10 Thermal Properties of Matter

Substances with a low specific heat capacity can be heated quickly, but they also experience a wide temperature change even when only a small amount of heat is applied. Substances with only a low specific heat capacity are excellent materials for cooking utensils such as frying pans, pots and kettles because they heat up quickly even when only a small amount of heat is provided. Hence, in this chapter, we will deal with heat and its measurement and the processes of heat transfer.

Topic Notes

- *Heat and Thermal Expansion*
- *Modes of Heat Transfer*

HEAT AND THERMAL EXPANSION 1

TOPIC 1

TEMPERATURE AND HEAT

How do we feel hot and cold? When we touch a piece of ice, heat transfers from our bodies to the ice, causing us to feel cold. Similarly, when we touch a hot cup of tea, heat flows from the hot cup of tea to our body, making us feel hot. The terms "hot" and "cold" are related with heat.

Temperature is "the degree of hotness or coldness of a body and it is the condition of the body which determines the direction of flow of heat". The S.I. unit of temperature is Kelvin (K).

Heat is "a form of energy which flows from one body to another body or its surroundings because of the temperature difference between the two bodies".

Heat is a measure of a body's total thermal energy, which is the sum of the kinetic energies of all molecules due to translational, rotational and vibrational motions. The 'Joule' is the SI unit of heat. Calorie is another type of heat unit. 1 calorie is the amount of heat required to raise the temperature of one gram of water by one degree Celsius.

1 Calorie = 4.18 J.

Example 1.1: Why will a watermelon stay cool for a longer time than sandwiches when both are removed from a fridge on a hot day?

Ans. Watermelon having higher specific heat will enhance its temperature slowly compared to the sandwiches which have lower specific heat.

TOPIC 2

MEASUREMENT OF TEMPERATURE

The body's temperature can be measured using a thermometer.

A thermometer makes use of some measurable property of a substance, like volume, changes linearly with temperature.

A common thermometer is the liquid-in-glass type, and the most commonly used liquids are mercury and alcohol.

Different Scales of Temperature

Two fixed reference points are required for the definition of any standard scale. Water's ice point (lower fixed point) and steam point (upper fixed point) are two useful fixed points.

The fixed point for different scales are:

Celsius or centigrade scale

Lower fixed point = 0°C;

Upper fixed point = 100°C;

No. of divisions = 100

Fahrenheit scale

Lower fixed point = 32°F;

Upper fixed point = 212°F;

No. of divisions = 180

Absolute scale of temperature or Kelvin scale

Kelvin scale is called as absolute scale because it is practically impossible to go beyond 0 K on the negative side.

Lower fixed point = 0 K = –273.15°C;

Upper fixed point = 100 K = – 173.15°C;

No. of divisions = 100

Relations between Celsius, Fahrenheit and Kelvin Scale:

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

Example 1.2: 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]

Ans. The relation between the Kelvin scale and the Celsius scale is:

$$T_K - 273.15 = T_C$$

$$\Rightarrow \quad T_C = T_K - 273.15$$

For neon, $T_K = 24.57$ K

$$T_C = 24.57 - 273.15$$

$$= -248.58°C$$

For CO_2, $T_K = 216.55$ K

$T_C = 216.55 - 273.15$

$= -56.60°C$

Also, the relation between the Kelvin scale and the Fahrenheit scale is:

$$\frac{T_K - 273.15}{100} = \frac{T_F - 32}{180}$$

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

Now,

For neon, $T_F = 24.57$ K

$$\therefore \quad T_F = \frac{9}{5}[24.57 - 273.15] + 32$$

$$= -415.44°F$$

For CO_2, $T_K = 216.55$ K

$$\therefore \quad T_F = \frac{9}{5}(216.55 - 273.15) + 32$$

$$= -69.88°F$$

Example 1.3: Two absolute scales A and B have triple points of water defined to be 200 A and 350 B. What is the relation between T_A and T_B?[NCERT]

Ans. Triple point of water on scale A = 200A

Triple point of water on scale B = 350B

As, that triple point of water on two scales A and B,

Then,

$$\frac{273.16}{200}T_A = \frac{273.16}{350}T_B$$

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

$$T_A = \frac{4}{7}T_B$$

Example 1.4: The pressure and temperature of a gas are 2 atm and 27°C respectively. Find:

(A) Number of moles per cm^3

(B) Number of molecules per m^3

Ans. (A) $PV = nRT$.

