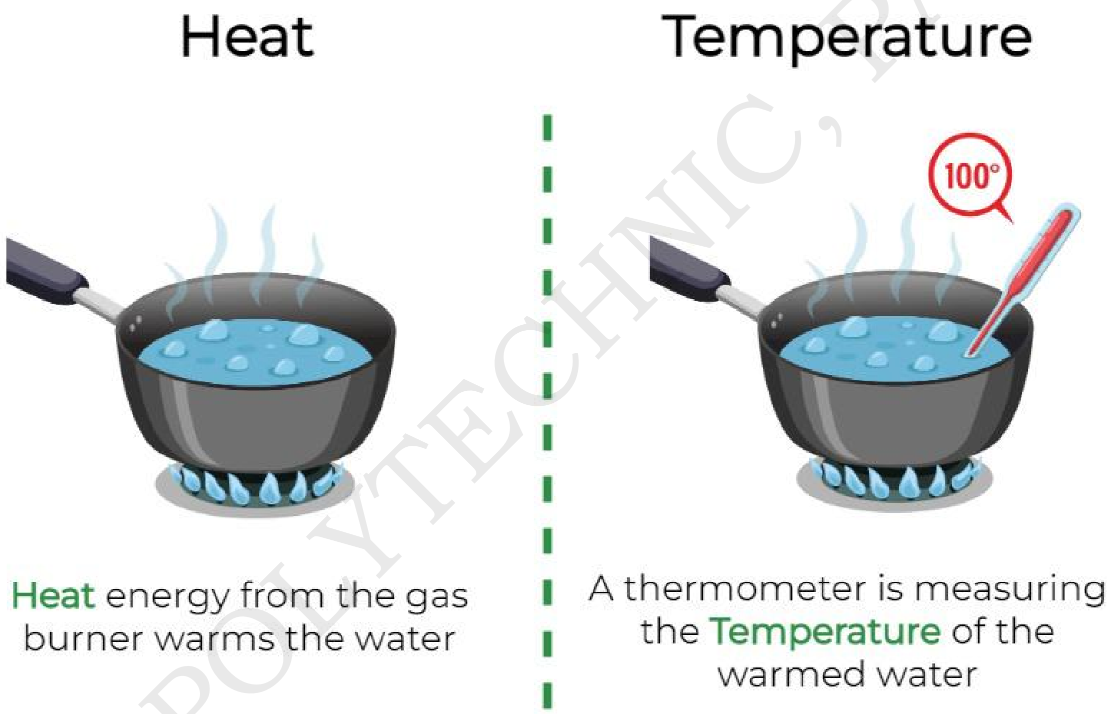
UNIT – 3 HEAT & THERMOMETRY

Prologue: We can feel heat by touching the other end of metal rod after some time on heating the other end of the metal rod.

We know that all matter in the universe is made up of atoms and atoms. These atoms and molecules are in constant motion. This motion may be a linear, rotational or vibrational. Such motions of atoms or molecules result in the generation of heat energy. All objects in the universe have such type of energy.



Heat	Temperature
Heat is a form of energy. It is thermal energy.	Temperature is not energy. It is the thermal state of physical matter. The average kinetic energy of all atoms in a given physical body is temperature.
Heat flow is the cause of temperature change.	A change in temperature may be the result of heat exchange (gaining or losing).
Two materials with same temperature do not necessarily have the amount of heat.	It is not necessary that two substances having the same amount of heat should also be at the same temperature.

(If the heat capacity of a given bodies are different)	
Heat can be exchanged. It can flow from one body to another. So, a body can lose or gain heat.	Temperature cannot be exchanged. Only heat can be exchanged. Therefore, the change in temperature may be the result of heat exchange.
The total amount of heat in any substance cannot be measured. Thus, only the amount of heat gained or lost (the amount of heat conduction between two bodies) can be measured.	The temperature of a body can be measured. But the temperature does not flow.
The conduction of heat between two bodies can be measured by a calorimeter.	The temperature of a given substance can be measured with a thermometer.
SI Unit: Joule CGS Unit: erg	Unit: $°C$ or K
Heat is not a fundamental physical quantity.	Temperature is the fundamental physical quantity.
Heat is not a property of a thermal system. However, heat capacity and specific heat are properties of a thermal system.	Temperature is a property of a thermal system.
Heat is a path function. Therefore, moving from one state to another depends on the path followed by the thermodynamic system.	Temperature is a point function. Therefore, it is independent of the path followed by the system to move from one state to another. In each thermal state, the temperature has a definite value.
Whether heat will move from one object to another is not governed by the amount of heat present in the body. (That is, the amount of heat in the substance cannot determine whether the heat will be carried or not.)	It is the temperature of the body that determines whether the heat will flow between two bodies or not. Heat always flows from a body with a higher temperature to a body with a lower temperature.
Heat capacity (not heat) depends on the mass of the system. So, this is an extensive property. However, specific heat is an intensive property.	Temperature does not depend on matter; So, it an intensive property.

Que. 01. Define: Heat and Temperature.

Ans: Heat: Heat is the term used to describe the thermal energy carried between atoms in an atmosphere due to temperature differences.

