11

We are known to common sense notions of heat and temperature.

When heat is supplied to a body, the physical state of the body may be changed. These changes may follow certain laws. Thus, we can say that all the changes in characteristics (properties) of matter that appear due to heat are known as its thermal properties. Hence, in this chapter, we will deal with heat and its measurement and the process of heat transfer.

THERMAL PROPERTIES OF MATTER

|TOPIC 1|
Temperature and its Measurement

CHAPTER CHECKLIST

- Temperature and Heat
- Ideal Gas Equation and Absolute Temperature
- Thermal Expansion
- Thermal Strain and Thermal Stress
- Heat Capacity
- Calorimetry
- Change of State
- Triple Point
- Latent Heat
- Heat Transfer
- Newton's Law of Cooling

TEMPERATURE AND HEAT

Temperature

Temperature 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 T_1 and T_2 where $T_1 > T_2$, then the body with T_1 is called **hotter one** with respect to another one which is known as **colder body**.

Note

When a body is heated, the changes can take place in the body such as it may expand or its physical state may be changed.

Heat

Heat is the form of energy which flows from hotter body to colder body by virtue of temperature difference. The process of transfer of heat is a non-mechanical process i.e. there is no mechanical work involved in the process of heat transfer. 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).

One calorie is equal to the amount of heat energy required to raise the temperature of one gram of water through 1°C (from 14.5°C to 15.5°C)

Caloric Theory of Heat

According to this theory, heat is an invisible, weightless and odourless fluid called **caloric**. When some calorie is added to a body, its temperature rises and when some calorie is removed, its temperature falls.

Dynamic Theory of Heat

According to this theory, all substances (solids, liquids and gases) are made of molecules. These molecules are in a state of continuous random motion.

Depending on the nature and temperature of the substance, the molecules may possess three types of motion

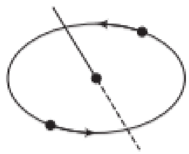
(i) **Translatory motion** This is the motion in a straight line which is common in gases.

Translatory motion

(ii) **Vibrational motion** This is the to and fro motion of the molecules about their mean positions. This is common in liquid and gases.

Vibrational motion

(iii) **Rotational motion** This is the motion of molecules about their axis. This type of motion occurs usually at high temperature.



Rotational motion

Note

Every type of motion provides some kinetic energy to the molecules of the body. In fact, heat possessed by the body is the total thermal energy of the body which is the sum of kinetic energies of all individual molecules of the body due to translational, vibrational and rotational motion of the molecules.

Measurement of Temperature

As temperature is a fundamental physical quantity and it need measurement. The measurement of temperature is done by some specified scales.

These scales are commonly called **thermometers**. The thermometers are calibrated so that a numerical value may be assigned to a given temperature.

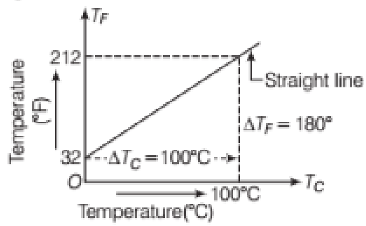
It measures the temperature of the body in the unit as **kelvin** (K), **degree centigrade** (°C), **degree fahrenheit** (°F), etc., among which kelvin (K) is taken as the SI unit of temperature. Many physical properties of materials change sufficiently with temperature to be used as the basis for constructing thermometers.

The commonly used properties are variation of the volume of a liquid with temperature, variation of pressure or volume of gas with temperature, the variation of resistance of metal with temperature, the variation of thermoemf with temperature of a junction in a thermocouple, etc.

As we know two reference points are needed to define any standard scale. In case of water, these points are ice point and steam point at which the pure water freezes and boils respectively under standard pressure.

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.

The graph of fahrenheit temperature (T_F) *versus* celsius or centigrade temperature (°C) is found to be



Celsius *versus* Fahrenheit graph

The equation of this straight line is given as

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

The size of the unit for kelvin temperature is the same celsius degree, so temperatures on these scales are related by

$$T_K = T_C + 273.15$$

Different Scales to Measure the Temperature

S. No.	Scale	Unit	Freezing or ice point (Lower fixed point)	Boiling or steam point (Upper fixed point)
1.	Celsius scale	Degree centigrade (°C)	0°C	100°C
2.	Fahrenheit scale	Degree Fahrenheit (°F)	32°F	212°F
3.	Reaumur scale	Degree Reaumur (°R)	0° R	80°R
4.	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

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

Here, C, F, R and K are the readings of different scales.

Constant-Volume Gas Thermometer

If p_0, p_{100}, p_{tr} and p_r are the pressures of gas at temperatures 0°C, 100°C, triple point of water and unknown temperature (t°C) respectively, keeping the volume constant, then

$$t=\left(\frac{p-p_0}{p_{100}-p_0}\times 100\right)°\text{C}$$

or $$T=\left(273.16\frac{p}{p_{tr}}\right)\text{K}$$

Platinum Resistance Thermometer

If R_0, R_{100}, R_{tr} and R_r are the resistances of a platinum wire at temperatures 0°C, 100°C, triple point of water and unknown temperature (t°C) respectively, then

$$t=\left(\frac{R-R_0}{R_{100}-R_0}\times 100\right)°\text{C or } T=\left(\frac{R_t}{R_{tr}}T_{tr}\right)\text{K}$$

$$=\left(\frac{R}{R_{tr}}\times 273.16\right)\text{K}$$

IDEAL GAS EQUATION AND ABSOLUTE TEMPERATURE

A special type of thermometer named **liquid-in-glass thermometer** shows the various readings for the temperature other than the fixed points because of different expansion properties of liquids. But a thermometer that uses a gas gives the unique reading regardless of which gas is used.

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** It is given by English chemist Robert Boyle (1627–1691). According to this law,

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

i.e. $$pV=\textbf{constant}$$

(ii) **Charles' Law** It is given by French scientist Jacques Charles (1747–1823). According to this law,

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

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

Ideal Gas Equation

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

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

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

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

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

From the ideal gas equation, $pV\propto T$

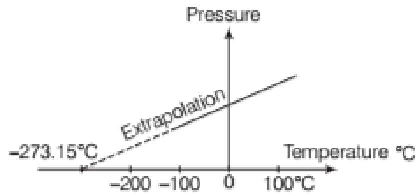
This is the cause for a gas to be used to measure temperature by a volume gas thermometer (for which $p\propto T$ as volume of the gas is constant).

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 variation of pressure (p) with temperature T(°C) is shown in figure.

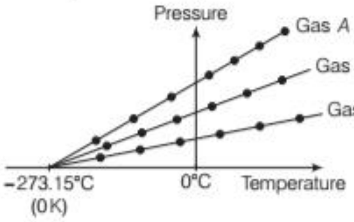


Graph of pressure *versus* temperature of a low density gas kept at constant volume

The graph is extrapolated, it meets the temperature axis at – 273.15°C, Kelvin (after British Scientist Lord Kelvin) called this value of temperature as **absolute zero** (0 A) or (0 K). This is because at this temperature, pressure and volume of the gas become zero.

Hence, the lowest temperature of $-273.15°C$ at which gas is supposed to have zero volume (or zero pressure) and at which entire molecular motion stops, is called **absolute zero** of temperature. If we were imagine to going below this temperature, volume of gas would be negative, which is impossible. This suggests that the **lowest attainable temperature is absolute zero.**

The plot for pressure *versus* temperature and extrapolation of lines for low density gases (*A*, *B* and *C*) indicates the same absolute zero temperature is given below.



p-T diagram for low density gases

The absolute zero temperature is regarded as 0 K or $-273.15°C$. This implies 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

It is generally observed that sealed bottles with metallic lids are so tightly screwed that it has to put the lid in hot water to open the lid. It would allow the metallic cover to expand and thereby loosening it to unscrew easily.

So, when heat is supplied to material, its dimensions (length, area and volume) can be changed due to change in its temperature.

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

Types of Thermal Expansion

There are three types of thermal expansion

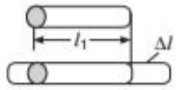
(i) Linear expansion
(ii) Area (or superficial) expansion and
(iii) Volume (or cubical) expansion

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 l_1 at temperature T_1 and final increased length l_2 at increased temperature T_2, then fractional change in its length is given by

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



Linear expansion

Here, $\Delta l \propto l_1$ and $\Delta l \propto \Delta T$ $\therefore$ $\Delta l \propto l_1 \Delta T$

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

The quantity, α_l is known as **coefficient of linear expansion.** It is a characteristic of the material of the rod. Normally, metals expand more and hence relatively high values of α_l.

$$\alpha_l = \frac{\Delta l}{l \Delta T}$$

$$= \frac{\text{Increase in length}}{\text{Original length} \times \text{Rise in temperature}}$$

Hence, the coefficient of linear expansion of a material of a solid rod is defined as increase in length per unit original length per degree rise in temperature. Its unit is $°C^{-1}$ or K^{-1}.

EXAMPLE |1| A Hardworking Blacksmith

A blacksmith fixes iron ring on the rim of the wooden wheel of a bullock cart. The diameter of the rim and the iron ring are 5.243 m and 5.231 m, respectively at 27°C. To what temperature should the ring be heated so as to fit the rim of the wheel? $(\alpha = 1.20 \times 10^{-5} K^{-1})$ **[NCERT]**

Sol. Given, initial temperature $T_1 = 27°C$

Initial length, $l_1 = 5.231$ m

Final length, $l_2 = 5.243$ m

Now, $\alpha_l = \frac{\Delta l}{l_1 \Delta T} = \frac{l_2 - l_1}{l_1 \Delta T}$

$\Rightarrow$ $l_2 = l_1 [1 + \alpha_l (T_2 - T_1)]$

i.e. $5.243 \text{ m} = 5.231\text{m} [1 + 1.20 \times 10^{-5} K^{-1} (T_2 - 27°C)]$

This gives $T_2 = 218°C$

EXAMPLE |2| Shrinkage in the Shaft

A large steel wheel is to be fitted on to a shaft of the same material. At 27°C, the outer diameter of the shaft is 8.70 cm and the diameter of the central hole in the wheel is 8.69 cm. The shaft is cooled using 'dry ice' (solid carbon dioxide). At what temperature of the shaft does the wheel slip on the shaft? Assume coefficient of linear expansion of the steel to be constant over the required temperature range. $\alpha_{steel} = 1.20 \times 10^{-5} K^{-1}$. **[NCERT]**

Sol. Given, $l_1 = 8.70$ cm, $l_2 = 8.69$ cm,

$T_1 = 27 + 273 = 300$ K, $T_2 = ?$

As, $l_2 - l_1 = \alpha l_1 (T_2 - T_1)$

$\therefore$ $T_2 - T_1 = \dfrac{l_2 - l_1}{\alpha l_1}$

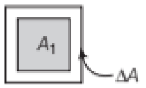
or $T_2 - 300 = \dfrac{8.69 - 8.70}{1.20 \times 10^{-5} \times 8.70} = -95.8$

or $T_2 = 300 - 95.8$

$= 204.2 \text{ K} = -68.95° \text{ C}$

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 A_1 at temperature T_1 and final area A_2 at temperature T_2 then fractional change in its area is given by

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

Here, $\Delta A \propto A_1$ and $\Delta A \propto \Delta T$

$\therefore$ $\Delta A \propto A_1 \Delta T$

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

where, α_A is known as **coefficient of area expansion.** It depends on nature of the material of the plate.

$$\alpha_A = \frac{\Delta A}{A_1 \Delta T}$$

$$\alpha_A = \frac{\text{Increase in surface area}}{\text{Original surface area} \times \text{Rise in temperature}}$$

Hence, coefficient of area expansion of metal sheet is defined as the increase in its surface area per unit original surface area per degree rise in its temperature. Its unit is $°C^{-1}$ or K^{-1}.

EXAMPLE |3| Expansion in Metal Ball

A metal ball having a diameter of 0.4 m is heated from 273 to 360 K. If the coefficient of area expansion of the material of the ball is 0.000034 K^{-1}, then determine the increase in surface area of the ball.

Sol. Given, Diameter = 0.4 m

Radius, $r = \dfrac{0.4}{2} = 0.2 \text{ m}$

$\Delta T = T_2 - T_1 = 360 \text{ K} - 273 \text{ K} = 87 \text{ K}$

$\alpha_A = 0.000034 \text{ K}^{-1}$

$\Delta A = ?$

Apply, $\Delta A = \alpha_A A_1 \Delta T$

where, $A_1 = 4\pi r^2 = 4 \times \pi \times (0.2)^2$

$= 0.5024 \text{ m}^2$

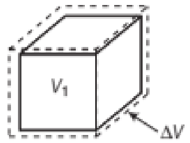
$\Delta A = 0.000034 \times 0.5024 \times 87$

$\Delta A = 0.001486$

$= 1.486 \times 10^{-3} \text{ m}^2$

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

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

Here, $\Delta V \propto V_1$ and $\Delta V \propto \Delta T$

$\therefore$ $\Delta V \propto V_1 \Delta T$

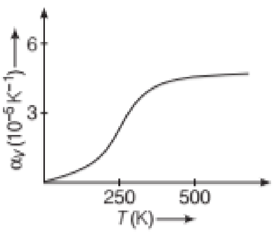
$\Rightarrow$ Expansion in volume, $\Delta V = \alpha_V V_1 \Delta T$

where, α_V is known as coefficient of volume expansion.

$$\alpha_V = \frac{\Delta V}{V_1 \Delta T}$$

Hence, the coefficient of volume (cubical) expansion of a substance is defined as the increase in volume per unit original volume per degree rise in its temperature. Its unit is $°C^{-1}$ or K^{-1}.

