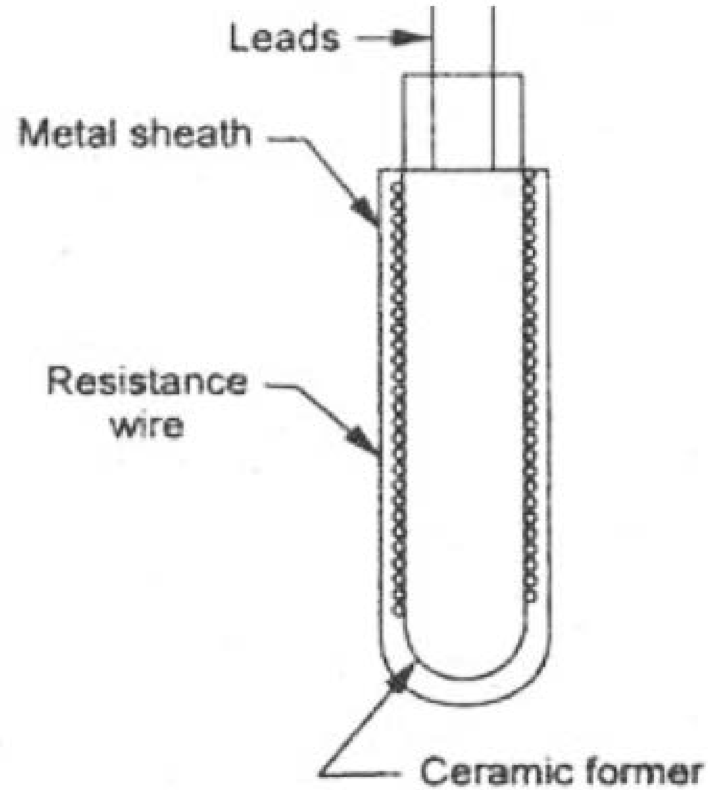
**Working principle**

- In each metallic conductor, their resistance changes when its temperature is changed.
- By calculating the variation in resistance, the temperature variations may be calculated.
- The thermometer which utilizes this phenomenon is called “resistance thermometer”.

