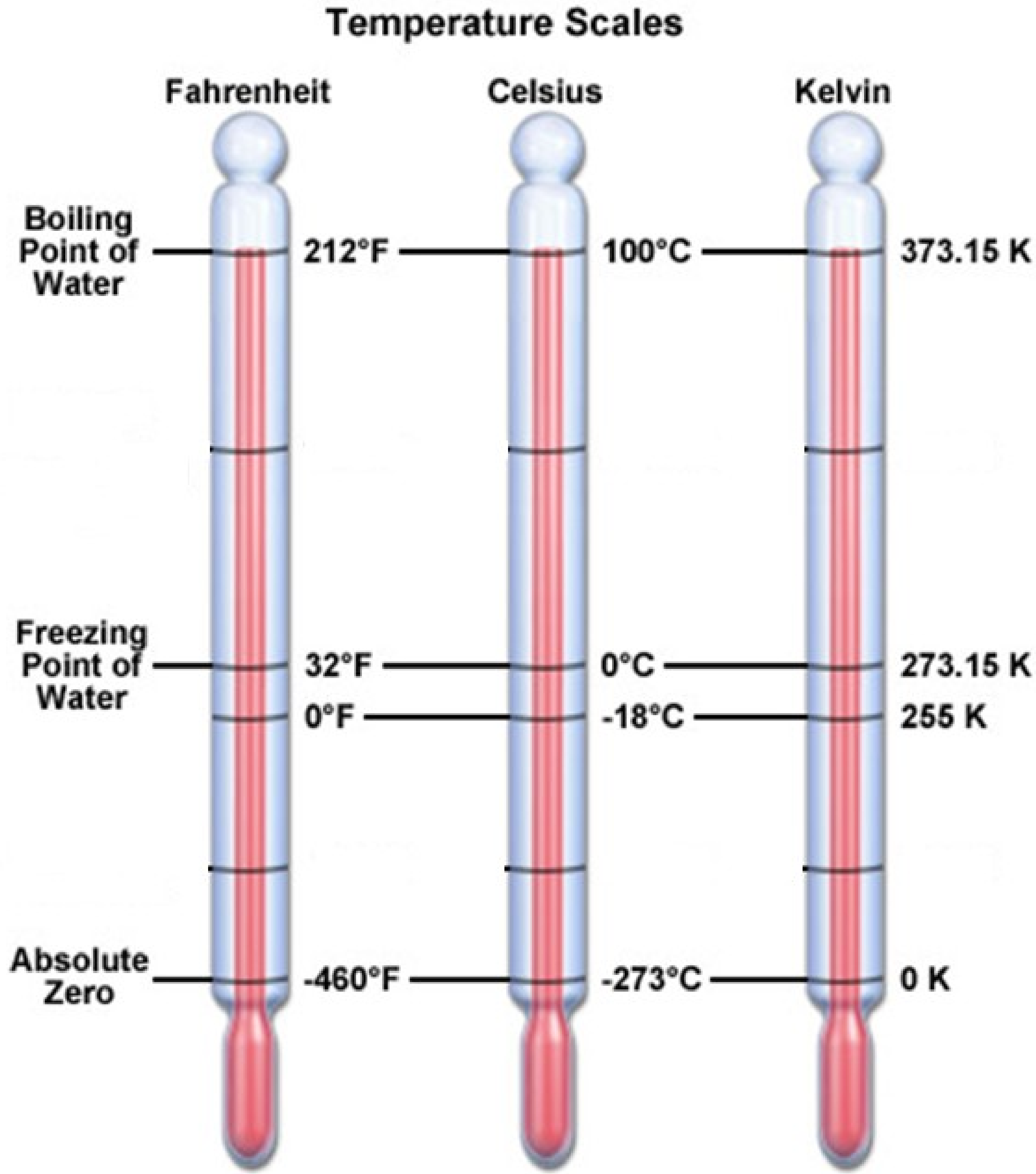
- The means of accurately measuring temperatures has long fascinated people.
- One of the differences between temperature and other physical concepts, such as mass or length, is that it is subjective.
- Different people will have different perceptions of what is hot and what is cold.
- To make objective measurements, we must use thermometer in which some physical property of a substance changes with temperature in a reliable and reproducible way.

Scale

- Temperature is a measure of the thermal energy in the body. Normally measured in degrees [°]using one of the following scales.

1. Fahrenheit.[°F]
2. Celsius or centigrade. [°C]
3. Kelvin .[°K]


Temperature Scales
Fahrenheit
Celsius
Kelvin
Boiling Point of Water
212°F
100°C
373.15 K
Freezing Point of Water
32°F
0°C
273.15 K
0°F
-18°C
255 K
Absolute Zero
-460°F
-273°C
0 K

Temperature measurement

- The following characteristics can be used to measure the temperature
  - A change in dimentions - expansion or contraction of material w.r.t. Temp change
  - A change in electrical resistance of metals and semi-conductors w.r.t. Temp change
  - A thermo-electric emf produced due to temp difference at two junctions of two metal alloy joined together
  - A change in intensity and colour of radiation emitted by the hot body w.r.t to change in temp

Expansion thermometers

- (1)Bimetalic thermometer -solid expansion
- (2)Liquid in glass thermometers

Methods of Temperature Measurement

- **Expansion Thermometer**
  - Bimetallic Thermometer (Expansion of Solid)
  - Liquid in Glass Thermometer (Expansion of Liquid)
  - Liquid in Metal Thermometer (Expansion of Liquid)
  - Gas Thermometer
- **Filled System Thermometer**
  - Liquid filled Thermometer
  - Mercury filled Thermometer
  - Vapour pressure Thermometer

- Electrical Temperature Instrument
  - Resistance Thermometer
  - Thermocouple
  - Thermistor
  - Thermopile

- Electrical Temperature Instrument
  - Resistance Thermometer
  - Thermocouple
  - Thermistor
  - Thermopile

- Other Methods of Temperature Measurement
- Quartz Thermometer
- Solid State Temperature Measurement
- Optical Fibre Temperature Measurement
- Ultrasonic Thermometer