It is also a characteristic of material of the object but not strictly a constant. The coefficient of volume expansion α_V depends generally on temperature, its value first increases with temperature and then becomes constant at a high temperature (above 500K). The dependency is shown alongside.



Coefficient of volume expansion of with temperature

The values of volume expansion for some substances are given in the table.

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 can be given as

$$\alpha_l = \frac{\Delta l}{l_1 \Delta T} = \frac{\Delta l}{l \Delta T} \qquad (\text{When } l_1 = l)$$

$$\alpha_A = \frac{\Delta A}{A_1 \Delta T} = \frac{\Delta A}{A \Delta T} \qquad (\text{When } A_1 = A)$$

and $$\alpha_V = \frac{\Delta V}{V_1 \Delta T} = \frac{\Delta V}{V \Delta T} \qquad (\text{When } V_1 = V)$$

Its ratio is given by

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

i.e. $\alpha_A = 2\alpha_l$

and $\alpha_V = 3\alpha_l$

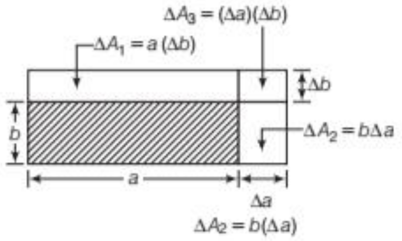
Coefficient of Thermal Expansion at High Temperature

The coefficients α_l, α_A and α_V for a given solid are constants only at a given temperature. The value of these coefficients, however changes with change in the temperature range and become constant only at a high temperature.

EXAMPLE |4| Expansion of Solid Sheet

Show that the coefficient of area expansions (α_A) for rectangular solid sheet is twice of its linear expansion (α_l). **[NCERT]**

Sol. Consider a rectangular solid sheet having length a and breadth b as shown in figure



When temperature of sheet is increased by ΔT, its length a is increased by Δa and breadth is increased by Δb. Then,

$$\Delta a = \alpha_l a \Delta T$$

and $$\Delta b = \alpha_l b \Delta T$$

Increase in area of sheet is

$$\Delta A = \Delta A_1 + \Delta A_2 + \Delta A_3$$

$$\Delta A = a\,\Delta b + b\,\Delta a + (\Delta a)(\Delta b)$$

$$= a\,\alpha_l b\,\Delta T + b\,\alpha_l a \Delta T + (\alpha_l)^2\, ab(\Delta T)^2$$

$$= \alpha_l ab\Delta T\,(2 + \alpha_l \Delta T)$$

$$= \alpha_l A \Delta T (2 + \alpha_l \Delta T)$$

For small values of α_l and ΔT, the value of $\alpha_l \Delta T$ would be much smaller so, it can be neglected then

$$\Delta A = 2\alpha_l\, ab\Delta T = 2\alpha_l A \Delta T \qquad \text{...(i)}$$

As we know, $\Delta A = \alpha_A A \Delta T$ ...(ii)

From Eqs. (i) and (ii), we get $\alpha_A = 2\alpha_l$

EXAMPLE |5| Expansion in a Glass Block

The volume of a glass block initially was 15000 cm^3 but when the temperature of that glass block increases from 20°C to 45°C, then its volume increases by 5cm^3. Determine the coefficient of linear expansion.

Sol. Given, $V_1 = 15000\ cm^3$,

$$\Delta T = T_2 - T_1 = 45°C - 20°C = 25°C$$

Change in volume, $\Delta V = 5\ cm^3$

Coefficient of volume expansion,

$$\alpha_V = \frac{\Delta V}{V_1\, \Delta T} = \frac{5}{15000 \times 25}$$

$$\alpha_V = 0.0133 \times 10^{-3}\ °C^{-1}$$

Coefficient of linear expansion

$$\alpha_l = \frac{\alpha_V}{3} = \frac{0.0133 \times 10^{-3}}{3}$$

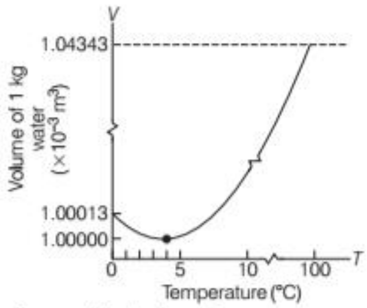
$$\alpha_l = 4.4 \times 10^{-6}\ °C^{-1}$$

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

The lake cools towards 4°C water near the surface loses energy to the atmosphere becomes denser and sinks, the warmer, less dense water near the bottom rises.

However, once colder water on top reaches temperature below 4°C, it becomes less dense and remains at the surface, where it freezes. This phenomenon allows the marine animals to remain alive and move freely near the bottom.

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.

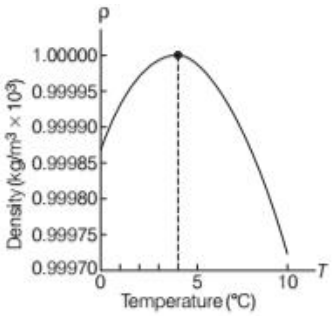
For an ideal gas, the volume expansion at constant pressure can be obtained from the equation,

$$pV = \mu RT \quad \Rightarrow \quad p\Delta V = \mu R \Delta T$$

$$\Rightarrow \quad \frac{\Delta V}{V} = \frac{\Delta T}{T} \quad \text{i.e. } \alpha_V = \frac{1}{T} \text{ for an ideal gas.}$$

At 0°C, $\alpha_V = 3.7 \times 10^{-3}\ K^{-1}$ which is much larger than the solids and liquids. For a gas, room temperature and constant pressure α_V is about $3300 \times 10^{-6}\ K^{-1}$.

The curve shows the variation of density of water with respect to temperature from 0°C to 10°C as shown in figure.



Variation of density of water w.r.t. 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, undergoes a change in temperature, thermal strains and thermal stresses are developed in the rod. This is because if the temperature is increased, the rod has a tendency to expand. However, as it is fixed at two ends, the rod exerts a force on supports.

If a rod of length l is heated by a temperature ΔT, then increase in length of rod should have been $\Delta l = l\alpha\Delta T$.

But due to being fixed at ends rod does not expand and a compressive thermal strain is developed in it whose value is

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

Here, α = linear expansion coefficient of the material of rod. Due to this strain, a thermal stress is developed in the rod having a value.

Thermal stress = $Y \times$ thermal strain = $Y\alpha\Delta T$

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

Here, Y = Young's modulus of the material of given rod. If A be the cross-section area of the rod, then force exerted by the rod on the supports will be $F = Y\alpha\Delta T A$.

EXAMPLE |6| Cool the Brass Wire

A brass wire 1.8 m long at 27°C is held taut with little tension between two rigid supports. If the wire is cooled to a temperature of −39°C, what is the tension developed in the wire, if its diameter is 2.0 mm? Coefficient of linear expansion of brass = $2.0 \times 10^{-5}\ °C^{-1}$, Young's modulus of brass = 0.91×10^{11} Pa. **[NCERT]**

Sol. Here, $l = 1.8$ m, $T_1 = 27°C$, $T_2 = -39°C$

$$r = \frac{2.0}{2} = 1.0 \text{ mm} = 1.0 \times 10^{-3} \text{ m}$$

$$\alpha = 2.0 \times 10^{-5}\ °C^{-1},\ Y = 0.91 \times 10^{11} \text{ Pa}$$

As, $\Delta l = l\alpha(T_2 - T_1)$

$\therefore$ Strain, $\frac{\Delta l}{l} = \alpha(T_2 - T_1) = \alpha\Delta T$

Stress = Strain × Young's modulus

$= \alpha(T_2 - T_1) \times Y = 2.0 \times 10^{-5} \times (-39 - 27) \times 0.91 \times 10^{11}$

$= -1.2 \times 10^8\ Nm^{-2}$

$\therefore$ Tension developed in the wire

= Stress × Area of cross-section = Stress × πr^2

$= -1.2 \times 10^8 \times 3.14 \times (1.0 \times 10^{-3})^2 = -3.77 \times 10^2$ N

EXAMPLE |7| Cool the Steel Wire

Consider the steel wire having diameter 3 mm is stretched between two clamps, calculate the tension in the wire when its temperature falls from 50°C to 40°C. Given α_l for steel is $1.1 \times 10^{-6}\ °C^{-1}$ and Young's modulus 21×10^{11} dyne cm^{-2}.

Sol. Given, Diameter = 3 mm = 0.3 cm, $r = \frac{0.3}{2} = 0.15$ cm

Change in temperature, $\Delta T = 50°C - 40°C = 10°C$

Coefficient of linear expansion, $\alpha_l = 1.1 \times 10^{-6}\ °C^{-1}$

Young's modulus, $Y = 21 \times 10^{11}$ dyne cm^{-2}

Apply the formula for linear expansion.

$$\Delta l_1 = l_1 \alpha_l \Delta T = l_1 \times 1.1 \times 10^{-6} \times 10°C$$

$$\Rightarrow \quad \Delta l = 11 \times 10^{-6}\ l_1$$

Young's modulus $(Y) = \dfrac{F \times l}{A \times \Delta l} = \dfrac{F \times l}{\pi r^2 \times \Delta l}$

$$F = \frac{Y \times \pi r^2 \times \Delta l}{l_1}$$

$$= \frac{21 \times 10^{11} \times \pi \times (0.15)^2 \times 11 \times 10^{-6}\ l_1}{l_1}$$

$$F = 16.32 \times 10^5 \text{ dyne}$$

TOPIC PRACTICE 1

OBJECTIVE Type 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

Sol. (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. The common physical property which is to be used as the basis for constructing thermometer is

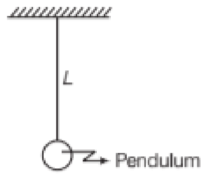
(a) the variation of the volume of a liquid with temperature
(b) the variation of the pressure of a gas with temperature
(c) the variation of the resistance of a wire with temperature
(d) All of the above

Sol. (d) Any physical property which varies linearly with temperature can be used in constructing thermometers.

3. As the temperature is increased, the period of a pendulum

(a) increases as its effective length increases even though its centre of mass still remains at the centre of the bob
(b) decreases as its effective length increases even though its centre of mass still remains at the centre of the bob
(c) increases as its effective length increases due to shifting to centre of mass below the centre of the bob
(d) decreases as its effective length remains same but the centre of mass shifts above the centre of the bob

Sol. (a) As the temperature is increased length of the pendulum increases.



We know that, time period of pendulum $T = 2\pi\sqrt{\dfrac{L}{g}}$

$$\Rightarrow \quad T \propto \sqrt{L}$$

As L, increases so, time period (T) also increases.

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

(a) 11×10^{-6} cm longer (b) 11×10^{-5} cm shorter
(c) 11×10^{-6} cm shorter (d) 11×10^{-5} cm longer

Sol. (b) According to linear expansion, we get

$$L = L_0 (1 + \alpha \Delta\theta)$$

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

$$\Rightarrow \quad \frac{10}{L_2} = \frac{1 + 11 \times 10^{-6} \times 20}{1 + 11 \times 10^{-6} \times 19}$$

$$\Rightarrow \quad L_2 = 9.99989$$

Length is shorter by $= 10 - 9.99989 = 0.00011$
$= 11 \times 10^{-5}$ cm

5. 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°C depending on the radius of the sphere

Sol. (a) Let volume of the sphere is V and ρ is the density of water, then we can write buoyant force

$$F = V\rho g \quad (g = \text{acceleration due to gravity})$$

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

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

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

Hence, buoyancy will be less in water at 0°C than that in water at 4°C.

VERY SHORT ANSWER Type Questions

6. Is it correct to call heat as the energy in transit?

Sol. Yes, it is perfect correct to call heat as the energy in transit because it is continuously flowing on account of temperature difference between bodies or parts of a system.

7. Give the relation between celsius, fahrenheit and reaumur scale temperature.

Sol. $\frac{C-0}{100-0} = \frac{F-32}{212-32} = \frac{R-0}{80-0}$

8. Can temperature on celsius scale and kelvin scale related?

Sol. $t(°C) = T(k) - 273.15$

or $T(K) = t(°C) + 273.15$

9. Two absolute scales A and B have triple points of water defined to be 200 A and 350 B. What is relation between T_A and T_B? **[NCERT]**

Sol. $\frac{T_A}{T_B} = \frac{200}{350} = \frac{4}{7}$ or $T_A = \frac{4}{7} T_B$

10. Why should a thermometer bulb have a small heat capacity?

Sol. The thermometer bulb having small heat capacity will absorb less heat from the body whose temperature is to be measured. Hence, the temperature of that body will practically remain unchanged.

11. Why the temperature above 1200°C cannot be measured accurately by a platinum resistance thermometer?

Sol. This is because platinum begins to evaporate above 1200°C.

12. Each side of a cube increases by 0.01% on heating. How much is the area of its faces and volume increased?

Sol. The area of the faces will increased by 0.02% and the volume by 0.03%.

13. Why is a gap left between the ends of two railway lines in a railway track?

Sol. It is done to accommodate the linear expansion of railway line during summer. If the gap is not left in summer, the lines will bend causing a threat of derailment.

SHORT ANSWER Type Questions

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

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

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

$$\Rightarrow \quad \frac{\theta}{5} = \frac{\theta - 32}{9} \quad [\because \theta°C = \theta°F = \theta, \text{ given}]$$

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

$$-4\theta = 160$$

$$\therefore \quad \theta = -40°$$

$$\theta = -40°C$$

$$= -40°F$$

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

Sol. 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.

16. Gas thermometers are more sensitive than mercury thermometers. Why?

Sol. The coefficient of increase of pressure (or volume) of a gas is $\frac{1}{273.15}\,°C^{-1}$. It is very large as compared to coefficient of expansion of mercury. Therefore, for a certain increase in temperature, increase in volume of the gas will be large compared to that of mercury and hence a gas thermometer is more sensitive.

