CHAPTER 03

Thermal Properties of Matter

In this Chapter...

- Ideal Gas Equation and Absolute Temperature
- Thermal Expansion
- Heat Capacity
- Change of State
- Heat Transfer
- Newton's Law of Cooling
- Greenhouse Effect

Temperature

It is the measure of degree of hotness or coldness of a body. The measurement of temperature of a body is a relative measure.

Consider, there are two bodies with temperatures $\mathbf{T_1}$ and $\mathbf{T_2}$, where $\mathbf{T_1} > \mathbf{T_2}$, then the body with $\mathbf{T_1}$ is called **hotter one** with respect to another one which is known as **colder body**.

Heat

It is the form of energy which flows from hotter body to colder body by virtue of temperature difference. The amount of heat is measured in joule (SI unit). Another widely used unit for the heat is calorie (in CGS), where 1 joule equals 4.2 calorie (cal).

Measurement of Temperature

The measurement of temperature is done by some specified scales called **thermometers**.

The ice and steam point of water are 32°F and 212°F on the Fahrenheit scale and 0°C and 100°C on Celsius scale.

On the Celsius scale, there are 100 equal intervals between two reference points (i.e. ice and steam point) while on the Fahrenheit scale, they are 180.

Different Scales to Measure the Temperature

Scale	Unit	Freezing or ice point (Lower fixed point)	Boiling or steam point (Upper fixed point)
Celsius scale	Degree centigrade (°C)	0°C	100°C
Fahrenheit scale	Degree Fahrenheit (°F)	32°F	212°F
Reaumur scale	Degree Reaumur (°R)	0° R	80°R
Kelvin scale	Kelvin (K)	273.15 K	373.15 K

Relation among the Temperatures Measured by Different Scales

The temperature measured by different scales is given as

$$\frac{\mathbf{C-0}}{\mathbf{100}} = \frac{\mathbf{F-32}}{\mathbf{180}} = \frac{\mathbf{R-0}}{\mathbf{80}} = \frac{\mathbf{K-273.15}}{\mathbf{100}}$$

Here, C, F, R and $\mathbf{K}$ are the readings of different scales.

Ideal Gas Equation and Absolute Temperature

At low densities, the gases exhibit same behaviour of expansion. There are three characteristics of a gas which describe its behaviour, these are pressure (**p**), volume (**V**) and temperature (**T**).

The relation among the characteristics of a gas is given by

(i) **Boyle's Law** According to this law,

$$\mathbf{p \propto \frac{1}{V}} \quad \text{(at constant temperature)}$$

i. e. $\quad \mathbf{pV = constant}$

(ii) **Charles' Law** According to this law,

$$\mathbf{V \propto T} \quad \text{(at constant pressure)}$$

i. e. $\quad \mathbf{\frac{V}{T} = constant}$

Ideal Gas Equation

On combining these two laws (above mentioned), we get

$$\mathbf{\frac{pV}{T} = constant} \text{ (for a given quantity of gas)}$$

This relation is known as **ideal gas law.** It can be written in more general forms for a given amount of gas as

$$\mathbf{pV = \mu RT}$$

where, μ is **number of moles** of a gas and **R** is known as **universal gas constant** valued $\mathbf{8.31\ J\ mol^{-1}\ K^{-1}}$. This equation is known as **ideal gas equation**.

Absolute Zero Temperature

Theoretically, there is no limit for maximum temperature but there is a sharp point for minimum temperature that no body can have the temperature lower than this minimum value of temperature which is known as absolute zero temperature.

Absolute Zero Temperature from *p-T* Graph

The absolute zero temperature is regarded as 0 K or **– 273.15° C.** This implies $\mathbf{273.15\ K = 0°\ C}$.

The temperature measured in Kelvin scale is known as absolute temperature and the scale itself is known as absolute scale.

Thermal Expansion

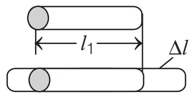
The phenomenon of change in dimensions of an object due to heat supplied is known as **thermal expansion**.

There are three types of thermal expansion

(i) **Linear Expansion** The expansion in length of a body due to increase in its temperature is called the linear expansion.

If a rod having initial length $\mathbf{l_1}$ at temperature $\mathbf{T_1}$ and final increased length $\mathbf{l_2}$ at increased temperature $\mathbf{T_2}$, then fractional change in its length is given by

$$\mathbf{\frac{\Delta l}{l_1} = \frac{(l_2 - l_1)}{l_1} = \alpha_l\ (T_2 - T_1) = \alpha_l \Delta T}$$



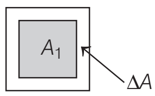
Linear expansion

Here, $\mathbf{\Delta l \propto l_1}$ and $\mathbf{\Delta l \propto \Delta T}$, therefore $\mathbf{\Delta l \propto l_1 \Delta T}$

$\Rightarrow$ Expansion in length, $\mathbf{\Delta l = \alpha_l\ l_1\ \Delta T}$

The quantity α_l is known as **coefficient of linear expansion** and its unit is $°C^{-1}$ or K^{-1}.

(ii) **Area Expansion** The expansion in the area of a surface due to increase in its temperature is called area expansion.



Area expansion

If a plate having initial area $\mathbf{A_1}$ at temperature $\mathbf{T_1}$ and final area $\mathbf{A_2}$ at temperature $\mathbf{T_2}$, then fractional change in its area is given by

$$\mathbf{\frac{\Delta A}{A_1} = \frac{(A_2 - A_1)}{A_1} = \alpha_A\ (T_2 - T_1) = \alpha_A \Delta T}$$

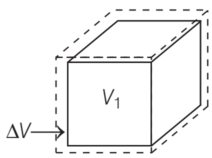
Here, $\quad \mathbf{\Delta A \propto A_1}$ and $\mathbf{\Delta A \propto \Delta T}$

$\therefore \quad \mathbf{\Delta A \propto A_1\ \Delta T}$

$\Rightarrow$ Expansion in area, $\mathbf{\Delta A = \alpha_A\ A_1\ \Delta T}$

where, α_A is known as **coefficient of area expansion.**

(iii) **Volume Expansion** The expansion in the volume of an object due to increase in its temperature is known as volume expansion.



Volume expansion

The fractional change in volume of an object is given by

$$\mathbf{\frac{\Delta V}{V_1} = \frac{(V_2 - V_1)}{V_1} = \alpha_V\ (T_2 - T_1) = \alpha_V\ \Delta T}$$

Here, $\quad \mathbf{\Delta V \propto V_1}$ and $\mathbf{\Delta V \propto \Delta T}$

$\therefore \quad \mathbf{\Delta V \propto V_1\ \Delta T}$

$\Rightarrow$ Expansion in volume, $\mathbf{\Delta V = \alpha_V\ V_1\ \Delta T}$

where, α_V is known as **coefficient of volume expansion**.

Note *The dimensions of all types of coefficients of expansion is* $[K^{-1}]$ *and SI unit is per kelvin*, i.e. K^{-1}.

Relation among the Coefficients of Expansion

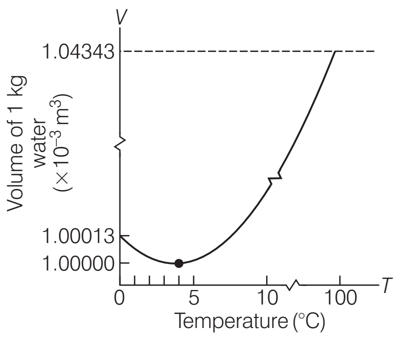
The coefficients of expansion are in ratio

$$\alpha_l : \alpha_A : \alpha_V = 1 : 2 : 3$$

Anomalous Expansion of Water

Water shows an anomalous behaviour, it contracts on heating between the temperature 0°C to 4°C. When water is cooled below the room temperature (i. e. normal temperature), the volume of given amount of water decreases. Until its temperature reaches to 4°C and below 4°C, the volume increases (and hence density decreases). So, it is clear that water has maximum density (and hence minimum volume) at 4°C.

The figure shows the variation of volume of 1 kg of water with temperature (°C).



Abnormal behaviour of water

Comparison of Expansions in Solids, Liquids and Gases

The expansion in solids and liquids is rather small as compared to the gases at ordinary temperature. The coefficient of volume expansion for the liquids is relatively independent of the temperature.

Thermal Strain and Thermal Stress

When a metal rod whose ends are rigidly fixed so as to prevent the rod from expansion or contraction, it undergoes a change in temperature, this way thermal strains and thermal stresses are developed in the rod.

$$\text{Thermal (compressive) strain} = \frac{\Delta l}{l} = \alpha\,\Delta T$$

and $$\text{Thermal stress} = Y\alpha\Delta T$$

Here, α = linear expansion coefficient of the material of rod and Y = Young's modulus of the material of given rod.

Heat Capacity

To change the temperature of substance, a given quantity of heat is absorbed or rejected by it, which is characterised by a quantity is known as **heat capacity**.

It is defined as amount of heat needed to change the temperature by unity, i.e. $1°$ C, it is denoted by **S** and having SI unit JK^{-1}.

$$\text{Heat capacity, } S = \frac{\Delta Q}{\Delta T}$$

where, ΔQ = heat absorbed or rejected by body and

ΔT = change in temperature.

Dimensional formula of heat capacity = $[ML^2T^{-2}K^{-1}]$

Note *Mass of water having the same heat capacity as a given body is called **water equivalent** of the body. The unit of water equivalent is gram.*

Specific Heat Capacity

The amount of heat needed to raise the temperature of unit mass of a substance by unity is known as the **specific heat capacity** or **specific heat**. It is denoted by *s*.

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

where, m = mass of given substance.

The SI unit of specific heat capacity is $Jkg^{-1}K^{-1}$.

Note *Water has the highest specific heat capacity (4.18×10^3 J kg^{-1} °C^{-1}) compared to other substances. For this reason, water is used as a coolant in automobile radiators as well as a heater in hot water bags.*

Molar Specific Heat Capacity

The amount of heat needed to raise the temperature of one mole of a substance (gas) by unity is known as the **molar heat capacity** of that substance. It is denoted by **C**. Its SI unit is $Jmol^{-1}K^{-1}$.

$$C = \frac{S}{\mu} = \frac{\Delta Q}{\mu\Delta T}$$

where, μ = number of moles of substance (gas).

Relation between Specific Heat and Molar Specific Heat Capacity

As, number of moles, $\mu = \frac{m}{M}$

where, m = mass of the substance
and M = molecular mass,

$$m = \mu M$$

$$C = \frac{1}{\mu}\left(\frac{\Delta Q}{\Delta T}\right) = M\left(\frac{\Delta Q}{m\Delta T}\right)$$

But $$\frac{\Delta Q}{m\Delta T} = s \Rightarrow C = Ms$$

where, s = specific heat capacity,
M = molecular mass of the substance
and C = molar specific heat capacity.

Types of Molar Specific Heat Capacity

There are two types of molar specific heat capacity as given below

(i) **Molar Specific Heat Capacity at Constant Pressure** It is molar heat capacity of a gas at constant pressure, **i. e.** the amount of heat required to raise the temperature of 1 mole of a gas by unity at constant pressure and is denoted by C_p.

(ii) **Molar Specific Heat Capacity at Constant Volume** It is molar heat capacity of a gas at constant volume, **i. e.** the amount of heat required to raise the temperature of 1 mole of gas through $1°C$ at constant volume and denoted by C_V.

Calorimetry

It is the branch of science that deals with the measurement of heat. Calorimeter is a device used for measuring the quantities of heat.

According to the principle of calorimetry,

Heat lost by hotter body = Heat gained by colder body

If there are two bodies of masses m_1 and m_2 and having values of specific heats s_1 and s_2 respectively, then for temperature difference ΔT.

$$\Rightarrow \qquad m_1 s_1 \Delta T = m_2 s_2 \Delta T$$

Change of State

The process of converting one state of a substance into another state is known as **change of state** of a substance or matter.

For a constant heat supply, the change of state takes place with no variation in temperature of the system.

Terms Related to Change of State

There are some important terms related to change of state as given below

(i) **Melting and Melting Point** The process of change of state from solid to liquid is called melting. The temperature at which solid starts to liquify is known as the melting point of that solid.

(ii) **Fusion and Freezing Point** The process of change of state from liquid to solid is called **fusion**. The temperature at which liquid starts to freeze is known as the **freezing point** of the liquid.

(iii) **Vaporisation and Boiling Point** The process of change of state from liquid to vapour (or gas) is called **vaporisation**. The temperature at which the liquid and the vapour states of the substance co-exist is called the **boiling point** of the liquid.

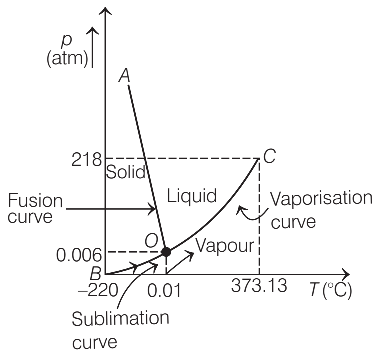
(iv) **Sublimation** The process of change of state directly from solid to vapour (or gas) is known as **sublimation**. There is no matter of liquid state of substance formed in the process. The reverse process of sublimation is not possible, e.g. camphor, nepthalene balls, etc.