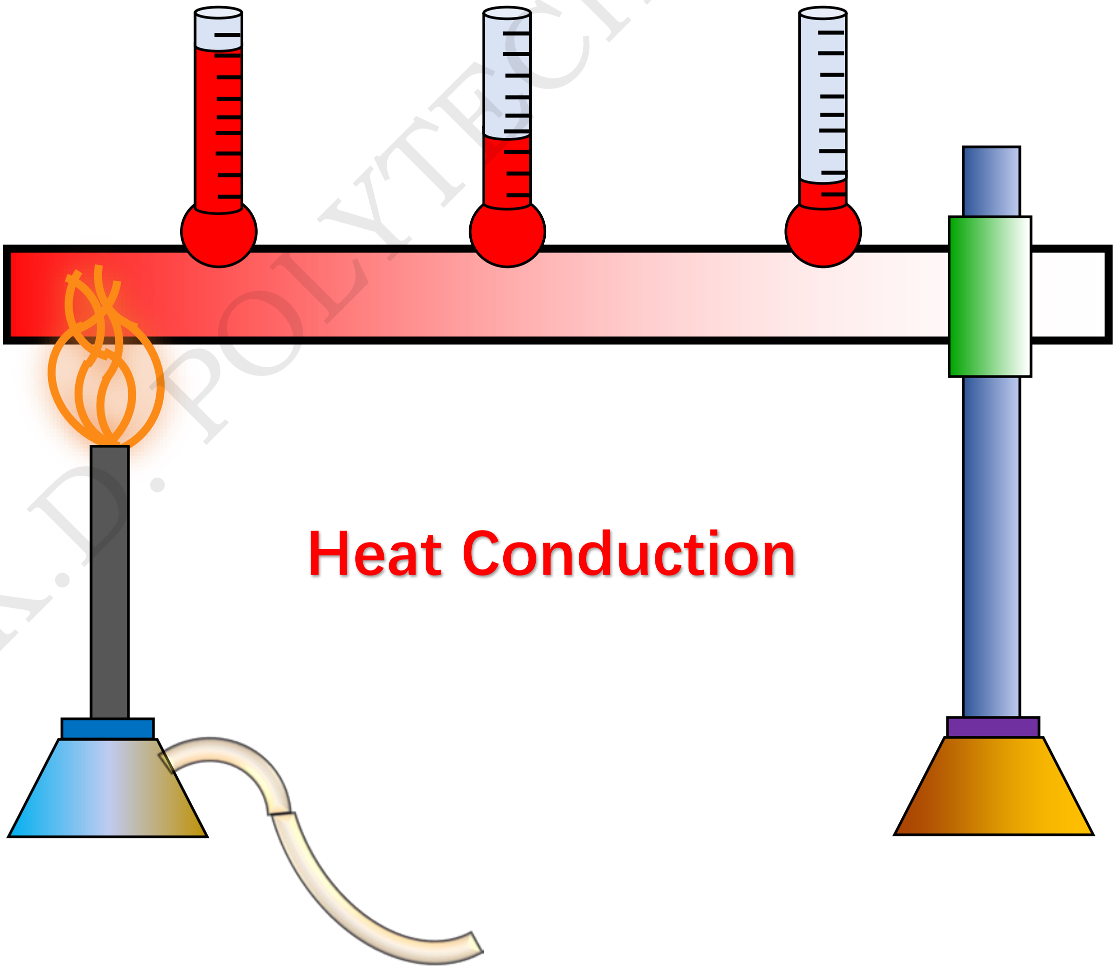
Temperature: Temperature defines the thermal state of an object which determines the direction of conduction of heat. That is, the temperature will determine whether a given object receives heat from another object or it will give heat to another object.

Que. 02. Describe heat conduction in conductor materials.

Que. 02. Short Note: Heat Conduction.

Que. 02. Describe the heat conduction in metals.

Ans: Heat Conduction: Heat conduction is possible only when solids are in direct contact with each other. When matter is a conductor of heat, heat conduction occurs more rapidly.



As shown in the figure, the metal rod is arranged with three thermometers on the stand. By heating one end of the rod, the molecules at that end receive heat, so their vibrations increase. These molecules pass on their energy to the neighboring molecules. These molecules increase their vibrations and give the heat energy to the next molecules gradually. Thus, the conduction of heat becomes possible.

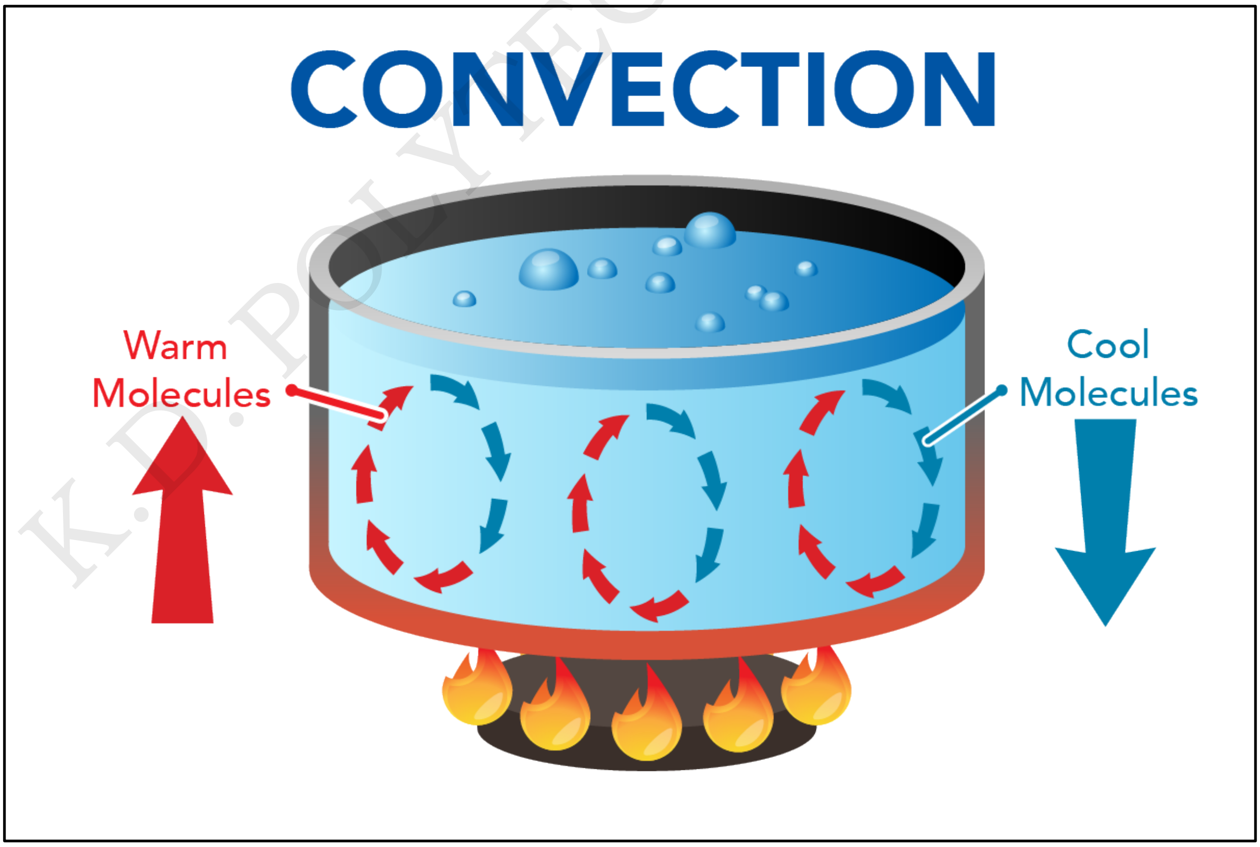
The atoms participating in the heat transfer do not leave their places or do not go to another place. They mostly vibrate around their central position.