# RTD

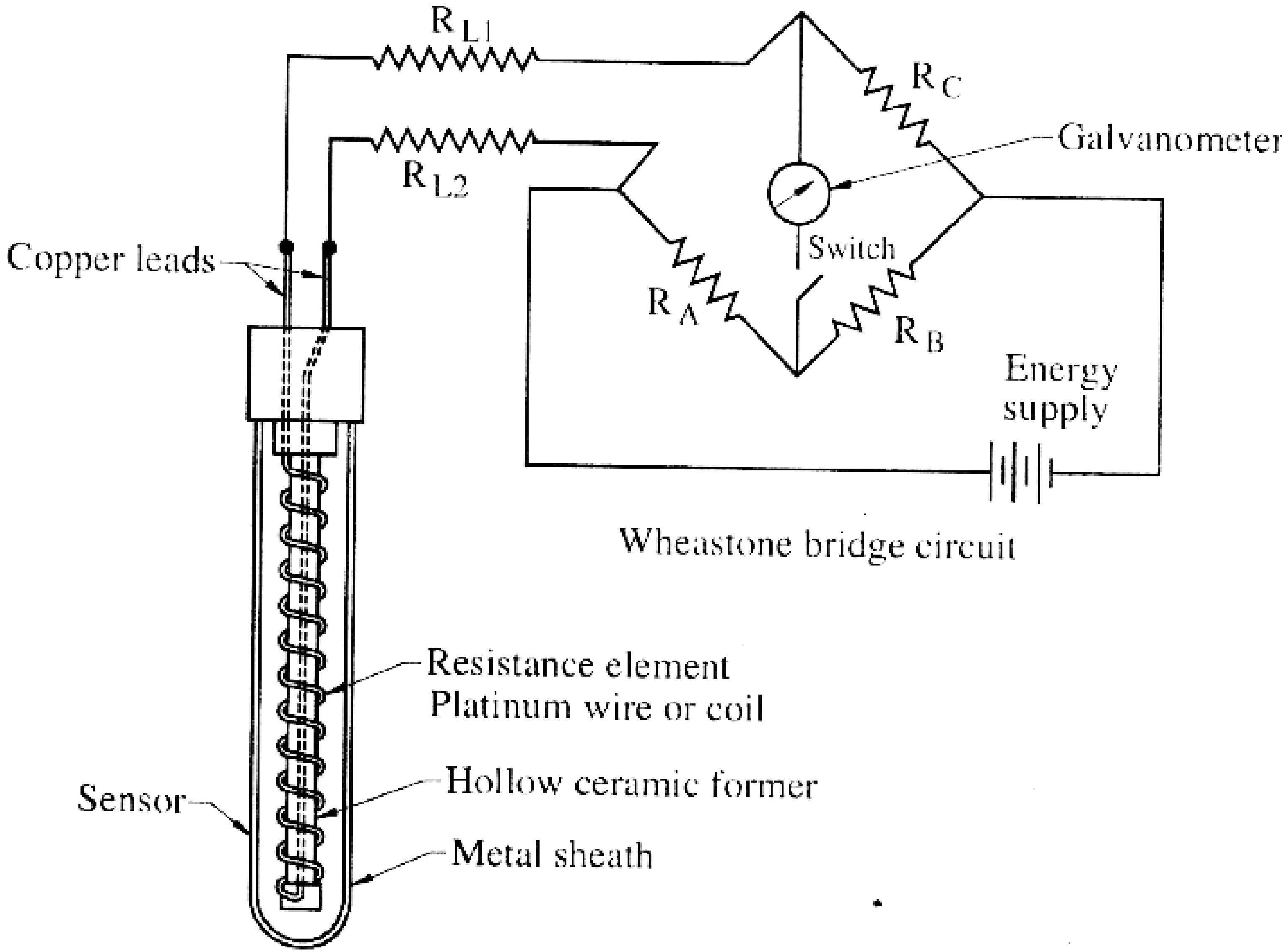



*(A) Laboratory type*




*(B). Industrial type*

# RTD



R L1
R L2
R C
Galvanometer
Copper leads
Switch
R A
R B
Energy supply
Wheastone bridge circuit
Resistance element
Platinum wire or coil
Hollow ceramic former
Sensor
Metal sheath

# RTD

Initial resistance is measured by using Wheatstone bridge. Probe tip of the RTD is placed near the heat source. Outer cover uniformly distributes heat to sensing resistance element. As the temperature varies, the resistance of the material also varies. Now, final resistance is again measured. From the above measurement, variation in temperature can be calculated as follows,