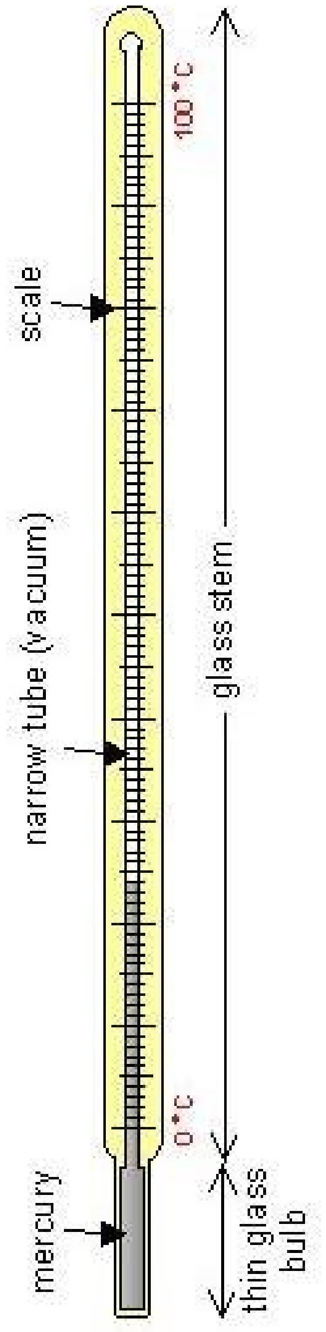
1.Liquid – in – Glass Thermometer

Construction

1.Bulb: The reservoir for containing most of the thermometric liquid (mercury).

2.Stem: The glass tube having a capillary bore along which the liquid moves with changes in temperature.

3. Scale: A narrow-temperature-range scale for reading a reference temperature .



- The volume of mercury changes slightly with temperature; the small change in volume drives the narrow mercury column a relatively long way up the tube.
- The space above the mercury may be filled with nitrogen or it may be at less than atmospheric pressure, a partial vacuum.

❖ Advantages

1) Simplicity in use & low cost.
2) Portable device.
3) Checking physical damage is easy.
4) Power source not require.

❖ Disadvantages

1) Can not used for automatic recording.
2) Time lag in measurement.
3) Range is limited to about 300 °C .

2.Bimetallic Thermometer

- In an industry, there is always a need to measure and monitor temperature of a particular spot, field or locality.

- The industrial names given to such temperature sensors are Temperature Indicators (TI) or Temperature Gauges (TG).

- All these temperature gauges belong to the class of instruments that are known as bimetallic sensors.

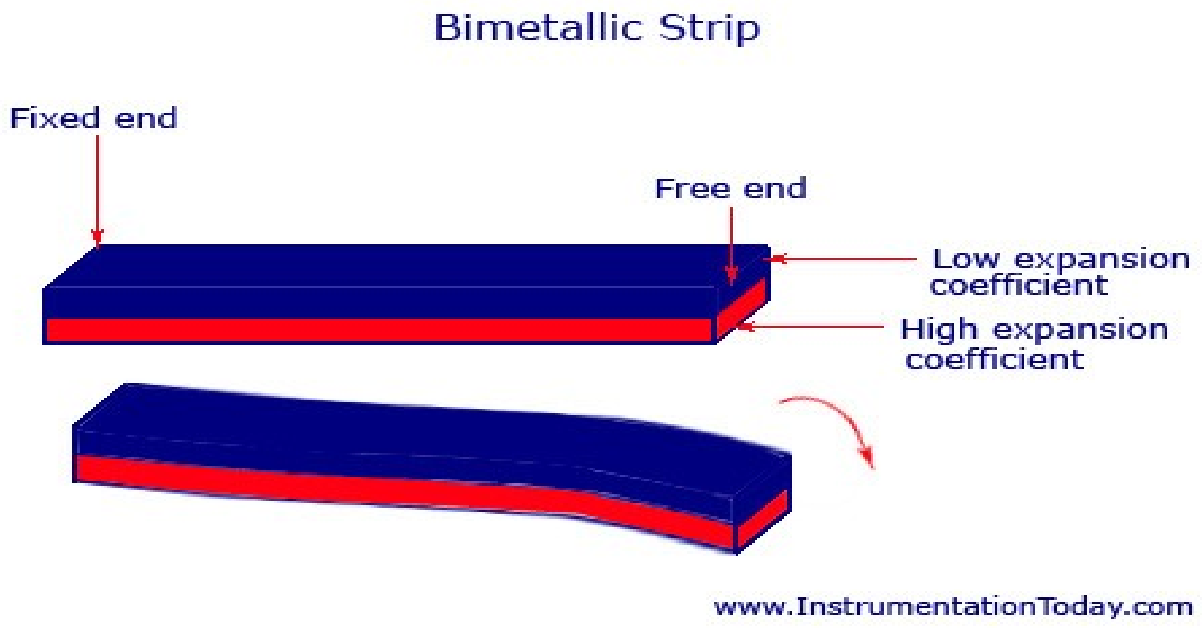
Bimetallic Thermometer

Two basic principles of operation is to be followed in the case of a bimetallic sensor.

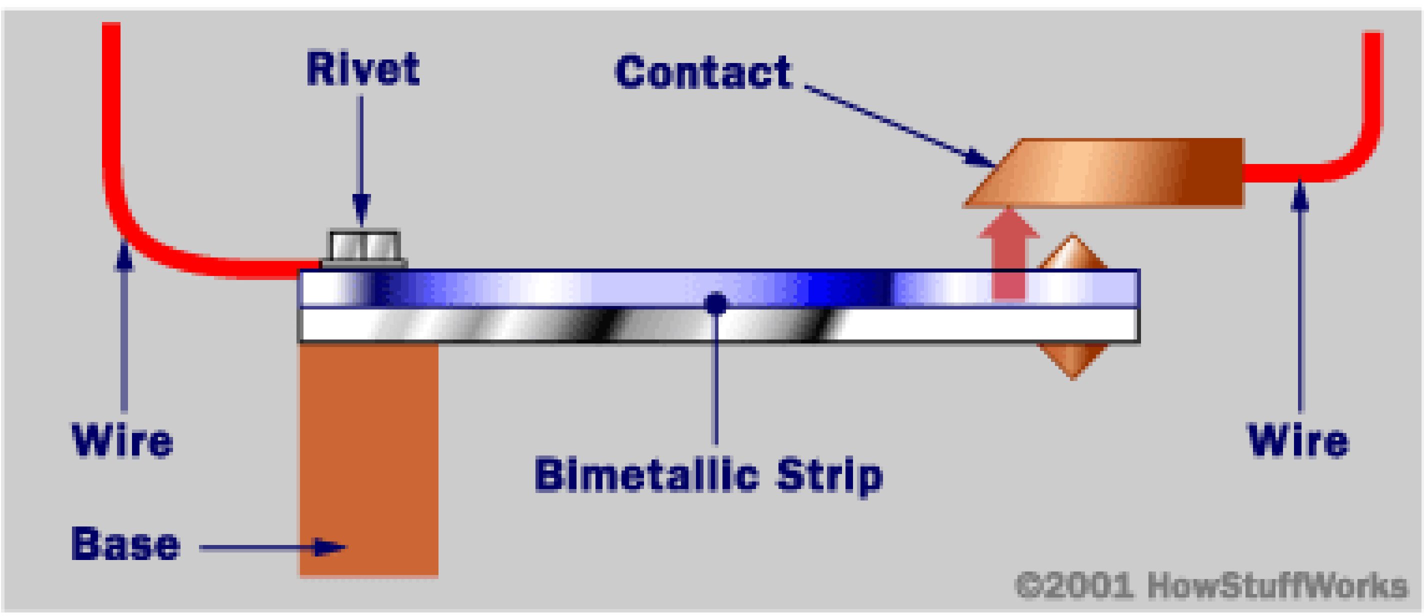
1) A metal tends to undergo a volumetric dimensional change (expansion/contraction), according to the change in temperature.