Que. 03. Describe heat convection in liquid and gas.

Que. 03. Short Note: Heat Convection

Que. 03. Describe the heat Convection in fluids.

Ans: Heat Convection: The atoms participating in the heat convection leave their places and move to another places. Therefore, heat convection is possible only in liquids or gases, i.e., fluids.



As the molecules at the bottom of the heat sink are heated, their size increases, thus reducing their density. But since the density of the atoms in the upper part is higher, under the force of gravity, the cold molecules move downwards and their place is taken by the heated molecules from below. Thus, a kind of current is produced in liquids. Thus, the heat convection occurs mainly in liquid and gaseous materials.

Que. 04. Describe the type of heat flow occurring without any physical contact between two materials.

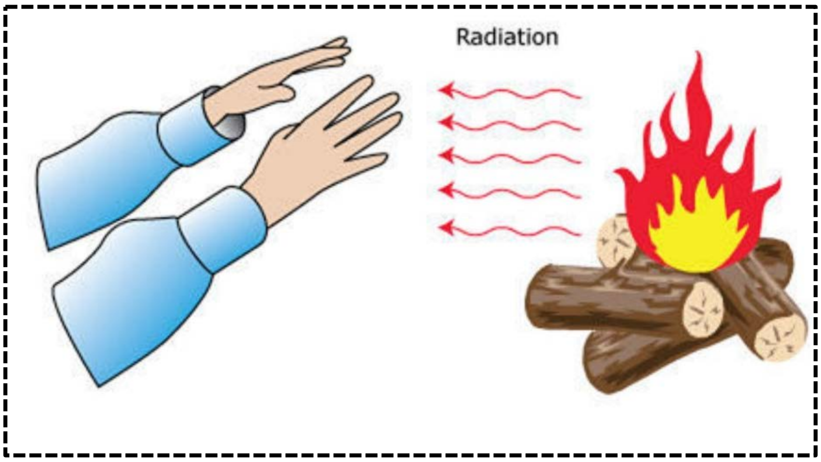
Que. 04. Describe the type of heat flow occurring at the speed of light.

Que. 04. Describe the type of heat flow occurring in all three states of matter i.e., solid, liquid and gas.

Que. 04. Short Note: Heat Convection and list its properties.

Ans: Heat Radiation: The process of transferring heat through electromagnetic radiation, which is produced by the thermal motion of particles in a material, is known as thermal radiation. This particular electromagnetic radiation occurs in the infrared region of the spectrum.

Thermal radiation is emitted by each particle with a temperature greater than neutral zero. This type of motion is completely at rest at neutral zero temperature.



When iron is heated, it is referred to as "red hot" because at that temperature most of the thermal energy emitted by the body falls into the red part of the spectrum. It will begin to emit a different color even at higher temperatures.

Properties of thermal radiation:

1. Radiation is the energy emitted by an object in the form of electromagnetic waves.
2. At any temperature, the thermal radiation of the object emits a variety of frequencies.
3. As the emitter's temperature increases, the frequency (or color) of the emitted radiation increases. Red hot iron, for example, mainly spreads over longer wavelengths (red and orange) of the visible spectrum. As it heats up, it begins to produce green and blue light.
4. As the temperature rises, the total amount of radiation of all frequencies increases sharply. And this energy is proportional to the fourth power of the absolute temperature of that object.

$$Q \propto T^4$$

This statement is called the Stefan-Boltzmann rule.

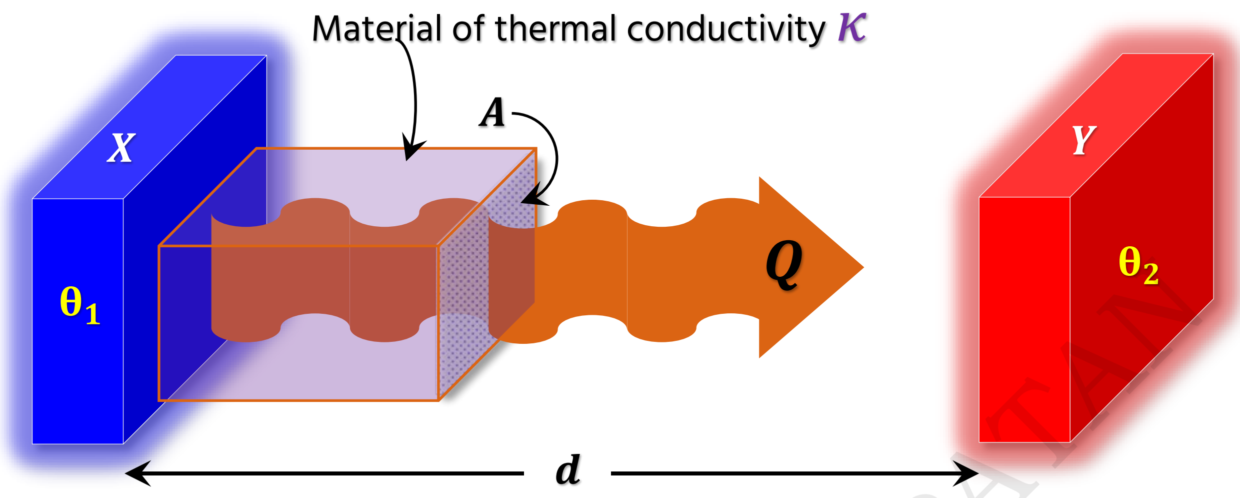
Que. 05. Explain Heat conduction in metals and derive an equation for heat flow rate. Write the unit of κ.