$$Rt = R0\ (1+Dt)$$

$$Dt = ((Rt/R0)-1)/x$$

Where,

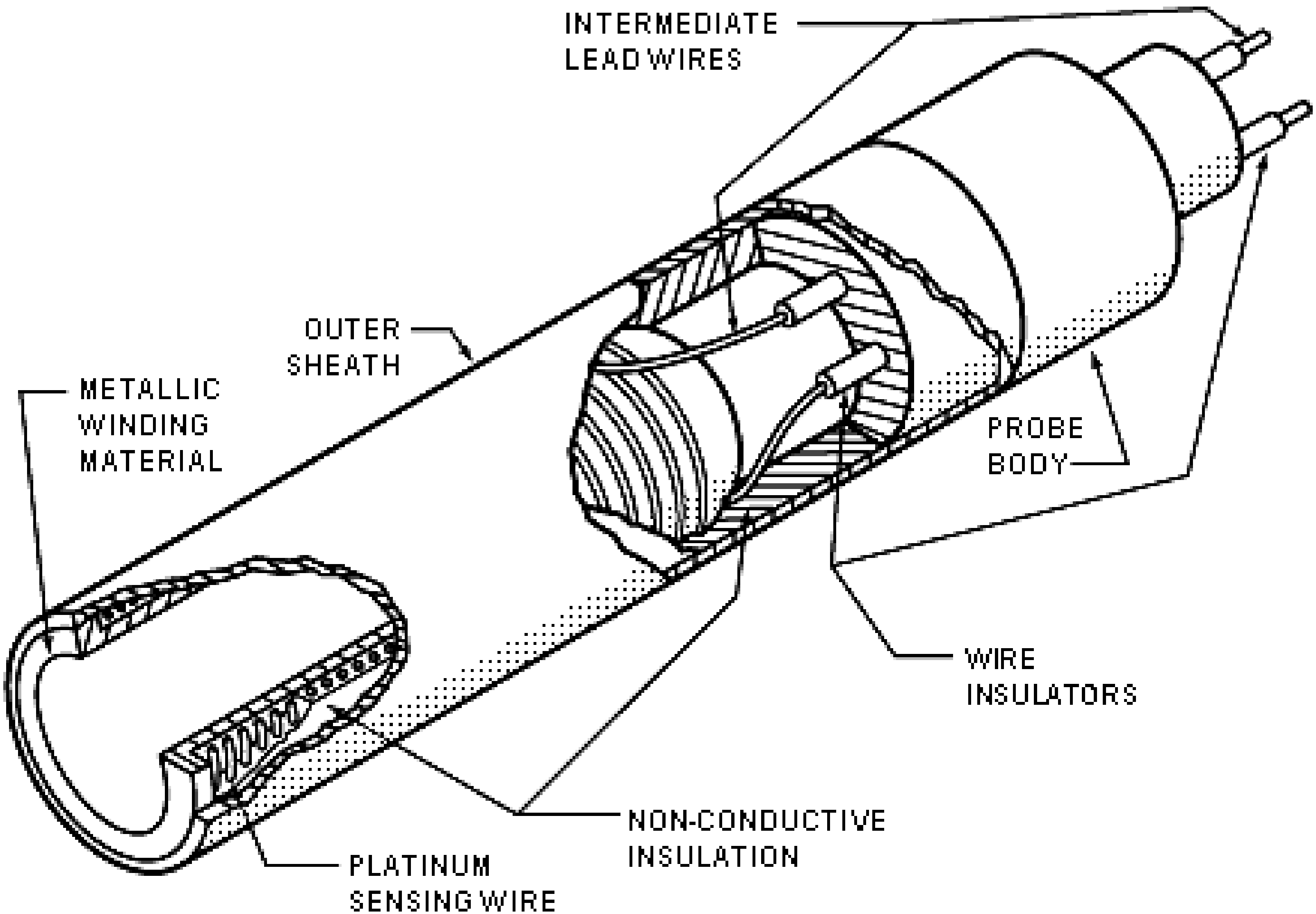
Rt = resistance at C.

R0 = Resistance at room temperature.

Dt = Difference in temperature.

X = Temperature coefficient of RTD material.

# RTD


INTERMEDIATE
LEAD WIRES
OUTER
SHEATH
METALLIC
WINDING
MATERIAL
PROBE
BODY
WIRE
INSULATORS
NON-CONDUCTIVE
INSULATION
PLATINUM
SENSING WIRE