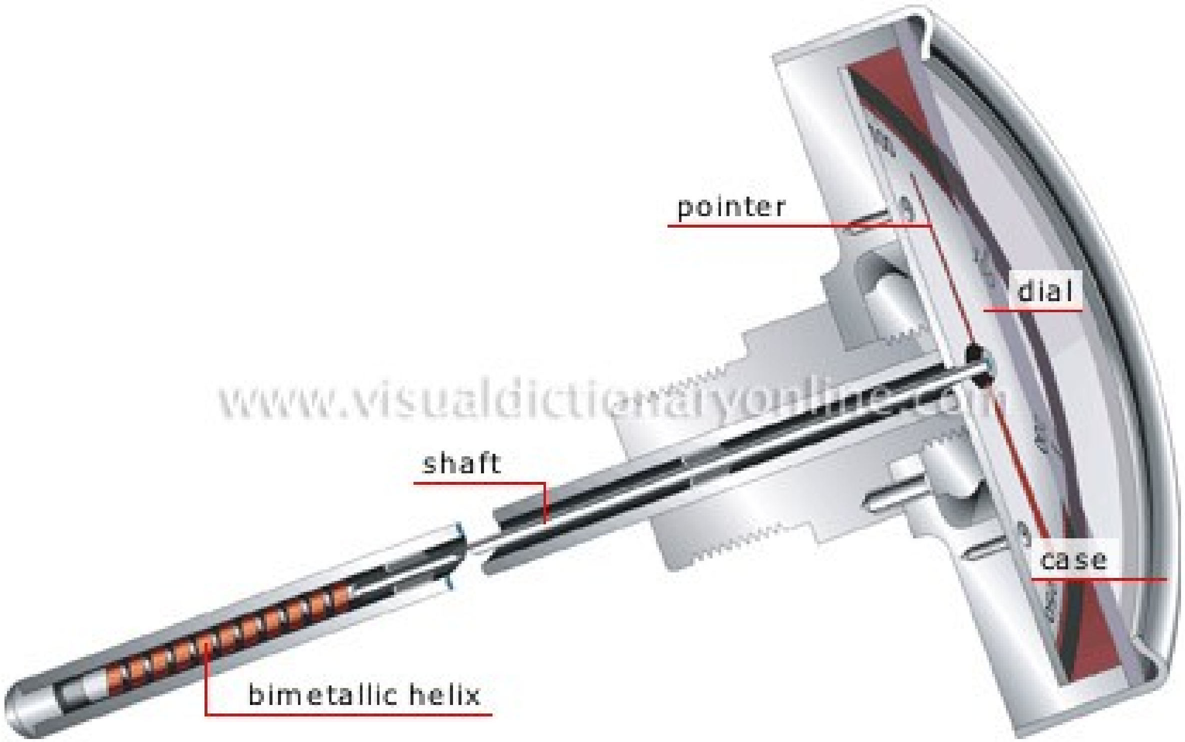
2) Different metals have different co-efficient of temperatures. The rate of volumetric change depends on this co-efficient of temperature.

Construction



- The device consists of a bimetallic strip of two different metals .
- They are bonded together to form a spiral or a twisted helix.
- Both these metals are joined together at one end by either welding or riveting.
- It is bonded so strong that there will not be any relative motion between the two.
- The image of a bimetallic strip is shown below.




pointer
dial
shaft
case
bimetallic helix

Construction

- A change in temperature causes the free end of the strip to expand or contract due to the different coefficients of expansion of the two metals.
- This movement is linear to the change in temperature and the deflection of the free end can be read out by attaching a pointer to it.
- This reading will indicate the value of temperature. Bimetallic strips are available in different forms like helix type, cantilever, spiral, and also flat type.

❖ Advantages

1) Power source not required
2) Robust, easy to use and cheap.
3) Can be used to 500 °C.

❖ Disadvantages

1) Not very accurate.
2) Limited to applications where manual reading is acceptable.
3) Not suitable for very low temperatures because the expansion of metals tend to be too similar, so the device becomes a rather insensitive thermometer

Filled System Thermometer

- Filled system thermometers consist of Bourdon tube, a capillary tube and a thermometer bulb all interconnected.
- The entire point is sealed after appropriate liquid filling at NTP and commonly used

liquids are mercury, ethyl alcohol, xylene and toluene.

- Liquid expands or contracts with gain or loss of heat till measured temperature is

attained leading to the expansion or contraction of the Bourdon tube which subsequently moves a pointer for indication.

- Types are:
- Gas filled (Gas Filled Thermometers)
- Liquid filled
- Mercury filled
- Vapour filled

Filled System Thermometer

- **Liquid Filled Thermometer:** They work on the principle of liquid expansion with temperature rise. The filling liquid is usually an inert hydrocarbon viz. xylen which has six times more expansion co-efficient than mercury decreasing the bulb p sition. One criterion to be maintained is that the pressure inside must be greater t an the vapour pressure of liquid to prevent formation of bubbles inside. Solidific on of liquid is also not permitted.

- **Mercury Filled Thermometer:** Similar to that of liquid filled thermome s but provides rapid response, accuracy and plenty of power. Pressure is as high as 1200 psig to as low as 400 psig. The high pressure reduces the head effect. They are normally contained in stainless steel bulb increasing the corrosion resistance.

- **Vapour Filled Thermometer:** Here the bulb is partially filled with liquid and partially with vapour. Some of the liquid vaporises during operation. The liquid inside boils and vaporises creating gas inside the system. The liquid continues to boil until pressure balance is obtained between systems and vapour pressure. Here liquid stops boiling unless temperature rises. Similarly, when temperature drops, liquid and vapour inside also cool causing some vapour to condense, bringing down the pressure inside. When pressure inside equals vapour pressure, this action stops. Due to changes in pressure, bourdon tube uncoils or tightens with increase or decrease of pressure indicating temperature on a pointer scale.

