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UNIT - 4

Heat and Thermometry

* Definitions :

1. Heat :

Heat is an energy which is transferred between two bodies or between body and its surrounding on account of the temperature difference between them.

SI unit - Joule (J), Calorie

CGS unit - erg

2. Calorie :

Calorie is the amount of heat required to raise the temperature of 1 gram of water through 1°C.

3. Conduction :

The process of heat transfer due

to the temperature difference between the adjacent parts of the solid object is called heat conduction.

4. Convection:

Convection is a mode of heat transfer from one part of the medium to another part by the actual movement of the heated particles of the medium.

5. Radiation:

Radiation is a mode of heat transfer from the source to the reciever without any actual movement of source or reciever and also without heating the intervening medium.

6. Heat Capacity:

The ratio of the amount of heat (Q) given to a body to the corresponding change in its temperature (ΔT) is called the heat capacity (H_c) of the body.

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∴ Heat capacity = $\frac{\text{heat given to a body}}{\text{change in temperature}}$

∴ $H_C = \frac{Q}{\Delta T}$

SI unit - J/K
CGS unit - cal/°C.

7. Specific Heat:

The quantity of heat required per unit mass for unit change in the temperature of a body is called specific heat (denoted by c) of the material of the body.

∴ Specific heat = $\frac{\text{heat capacity}}{\text{mass}}$

$= \frac{\Delta Q}{m \Delta T}$

SI unit - J/kg °K
CGS unit - cal/gm °C

8. Coefficient of Thermal Conductivity:

The coefficient of thermal conductivity of a solid is equal to the rate of flow of heat per unit area per unit temperature gradient.

across the solid.

$$k = \frac{Qd}{A(T_1 - T_2)t}$$

$$= \frac{\Delta Q d}{A \Delta T t}$$

where Q = amount of heat transfer
ΔT = temperature difference
t = flow time
d = distance between two temperature
A = cross sectional area of rod.

SI unit – J/ sec · m °K
CGS unit – cal / sec · cm °C

9. Temperature :

Temperature is the measure of average of thermal energy of the molecules.

SI unit – K
CGS unit – °C

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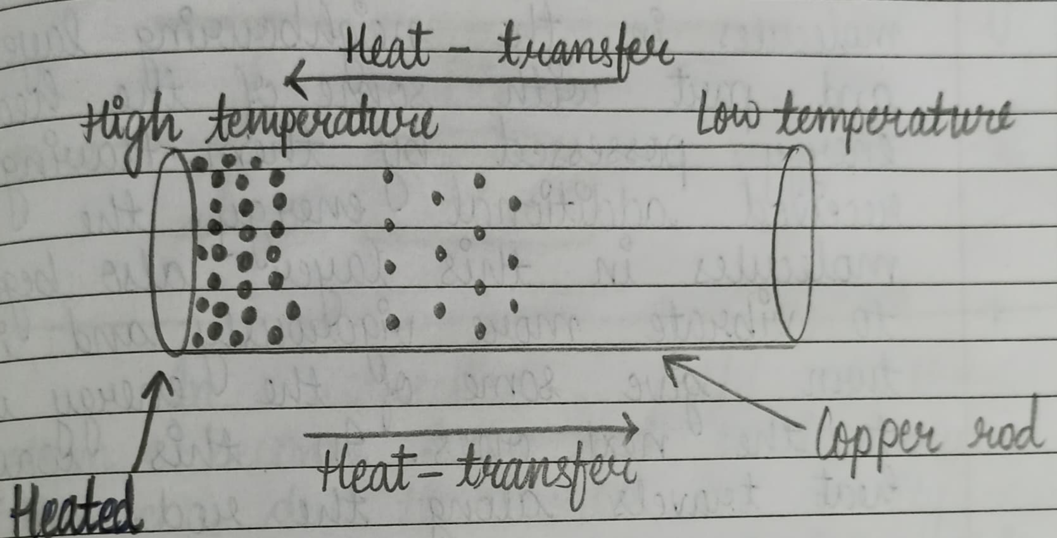
* Conduction:

The process of heat transfer due to the temperature differences between the adjacent parts of the solid object is called heat conduction.

⇒ Explanation:



When a metal rod is heated at one end, the opposite end of the rod gets heated after sometime. In this case, the molecules of the rod do not move from their positions, but the heat travels from one end of the rod to the other.

The process of conduction is explained on the basic of dynamical theory of heat as follows.

The molecules of every solid are

are continuously vibrating about their mean positions. The vibrations of molecules increase with supply of energy.

The molecules of the metal rod near the source of heat are the first to recieve heat. As soon as they receive heat, they begin to vibrate vigorously. These molecules colide with the molecules in the neighbouring layer and part with some of the heat energy possessed by them. Having received additional energy, the molecules in this layer also begin to vibrate more vigorously and in turn give some of the energy with to the next ones. In this way, heat travels along the rod.

The molecules of the solids are held rigidly in their mean position, hence conduction is the only mode of transfer to the heat in solid.

* Convection:

Convection is a mode of heat transfer from one part of the medium to another part by the actual movement of heated particles of the medium.

