Module 5

Temperature and its Measurements

1. What is Heat?

Heat is energy transfer due to a temperature difference between objects.

It always moves from a hotter object to a cooler one until equilibrium is reached.

2. Difference Between Heat and Temperature:

Heat: Energy in motion, measured in Joules (J) or Calories (cal).

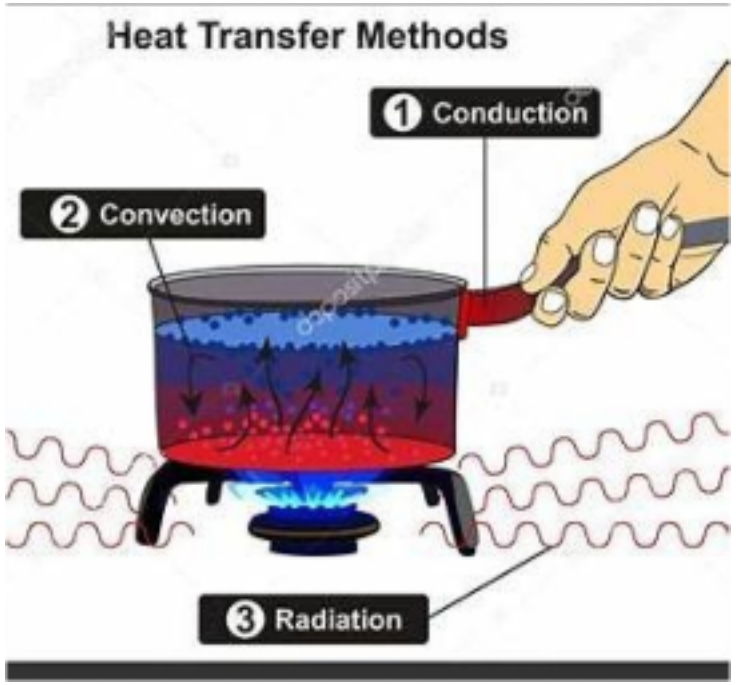
Temperature: Indicates hotness or coldness, measured in °C, K, °F.

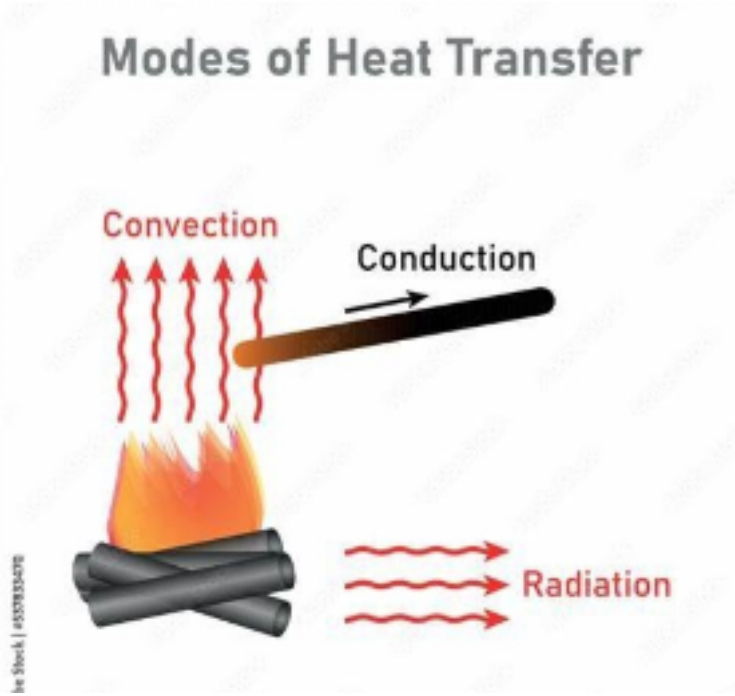
Types of Heat Transfer:

Conduction → Heat transfer by direct contact (e.g., metal spoon in hot tea).

Convection → Heat transfer by fluid movement (e.g., boiling water, sea breeze).

Radiation → Heat transfer through electromagnetic waves (e.g., warmth from the Sun).





Temperature and Its Measurement

Temperature is a fundamental physical quantity that describes how hot or cold an object is. It is related to the kinetic energy of the particles within a substance. Higher temperature means the particles are moving faster, while lower temperature means they are moving slower.

Temperature scales

1. Celsius (°C):- It is also called Centigrade.Commonly used in weather reports, cooking, and daily life.Water freezes at 0°C and boils at 100°C (at standard atmospheric pressure).

2. Fahrenheit (°F):-Used mainly in the United States.

Water freezes at 32°F and boils at 212°F.

3. Kelvin (K):- The scientific unit of temperature (SI unit).Absolute zero (0 K) is the temperature where molecular motion stops (-273.15°C or -459.67°F).Water freezes at 273.15 K and boils at 373.15 K.

4. Rankine (°R):- Used in engineering and thermodynamics.It is similar to Kelvin but scaled to Fahrenheit.0°R is absolute zero.

Types of Thermometers

Different applications require different thermometers:

1. Liquid-in-glass Thermometer:-

Uses mercury or alcohol that expands/contracts with temperature changes.

2. Digital Thermometer :-

Uses electronic sensors and displays temperature digitally

3. Infrared Thermometer:-

Measures infrared radiation emitted by an object (contactless measurement).