Ans: In the figure, a metal rod of length d is shown with an area A of intersection. The heat that heats the rod flows from one end X to the other end Y. The temperatures of the plane P and Q are T_1 and T_2 respectively. The conduction of heat is from X end to the Y end perpendicularly through planes P and Q. According to the law of heat conservation, the amount of heat enters the plane P is same as the amount of heat leaving the plane Q.

The amount of heat conduction depends on the following factors.

1. The amount of heat carried is proportional to the area of intersection of the rod.

$$Q \propto A$$



THERMAL CONDUCTIVITY

2. The amount of heat carried is proportional to the temperature difference between the two planes.

$$Q \propto (T_2 - T_1)$$

3. The amount of heat carried is proportional to time.

$$Q \propto t$$

4. The amount of heat carried is proportional to the distance between the two planes.

$$Q \propto \frac{1}{d}$$

Combining all of the above,

$$Q \propto \frac{A(T_2 - T_1)t}{d}$$

$$Q = \frac{\kappa\, A\, (T_2 - T_1)\, t}{d}$$

Here **κ** is the constant of proportionality and also known as the constant of **Heat Conductivity**. Its value depends only on the type of material used.

If we take, $d = 1\,m$, $A = 1\,m^2$, $t = 1\,s$ and $T_2 - T_1 = 1\,℃$ in the above formula,

$$Q = \kappa$$

Using this fact, the constant of heat conductivity can be defined as follows.

Definition: The amount of the heat flowing perpendicularly through a plane having unit cross-sectional area and having a unit temperature difference is called heat conductivity at a given temperature of that object.

In short, κ is the measure of the ability of a material to conduct heat through it.

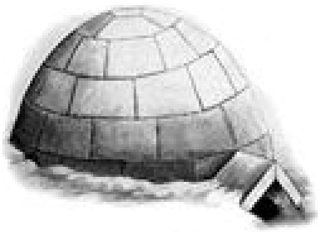
Unit $[\kappa] = \frac{W}{m \cdot K}$ or $\frac{W}{m \cdot {}^\circ C}$

Applications of Conductivity in Daily Life: (write any two)

(1) Cooking utensils are provided with wooden (or Ebonite) handles, because wooden (or Ebonite) is a poor conductor of heat. The hot utensils can be easily handled from the wooden (or Ebonite) handles and our hands are saved from burning.

(2) We feel warmer in a fur coat. The air enclosed in the fur coat being bad conductor heat does not allow the body heat to flow outside. Hence, we feel warmer in a fur coat.

(3) Eskimos make double walled houses of the blocks of ice. Air enclosed in between the double walls prevents transmission of heat from the house to the cold surroundings.



For exactly the same reason, two thin blankets are warmer than one blanket of their combined thickness. The layer of air enclosed in between the two blankets makes the difference.

(4) Wire gauze is placed over the flame of Bunsen burner while heating the flask or a beaker so that the flame does not go beyond the gauze and hence there is no direct contact between the flame and the flask. The wire gauze being a good conductor of heat, absorb the heat of the flame and transmit it to the flask.

Davy's safety lamp has been designed on this principle. The gases in the mines burn inside the gauze placed around the flame of the lamp.

The temperature outside the gauze is not high, so the gases outside the gauze do not catch fire.

(5) Birds often swell their feathers in winter. By doing so, they enclose more air between their bodies and the feathers. The air, being bad conductor of heat prevents the out flow of their body heat. Thus, birds feel warmer in winter by swelling their feathers.

More about κ: (For More Understanding ONLY- Do not Write)

a) The magnitude of K depends only on nature of the material.

b) Material in which heat flows quickly and easily are known as good conductor of heat. They possess large thermal conductivity due to large number of free electrons e.g. Silver, brass etc.

c) For perfect conductors, $\kappa = \infty$

d) Materials which do not permit easy flow of heat are called bad conductors. They possess low thermal conductivity due to very few free electrons. e.g., Glass, wood, Rubber, leather etc. and for perfect insulators, $\kappa = 0$.

e) The thermal conductivity of pure metals decreases with rise in temperature but for alloys thermal conductivity increases with increase of temperature.

f) Human body is a bad conductor of heat (but it is a good conductor of electricity).

Substance	Thermal conductivity (W/m-K)	Substance	Thermal conductivity (W/m-K)
Aluminum	240	Concrete	0.9
Copper	400	Water	0.6
Gold	300	Glass wool	0.04
Iron	80	Air	0.024
Lead	35	Helium	0.14
Glass	0.9	Hydrogen	0.17
Wood	0.1-0.2	Oxygen	0.024

g) Decreasing (Descending) order of Thermal conductivity:

$$K_{Ag} > K_{Cu} > K_{Al}$$

$$K_{Silver} > K_{Copper} > K_{Gold} > K_{Aluminium} > K_{Zinc} > K_{Steel} > K_{Lead} > K_{Water} > K_{Ice} > K_{Rubber} > K_{Wood} > K_{Ebonite}$$

$$K_{Solid} > K_{Insulator} > K_{Liquid} > K_{Gas}$$

$$K_{Metals} > K_{Non-metals}$$

Que. 06. Explain different Temperature Scales.