Effect of Pressure on the Boiling Point of a Liquid The boiling point of a liquid increases with the increase in pressure. The boiling point of water is $100°$C at 1 atm pressure and it is 128°C at 2 atm pressure.

Triple Point

The temperature and pressure at which all three phases of a substance co-exist simultaneously is known as the **triple point** of the substance, e.g. the triple point for water is represented by temperature 273.16 K and pressure 6.11×10^{-3} **Pa**.

The figure below shows the phase diagram with triple point for water.



Phase diagram for water

The three curves represent the states in which solid and vapour phases, solid and liquid phases and liquid and vapour phases co-exist.

Latent Heat

The amount of heat transferred per unit mass during the change of phase of a substance without any change in its temperature is called latent heat of the substance for particular change.

Latent heat is denoted by **L** and having SI unit $\mathbf{J\ kg^{-1}}$.

i. e. Latent heat, $L = Q/m$

There are two types of latent heat of materials

(i) **Latent Heat of Fusion or Melting** It is latent heat for solid-liquid state change. It is denoted by L_f and is given by

$$\text{Latent heat of fusion, } L_f = \frac{Q}{m}$$

Its SI unit is $\mathbf{Jkg^{-1}}$.

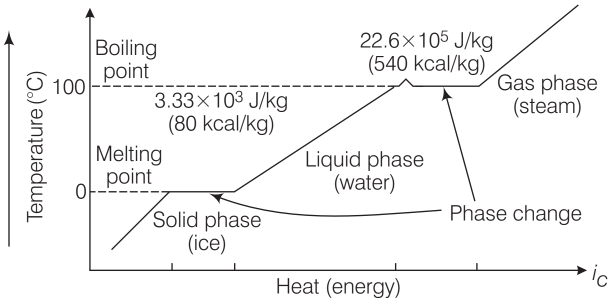
(ii) **Latent Heat of Vaporisation** It is in latent heat for liquid-gas state change. It is denoted by L_V and is given by

$$\text{Latent heat of vaporisation, } L_V = \frac{Q}{m}$$

Its SI unit is $\mathbf{Jkg^{-1}}$.

Variation of Temperature

A plot of temperature *versus* heat for a fixed quantity of water is shown below



Temperature *versus* heat for water at 1 atm pressure

Mechanical Equivalent of Heat

The temperature of a body may also be increased by doing mechanical work on the system. The mechanical equivalent of heat gives how many joules of mechanical work is needed to raise the temperature of 1 g of water by 1°C.

It is denoted by J expressed in J/cal.

Heat Transfer

Heat is the form of energy which can flow from one body to another due to their temperature difference in the form of radiations, molecular vibrations, molecular displacement, etc. These processes of heat flow are collectively known as heat transfer.

There are three modes of heat transfer

(i) Conduction

The transfer of heat taking place due to molecular vibrations (i. e. molecular collisions) is known as **heat conduction**. In this process, there is no mass movement of matter. Generally in solids, heat is transferred by the process of conduction.

Thermal Conductivity

The ability of material to conduct the heat through it is known as **thermal conductivity**. Thus, heat conduction is defined as the time rate of heat flow in a material for a given temperature difference.

$$\text{Rate of heat transfer } = \frac{\Delta \mathbf{Q}}{\Delta \mathbf{t}} = \frac{\mathbf{KA}\,(\mathbf{T}_1 - \mathbf{T}_2)}{\mathbf{L}} = \mathbf{KA}\frac{\Delta \mathbf{T}}{\mathbf{L}}$$

$$\because \quad \mathbf{H} = \frac{\mathbf{Q}}{\mathbf{t}}$$

$$\therefore \quad \text{Heat transfer, } \mathbf{Q} = \mathbf{KA}\frac{\Delta \mathbf{T}}{\mathbf{L}} \cdot \mathbf{t}$$

Here, K is known as **coefficient of thermal conductivity** of material of rod. The SI unit of K is $\mathbf{Js^{-1}m^{-1}K^{-1}}$ or $\mathbf{Wm^{-1}K^{-1}}$ and dimensions of $\mathbf{K}$ is $[\mathbf{MLT^{-3}K^{-1}}]$.

- The equivalent **thermal conductivity of series connection** of rods (as thermal conductor) is given by

$$\mathbf{K}_{eq} = \frac{\mathbf{2K_1K_2}}{\mathbf{K_1 + K_2}}$$

- The equivalent **thermal conductivity of parallel connection** of rods is given by

$$\mathbf{K}_{eq} = \frac{\mathbf{K_1 + K_2}}{\mathbf{2}}$$

Thermal Current and Thermal Resistance

The rate of flow of heat is known as **heat current**. It is denoted by **H**.

The SI unit of **thermal current** is J/s or watt (W) and its dimensions is $[\mathbf{ML^2T^{-3}}]$.

$$\mathbf{H} = \frac{\Delta \mathbf{Q}}{\Delta \mathbf{t}} = \mathbf{KA}\frac{(\mathbf{T_1 - T_2})}{\mathbf{L}} = \frac{\mathbf{T_1 - T_2}}{\left(\frac{\mathbf{L}}{\mathbf{KA}}\right)}$$

$$\text{Thermal resistance, } \mathbf{R} = \frac{\Delta \mathbf{T}}{\mathbf{H}} = \frac{\mathbf{T_1 - T_2}}{\mathbf{H}} = \frac{\mathbf{L}}{\mathbf{KA}}$$

The SI unit of **thermal resistance** (R) is K-s/J or K/W and its dimension is $[\mathbf{M^{-1}L^{-2}T^3K}]$.

(ii) Convection

Convection is the process in which heat is transferred from one point to another by the actual motion of matter from a region of high temperature to a region of lower temperature. This process of heat transfer takes place only in fluids.

There are two types of convections

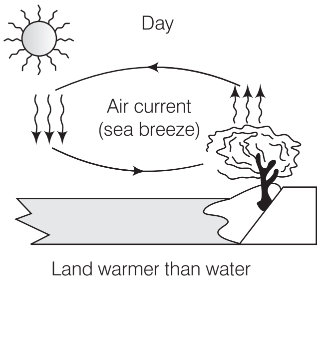
(i) **Forced Convection** This convection is the process in which heat is transferred from one place to other by actual transfer of heated material (or molecules). If heated material is forced to move say by a blower or a pump, the process of heat transfer is called **forced convection**.

(ii) **Natural or Free Convection** In the process of convection, if the heated material moves due to difference in density. This process of heat transfer is **called natural** or **free convection**.

Some natural examples of convection are given below

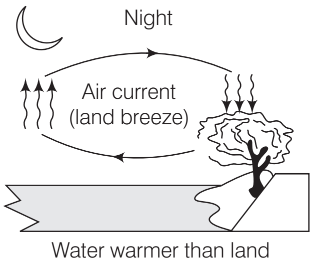
Land and Sea Breezes

During the day, the **land heats up faster than the sea**. This creates a breeze from the sea to the land which is called a **sea breeze**.



Land warmer than water

During the night, the opposite happens, creating a **land breeze**.



Formation of Trade Winds

As equatorial and polar regions of the earth receive unequal solar heat. At the equator, air near the earth's surface is hot while the air in upper atmosphere of the pole's is cool.

Hence, the steady wind blowing from North-East to equator, near the surface of earth is called **trade wind**. It is an example of natural convection.

(iii) Radiation

It is a mode of heat transfer from one place to another without heating the intervening medium. The heat is transferred by the mean of thermal radiations, radiant energy or simply radiation.

Thermal Radiation

The electromagnetic radiation emitted by a body, by virtue of its temperature like the radiation by a red hot iron or light form filament lamp is called thermal radiation.

Black Body Radiation

A body that absorbs all the radiations falling on it is known as a **black body**. It emits the radiations at the fastest rate. The radiations emitted by a black body is known as black body radiation. The black body is also called the ideal radiator.

Absorptive and Emissive Powers and Emissivity

The ratio of the amount of thermal radiation absorbed by a body in a given time to the total amount of thermal radiations incident on the body in the same time is known as **absorptance** (*a*) or **absorptive power** of the body.

$\Rightarrow$ $$\mathbf{a = \frac{Energy\ absorbed}{Energy\ incident}}$$

The **emissive power** of a body at a given temperature and for a given wavelength λ is defined as the amount of radiant energy per unit time per unit surface area of the body within a unit wavelength range around the wavelength λ.

The ratio of emissive power (**e**) of a body to the emissive power (**E**) of a perfect black body at the same temperature is called **emissivity**. It is denoted by ε.

Thus, $$\text{Emissivity, } \varepsilon = \frac{\mathbf{e}}{\mathbf{E}}$$

Stefan-Boltzmann Law

This states that the total energy emitted per second by a unit area of a perfect black body is proportional to the fourth power of its absolute temperature.

i.e. $$\mathbf{E \propto T^4}$$

i.e. $$\text{Total energy, } \mathbf{E = \sigma T^4}$$

where, σ is a universal constant called Stefan-Boltzmann constant, $\sigma = \mathbf{5.67 \times 10^{-8}\ Wm^{-2}\ K^{-4}}$.

If the body is not a perfect black body and has emissivity ε, then above relations get modified as

$$\mathbf{E} = \varepsilon\sigma\mathbf{T}^4$$

where, ε = **emissivity** of that body.

If $\mathbf{T_0}$ be the surrounding temperature,

then $$\mathbf{H = e\sigma A(T^4 - T_0^4)}$$

Wien's Displacement Law

This states that the wavelength (λ_m) corresponding to which the energy emitted by a black body is maximum and is inversely proportional to its absolute temperature (**T**).

Thus, $$\lambda_m \propto \frac{1}{\mathbf{T}} \quad \text{or} \quad \lambda_m \mathbf{T} = \mathbf{b}$$

where, **b** = Wien's constant $= \mathbf{2.9 \times 10^{-3}}$ mK.

Newton's Law of Cooling

This law states that the rate of cooling of a body is directly proportional to the temperature difference between the body and its surroundings, provided the temperature difference is small .

$$\text{Rate of loss of heat, } -\frac{\mathbf{dQ}}{\mathbf{dt}} = \mathbf{k\,(T - T_0)}$$

Greenhouse Effect

The gas such as carbon dioxide is known as the **greenhouse gas** as it is transparent to the solar radiations but have the ability to absorb infrared waves. These are also known as the **long waves**.

The carbon dioxide concentration in the atmosphere has increased which may be attributed to the increase in the temperature of atmosphere. This effect is known as the greenhouse effect. It melts the ice caps on the mountains and increases the sea level.

Solved Examples

Example 1. An arbitrary scale has the ice point at $-20°$ and the steam point at 180°. When the thermometer reads 5°, then find the reading of centigrade thermometer.

Sol. In order to convert the temperature from one scale to another, $\dfrac{C-0}{100-0}=\dfrac{t-(-20)}{180-(-20)}$

Here, $t=5° \Rightarrow \dfrac{C}{100}=\dfrac{5+20}{200}$

$\therefore$ Reading of centigrade thermometer, $C=12.5°C$

Example 2. The following observations were recorded on a platinum resistance thermometer. Resistance at melting point of ice $=3.70\ \Omega$, resistance at boiling point of water at normal pressure $=4.71\ \Omega$ and resistance at $t°C=5.29\ \Omega$. Calculate

(i) temperature coefficient of resistance of platinum

(ii) and value of temperature t.