4. Thermocouple :-

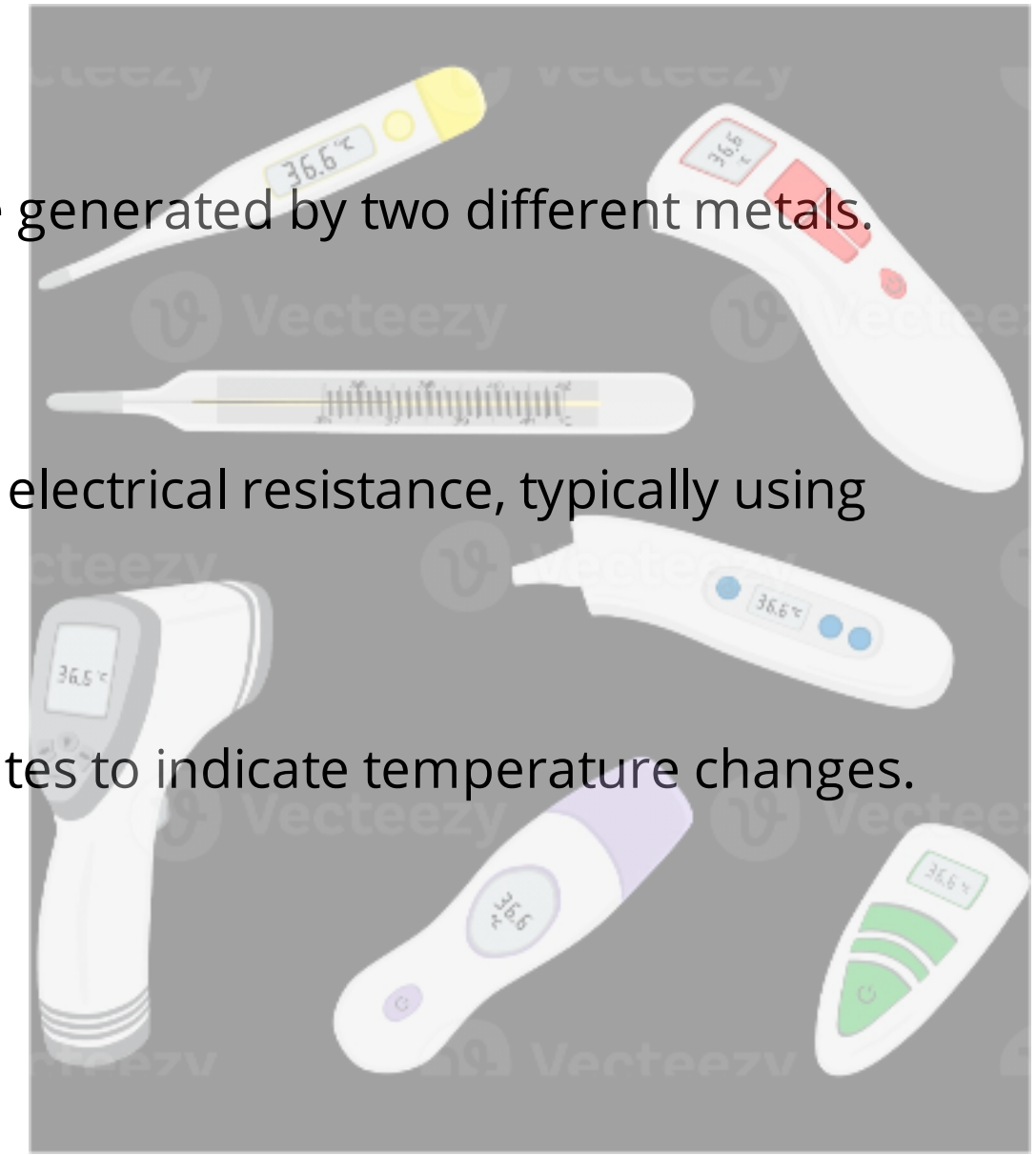
Measures temperature based on the voltage generated by two different metals. joined at one end.