Ans: Temperature is a numerical measure of the coolness or hotness of an object. A change in the temperature expands the size of solid, liquid or gaseous substance. Due to increase in temperature, the resistance of metal wires increases. The temperature of a substance can be measured using any of the things mentioned herein.

Thermometers are used to measure temperature according to a well-defined scale of measurement. For this, physical quantities can be compared using pre-determined reference points.

The three most common temperature scales are Fahrenheit, Celsius, and Kelvin. A temperature scale can be created by identifying two different easily recoverable temperatures. Generally, melting point of ice and boiling point of water temperatures are used at standard atmospheric pressure.

Celsius Scale: In this scale, the melting point of ice and boiling point of boiling water are taken as reference points. Its unit is degree Celsius ℃. The melting point of ice $\mathbf{0}$ ℃ and the boiling point of boiling water $\mathbf{100}$ ℃ are taken.

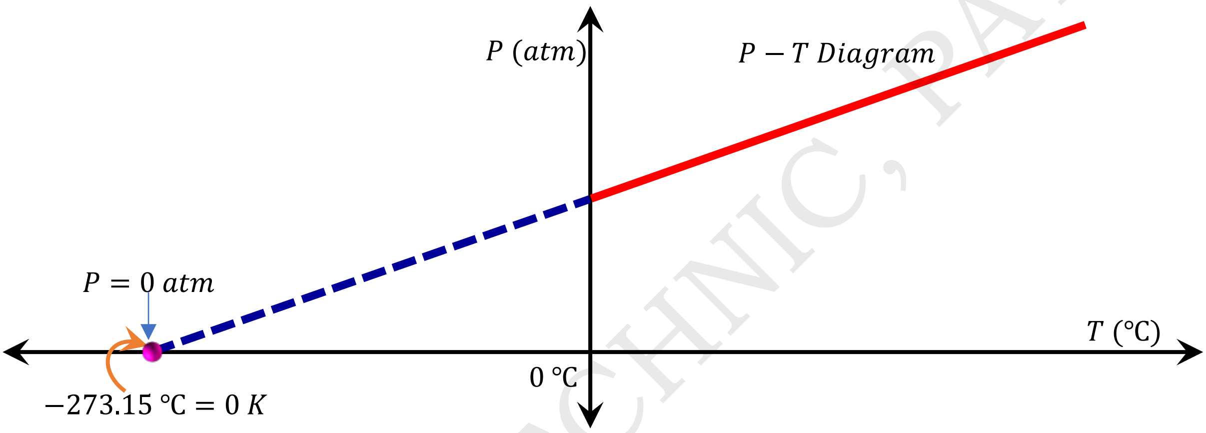
Fahrenheit Scale: In this scale the melting point of ice and boiling points of boiling water are taken as reference points. Its unit degree is Fahrenheit °F. The melting point of ice $\mathbf{32}$ °F and the boiling point of boiling water $\mathbf{180}$ °F are taken.

The temperature difference of one degree Celsius is greater than the temperature difference of one degree Fahrenheit. Only $\mathbf{100}$ ℃ has the same range as $\mathbf{180}$ °F.

$$\mathbf{1}\ ℃ = \mathbf{1.8}\ °F$$

Kelvin Scale: The Kelvin scale is commonly used in science. It is an absolute temperature defined for $0\ K$. The lowest possible temperature at $0\ K$ is called neutral zero. The official temperature unit on this scale is Kelvin, denoted by K. (Kelvin: The unit is not written with the degree mark °)."

The melting point of ice and boiling point of water are 273.15 K and 373.15 K respectively. Thus, the temperature difference between the Kelvin scale and the Celsius scale is the same. Unlike other scales, the Kelvin scale is a complete scale. It is widely used in scientific work because a number of physical quantities such as the size of the ideal gas are directly related to the absolute temperature.



Conversion: °C → °F → K

$$\frac{T_C - 0}{5} = \frac{T_F - 32}{9} = \frac{T_K - 273.15}{5}$$

Celsius (°C) and Kelvin (K)

$$\frac{T_C - 0}{5} = \frac{T_K - 273.15}{5}$$

$$\therefore \frac{T_C}{5} = \frac{T_K - 273.15}{5}$$

$$\therefore T_C = T_K - 273.15$$

$$\therefore T_K = T_C + 273.15$$

Celsius (°C) and Fahrenheit (°F)

$$\frac{T_C - 0}{5} = \frac{T_F - 32}{9}$$

$$\therefore \frac{T_C}{5} = \frac{T_F - 32}{9}$$

$$\therefore T_C = \frac{5}{9}(T_F - 32)$$

$$\therefore T_F = \frac{9}{5}T_C + 32$$

Fahrenheit (°F) and Kelvin (K)

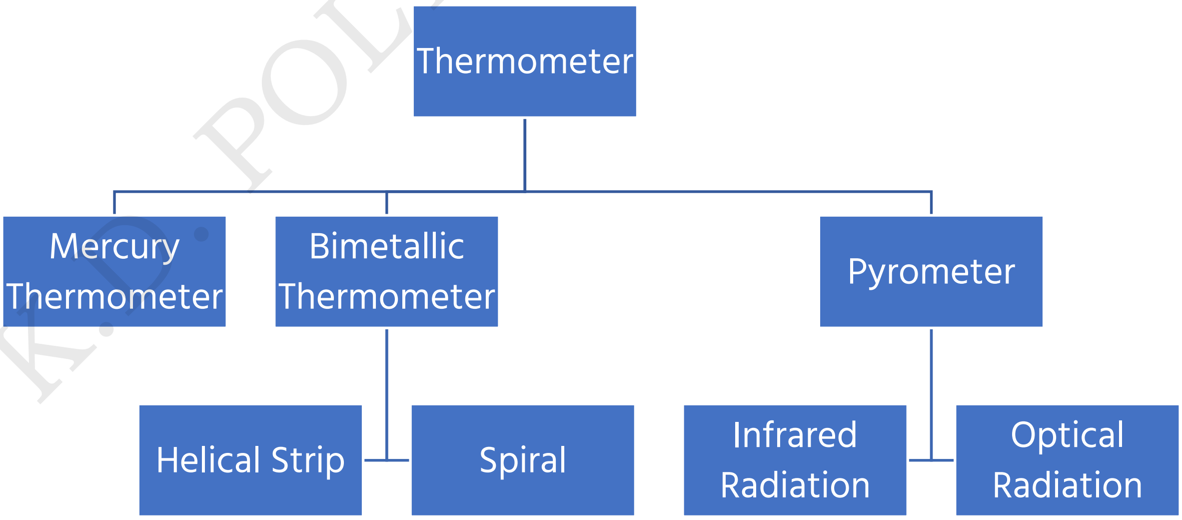
$$\frac{T_F - 32}{9} = \frac{T_K - 273.15}{5}$$