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

Sol. 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.

18. A steel tape 1 m 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 $= 1.20 \times 10^{-5}\,°C^{-1}$? **[NCERT]**

Sol. Here, $t_1 = 27°C$, $l_1 = 63$ 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.

19. **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?**

Sol. Yes, it is possible to describe the difference of length to remain constant. So, the change in length of each rod must be equal at all temperature. Let L_b and L_s be the length of the brass and the steel rod and α_b and 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 $\alpha_b L_b = \alpha_s L_s$

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

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

20. **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 (ii) same amount of heat is given to each of them?**

Sol. (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 $\Delta V = \gamma V \Delta T$.

21. **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]**

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

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

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

$\therefore$ Fractional change in density,

$$\frac{\rho_0 - \rho_t}{\rho_0} = \gamma \Delta T$$

$$= 49 \times 10^{-5} \times 30 = 0.0147$$

22. **Two identical rectangular strips-one of copper and the other of steel are riveted to form a bimetallic strip. What will happen on heating?**

Sol. The coefficient of linear expansion of copper is more than steel. On heating, the expansion in copper strip is more than the steel strip. The bimetallic strip will bend with steel strip on inner (concave) side.

LONG ANSWER Type I Questions

23. **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.**

Sol. Let if reading on celsius scale is 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

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

24. **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]**

Sol. For neon Triple point $T = 24.57$ K

$$\therefore \quad T_C = T(\text{K}) - 273.15$$
$$= 24.57 - 273.15 = -248.58°\text{C}$$
$$T_F = \frac{9}{5}T_C + 32 = \frac{9}{5} \times (-248.58) + 32 = -415.44°\text{F}$$

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

$$\therefore \quad T_C = T(K) - 273.15$$
$$= 216.55 - 273.15 = -56.6°\text{C}$$
$$T_F = \frac{9}{5}T_C + 32 = \frac{9}{5} \times (-56.6) + 32$$
$$= -69.88°\text{C}$$

25. **Two ideal gas thermometers A and B use oxygen and hydrogen, respectively. The following observations are made** **[NCERT]**

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]**

Sol. (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,

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

$$= \frac{1.795 \times 10^5 \times 273}{1.250 \times 10^5} = 392.028 \text{ K}$$

(b) For pressure thermometer *B*,

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

$$p = 0.287 \times 10^5 \text{ Pa}$$

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

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

26. 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 1.2×10^{-5} K^{-1}.

Sol. As radius of ball, $r_0 = 9.0$ cm $= 0.090$ m at 0°C, hence its volume,

$$V_0 = \frac{4}{3}\pi r_0^3 = \frac{4}{3} \times 3.14 \times (0.090)^3$$

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

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

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

Moreover rise in temperature

$$\Delta T = 90°\text{C} - 0°\text{C} = 90°\text{C} = 90 \text{ K}$$

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

$$= 3.05 \times 10^{-3} \times 3.6 \times 10^{-5} \times 90$$

$$= 9.88 \times 10^{-6} \text{ m}^3 = 9.88 \text{ cm}^3$$

27. 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?

Given that 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.

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

$$\alpha = 1.1 \times 10^{-5} \text{ /°C}.$$

$\therefore$ Tension developed in the rod,

$$F = YA\alpha\Delta T$$

$$= 2 \times 10^{11} \times 2 \times 10^{-6} \times 1.1 \times 10^{-5} \times 25$$

$$F = 110 \text{ N}$$

28. 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?

Sol. 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

$$= \text{observed scale reading} \times (1 + \alpha\Delta T)$$

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

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

$$= 75.00\,(1 + 54 \times 10^{-5}) \text{ cm}$$

$$= 75.04 \text{ cm}$$

LONG ANSWER Type II Questions

29. 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]**

Sol. When $T = 273$ K, $R = 101.6\ \Omega$

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

Given, $T = 600.5$ K, $R = 165.5\ \Omega$

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

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, $T_0 = -49.3$ K

Substituting in Eq. (i), we get

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

or

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

For $R = 123.4\ \Omega$, we have

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

On solving, we get $T = 384.8$ K

30. **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 = 2.0×10^{-5}°C^{-1} and that of steel = 1.2×10^{-5}°C^{-1}.** **[NCERT]**

Sol. For brass rod,

$l = 50$ 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, $l = 50$ 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.

31. **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]**

Sol. Given, diameter of the hole $(d_1) = 4.24$ cm

Initial temperature $T_1 = 27 + 273 = 300$ K

Final temperature $T_2 = 227 + 273 = 500$ K

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

Coefficient of superficial expansion

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

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 d_2 at 227°C then $A_2 = \dfrac{\pi d_2^2}{4}$

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

$\Rightarrow \quad d_2 = 4.2544$ cm

$\therefore$ Change in diameter $(\Delta d) = d_2 - d_1 = 4.2544 - 4.24$
$= 0.0144$ cm
$= 1.44\times 10^{-2}$ cm

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

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

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

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

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

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

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

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.

ASSESS YOUR TOPICAL UNDERSTANDING

OBJECTIVE Type Questions

1. 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)

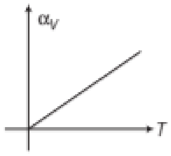
2. On a hilly region, water boils at 95°C. The temperature expressed in fahrenheit is

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

3. A uniform metallic rod rotates about its perpendicular bisector with constant angular speed. If it is heated uniformly to raise its temperature slightly **[NCERT Exemplar]**

(a) its speed of rotation increases
(b) its speed of rotation decreases
(c) its speed of rotation remains same
(d) its speed increases because its moment of inertia increases

4. Coefficient of volumetric expansion α_V is not a constant. It depends on temperature. Variation of α_V with temperature for metals is

(a)


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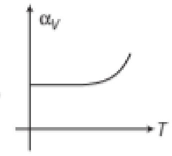

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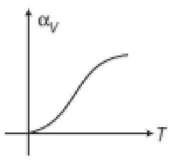

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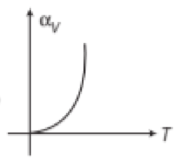

5. Variation of the density of water with respect to temperature from 0°C to 10°C is correctly represented by

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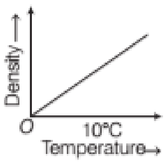

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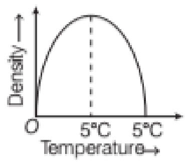

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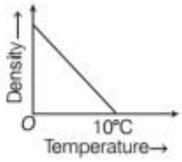

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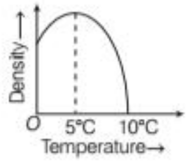


Answer

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

VERY SHORT ANSWER Type Questions

6. Which physical quantity governs the direction of flow of heat?

7. A body at higher temperature contains more heat. Comment.

8. Why does a solid expand on heating?

9. A tightened glass stopper can be taken out easily by pouring hot water around the neck of the bottle. Why?

10. Why are gas thermometers are more sensitive than mercury thermometers?

SHORT ANSWER Type Questions

11. By how much the temperature of a copper rod to be raised so as to increase its length by 1%? Given that coefficient of linear expansion of copper $= 1.7 \times 10^{-5}\ K^{-1}$. **[Ans.** 588.2°C]

12. The length of a steel pan of a river bridge is 50 m and the bridge has to withstand temperature ranging from 4°C to 52°C.

What allowance should be kept for its change in length with temperature? Given that for a steel, $\alpha = 1.1 \times 10^{-5}$ C. **[Ans.** 2.6 cm]

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

14. What is mean of metals and alloys, which have a greater value of temperatures coefficient of expansion and why?

15. At what temperature, if any, do the following pair of scales gives the same reading?
Fahrenheit and Kelvin. **[Ans.** 574.6°]

LONG ANSWER Type I Questions

16. Cooking is easier in pressure cooker but difficult on hills, why?

17. A clock with an iron pendulum keeps correct time at 20°C. How much will it lose or gain per day, if temperature changes to 40°C? Coefficient of cubical expansion of iron is $36 \times 10^{-6}\ °C^{-1}$.

[**Ans.** 10.368 s]

18. What are coefficients of linear, superficial and cubical expansions? What is the relation amongst them?

19. How does thermal expansion of liquids differ from that of solid? Is real expansion always greater than the apparent expansion?

LONG ANSWER Type II Questions

20. A resistance thermometer reads the resistance $R = 20.0\ \Omega$, $27.5\ \Omega$ and $50.0\ \Omega$ at the ice point (0°C), the steam point (100°C), the zinc point (420°C), respectively. Assuming that the resistance varies with temperature as $R_t = R_0(1 + \alpha t + \beta t^2)$, where t is temperature in Celsius scale. Determine the value R_0, α and β.

[**Ans.** $20\ \Omega$, $3.8 \times 10^{-3}\ °C^{-1}$, $-5.6 \times 10^{-7}\ °C^{-2}$]

21. A circular disc made by iron is rotating about its axis of rotation with a uniform angular speed ω.
Determine the change in the linear speed of particle at the rim in percentage. The disc of rim is slowly heated from 20°C to 50°C keeping the angular speed uniform. Given that coefficient of linear expansion for the material of iron is $1.2 \times 10^{-5}\ °C^{-1}$.

[**Ans.** 3.6×10^{-2}]

22. What do you mean by thermal expansion, describe its types with units. Also, give the relation among the expansion coefficient?

23. A hole is drilled in a copper sheet. The diameter of the hole is 4.24 cm at temperature 27°C. What is the change in the diameter of the hole when the sheet is heated upto temperature 227°C. Given that coefficient of linear expansion for the copper is $1.7 \times 10^{-5}\ °C^{-1}$.

[**Ans.** 0.0144 cm]

|TOPIC 2|
Calorimetry and Heat Transfer

HEAT CAPACITY

The quantity of heat is given to any substance depends on its mass m, the change in temperature ΔT and the nature of substance which is being warmed. 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**. The heat capacity 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 and its SI unit is $Jkg^{-1}K^{-1}$.

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

$$\Rightarrow \quad \text{Specific heat capacity, } s = \frac{1}{m}\frac{\Delta Q}{\Delta T}$$

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 ($4.18 \times 10^3\ Jkg^{-1}°C^{-1}$) 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 $\text{Jmol}^{-1}\text{K}^{-1}$.

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

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

> Molar specific heat capacity, $C = \frac{\Delta Q}{\mu \Delta T}$

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

$$\boxed{C = Ms}$$

where, s = specific heat capacity,

M = molecular mass of the substance

and C = molar specific heat capacity.

Hence, molar specific heat capacity

= molecular mass × specific heat capacity.

The molar specific heat capacity and specific heat capacity play an important role in calorimetry.

EXAMPLE |1| A Drilling Machine

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 $= 0.91\ \text{Jg}^{-1}\ {}^\circ\text{C}^{-1}$. **[NCERT]**

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

Time, $t = 2.5\ \text{min} = 2.5 \times 60\ \text{s}$

Total energy used

$$= Pt = 10 \times 10^3 \times 2.5 \times 60$$

$$= 1.5 \times 10^6\ \text{J}$$

Energy absorbed by aluminium block,

$$Q = 50\% \text{ of the total energy} = \frac{1.5 \times 10^6}{2}$$

$$= 0.75 \times 10^6\ \text{J}$$

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

As, $Q = ms\,\Delta T$

$$\therefore \quad \Delta T = \frac{Q}{ms} = \frac{0.75 \times 10^6}{8.0 \times 10^3 \times 0.91}$$

$$= 103.02^\circ\text{C}$$

CALORIMETRY

It is the branch of science that deals with the measurement of heat. When a body at higher temperature is brought in contact with another body at lower temperature, then the heat flows from the body kept at higher temperature to the body kept at lower temperature till the both bodies acquire the same temperature.

Thus, the principle of calorimetry states that total heat given by a hotter body equals to the total heat received by colder body.

i.e. **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.

$$\Rightarrow \quad \boxed{m_1 s_1\,\Delta T = m_2 s_2\,\Delta T}$$

Note

A system is said to isolated one if no exchange of heat takes place between the system and surrounding. During calorimetry, it is assumed that no heat is allowed to escape to the surrounding.

Types of Molar Specific Heat Capacity

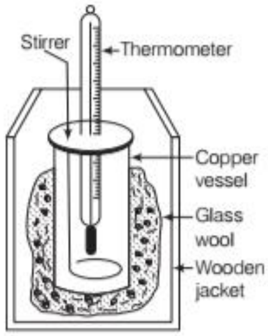
There are two types of molar specific heat capacity

(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.

Calorimeter

It is a device used for measuring the quantities of heat. It consists of a cylindrical vessel of copper provided with a stirrer. The vessel is kept inside a wooden jacket. The space between the calorimeter and the jacket is packed with a heat insulating material like glass wool, etc.



Thus, the calorimeter gets thermally isolated from the surroundings. The loss of heat due to radiation is further reduced by polishing the outer surface of the calorimeter and the inner surface of the jacket.

The lid is provided with holes for inserting a thermometer and a stirrer into the calorimeter.

When bodies at different temperatures are mixed together in the calorimeter, heat is exchanged between the bodies as well as with the calorimeter.

If there is no loss of heat to the surroundings, then according to the principle of calorimetry,

Heat gained by cold bodies = Heat lost by hot bodies

EXAMPLE |2| Experiment for Specific Heat

In an experiment on the specific heat of a metal, a 0.20 kg block of the metal at 150°C is dropped in a copper calorimeter (of water equivalent 0.025 kg) containing 150 cm^3 of water at 27°C. The final temperature is 40°C. Compute the specific heat of the metal.