5. Resistance Temperature Detector (RTD):-

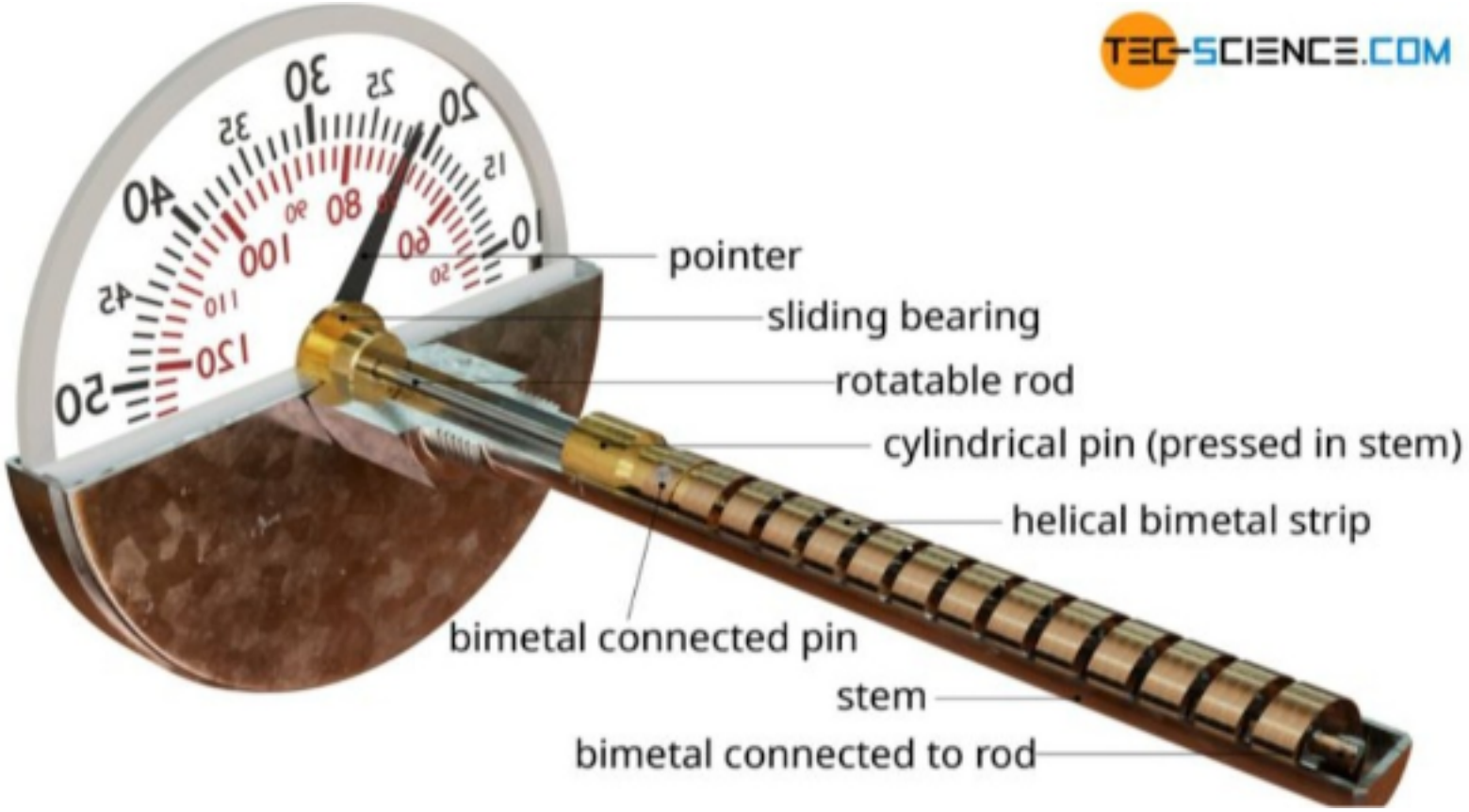
Measures temperature based on changes in electrical resistance, typically using platinum

6. Bimetallic Strip Thermometer:-

Uses two metals with different expansion rates to indicate temperature changes.



Bimetallic Thermometer



Bimetallic Thermometer

A bimetallic thermometer is a temperature-measuring device that works on the principle of thermal expansion of metals. It consists of two metal strips with different thermal expansion coefficients bonded together. When temperature changes, the metals expand at different rates, causing the strip to bend or curl.This bending motion is converted into a mechanical movement that drives a pointer across a calibrated scale, indicating the temperature. For better sensitivity, the strip is often shaped into a spiral or helical coil.Bimetallic thermometers are simple, durable, and do not require power, making them useful in industrial, household, and refrigeration applications.

Components of Bimetallic Thermometer

1. Bimetallic Strip:

Made of two metals with different expansion rates (e.g., brass and steel)

Bends when temperature changes due to thermal expansion

2. Housing:

Protects the internal components from damage.

3. Pointer and Scale:

The mechanical movement of the strip drives a pointer.

The calibrated scale converts the pointer’s position into a temperature reading.

4. Helical or Spiral Design (Optional):

Some designs use a helical or spiral coil for increased sensitivity and range.

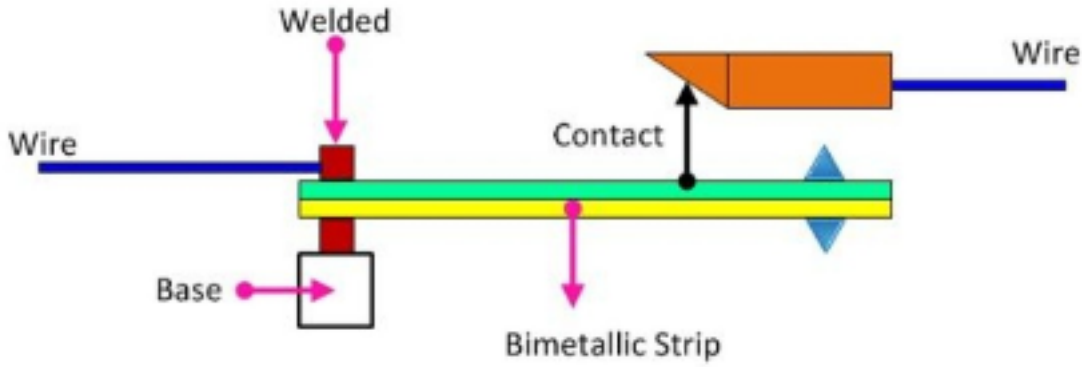
Working Principle of Bimetallic Thermometer :-

The bimetallic strip is made of two metals with different thermal expansion coefficients.

When heated, the metal with the higher expansion rate expands more, causing the strip to bend towards the metal with the lower expansion rate.