Resistance Thermometer

- Also called resistance temperature detectors (RTDs).
- They are used to measure temperature by correlating the resistance of the RTD element with temperature.
- The RTD element is made from a pure material, typically platinum, nickel or copper.
- The material has a predictable change in resistance as the temperature changes and it is this predictable change that is used to determine temperature.
- The elements are pretty fragile and therefore they are kept inside a sheathed probe.
- RTD sensing elements constructed of platinum, copper or nickel have a repeatable resistance versus temperature relationship (R vs T) and operating temperature range.
- R vs T relationship is defined as the amount of resistance change of the sensor per degree of temperature change.

Resistance Thermometer

- Platinum is a noble metal having the most stable resistance – temperature relationship over the largest temperature range making it the best element for RTD with a very high repeatability over the range of **-272.5 °C to 961.7 °C**. Platinum is also chemically inert.

- Nickel has limited temperature range as over 572 °F (300 °C), the relationship tends to become non – linear. Cooper, though has very linear relationship towards R vs T but it oxidizes at moderate temperature and cannot be used over 302 °F (150 °C).

- RTDs use electrical resistance as function of temperature change and require a power source to operate. The resiatance value varies nearly linearly with temperature following **Callendar- Van Dusen equation.**

- $R_T = R_0\ 1 + AT + BT^2 + CT^3\ T - 100$ $(-200\ °C < T < 0°C)$

- $R_T = R_0\ 1 + AT + BT^2$ $(0\ °C < T < 850°C)$

- $A = 3.9083 * 10^{-3}\ °C^{-1}; B = -5.775 * 10^{-7}\ °C^{-2}, C = -4.183 * 10^{-12}\ °C^{-4}$

Resistance Thermometer

- The significant characteristic of metals used as resistive elements is the linear approximation of the resistance versus temperature relationship between 0 and 100 °C. This temperature coefficient of resistance is called alpha, α. The equation below defines α; its units are ohm/ohm/°C.

$$\alpha = \frac{R_{100} - R_0}{100\, R_0}$$

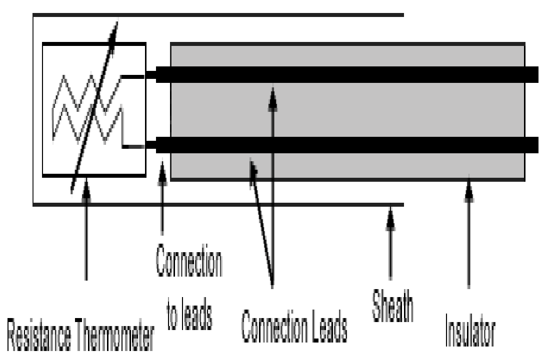
R_{100} = resistance of element at 100 ° C

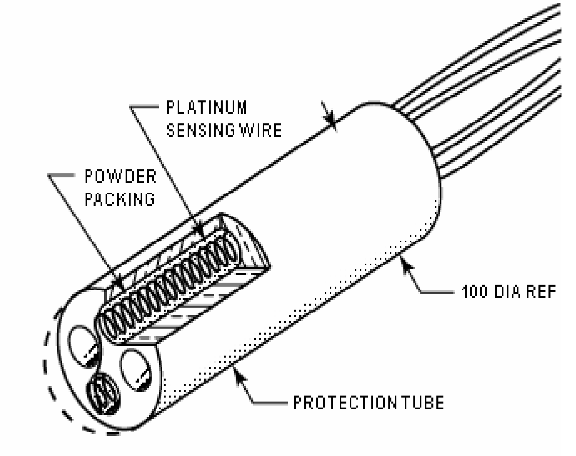
R_0 = resistance of element at 0 ° C

- Pure platinum has an alpha of 0.003925 ohm/ohm/°C in the 0 to 100 °C range and is used in the construction of laboratory grade RTDs. Alpha of platinum can be altered by doping. Copper has an alpha value 0.0043 ohm/ohm/°C and nickel has 0.0068 ohm/ohm/°C.

Resistance Thermometer - Construction

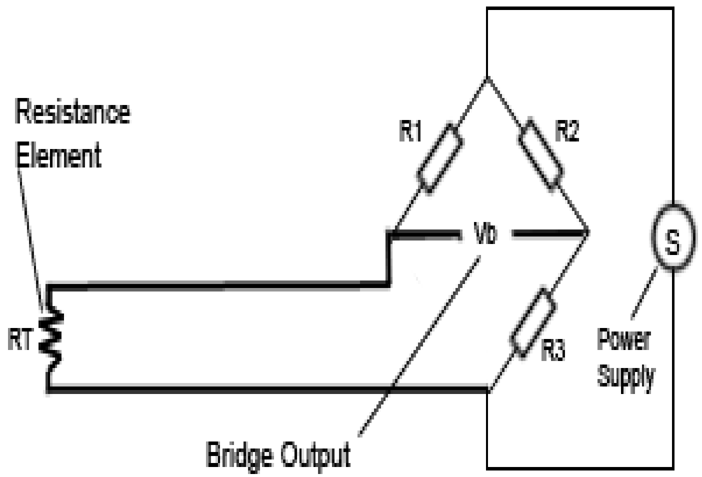
- These elements nearly always require insulated leads attached.
- At temperatures below about 250 °C PVC, silicone rubber or PTFE insulators are used.
Above this, glass fibre or ceramic are used.
- The measuring points, and usually most of the leads, require a housing or protective sleeve, often made of a metal alloy which is chemically inert to the process being monitored.