Sol. Given, mass of metal block, $m = 0.20 \text{ kg} = 200 \text{ g}$

Fall in temperature of metal block,

$$\Delta T = 150° - 40° = 110°C$$

Let specific heat of metal block $= 5 \text{ cal g}^{-1} °C^{-1}$

$\therefore$ Heat lost by metal block $= mc\,\Delta T = 200 \times 5 \times 110$ cal

Volume of water in calorimeter $= 150 \text{ cm}^3$

Mass of water, $m' = 150$ g

Water equivalent of calorimeter, $w = 0.025 \text{ kg} = 25 \text{ g}$

Specific heat of water, $s' = 1 \text{ cal g}^{-1} °C^{-1}$

$\therefore$ Heat gained by water and calorimeter

$$= (m' + w)\, s' \Delta T' = (150 + 25) \times 1 \times (40 - 27) \text{ cal}$$
$$= 175 \times 13 \text{ cal}$$

According to principle of calorimetry, we get

Heat lost = Heat gained

$$\therefore \quad 200 \times s \times 110 = 175 \times 13$$

or

$$s = \frac{175 \times 13}{200 \times 110} = 0.1 \text{ cal g}^{-1} °C^{-1}$$

EXAMPLE |3| Energy Transfer through a Concrete Wall

A sphere made of aluminium of 0.047 kg placed for sufficient time in a vessel containing boiling water, so that the sphere is at 100° C .

After that it is allowed to transform to 0.14 kg copper calorimeter containing 0.25 kg of water kept at the temperature 20° C. The temperature of water rises and attains a steady state at 23° C. Calculate the specific heat capacity of aluminium. **[NCERT]**

Sol. Given, mass of aluminium, $m_1 = 0.047$ kg

Initial temperature of sphere = 100°C

Final temperature = 23°C

Change in temperature $(\Delta T) = (100°C - 23°C) = 77°C$

We have to find, s_{Al} = specific heat of aluminium

The amount of heat lost by aluminium sphere

$$= m_1 s_{Al} \Delta T_1 = \Delta Q_1$$
$$= 0.047 \text{ kg} \times s_{Al} \times 77°C$$

Mass of water, $m_2 = 0.25$ kg

Mass of calorimeter, $m_3 = 0.14$ kg

Initial temperature calorimeter with water = 20°C

Final temperature (mixture) = 23°C

Change in temperature $(\Delta T_2) = 23°C - 20°C = 3°C$

Specific heat capacity of water $= s_w = 4.18 \times 10^3 \text{ Jkg}^{-1}\text{K}^{-1}$

Specific heat capacity of copper

$= s_{Cu} = 0.386 \times 10^3 \text{ Jkg}^{-1}\text{K}^{-1}$

Thus, heat gained by water and calorimeter

$$\Delta Q_2 = m_2 s_w \Delta T_2 + m_3 s_{Cu} \Delta T_2$$
$$= (m_2 s_w + m_3 s_{Cu})\, \Delta T_2$$

$$\Rightarrow \quad \Delta Q_2 = 0.25 \text{ kg} \times 4.18 \times 10^3 \text{ Jkg}^{-1}\text{K}^{-1} + 0.14 \text{ kg} \times 0.386 \times 10^3 \text{ Jkg}^{-1}\text{K}^{-1}\,(23°C - 20°C)$$

According to the principle of calorimetry, we get

Heat lost by aluminium sphere = Heat gained by water and calorimeter

$$\Rightarrow \quad 0.047 \text{ kg} \times s_{Al} \times 77°C = (0.25 \text{ kg} \times 4.18 \times 10^3 \text{ Jkg}^{-1}\text{K}^{-1} + 0.14 \text{ kg} \times 0.386 \times 10^3 \text{ Jkg}^{-1}\text{K}^{-1})(3°C)$$

$$\Rightarrow \quad s_{Al} = 0.911 \text{ kJ kg}^{-1}\text{K}^{-1}$$

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. Matter generally exists in three states

(i) Solid (ii) Liquid

(iii) Gas

These states can be changed into one another by absorbing heat or rejecting heat. The process is so called the **change of state.**

The common changes of states are

(i) Solid to liquid (and *vice-versa*)

(ii) Liquid to gas (and *vice-versa*)

The changes can be occur when the exchange of heat takes place between substance and its surroundings.

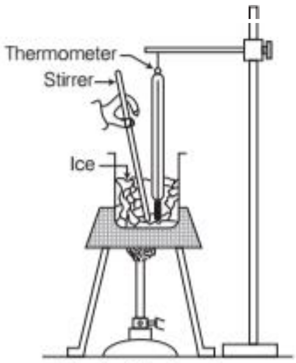
Note

- Besides these three states i.e. solid, liquid and gas, the fourth state of matter also exist which is known as **plasma.**
- When a substance is heated to a very high temperature, many electrons around the nucleus of the atom of the substance are free. The collection of these free electrons and the positive ions forms a plasma.

Effect of Heat on Ice

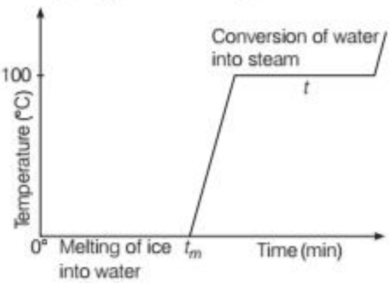
Take some cubes of ice in a beaker at 0°C. Start heating it slowly on a constant heat supplying source.

Note, the temperature after every minute and stir the mixture of water and ice continuously.



Effect of heat on ice

We will find a graph between temperature and time as shown in figure. It is also observed that there is no change in temperature for so long as there is ice in the beaker even heat being continuously supplied to the system.



Plot of change of state of ice on heating

It is seen that the temperature remains constant until the entire amount of the solid substance (i.e. ice) melts. Thus, both the solid and liquid states of the substance co-exist in **thermal equilibrium** during the change of state from solid to liquid. After the whole of ice gets melted into water and as we continue heating the beaker, we note that the temperature begins to increase till it reaches nearly 100°C when it again becomes steady. This point is *t* in the graph.

The heat supplied is now being used to change the state of water from liquid to vapour. It is noted that temperature remains constant until the entire amount of liquid is converted into vapour.

Note

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

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.

Note

The melting point of a substance at standard atmospheric pressure is called **normal melting point.**

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.

Vaporisation and Boiling Point

The process of change of state from liquid to vapour (or gas) is called **vaporisation**. During the change of state (completely), the temperature remains constant which implies both liquid and vapour states of the substance co-exist in thermal equilibrium. The temperature at which the liquid and the vapour states of the substance co-exist is called the **boiling point** of the liquid.

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

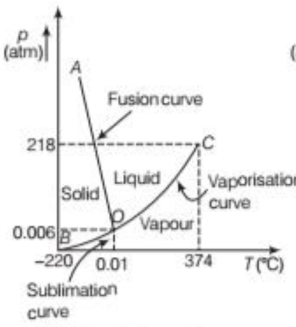
The graph between temperature and pressure of substance can be plotted which is called **phase diagram** or p-T diagram.

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**.

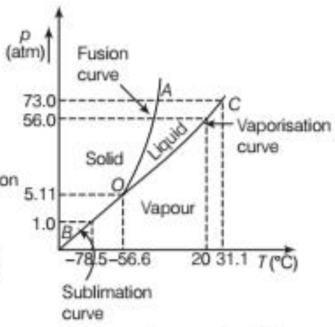
These three curves represent the states in which solid and vapour phases, solid and liquid phases and liquid and vapour phases co-exist.

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

Two figures below show the phase diagram with triple point for (a) water (b) CO_2.



(a) Phase diagram for water



(b) Phase diagram for CO_2

The point on sublimation curve BO represents states in which the solid and vapour phases co-exist. The point on vaporisation curve co-represent the states in which the liquid and vapour phases co-exist.

The point on the fusion curve AO represents the states in which solid 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 J kg^{-1}. The value of latent heat is usually quoted at standard atmospheric pressure because it also depends upon the pressure.

Thus, if a mass m of a substance undergoes a change from one state to the other, then the quantity of heat required is given by

$$\boxed{Q = mL}$$

i.e. $$\boxed{\text{Latent heat, } L = Q/m}$$

Hence, during the phase change, the heat required by the substance depends on the mass m of the substance and heat of transformation Q.

Types of Latent Heat

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

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

Its SI unit is Jkg^{-1}.

(ii) **Latent Heat of Vaporisation**

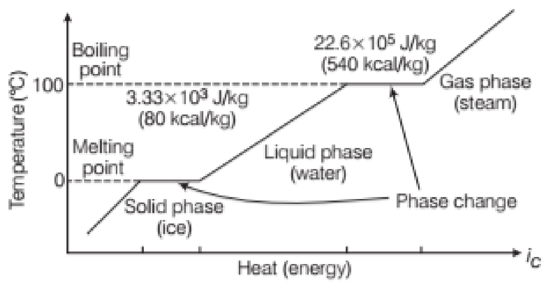
It is in latent heat for liquid-gas state change. It is denoted by L_V and often referred to as heat of fusion and heat of vaporisation. It is given by

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

and its SI unit is Jkg^{-1}. The latent heats of state change of some substances are given below in the table.

Variation of Temperature During Change of State

It is observed from the above graph as heat is added or removed during a change of state, the temperature remains constant, hence the slopes of the phase lines are not all the same, which indicates the specific heats of the various states are not equal.



Temperature *versus* heat for water at 1 atm pressure e.g. Water having $L_f = 3.33 \times 10^5 \text{ Jkg}^{-1}$ and $L_V = 22.6 \times 10^5 \text{ Jkg}^{-1}$, it means 3.33×10^5 J of heat is needed to melt 1 kg of ice at 0°C and 22.6×10^5 J of heat is needed to convert 1 kg of water to steam at 100°C.

EXAMPLE |4| Partial Melting

The ice of 0.15 kg mass at 0°C is mixed with 0.30 kg of water at 50°C in a container. The resulting temperature of the container (after mixing) is 6.7°C. Determine the heat of fusion of ice if specific heat (s_w) for the water is $4186 \text{ Jkg}^{-1}\text{K}^{-1}$. **[NCERT]**

Sol. According to the calorimetry principle, we get

Heat lost by water $= ms_w (\theta_f - \theta_i)_w$

$$= (0.30 \text{ kg}) (4186 \text{ Jkg}^{-1}\text{K}^{-1}) (50.0 - 6.7)°\text{C}$$

$$= 54376.14 \text{ J}$$

Heat required to melt ice = mass of ice $\times L_f$

$$= m_I L_f = (0.15 \text{ kg}) L_f$$

Heat required to raise temperature of ice water to final temperature (from the calorimetry)

$$= m_I s_w (\theta_f - \theta_i)_I$$

$$= (0.15 \text{ kg}) (4186 \text{ Jkg}^{-1}\text{K}^{-1}) (6.7°\text{C} - 0°\text{C})$$

$$= 4206.93 \text{ J}$$

Principle of calorimetry i.e. heat lost = heat gained

$$\Rightarrow \quad 54376.14 \text{ J} = (0.15 \text{ kg}) L_f + 4206.93 \text{ J}$$

$$\Rightarrow \quad L_f = 3.34 \times 10^5 \text{ Jkg}^{-1}$$

This is required value of heat of fusion of ice.

EXAMPLE |5| Velocity of Bullet

A lead bullet penetrates into a solid object and melts. If half of its kinetic energy was used to heat it, calculate the initial velocity of the bullet. The initial temperature of the bullet is 27°C and the melting point of the material of bullet is 327°C. Given that latent heat of fusion of lead is $2.5 \times 10^4 \text{ J kg}^{-1}$ and specific heat capacity of lead is $125 \text{ J kg}^{-1}\text{K}^{-1}$.

Sol. From the calorimetry, heat required $\Delta Q_1 = ms\Delta\theta_1$.

Let mass of bullet is m and given

$$s = 125 \text{ Jkg}^{-1} \text{ K}^{-1}$$

$$\Delta\theta = 327° - 27° = 300°\text{C}$$

$$\Rightarrow \quad \Delta Q_1 = m \times 125 \times 300 = m \times 3.75 \times 10^4 \text{ Jkg}^{-1}$$

Heat required to melt the bullet $\Delta Q_2 = mL_b$.

Latent heat of bullet, $L_b = 2.5 \times 10^4 \text{ J kg}^{-1}$

$$\Rightarrow \quad \Delta Q_2 = m \times 2.5 \times 10^4 \text{ J kg}^{-1}$$

The kinetic energy of bullet $= \frac{1}{2}mv^2$, where v is velocity.

Half of kinetic energy $= \frac{1}{2}\left(\frac{1}{2}mv^2\right) = \frac{1}{4}mv^2$

From principle of calorimetry,

Loss in kinetic energy $= \Delta Q_1 + \Delta Q_2$

$$\therefore \quad 1/4\, mv^2 = m\,(3.75 + 2.5) \times 10^4 \text{ Jkg}^{-1}$$

$$\Rightarrow \quad v = 500 \text{ ms}^{-1}$$

EXAMPLE |6| Change of State of Ice

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.

Given, 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 $3.35 \times 10^5 \text{ Jkg}^{-1}$ and latent heat of steam is $2.256 \times 10^6 \text{ Jkg}^{-1}$. **[NCERT]**

Sol. Heat required to convert ice at −12°C to ice at 0°C

$$Q_1 = ms_{\text{ice}}\, \Delta T_1.$$

Mass of ice, $m = 3$ kg ; specific heat of ice,

$$s_{\text{ice}} = 2100 \text{ Jkg}^{-1} \text{ K}^{-1}$$

Change in temperatures = [0 − (−12)]

$$\Rightarrow \quad \Delta T_1 = 12°\text{C}$$

$$\therefore \quad Q_1 = 3 \text{ kg} \times 2100 \text{ J kg}^{-1} \text{ K}^{-1} \times 12°\text{C}$$

$$= 75600 \text{ J}$$

Heat required to melt ice at 0° C to water at 0° C.

$$Q_2 = mL_{\text{ice}}$$

Latent heat of ice, $L_{\text{ice}} = 3.35 \times 10^5 \text{ Jkg}^{-1}$

$$\therefore \quad Q_2 = 3 \text{ kg} \times 3.35 \times 10^5 \text{ Jkg}^{-1} = 1005000 \text{ J}$$

Heat required to convert water at 0°C to water at 100°C, $Q_3 = ms_w \Delta T_2$.