This bending motion is transferred to a pointer, which moves over a calibrated scale, displaying the temperature.

In spiral or helical designs, the coiled strip enhances movement, making the thermometer more sensitive and accurate.



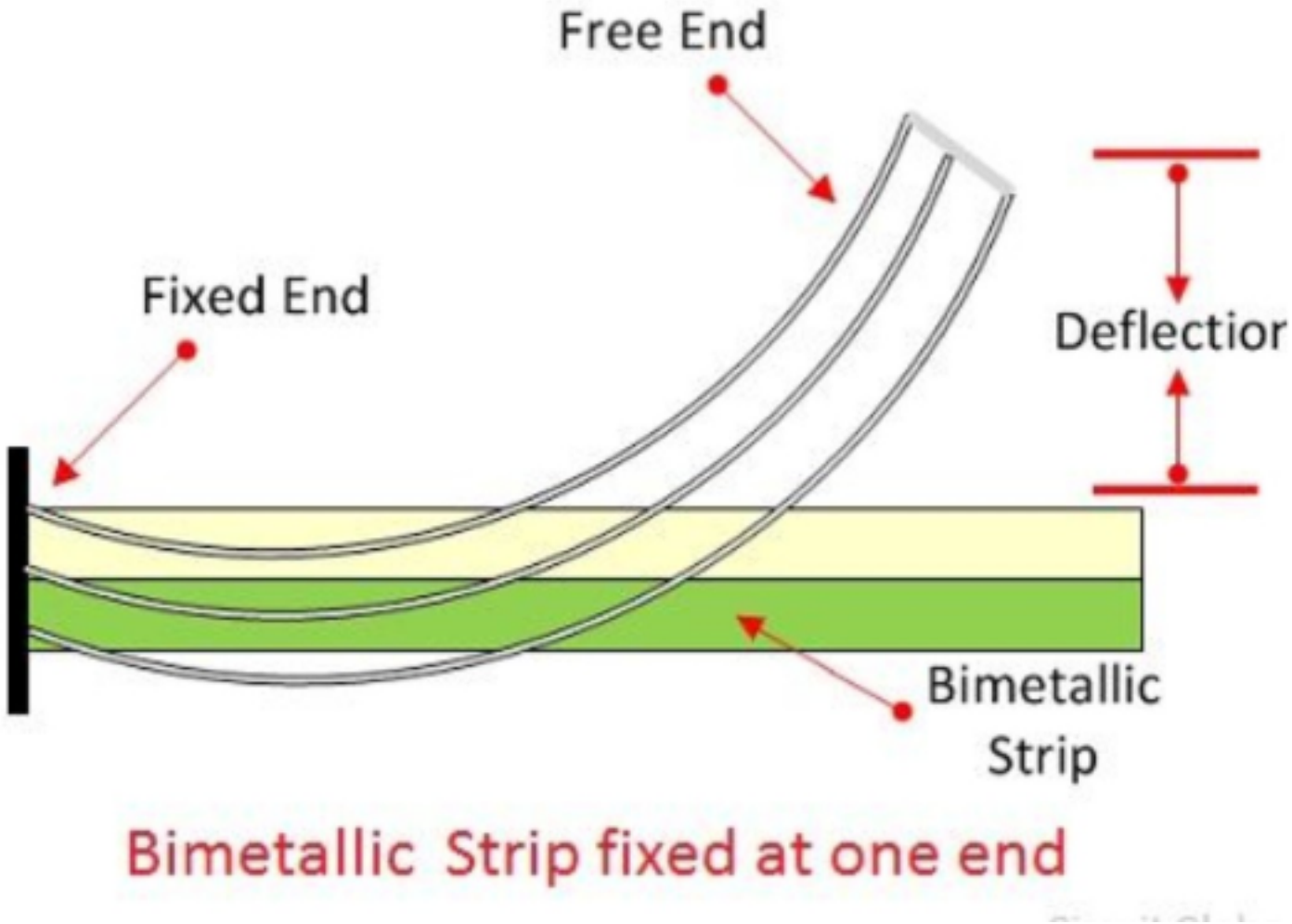
Bimetallic Thermometer

Construction of Bimetallic Thermometer :-

The bimetallic strip is constructed by bonding together the two thin strips of different metals. The metals are joined together at one end with the help of the welding. The bonding is kept in such a way that there is no relative motion between the two metals. The physical dimension of the metals varies with the variation in temperature.

Since the bimetallic strip of the thermometer is constructed with different metals. Thereby, the length of metals changes at different rates. When the temperature increases, the strip bends towards the metal which has a low-temperature coefficient. And when the temperature decreases, the strip bends towards the metal which has a high-temperature coefficient.