$$2 \times 10^5 \times V = n \times 8.3 \times 300$$

$$\frac{n}{V} = \frac{2 \times 10^3}{8.3 \times 3} \text{ moles/m}^3$$

Number of moles per cm^3

$$= \frac{2 \times 10^3}{8.3 \times 3} 10^{-6}$$

$$= 8.03 \times 10^{-5} \text{ moles/cm}^3$$

(B) Number of moles per m^3

$$= \frac{2 \times 10^3}{8.3 \times 3} \text{ moles/m}^3$$

Number of molecules per m^3

$$= \frac{2 \times 10^3}{8.3 \times 3} \times 6 \times 10^{23}$$

$$= 4.8 \times 10^{25} \text{ molecules/m}^3$$

TOPIC 3

IDEAL-GAS EQUATION AND ABSOLUTE TEMPERATURE

The properties of gases are entirely different from those of solids and liquids. In the case of gases, thermal expansion is very large as compared to solids and liquids. To state the conditions of a gas, its volume, pressure and temperature must be specified.

Intermolecular force

Solid > Liquid > Real gas > Ideal gas (zero)

Potential energy

Solid < Liquid < Real gas < Ideal gas (zero)

Ideal Gas Concept

Volume of gas molecules is negligible as compared to the volume of the container.

So, Volume of gas = Volume of container (Except 0 K).

No intermolecular forces act between gas molecules.

Properties of Ideal Gas

A gas which follows all gas laws and gas equations at every possible temperature and pressure is known as an Ideal or Perfect gas. Ideal gas molecules can do only translational motion, so their kinetic energy is only translational kinetic energy. Ideal gas cannot be liquefied because the intermolecular force is zero. Potential energy of ideal gas is zero so internal energy of ideal gas is perfectly translational K.E. of gas. It is directly proportional to absolute temperature. So, Internal energy depends only and only on its temperature.

$$E_{Trans} \propto T$$

All real gases behave as an ideal gas at high temperatures, low pressure and low density. Gas molecules have point mass, negligible volume and velocity are very high (10^7 cm/s). That's why there is no effect of gravity on them.

Equation of State for Ideal Gas

$$PV = \mu RT$$

$$PV = \frac{M}{M_W}RT$$

$$= \left[\frac{mN}{mN_0}\right]RT$$

$$= \left[\frac{N}{N_0}\right]RT$$

$$= NKT$$

[Where, μ = number of moles of gas.]

$$\frac{P}{\rho} = \frac{RT}{M_W} = \frac{KT}{m}$$

(K = Boltzmann constant)

Gas Laws

Boyle's law

According to it, for a given mass of an ideal gas at constant temperature, the volume of a gas is inversely proportional to its pressure. *i.e.*,

$$V \propto \frac{1}{P}$$

If m and T = constant.

$$P_1V_1 = P_2V_2$$

Charles's law

According to this law, for a given mass of an ideal gas at constant pressure, the volume of a gas is directly proportional to its absolute temperature.

If m and P = constant.

i.e., $V \propto T$.

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

Gay-lussac's law

According to this law, for a given mass of an ideal gas at constant volume, the pressure of a gas is directly proportional to its absolute temperature.

If m and V = constant.

i.e., $P \propto T$.

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

Avogadro's law

According to this law, at the same temperature and pressure, an equal volume of all gases contains an equal number of molecules. *i.e.*, $N_1 = N_2$.

If P, V and T are the same.

⚠ **Caution**

➥ *Students should know that the molecules of a gas are in a state of continuous random motion. They move with all possible velocities in all possible directions and obey Newton's law of motion.*

Example 1.5: Two ideal gas thermometers *A* and *B* use oxygen and hydrogen respectively. The following observations are made:

Temperature	Pressure Thermometer (A)	Pressure Thermometer (B)
Triple point of water	1.250×10^5 Pa	0.200×10^5 Pa
Normal melting point of Sulphur	1.797×10^5 Pa	0.287×10^5 Pa

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

(B) What do you think is the reason behind the slight difference in answers of thermometers A and B? (The thermometers are not faulty). What further procedure is needed in the experiment to reduce the discrepancy between the two readings? [NCERT]

Ans. (A) Triple point of water = 273.16 K.

Let T be the melting point of sulphur.