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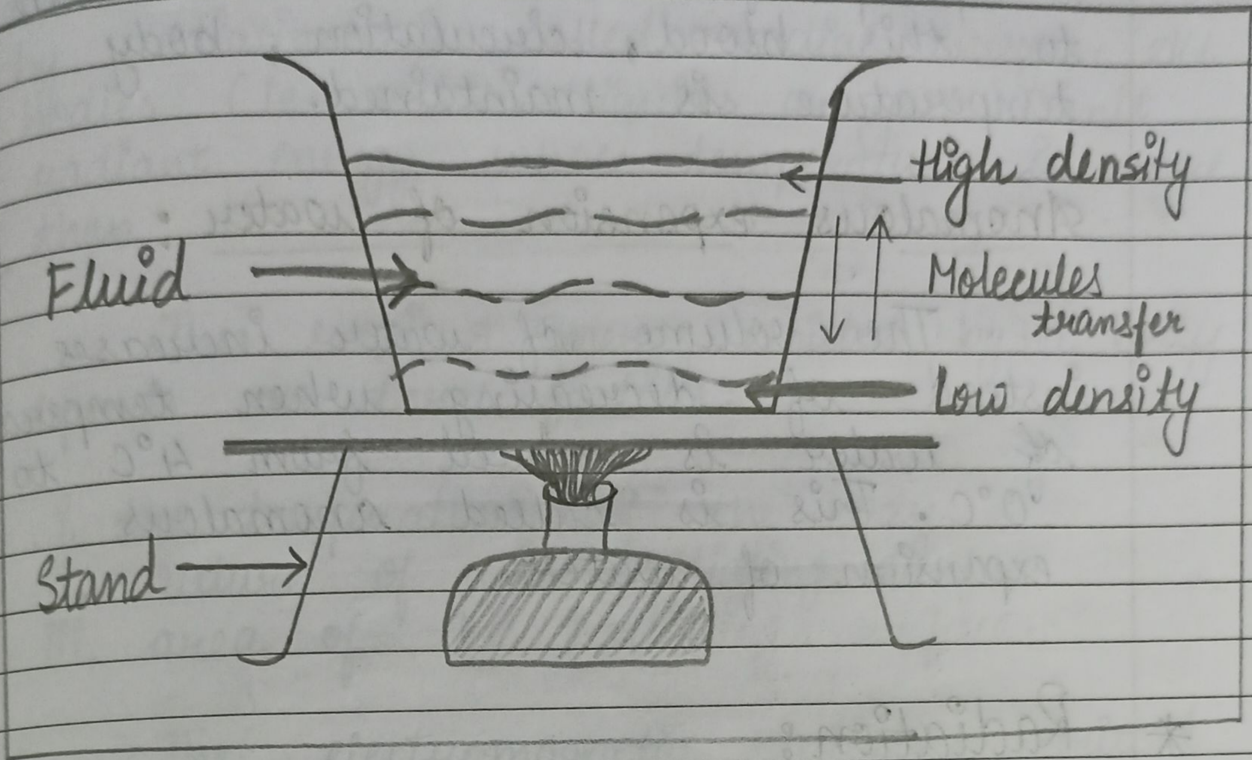
⇒ Explanation :



In convection, fuild at the bottom becomes hot and so its volume increases, due to which its density decreases. So due to buoyant force this 'lighter' fluid moves upwards and due to gravitional effect, the fluid with greater density is transferred from top to the bottom. Due to such a continuous process, the fuild is heated. If you add potassium permanganate into water while heating it in a flask you can observe this phenomenon.

In forced conversion a fluid is forced to move using some appliance, like a pump or a stirrer.

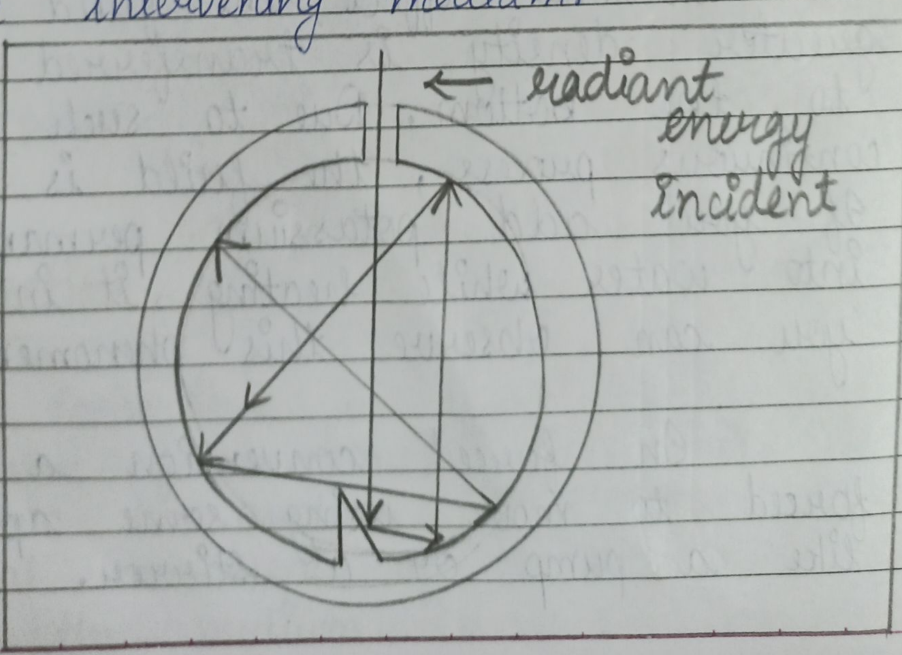
In human body heart acts as a pump for blood circulation. Due to this blood, circulation, body temperature is maintained.

Anomalous expansion of water:

The volume of water increases instead of decreasing when temperature of water is reduced from 4°C to 0°C. This is called anomalous expansion of water.

* Radiation:

Radiation is a mode of heat transfer from the source ~~of~~ to the receiver without any actual movement of source or receiver and also without heating the intervening medium.



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The transfer of heat by radiation needs no medium. The heat energy transferred by radiation is called radiat energy. All bodies (ie solids, liquids or gases) emit radiant energy whose temperature is more than 0K.

The radiant energy emitted by a body depends on three factors:

i. the temperature of the body
ii. nature of the radiating surface
iii. area of the radiating surface.

The electromagnetic radiation emitted by a body by virtue of its temperature is called heat radiation or thermal radiation. Heat radiations are the electromagnetic waves of wavelength range 8×10^{-7} m to 4×10^{-4} m. They belong to infrared region of electromagnetic spectrum. They are not visible to eye but produces the sensation of warmth. The heat radiation can travel through vacuum with the speed of light ($= 3 \times 10^{8}$ m s^{-1}).

When thermal radiation falls on a body, it is partly reflected and partly absorbed. The amount of radiant energy that a body can absorb out of the incident energy depends on the colour of the body. It is found that the black bodies absorb and emit radiant energy better than bodies of lighter colours.