$$\therefore T_F - 32 = \frac{9}{5}(T_K - 273.15)$$

$$\therefore T_F = \frac{9}{5}(T_K - 273.15) + 32$$

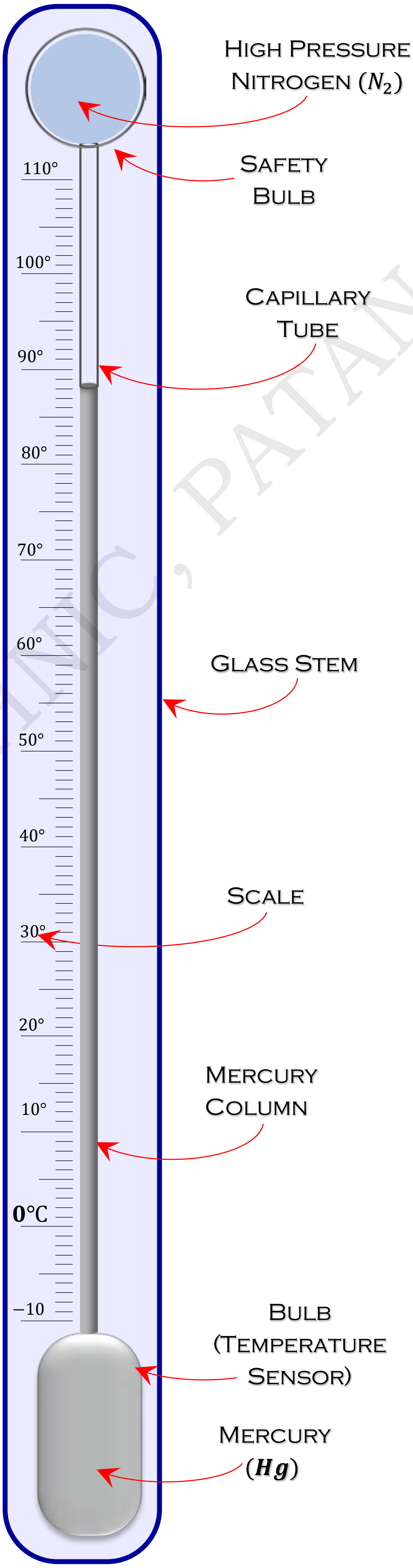
$$\therefore T_K = \frac{5}{9}(T_F - 32) + 273.15$$

Types of Thermometers: Thermometers can be classified to three categories.



Que. 07. Explain Principle, Construction, working, advantages and disadvantages of Mercury Thermometer by drawing proper diagram.

Ans: Principle: Metals such as mercury increase or decrease in temperature lead to an expansion or contraction in their size.(Hg)



Construction: A glass thermometer is shown in the figure. It is mainly made up of three parts.

1. **Stem:** A stem is actually a transparent glass tube containing a small diameter capillary. The diameter (bore) of the glass casserole increases the expansion and contraction of mercury size further. Boiling point of Mercury is $356.7\ ^\circ\mathrm{C}$, so, an inert gas like nitrogen (N2) is filled under pressure in the empty part of the stem to measure a higher temperature like $500\ ^\circ\mathrm{C}$. (The boiling point of the liquid increases at higher pressure.)
2. **Bulb:** The structure for storing mercury at the lower end of the stem is called a bulb. When heated,

the mercury in the bulb expands and moves into the stem.

3. **Scale:** To find the size of the expansion or contraction of mercury, the stem is divided at a fixed distance. With this section ℃ and/or °F the scale is displayed.

Working: When the thermometer is kept in contact with the object whose temperature is to be measured. Therefore, the mercury in the bulb expands into the stem due to heat. Until the temperature of the mercury is equal to the temperature of the object, the flow of heat from the object to the thermometer continues. The temperature of both of them equals prevents further expansion of mercury by the measurement on the stem.

Advantages:

1. Mercury boils at high temperatures and freezes at low temperatures, therefore wider range of temperatures can be measured.
2. Mercury being a shiny and opaque metal makes it easier to take measurements.
3. Since the cohesive force between mercury and mercury is much greater than the adhesive force with glass, it can easily move into the stem without wetting the surface of the glass.
4. It does not require electricity to run its operation.
5. Despite repeated use, it does not need to be calibrated every time.
6. It is extremely cheap compared to other thermometers.

Disadvantages/Limitations:

1. The nature of mercury is harmful.
2. Freezing point of Mercury is $\mathbf{-39}$ ℃. Therefore, mercury thermometers cannot be used to measure temperatures below it.
3. Mercury thermometers cannot be used to measure precise temperatures.
4. They cannot measure temperature automatically.

5. It is influenced by external factors such as the temperature of the atmosphere, the exchange of heat during the holding of the thermometer (by hand).