For thermometer A,

$$T = \frac{P}{P_W} \times 273.16$$

$$= \frac{1.797 \times 10^5}{1.250 \times 10^5} \times 273.16$$

$$= 392.69 \text{ K} \qquad [\because P \propto T]$$

For thermometer B,

$$T = \frac{0.287 \times 10^5}{0.200 \times 10^5} \times 273.16$$

$$= 391.98 \text{ K}$$

(B) The cause of this slight difference in the two temperatures is that the oxygen and the hydrogen gases are not perfectly ideal.

To reduce the discrepancy, the readings should be taken at a very low pressure where the gases approach to the ideal gas behaviour.

Example 1.6: Given below are observations on molar specific heats at room temperature of some common gases.

Gas	Molar specific heat (C_v) (cal mol^{-1} K^{-1})
Hydrogen	4.87
Nitrogen	4.97
Oxygen	5.02
Nitric oxide	4.99

Gas	Molar specific heat (C_v) (cal mol^{-1} K^{-1})
Carbon monoxide	5.01
Chlorine	6.17

The measured molar specific heats of these gases are markedly different from those for mono-atomic 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? [NCERT]

Ans. The gases are diatomic and have other degrees of freedom (*i.e.*, have other modes of motion) possible besides the translational degrees of freedom. To raise the temperature of the gas by a certain amount, heat is to be supplied to increase the average energy of all the modes. Consequently, molar specific heat of diatomic gases is more than that of monoatomic gases. It can be shown that if only rotational modes of motion are considered, the molar specific heat of diatomic gases is nearly $\frac{5}{2}R$ which agrees with the observations for all the gases listed in the table, except chlorine. The higher value of molar specific heat of chlorine indicates that besides rotational modes, vibrational modes are also present in chlorine at room temperature.

Example 1.7: Case Based:

Ideal gas laws are also at work in closed, sealed areas like aeroplanes where there must be a proper pressure balance between the air inside and outside the aircraft. Information on the average pressure in the cabin and the surrounding atmosphere, along with the percentage of oxygen in the atmosphere and the ideal gas laws, indicate how much oxygen is required to maintain the proper equilibrium between the air inside and outside the cabin and keep the air in the cabin fresh.

(A) If increasing the temperature of a gas by 5°C, increases its pressure by 0.5 percent from its initial value at a constant volume, what is the initial temperature of the gas?

(B) Calculate the value of the universal gas constant at STP.

(C) At a temperature of 27°C and a pressure of 1×10^5 N/m², a closed container with a volume of 0.02 m³ contains a mixture of neon and argon gases. The mixture has a total mass of 28 g. If neon and argon have gramme molecular weights of 20 g and 40 g, respectively. Determine the mass of each individual gas in the container, assuming they are ideal. Assume, R = 8.314J/mol-K.

(a) 12 g (b) 24 g
(c) 36 g (d) 48 g

(D) Determine the Sun's temperature. If the density is 1.4 g cm³, the pressure is 1.4×10^9 atmospheres and the average molecular weight of gases in the sun is 2 g/mole, and Assume, R = 8.314 J/mol-K.

(a) 1.0×10^5K (b) 2.4×10^5K
(c) 2.4×10^7K (d) 1.0×10^7K

(E) Assertion (A): We cannot change the temperature of a body without giving (or taking) heat to (or from) it.

Reason (R): According to principle of conservation of energy the total energy of the system should remain conserved.

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

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Ans. (A) At constant volume.

$$T \propto P$$

$$\frac{\Delta T}{T} \times 100 = \frac{\Delta P}{P} \times 100 = 0.5$$

$$T = \frac{5 \times 100}{0.5} = 1000 \text{ K}$$

(B) Universal gas constant is given by

$$R = \frac{PV}{T}$$

One mole of all gases at S.T.P occupy volume,

$V = 22.4$ liter $= 22.4 \times 10^{-3} m^3$

$P = 760$ mm of Hg

$= 760 \times 10^{-3} \times 13.6 \times 10^3 \times 9.80$ Nm^{-2}.

$T = 273.16$ K

$$R = \frac{760 \times 10^{-3} \times 13.6 \times 10^3 \times 9.80 \times 22.4 \times 10^{-3}}{273.16}$$

$= 8.314$ J $mol^{-1}K^{-1}$

(C) *(b) 24 g*

Explanation: Let m gram be the mass of neon.