The range of deflection of bimetallic strip depends on the type of metals used for construction. The deflection of the metal is directly proportional to the length of the strip and the variation of temperature and is inversely proportional to the thickness of the strips



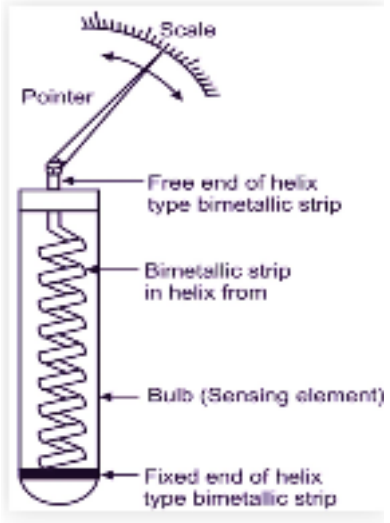
Types of Bimetallic Thermometers:-

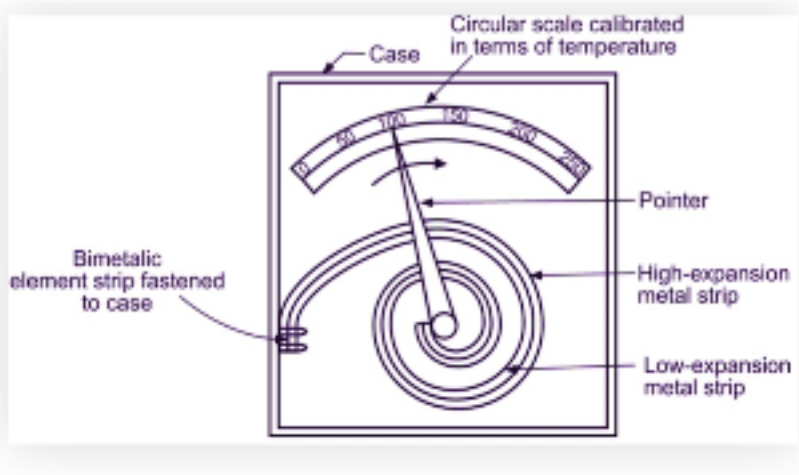
1. Spiral Type:

The bimetallic strip is wrapped into a spiral.The inner side of the spiral moves the pointer on a scale.Saves space but does not allow separate sensing and display.Used in room temperature measurement and refrigerators.

2. Helical Type:

The strip is wound into a helical coil.One end is fixed, and the other end moves the pointer.Used in pipes and industrial applications where the sensor and display need to be separate.





Applications

1. Used in control device
2. A spiral strip- type thermometer is utilized in AC thermometers
3. The helix strip type is used in refineries, oil burners.
4. These thermometers are utilized in household devices which includes AC, Oven,and apparatus in industries like hot wires, refineries tempering tanks, heater etc.

Platinum Resistance Thermometer

The platinum thermal resistance (PTR) uses platinum for determining the temperature. It works on the principle that the resistance of platinum changes with the change of temperature. The thermometer measures the temperature over the range of 200°C to1200°C.

How Platinum Resistance Thermometer Works?

The resistance of platinum increases linearly with the temperature, and this property of the metal is used for measuring the temperature. The resistance of the platinum is measured by passing the alternating or direct current through it. Because of the current, the voltage induces across the metal which measures through the voltmeter. The reading of voltage is converted into the temperature with the help of the calibration equation.

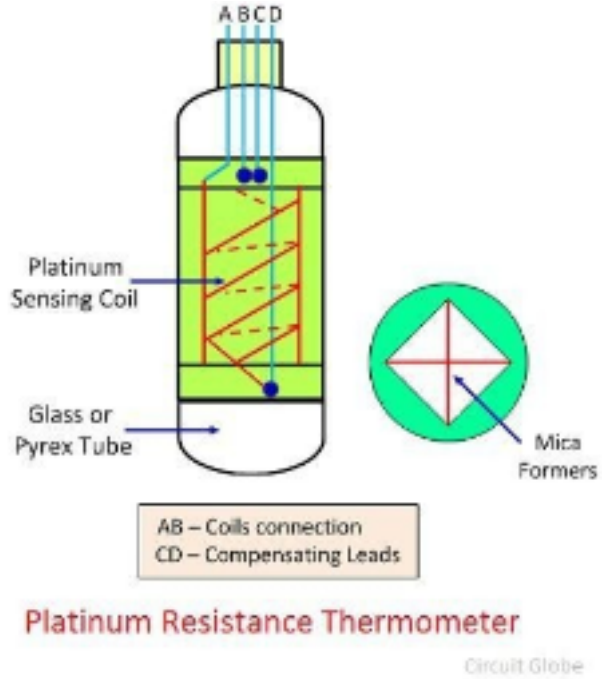
Construction of Platinum Resistance Thermometer:-

- The platinum sensing coil is enclosed inside a glass or Pyrex bulb, which protects it from external damage and environmental factors.
- A mica strip is used as an insulator, and the platinum wire is wound in a double-loop pattern around it. The double wiring helps reduce inductive effects, improving accuracy.
- The open end of the tube is covered with an ebonite cap,

which holds the terminals of the copper wires securely.

- The platinum wire is connected to thick copper leads,

which further connect to terminals AB inside the ebonite cap.