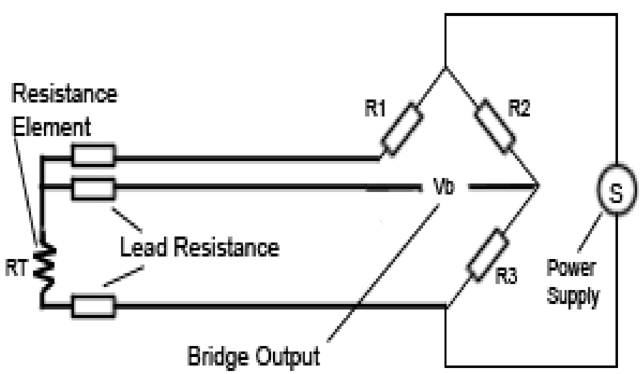
Resistance Thermometer – Wiring Configuration

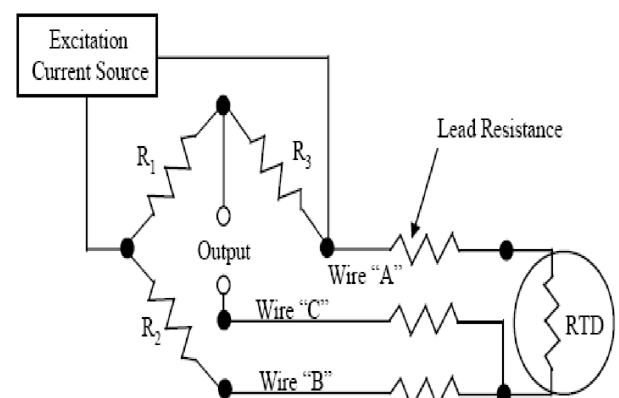
- **Two-wire configuration:** The simplest resistance thermometer configuration uses two wires. It is only used when high accuracy is not required, as the resistance of the connecting wires is added to that of the sensor, leading to errors of measurement. This configuration allows use of 100 meters of cable. This applies equally to balanced bridge and fixed bridge system.



Resistance Thermometer – Wiring Configuration

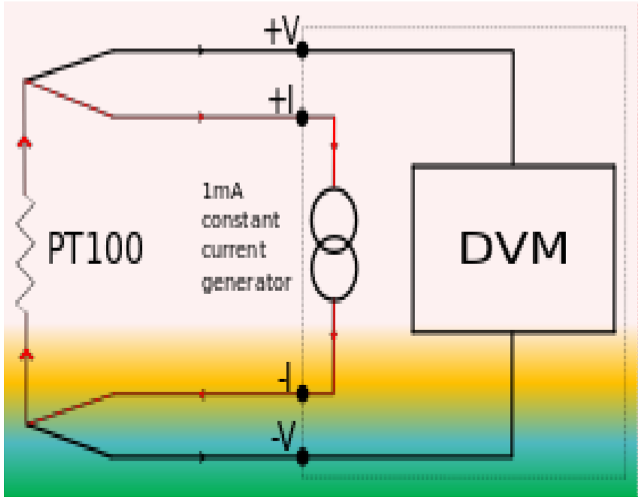
- **Three-wire configuration:** In order to minimize the effects of the lead resistances, a three-wire configuration can be used. Using this method the two leads to the sensor are on adjoining arms. There is a lead resistance in each arm of the bridge so that the resistance is cancelled out, so long as the two lead resistances are accurately the same. This configuration allows up to 600 meters of cable.
- In the circuit shown below, if wires A and B are perfectly matched in length, their impedance effects will cancel because each is in an opposite leg of the bridge. The third wire, C, acts as a sense lead and carries a very small current.

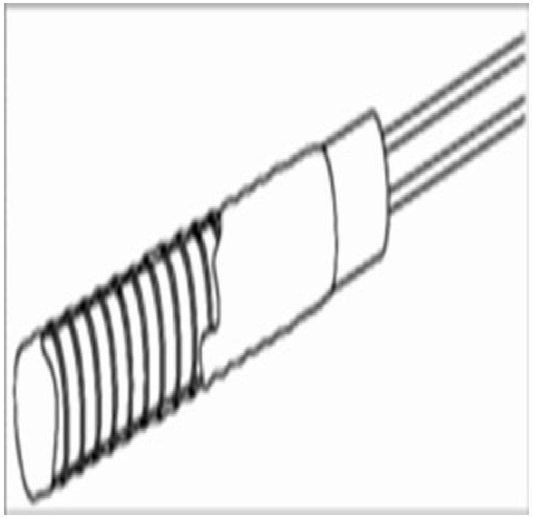




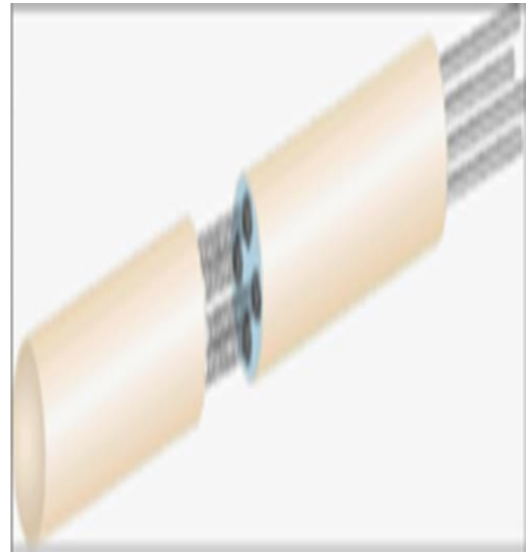
Resistance Thermometer – Wiring Configuration

- **Four-wire configuration:** The four-wire resistance configuration increases the accuracy of measurement of resistance. Four-terminal sensing eliminates voltage drop in the measuring leads as a contribution to error. To increase accuracy further, any residual thermoelectric voltages generated by different wire types or screwed connections are eliminated by reversal of the direction of the 1 mA current and the leads to the DVM (Digital Voltmeter). The thermoelectric voltages will be produced in one direction only. By averaging the reversed measurements, the thermoelectric error voltages are cancelled out.





Wire-wound elements



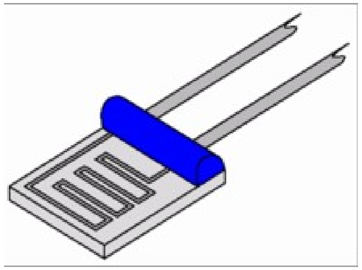
Coiled elements

Resistance Thermometer – Element Types

▶ Three main categories of RTD sensors are thin film, wire-wound, and coiled elements.
Carbon resistors are used at ultra-low temperatures **(-173 °C to -273 °C).**

▶ Carbon resistor elements are widely available and are very inexpensive. They are most reliable at extreme low temperature and do not suffer hysteresis and strain gauge effects.

▶ Strain free elements use a wire coil minimally supported within a sealed housing filled with an inert gas. These sensors are used up to 961.78 °C and they consist of platinum wire loosely coiled over a support structure to provide free expansion and contraction with temperature. They are highly sensitive to vibration and shock.



Resistance Thermometer - Features

- <u>Advantages of Resistance Thermometers:</u>
- High accuracy
- Wide temperature range, normally between – 200 ° and 650 °C
- Smaller in size, faster in response
- Good repeatability stable and accurate performance over many years
- Temperature compensation is not required
- <u>Disadvantages of Resistance Thermometers:</u>
- Higher cost
- Bridge circuit and power supply are needed
- Heating of resistance elements and current through bridge circuits lead to inaccuracy
- Mechanical abuse induced because of vibration
- Larger bulb size than thermocouples
- Slower response time than thermistors.