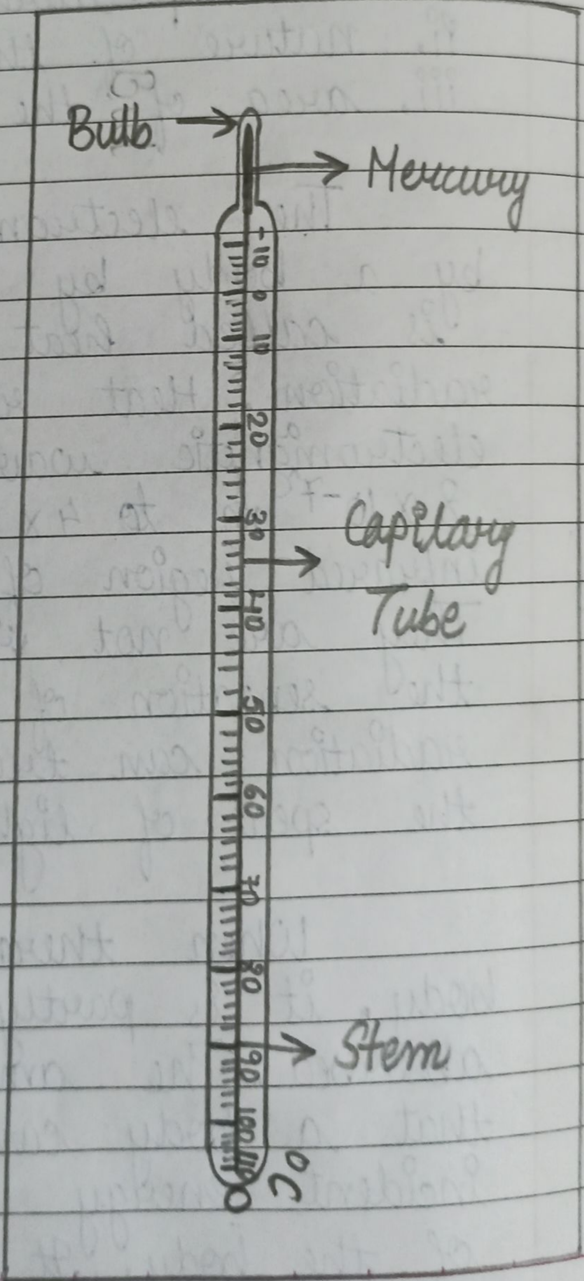
* Types of thermometers:

1. MERCURY THERMOMETER:

★ Principle:

Mercury is a metal which is in liquid state at room temperature. It expands or contracts linearly with an increase or decrease in temperature.

★ Diagram of Mercury Thermometer ▶



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Construction :

A typical mercury-in-glass thermometer is shown in the figure.

Main parts of Mercury thermometer are:
a) Stem
b) Bulb
c) Scale

⇒ Stem: A stem is a long glass tube having a thin uniform bore in it. The thin bore is called a capillary.

⇒ Bulb: A bulb which acts as a container for the mercury where it can easily expand or contract in capacity. Mercury expands in response to heat. If the temperature is sufficiently high, mercury in the bulb moves up the capillary.

⇒ Scale: A temperature scale is the series of lines that are etched on the stem for displaying temperature readings. Two commonly used temperature scales are degrees Celsius (°C) and degrees Farenheit (°F), which are found on everyday thermometers. An alternative scale that measures temperature in Kelvin (K) is often used by scientists and engineers.

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Mercury has a freezing point of -39°C and therefore cannot be used in a thermometer below this temperature. Its boiling point is 375°C but before this temperature is reached some distillation of the mercury occurs if the space above the mercury is a vacuum. To prevent this, and to extend the upper temperature limits to over 500°C, an inert gas such as nitrogen under pressure is used to fill the remainder of the capillary tube.

★ The Advantages (Merits) of Mercury Thermometer:

i) Mercury thermometers are simple and can give an accurate measurement.

ii) They are comparatively cheaper than other temperature measurement devices.

iii) They are handy and convenient to use.

iv) Unlike electrical thermometers, they do not need a power supply or batteries for charging.

v) They can be frequently applied in areas where there is the problem of electricity.

vi) They provide very good repeatability and their calibration remains unaffected.

★ **Disadvantages (limitations) of Mercury thermometer:-**

i) They are not suitable for applications involving extremely high or low temperatures.

ii) They cannot be applied in regions where highly accurate results ~~and~~ are desirable.

iii) As compared to electrical thermometers, they are very weak and delicate. Therefore, they must be handled with extra care because they are likely to break.

iv) Besides, they cannot provide digital and automated results. Hence, their use ~~of~~ is limited to areas where only manual reading is adequate, for example, a household thermometer.

v) Reading temperature via mercury thermometer call for brilliant eyesight.

★ **Application:**

Mercury thermometers are used in laboratories, chemical industries, power plants.

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2. BIMETALLIC THERMOMETER:

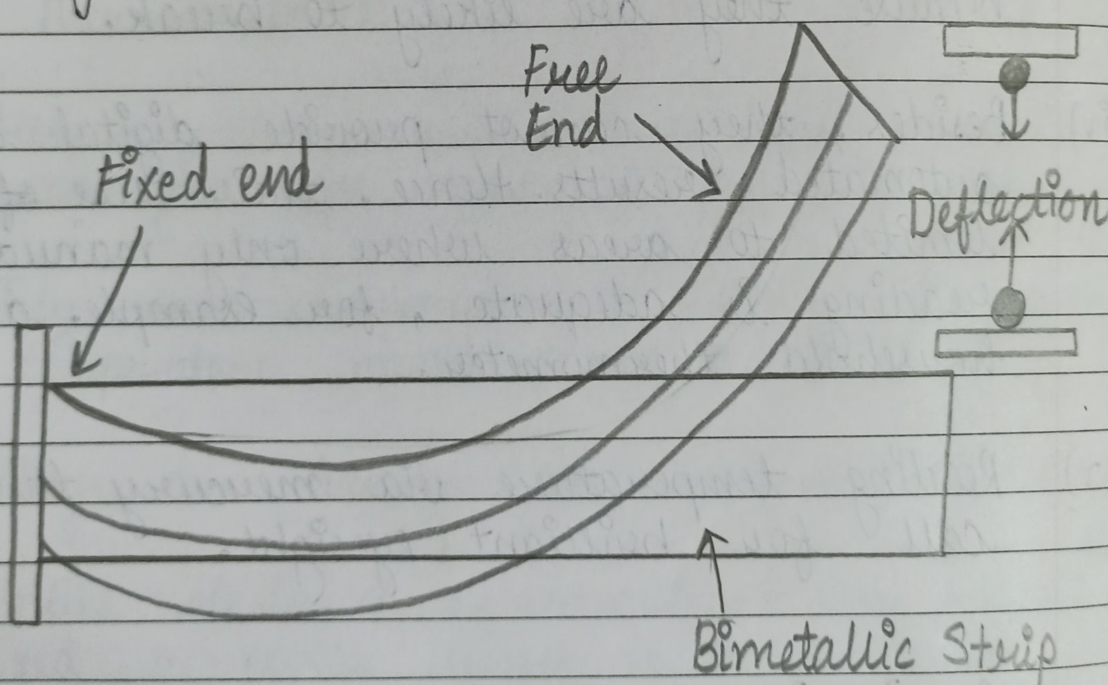
⇒ **Principle:**

A bimetallic thermometer works by using two basic properties of metal:

i.) The thermal expansion property of the metal.

ii.) The coefficient of thermal expansion of different metals is different for the same temperature.

⇒ **Diagram:**



⇒ **Construction:**

The main component of the bimetallic thermometer is the bimettalic strip. The bimetallic strip consists of two thin strips of different metals, each having different coefficients of thermal expansion. Thermal expansion is the property of a metal to change its shape or volume with a change in temperature. The metal strips are connected along their length by fusing them together or riveting, so that the relative motion between them is prevented. The strips are fixed at one end and free to move on the other end.

The two metals typically used are steel and copper, but steel and brass can also be used. Since their thermal expansion is different, the length of these metals changes at different rates for the same temperature. Due to this property, when the temperature changes, the metal strip at one side expands and the other doesnot, which creates a bending effect. This can be seen in the diagram.

When the temperature rises, the strip will turn in the direction of metal with the lower temperature coefficient. When the temperature decreases, the strip bends in the direction of metal having a higher temperature coefficient. The deflection of the strip indicates the temperature variation. This bending motion is connected to the

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dial on the thermometer, outputting the media's temperature. Calibration is an important step to ensure the correct temperature reading. A plain bimetallic strip is somewhat insensitive, but sensitivity is increased by longer strip with either helical or spiral shape. One end of the helix is anchored to the casingand the other end, which is free, is conveniently connected to the pointer which sweeps over a circular dial graduated in degrees of temperature. In response to the temperature change, the bimetal expands and the helical or spiral bimetal rotates at its free end, thus turning the stem and the pointer to a new position on the dial. The entire mechanism and working is depicted in diagram.

⇒ The advantages of bimetallic thermometers are:

i) Simple and robust design.

ii) less expensive than other thermometers.

iii) They are fully mechanical and donot require any power source to operate.

iv) Easy installation and maintenance.

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v) Nearly linear response to temperature change.

vi) Suitable for wide temperature ranges [-30°C to 550°C].

⇒ Disadvantages of bimetallic thermometers are:

i) They are not advised to use for very high temperatures.

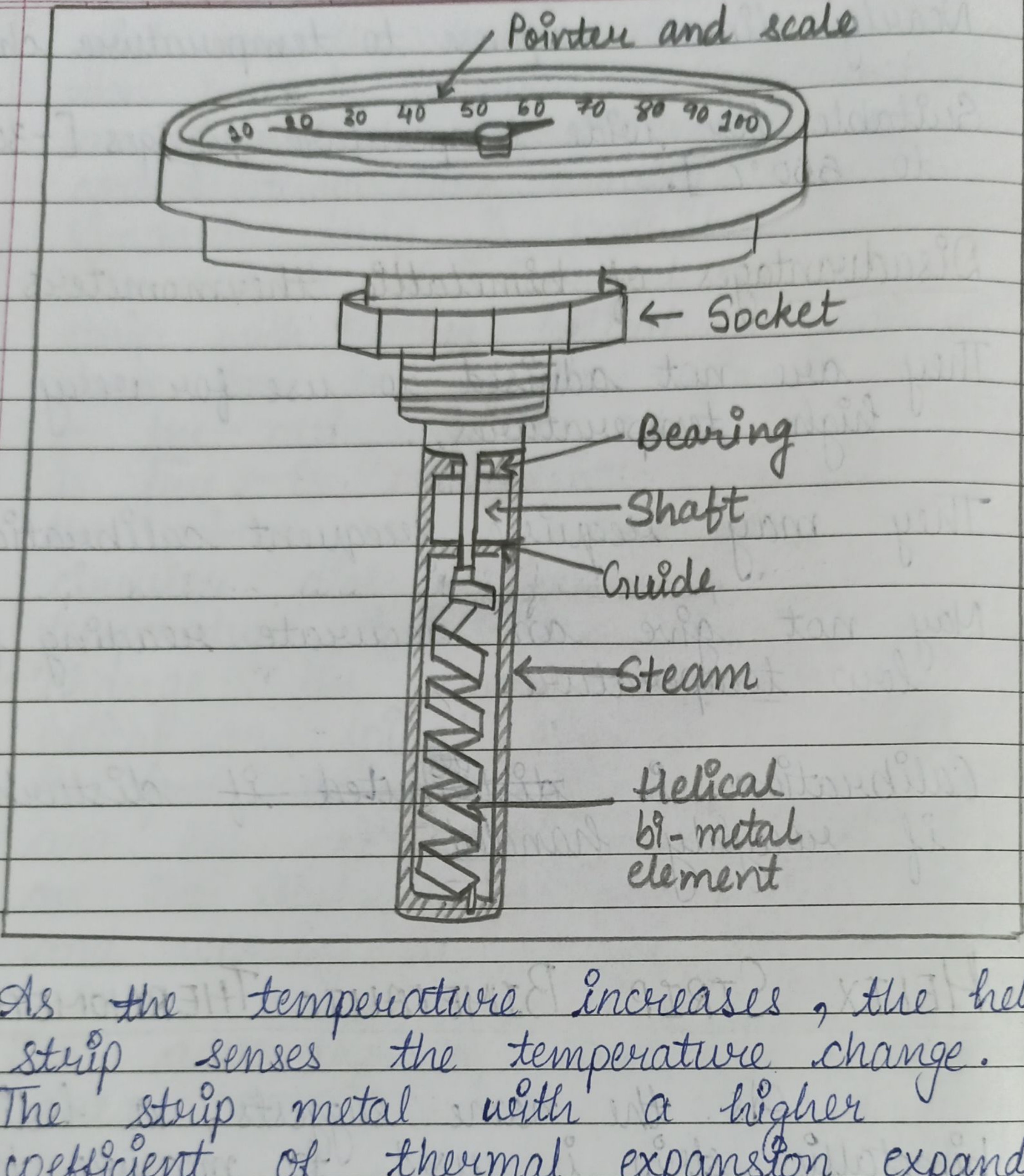
ii) They may require frequent calibration.