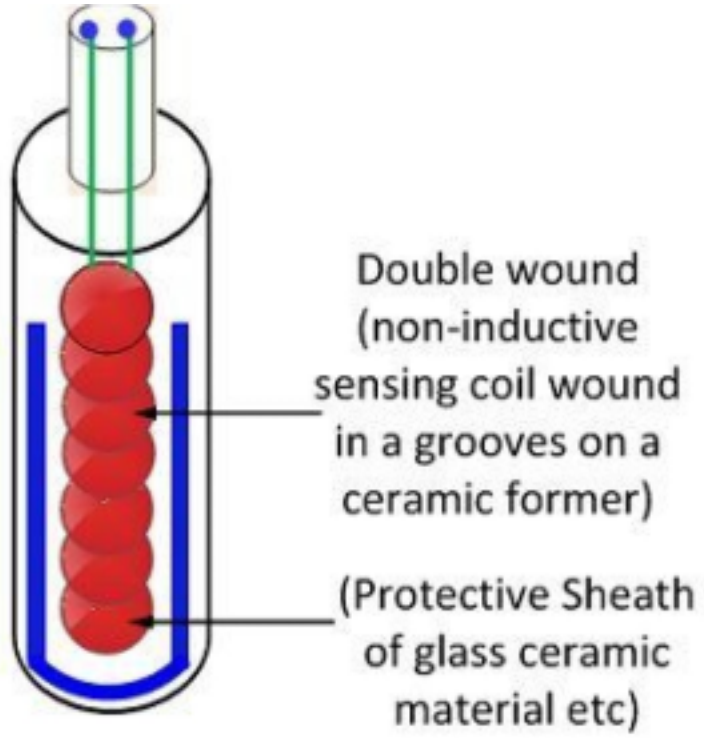
- To minimize the effect of copper wire resistance, two compensating wires (CD) are connected at the upper terminals. These wires ensure that the resistance measured is primarily due to the platinum element.
- In industrial-type thermometers, the platinum wire is enclosed in a stainless steel tube or covered with glass coating for additional protection.
- The sensing element is sealed using glass or ceramic,

which serves two purposes:

1. Provides mechanical strength to the thermometer.

2. Prevents chemical reactions that could affect accuracy

and durability.



Advantages of Platinum Resistance Thermometer

- The temperature measurement through platinum resistance thermometer is easier as compared to the gas thermometer.
- The meter gives the precise reading of temperature.
- The thermometer has a wide range from 200 to 1200° Celsius.
- The thermometer is quite sensitive.
- The platinum has same resistance at the same temperature.

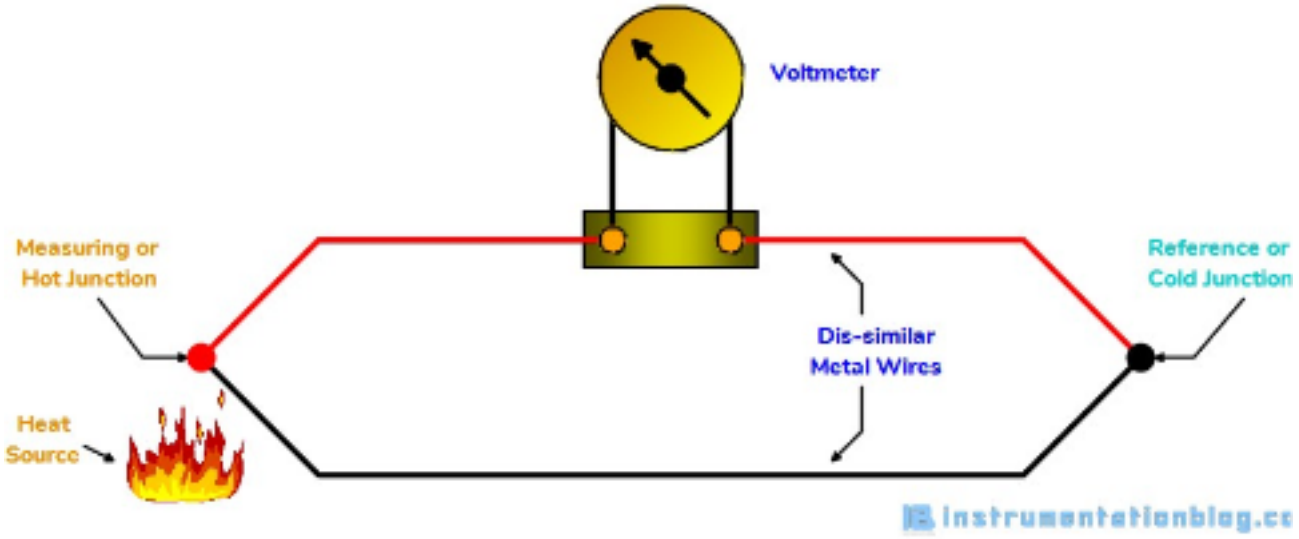
Disadvantages of Platinum Resistance Thermometer

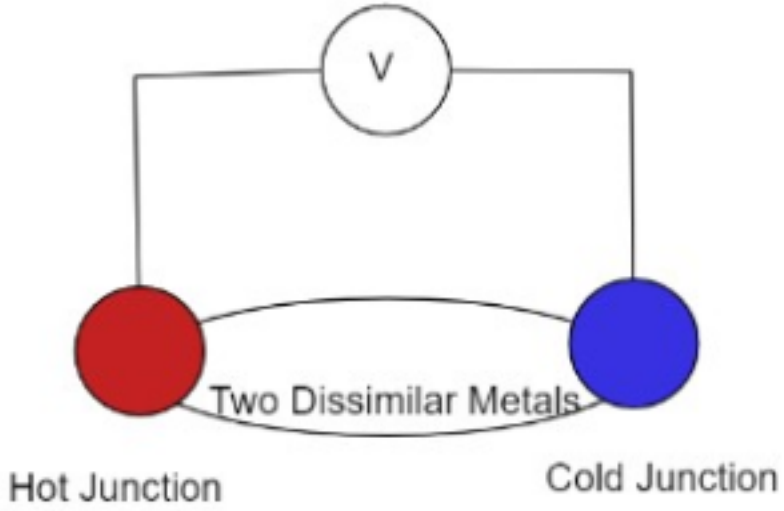
- The following are the disadvantages of platinum thermal resistance.
- The thermometer gives the slow response.
- The melting point of the thermometer is 1800° Celcius. But when platinum measures the temperature higher than 1200°C they start evaporating.