Then, the mass of argon is $(28 - m)$gram

Total number of moles of the mixture,

$$\mu = \frac{m}{20} + \frac{28-m}{40}$$

$$= \frac{28+m}{40}$$

Now, $$\mu = \frac{PV}{RT}$$

$$= \frac{1 \times 10^5 \times 0.02}{8.314 \times 300} = 0.8$$

So, by both equations,

$$\frac{28+m}{40} = 0.8$$

$$28 + m = 32$$

$$m = 4 \text{ gram}$$

or mass of argon = (28 – 4) g = 24 g

(D) *(c) 2.4×10^7 K*

Explanation:

$$PV = \mu RT$$

$$T = \frac{PV}{\mu R}$$

But $\mu = \frac{M}{M_W}$ and $\rho = \frac{M}{V}$

$$\therefore \quad \mu = \frac{\rho V}{M_W}$$

$$T = \frac{PVM_W}{\rho VR} = \frac{PM_W}{\rho R}$$

$$= \frac{1.4 \times 10^9 \times 1.01 \times 10^5 \times 2 \times 10^{-3}}{1.4 \times 1000 \times 8.4}$$

$$= 2.4 \times 10^7 \text{ K}$$

(E) *(d) A is false and R is also false.*

Explanation: A body's temperature can be altered without adding or removing heat. While no heat is supplied to or removed from the system during the corresponding changes, for instance, the temperature increases during adiabatic compression and falls during adiabatic expansion.

TOPIC 4

THERMAL EXPANSION

In most materials, it is widely observed, that they expand when heated and contract when cooled. This expansion is multi-dimensional. It has been demonstrated experimentally that a fractional change in any dimension is proportional to a change in temperature.

Types of Thermal Expansion

Linear Expansion

The increase in length of a solid caused by heating is known as linear expansion.

Coefficient of linear expansion,

$$\alpha = \frac{\text{Change in length}}{\text{Initial length} \times \text{Increase in temperature}}$$

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

Final length of the solid,

$$l_2 = l_1 [1 + \alpha (T_2 - T_1)].$$

Superficial Expansion

The increase in surface area of a solid caused by heating is known as superficial expansion.

Coefficient of superficial expansion,

$$(\beta) = \frac{\text{Change in area}}{\text{Original area} \times \text{increase in temperature}}$$

$$\beta = \frac{\Delta S}{S \Delta T}$$

Final surface area of the solid

$$S_2 = S_1 [1 + \beta (T_2 - T_1)].$$

Cubical Expansion

The increase in volume of a solid caused by heating is known as cubical expansion.

Coefficient of cubical expansion

$$\gamma = \frac{\text{Change in volume}}{\text{Initial volume} \times \text{Increase in temperature}}.$$

$$\gamma = \frac{\Delta V}{V \Delta T}$$

Final volume of the solid

$$V_2 = V_1 [1 + \gamma (T_2 - T_1)]$$

The S.I. unit of α, β and γ is K^{-1} (per Kelvin).

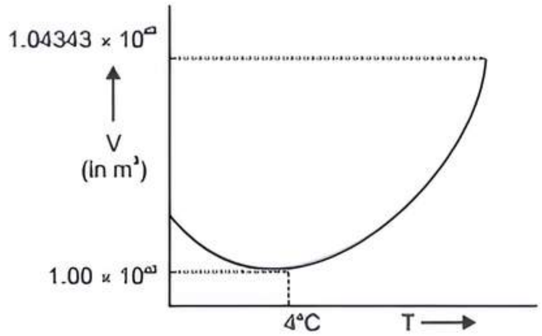
Relation Between α, β and γ:

$$\alpha = \frac{\beta}{2} = \frac{\gamma}{3}$$

α, β and γ are characteristics of the substance.

Anomalous Expansion of Water

Water exhibits unusual behaviour. It shrinks when heated between 0°C and 4°C. At 4°C, water has the highest density. This property has a significant environmental impact. The water at the bottom of lakes and ponds does not freeze. This allows marine animals to survive and move freely near the seafloor.