# Pyrometers

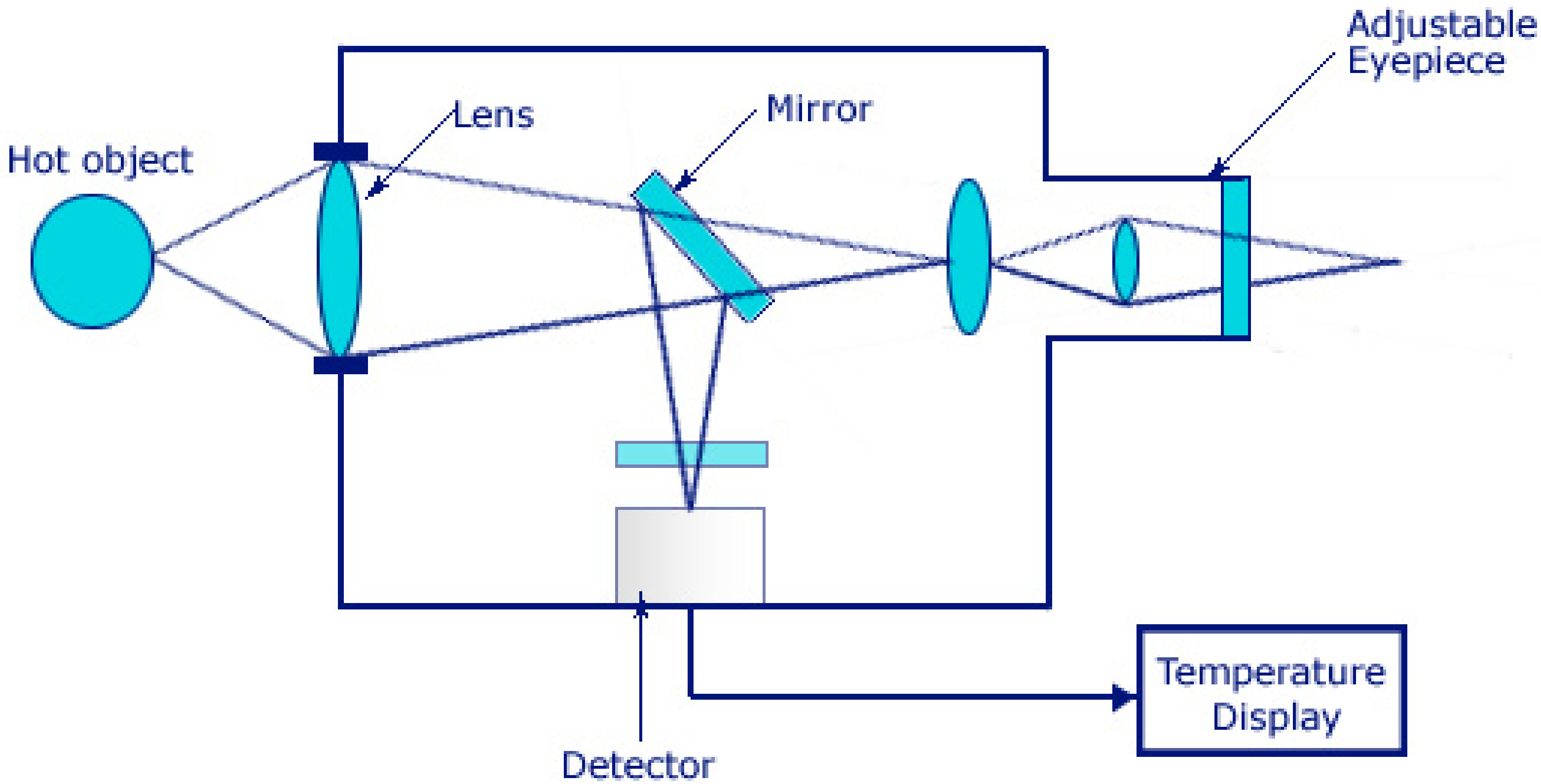
A pyrometer is a type of remote-sensing thermometer used to measure the temperature of a surface.

Various forms of pyrometers have historically existed. In the modern usage, it is a device that from a distance determines the temperature of a surface from the spectrum of the thermal radiation it emits, a process known as pyrometry and sometimes radiometry.

There are two types of pyrometer in industries:

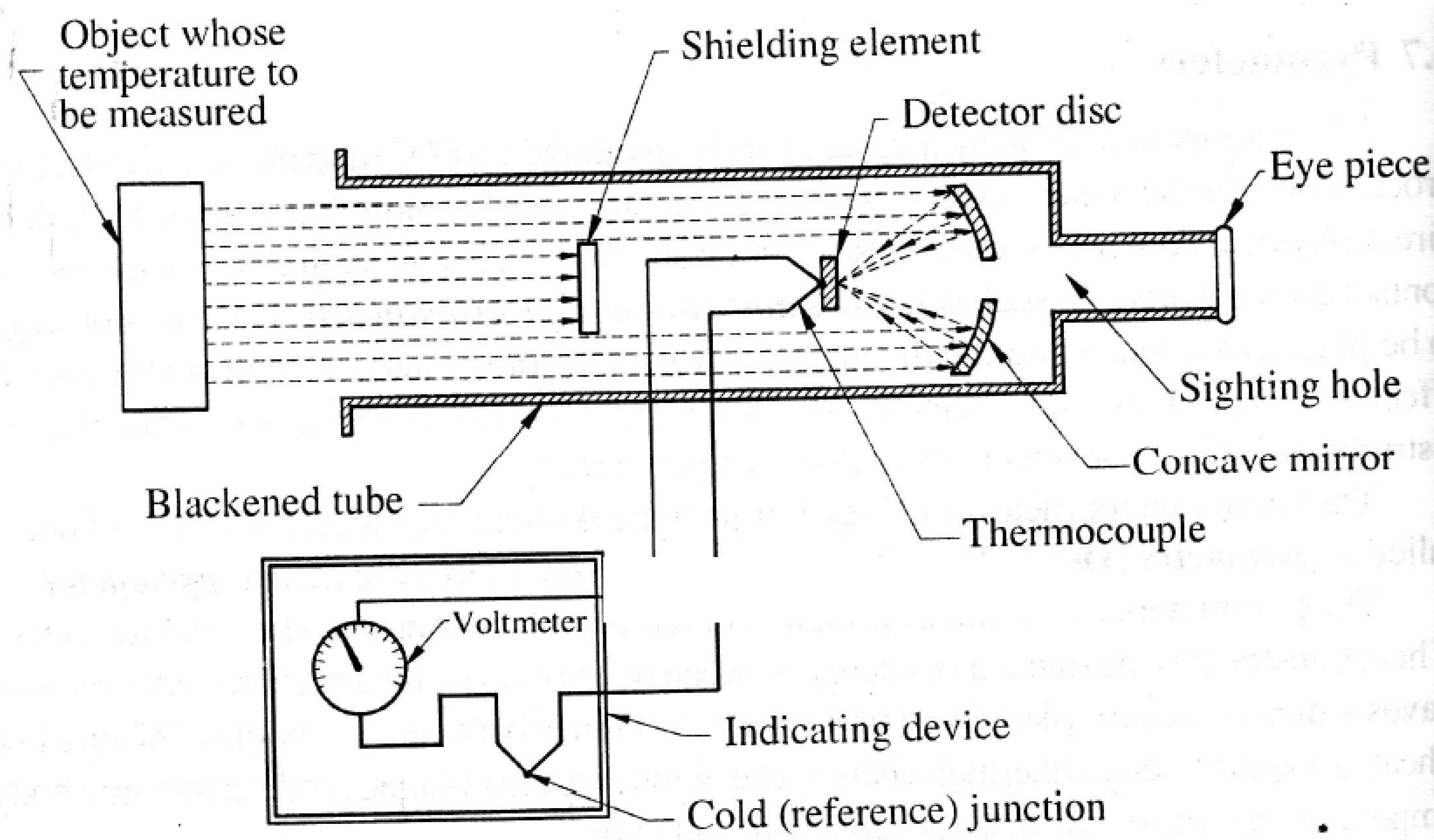
1. Total radiation pyrometer
2. Optical pyrometer