RTDs vs Thermocouples

▶ Temperature: If process temperatures are between −200 to 500 °C (−328.0 to 932.0 °F), an industrial RTD is the preferred option. Thermocouples have a range of −180 to 2,320 °C (−292.0 to 4,208.0 °F), so for temperatures above 500 °C (932 °F) they are the only contact temperature measurement device.

▶ Response time: If the process requires a very fast response to temperature changes— fractions of a second as opposed to seconds (e.g. 2.5 to 10 s)– then a thermocouple is the best choice. Time response is measured by immersing the sensor in water moving at 1 m/s (3 ft/s) with a 63.2% step change.

▶ Size: A standard RTD sheath is 3.175 to 6.35 mm (0.1250 to 0.2500 in) in diameter; sheath diameters for thermocouples can be less than 1.6 mm (0.063 in).

▶ Accuracy and stability requirements: If a tolerance of 2 °C is acceptable and the highest level of repeatability is not required, a thermocouple will serve. RTDs are capable of higher accuracy and can maintain stability for many years, while thermocouples can drift within the first few hours of use.

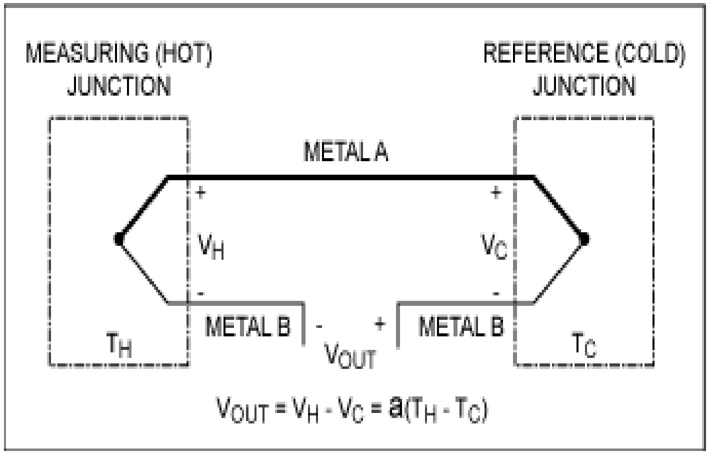
Thermocouple

- Thermocouples consist of two wire legs made from different metals.
- The wire's legs are welded together at one end, creating a junction.
- This junction is where the temperature is measured.
- When the junction experiences a change in temperature, a voltage is create
- The voltage can then be interpreted using thermocouple reference tables to calculate the temperature.
- There are many types of thermocouples, each with its own unique characteristics in terms of temperature range, durability, vibration resistance, chemical resistance, and application compatibility.
- Type J, K, T, & E are "Base Metal" thermocouples, the most common types of thermocouples.
- Type R, S, and B thermocouples are "Noble Metal" thermocouples, which are used in high temperature applications.
- Thermocouples are self-powered and require no external form of excitation.
- Thermocouples do not actually measure an absolute temperature; they only measure the temperature difference between two points, commonly known as the hot and cold junctions.

Thermocouple – Working Principle

- Thomas Johann Seebeck discovered that when any conductor is subject to a thermal gradient, it generates a voltage. This is now known as the thermoelectric effect or Seebeck effect.
- Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end.
- The additional conductor experiences the same temperature gradient and also develops

a voltage, which normally opposes the original.



Thermocouple – Working Principle

- *Seebeck Effect:* Energetic electrons at the hot end diffuse toward the cold end, pushing less energetic electrons along with them, resulting in a higher static potential at the hot end relative to the cold end. The larger the temperature gradient, the larger is the potential difference.

$$E_{emf} = -S\nabla T$$

- *Classical Configuration:* To make the thermal effects measurable, two different metal conductors are used.
- They must be chemically, electrically, and physically compatible. They produce different electric potentials when subject to the same thermal gradient.
- In the classical configuration, the dissimilar thermocouple wires are welded together at the measurement end (hot junction), and again at the reference end (cold junction), forming a loop.
- The hot junction assures that the potential at that point matches in the two metals. Immersing the reference-end junction in an ice-water slurry assures that the temperature gradients are the same across both materials.
- The ice-water slurry establishes a reference temperature at 0 ° C.

Thermocouple - Features

- Advantages of Thermocouple:
- Capable of being used to directly measure temperatures up to 2600°C
- Maybe brought into direct contact with the material being measured
- High resolution
- Rugged and reliable
- Disadvantages of Thermocouple:

Non-linear Complex operation

Two measurements required

Calibration required when in use

Thermocouple - Types

- There are several types of thermocouple based on the combination of metals/alloys for the two junctions which are chosen on the merit of temperature range, sensitivity, inertness and magnetic effects.
- Few types are J, K, T, N, E, B, R, S, M, C, D, G, P and W.
- Type J, K, T, & E are “Base Metal” thermocouples, the most common types of thermocouples.
- Type R, S, and B thermocouples are “Noble Metal” thermocouples, which are used in

high temperature applications.

Thermocouple - Types

Type	Material	Temperature Range	Accuracy %	Remark
J	Iron – Constantan	−40 °C to +750 °C	+/- .75%	Reliable, shorter lifespan, narrow range
K	Nickel-Chromel/ Nickel-Alumel	−200 °C to +1350 °C	+/- 0.75	Inexpensive, accurate, reliable and wide range
T	Copper-Constantan	−250 °C to 350 °C	+/- 0.75	Stable, cryogenic measurement
E	Nickel-Chromel/ Constantan	−270 °C to 870 °C	+/- 0.50	Stronger signal and higher accuracy than k & J type
R	Platinum-Rhodium (87:13)	−50 °C to 1600 °C	+/- 0.25	High accuracy and stability. High resistance to oxidation and corrosion
B	Platinum-Rhodium (70:30)	0 °C to 1700 °C	+/- 0.5%	Extreme high temperature
S	Platinum-Rhodium (90:10)	−50 °C to 1600 °C	+/- .25%	Extreme high temperature. High resistance to oxidation and corrosion
M	Nickel-	Upper limit: 1400 °C	+/- 0.75%	Rare in use

RTD – Thermocouple - Thermister

Criteria	Thermocouple	RTD	Thermistor
Temp Range	-267°C to 2316°C	-240°C to 649°C	-100°C to 500°C
Accuracy	Good	Best	Good
Linearity	Better	Best	Good
Sensitivity	Good	Better	Best
Cost	Best	Good	Better

Thermister

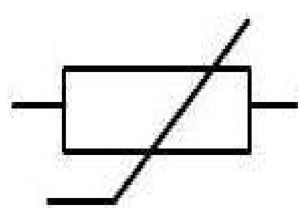
- Thermistors are thermally sensitive resistors whose prime function is to exhibit a large, predictable and precise change in electrical resista :e when subject to a corresponding change in body temperature.