Sol. Given, resistance at melting point of ice, $R_0=3.70\ \Omega$

Resistance at boiling point of water at normal pressure,

$$R_{100}=4.71\ \Omega$$

Resistance at $t°C$, $R_t=5.29\ \Omega$

(i) According to the formula, temperature coefficient of resistance is given by

$$\alpha=\frac{R_{100}-R_0}{R_0\times 100}=\frac{4.71-3.70}{3.70\times 100}=\frac{1.01}{370}=2.73\times 10^{-3}/°C$$

(ii) According to the formula, for temperature t, we have

$$t=100°C\times\frac{R_t-R_0}{R_{100}-R_0}$$

$$=100°C\times\frac{5.29-3.70}{4.71-3.70}=100°C\times\frac{1.59}{1.01}=157.4°C$$

Example 3. The length of a steel rod is 5 cm longer than that of a brass rod. If this difference in their lengths is to remain same at all temperatures, then find the length of brass rod. (Coefficients of linear expansion for steel and brass are $12\times 10^{-6}/°C$ and $18\times 10^{-6}/°C$, respectively)

Sol. Given, $\Delta l_s-\Delta l_b=\Delta l$

Let $l_s=l\text{ cm}\Rightarrow l_b=(l-5)\text{ cm}$

($\because$ steel rod is 5 cm longer than that of a brass rod)

$\alpha_s=12\times 10^{-6}/°C$ and $\alpha_b=18\times 10^{-6}/°C$

As, $\Delta l_s=l_s\,\alpha_s\,t_1$

$$\therefore\quad \alpha_s=\frac{\Delta l_s}{l_s\times t_1}$$

$$\Rightarrow\quad 12\times 10^{-6}=\frac{\Delta l}{l\times t}\qquad\ldots\text{(i)}$$

Similarly, $\Delta l_b=l_b\,\alpha\,t_2\Rightarrow \alpha_b=\dfrac{\Delta l_b}{l_b\times t_2}$

$$\Rightarrow\quad 18\times 10^{-6}=\frac{\Delta l}{(l-5)\times t}\qquad\ldots\text{(ii)}$$

Dividing Eq. (i) by Eq. (ii), we get

$$\frac{12\times 10^{-6}}{18\times 10^{-6}}=\frac{\Delta l/l\times t}{\Delta l/(l-5)\times t}\Rightarrow\frac{2}{3}=\frac{l-5}{l}$$

$\Rightarrow\quad 2l=3l-15\Rightarrow l=15$ cm

So, $l_s=15\text{ cm}$ and $l_b=l-5=15-5=10$ cm

Example 4. The volume of mercury in the bulb of a thermometer is $10^{-6}\ m^3$. The area of cross-section of the capillary tube is $2\times 10^{-7}\ m^2$. If the temperature is raised by $100°C$, then find the increase in the length of the mercury column. (Take, $\gamma_{Hg}=18\times 10^{-5}/°C$)

Sol. From volume expansion relation, $\Delta V=V\times\gamma\Delta T$ ...(i)

where, $\gamma=18\times 10^{-5}/°C$, initial volume, $V=10^{-6}m^3$

and increase in temperature, $\Delta T=100°C$

Putting these values in Eq. (i), we get

$$\Delta V=10^{-6}\times 18\times 10^{-5}\times 10^2=18\times 10^{-9}\ m^3$$

Now, $\Delta V=A\times\Delta l\Rightarrow 18\times 10^{-9}=2\times 10^{-7}\times\Delta l$

or $9\times 10^{-2}=\Delta l$ or $\Delta l=9$ cm

Example 5. An aluminium cylinder 10 cm long, with a cross-sectional area of 20 cm^2, is to be used as a spacer between two steel walls. At 17.2°C, it just slips in between the walls. When it warms to 22.3°C, calculate the stress in the cylinder and the total force, it exerts on each wall. Assuming that, the walls are perfectly rigid and a constant distance apart. (For aluminium, $\alpha=2.4\times 10^{-5}K^{-1}$)

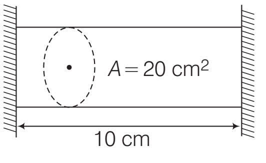
[NCERT Exemplar]

Sol. As we know, for aluminium, $Y=7.0\times 10^{10}$ Pa

and $\alpha=2.4\times 10^{-5}K^{-1}$

Change in temperature, $\Delta T=T_2-T_1=(22.3-17.2)°C$
$=5.1°C$

Area, $A=20\text{ cm}^2=20\times 10^{-4}\ m^2$



$\therefore$ Stress $= \dfrac{F}{A} = \mathbf{Y\alpha\Delta T}$

$= (0.70 \times 10^{11} Pa)(2.4 \times 10^{-5}\ K^{-1})(5.1\ K)$

$= 1.68 \times 5.1 \times 10^6 = 8.6 \times 10^6\ Pa$

The total force **F** is the product of cross-sectional area and the stress.

$F = \text{Stress} \times \text{Area}$

$= (8.6 \times 10^6\ Pa)\ (20 \times 10^{-4} m^2) \qquad = 1.7 \times 10^4 N$

Example 6. The coefficient of apparent expansion of a liquid when determined using two different vessels *A* and *B* are γ_1 and γ_2, respectively. If the coefficient of linear expansion of vessel *A* is α. Find the coefficient of linear expansion of the vessel *B*.

Sol. From thermal expansion in liquid, $\gamma_{real} = \gamma_{app} + \gamma_{vessel}$

Given, $\gamma_{vessel} = 3\alpha$

For vessel **A**, $\gamma_{real} = \gamma_1 + 3\alpha_A$

For vessel **B**, $\gamma_{real} = \gamma_2 + 3\alpha_B$

Hence, $\gamma_1 + 3\alpha_A = \gamma_2 + 3\alpha_B \Rightarrow \alpha_B = \dfrac{\gamma_1 - \gamma_2}{3} + \alpha_A$

Example 7. A 10 kW drilling machine is used to drill a bore in a small aluminium block of mass 8.0 kg. How much is the rise in temperature of the block in 2.5 min? Assuming 50% of power is used up in heating the machine itself or lost to the surroundings. Specific heat of aluminium $= 0.91\ Jg^{-1} {}^\circ C^{-1}$.

Sol. Given, power, $P = 10$ kW $= 10 \times 10^3$ W

Time, $t = 2.5$ min $= 2.5 \times 60$ s

As power is defined as rate at which energy is consumed,

i.e. $P = \dfrac{E}{t}$

$\therefore$ Total energy used,

$E = Pt = 10 \times 10^3 \times 2.5 \times 60 = 1.5 \times 10^6 J$

Energy absorbed by aluminium block,

$Q = 50\%$ of the total energy $= 50\%$ of $1.5 \times 10^6 = 0.75 \times 10^6 J$

Also, $m = 8.0\ kg = 8.0 \times 10^3 g$, $c = 0.91\ Jg^{-1} {}^\circ C^{-1}$

As, $\quad Q = mc\Delta T$

$\therefore \quad \Delta T = \dfrac{Q}{mc} = \dfrac{0.75 \times 10^6}{8.0 \times 10^3 \times 0.91} = 103.02^\circ C$

Example 8. In a container of negligible mass, 30 g of steam at 100°C is added to 200 g of water that has a temperature of 40°C. If no heat is lost to the surroundings, what is the final temperature of the system? Also, find masses of water and steam in equilibrium.
(Take, $L_V = 539\ cal\ g^{-1}$ and $c_{water} = 1\ cal\ g^{-1}\ {}^\circ C^{-1}$)

Sol. Given, mass, $m = 200$ g, $m_1 = 30$ g

Temperature, $T_1 = 100^\circ C$, $T_2 = 40^\circ C$

Latent heat, $L_V = 539\ cal\ g^{-1}$

Specific heat, $c_w = 1\ cal\ g^{-1} {}^\circ C^{-1}$

Let *Q* be the heat required to convert 200 g of water at 40°C into 100°C, then $Q = mc\Delta T$

$= (200)\ (1.0)\ (100 - 40) = 12000\ cal$

Now, suppose m_0 mass of steam converts into water to liberate this much amount of heat, then

$$m_0 = \frac{Q}{L} = \frac{12000}{539} = 22.26\ g$$

Since, it is less than 30 g, the temperature of the mixture is 100°C.

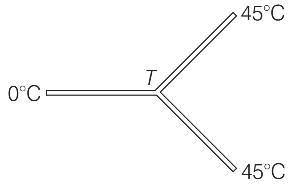
Mass of steam in the mixture

$= m_1 - m_0 = 30 - 22.26 = 7.74\ g$

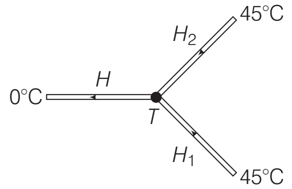
and mass of water in the mixture $= m + m_0$

$= 200 + 22.26 = 222.26\ g$

Example 9. Three identical rods have been joined at a junction to make it a **Y** shape structure. If two free ends are maintained at 45°C and the other end is at 0°C, then what is the junction temperature **T**?



Sol. According to the question,



Rods are in steady state, so $H = H_1 + H_2$.

$\Rightarrow \dfrac{KA(T-0)}{L} = \dfrac{KA(45-T)}{L} + KA\dfrac{(45-T)}{L}$

$\Rightarrow \quad T = 45 - T + 45 - T \Rightarrow 3T = 90 \Rightarrow T = 30^\circ C$

Example 10. A body cools in 10 min from 60°C to 40°C. What will be its temperature after next 10 min? The temperature of the surroundings is 10°C.

Sol. According to Newton's law of cooling,

$$\left(\frac{T_1 - T_2}{t}\right) = k\left[\left(\frac{T_1 + T_2}{2}\right) - T_0\right]$$

For the given conditions, $\dfrac{60-40}{10} = k\left[\dfrac{60+40}{2} - 10\right]$ ...(i)

Let **T** be the temperature after next 10 min and now take $T_1 = 40^\circ C$, then

$$\frac{40-T}{10} = k\left[\frac{40+T}{2} - 10\right] \qquad \text{...(ii)}$$

Solving Eqs. (i) and (ii), we get

$T = 28^\circ C$

Chapter Practice

PART 1

Objective Questions

• Multiple Choice Questions

1. Heat is associated with **[NCERT Exemplar]**

(a) kinetic energy of random motion of molecules
(b) kinetic energy of orderly motion of molecules
(c) total kinetic energy of random and orderly motion of molecules
(d) kinetic energy of random motion in some cases and kinetic energy of orderly motion in other

2. A glass of ice-cold water left on a table on a hot summer day eventually warms up, whereas a cup of hot tea on the same table cools down because

(a) its surrounding media are different
(b) the direction of heat flow depends on the surrounding temperature with respect to the object
(c) heating or cooling does not depend on surrounding temperature
(d) Both (a) and (b)

3. The common physical property which is to be used as the basis for constructing thermometer is the variation of the

(a) volume of a liquid with temperature
(b) pressure of a gas with temperature
(c) resistance of a wire with temperature
(d) All of the above

4. On a hilly region, water boils at $95°$C. The temperature expressed in Fahrenheit is

(a) 100°F (b) 20.3°F
(c) 150°F (d) 203°F

5. A uniform metallic rod rotates about its perpendicular bisector with constant angular speed. If it is heated uniformly to raise its temperature slightly, its speed of rotation

(a) increases **[NCERT Exemplar]**
(b) decreases
(c) remains same
(d) increases because its moment of inertia increases

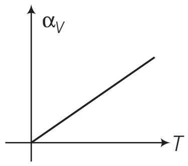
6. A bar of iron is 10 cm at 20°C. At 19°C, it will be (Take, α of iron $= \mathbf{11 \times 10^{-6}}$°C^{-1})

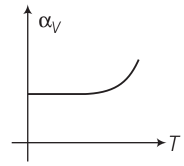
(a) $\mathbf{11 \times 10^{-6}}$ **cm**, longer (b) $\mathbf{11 \times 10^{-5}}$ cm, shorter
(c) $\mathbf{11 \times 10^{-6}}$ cm, shorter (d) $\mathbf{11 \times 10^{-5}}$ cm, longer

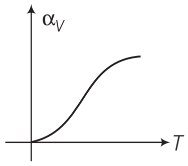
7. The radius of a metal sphere at room temperature T is R and the coefficient of linear expansion of the metal is α. The sphere heated a little by a temperature ΔT, so that its new temperature is $T + \Delta T$. The increase in the volume of the sphere is approximately **[NCERT Exemplar]**

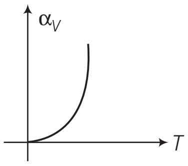
(a) $2\pi R\alpha\Delta T$ (b) $\pi R^2\alpha\Delta T$
(c) $4\pi R^3\alpha\Delta T/3$ (d) $4\pi R^3\alpha\Delta T$

8. Coefficient of volumetric expansion α_V is not a constant and it depends on temperature. Variation of α_V with temperature for metals is

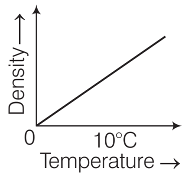
(a) 

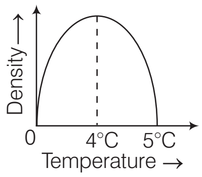
(b) 

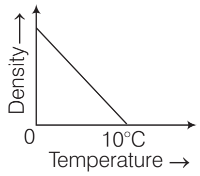
(c) 

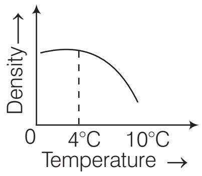
(d) 

9. Variation of the density of water with respect to temperature from 0°C to 10°C is correctly represented by

(a) 

(b) 

(c) 

(d) 

10. An aluminium sphere is dipped into water. Which of the following is true? **[NCERT Exemplar]**

(a) Buoyancy will be less in water at 0°C than that in water at 4°C
(b) Buoyancy will be more in water at 0°C than that in water at 4°C
(c) Buoyancy in water at 0°C will be same as that in water at 4°C
(d) Buoyancy may be more or less in water at $4^\circ C$ depending on the radius of the sphere

11. A normal diet furnishes 200 kcal to a 60 kg person in a day. If this energy was used to heat the person with no losses to the surroundings, how much would the person's temperature increases? (The specific heat of the human body is $0.83 \text{ cal g}^{-1} \,^\circ\text{C}^{-1}$).

(a) 8.2°C (b) 4.01°C (c) 6.0°C (d) 5.03°C

12. Time taken to heat water upto a temperature of $40^\circ C$ (from room temperature) is t_1 and time taken to heat mustard oil (of same mass and at room temperature) upto a temperature of $40^\circ C$ is t_2, then (given mustard oil has smaller heat capacity)

(a) $t_1 = t_2$
(b) $t_1 > t_2$
(c) $t_2 > t_1$
(d) t_1 and t_2 both are less than 10 min

13. When water boils or freezes, during these processes its temperature

(a) increases
(b) decreases
(c) does not change
(d) sometimes increase and sometimes deceases

14. At atmospheric pressure, water boils at 100°C. If pressure is reduced, then it

(a) still boils at same temperature
(b) now boils at a lower temperature
(c) now boils at a higher temperature
(d) does not boil at all

15. The latent heat of vaporisation of a substance is always

(a) greater than its latent heat of fusion
(b) greater than its latent heat of sublimation
(c) equals to its latent heat of sublimation
(d) less than its latent heat of fusion

16. Two rods of same length and material transfer a given amount of heat in 12 s, when they are joined end-to-end (i.e. in series). But when they are joined in parallel, they will transfer same heat under same temperature difference across their ends in

(a) 24 s (b) 3 s (c) 38 s (d) 1.5 s

17. The amount of heat that a body can absorb by radiation depends on

(a) colour and temperature both of body
(b) colour of body only
(c) temperature of body only
(d) density of body only

18. Due to the change in main voltage, the temperature of an electric bulb rises from 3000K to 4000K. What is the percentage rise in electric power consumed?