Specific heat of water, $s_w = 4186 \text{ JKg}^{-1} \text{ K}^{-1}$

Change in temperatures = (100 − 0)°C

$$\Rightarrow \quad \Delta T_2 = 100°\text{C}$$

$$\therefore \quad Q_3 = 3 \text{ kg} \times 4186 \text{ J kg}^{-1} \text{ K}^{-1} \times 100°\text{C}$$

$$= 1255800 \text{ J}$$

Heat required to convert water at 100°C to steam at 100°C, $Q_4 = mL_{\text{steam}}$.

Latent heat of steam,

$$L_{\text{steam}} = 2.256 \times 10^6 \text{ J kg}^{-1}$$

$$\therefore \quad Q_4 = 3 \text{ kg} \times 2.256 \times 10^6 \text{ J kg}^{-1}$$

$$= 6768000 \text{ J}$$

Total heat is equal to sum of heat of individual thermodynamic process.

$$\Rightarrow \quad Q = Q_1 + Q_2 + Q_3 + Q_4$$

$$\Rightarrow \quad Q = 75600 \text{ J} + 1005000 \text{ J} + 1255800 \text{ J} + 6768000 \text{ J}$$

$$= 9.1 \times 10^6 \text{ J}$$

Mechanical Equivalent of Heat

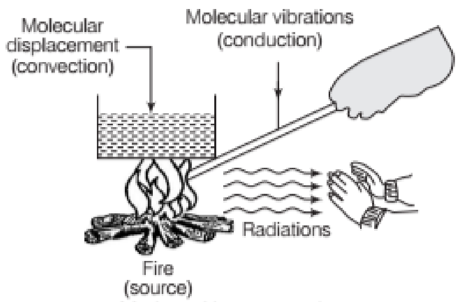
The temperature of a body may also be increased by doing mechanical work on the system. The mechanical equivalent of heat gives how many joules of mechanical work is needed to raise the temperature of 1 g of water by 1°C.

It is denoted by J expressed in J/cal and can have only numerical values.

Thus, W is work done in Joule (SI unit) = JH heat given or taken out in calories (CGS unit).

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 (ii) Convection (iii) Radiation

Conduction

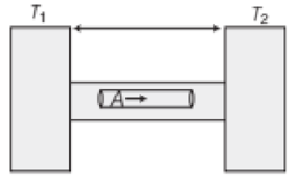
The transfer of heat taking place due to molecular vibrations (i.e. molecular collisions) is known as **heat conduction**. In this process, there is no change in average position of the molecule and hence there is no mass movement of matter generally in solids, heat is transferred by the process of conduction.

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.

Consider a metal rod of length l and area of cross-section A. Let the ends of the rod are at the temperatures T_1 and T_2. Then, the rate of flow of heat (H) conducted through any section (in steady state) of the rod is directly proportional to the temperature difference ΔT, time t for which the heat flows and the area of cross-section A and is inversely proportional to the length L of the rod.

Thus, the rate of heat transfer is given by



Calculation of thermal conductivity of a metal rod

$$\text{Rate of heat transfer} = \frac{\Delta Q}{\Delta t} = \frac{KA(T_1 - T_2)}{L}$$

$$H = KA\frac{\Delta T}{L}$$

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

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

Here, K is known as **coefficient of thermal conductivity** of material of rod. The greater value of K implies that material will conduct the heat more rapidly. The SI unit of K is $Js^{-1}m^{-1}K^{-1}$ or $Wm^{-1}K^{-1}$ and dimensions of K is $[MLT^{-3}K^{-1}]$. The value of thermal conductivity vary slightly with temperature, but it can be considered to be constant over normal temperature range. The term $\frac{\Delta T}{L}$ is known as **temperature gradient.**

If $A = 1, T_1 - T_2 = \Delta T = 1, L = 1$ and $t = 1$, then $Q = K$

Hence, the **coefficient of thermal conductivity of a material may be defined as the quantity of heat that flows per unit time through a unit cube of the material when its opposite faces are kept at a temperature difference of one degree.**

Note Steady state means that the temperature of each part of the body remains constant during the conduction of heat through it.

Also, the metals are much better conductors than the non-metals. This is because the metals have large number of free electrons which can carry heat from hotter part to colder part.

Thermal Current and Thermal Resistance

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

SI unit of thermal current is J/s or Watt (W) and its dimensions $[ML^2T^{-3}]$

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

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

$\therefore$ Thermal resistance, $R = \frac{L}{KA}$

It is just resemble to current, $i = \frac{V_1 - V_2}{R}$

where, $V_1 - V_2$ = voltage difference and R = resistance.

So, the terms $\frac{T_1 - T_2}{(L/KA)}$ and $\frac{L}{KA}$ can be treated as thermal current (heat flow) and thermal resistance, respectively.

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

EXAMPLE |7| Heat Flow through a Glass

Calculate the rate of loss of heat through a glass window of area 1000 cm^2 and thickness 0.4 cm. When temperature inside is 37°C and outside is −5°C. Coefficient of thermal conductivity of glass is 2.2×10^{-3} cal s^{-1} cm^{-1} K^{-1}.

Sol. Given, $A = 1000\,cm^2$, $L = 0.4$ cm

$$\Delta T = T_1 - T_2 = 37 - (-5) = 42°C$$
$$K = 2.2 \times 10^{-3}\,cal\,s^{-1}cm^{-1}K^{-1}$$

Rate of loss of heat,

$$H = \frac{Q}{T} = \frac{KA(T_1 - T_2)}{L} = \frac{2.2 \times 10^{-3} \times 1000 \times 42}{0.4}$$
$$H = 231\ cal\,s^{-1}$$

EXAMPLE |8| Heat Flow through Two Rods

Two rods A and B are of equal length. Each rod has its ends at temperatures T_1 and T_2. What are the conditions that will ensure equal rates of flow of heat through the rods A and B?

and B.

Sol. Heat transferred rate by rod A is $\frac{\Delta Q_1}{\Delta t}$.

Length of rod A is L and temperature difference,

$$\Delta T = T_1 - T_2$$

Area of cross-section of rod, $A = A_1$,

thermal conductivity $= K_1 \Rightarrow \frac{\Delta Q_1}{\Delta t} = K_1 A_1 \frac{\Delta T}{L}$

Heat transferred rate by rod B is $\frac{\Delta Q_2}{\Delta t}$.

Length of rod B is L, temperature difference $= T_1 - T_2$, area of cross-section of rod $B = A_2$,

Thermal conductivity $= K_2$

$$\Rightarrow \quad \frac{\Delta Q_2}{\Delta t} = K_2 A_2 \frac{\Delta T}{L}$$

For equal rate of heat transfer,

$$\frac{\Delta Q_1}{\Delta t} = \frac{\Delta Q_2}{\Delta t} \Rightarrow \frac{K_1 A_1 \Delta T}{L} = \frac{K_2 A_2 \Delta T}{L}$$

$$\Rightarrow K_1 A_1 = K_2 A_2 \Rightarrow \frac{K_2}{K_1} = \frac{A_1}{A_2}$$

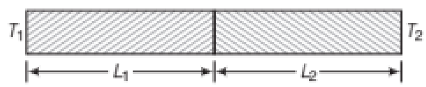
This is the required condition for equal **rate of heat transferred** from both the rods.

Connection of Rods with Different Thermal Conductivities

If two or more rods or conductors are connected with one another, the equivalent thermal conductivity as a whole may be altered.

(a) **Series combination of two thermal conductors**
We know that the series combination of resistances gives the equivalent resistance as $R_{eq} = R_1 + R_2$

This gives $\frac{L_1 + L_2}{K_{eq}A} = \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A}$ $\left[\because R = \frac{L}{KA}\right]$

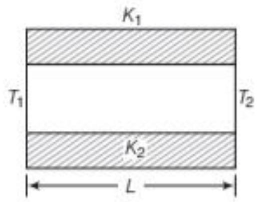


If $L_1 = L_2 = L$, then $\frac{2L}{K_{eq}A} = \frac{L}{K_1 A} + \frac{L}{K_2 A}$

$\Rightarrow$ Equivalent thermal conductivity, $K_{eq} = \frac{2K_1 K_2}{K_1 + K_2}$

Here, K_{eq} is the equivalent thermal conductivity of series connection of rods (as thermal conductor).

(b) **Parallel combination of two thermal conductors**
We know that the parallel combination of resistances gives the equivalent resistances as $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$



This gives, $\frac{1}{\frac{L}{K_{eq}2A}} = \frac{1}{\left(\frac{L}{K_1 A}\right)} + \frac{1}{\left(\frac{L}{K_2 A}\right)}$

(For equal area of cross-sections and length)

$$\Rightarrow \quad \frac{2A\,K_{eq}}{L} = \frac{K_1 A}{L} + \frac{K_2 A}{L}$$

$$\Rightarrow \quad \boxed{\text{Equivalent thermal conductivity, } K_{eq} = \frac{K_1 + K_2}{2}}$$

EXAMPLE |9| Thermal Equivalence of Composite Bar

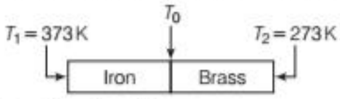
An iron bar having length $L_1 = 0.1$ m, area of cross-section $0.02\,m^2$ thermal conductivity $K_i = 79\ Wm^{-1}K^{-1}$ and brass bar having length $L_2 = 0.1$ m area of cross-section, $A_2 = 0.02\ m^2$ and thermal conductivity $K_2 = 109 Wm^{-1}K^{-1}$ are soldered end to end as shown in figure.

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 **[NCERT]**



Sol. Given, $L_1 = L_2 = L = 0.1$ m

$A_1 = A_2 = A = 0.02\ m^2$

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

$T_1 = 373$ K and $T_2 = 273$ K

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

i.e. $$H_1 = H_2 = H$$

$$\Rightarrow \quad \frac{K_1 A_1 (T_1 - T_0)}{L_1} = \frac{K_2 A_2 (T_0 - T_2)}{L_2} \qquad \text{...(i)}$$

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

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

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

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

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

(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

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

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

$$= 916.1\ W$$

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 liquids.

There are two types of convections

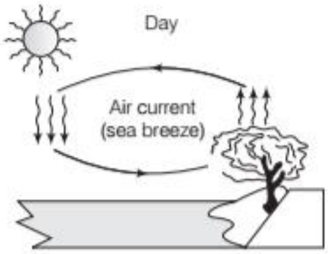
(i) **Forced Convection** This convection is the process in which heat is transferred from one place to other by actual transfer of heated material (or molecules). If heated material is forced to move say by a blower or a pump, the process of heat transfer is called **forced convection.** The heat transfer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

Land and Sea Breezes

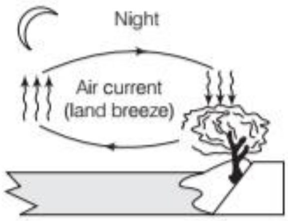
During the day, the **land heats up faster than the sea.** This occurs because the water has greater specific heat and because mixing currents disperse the absorbed heat throughout the great volume of water.

The hot air above the land expands and becoming less dense and hence the warmer air rises and colder air from the sea takes it place. The warmer air from the land moves towards the sea to complete the cycle. This create a breeze from the sea to the land which is called a **sea breeze.**



Land warmer than water

During the night, the opposite happens. The **land cools faster than sea.** The warm air above the sea rises. This warm air is replaced by colder air from the land creating a **land breeze.**



Water warmer than land

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 poles is cool.

So, there is a convection current in between two positions, air at the equatorial surface rising and moving out towards the poles, descending and streaming in towards the equator. The rotation of the earth, however, modifies this convection current because of this air has the Eastward speed of 1600 km/h.

While the speed of air closer to the poles is zero. So, air descends not at the poles but at 30° North latitude and returns to the equator. This is called **trade wind**. 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.

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. Here, the term radiation is used in two meanings. The first is the process by which the energy is emitted by a body, is transmitted in space and falls on another body. The second one is the energy itself is being transmitted in space.

The heat from the sun reaches to the earth by radiation. These are travelling millions of kilometers of empty space (i.e. without any material medium).

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**.

Colour of a Body

When thermal radiation falls on some other body, it may partly reflected and partly absorbed. The amount of heat that a body absorbed by radiation depends on the colour of the body. The colour of object shows that radiation of that particular wavelength is reflected back by the body.

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**. A perfect body absorbs 100% of radiations falling on it, is only an ideal concept because within the universe there is no existence of black body. However, lamp black is close to a black body because, it reflects only 1% of radiation falling on it.