- These are semiconductors made from a specific mixture of pure oxides f nickel,

manganese, copper, cobalt, iron, magnesium, titanium and other metals sintered at 982

°C.

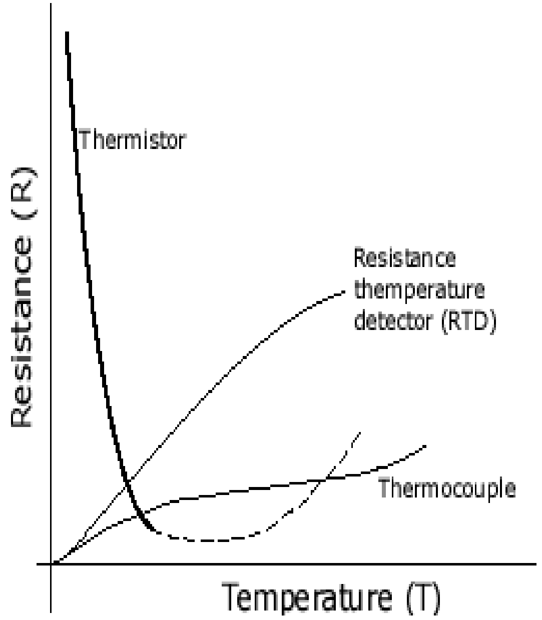
- Negative Temperature Coefficient (NTC) thermistors exhibit a decrease in electrical resistance when subject to an increase in body temperature and Positive Temperature Coefficient (PTC) thermistors exhibit an increase in electrical resistance when subject to an increase in body temperature.

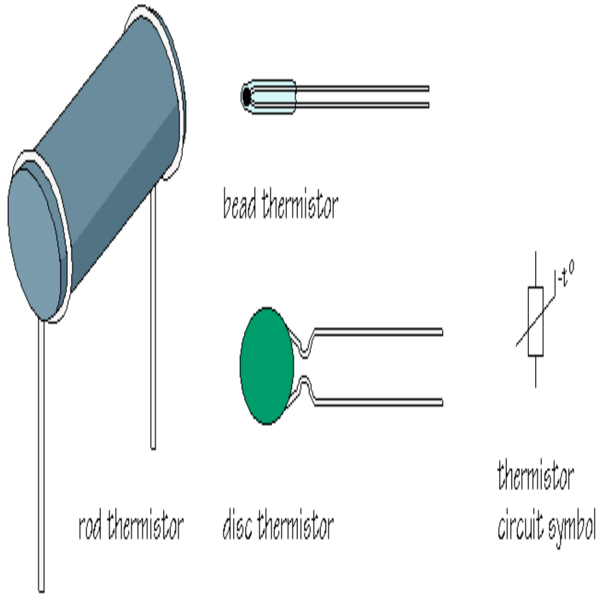


Thermister

- Thermistors differ from resistance temperature detectors (RTDs) in that the material
used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals.

- Range of Operation: −90 °C to 130 °C. Accuracy: ±0.1°C or ±0.2°C.





Thermister - Principle

- The Steinhart-Hart equation gives the reciprocal of absolute temperature as a function of the resistance of a thermistor. Using the Steinhart-Hart equation, we calculate the temperature of the thermistor from the measured resistance.
-

- Where A, B and C are Steinhart–Hart parameters. R is the resistance and T is temperature; A = 0.001284; B = 2.364x 10^{-4}; C = 9.304x 10^{-8}
- The resistance value of a thermistor is given by the following equatio

$$R = R_{Ref} \cdot e^{\beta\left(\frac{1}{T} - \frac{1}{T_{Ref}}\right)}$$

- R= the resistance at temperature T in Kelvin (= °C +273)
- R_{Ref}= the resistance at a reference temperature T_0 in Kelvin
- β = B-value specified for this thermistor
- T = Temperature under measurement, T_{Ref}= Reference temperature

Thermister - Principle

- To measure temperature with a thermistor, it is placed in the measuring environment and as temperature increases, the resistance decreases (assuming NTC), and vice versa.

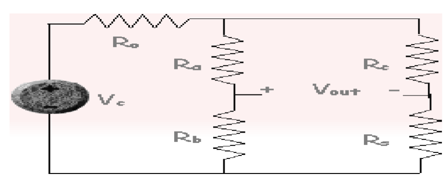
- The thermistor is placed in one leg of a Wheatstone bridge circuit and at balanced condition with

no change of temperature, the meter indicates zero.

- With changes in temperature, the Wheatstone bridge becomes unbalanced and an electric current flows in the circuit.

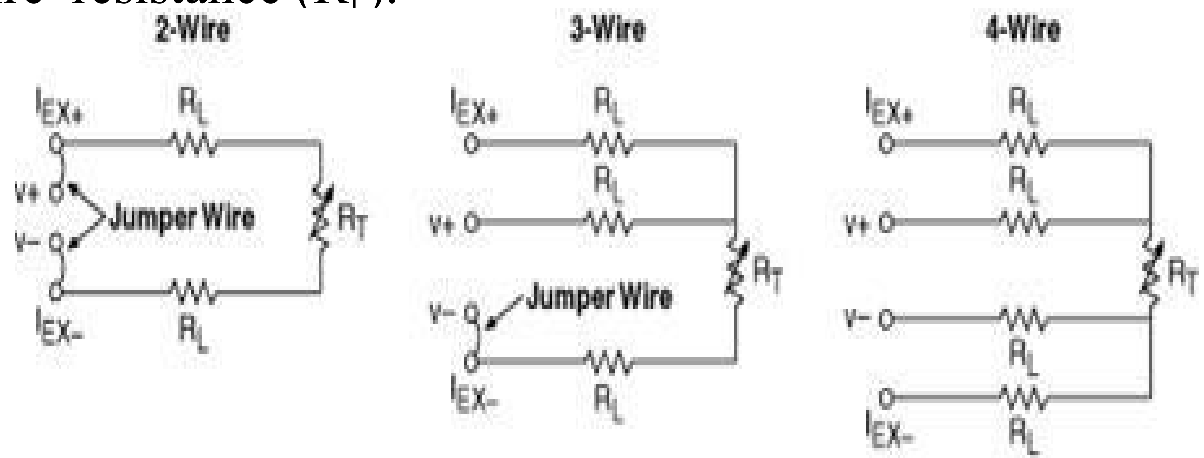
- In this bridge circuit, three resistors are constant, R_a, R_b, and R_c, while the resistive sensor, R_S, varies depending upon some physical variable - like temperature, light level, etc. That's where the thermistor can be used.