(a) 216 (b) 100
(c) 150 (d) 178

19. According to Newton's law of cooling, the rate of loss of heat depends on the

(a) sum of temperature of the body and its surroundings
(b) difference in temperature of the body and its surroundings
(c) product of temperature of the body and its surroundings
(d) ratio of temperature of the body and its surroundings

• Assertion-Reasoning MCQs

Direction (Q. Nos. 20-26) *Each of these questions contains two statements Assertion (A) and Reason (R). Each of these questions also has four alternative choices, any one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.*

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true, but R is not the correct explanation of A
(c) A is true, but R is false
(d) A is false and R is also false

20. **Assertion** A hotter body has more heat content than a colder body.

Reason Temperature is the measure of degree of hotness of a body.

21. **Assertion** If equal amount of heat is added to equal masses of different substances, the resulting change in temperature is also equal.

Reason Every substance requires same value of heat to change its temperature per unit mass, per degree centigrade (or per kelvin).

22. **Assertion** Water kept in an open vessel will quickly evaporate on the surface of the moon.

Reason The temperature at the surface of the moon is much higher than boiling point of water.

23. **Assertion** When a rod is heated freely, it expands and thermal strain set up in rod due to heating.

Reason Strain is a change in length per unit original volume.

24. **Assertion** The triple point of water is a standard fixed point in modern thermometry.

Reason Melting point of ice and the boiling point of water changes due to change in atmospheric pressure.

25. **Assertion** The radiation from the sun's surface varies as the fourth power of its absolute temperature.

Reason Sun is not a black body.

26. **Assertion** The rate of loss of heat of a body at 300 K is **R**. At 900 K, the rate of loss becomes 81 R.

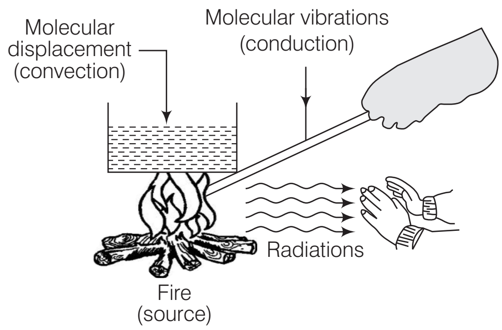
Reason This is as per Newton's law of cooling.

• Case Based MCQs

27. **Direction** *Read the following passage and answer the questions that follows*

Heat Transfer

Heat is the form of energy which can flow from one body to another due to their temperature difference in the form of radiations, molecular vibrations, molecular displacement, etc. These processes of heat flow are collectively known as heat transfer.
The processes of heat transfer are shown in figure



Modes of heat transfer

There are three modes of heat transfer namely

I. **Conduction** is the made of transfer of heat taking place due to molecular vibrations (i.e. molecular collisions).

II. **Convection** is the process in which heat is transferred from one point to another by the actual motion of matter from a region of high temperature to a region of lower temperature.

III. **Radiation** is a mode of heat transfer from one place to another without heating the intervening medium. The heat is transferred by the mean of thermal radiations, radiant energy or simply radiation.

(i) On a cold morning, a metal surface will feel colder to touch than a wooden surface because metal has
(a) high specific heat
(b) high thermal conductivity
(c) low specific heat
(d) low thermal conductivity

(ii) Woolen clothes keep the body warm, because wool
(a) is a bad conductor
(b) increases the temperature of body
(c) decreases the temperature of body
(d) All of the above

(iii) Heat travels through vacuum by
(a) conduction (b) convection
(c) radiation (d) Both (a) and (b)

(iv) Ratio of the amount of heat radiation, transmitted through the body to the amount of heat radiation, incident on it, is known as
(a) conductance (b) inductance
(c) transmittance (d) absorptance

(v) The unit of thermal conductivity is
(a) $Wm^{-1}K^{-1}$ (b) JK^{-1} (c) WmK (d) JK

PART 2
Subjective Questions

• Short Answer (SA) Type Questions

1. Find out the temperature which has same numerical value on celsius and fahrenheit scale.

2. In what ways are the gas thermometers superior to mercury thermometers?

3. There is a slight temperature difference between the water fall at the top and the bottom. Why?

4. A steel tape 1m long is correctly calibrated for a temperature of 27.0°C. The length of a steel rod measured by this tape is found to be 63.0 cm on a hot day, when the temperature is 45.0°C.

What is the actual length of the steel rod on that day? What is the length of the same steel rod on a day, when the temperature is 27.0°C? Coefficient of linear expansion of steel = $\mathbf{1.20 \times 10^{-5}\ {}^{\circ}C^{-1}}$? **[NCERT]**

5. The difference between length of a certain brass rod and that of a steel rod is claimed to be constant at all temperatures. Is this possible?

6. There are two spheres of same radius and material at same temperature but one being solid while the other hollow. Which sphere will expand more, if (i) they are heated to the same temperature and (ii) same amount of heat is given to each of them?

7. The coefficient of volume expansion of glycerine is $49\times 10^{-5}\ {}^{\circ}C^{-1}$. What is the fractional change in its density for a 30°C rise in temperature? **[NCERT]**

8. What kind of thermal conductivity and specific heat requirements would you specify for cooking utensils?

9. Two thermos flasks are of the same height and same capacity. One has a circular cross-section while the other has a square cross-section. Which of the two is better?

10. The coolant used in a nuclear reactor should have high specific heat. Why?

11. Given below are observations on molar specific heats at room temperature of some common gases. **[NCERT]**

Gas	Molar specific heat) (C_V) (cal mol^{-1} K^{-1})
Hydrogen	4.87
Nitrogen	4.97
Oxygen	5.02
Nitric oxide	4.99
Carbon monoxide	5.01
Chlorine	6.17

The measured molar specific heats of these gases are markedly different from those for monoatomic gases. (Typically, molar specific heat of a monoatomic gas is 2.92 cal/mol K). Explain this difference. What can you infer from the somewhat larger (than the rest) value for chlorine?

12. On a hot day, a car is left in sunlight with all the windows closed. After sometime, it is found that the inside of the car is considerably hotter than the air outside. Explain, why?

13. Two vessels of different materials are identical in size and wall thickness. They are filled with equal quantities of ice at $0^{\circ}C$.

If the ice melts completely in 10 and 25 min respectively, compare the coefficients of thermal conductivity of the materials of the vessels.

14. A piece of paper wrapped tightly on a wooden rod is observed to get burnt quickly when held over a flame as compared to a similar piece of paper when wrapped on a brass rod. Explain why?

15. In a coal fire, the pockets formed by coals appear brighter than the coals themselves. Is the temperature of such a pocket higher than the surface temperature of a glowing coal?

16. Why rooms are provided with the ventilators near the roof?

17. The earth constantly receives heat radiation from the sun and gets warmed up. Why does the earth not get as hot as the sun?

18. If a drop of water falls on a very hot iron, it does not evaporate for a long time. Give reason.

19. Why it is much hotter above a fire than by its side?

20. How does tea in a thermoflask remain hot for a long time?

21. Two bodies of specific heats C_1 and C_2 having same heat capacities are combined to form a single composite body. What is the specific heat of the composite body?

22. A Celsius and Fahrenheit thermometer are put in an hot bath. The reading of Fahrenheit thermometer is (3/2) times the reading of Celsius thermometer. What is the temperature of bath on Celsius, Fahrenheit and Kelvin's scales.

23. The triple points of neon and carbon dioxide are 24.57 K and 216.55 K, respectively. Express these temperatures on the celsius and fahrenheit scales. **[NCERT]**

24. Two ideal gas thermometers *A* and *B* use oxygen and hydrogen, respectively. The following observations are made

Temperature	Pressure thermometer A	Pressure thermometer B
Triple point of water	1.250×10^5 Pa	0.200×10^5 Pa
Normal melting point of sulphur	1.797×10^5 Pa	0.287×10^5 Pa

(i) What is the absolute temperature of normal melting point of sulphur as read by thermometers *A* and *B*?

(ii) What do you think is the reason for slightly different answers from *A* and *B*? **[NCERT]**

25. A metallic ball has a radius of 9.0 cm at 0°C. Calculate the change in its volume, when it is heated to 90°C. Given that, coefficient of linear expansion of metal of ball is $1.2\times 10^{-5}\ K^{-1}$.

26. A steel wire of 2.0 mm^2 cross-section is held straight (but under no tension) by attaching it firmly to two points a distance 1.50 m apart at 30°C. If the temperature now decreases to 5°C and if the two points remain fixed, what will be the tension in the wire?

(Take, Young's modulus of steel $= 2 \times 10^{11}$ Nm^{-2} and coefficient of thermal expansion of steel $\alpha = 1.1 \times 10^{-5}/°C$.)

27. The brass scale of a barometer gives correct reading at 0°C. Coefficient of linear expansion of brass is 2.0×10^{-5}/°C. The barometer reads 75.00 cm at 27°C. What is the true atmospheric pressure at 27°C?

28. A brass boiler has a base area of $0.15 \ m^2$ and thickness 1.0 cm. It boils water at the rate of $6.0 \ kg \ min^{-1}$, when placed on a gas stove. Estimate the temperature of the part of the flame in contact with the boiler. Thermal conductivity of brass = $109 \ Js^{-1} m^{-1} °C^{-1}$ and heat of vaporisation of water = $2256 \ Jg^{-1}$. **[NCERT]**

29. Explain the following

(i) Hot tea cools rapidly, when poured into the saucer from the cup.

(ii) Temperature of a hot liquid falls rapidly in the beginning but slowly afterwards.

(iii) A hot liquid cools faster, if outer surface of the container is blackened.

30. A copper block of mass 2.5 kg is heated in a furnace to a temperature of $500°C$ and then placed on a large ice block. What is the maximum amount of ice that can melt? (Take, specific heat of copper = $0.39 \ Jg^{-1} °C^{-1}$, and heat of fusion of water = $335 \ Jg^{-1}$.) **[NCERT]**

31. A thermocol cubical ice box of side 30 cm has a thickness of 5.0 cm. If 4.0 kg of ice are put in the box, estimate the amount of ice remaining after 6 h. The outside temperature is $45°C$ and coefficient of thermal conductivity of thermocol = $0.01 \ Js^{-1} m^{-1} °C^{-1}$. Given, heat of fusion of water = $335 \times 10^3 \ J \ kg^{-1}$ **[NCERT]**

32. Two rods of the same area of cross-section, but of lengths l_1 and l_2 and conductivities K_1 and K_2 are joined in series. Show that the combination is equivalent of a material of conductivity

$$K = \frac{l_1 + l_2}{\left(\frac{l_1}{K_1}\right) + \left(\frac{l_2}{K_2}\right)}$$

• Long Answer (LA) Type Questions

33. The electrical resistance in Ohms of a certain thermometer varies with temperature according to the approximate law $R = R_0 [1 + 5 \times 10^{-3} (T - T_0)]$

The resistance is 101.6 Ω at the triple point of water and 165.5 Ω at the normal melting point of lead (600.5 K). What is the temperature, when the resistance is 123.4 Ω? **[NCERT]**

34. A brass rod of length 50 cm and diameter 3.0 mm is joined to a steel rod of the same length and diameter. What is the change in length of the combined rod at 250°C, if the original length are at 40.0°C? Is there a 'thermal stress' developed at the junction? The ends of the rod are free to expand. Coefficient of linear expansion of brass = $2.0 \times 10^{-5} °C^{-1}$ and that of steel = $1.2 \times 10^{-5} °C^{-1}$. **[NCERT]**

35. A hole is drilled in a copper sheet. The diameter of the hole is 4.24 cm at 27°C. What is the change in the diameter of the hole, when the sheet is heated to 227°C? Coefficient of linear expansion of copper is 1.70×10^{-5}/°C. **[NCERT]**

36. Show that the coefficient of volume expansion for a solid substance is three times its coefficient of linear expansion.

37. Answer the following .

(i) The triple point of water is a standard fixed point in modern thermometry. Why? What is wrong in taking the melting point of ice and the boiling point of water as standard fixed points (as was originally done in the Celsius scale)?

(ii) There were two fixed points in the original celsius scale as mentioned above which were assigned the number 0°C and 100°C, respectively. On the absolute scale, one of the fixed points is the triple point of water, which on the Kelvin absolute scale is assigned the number 273.16 K. What is the other fixed point on this (Kelvin) scale?

(iii) The absolute temperature (Kelvin scale) T is related to the temperature T_C on the Celsius scale by $T_c = T - 273.15$. Why do we have 273.15 in this relation and not 273.16?