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.

$$\Rightarrow \qquad \frac{\text{Energy absorbed}}{\text{Energy incident}}$$

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

Stefan-Boltzmann Law

Stefan-Boltzmann law 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. $E \propto T^4$

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

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

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

$$E = \varepsilon\sigma T^4$$

where, ε = emissivity of that body

EXAMPLE |10| Perfect Black Body

Calculate the temperature (in K) at which a perfect black body radiates energy at the rate of 5.67 W/cm^2. Given, $\sigma = 5.67 \times 10^{-8}\ \text{Wm}^{-2}\ \text{K}^{-4}$

Sol. Given, $E = 5.67\ \text{W / cm}^2 = 5.67 \times 10^4\ \text{W / m}^2$

$$\sigma = 5.67 \times 10^{-8}\ \text{Wm}^{-2}\ \text{K}^{-4}$$

Apply Stefan's law, $E = \sigma T^4$

$$T^4 = \frac{E}{\sigma} \Rightarrow T = \left(\frac{E}{\sigma}\right)^{1/4} = \left(\frac{5.67 \times 10^4}{5.67 \times 10^{-8}}\right)^{1/4}$$

$$T = (10^{12})^{1/4} = 10^3$$

$$T = 1000\ \text{K}$$

EXAMPLE |11| Heat Lost by the Sheet

A thin brass rectangular sheet of sides 15.0 cm and 12.0 cm is heated in a furnace to 600°C, and taken out. How much electric power is needed to maintain the sheet at this temperature, given that its emissivity is 0.0250? Neglect heat loss due to convection. (Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}\ \text{Wm}^{-2}\text{K}^{-4}$). **[NCERT]**

Sol. As the energy is radiated from both surfaces of the sheet, so

$$A = 2 \times 15.0 \times 12.0 \times 10^{-4}\ \text{m}^2$$

$$= 3.60 \times 10^{-2}\ \text{m}^2$$

$$T = 600 + 273 = 873\ \text{K}$$

$$\varepsilon = 0.250,$$

$$\sigma = 5.67 \times 10^{-8}\ \text{Wm}^{-2}\ \text{K}^{-4}.$$

The rate of heat loss by the sheet,

$$H = \frac{Q}{t} = \varepsilon\sigma A T^4$$

$$= 0.250 \times 5.67 \times 10^{-8} \times 3.60 \times 10^{-2} \times (873)^4$$

$$= 296\ \text{Js}^{-1} = 296\ \text{W}.$$

Wien's Displacement Law

Wien's displacement law 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, $\lambda_m \propto \frac{1}{T}$ or $\boxed{\lambda_m T = b}$

where, b = Wien's constant $= 2.9 \times 10^{-3}$ m K

EXAMPLE |12| A Hot Body Radiating Energy

A hot body having the surface temperature 1327°C. Determine the wavelength at which it radiates maximum energy. Given Wien's constant $= 2.9 \times 10^{-3}$ mK.

Sol. Given, $T = 1327 + 273 = 1600\ \text{K}$

Wien's constant, $b = 2.9 \times 10^{-3}$ m K

$$\lambda_m = \frac{b}{T} = \frac{2.9 \times 10^{-3}}{1600} = 1.81 \times 10^{-6}\ \text{m}$$

EXAMPLE |13| Rate of Energy Lost

Consider a filament which is indirectly heated. The radiating maximum energy having wavelength 3.4×10^{-5} cm. Determine the amount of heat energy lost per second per unit area if the temperature of surrounding air is 17°C.

Given, $\sigma = 5.67 \times 10^{-8}\ \text{Wm}^{-2}\ \text{K}^{-4}$, $b = 2.9 \times 10^{-3}$ mK

Sol. Given, wavelength, $\lambda_m = 3.4 \times 10^{-5}\ \text{cm} = 3.4 \times 10^{-7}\ \text{m}$

Temperature surrounding,

$$T_0 = 17°\text{C} + 273 = 290\ \text{K}$$

$$\sigma = 5.67 \times 10^{-8}\ \text{Wm}^{-2}\ \text{K}^{-4}$$

$$b = 2.9 \times 10^{-3}\ \text{mK}$$

According to Wien's law

$$T = \frac{b}{\lambda_m} = \frac{2.9 \times 10^{-3}\ \text{mK}}{3.4 \times 10^{-7}} = 8529.4\ \text{K}$$

According to Stefan-Boltzmann law,

$$E = \sigma(T^4 - T_0^4) = 5.67 \times 10^{-8}\ [(8529.4)^4 - (290)^4]$$

$$E = 30016.98 \times 10^4\ \text{W / m}^2$$

NEWTON'S LAW OF COOLING

Newton's law of cooling 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

i.e. Rate of loss of heat $\propto$ Temperature difference between the body and its surroundings.

$$-\frac{dQ}{dt} \propto (T - T_0)$$

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

EXAMPLE |14| Temperature of Cool Body

A body cools in 7 min from 60°C to 40°C. What will be its temperature after the next 7 min? The temperature of the surroundings is 10°C.

Sol. According to the Newton's law of cooling, we have

$$\frac{dQ}{dt} = k\left(\frac{T_1 + T_2}{2} - T_0\right)$$

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

$$\frac{ms\,(60 - 40)}{7 \times 60} = k\left(\frac{60 + 40}{2} - 10\right)$$

$$\frac{m \times 20}{420} = k \times 40$$

Suppose, after the next 7 min = 420 seconds, the temperature is T. Then,

$$\frac{ms\,(40 - T)}{420} = k\left(\frac{40 + T}{2} - 10\right) \quad \text{...(ii)}$$

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

$$\frac{20}{40 - T} = \frac{40}{\left(\frac{40 + T}{2} - 10\right)}$$

On solving, we get $T = 28°$ C

TOPIC PRACTICE 2

OBJECTIVE Type Questions

1. A normal diet furnishes 2000 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 $\text{cal g}^{-1}\,°\text{C}^{-1}$.

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

Sol. (b) Here, $m = 60 \text{ kg} = 60 \times 10^3 \text{g}$, $c = 0.83 \text{ cal g}^{-1}\,°\text{C}^{-1}$

$$Q = 200 \text{ kcal} = 2 \times 10^5 \text{ cal}$$

Amount of heat required for a person,

$\because \quad Q = mc\Delta T$

$$\Rightarrow \quad \Delta T = \frac{Q}{mc} = \frac{2 \times 10^5}{60 \times 10^3 \times 0.83} = 4.016°\text{C}$$

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

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

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

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

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

Sol. (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.

4. A liquid boils when its vapour pressure is equal to

(a) 6.0 cm of Hg column
(b) atmospheric pressure
(c) double of atmospheric pressure
(d) 1000 Pa or more

Sol. (b) When vapour pressure is equal to atmospheric pressure, then boiling occurs.

5. The amount of heat that a body can absorb by radiation

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

Sol. (a) The thermal radiation that falls on a body 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 body.

6. 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

Sol. (a) Electric power consumed in first case,

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

Electric power consumed in second case,

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

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

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

As we know percentage rise in power

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

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

VERY SHORT ANSWER Type Questions

7. Why water is used as an coolant in the radiator of cars?

Sol. Because, specific heat of water is very high due to this it absorbs a large amount of heat. This helps in maintaining the temperature of the engine low.

8. Black body radiation is white. Comment.

Sol. The statement is true. A black body absorbs radiations of all wavelengths. When heated to a suitable temperature, it emits radiations of all wavelengths. Hence, a black body radiation is white.

9. Does the boiling point of water change with pressure?

Sol. The boiling point of water increases with the increase in pressure (and *vice-versa*).

10. If all the objects radiate electromagnetic energy, why do not the objects around us in everyday life become colder and colder?

Sol. According to the Principal of heat exchange, all the objects (above 0 K) not only radiate electromagnetic energy but also absorb at the same rate from their surroundings. Thus, they do not become colder.

11. White clothes are more comfortable in summer while colourful clothes are more comfortable in winter. Why?

Sol. White clothes absorb very little heat radiation and hence they are comfortable in summer. Coloured clothes absorb almost whole of the incident radiation and keep the body warm in winter.

12. Can we boil water inside in the earth satellite?

Sol. No, the process of transfer of heat by convection is based on the fact that a liquid becomes lighter on becoming hot and rise up. In condition of weightlessness, this is not possible. So, transfer of heat by convection is not possible in the earth satellite.

13. Stainless steel cooking pans are preferred with extra copper bottom. Why?

Sol. The thermal conductivity of copper is much larger than that of steel. The copper bottom allows more heat to flow into the pan and hence helps in cooking the food faster.

14. Why an ice box is constructed with a double wall?

Sol. An ice box is made of double wall and the space in between the walls is filled with some non-conducting material to provide heat insulation, so that the loss of heat can be minimised.

15. Why birds are often seen to swell their feathers in winter?

Sol. When the birds swell their feathers, they are able to enclose air in the feathers. Air, being a poor conductor of heat, so it prevents the loss of heat from the bodies of the birds to the surroundings and as such they do not feel cold in winter.

16. Two bodies at different temperatures T_1 and T_2, if brought in thermal contact do not necessarily settle at the mean temperature $\frac{(T_1 + T_2)}{2}$. Why?

Sol. The two bodies may have different masses and different materials i.e. they may have different thermal capacities.

In case the two bodies have equal thermal capacities, they would settle at the mean temperature $\frac{T_1 + T_2}{2}$.

17. Usually a good conductor of heat is a good conductor of electricity also. Give reason.

Sol. Electrons contribute largely both towards the flow of electricity and the flow of heat. A good conductor contains a large number of free electrons. So, it is both a good conductor of heat and electricity.

18. Place a safety pin on a sheet of paper. Hold the sheet over a burning candle, until the paper becomes yellow and charr. On removing the pin, its white trace is observed on the paper. Why?

Sol. The safety pin is made of steel which is good conductor of heat. So, the safety pin takes heat from the paper under it and transfer it away to the surroundings. The portion of the paper under the safety pin remains comparatively colder than the remaining part.

19. When we step barefoot into an office with a marble floor, we feel cold. Why?

Sol. This is because marble is a better conductor of heat than concrete. When we walk barefooted on a marble floor, heat flows our body through the feet and we feel cold.

20. Is it possible to convert water into vapour form without increasing its temperature, if temperature and pressure of water are 30°C and 1 atm respectively?

Sol. Yes, water at 30°C can be converted into vapour by reducing its pressure until it equals to the vapour pressure of water at 30°C.

21. **Calorimeters are made of metals not glass. Why?**

Sol. This is because metals are good conductors of heat and have low specific heat capacity.

22. **Which object will cool faster when kept in open air, the one at 300°C or the one of 100°C? Why?**

Sol. The object at 300°C will cool faster than the object at 100°C. This is in accordance with Newton's law of cooling.

As we know, rate cooling of an object ∝ temperature between the object and its surroundings.

SHORT ANSWER Type Questions

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

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

24. **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?**

Sol. 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.

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

Sol. 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.

26. **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?

Sol. 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).

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

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 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.

27. **On a hot day, a car is left in sunlight with all the windows closed. After some time, it is found that the inside of the car is considerably warmer than the air outside. Explain, why?**

Sol. 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 warmer.

28. **Two vessels of different materials are identical in size and wall thickness. They are filled with equal quantities of ice at 0°C.**

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

Sol. 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.

$$\because \quad Q = \frac{K_1 A (T_1 - T_2) t_1}{x} = \frac{K_2 A (T_1 - T_2) t_2}{x}$$

$$\Rightarrow \quad K_1 t_1 = K_2 t_2$$

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

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

Sol. Brass is a good conductor of heat. It quickly conducts away the heat. So, the paper does not alter 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 charred.

30. **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?**

Sol. 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.

31. **Woollen clothes are warm in winter. Why?**

Sol. Woollen fibres enclose a large amount of air in them. Both wool and air are bad conductors of heat. The small coefficient of thermal conductivity prevents the loss of heat from our body due to conduction. So, we feel warm in woollen clothes.

32. **Why rooms are provided with the ventilators near the roof?**

Sol. 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.

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

Sol. 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.

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

Sol. 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.

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

Sol. 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.

36. **How does tea in a thermo flask remain hot for a long time?**

Sol. The air between the two walls of the thermo flask 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.

37. **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?**

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

Let C be the specific heat of the composite body. Then,

$$(m_1 + m_2)C = m_1C_1 + m_2C_2$$
$$= m_1C_1 + m_1C_1 = 2\,m_1C_1$$

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

LONG ANSWER Type I Questions

38. **Two vessels A and B of different materials but having identical shape, size and wall thickness are filled with ice and kept at the same place. Ice melts at the rate of 100 g min^{-1} and 150g min^{-1} in A and B, respectively. Assuming that heat enters the vessels through the walls only, calculate the ratio of thermal conductivities of their materials.**

Sol. Let m_1 and m_2 be the masses of ice melted in same time ($t = 1$ min) in vessels A and B, respectively.

Then, the amounts of heat flowed into the two vessels will be

$$Q_1 = \frac{K_1A(T_1 - T_2)t}{x} = m_1L \quad \text{...(i)}$$

$$Q_2 = \frac{K_2A(T_1 - T_2)t}{x} = m_2L \quad \text{...(ii)}$$

where, L is latent heat of ice.

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

$$\frac{K_1}{K_2} = \frac{m_1}{m_2} = \frac{100\text{ g}}{150\text{ g}} = \frac{2}{3} = 2:3$$

39. 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 = $109\text{ Js}^{-1}\text{m}^{-1}{}^\circ\text{C}^{-1}$ and heat of vaporisation of water = 2256Jg^{-1}. **[NCERT]**

Sol. Here, $A = 0.15\text{ m}^2$, $x = 1.0\text{ cm} = 0.01\text{ m}$,

$$K = 109\text{ Js}^{-1}\text{m}^{-1}{}^\circ\text{C}^{-1},\ L = 2256\text{ Jg}^{-1}$$

$$T_2 = 100^\circ\text{C},\ t = 1\text{ min} = 60\text{ s}$$

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.

$$Q = \frac{KA(T_1 - T_2)t}{x}$$

$$= \frac{109 \times 0.15 \times (T_1 - 100) \times 60}{0.01}\text{ J}$$

Mass of water boiled per min = 6 kg = 6000 g
Heat used to boil water,

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

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

or $$T_1 - 100 = \frac{6000 \times 2256 \times 0.01}{109 \times 0.15 \times 60} = 138^\circ\text{C}$$

or $$T_1 = 138 + 100 = 238^\circ\text{C}$$

40. 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.