iii) May not give an accurate reading for low temperature.

iv) Calibration is ~~distributed if~~ disturbed if roughly handled.

a. HELIX STRIP BIMETALLIC THERMOMETER:

As the name suggests, a helix-shaped bimetallic strip is used to measure the temperature in this type of thermometer. The pointer is connected through the shaft at the free end of the strip. The strip is wound helically inside the stem, as illustrated in the diagram below.



As the temperature increases, the helical strip senses the temperature change. The strip metal with a higher coefficient of thermal expansion expands and winds up along the stem, rotating the shaft. This rotation causes the pointer to move its position in the dial which indicates the media's temperature. As the temperature decreases, the metal with a lower co-efficient of thermal expansion shrinks and rotates the Shaft. The poienter then reads the lower temperature in the dial.

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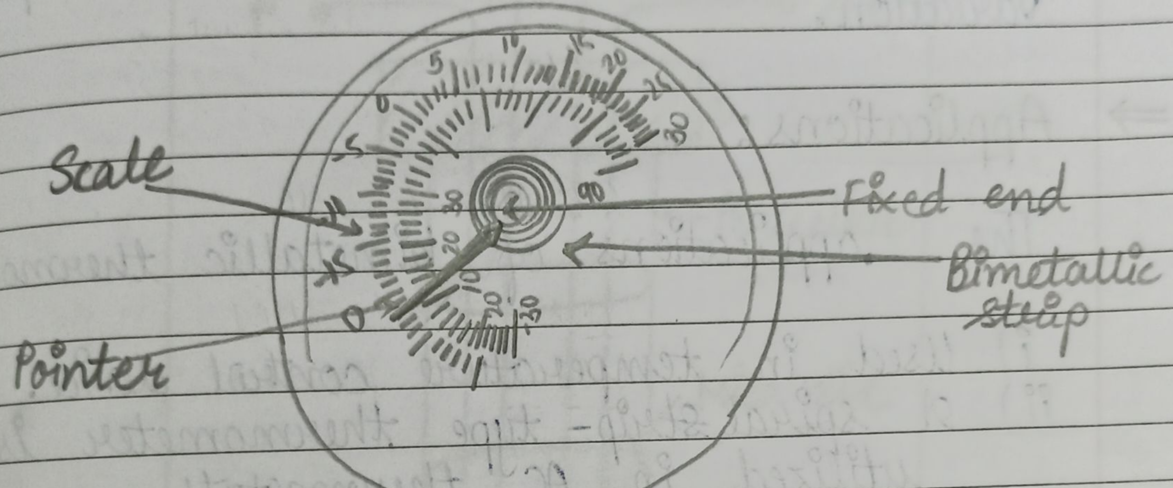
These are mostly used for industrail applications, as they can be placed inside a thermowell which provides operation in high temperature and pressure environment.

b. SPIRAL STRIP BIMETALLIC THERMOMETER:



A spiral-shaped strip is used to measure the temperature in a bimetallic spiral strip thermometer, as seen in the figure. As the temperature rises, the two metal strips expand differently. This creates a bending effect and the strip coils in such a way that the metal with a higher thermal coefficient forms the outer side of the arc. As the temperature decreases, the metal with a lower thermal coefficient forms the inner layer of the arc. The pointer and dial attached to the spiral read this deformation which indicates the media's temperature.

These are mostly used for thermostats or measuring the ambient temperature, as they're sensitive to lower temperature variation.

⇒ **Applications:**

The applications of bimetallic thermometer are

i) Used in temperature control device.
ii) A spiral ~~strip~~- type thermometer is utilized in AC thermostats.
iii) The helix strip type is used in refineries, tire vulcanizers, oil burners.
iv) These thermometers are utilized in house hold devices which include
v) AC (air conditioner), oven and apparatus in industries like hot wires, refineries, tempering tanks, heater etc.