(iv) What is the temperature of the triple point of water on an absolute scale, whose unit interval size is equal to that of the Fahrenheit scale? **[NCERT]**

38. A child running a temperature of 101°F is given an antipyretic (**i. e.** a medicine that lowers fever) which causes an increase in the rate of evaporation of sweat from his body. If the fever is brought down to 98 °F in 20 min. What is the average rate of extra evaporation caused by the drug? Assume, the evaporation mechanism to be the only way by which heat is lost. The mass of the child is 30 kg. The specific heat of human body is approximately the same as that of water and latent heat of evaporation of water at that temperature is about **580 cal g^{-1}**. **[NCERT]**

39. Explain, why

(i) a body with large reflectivity is a poor emitter.

(ii) a brass tumbler feels much colder than a wooden tray on a chilly day.

(iii) an optical pyrometer (for measuring high temperature) calibrated for an ideal black body radiation gives too low a value for the temperature of a red hot iron piece in the open, but gives a correct value for the temperature when the same piece is in the furnace.

(iv) the earth without its atmosphere would be inhospitably cold.

(v) heating systems based on circulation of steam are more efficient in warming a building than those based on circulation of hot water. **[NCERT]**

40. Distinguish between conduction, convection and radiation.

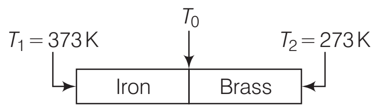
41. An iron bar having length $\mathbf{L_1 = 0.1\ m}$, area of cross-section $\mathbf{0.02\ m^2}$ thermal conductivity $\mathbf{K_i = 79\ Wm^{-1}K^{-1}}$ and brass bar having length $\mathbf{L_2 = 0.1\ m}$ area of cross-section, $\mathbf{A_2 = 0.02\ m^2}$ and thermal conductivity $\mathbf{K_2 = 109\ Wm^{-1}K^{-1}}$ are soldered end to end as shown in figure.

The terminal ends of two rods are maintained at 373 K and 273 K, respectively. Find the expression and compute

(i) the temperature of the junction of two bars.

(ii) equivalent thermal conductivity of composite bar and

(iii) the heat current through the composite bar



42. A body cools from 80°C to 50°C in 5 min. Calculate the time it takes to cool from 60°C to 30°C, the temperature of the surrounding is 20°C. **[NCERT]**

• Case Based Questions

43. **Direction** *Read the following passage and answer the questions that follows*

Triple Point

The temperature of a substance remains constant during its phase change (or change of state).

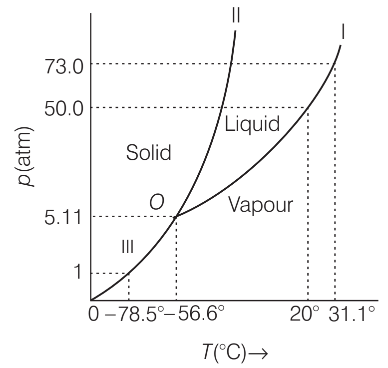
The graph between temperature and pressure of substance can be plotted which is called **phase diagram** or ***p-T* diagram**.

The diagram (phase diagram of water and CO_2) shows p-T plane divided into three regions, i.e. solid region, liquid region and vapour region which are separated by sublimation curve, fusion curve and vaporisation curve.

These three curves represent the states in which solid and vapour phases, solid and liquid phases and liquid and vapour phases co-exist.

The temperature and pressure at which all three phases of a substance co-exist simultaneously is known as the **triple point** of the substance.

The p-T phase diagram of carbon dioxide as shown in the figure



(i) At what temperature and pressure can the solid, liquid and vapour phases of $\mathbf{CO_2}$ co-exist in equilibrium?

(ii) What is the effect of decrease of pressure on the fusion and boiling point of $\mathbf{CO_2}$?

(iii) What are the critical temperature and pressure for $\mathbf{CO_2}$? What is their significance?

(iv) Is $\mathbf{CO_2}$ solid, liquid or gas at (a) $\mathbf{-70°C}$ under 1 atm, (b) $\mathbf{-60°C}$ under 10 atm and (c) $\mathbf{15°C}$ under 56 atm?

Chapter Test

Multiple Choice Questions

1. Temperature of atmosphere in Kashmir falls below $-10°C$ in winter. Due to this, water animal and plant life of Dal-lake

(a) is destroyed in winters
(b) frozen in winter and regenerated in summers
(c) survives as only top layer of lake in frozen
(d) None of the above

2. When temperature of water is raised from 0°C to 4°C, it

(a) expands
(b) contracts
(c) expands upto 2°C and then contracts upto 4°C
(d) contracts upto 2°C and then expands upto 4°C

3. A bimetallic strip is made of aluminium and steel ($\alpha_{Al} > \alpha_{steel}$). On heating, the strip will **[NCERT Exemplar]**

(a) remain straight
(b) get twisted
(c) will bend with aluminium on concave side
(d) will bend with steel on concave side

4. The temperature of two bodies A and B are respectively (Take, 727°C and 327°C). The ratio $H_A : H_B$ of the rates of heat radiated by them is

(a) 727 : 327 (b) 5 : 3
(c) 25 : 9 (d) 625 : 81

5. The rate of cooling due to conduction, convection and radiation combined, is proportional to the difference in temperature, for

(a) large temperature differences
(b) small temperature differences
(c) any temperature difference
(d) None of the above

Short Answer Type Questions

6. The density of mercury is $13.6 \times 10^3 \text{kg m}^{-3}$ at 0°C and its coefficient of volume expansion is $1.82 \times 10^{-4} \text{K}^{-1}$. Find the density at 50°C. (**Ans.** 13.48 g cm^{-3})

7. What should be the length of steel and copper rods at 0°C, so that the length of the steel rod is 5 cm longer than the copper rod at any temperature? (Take, linear expansion coefficient of steel $= 12 \times 10^{-5} /°C$ and for copper= $1.6 \times 10^{-5} /°C$) (**Ans.** 20 cm and 15 cm)

8. A metal ball having a diameter of 0.4 m is heated from 273K to 360 K. If the coefficient of areal expansion of the material of the ball is 0.000034 K^{-1}, then determine the increase in surface area of the ball. (**Ans.** 1.486×10^{-3} m^2)

9. A steel rod is 50 m long and has a cross- sectional area 250 cm^2. What is the force exerted by the rod, when heated from 5°C to 25°C? (Take, $\alpha_s = 11 \times 10^{-6} /°C$ and Y_s or $\alpha_V = 2 \times 10^{11} /°C$) (**Ans.** 11×10^5 N)

Long Answer Type Questions

10. A specific book describes a new temperature scale called Z, in which boiling and freezing points of water are referred as 65°Z and $-15°$ Z, respectively.

(i) To what temperature on Fahrenheit scale would a temperature $-95°$ Z correspond?

(ii) What temperature change on the Z scale would correspond to a change of 40° on Celsius scale?

[**Ans.** (a) -148°F and (b) 17°Z]

11. A box having total surface area 0.05 m^2 and of 6 mm thick side walls is filled with melting ice and kept in a room. Calculate the thermal conductivity of the box material, if 0.5 kg of ice melts in 1 h. The room temperature = 40°C and latent heat of fusion of ice $= 3.33 \times 10^5 \text{ J kg}^{-1}$.

(**Ans.** 0.138 $\text{Js}^{-1}\text{m}^{-1}°\text{C}^{-1}$)

12. Calculate the heat required to convert 3 kg of ice at $-12°C$ kept in a calorimeter to steam at 100°C at atmospheric pressure.

(Take, specific heat capacity of ice is 2100 $\text{Jkg}^{-1}\text{K}^{-1}$, specific heat capacity of water is 4186 $\text{Jkg}^{-1}\text{K}^{-1}$, latent heat of fusion of ice is 3.35×10^5 Jkg^{-1} and latent heat of steam is 2.256×10^6 Jkg^{-1}) (**Ans.** 9.1×10^6 J)

Answers

Multiple Choice Questions

1. (c) *2. (b)* *3. (d)* *4. (d)* *5. (b)*

EXPLANATIONS

PART 1

1. (*a*) We know that, as temperature increases vibration of molecules about their mean position increases, hence kinetic energy associated with random motion of these molecules increases. Thereby leading to production of heat.
2. (*d*) In given case, the ice-cold water having lower temperature than the surrounding, when left on a table on a hot summer day takes heat from surrounding and warms up, whereas a cup of tea having higher temperature than surrounding cools down by releasing heat to surrounding. Therefore, surrounding media are different for both.

   Thus, both the statements given in options (a) and (b) are correct.
3. (*d*) Any physical property which varies linearly with temperature can be used in constructing thermometers.
4. (*d*) It is given that on a hilly region, water boils at 95° C.

   ∴ Temperature in centigrade, $\mathbf{C = 95° }$ C.

   So, the temperature in Fahrenheit can be calculated.

   By using relation $\frac{\mathbf{F-32}}{\mathbf{180}}=\frac{\mathbf{C}}{\mathbf{100}}$, we get

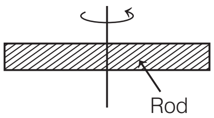
   $$\frac{\mathbf{F-32}}{\mathbf{9}}=\frac{\mathbf{95}}{\mathbf{5}} \qquad (\because\ \mathbf{C = 95° C})$$

   $$\Rightarrow \quad \mathbf{F-32 = 9\times 19}$$

   $$\Rightarrow \quad \mathbf{F-32 = 171}$$

   $$\Rightarrow \quad \mathbf{F = 171 + 32}$$

   $$\mathbf{= 203° \, F}$$
5. (*b*) As the rod is heated, it expands. As, no external torque is acting on the system, so angular momentum should be conserved.

   L = Angular momentum

   $= I\omega$ = constant $\Rightarrow I_1\omega_1 = I_2\omega_2$

   Due to expansion of the rod, $\mathbf{I_2 > I_1}$

   $$\Rightarrow \frac{\omega_2}{\omega_1}=\frac{I_1}{I_2}<1 \quad \Rightarrow \omega_2<\omega_1$$

   So, angular velocity (speed of rotation) decreases.
6. (*b*) According to linear expansion, we get

   $$\mathbf{L = L_0\,(1+\alpha\Delta\theta)}$$

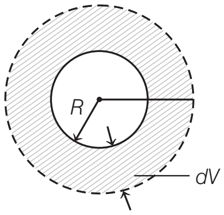
   $$\frac{\mathbf{L_1}}{\mathbf{L_2}}=\frac{\mathbf{1+\alpha\,(\Delta\theta_1)}}{\mathbf{1+\alpha\,(\Delta\theta_2)}}$$

   $$\Rightarrow \quad \frac{\mathbf{10}}{\mathbf{L_2}}=\frac{\mathbf{1+11\times10^{-6}\times20}}{\mathbf{1+11\times10^{-6}\times19}}$$

   $$\Rightarrow \quad \mathbf{L_2 = 9.99989}$$

   Length is shorter by = $\mathbf{10 - 9.99989 = 0.00011}$

   $\mathbf{= 11\times10^{-5}}$ **cm**
7. (*d*) Let the radius of the sphere is R. As, the temperature increases, radius of the sphere increases as shown in figure

   Original volume, $\mathbf{V}=\frac{\mathbf{4}}{\mathbf{3}}\pi\mathbf{R^3}$

   Coefficient of linear expansion $=\alpha$

   ∴ Coefficient of volume expansion $= 3\alpha$

   $$\therefore \quad \frac{\mathbf{1}}{\mathbf{V}}\frac{\mathbf{dV}}{\mathbf{dT}}=3\alpha$$

   $$\Rightarrow \quad \mathbf{dV = 3V\alpha dt \simeq 4\pi R^3\alpha\Delta T}$$

   = Increase in the volume
8. (*c*) α_V is a characteristic of the substance but is not strictly a constant. It depends in general on temperature as shown in Fig. (c). It is seen that, α_V becomes constant only at a higher temperature. Hence, option (c) is correct.
9. (*d*) Water contracts when it is heated from 0°C to 4°C. Thus, its density increases and volume decreases. Density of water is maximum at 4°C and hence volume is minimum. When the water is further heated, it expands and density decreases.

   So, the graph given in option (d) shows the correct variation of density of water.
10. (*a*) Let volume of the sphere is V and ρ is the density of water, then we can write buoyant force

    $F = V\rho g$ (g = acceleration due to gravity)

    $$\Rightarrow \quad \mathbf{F}\propto\rho \qquad (\because\ V \text{ and } g \text{ are almost constants})$$

    $$\Rightarrow \quad \frac{\mathbf{F_{4°C}}}{\mathbf{F_{0°C}}}=\frac{\rho_{4°C}}{\rho_{0°C}}>\mathbf{1} \qquad (\because\ \rho_{4°C}>\rho_{0°C})$$

    $$\Rightarrow \quad \mathbf{F_{4°C}>F_{0°C}}$$

    Hence, buoyancy will be less in water at 0°C than that in water at 4° C.
11. (*b*) Given, $\mathbf{m = 60\ kg = 60\times10^3\,g, c = 0.83\ cal\ g^{-1}\,°C^{-1}}$,

    $$\mathbf{Q = 200\ kcal = 2\times10^5\ cal}$$

    Amount of heat required for a person,

    $$\mathbf{Q = mc\Delta T}$$

    $$\Rightarrow \quad \mathbf{\Delta T}=\frac{\mathbf{Q}}{\mathbf{mc}}=\frac{\mathbf{2\times10^5}}{\mathbf{60\times10^3\times0.83}}=\mathbf{4.016°\,C}$$

12. (*b*) The heat capacity of a substance is $\mathbf{S} = \frac{\Delta \mathbf{Q}}{\Delta \mathbf{T}}$.