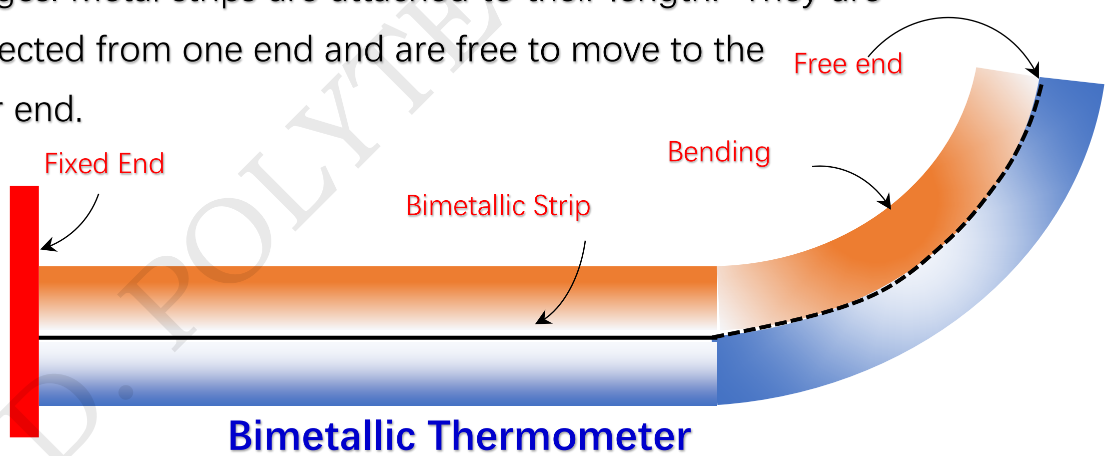
Que. 08. Explain Principle, Construction, working, advantages and disadvantages of Bimetallic Thermometer by drawing proper diagram.

Ans: Temperature corresponding to expansion can be measured using strips of two different metals.

Principle: A bimetallic thermometer works on two basic properties.

1. Thermal expansion of metals
2. At the same temperature, different metals have different thermal linear expansion co-efficients.

Construction: The main component of the bimetallic thermometer is the bimetallic strip. The bimetallic strip consists of two thin strips of metals with different thermal diffusion digits. As temperature changes, its shape or size changes. Metal strips are attached to their length. They are connected from one end and are free to move to the other end.



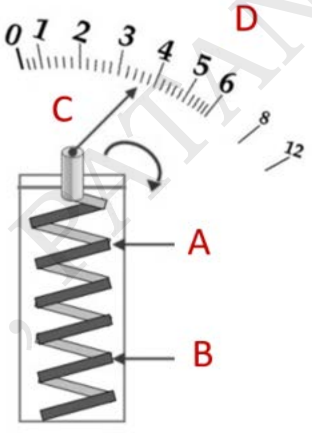
Bimetallic Thermometer

Method: The two commonly used metals are steel and copper. Because of their thermal diffusion being different, the length of these metals varies at different rates for the same temperature. Due to this property, when the temperature changes, the metal strip on one side expands more and the other expands less, due to which the two stripes attached bend.

When the temperature rises, it bends towards a strip of metal with a lower temperature coefficient.

When the temperature drops, the strip turns in the direction of a metal with a higher temperature coefficient. The deviation of the strip shows a change in temperature. Measurements are carried out to ensure a proper temperature reading.

Helical Strip Bimetallic Thermometer:

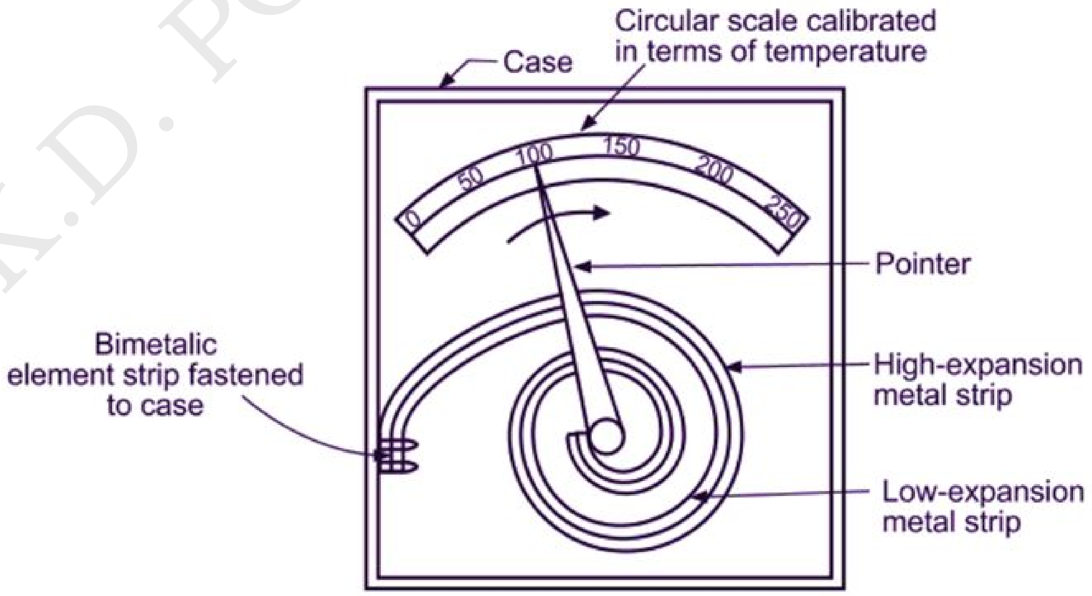


Helix or helical-shaped bimetallic strip thermometers are mostly used in industrial applications. Changes in the temperature of the strip cause its contraction and expansion. It has a helical-shaped bimetallic strip and the lower end is fixed and the upper end is free to move.

The free end of the bimetallic helix is connected to the shaft. The other end of the shaft is connected to the pointer which shows on the measured dial.

Usage: A helical strip thermometer can be placed inside a thermowell that also works in environments with high temperature and pressure.