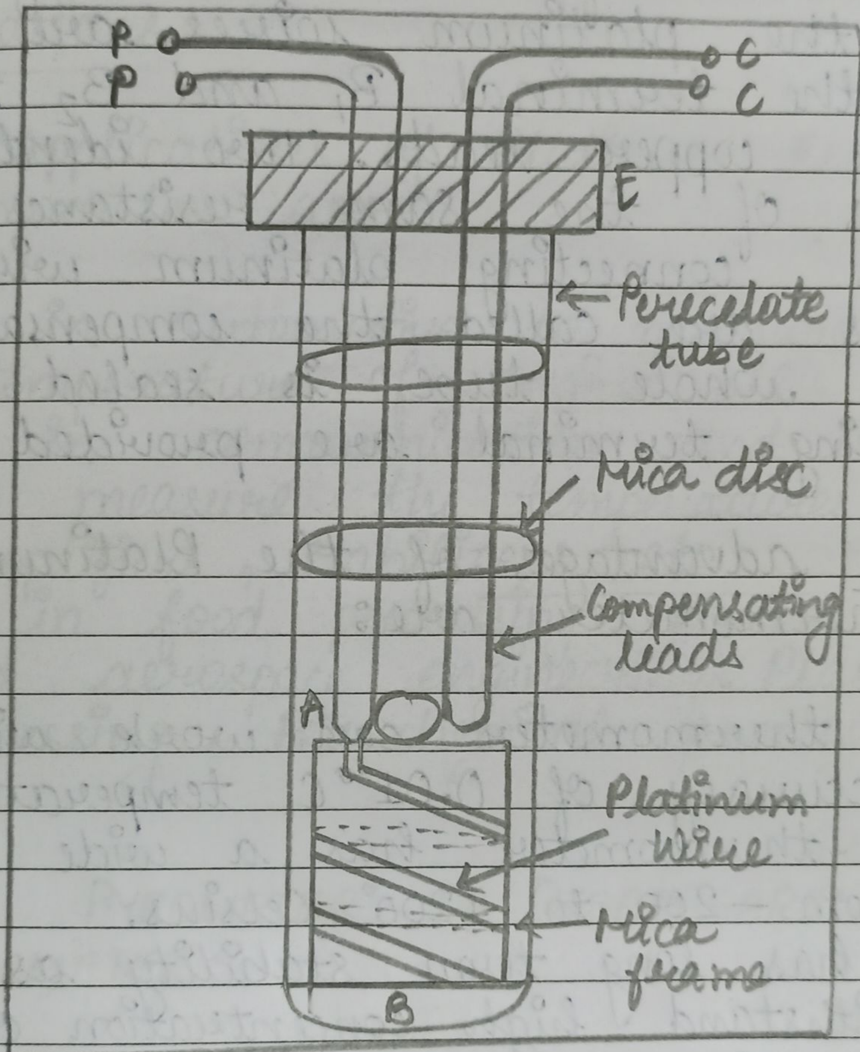
3. PLATINUM RESISTANCE THERMOMETER (PRT):

★ **Principle:**

The resistance of platinum changes lineraly with the change of temperature.

The platinum is an unreactive metal and can easily be drawn into fine wires. Because of these properties of platinum, it is used as a sensing element in thermometer.

* Diagram:



* Construction:

The figure above shows the platinum resistance thermometer. The platinum sensing coil is enclosed inside a porcelain tube. Double wire of the pure platinum is wound on the frame of mica.

Here the double wires are used for reducing the inductive effect. The mica is used as an insulator, and it is placed at the ends of the tube.

The Ebonite cap is placed at the open end of the tube. The free ends of the platinum wires are connected to the terminal B_1 and B_2 through thick copper leads. Two identical leads of the same resistance of the leads connecting platinum wire. These leads are called the compensating lead. The whole tube is sealed and binding terminal are provided at top.

* The advantages of the Platinum Resistance Thermometer are:

i) The thermometer can work with an accuracy of 0.01 °C temperature.
ii) The thermometer has a wide range from -200 to 1200° Celsius.
iii) It has long term stability as it can withstand high concentration of chemicals, humidity and contaminations.

* Disadvantages of Platinum Resistance Thermometer are:

i) The thermometers gives the slow ~~re~~ response
ii) The cost is High.

iii) Need for bridge circuit and power source.
iv) Large bulb size, compared to a thermocouple.
v) The melting point of the platinum is 1800 °C. But when platinum measures the temperature higher than 1200 °C they start evaporating.

Applications:

The applications of Platinum Resistance Thermometer are:

i) Used in automotive to measure the temperature of engine oil.
ii) Used in communication and instrumentation to measure the temperatures of amplifiers, stabilizers etc.
iii) Used in food processing, power electronics and aerospace engineering, Plastics processing, Petrochemical processing.

4. PYROMETER :

Principle:

Each object whose temperature is above absolute zero (−273.15°C) emits radiation. This emission is heat radiation and depends on temperat[ure]

Temperature measurement is based on measurem[ent] of radiation either directly by sensor or by comparing with radiation of body of known temperat[ure]

Pyrometers are classified into two categories:

I. OPTICAL PYROMETER OR DISAPPEARING FILAMENT PYROMETER:

⇒ Construction:

From the diagram, we can see the parts of the optical pyrometer.

An eyesight is on the left side and an optical lens on the right side.

A lamp that generates reference temperature using a power source and rheostat.

An ampere meter to measure the current to calculate the temperature.

An absorption screen is installed

between the lens and a reference lamp.

A red filter between the reference lamp and eyepiece. The red filter passes only a narrow band of wavelengths around 0.65 μm.

⇒ **Advantages of optical (Disappearing Filament) pyrometer:**

i) Physical contact of the instrument is not required to measure the temperature of the temperature source.
ii) Accuracy is high ie. ±5°C accuracy in the range of 850°C to 1200°C and ±10°C accuracy in the extended range of 1100°C to 1950°C.
iii) Provided a properly sized image of the temperature source is obtained in the instrument, the distance between the instrument and the temperature source doesnot matter.
iv) The instrument is easy to operate.
v) It is most accurate of all radiation pyrometers.

⇒ **Limitations or Disadvantages of the Optical (Disappearing Filament) Pyrometer:**

i) The temperature of more than 700°C can only be measured since illustration of the temperature source is a must for measurement.
ii) Since it is manually operated, it cannot

be used for the continuous monitoring and controlling purpose.