## Block Diagram of Radiation Pyrometer

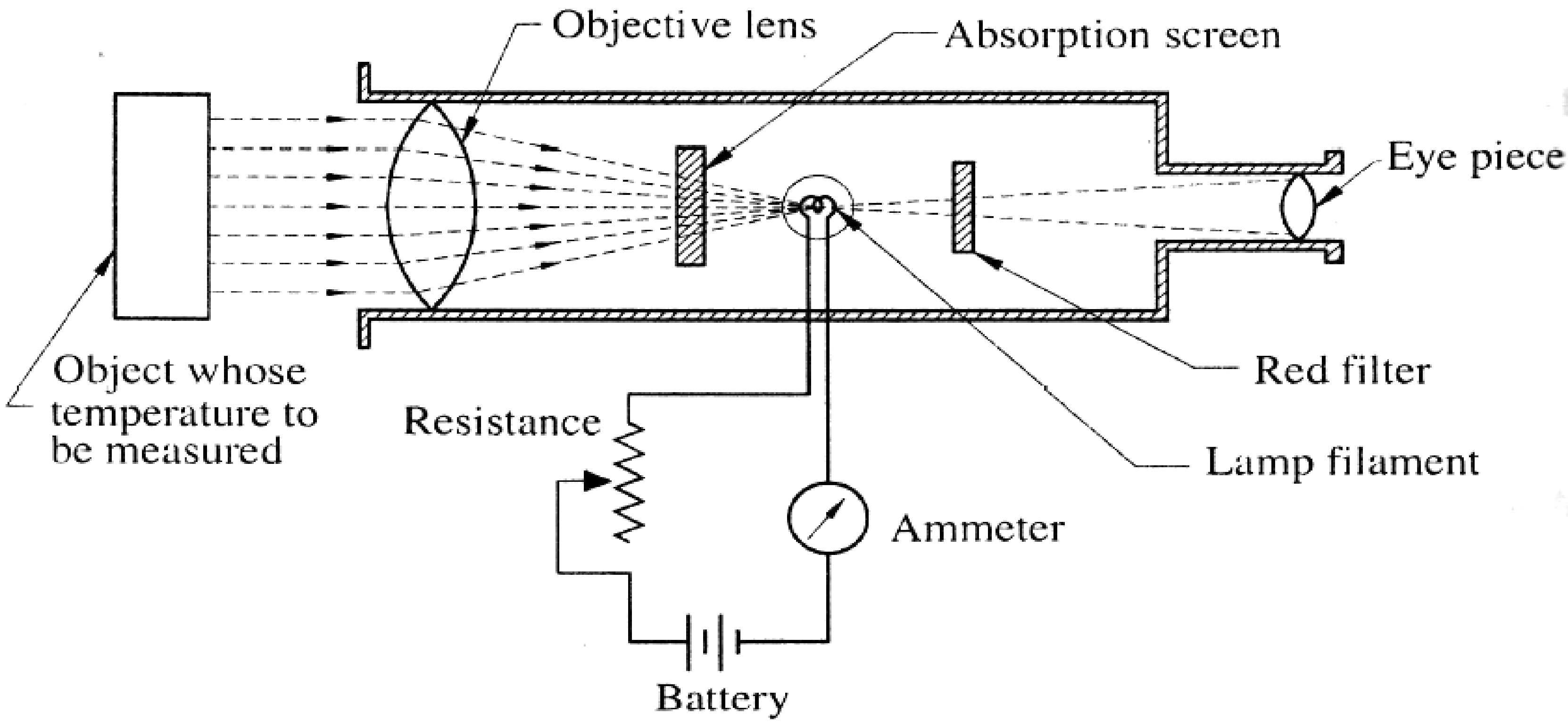


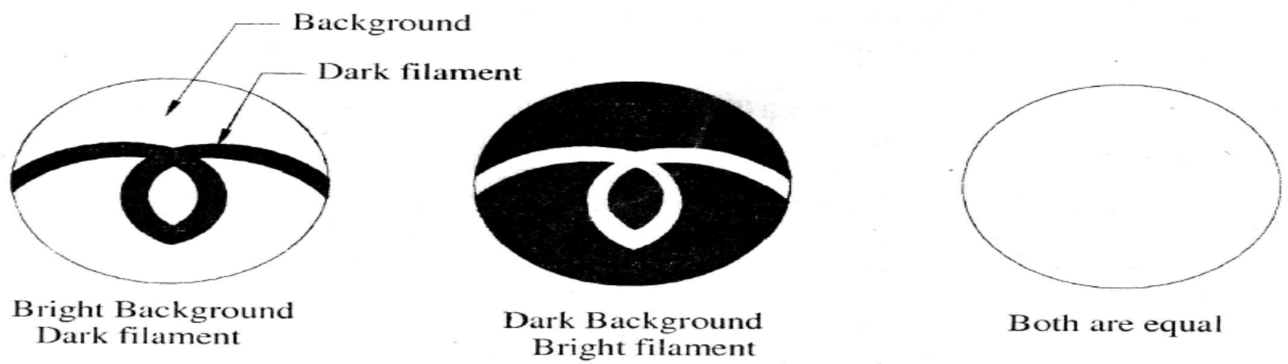

www.InstrumentationToday.com

# Total radiation pyrometer



# Optical pyrometer

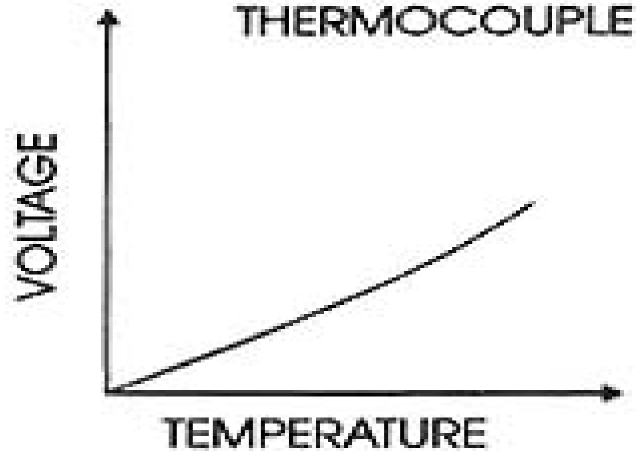


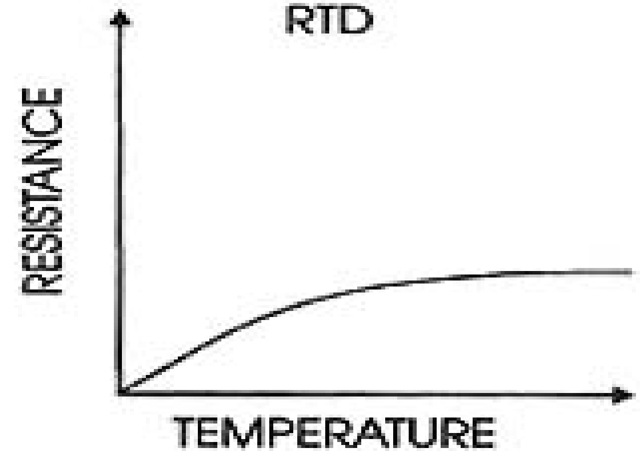



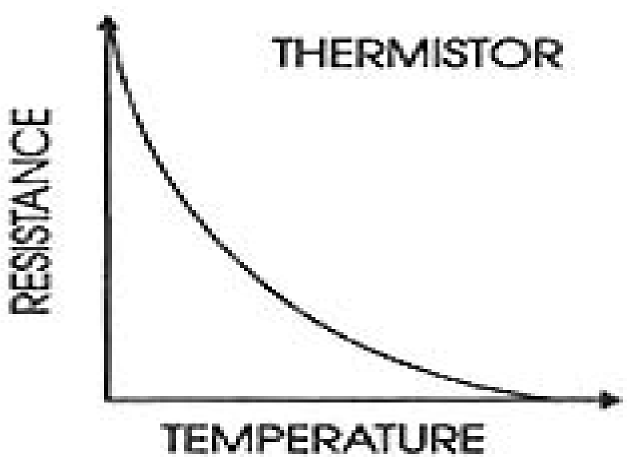

*(a) Filament to dark Low intensity*

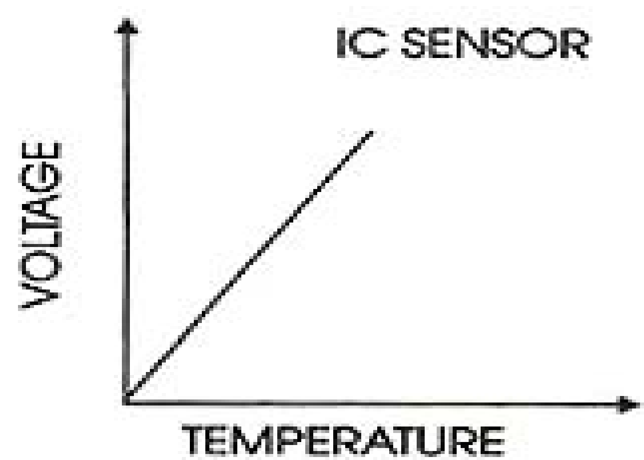
*(b) Filament Brightness in more High intensity*

*(c) correct intensity*


THERMOCOUPLE
VOLTAGE
TEMPERATURE


RTD
RESISTANCE
TEMPERATURE


THERMISTOR
RESISTANCE
TEMPERATURE


IC SENSOR
VOLTAGE
TEMPERATURE

| Criteria | RTD | Thermistor | Thermocouple |
| --- | --- | --- | --- |
| Temperature range | -250°C to +750°C | -100°C to +500°C | -267°C to +2316°C |
| Accuracy | Best | Depends on calibration | Good |
| Linearity | Good | Worst | Good |
| Sensitivity | Less | Best | Worst |
| Circuitry | Complex | Depends on accuracy/power requirements | Complex |
| Power consumption | High when taking measurement | | Low-high |