The heat capacity of mustard oil is less than that of water for same mass. So, same temperature rise ($\Delta \mathbf{T} = 40° \mathbf{C}$), the quantity of heat $\Delta \mathbf{Q}$ would be less than that is required by the same amount of water.

Hence, the time taken by water ($\mathbf{t_1}$) to heat upto 40°C will be higher than that of mustard oil ($\mathbf{t_2}$), i.e. $\mathbf{t_1} > \mathbf{t_2}$.

13. (*c*) When water boils or freezes, its temperature does not change during these processes. Heat here is absorbed or liberated as latent heat.

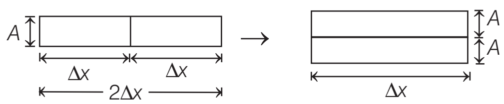
14. (*b*) When pressure is increased, boiling point is elevated. i.e. At higher pressure, water boils at temperature greater than 100°C. Similarly, at reduced pressure, water boils at a lower temperature.

15. (*a*) The energy required to completely separate the molecules, moving from liquid to gas is much greater than the energy required to separate from solid to liquid. Hence, the latent heat of vaporisation is greater than the latent heat of fusion.

16. (*b*) When two rods of same length are joined in parallel, the time required for heat transfer,

$$\Delta \mathbf{t} = \frac{\Delta \mathbf{Q}\,(\Delta \mathbf{x})}{\mathbf{KA}(\Delta \mathbf{T})}$$

Two rods of same length, which are joined in series, when connect in parallel combination, the area of heat conduction becomes twice, i.e. $\mathbf{A} \rightarrow \mathbf{2}$ times and length becomes half, i.e. $\Delta \mathbf{x} \rightarrow \frac{\mathbf{1}}{\mathbf{2}}$ times as shown in figure



In series In parallel

$$\therefore \quad \frac{\Delta \mathbf{t_1}}{\Delta \mathbf{t_2}} = \frac{\Delta \mathbf{x_1}}{\mathbf{A_1}} \times \frac{\mathbf{A_2}}{\Delta \mathbf{x_2}}$$

$$= \frac{\Delta \mathbf{x_1}}{\Delta \mathbf{x_2}} \times \frac{\mathbf{A_2}}{\mathbf{A_1}}$$

$$= \mathbf{2} \times \mathbf{2} = \mathbf{4}$$

$$\Rightarrow \quad \Delta \mathbf{t_2} = \frac{\mathbf{1}}{\mathbf{4}} \Delta \mathbf{t_1} = \frac{\mathbf{1}}{\mathbf{4}} \times \mathbf{12} = \mathbf{3}\text{ s}$$

17. (*a*) The thermal radiation that falls on a body is partly reflected and partly absorbed. The amount of heat that a body can absorb, by radiation depends on the colour of the body and temperature of the body.

18. (*a*) Electric power consumed in first case,

$$\mathbf{P_1} = \sigma \mathbf{T_1^4} = \sigma\,(\mathbf{3000})^4 \quad \ldots\text{(i)}$$

Electric power consumed in second case,

$$\mathbf{P_2} = \sigma \mathbf{T_2^4} = \sigma\,(\mathbf{4000})^4 \quad \ldots\text{(ii)}$$

On dividing Eq. (ii) by Eq. (i), we get

$$\frac{\mathbf{P_2}}{\mathbf{P_1}} = \frac{(\mathbf{4000})^4}{(\mathbf{3000})^4} = \frac{\mathbf{256}}{\mathbf{81}}$$

As we know, percentage rise in power

$$= \frac{\mathbf{P_2} - \mathbf{P_1}}{\mathbf{P_1}} \times \mathbf{100} = \frac{\mathbf{256} - \mathbf{81}}{\mathbf{81}} \times \mathbf{100}$$

$$= \frac{\mathbf{175}}{\mathbf{81}} \times \mathbf{100} = \mathbf{216\%}$$

19. (*b*) According to Newton's law of cooling, the rate of loss of heat is directly proportional to the difference in temperature of the body and its surroundings.

20. (*d*) Temperature is the measure of degree of hotness or coldness of a body. It is not true that a hotter body has more heat content than a colder body.

Therefore, A is false and R is also false.

21. (*d*) If equal amount of heat is added to equal masses of different substances, then the resulting temperature changes will not be the same.

Because every substance has a unique value for the amount of heat absorbed or rejected to change the temperature of unit mass of it by one unit.

Therefore, A is false and R is also false.

22. (*c*) As there is no atmosphere on the moon, so water kept in an open vessel quickly evaporates or boils due to reduced pressure, which causes reduction in boiling point.

Therefore, A is true but R is false.

23. (*d*) In freely heated rod, there is no thermal stress and no thermal strain, there is thermal expansion only.

When a rod (whose ends are fixed) is heated, thermal expansion of rod is prevented but this in turn, develops a compressive strain due to external forces provided by the rigid support at the ends.

The thermal stress, so set up is given by

$$\text{Stress} = \frac{\Delta \mathbf{F}}{\mathbf{A}} = \mathbf{Y}\left(\frac{\Delta l}{l}\right)$$

where, Y is the Young's modulus of the rod.

Also, thermal strain $= \frac{\Delta l}{l} = \frac{l \alpha_l \Delta \mathbf{T}}{l} = \alpha_l \Delta \mathbf{T}$

which means that strain is a change in length per unit original length.

Therefore, A is false and R is also false.

24. (*a*) In modern thermometry, the triple point of water is taken as a standard fixed point because its value does not change under any condition.

Melting point of ice and the boiling point of water changes due to change in atmospheric pressure. Due to this factor, callibration of a thermometer is affected.

Therefore, both A and R are true and R is the correct explanation of A.

25. (*c*) At a high temperature of 6000 K, the sun acts like a black body emitting complete radiation.

It follows from Stefan's law that $\mathbf{E} \propto \mathbf{T^4}$, i.e. the radiation from the sun's surface varies as the fourth power of its absolute temperature.

Therefore, A is true but R is false.

26. (*c*) Stefan's law is applied here not the Newton's law of cooling.
According to Stefan's law,

$$\frac{E_2}{E_1} = \left(\frac{T_2}{T_1}\right)^4 = \left(\frac{900}{300}\right)^4 = 81 \Rightarrow \frac{E_2}{R} = 81$$

Therefore, $E_2 = 81\,R$
Therefore, A is true but R is false.

27. (i) (*b*) Due to higher thermal conductivity of metal than wood, heat begins to flow readily from our body to the metal surface and so we feel colder.
(ii) (*a*) Woolen fibres enclose a large amount of air in them. Both wool and air are bad conductors of heat and do not allow loss of heat from our body due to conduction.
(iii) (*c*) Heat travels through vacuum due to radiation.
(iv) (*c*) The ratio of amount of heat transmitted through an object to the amount of heat incident on it is called transmittance.
(v) (*a*) The SI unit of thermal conductivity **K** is $\mathbf{Wm^{-1}K^{-1}}$.

PART 2

1. Let θ be the same numerical value of temperature on the both scales.

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

$$\Rightarrow \quad \frac{\theta}{5} = \frac{\theta - 32}{9} \qquad (\because \theta°C = \theta°F = \theta)$$

$$\Rightarrow \quad 9\theta = 5\theta - 160$$

$$\Rightarrow \quad -4\theta = 160$$

$$\therefore \quad \theta = -40°$$

$$\theta = -40°C = -40°F$$

2. A gas thermometer is more superior to a mercury thermometer, as its working is independent of the nature of gas (working substance) used. As the variation of pressure (or volume) with temperature is uniform, the range, in which temperature can be measured with a gas thermometer is quite large. Further, a gas thermometer is more sensitive than mercury thermometer.

3. The potential energy of water at the top of the fall gets converted into heat (kinetic energy) at the bottom of the fall. When water hits the ground, a part of its kinetic energy gets converted into heat which increases its temperature slightly.

4. Given, $t_1 = 27°C, l_1 = 63$ cm,
$t_2 = 45°C, \alpha = 1.20 \times 10^{-5}°C^{-1}$
Length of the rod on the hot day is

$$l_2 = l_1[1 + \alpha(t_2 - t_1)]$$
$$= 63\,[1 + 1.20 \times 10^{-5}\,(45 - 27)] = 63.0136 \text{ cm}$$

As the steel tape has been calibrated for a temperature of 27°C, so length of the steel rod at 27°C = **63 cm.**

5. Yes, it is possible to describe the difference of length to remains constant. So, the change in length of each rod must be equal at all temperature. Let L_b & L_s be the length of the brass & the steel rod and α_b & α_s be the coefficients of linear expansion of the two metals. Let there is change in temperature be ΔT, then

$$\alpha_b L_b \Delta T = \alpha_s L_s \Delta T$$

or $\quad \alpha_b L_b = \alpha_s L_s$

$\Rightarrow \quad L_b / L_s = \alpha_s / \alpha_b$

Hence, the lengths of the rods must be in the inverse ratio of the coefficient of linear expansion of their materials.

6. (i) As thermal expansion of isotropic solids is similar to true photographic enlargement, the expansion of a cavity is same, as if it were a solid body of the same material, i.e. $\Delta V = \gamma V \Delta T$. As here **V,** γ and ΔT are same for both solid and hollow spheres, so the expansions of both will be equal.
(ii) If same amount of heat is given to the two spheres, then due to lesser mass, rise in temperature of hollow sphere will be more (as $\Delta T = Q/Mc$) and hence the expansion will be more as $\Delta V = \gamma V \Delta T$.

7. Let **M** be the mass of glycerine, ρ_0 its density at 0°C and ρ_t its density at **t**°C.

Then, $$\gamma = \frac{V_t - V_0}{V_0 \Delta T} = \frac{\frac{M}{\rho_t} - \frac{M}{\rho_0}}{(M/\rho_0)\Delta T}$$

$$\gamma = \frac{\frac{1}{\rho_t} - \frac{1}{\rho_0}}{(1/\rho_0)\,\Delta T} = \frac{\rho_0 - \rho_t}{\rho_0 \Delta T}$$

∴ Fractional change in density,

$$\frac{\rho_0 - \rho_t}{\rho_0} = \gamma \Delta T$$
$$= 49 \times 10^{-5} \times 30 = 0.0147$$

8. A cooking utensil should have (i) high conductivity, so that it can conduct heat through itself and transfer it to the contents quickly (ii) and low specific heat, so that it immediately attains the temperature of the source.

9. As both flasks have same height and capacity, the area of the cylindrical wall will be less than that of the square wall. Hence, the thermos flask of circular cross-section will transmit less heat as compared to the thermos flask of square cross-section and it will be better.

10. The purpose of a coolant is to absorb maximum heat with least rise in its own temperature. This is possible only, if specific heat is high because $Q = mc\,\Delta T$. For a given value of **m** and **Q**, the rise in temperature ΔT will be small, if **c** is large. This will prevent different parts of the nuclear reactor from getting too hot.

11. A monoatomic gas has three degrees of freedom, while a diatomic gas possesses five degrees of freedom. Therefore, molar specific heat of a diatomic gas (at constant volume).

$$C_V = \frac{f}{2}R = \frac{5}{2}R = \frac{5}{2} \times \frac{8.31}{4.2} = 5 \text{ cal mol}^{-1}K^{-1}$$

In the given table, all the gases are diatomic gases and for all of them (except chlorine), the value of C_V is about $5 \text{ cal mol}^{-1}K^{-1}$.

The slightly higher value of C_V for chlorine is due to the fact that even at room temperature, a chlorine gas molecule possesses the vibrational mode of motion also.

12. Glass transmits about 50% of heat radiation coming from a hot source like the sun but does not allow the radiation from moderately hot bodies to pass through it. Due to this, when a car is left in the sun, heat radiation from the sun gets into the car but as the temperature inside the car is moderate, they do not pass back through its windows. Hence, inside of the car becomes considerably hotter.

13. Let K_1 and K_2 be the coefficients of thermal conductivity of the materials and t_1 and t_2 be the times in which ice melts in the two vessels.

As the same quantity of ice melts in the two vessels, the quantity of heat flowed into the vessels must be same.

$$\because \quad Q = \frac{K_1A(T_1 - T_2)t_1}{x} = \frac{K_2A(T_1 - T_2)t_2}{x}$$

$$\Rightarrow \quad K_1t_1 = K_2t_2$$

$$\therefore \quad \frac{K_1}{K_2} = \frac{t_2}{t_1} = \frac{25 \text{ min}}{10 \text{ min}} = 5:2$$

14. Brass is a good conductor of heat. It quickly conducts away the heat, so the paper does not reaches its ignition point easily. On the other hand, wood is a bad conductor of heat and is unable to conduct away the heat. So, the paper quickly reaches its ignition point and is charged.