- The thermistor can be placed anywhere in the bridge with three constant resistors, but different placements can produce different behaviour in the bridge. For example, different placements might cause the output voltage to go in different directions as the temperature changes.



Thermister - Configuration

- Thermistors come in two-, three-, or four-wire configurations
- When there are more than two wires, the additional wires are solely used for connecting to the excitation source.
- A three- or four-wire connection method places leads on a high-impedance path through the measurement device, effectively attenuating error caused by lead-wire resistance (R_L).

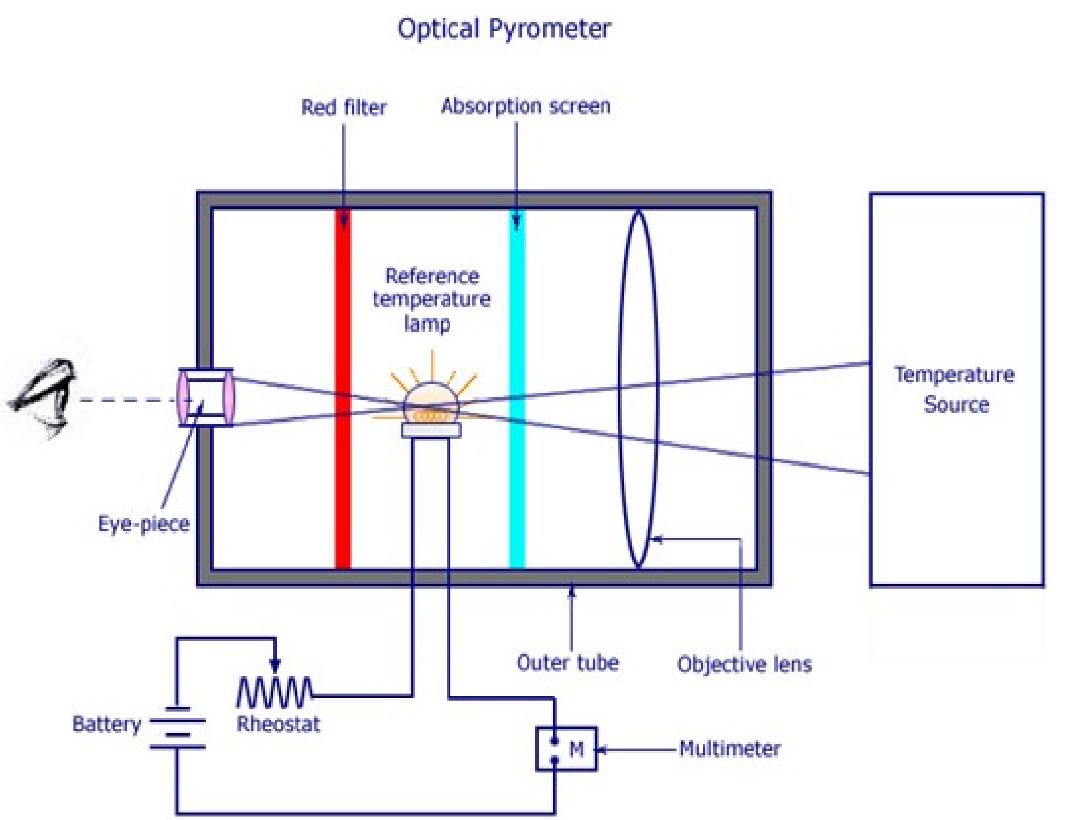


Thermister - Features

- Advantages of Thermistors:
- Thermistors offer better accuracy in comparison to RTDs and thermocoupl .
- Unlike RTDs and thermocouples, they are highly sensitive.
- They are smaller in size as compared to thermocouples.
- Thermistors provide faster response than RTDs.
- They offer high stability and brilliant repeatability.
- They are very reliable and convenient to use.
- Unlike thermocouples which provide millivolt outputs, use of thermistors result in reasonable output voltages.
- Thermistors are particularly low cost and easily adaptable temperature sensors.
- Disadvantages of Thermistors:
- Highly non-linear
- Limited temperature range

Pyrometer

- It measures the amount of heat that is radiated from an object.
- The device compares the brightness produced by the radiatio
of the object whose tem

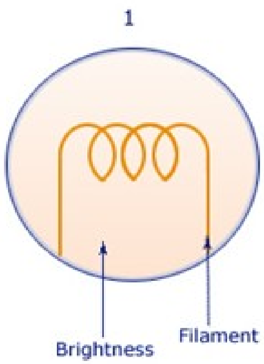


- An eye piece at the left side and an optical lens on the right
- A reference lamp
- A rheostat to change the current and brightness
- An absorption screen is fitted between the optical lens and the reference bulb, so as to increase the temp range

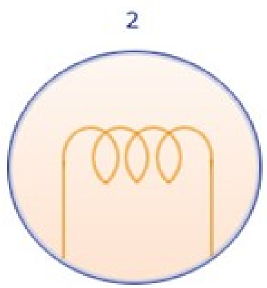
Working

1.The radiation from the source is emitted and the optical objective lens captures it.
2.The lens helps in focusing the thermal radiation on to the reference bulb.
3.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.
4.The observer starts changing the rheostat values and the current in the reference lamp changes.
5.This in turn, changes its intensity.

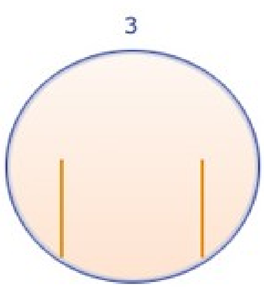
This change in current can be observed in three different ways.



The filament is dark. That is, cooler than the temperature source.



Filament is bright. That is, hotter than the temperature source.



Filament disappears. Thus, there is equal brightness between the filament and temperature source

- ***Advantages***

1. Provides a very high accuracy with +/-5° Celsius.
2. The biggest advantage of this device is that, there is no direct contact between the pyrometer and the object whose temperature is to be found out.

- ***Disadvantages***

1. As the measurement is based on the light intensity, the device can be used only in applications with a minimum temperature of 700° Celsius.
2. The device is not useful for obtaining continuous values of temperatures at small intervals.

THANK YOU