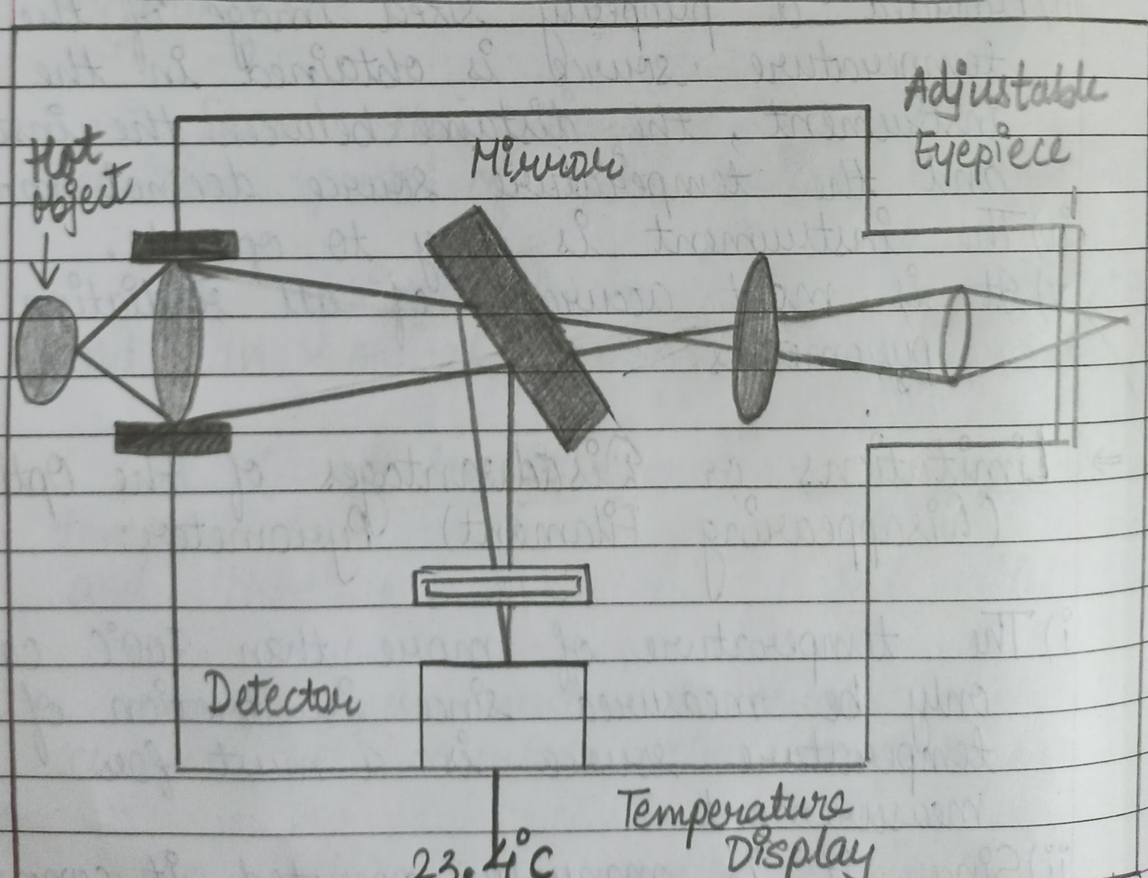
iii) The optical pyrometer has a range of measuring the temperature of 1400°C to near about 3500°C.

⇒ **Applications of Optical (Disappearing Filament) Pyrometer:**

i) Used to measure the temperature of molten metals or heated materials.

ii) Used to measure the temperature of the furnance and hot bodies.

II. INFRARED / RADIATION PYROMETERS:



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Construction:

A radiation pyrometer consists of optical component such as an optical lens, mirror, adjustable eyepiece, detector and display unit. The heat energy is transferred through the optical lens to the mirror. The mirror focuses this energy on the detector. The ~~det~~ detector which is usually a thermocouple or thermopile produces emf proportional to the temperature and its is given to the display unit. Thermopile and the optical components are fitted in the blackened tube.

Advantages of Radiation Pyrometer:

i) Can measure very high temperature.
ii) No direct contact with the object is required.
iii) High speed of response.
iv) Reasonable price.

Disadvantages of Radiation Pyrometer:

i) The scale is highly non-linear.
ii) Presence of smoke and dust-particles in the vincity may result in measurement errors.
iii) Cooling is required to protect the instrument where the operating conditions

are very hot.

iv) The caliberation depends on the emissivity of the target material.

* Applications of Radiation Pyrometer:

i) For high-temperature measurement.

ii) For measurement of temperature where direct contact of the sensor is not possible.

iii) Capable to measure the temperature of the moving or stationary objects.

iv) For the temperature measurement of a large surface or object.

* Thermal Conductivity:

⟹ **Definition:**

The capacity of a substance to conduct heat is called conductivity of given substance.

⟹ **Co-efficient of Thermal Conductivity:**

The thermal conductivity is defined as quantity of heat flowing normally across unit cross-sectional area of a material of unit thickness in one second, when the temperature difference between its end is unity.

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⇒ **Law of thermal conductivity:**

Consider the two plane X and Y placed at a distance having temperature θ_1 and θ_2 are placed at d. Cross sectional area of a rod is A.

* The amount of heat transfer by the rod (Q):

i) Directly proportional to the cross-sectional area of rod:

$$\therefore Q \propto A$$

ii) Directly proportional to the temperature difference:

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

iii) Directly proportional to the time of flow.

$$\therefore Q \propto t$$

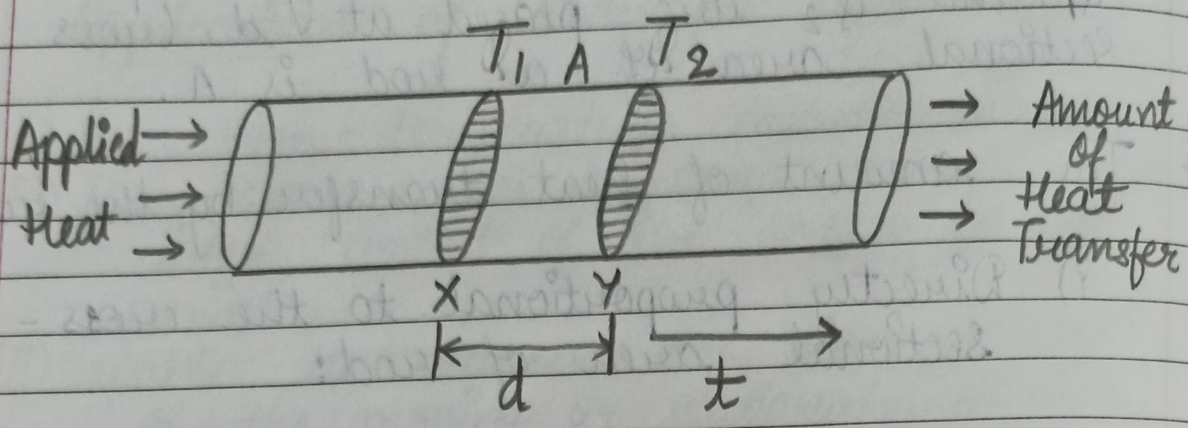
iv) Inversely proportional to the distance between two plates.

$$\therefore Q \propto 1/d$$

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

i.e, $$Q = \frac{kA(T_1 - T_2)t}{d}$$

where, k = co-efficient of thermal conductivity



* Applications of Thermal Conductivity:

i) Thick walls are used in the construction of cold storage rooms. Brick being a bad conductor of heat is used to reduce the flow of heat from the surroundings to the rooms. Better heat insulation is obtained by using hollow bricks.

ii) During winter, the temperature of a door and handle is less than body temperature. Therefore, heat flows from the body into the object touched. Since, metallic handle being a good conductor takes more heat from the finger touching it, we feel cold.