Sol. (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.

41. 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 = $0.01\text{ Js}^{-1}\text{m}^{-1}{}^\circ\text{C}^{-1}$. Given, heat of fusion of water = $335 \times 10^3\text{J kg}^{-1}$ **[NCERT]**

Sol. Here, $A = 6 \times \text{side}^2 = 6 \times 30 \times 30$

$$= 5400\text{ cm}^2 = 0.54\text{ m}^2$$

$$x = 5\text{ cm} = 0.05\text{ m},\ t = 6\text{ h} = 6 \times 3600\text{s}$$

$$T_1 - T_2 = 45 - 0 = 45^\circ\text{C},$$

$$K = 0.01\text{ Js}^{-1}\text{m}^{-1}{}^\circ\text{C}^{-1}$$

$$L = 335 \times 10^3\text{ J kg}^{-1}$$

Total heat entering the box through all the six faces,

$$Q = \frac{KA(T_1 - T_2)t}{x}$$

$$= \frac{0.01 \times 0.54 \times 45 \times 6 \times 3600}{0.05} = 104976\text{ J}$$

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

$$Q = mL$$

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

Mass of ice left after six hours = 4 − 0.313 = 3.687 kg

42. 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? (specific heat of copper = $0.39\text{ Jg}^{-1}{}^\circ\text{C}^{-1}$, and heat of fusion of water = 335 Jg^{-1}). **[NCERT]**

Sol. Mass of copper block, $M = 2.5\text{ kg} = 2.5 \times 10^3\text{g}$

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

Fall in temperature, $\Delta T = 500 - 0 = 500^\circ\text{C}$
Heat lost by copper block = $mc\,\Delta T$

$$= 2.5 \times 10^3 \times 0.39 \times 500\text{ J}$$

Let mass of ice melted = M gram

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

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

$$= 1455.2\text{ g} = 1.455\text{ kg}$$

43. A fat man is used to consuming about 3000 kcal worth of food everyday. His food contains 50 g of butter plus a plate of sweets everyday, besides items which provide him with other nutrients (proteins, vitamins, minerals, etc.) in addition to fats and carbohydrates. The calorific value of 10 g of butter is 60 kcal and that of a plate of sweets is of average 700 kcal. What dietary strategy should he adopt to cut down his calories to about 2100 kcal per day? Assume the man cannot resist eating the full plate of sweets once it is offered to him.

Sol. The man intends to cut down $=3000-2100=900$kcal.

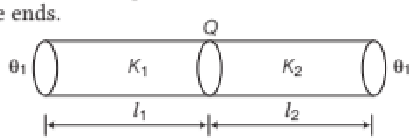
But avoiding sweets completely, he will cut down 700 kcal. To cut down another 200 kcal, he should cut down butter by $\frac{10}{60}\times 200 \simeq 33$ g per day.

He should not cut down consumption of food, that provides him with vitamins and other vital nutrients.

44. 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

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

Sol. It is given that conductivities K_1 and 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. $\quad \frac{\theta}{t}\cdot\frac{l_1}{K_1 A} + \frac{\theta}{t}\frac{l_2}{K_2 A} = \frac{\theta}{t}\cdot\frac{(l_1 + l_2)}{K_{eq} A}$

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

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

LONG ANSWER Type II Questions

45. 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]

Sol. (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

$$t_c - 0.01 = T - 273.16$$

$$\therefore \quad t_c = T - 273.15$$

(iv) One degree on fahrenheit scale

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

But one celsius scale division is equal to one division on kelvin scale.

$\therefore$ Triple point on kelvin scale (whose size of a degree is equal to that of the fahrenheit scale)

$$= 273.16 \times 9/5 = 491.69$$

46. 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]**

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

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

Specific heat of human body,

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

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

$$Q = Mc\Delta T = 30 \times 10^3 \times 1 \times \frac{5}{3}$$
$$= 50000 \text{ cal}$$

If M' gram of sweat evaporates from the body of the child, then heat gained by sweat

$$Q = M'L = M' \times 580 \text{ cal} \quad [\because L = 580 \text{ cal g}^{-1}]$$

$\because$ Heat gained = Heat lost

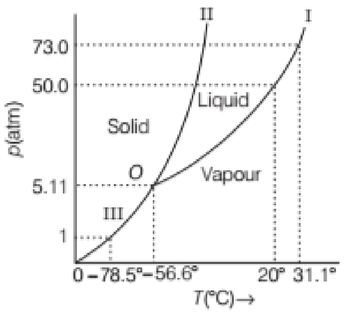
$$M' \times 580 = 50000$$

$$\Rightarrow \quad M' = \frac{50000}{580} = 86.2 \text{ g}$$

Time taken by sweat to evaporate = 20 min

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

47. Answer the following questions based on the p-T phase diagram of CO_2.



(i) CO_2 at 1 atm pressure and temperature $-60°C$ is compressed isothermally. Does it go through the liquid phase?

(ii) What happens when CO_2 at 4 atm pressure is cooled from room temperature at constant pressure?

(iii) Describe qualitatively the changes in a given mass of solid CO_2 at 10 atm pressure and temperature $-65°C$ as it heated upto room temperature at constant pressure.

(iv) CO_2 is heated to a temperature 70°C and compressed isothermally. What changes in its properties, do you expect to observe? **[NCERT]**

Sol. (i) No, when CO_2 at 1 atm pressure and at $-60°C$ is compressed isothermally, it changes directly from vapour phase to solid phase without going through the liquid phase.

This can be checked by drawing a vertical line at $-60°C$ which intersects the sublimation curve III.

(ii) CO_2 at 4 atm pressure and at temperature (say 25°C) is vapour. If it is cooled at constant temperature, it condenses directly into solid without going through liquid phase.

This can be checked by drawing a horizontal line at p=4 atm which intersects the sublimation curve III.

(iii) CO_2 at 10 atm pressure and at $-65°C$ is solid. As CO_2 is heated at constant pressure, it will go to liquid phase and then to the vapour phase. It is because, the horizontal line through the initial point intersects both the fusion and the vaporisation curves. The fusion and boiling points can be known from the points, where the horizontal line at 10 atm (initial point) intersects the respective curves.

(iv) When the carbon dioxide is heated to 70°C (which is greater than its critical temperature), it will not exhibit any clear phase transition to the liquid phase. At this state, it will deviate more and more from ideal gas behaviour, as its pressure increases.

48. 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]**

Sol. (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, $E = \sigma T^4$

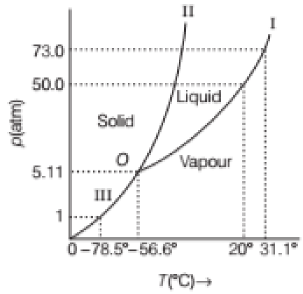
When the body is placed in the open at temperature T_0, the heat radiated/second/unit area, $E' = \sigma(T_4 - T_0^4)$.

Clearly, $E' < E$. So, the optical pyrometer gives too low a 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.

49. Answer the following questions based on 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 CO_2 co-exist in equilibrium?

(ii) What is the effect of decrease of pressure on the fusion and boiling point of CO_2?

(iii) What are the critical temperature and pressure for CO_2? What is their significance?

(iv) Is CO_2 solid, liquid or gas at (a) − 70°C under 1 atm (b) − 60°C under 10 atm (c) 15°C under 56 atm? **[NCERT]**

Sol. (i) The solid, liquid and vapour phases of CO_2 co-exist in equilibrium at its triple point O for which

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

(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.

50. Distinguish between conduction, convection and radiation.

Sol.

	Conduction	Convection	Radiation
1.	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 electromagne tic waves.
2.	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.
3.	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.
4.	It is a slow process.	It is also a slow process.	It propagates at the speed of light.
5.	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.

51. 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]**

Sol. 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.

Here, $T_1 = 80°C$, $T_2 = 50°$, $T_0 = 20°C$,
$t = 5$ min $= 300$ s

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

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

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

$$T = \frac{60 + 30}{2} = 45°C$$

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

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

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

or

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

ASSESS YOUR TOPICAL UNDERSTANDING

OBJECTIVE Type Questions

1. Time taken to heat water upto a temperature of 40°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°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

2. Cooking is difficult on hills becuase

(a) atmospheric pressure is higher
(b) atmospheric pressure is lower
(c) boiling point of water is reduced
(d) Both (b) and (c)

3. Change of state from solid to vapour state without passing through the liquid state is called

(a) regelation (b) sublimation
(c) condensation (d) sedimentation

4. The bottoms of utensils for cooking food are blackened to

(a) absorb minimum heat from fire
(b) absorb maximum heat from fire
(c) emit radiations
(d) reflect heat to surroundings

5. The rate of loss of heat depends on

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

6. A spherical body with radius 12 cm radiates 450 W power at 500 K. If the radius were halved and the temperature doubled, what would be the power radiated?

(a) 2000 W (b) 1500 W
(c) 1800 W (d) 2500 W

Answers

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

VERY SHORT ANSWER Type Questions

7. In which unit the water equivalent of unit is measured?

8. What is the heat capacity of boiling water?

9. Heat and work are equivalent to each other. What does it mean?

10. What will be ratio of specific heat capacity and molar heat capacity of a material?

11. When hot liquid is mixed with a cold liquid, what will be effect on final temperature?

12. Out of three modes of transmission of heat, which one is fastest?

SHORT ANSWER Type I Questions

13. Why snow is a better heat insulator than ice?

14. Why do we use copper gauze in Davy's safety lamp?

15. Is it necessary that all black coloured objects should be considered black bodies?

16. Why felt rather than air is employed for thermal insulation?

LONG ANSWER Type I Questions

17. State and explain three different modes of transference of heat. Explain how the loss of heat due to these three modes are minimised in a thermo flask.

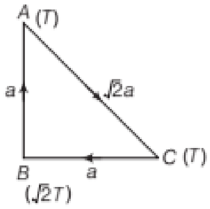
18. What is calorimetry? Briefly explain its principle.

19. Can a gas be liquified at any temperature by increase of pressure alone?

20. A cup of tea cools from 81°C to 79°C in 1 min. The ambient temperature is 30°C. What time is needed for cooling of same cup of tea in same ambience from 61°C to 59°C?

LONG ANSWER Type II Questions

21. Three rods of identical cross-sectional area and made from the same metal from the sides of an isosceles triangle ABC (shown in figure), right-angled at B. The points A and B are maintained at temperatures T and $\sqrt{2}T$, respectively. In the steady state, the temperature of the point C is T_C. Assuming that only heat conduction takes place. Then, determine the value of $\frac{T_C}{T}$.



Hence, a, a and $\sqrt{2}a$ are the respective side lengths.

$\left[\textbf{Ans.}\ \frac{3}{\sqrt{2}+1}\right]$

22. Three rods of equal lengths of thermal conductivities K, $2K$ and $3K$ are symmetrically joined to a point. If temperatures of ends are 0°C, 50°C and 100°C, respectively. Determine the temperature of junction point.

$\left[\textbf{Ans.}\ \frac{200}{3}\,°\text{C}\right]$

23. A copper cube of mass 200 g slides down on a rough inclined plane having inclination 37° at a constant speed. If any loss in mechanical energy goes into the copper block as thermal energy. Find the increase in the temperature of the block as it slides down through 60 cm. Given, specific heat of copper is 420 J kg^{-1} K^{-1}.

[**Ans.** 8.6×10^{-3} °C]

24. On a winter day the temperature of the tap water is 20°C whereas the atmospheric temperature is 5°C. Water is stored in a tank of capacity 0.5 m^3 for household use. If it were possible to use the heat liberated by the water to left a 10 kg mass vertically. How high can it be lifted as the water comes to the room temperature. Take $g = 10\ ms^{-2}$?

[**Ans.** 315 km]

25. Explain what is meant by specific heat of a substance what are its units. Define two types of specific heat of gases and which one is greater?

SUMMARY

- **Temperature** is the property of a state of matter by virtue of which we predict its hotness or coldness, relative to some body.
- **Heat** is form of energy which determines the change in thermal state of a body. It flows from the body which is at a high temperature to the other at low temperature.
- The devices which are used to measure the temperature are termed as **thermometers**.
- **Relation between C, F and K Scales**

$$\frac{C}{5} = \frac{F-32}{9} = \frac{K-273.15}{5}$$

- **Boyle's Law** $p \propto \frac{1}{V}$ (at constant temperature)

$\therefore$ $$pV = \text{constant}$$

- **Charles'Law** $V \propto T$ (at constant pressure)

$$\frac{V}{T} = \text{constant}$$

- **Ideal Gas Equation**

$$pV = \mu RT$$

where, p = pressure of gas, V = volume of gas, T = temperature of gas
μ = number of moles, R = universal gas constant $= 8.31\,\text{Jmol}^{-1}\text{K}^{-1}$

- If a rod is having length l_0 at temperature T, then expansion in length of rod due to rise in temperature by ΔT, is given by

$$\Delta l = l_0 \Delta \alpha T$$

where, α is the coefficient of linear expansion, whose value depends on the nature of the material.
Final length, $l_f = l_0 + l_0\alpha\Delta T = l_0(1+\alpha\Delta T)$

- Area expansion is valid only for solids. This is given by $A_f = A_0(1+\beta\times\Delta T)$
where, A_f is the area of body when temperature has been changed by ΔT, A_0 is the area of body at temperature T and β is the coefficient of superficial expansion.
- Volume after expansion, $V = V_0(1+\gamma\Delta T)$, where, γ is the coefficient of cubical expansion.