When the thermometer constructed carefully, it provides the excellent sensitivity and high range of measurement.

Thermoelectric Thermometers (Thermocouples):-

Thermoelectric thermometers, commonly known as thermocouples, function based on the Seebeck effect. This phenomenon occurs when two dissimilar metals are joined at one end; a temperature difference between the joined end and the open ends generates a voltage proportional to that temperature difference. The Seebeck coefficient quantifies this voltage response to temperature changes.





Advantages:

Wide Temperature Range:- Thermocouples can measure a broad spectrum of temperatures, making them versatile for various industrial applications.

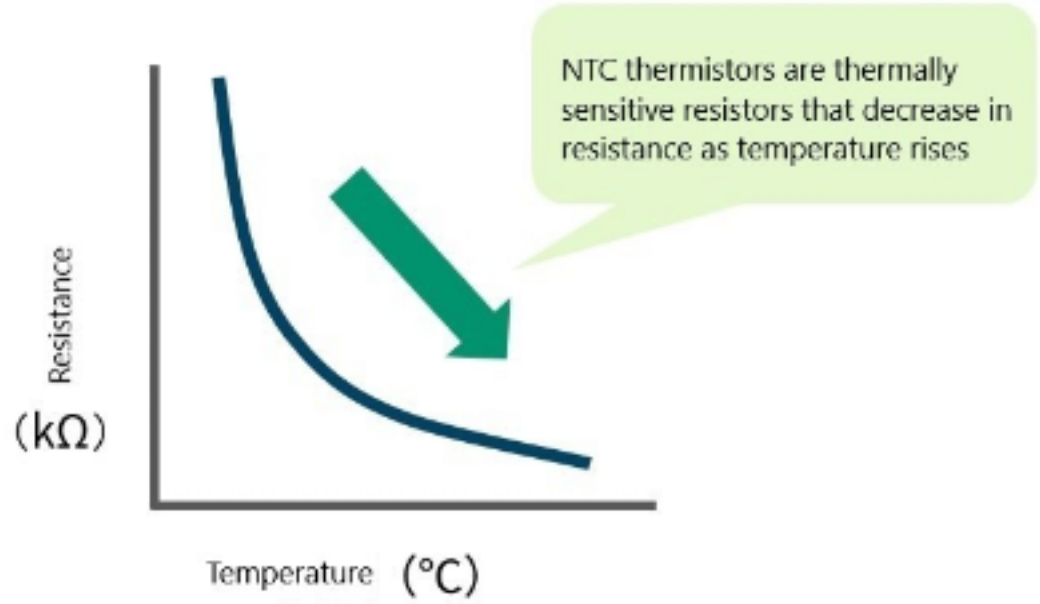
Durability:-They are robust and can withstand harsh environments, including high temperatures and pressures.

Disadvantages:

Accuracy: Thermocouples may exhibit less accuracy compared to other temperature sensors and can drift over time, necessitating regular calibration.

Negative Temperature Coefficient (NTC) Thermometers:-

NTC (Negative Temperature Coefficient) thermistors are temperature-sensitive resistors whose resistance decreases as temperature increases. They are made from ceramic materials composed of metal oxides like manganese, nickel, cobalt, and iron. Due to their high sensitivity to temperature changes, NTC thermistors are widely used in temperature sensing, control, and compensation applications.



Working of NTC Thermistor

An NTC thermistor operates based on semiconductor behavior. As the temperature increases, more charge carriers (electrons and holes) are generated in the material, reducing its resistance. This allows the thermistor to provide precise temperature readings. However, the relationship between resistance and temperature is nonlinear, requiring calibration for accurate measurements.

Principle of NTC Thermistor

The principle of NTC thermistors is based on the variation of electrical resistance with temperature. The resistance-temperature relationship follows the formula:

$$R_T = R_0\, e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)}$$

R(T)is the resistance at temperature T ,

Ro is the resistance at a reference temperature (usually 25°C),

β is a material-dependent constant

T is the absolute temperature in Kelvin.

This equation explains how resistance exponentially decreases with increasing temperature.

- Advantages and Disadvantages of NTC Thermistor

Advantages:

- High sensitivity to temperature changes.
- Small size and cost-effective.
- Fast response time for real-time temperature monitoring.
- Can be used for temperature compensation in circuits.

Disadvantages:

- Limited temperature range compared to thermocouples.
- Non-linear response, requiring calibration.
- Self-heating effect can slightly affect accuracy.
- Susceptible to aging and long-term resistance drift.

Factors for the selection of a thermometer for a particular use

1. Temperature Range – Make sure the thermometer can measure the temperatures you need.
2. Accuracy – Some thermometers give more precise readings than others (e.g., RTDs are very accurate).
3. Response Time – How quickly the thermometer shows temperature changes (e.g., thermocouples respond fast).
4. Environment – Think about where you'll use it (e.g., humid, high pressure, or chemical exposure)
5. Size & Shape – It should fit the space and be easy to handle.
6. Calibration & Maintenance – Some need frequent calibration, while others work for a long time without it.
7. Cost – Pick one that fits your budget while still meeting your needs.