Related Theory

➥ *When a gas expands, its volume increases, then final pressure is less for adiabatic expansion. But, when a gas compresses, its volume decreases, then the final pressure is more in case of adiabatic compression.*

Thermal Stress and Thermal Strain

Thermal stress forms in a rod when its thermal expansion is prevented by rigidly fixing its ends. The associated compressive strain is given by,

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

Thermal stress, $\frac{\Delta F}{A} = Y\left(\frac{\Delta l}{l}\right)$

Some Applications of Thermal Expansion in Solids

(1) Bimetallic strips

(2) Effect of temperature on the pendulum clock

Example 1.8: 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 lengths are at 40.0°C? Is there a thermal stress developed at the function? The ends of the rod are free to expand (coefficient of linear expansion of brass = 2.0 × 10^{-5} K^{-1}, steel = 1.2 × 10^{-5} K^{-1}). [NCERT]

Ans. $\Delta l_1 = l_2\alpha_1 . \Delta T = 50 \times (2.1 \times 10^{-5}) \times (250 - 40)$
$= 0.2205$ cm

$\Delta l_2 = l_2\alpha_2 . \Delta T = 50 \times (1.2 \times 10^{-5}) \times (250 - 40)$
$= 0.126$ cm

Change in length of the combined rod

$\Delta l = \Delta l_1 + \Delta l_2 = 0.2205 + 0.126 = 0.3465$ cm.

Example 1.9: Find the length of a steel rod which would have the same difference in length with a copper rod of length 24 cm at all temperatures. (α_{copper} = 18 × 10^{-6} K^{-1}, α_{steel} = 12 × 10^{-6} K^{-1}). [NCERT]

Ans. As $\Delta l = l_0 \alpha \Delta T$

According to the question,

$$l_{steel}\ \alpha_{steel}\ \Delta T = l_{copper}\ \alpha_{copper}\ \Delta T$$

$$l_{steel} = \frac{l_{copper}\ \alpha_{copper}}{\alpha_{steel}}$$

$$= \frac{24 \times 18 \times 10^{-6}}{12 \times 10^{-6}} = 36 \text{ cm}$$

TOPIC 5

SPECIFIC HEAT CAPACITY

Change in Temperature

When the temp changes on heating,

Then,

Heat supplied ∝ Change in temperature (ΔT)
∝ Amount of substance (m/n)
∝ Nature of substance (s/C)

$\Delta H = ms\Delta T$

Where, m = Mass of a body
s = specific heat capacity per kg
ΔT = Change in temperature

or $\Delta H = nC\Delta T$

Where, n = Number of moles
C = Specific/Molar heat Capacity per mole
ΔT = Change in temperature

Specific Heat Capacity

Amount of heat required to raise the temperature of unit mass of the substance through one degree.

Specific heat capacity, $c = \frac{S}{m} = \frac{Q}{m\Delta T}$

Its S.I. unit is J/kgK.

The specific heat capacity of water is 4186.0 J $kg^{-1}K^{-1}$ = 4200 J $kg^{-1}K^{-1}$ at 20°C.

Molar Heat Capacity

The amount of heat needed to raise the temperature of a unit mole of a substance by one degree.

Molar specific heat capacity (C) = Molar mass × Specific heat

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

Where m is the number of moles. The S.I. unit of molar specific heat capacity is J $mol^{-1}K^{-1}$.

Specific Heat of a Gas

There are two types of specific heat in a gas:

Specific heat at constant volume (C_v)

If heat is transferred to a sample while the volume of the sample remains constant, the specific heat obtained using this method is known as molar specific heat capacity at constant volume.

Molar specific heat of a gas at constant volume: $C_V = mC_V$

Specific heat at constant pressure (C_P)

When heat is transferred to a sample while it is held at constant pressure, the specific heat obtained is referred to as molar specific heat capacity at constant pressure.

Molar specific heat of a gas at constant pressure,

$$C_P = mC_P$$

The ratio of two specific heats of a gas is a constant for each gas and depends on its atomicity.

$$\frac{C_P}{C_V} = \gamma$$

Also, $C_P - C_V = R$ as $C_P > C_V$

When heated to the same temperature, the water equivalent of a body is defined as the mass of water that absorbs the same amount of heat as the body itself.

Example 1.10: **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 minutes, assuming 50% of power is used up in heating the machine itself or lost to the surroundings?**

Specific heat of aluminium = 0.91J/$g^{-1}K^{-1}$. **[NCERT]**

Ans. Total energy = P × t = 10^4W ×150 S = 15 × 10^5J

As 50% of the heat is lost.

$$\text{Energy available} = \frac{50}{100} \times 15 \times 10^5$$

$$= 7.5 \times 10^5 \text{J}$$

$$Q = m\,C\Delta T$$

$$= 8 \times 10^3 \times 0.91 \times \Delta T$$

$$7.5 \times 10^5 = 8 \times 10^3 \times 0.91 \times \Delta T$$

$$\Delta T = \frac{7.5\times10^5}{8\times10^3\times0.91} = 103°C$$

Example 1.11: **In an experiment on the specific heat of a metal, a 0.20 kg block of a 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. If heat losses to the surroundings are not negligible, what is your answer, greater or smaller than the actual value for specific heat of the metal?** **[NCERT]**