15. The temperature of pockets formed by coals are not appreciably different from the surface temperature of glowing coals.

However, the pockets formed by coals act as cavities. The radiations from these cavities are black body radiations and so have maximum intensity. Hence, the pockets appear brighter than the glowing coals.

16. It is done so to remove the harmful impure air and to replace it by the cool fresh air. The air we breath out is warm and so it is lighter. It rises upwards and can go out through the ventilator provided near the roof.

The cold fresh air from outside enters the room through the doors and windows. Thus, the convection current is set up in the air.

17. Because the earth is located at a very large distance from the sun, hence it receives only a small fraction of the heat radiation emitted by the sun. Further, due to loss of heat from the surface of the earth due to convection and radiation also, the earth does not become as hot as the sun.

18. When a drop of water falls on a very hot iron, it gets insulated from the iron by a layer of poor conducting water vapour. As the heat is conducted very slowly through this layer, it takes quite long for the drop to evaporate. But if the drop of water falls on iron which is not very hot, then it comes in direct contact with iron and evaporates immediately.

19. Heat carried away from a fire sideways mainly by radiation. Above the fire, heat is carried by both radiation and convection of air but convection carries much more heat than radiation. So, it is much hotter above a fire than by its sides.

20. The air between the two walls of the thermoflask is evacuated. This prevents heat loss due to conduction and convection.

The loss of heat due to radiation is minimised by silvering the inside surface of the double wall. As, the loss of heat due to the three processes is minimised and the tea remains hot for a long time.

21. As the heat capacities are equal, so $m_1C_1 = m_2C_2$.

Let C be the specific heat of the composite body, then

$$(m_1 + m_2)C = m_1C_1 + m_2C_2$$

$$= m_1C_1 + m_1C_1 = 2m_1C_1$$

or $$C = \frac{2m_1C_1}{m_1 + m_2} = \frac{2m_1C_1}{m_1 + m_1\frac{C_1}{C_2}} = \frac{2C_1C_2}{C_1 + C_2}$$

22. Let the reading on Celsius scale be θ.

Reading on $T_F = \frac{3}{2}\theta$

As, $$\frac{\theta}{100} = \frac{T_F - 32}{180}$$

$$\frac{\theta}{5} = \frac{\frac{3}{2}\theta - 32}{9}$$

On solving , we get

$$\theta = -106.67\,°C$$

Temperature on Kelvin's scale,

$$T_K = -106.67 + 273.15 = 166.48 \text{ K}$$

$$T_F = 160.005° \text{ F}$$

23. For neon triple point, $T = 24.57$ K

$$\therefore \quad T_C = T(K) - 273.15$$

$$= 24.57 - 273.15 = -248.58° C$$

$$T_F = \frac{9}{5}T_C + 32 = \frac{9}{5} \times (-248.58) + 32 = -415.44° F$$

For carbon dioxide, triple point, $T = 216.55$ K

$$\therefore \quad T_C = T(K) - 273.15$$

$$= 216.55 - 273.15 = -56.6° C$$

$$T_F = \frac{9}{5}T_C + 32 = \frac{9}{5} \times (-56.6) + 32 = -69.88° F$$

24. (i) (a) For pressure thermometer **A**,

$$T_{tr} = 273 \text{ K}, \; p_{tr} = 1.250 \times 10^5 \text{ Pa},$$

$$p = 1.797 \times 10^5 \text{ Pa}$$

Normal freezing point of sulphur,

$$T = \frac{p}{p_{tr}} \times T_{tr}$$

$$= \frac{1.797 \times 10^5 \times 273}{1.250 \times 10^5} = 392.028\ K$$

(b) For pressure thermometer **B**,

$$T_{tr} = 273\ K,\ p_{tr} = 0.200 \times 10^5\ Pa,$$

$$p = 0.287 \times 10^5\ Pa$$

$$\therefore \quad T = \frac{0.287 \times 10^5 \times 273}{0.200 \times 10^5} = 391.75\ K$$

(ii) The slight difference is due to the fact that, oxygen and hydrogen do not behave strictly as ideal gases.

25. As radius of ball, $r_0 = 9.0\ cm = 0.090\ m$ at 0°C, hence its volume, $V_0 = \frac{4}{3}\pi r_0^3 = \frac{4}{3} \times 3.14 \times (0.090)^3$

$$= 3.05 \times 10^{-3}\ m^3$$

Again as, $\alpha = 1.2 \times 10^{-5}\ K^{-1}$,

$$\therefore \quad \gamma = 3\alpha = 3 \times 1.2 \times 10^{-5} = 3.6 \times 10^{-5}\ K^{-1}$$

Moreover rise in temperature,

$$\Delta T = 90°C - 0°C = 90°C = 90\ K$$

$\therefore$ Increase in volume, $\Delta V = V\gamma\Delta T$

$$= 3.05 \times 10^{-3} \times 3.6 \times 10^{-5} \times 90$$
$$= 9.88 \times 10^{-6}\ m^3$$
$$= 9.88\ cm^3$$

26. Given, cross-section area, $A = 2.0\ mm^2 = 2 \times 10^{-6}\ m^2$

Change in temperature, $\Delta T = 30 - 5 = 25°C$

Young's modulus of steel wire, $Y = 2 \times 10^{11}\ Nm^{-2}$

and coefficient of linear expansion of steel,

$$\alpha = 1.1 \times 10^{-5} / °C.$$

$\therefore$ Tension developed in the rod,

$$F = YA\alpha\Delta T$$
$$= 2 \times 10^{11} \times 2 \times 10^{-6} \times 1.1 \times 10^{-5} \times 25$$
$$F = 110\ N$$

27. As the brass scale of a barometer gives correct reading at $T_1 = 0°C$, hence at temperature $T_2 = 27°C$, the scale will expand and will not give correct reading.

In such a case, true value

= observed scale reading × $(1 + \alpha\Delta T)$]

$\therefore$ True pressure = $75.00\ cm \times [1 + 2.0 \times 10^{-5} \times (27 - 0)]$

$$= 75 \times (1 + 2.0 \times 10^{-5} \times 27)$$
$$= 75.00\ (1 + 54 \times 10^{-5})\ cm$$
$$= 75.04\ cm$$

28. Here, $A = 0.15\ m^2$, $x = 1.0\ cm = 0.01\ m$,

$$K = 109\ Js^{-1}m^{-1}°C^{-1},\ L = 2256\ Jg^{-1},$$
$$T_2 = 100°C,\ t = 1\ min = 60\ s$$

Let T_1 be the temperature of the part of the flame in contact with boiler, then amount of heat that flows into water in 1 min.

$$Q = \frac{KA(T_1 - T_2)t}{x} = \frac{109 \times 0.15 \times (T_1 - 100) \times 60}{0.01}\ J$$

Mass of water boiled per min = **6** kg = **6000** g

Heat used to boil water,

$$Q = mL = 6000\ g \times 2256\ Jg^{-1} = 6000 \times 2256\ J$$

$$\therefore \quad \frac{109 \times 0.15 \times (T_1 - 100) \times 60}{0.01} = 6000 \times 2256$$

or $\quad T_1 - 100 = \frac{6000 \times 2256 \times 0.01}{109 \times 0.15 \times 60} = 138°C$

or $\quad T_1 = 138 + 100 = 238°C$

29. (i) As surface area increases on pouring hot tea in saucer from the cup and the rate of loss of heat is directly proportional to surface area of the radiating surface, so the tea will cool faster in the saucer.

(ii) Temperature of a hot liquid falls exponentially in accordance with Newton's law of cooling. In other words, rate of cooling is directly proportional to the temperature difference between hot liquid and the surroundings. It is due to this reason that, a hot liquid cools rapidly in the beginning but slowly afterwards.

(iii) When outer surface of container is blackened, the surface becomes good emitter of heat and so the hot liquid in it cools faster.

30. Mass of copper block, $M = 2.5\ kg = 2.5 \times 10^3\ g$

Specific heat of copper, $c = 0.39\ J\ g^{-1}°C^{-1}$

Fall in temperature, $\Delta T = 500 - 0 = 500°C$

Heat lost by copper block = $mc\Delta T$

$$= 2.5 \times 10^3 \times 0.39 \times 500\ J$$

Let mass of ice melted = **M** gram

Heat of fusion of ice, $L = 335\ Jg^{-1}$

Heat gained by ice = $ML = M \times 335\ J$

$\because$ Heat gained = Heat lost

$\therefore \quad M \times 335 = 2.5 \times 10^3 \times 0.39 \times 500$

or $\quad M = \frac{2.5 \times 10^3 \times 0.39 \times 500}{335}$

$$= 1455.2\ g = 1.455\ kg$$

31. Here, $A = 6 \times side^2 = 6 \times 30 \times 30$

$$= 5400\ cm^2 = 0.54\ m^2$$
$$x = 5\ cm = 0.05\ m,\ t = 6\ h = 6 \times 3600\ s$$
$$T_1 - T_2 = 45 - 0 = 45°C,$$
$$K = 0.01\ Js^{-1}m^{-1}°C^{-1}$$
$$L = 335 \times 10^3\ J\ kg^{-1}$$

Total heat entering the box through all the six faces,

$$Q = \frac{KA(T_1 - T_2)t}{x}$$
$$= \frac{0.01 \times 0.54 \times 45 \times 6 \times 3600}{0.05} = 104976\ J$$

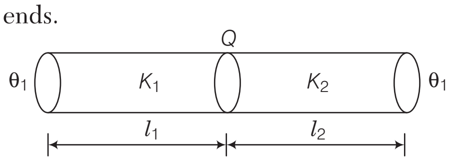
Let **m** kg of ice melt due to this heat. Then,

$$Q = mL$$

or $\quad m = \frac{Q}{L} = \frac{104976\ J}{336 \times 10^3\ J\ kg^{-1}} = 0.313\ kg$

Mass of ice left after six hours = $4 - 0.313 = 3.687\ kg$

32. It is given that conductivities $\mathbf{K_1}$ and $\mathbf{K_2}$ are in series, so rate of flow of heat energy is same. But the sum of the difference in temperature is the difference across their free ends.



$\therefore \quad (\theta_1 - \theta) + (\theta - \theta_2) = (\theta_1 - \theta_2)$

i.e. $\quad \dfrac{\theta}{t} \cdot \dfrac{l_1}{K_1 A} + \dfrac{\theta}{t} \dfrac{l_2}{K_2 A} = \dfrac{\theta}{t} \cdot \dfrac{(l_1 + l_2)}{K_{eq} A}$

$\Rightarrow \quad \dfrac{l_1}{K_1} + \dfrac{l_2}{K_2} = \dfrac{l_1 + l_2}{K_{eq}}$

$\therefore \quad K_{eq} = \dfrac{l_1 + l_2}{\left(\dfrac{l_1}{K_1} + \dfrac{l_2}{K_2}\right)}$

33. When $\mathbf{T = 273\ K, R = 101.6\ \Omega}$

$\therefore \quad 101.6 = R_0[1 + 5 \times 10^{-3}\ (273 - T_0)] \quad \ldots(i)$

Given, $\quad \mathbf{T = 600.5\ K}$, $\mathbf{R = 165.5\ \Omega}$

$\therefore \quad 165.5 = R_0[1 + 5 \times 10^{-3}(600.5 - T_0)] \quad \ldots(ii)$

Dividing Eq. (ii) by Eq. (i), we get

$$\frac{165.5}{101.0} = \frac{1 + 5 \times 10^{-3}\ (600.5 - T_0)}{1 + 5 \times 10^{-5}\ (273 - T_0)}$$

On solving, we get $\quad T_0 = -\ 49.3$ K

Substituting in Eq. (i), we get

$$101.6 = R_0[1 + 5 \times 10^{-3}\ (273 + 49.3)]$$

or $\quad R_0 = \dfrac{101.6}{1 + 5 \times 10^{-3} \times 322.3} = 38.9\ \Omega$

For $\quad \mathbf{R = 123.4\ \Omega}$, we have

$$123.4 = 38.9[1 + 5 \times 10^{-3}\ (T + 49.3)]$$

On solving, we get $\mathbf{T = 384.8\ K}$

34. For brass rod,

$$l = 50\ \text{cm},\ t_1 = 40°\ C,\ t_2 = 250°\ C,$$
$$\alpha = 2.0 \times 10^{-5}\ °C^{-1}$$

Change in length of brass rod is

$$\Delta l = \alpha l\,(t_2 - t_1)$$
$$= 2.0 \times 10^{-5} \times 50 \times (250 - 40) = 0.21\ \text{cm}$$

For steel rod, $\mathbf{l = 50\ cm,\ t_1 = 40°\ C,\ t_2 = 250°\ C,}$

$$\alpha = 1.2 \times 10^{-5}\ °C^{-1}$$

Change in length of steel rod is

$$\Delta l' = \alpha l\,(t_2 - t_1)$$
$$= 1.2 \times 10^{-5} \times 50 \times (250 - 40) = 0.13\ \text{cm}$$

Change in length of the combined rod at 250°C

$$= \Delta l + \Delta l' = 0.21 + 0.13 = 0.34\ \text{cm}$$

As the rods expand freely, so no thermal stress is developed at the junction.