Temperature Range of a thermometer :-

The temperature range of a thermometer refers to the minimum and maximum temperatures it can accurately measure. Choosing the right thermometer depends on the expected temperature range in your application.

Here are some common thermometers and their typical temperature ranges:-

1. Mercury Thermometer – -39°C to 356°C (used in labs and weather stations).

2.Thermocouple – -200°C to 1700°C (used in industrial applications, furnaces, and engines).

3.Resistance Temperature Detector (RTD) – -200°C to 850°C (used in scientific and industrial processes).

4. Thermistor – -100°C to 300°C (used in medical and electronic applications).

5. Infrared Thermometer – -50°C to 3000°C (used for non-contact temperature measurement in industries and medicine).

Comparison of various Thermometers

Thermometer type	Temperature Range	Accuracy	Response Time	Advantages	Disadvantages	Best for
Mercury Thermometer	-39°C to 356°C	High	Slow	Highly accurate, durable	Contains toxic mercury, fragile	Laboratory, medical use
Digital Thermometer	-50°C to 200°C	High	Fast	Easy to read, quick measurements	Battery- dependent	Home, medical use
Infrared Thermometer	-50°C to 380°C	Moderate	Very fast	Non-contact, quick readings	Affected by surface properties	Industrial, food safety
Thermocouple Thermometer	-200°C to 1750°C	Moderate	Fast	Wide temperature range, durable	Requires calibration	High temperature Industrial settings
Liquid crystal Thermometer	35°C to 40°C	Low	Moderate	Inexpensive, easy to use	Limited temperature range, less accurate	Quick checks(fever detection)
Bimetallic Thermometer	-50°C to 500°C	Low	Moderate	No power required	Less accurate	Industrial ovens
Glass Thermometer	-50°C to 100°C	High	Slow	Non-toxic , safe	Breakable,slow response time	Household use(ambient cooking)

Calibration of Pt100 for Temperature Measurement:-

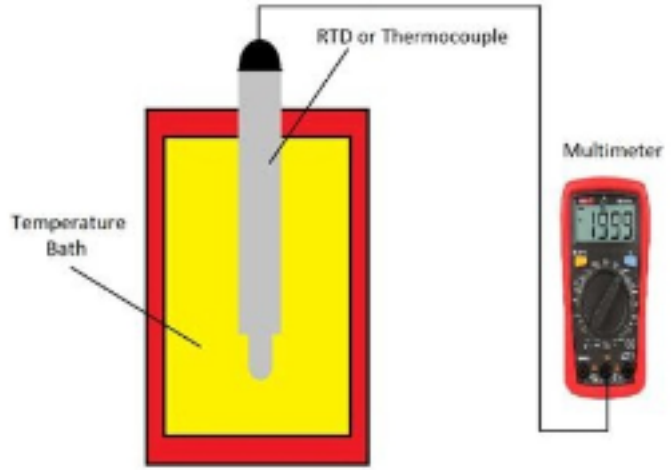
Calibration of a Pt100 sensor is crucial for ensuring accurate temperature measurements in industrial and laboratory applications. The process involves comparing the Pt100 sensor’s readings with a high-accuracy reference thermometer and adjusting any deviations.

General Setup for Temperature Calibration

Components in the Calibration Setup:

Pt100 Sensor:- The temperature sensor being calibrated.

Reference Thermometer:- A high-accuracy thermometer used for comparison.



Temperature Calibration Bath/Dry Block Calibrator:-

Provides a stable reference temperature.

Multimeter/Calibrator:- Measures the resistance of the Pt100 sensor and compares it with expected values.

Temperature Controller (if applicable):- The device using the Pt100 sensor to regulate and display temperature.

Detailed Calibration Procedure

1. Connect the Pt100 Sensor:-

Attach the Pt100 sensor to both the temperature controller and the calibration device.

2. Set the Reference Temperature :-

Use a calibration bath or dry-block calibrator to set a stable temperature (e.g., 0°C, 50°C, and 100°C).

3. Compare Readings

Observe the temperature readings from:

Pt100 sensor (via the temperature controller display)

Reference thermometer

If the values do not match, record the deviation.

4. Adjust and Document:-

If an error is found, apply necessary corrections in the temperature controller or note the error for manual compensation.

Record the calibration results for future reference.

Importance of Calibration of Pt100 for Temperature Measurement:

1. Accuracy: Calibration ensures that the Pt100 sensor provides precise and reliable temperature readings, which is crucial in processes requiring exact temperature control, such as in industrial settings, laboratories, and healthcare.

2. Compliance with Standards: Calibration ensures that the Pt100 sensor meets national and international temperature standards, which is necessary for regulatory compliance and certifications in various industries.

3. Error Detection and Correction: Regular calibration helps to detect any drift or inaccuracies in the Pt100 sensor over time, allowing for timely correction and ensuring that measurements are always within acceptable limits.

4. Process Efficiency and Safety: Accurate temperature readings are essential for maintaining optimal operating conditions in systems. Calibration ensures that processes are safe, efficient, and do not lead to overheating or system failures.

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