Wooden door being a poor conductor takes less body heat and appears less cold.

iii) Street vendors keep ice blocks packed in saw dust to prevent them from melting rapidly. The air filled in the fine pores of saw dust is an insulator of heat. This air doesnot allow heat from outside to pass to the ice thereby preventing its melting.

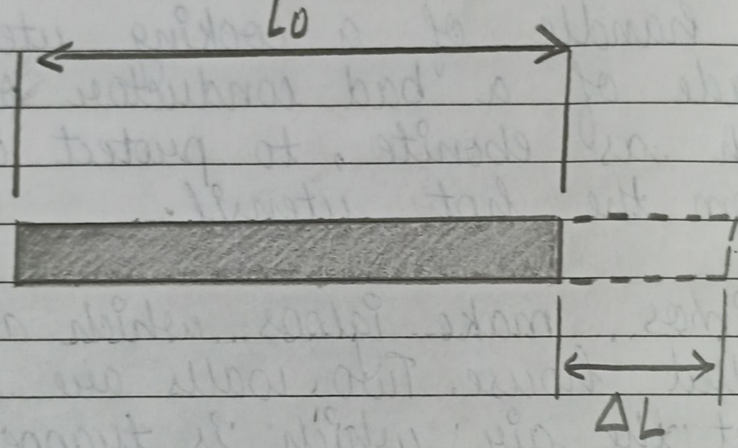
iv) The handle of a cooking utensil is made of a bad conductor of heat, such as ebonite, to protect our hand from the hot utensil.

v) Eskimos make igloos which are double walled house. Two walls are used so that the air which is trapped in between prevent conduction of heat from inside of the house to outside of the house, hence people inside would feel warm.

* Expansion of Solids:

When solids are heated without any change in its state, it usually expands. This is called thermal expansion. Solids are made up of atoms and molecules; and these atoms and molecules are arranged in definite manner in solids. They exert attractive and repulsive forces on one another and execute oscillations about their mean position. When the solid is heated, the amplitude of vibration of the atoms and molecules increases. Therefore, effective interatomic separation increases. This causes thermal expansion.

⇒ **Linear Expansion:**



Linear Expansion is the increase in length of a solid on heating. Suppose L is original length of a solid rod. Let ΔL be a small increase in length of the rod when its temperature is raised by a small amount ~~of~~ ΔT.

$$\therefore \Delta L \propto L_0$$
$$\therefore \Delta L \propto \Delta T$$
$$\therefore \Delta L \propto L_0 \cdot \Delta T$$
$$\therefore \Delta L = \alpha L_0 \cdot \Delta T$$

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α = co-efficient of linear expansion.

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

$$= \frac{\text{change in length}}{\text{original length} \times \text{change in temp.}}$$

Unit = $°K^{-1}$ or $°C^{-1}$.

The value of α depends on nature of material of the solid.

* Difference Between:

i) Heat and Temperature.

Heat	Temperature
a) Heat is a form of energy. It is total energy of molecules.	Temperature is measure of average of thermal energy of the molecules.
b) Unit of heat is calarie or joule. (Cal or J).	Unit of temperature is Kelvin, Celsius and Fahrenheit. (°K, °C, °F).

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ii) Celsius Scale, Kelvin Scale, Fahrenheit Scale

	Celsius Scale	Kelvin Scale	Fahrenheit Scale
a)	Melting point of ice in celsius scale is 0°C.	Melting point of ice in Kelvin scale is 273.15°K.	Melting point of ice in Fahrenheit scale is 32°F.
b)	Boiling point of water in Celsius scale is 100°C.	Boiling point of water in Kelvin scale is 370.5°K.	Boiling point of water in Fahrenheit scale is 212°F.
c)	Celsius temperature is represented by T_C.	Kelvin Temperature is represented by T_K.	Fahrenheit temperature is represented by T_F.

iii) Good Conductor and Bad Conductor.

	Good Conductor	Bad Conductor.
a)	The substance through which heat is conducted rapidly is called good conductors.	The substance through which heat is conducted very slowly is called bad conductor.
Example:	copper, iron, all metals etc.	glass wool, wood, all non-metals etc.

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iv) Conduction, Convection and Radiation.

	Conduction	Convection	Radiation
i)	The process of heat transfer due to the temperature difference between the adjacent parts of the solid object is called heat conduction.	Convection is a mode of heat transfer from one part of the medium to another part by the actual movement of the heated particles of the medium.	Radiation is a mode of heat transfer from the source to the reciever without any actual movement of source or reciever and also without heating the intervening medium
ii)	In this mode, heat to be transferred only in the solid object.	In this mode, heat to be transferred only in the fluid substance.	In this mode, energy is associated with radiant energy.
iii)	Molecules donot change their places and heat transfers by collision between them.	Fluid molecules change their place and heat transfers.	All bodies emit the radiant energy with temperature.

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1. A person has fever 101. Which temperature scale is used here? Convert this temperature into other two units.

Conventionally, Fahrenheit scale is used to measure the temperature of fever.

So temperature is 101 °F.

$$t_c = \frac{5}{9}(t_f - 32)$$

$$= \frac{5}{9}(101 - 32)$$

$$= 38.33\ ^\circ C$$

And to convert in kelvin scale

$$t_k = t_c + 273$$

$$= 38.33 + 273$$

$$= 311.33\ K$$