Spiral Strip Bimetallic Thermometer:



In this thermometer, a pointer arranged along the scale is attached to a spiral (spiral) bimetallic strip made up of strips of two different metals. As the temperature increases, the strips of the two metals expand in different ways. The spiral bimetal rotates clockwise. As a result, the pointer attached to it reflects the temperature on a scale measured.

Usage:

1. Spiral strip thermometers are sensitive even to low temperatures so they are used in thermostats.
2. These thermometers are used in household appliances including equipment in industries such as ACs (air conditioners), ovens and hot wires, refineries, tempering tanks, heaters, etc.

Advantages of a bimetallic thermometer:

1. Its installation is easy.
2. Its maintenance is easy.
3. It has high accuracy.
4. They are cheaper in price.
5. Its temperature range is huge.
6. It shows a linear response to higher temperatures.
7. They are completely mechanical and do not require any power source to operate them.
8. It is easy to use and has a strong design.

Disadvantages:

1. They cannot be used to measure very high temperatures.
2. They have to be calibrated repeatedly.
3. For low temperatures one cannot drink precisely at temperature because the expansion of metals is very small
4. When these thermometers are used frequently, the bimetallic strip of this device can rotate permanently resulting in a defect.

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Que. 12. Explain Linear thermal expansion in metals and derive an equation for change in length. Write definition and SI unit of Linear thermal expansion co-efficient.

Ans: **Linear thermal Expansion:** Thermal expansion is the tendency to respond to changes in the temperature of a substance. (An example of this is the buckling of a railroad track).

Molecules and atoms in a solid object move continuously around its equilibrium position. These types of movements are called thermal motion. When a substance is heated, its constituent particles start more movements. Each particle maintains a greater average distance with their neighboring particles. As a result, the substance expands.

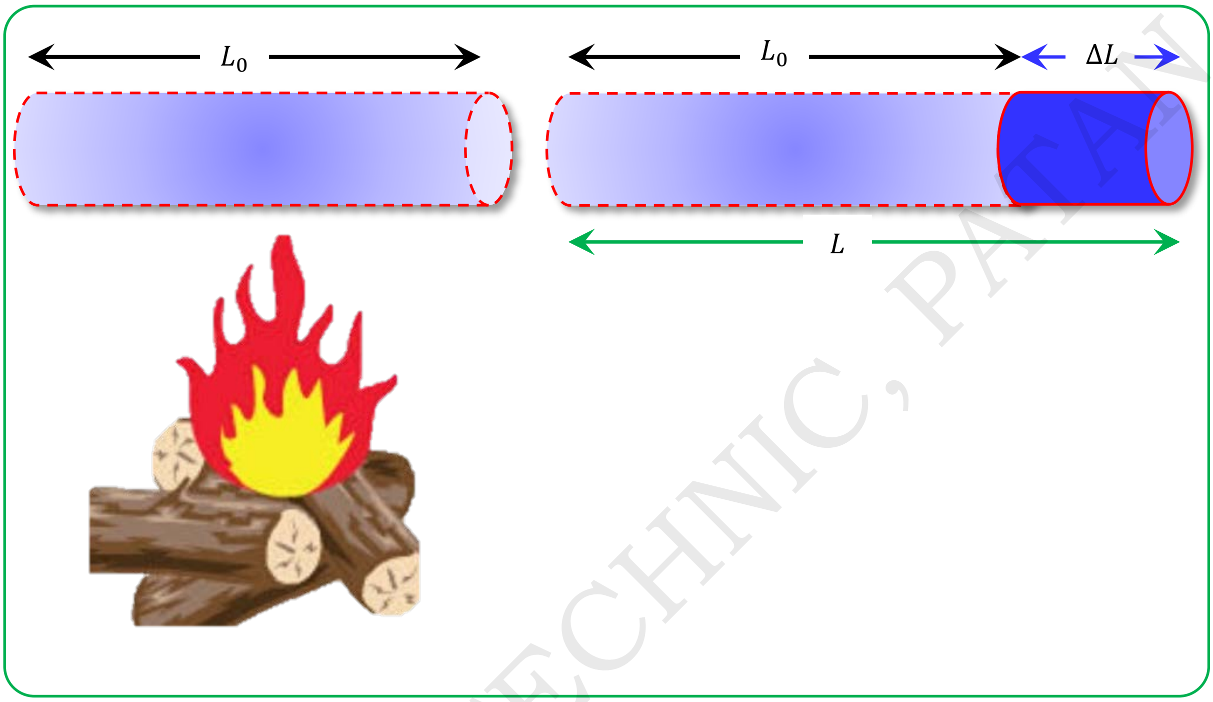
Suppose a metal rod has its original length L_0 and has an initial temperature T_1 . When this rod is heated to the temperature T_2, the length of the rod changes by ΔL. Thus, the increase in the length of the rod is proportional to the original length of the rod.

$$\Delta L \propto L_0$$

The increase in the length of the rod is proportional to the change in temperature in the rod.

$$\Delta L \propto (T_2 - T_1)$$

$$\Delta L \propto \Delta T$$



Combining these two things,

$$\Delta L \propto L_0 \times \Delta T$$

$$\Delta L = \boldsymbol{\alpha} \, L_0 \, \Delta T$$

So, the final length of the metal rod becomes,

$$L = \Delta L + L_0$$

Here, $\boldsymbol{\alpha}$ is known as the thermal linear expansion co-efficient of a given object. The thermal linear diffusion number (the coefficient of linear expansion) can also be mathematically written as follows,

$$\therefore \alpha = \frac{\Delta L}{L_0 \, \Delta T}$$

Definition: The change in length per unit degree change in the temperature of a unit length rod is called the thermal linear diffusion number of a given rod.

Unit:

$$[\alpha] = ℃^{-1} \text{ or } K^{-1} \text{ or } \frac{1}{℃} \text{ or } \frac{1}{K}$$

Properties:

- The thermal linear expansion co-efficient is the intrinsic property of every object. So, it varies from one substance to another.
- The rate at which matter expands depends on the intermolecular force between the atoms.