- **Heat Capacity** The heat capacity of a body is the quantity of heat required by the body to raise its temperature by 1°C. It is also known as thermal capacity.

  Heat capacity $= ms$ (mass $\times$ specific heat)

- **Water Equivalent** It is the quantity of water whose thermal capacity is same as the heat capacity of the body. It is denoted by W.

  $W = ms =$ Heat capacity of the body

- **Specific Heat** The specific heat (s) of a substance is the quantity of heat in calorie required to raise the temperature of 1g of that substance by 1°C. Its unit is cal $g^{-1}C^{-1}$.

- **Molar Heat Capacity** The amount of heat required to change the temperature of unit mole of substance by 1°C is termed as its molar heat capacity.

  $C = \frac{Q}{\mu \Delta T}$ where, μ = number of moles $= \frac{m}{M}$

- **Calorimetry** Heat lost by hotter body = Heat gained by colder body $m_1 s_1 \Delta T = m_2 s_2 \Delta T$

- **Latent Heat** The heat required to change the state of a system is proportional to mass of the system, i.e.

  $$Q \propto m \Rightarrow Q = mL$$

  where, L = **latent heat** of the material.

- **Transmission of Heat** There are three different ways in which heat can be transferred-conduction, convection and radiation.

- **Conduction** It is a process by which the heat is transferred in solid. In conduction, molecules vibrate about a fixed location and transfer the heat by collision.

- **Convection** It is a process by which heat is transferred in fluids (liquids and gases). In convection, transfer of heat takes place by transport of matter (in form of motion of particles).

- **Radiation** This mode of heat transfer doesn't require any medium, and it is the fastest mode of heat transfer. Instance of this mode of heat transfer is the radiation received by earth coming from sun.

- The amount of heat transmitted through a conductor is given by $Q = \frac{KA\Delta Tt}{l}$

  Thermal resistance of heat is given by $|H| = \left|\frac{\Delta Q}{\Delta t}\right| = \frac{KA}{l}\Delta T = \frac{\Delta T}{l/KA}$

  The term $\frac{l}{KA}$ is generally called the **thermal resistance.**

- **Stefan's Law** The energy emitted per second per unit area of a black body (emissive power = 1) is proportional to the fourth power of the absolute temperature.

  i.e. $E = \sigma T^4$

  Here, σ = Stefan's constant $= 5.67 \times 10^{-8}\, Jm^{-2}s^{-1}K^{-4}$

  For any other body $e = \varepsilon \sigma T^{-4}$

  Here, ε = emissivity of body ($\varepsilon = 1$ for a black body)

  If Q is the total energy radiated by the ordinary body, then $e = \frac{Q}{A \times t} = \varepsilon \sigma T^{-4} \Rightarrow Q = A\varepsilon\sigma T^{-4}t$

- **Wien's displacement law** It states that, "as temperature of black body T increases, the wavelength λ_m corresponding to maximum emission decreases' such that $\lambda_m \propto \frac{1}{T}$ or $\lambda_m T = b$

  where, b is known as Wien's constant and its value is 2.89×10^{-3}mK

- According to **Newton's law of cooling**, 'rate of cooling of a body is directly proportional to the temperature difference between the body and the surroundings provided that the temperature difference is small.'

  Mathematically, $-\frac{dT}{dt} \alpha (T - T_0)$, $-\frac{dT}{dt} = k(T - T_0)$

  where, k is a universal constant.

CHAPTER PRACTICE

OBJECTIVE Type Questions

1. Temperature of atmosphere in Kashmir falls below $-10^\circ C$ 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 $2^\circ C$ and then contracts upto $4^\circ C$
(d) contracts upto $2^\circ C$ and then expands upto $4^\circ C$

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 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) $4\pi R^3 \alpha \Delta T$

5. 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

6. If m mass of a substance undergoes a phase change, then amount of heat required will be
(a) $\Delta Q = mL$ (b) $\Delta Q = mC_p \Delta T$
(c) $\Delta = ms\Delta T$ (d) $\Delta Q = mC_V \Delta T$

7. 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 thier ends in
(a) 24 s (b) 3 s
(c) 38 s (d) 1.5 s

8. The temperature of two bodies A and B are respectively, 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

9. 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

ASSERTION AND REASON

Direction (Q. Nos. 10-18) *In the following questions, two statements are given- one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below*
(a) Both Assertion and Reason are true and Reason is the correct explanation of Assertion.
(b) Both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
(c) Assertion is true but Reason is false.
(d) Assertion is false but Reason is true.

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

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

11. **Assertion** When heat transfer takes place between a system and surroundings, the total heat content of system or surroundings separately remains same.

Reason Heat is a form of energy which follows the principle of conservation of energy.

12. **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 change due to change in atmospheric pressure but triple-point of water does not change.

13. **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.

14. **Assertion** Houses made of concrete roofs get very hot during summer days.

Reason Thermal conductivity of concrete is much smaller than metal.

15. **Assertion** When temperature difference across the two sides of a wall is increased, its thermal conductivity increases.

Reason Thermal conductivity depends on the nature of material of the wall.

16. **Assertion** A black body at higher temperature T radiates energy U. When temperature falls to one third, the radiated energy will be $U/81$.

Reason $U^2 \propto T^4$

17. **Assertion** The SI unit of Stefan's constant is $\text{Wm}^{-2}\,\text{K}^{-4}$.

Reason This follows from Stefan's law $E = \sigma T^4$

$$\therefore \sigma = \frac{E}{T^4} = \frac{\text{Wm}^{-2}}{\text{K}^4}$$

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

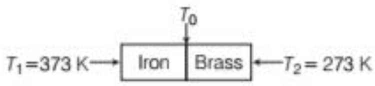
Reason Sun is not a black body.

CASE BASED QUESTIONS

Direction (Q. Nos. 19-20) *These questions are case study based questions. Attempt any 4 sub-parts from each question.*

19. **Temperature of Junction**

An iron bar ($L_1 = 0.1$ m, $A_1 = 0.02\ \text{m}^2, K_1 = 79\ \text{Wm}^{-1}\text{K}^{-1}$) and a brass bar ($L_2 = 0.1$ m, $A_2 = 0.02\ \text{m}^2, K_2 = 109\ \text{Wm}^{-1}\text{K}^{-1}$) are soldered end to end as shown in figure. The free ends of the iron bar and brass bar are maintained at 373 K and 273K, respectively.



(i) What is the temperature of the junction of two bars in steady state?

(a) 315 K (b) 420 K
(c) 520 K (d) 600 K

(ii) Compute the equivalent thermal conductivity of the compound bar.

(a) $100\ \text{Wm}^{-1}\ \text{K}^{-1}$
(b) $91.6\ \text{Wm}^{-1}\ \text{K}^{-1}$
(c) $110\ \text{Wm}^{-1}\ \text{K}^{-1}$
(d) $120\ \text{Wm}^{-1}\ \text{K}^{-1}$

(iii) How much heat current flows through the compound bar?

(a) 920 W (b) 916.1 W
(c) 102.5 W (d) 112.5 W

(iv) 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 thier ends in

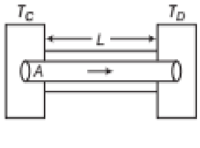
(a) 24 s (b) 3 s
(c) 38 s (d) 1.5 s

(v) The two ends of a metal rod are maintained at temperatures 100°C and 110°C. The rate of heat flow in the rod is found to be 4.0 J/s. If the ends are maintained at temperatures 200°C and 210°C, the rate of heat flow will be

(a) $44.0\ \text{Js}^{-1}$ (b) $16.8\ \text{Js}^{-1}$
(c) $8.0\ \text{Js}^{-1}$ (d) $4.0\ \text{Js}^{-1}$

20. **Heat Exchange**

Consider a metallic bar of length L and uniform cross-section A with its two ends maintained at different temperatures. This can be done, *e.g.*, By putting the ends in thermal contact with large reservoirs at temperatures, say, T_C and T_D, respectively shown in figure.Let us assume the ideal condition that the sides of the bar are fully insulated so that no heat is exchanged between the sides and the surroundings.



After sometime, steady state is reached; the temperature of the bar decreases uniformly with distance from T_C to T_D; $(T_C > T_D)$. The reservoir at C supplies heat at a constant rate, which transfers through the bar and is given out at the same rate to the reservoir at D.

It is found experimentally that in this steady state heat flow by conduction in a bar with its two ends maintained at temperatures T_C and T_D; $(T_C > T_D)$.

(i) The rate of flow of heat (H) is proportional to

(a) $(T_D + T_C)$ (b) $(T_C - T_D)$

(c) T_C (d) T_D

(ii) In $H = \frac{\Delta Q}{\Delta t} = \frac{KA}{L}(T_C - T_D)$, the proportionality constant K is called the

(a) thermal conductivity

(b) specific heat

(c) latent heat

(d) coefficient of linear expansion

(iii) The SI unit of K is

I. $Js^{-1}m^{-1}K^{-1}$ II. WmK^{-1}

III. $Wm^{-1}K^{-1}$ IV. $Js\, m^{-1}K$

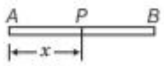
(a) Only III

(b) Both I and III

(c) Only IV

(d) Only II

(iv) Heat is flowing steadily from A to B temperature T at P, at distance x from A is such that



(a) T decreases linearly with x

(b) T increases linearly with x

(c) T decreases exponentially with x

(d) T increases with x as $T \propto x^2$

(v) Calculate the rate of loss of heat through a glass window of area $1000\ cm^2$ and thickness 0.4 cm when temperature inside is 37°C and outside is –5°C. Coefficient of thermal conductivity of glass is 2.2×10^{-3} cal $s^{-1}cm^{-1}K^{-1}$.

(a) 450 cal s^{-1} (b) 231 cal s^{-1}

(c) 439 cal s^{-1} (d) 650 cal s^{-1}

Answers

1. (c)	**2.** (b)	**3.** (d)	**4.** (d)	**5.** (a)
6. (a)	**7.** (b)	**8.** (d)	**9.** (b)	**10.** (d)
11. (d)	**12.** (a)	**13.** (c)	**14.** (b)	**15.** (d)
16. (c)	**17.** (c)	**18.** (c)		
19. **(i)** (a)	**(ii)** (b)	**(iii)** (b)	**(iv)** (b)	**(v)** (d)
20. **(i)** (b)	**(ii)** (a)	**(iii)** (b)	**(iv)** (a)	**(v)** (b)

VERY SHORT ANSWER Type Questions

21. A body at high temperature contains more heat. Comment.

22. Two copper balls having masses 5 g and 10 g collide with a target with the same velocity. If the total energy is used in heating the balls, which ball will attain higher temperature? Justify?

23. What should be the absorbing power and reflecting power of a perfectly black body?

SHORT ANSWER Type Questions

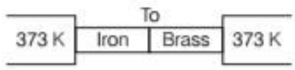
24. The density of mercury is $13.6 \times 10^3 kg\ m^{-3}$ at 0°C and its coefficient of volume expansion is $1.82 \times 10^{-4} K^{-1}$. Find the density at 50°C.

[**Ans.** $13.47 \times 10^3 kg\ m^{-3}$]

25. Figure shows two bars of iron and brass having same length and same area of cross-section in steady state. Determine temperature at common junction. Given that

$K_{iron} = 79\ W\ m^{-1}K^{-1}$

and $K_{brass} = 109\ W\ m^{-1}\ K^{-1}$.



[**Ans.** 315 K]

26. 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? Given that linear expansion coefficient of steel $= 12 \times 10^{-5}/°C$ and for copper= $1.6 \times 10^{-5}/°C$

27. An aluminium cube 10 cm on a side at 0°C is heated to 30°C. Find the change in its density. Given that coefficient of volume expansion of aluminium $= 7.2 \times 10^{-5}/°C$ and density of aluminium at 0°C= 2700 kg / m^3.

[**Ans.** – 5.8 kg / m^3]

28. Determine the temperature at which a wooden block and a metallic block are equally cold or equally hot when touched.

29. Air is a bad conductor of heat why is it so that we do not feel warm without cloth?

30. Animal curl into a ball when they feel very cold. Why?

LONG ANSWER Type I Questions

31. 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 is 40°C and latent heat of fusion of ice $= 3.33 \times 10^5 \text{J kg}^{-1}$.

[**Ans.** $0.42 \text{ W m}^{-1}\text{K}^{-1}$]

32. 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 maximum amount of ice that can melt? Given that specific heat of water = 390 $\text{J kg}^{-1}\text{K}^{-1}$ and latent heat of fusion of water $= 3.35 \times 10^5 \text{J kg}^{-1}$

33. A steel girder is 50 m long and has a cross-sectional area 250 cm^2. What is the force exerted by the girder when heated from 5°C to 25°C?

Given that $\alpha_s = 11 \times 10^{-6}/°\text{C}$ and $Y_s(\text{or } \alpha_V) = 2 \times 10^{11}/°\text{C}$

[**Ans.** 11×10^5 N]

34. The window panes of a room have an area of 4.8 m^2 and of 4 mm thickness. At what rate does the heat energy flow through the window if the temperature inside the room is 25°C and that outside is 10°C. Given that the thermal conductivity of glass is $0.75 \text{ W m}^{-1}\text{K}^{-1}$.

[**Ans.** 1.35×10^4 W]

35. A pan filled by hot food cools from 94°C to 86°C in 120 s when the room temperature is 293 K. How long will it take to cool from 71°C to 69°C?

[**Ans.** 42 s]

LONG ANSWER Type II Questions

36. Establish the relationship among thermal expansions α_l, α_A and α_V.

37. 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.

(a) To what temperature on Fahrenheit scale would a temperature –95°Z correspond?

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

[**Ans.** (a) –148°F (b) 32°Z]