35. Given, diameter of the hole, $\mathbf{d_1 = 4.24\ cm}$

Initial temperature, $\mathbf{T_1 = 27 + 273 = 300\ K}$

Final temperature, $\mathbf{T_2 = 227 + 273 = 500\ K}$

Coefficient of linear expansion, $\alpha = \mathbf{1.70 \times 10^{-5}\ /°\ C}$

Coefficient of superficial expansion,

$$\beta = 2\alpha = 3.40 \times 10^{-5}/°\ C$$

Initial area of hole at 27°C, $A_1 = \pi r^2 = \dfrac{\pi d_1^2}{4}$

$$= \frac{\pi}{4}(4.24)^2 = 4.494\ \pi\ \text{cm}^2$$

Area of hole at 227°C, $A_2 = A_1(1 + \beta\,\Delta t)$

$$= 4.494\pi\ [1 + 3.40 \times 10^{-5} \times (227 - 27)]$$
$$= 4.494\pi\ (1 + 3.40 \times 10^{-5} \times 200)$$
$$= 4.495\pi \times 1.0068 = 4.525\ \pi\,\text{cm}^2$$

If diameter of hole becomes $\mathbf{d_2}$ at 227°C, then $A_2 = \dfrac{\pi d_2^2}{4}$

or $\quad 4.525\ \pi = \dfrac{\pi d_2^2}{4} \Rightarrow d_2^2 = 4.525 \times 4$

$\Rightarrow \quad d_2 = 4.2544\ \text{cm}$

$\therefore$ Change in diameter, $\Delta d = d_2 - d_1 = 4.2544 - 4.24$

$$= 0.0144\ \text{cm}$$
$$= 1.44 \times 10^{-2}\ \text{cm}$$

36. Consider a solid in the form of a rectangular parallelopiped of sides **a, b** and **c** respectively, so that its volume $\mathbf{V = abc}$.

If the solid is heated, so that its temperature rises by ΔT, then increase in its sides will be

$$\Delta a = a \cdot \alpha \cdot \Delta T, \Delta b = b \cdot \alpha \cdot \Delta T \text{ and } \Delta c = c \cdot \alpha \cdot \Delta T$$

or $\quad a' = a + \Delta a = a(1 + \alpha \cdot \Delta T)$

$\quad\quad b' = b + \Delta b = b(1 + \alpha \cdot \Delta T)$

and $\quad c' = c + \Delta c = c(1 + a \cdot \Delta T)$

$\because$ New volume, $V' = V + \Delta V = a'b'c'$

$$= abc(1 + \alpha \cdot \Delta T)^3$$

$\therefore$ Increase in volume,

$$\Delta V = V' - V = [abc(1 + \alpha \cdot \Delta T)^3 - abc]$$

$\therefore$ Coefficient of volume expansion,

$$\gamma = \frac{\Delta V}{V \cdot \Delta T} = \frac{abc(1 + \alpha \cdot \Delta T)^3 - abc}{abc \cdot \Delta T}$$

$\therefore \quad \gamma = \dfrac{(1 + \alpha \cdot \Delta T)^3 - 1}{\Delta T}$

$$= \frac{(1 + 3\alpha \cdot \Delta T + 3\alpha^2 \cdot \Delta T^2 + \alpha^3 \cdot \Delta T^3) - 1}{\Delta T}$$

$$= 3\alpha + 3\alpha^2\ \Delta T + \alpha^3 \cdot \Delta T^2.$$

However, as α has an extremely small value for solids, hence terms containing higher powers of α may be neglected. Therefore, we obtain the relation $\gamma = 3\alpha$.

i.e. Coefficient of volume expansion of a solid is three times of its coefficient of linear expansion.

37. (i) The melting point of ice as well as the boiling point of water change with change in pressure. The presence of impurities also changes the melting and boiling points. However, the triple point of water has a unique temperature and is independent of external factors.

(ii) The other fixed point on Kelvin scale is absolute zero, which is the temperature at which the volume and pressure of any gas become zero.

(iii) As the triple point of water on Celsius is 0.01°C (and not 0°C) and on Kelvin scale 273.16 and the size of degree on the two scales is same, so

$$\mathbf{T_c - 0.01 = T - 273.16}$$

$$\therefore \quad \mathbf{T_c = T - 273.15}$$

(iv) One degree on Fahrenheit scale

$$= \frac{\mathbf{180}}{\mathbf{100}} = \frac{\mathbf{9}}{\mathbf{5}} \text{ divisions on Celsius scale.}$$

But one Celsius scale division is equal to one division on Kelvin scale.

∴ Triple point on Kelvin scale (whose size of a degree is equal to that of the Fahrenheit scale)

$$= \mathbf{273.16 \times 9 / 5 = 491.69}$$

38. Mass of child, $\mathbf{M = 30}$ kg $= \mathbf{30 \times 10^3}$g

Fall in temperature, $\Delta\mathbf{T = 101 - 98 = 3°F = 3} \times \frac{\mathbf{5}}{\mathbf{9}} = \frac{\mathbf{5}}{\mathbf{3}}\,°\text{C}$

Specific heat of human body,

$$\mathbf{c} = \text{specific heat of water} = \mathbf{1\ cal\ g^{-1}\,°C^{-1}}$$

Heat lost by child in the form of evaporation of sweat,

$$\mathbf{Q = Mc\Delta T = 30 \times 10^3 \times 1 \times \frac{5}{3}}$$

$$= \mathbf{50000\ cal}$$

If $\mathbf{M'}$ gram of sweat evaporates from the body of the child, then heat gained by sweat,

$$\mathbf{Q = M'L = M' \times 580}\ \text{cal} \qquad [\because \mathbf{L = 580}\ \text{calg}^{-1}]$$

∵ Heat gained = Heat lost

$$\mathbf{M' \times 580 = 50000 \Rightarrow M' = \frac{50000}{580} = 86.2\ g}$$

Time taken by sweat to evaporate = **20** min

$$\therefore \text{ Rate of evaporation of sweat} = \frac{\mathbf{86.2}}{\mathbf{20}} = \mathbf{4.31\ g\ min^{-1}}$$

39. (i) A body with large reflectivity is a poor absorber of heat. According to Kirchhoff's law, a poor absorber of heat is a poor emitter. Hence, a body with large reflectivity is a poor emitter.

(ii) Brass is a good conductor of heat. When a brass tumbler is touched, heat quickly flows from human body to tumbler. Consequently, the tumbler appears colder. Wood is a bad conductor, so, heat does not flow from the human body to the tray in this case. Thus, it appears comparatively hotter.

(iii) Let **T** be the temperature of the hot iron in the furnace.

Heat radiated per second per unit area, $\mathbf{E = \sigma T^4}$

When the body is placed in the open at temperature $\mathbf{T_0}$, the heat radiated/second/unit area,

$\mathbf{E'} = \sigma\ (\mathbf{T_4 - T_0^4})$.

Clearly, $\mathbf{E' < E}$. So, the optical pyrometer gives lower value for the temperature in the open.

(iv) Heat radiated out by the earth is reflected back by the atmosphere. In the absence of atmosphere, at night all heat would escape from the earth's surface and thereby the earth's surface would be inhospitably cold. Also, atmosphere helps in maintaining the temperature through convection current.

(v) Though steam and boiling water are at the same temperature but each unit mass of steam contains a larger amount of additional heat called the latent heat. e.g. Each gram of steam has 540 cal of more heat than each gram of boiling water. Hence, steam loses more heat than boiling water.

40.

Conduction	**Convection**	**Radiation**
It is the transfer of heat by direct physical contact.	It is the transfer of heat by the motion of a fluid.	It is the transfer of heat by electromagnetic waves.
It is due to temperature difference. Heat flows from high temperature region to low temperature region.	It is due to difference in density. Heat flows from low density region to high density region.	It occurs from all bodies at temperatures above 0 K.
It occurs in solids through molecular collisions, without actual flow of matter.	It occurs in fluids by actual flow of matter.	It can take place at large distances and does not heat the intervening medium.
It is a slow process.	It is also a slow process.	It propagates at the speed of light.
It does not obey the laws of reflection and refraction.	It does not obey the laws of reflection and refraction.	It obeys the laws of reflection and refraction.

41. Given, $\mathbf{L_1 = L_2 = L = 0.1\ m}$

$$\mathbf{A_1 = A_2 = A = 0.02\ m^2}$$

$$\mathbf{K_1 = 79\ Wm^{-1}K^{-1}, K_2 = 109\ Wm^{-1}K^{-1}}$$

$$\mathbf{T_1 = 373\ K} \text{ and } \mathbf{T_2 = 273\ K}$$

At steady state, heat transferred from each section of thermal conductor is same

i.e. $\mathbf{H_1 = H_2 = H}$

$$\Rightarrow \quad \frac{\mathbf{K_1A_1(T_1 - T_0)}}{\mathbf{L_1}} = \frac{\mathbf{K_2A_2\ (T_0 - T_2)}}{\mathbf{L_2}} \qquad \text{...(i)}$$

For $\mathbf{A_1 = A_2 = A}$ and $\mathbf{L_1 = L_2 = L}$, Eq. (i) becomes

$$K_1 (T_1 - T_0) = K_2 (T_0 - T_2)$$

$$\Rightarrow \qquad T_0 = \frac{K_1 T_1 + K_2 T_2}{K_1 + K_2}$$

Therefore, heat current through each bar

$$H = \frac{K_1 A (T_1 - T_0)}{L} = \frac{K_2 A (T_0 - T_2)}{L}$$

$$= \frac{A(T_1 - T_2)}{L\left(\frac{1}{K_1} + \frac{1}{K_2}\right)}$$

$$= \frac{K_1 K_2 A (T_1 - T_2)}{L(K_1 + K_2)} \qquad \text{...(ii)}$$

Now, heat current through composite bar of length $L_1 + L_2 = 2L$ and equivalent thermal conductivity K', can be given by

$$H' = \frac{K' A (T_1 - T_2)}{2L} = H \qquad \text{...(iii)}$$

From Eqs. (ii) and (iii), we get

$$\Rightarrow \qquad K' = \frac{2K_1 K_2}{K_1 + K_2}$$

(i) So, the temperature of the junction of two bars is

$$T_0 = \frac{K_1 T_1 + K_2 T_2}{K_1 + K_2}$$

$$= \frac{79 Wm^{-1}K^{-1} \times 373\ K + 109 Wm^{-1}K^{-1} \times 273\ K}{79\ Wm^{-1}K^{-1} + 109 Wm^{-1}K^{-1}}$$

$= 315$ K

(ii) Equivalent thermal conductivity

$$K' = \frac{2K_1 K_2}{K_1 + K_2}$$

$$= \frac{2 \times 79\ Wm^{-1}K^{-1} \times 109\ Wm^{-1}K^{-1}}{79\ Wm^{-1}K^{-1} + 109\ Wm^{-1}K^{-1}}$$

$$= 91.6\ Wm^{-1}K^{-1}$$

(iii) Heat current through the composite bar

$$H' = H = \frac{K' A (T_1 - T_2)}{2L}$$

$$= \frac{91.6\ Wm^{-1}K^{-1} \times 0.02\ m^2 \times (373 - 273)\ K}{2 \times 0.1\ m}$$

$$= 916.1\ W$$

42. According to Newton's law of cooling, when the temperature difference is not large, rate of loss of heat is proportional to the temperature difference between the body and the surroundings.

$$mc \frac{T_1 - T_2}{t} = K (T - T_0)$$

where, $T = \frac{T_1 + T_2}{2}$ = average of the initial and final temperatures of the body and T_0 is the temperature of the surroundings.

Given, $T_1 = 80° C$, $T_2 = 50°C$, $T_0 = 20° C$,

$$t = 5 \text{ min} = 300 \text{ s}$$

$$T = \frac{T_1 + T_2}{2} = \frac{80 + 50}{2} = 65°C$$

$$\therefore \qquad mc \frac{80 - 50}{300} = K (65 - 20) \qquad \text{...(i)}$$

If the liquid takes t seconds to cool from 60°C to 30°C, then

$$T = \frac{60 + 30}{2} = 45°C$$

$$\therefore \qquad mc \frac{60 - 30}{t} = K (45 - 20) \qquad \text{...(ii)}$$

Dividing Eq. (i) by Eq. (ii), we get

$$\frac{30}{300} \times \frac{t}{30} = \frac{45}{25}$$

or $\qquad t = \frac{45}{25} \times 300 = 540 s = 9$ min

43. (i) The solid, liquid and vapour phases of CO_2 coexist in equilibrium at its triple point **O** for which

$$p_{tr} = 5.11 \text{ atm and } T_{tr} = -56.6° C$$

(ii) The vaporisation curve I and fusion curve II show that, both the boiling point and fusion point of CO_2 decrease with decrease of pressure.

(iii) For CO_2, $p_c = 73.0$ atm and $T_c = 31.1° C$. Above its critical temperature, CO_2 gas cannot be liquefied, however large pressure may be applied.

(iv) (a) $-70° C$ under 1 atm, this point lies in vapour region.

Therefore, at $-70° C$ under 1 atm, CO_2 is vapour.

(b) $-60° C$ under 10 atm. This point lies in solid region, therefore CO_2 is solid at $-60° C$ under 10 atm.

(c) 15°C under 56 atm. This point lies in liquid region, therefore CO_2 is liquid at 15°C under 56 atm.