Ans. Mass of the metal m_1 = 0.2 kg = 200 g

Fall in temperature Δt_1 = 150 – 40 = 110°C

Heat lost by the metal = $\Delta Q_1 = mC\,\Delta T_1$

[C = specific heat of metal] = 200 × C ×110

Volume of water = 150 cm^3;

Mass of water, m_2 = 150 g

Water equivalent of calorimeter,

w = 0.025 kg

= 25 g

Rise in temperature of water and calorimeter

$= \Delta T_2 = 40 - 27 = 13°C$

Heat gained by water and calorimeter

$= \Delta Q_2 = (m_2 + w)\,\Delta T_2$

= (150 + 25) × 13

= 175 × 13

∴ Heat lost = Heat gained,

200 × C × 110 = 175 × 13

C = 0.1

OBJECTIVE Type Questions

[1 mark]

Multiple Choice Questions

1. **A liquid cools from 60°C to 40°C in 10 minutes. What is the temperature of the liquid in the next 10 minutes? Given the temperature of the surroundings is 5°C.**

(a) 20.27°C (b) 27.27°C

(c) 22.27°C (d) 23.27°C

Ans. *(b) 27.27°C*

Explanation: In first case, θ_1 = 60°C, θ_2 = 40°C and θ_0 = 5°C, t = 10 minutes

$$\frac{\theta_1-\theta_2}{t}=K\left(\frac{\theta_1+\theta_2}{2}-\theta_0\right)$$

$$\frac{20}{10}=K(50-5)=45K$$

$$K=\frac{2}{45}$$

and in second case,

$\theta_1 = 40°C, \theta_2 = ?$

and $\theta_0 = 5°C, t = 10$ minutes

$$\frac{\theta_1-\theta_2}{t}=K\left(\frac{\theta_1+\theta_2}{2}-\theta_0\right)$$

$$\frac{40-\theta_2}{10}=\frac{2}{45}\left(\frac{40+\theta_2}{2}-5\right)$$

$$\frac{40-\theta_2}{10}=\frac{30+\theta_2}{45}$$

$$\theta_2 = 27.27°C$$

Caution

➥ *Students must know that although the temperature can be raised without limit, it cannot be lowered without limit and theoretically limiting low temperature is taken to be zero on the Kelvin scale (i.e. no negative temperature on the Kelvin scale is possible).*

2. **The solar constant, which is the energy arriving per second at the earth from the sun, is 1400 Wm^{-2}. Calculate the surface temperature of the sun, given that the sun's radius = 7 × 10^5 km, the distance of the sun from the earth = 1.5 × 10^8 km and Stefan's constant = 5.7 × 10^{-8} Wm^{-2} K^{-4}.**

(a) 5000 K **(b) 5400 K**

(c) 5800 K **(d) 6000 K**

Ans. *(c) 5800 K*

Explanation: Let the temperature of sun's surface = T

Area of sun, A = $4\pi r_s^2$ where, r_s =radius of sun

Total energy per second radiated from the sun's surface.

According to Stefan's law, $A\sigma T^4 = 4\pi r_s^2 \sigma T^4$.

This energy falls all around a sphere of radius r_0, where r_0 is the radius of the earth's circular orbit around the sun.

Since the area of the sphere = $4\pi r_0^2$ therefore, Energy per second falling on a unit Area.

$$=\frac{1}{4\pi r_0^2}\times 4\pi r_s^2\sigma T^4=\left(\frac{s}{r_0}\right)^2\sigma T^4$$

$$T^4=\frac{1400}{5.7\times10^{-8}}\times\left(\frac{1.5\times10^8}{7\times10^5}\right)^2$$

$$T = 5800K$$

Related Theory

➥ *The force of attraction between a hollow spherical shell of uniform density and a point mass situated outside is just as if the entire mass of the shell is concentrated at the centre of the shell.*

3. **Two stars radiate maximum energy at wavelength 3.6 × 10^{-7} m and 4.8 × 10^{-7} m respectively. What is the ratio of their temperature?**

(a) 2 : 3 **(b) 5 : 1**

(c) 4 : 3 **(d) 1 : 1**

Ans. *(c) 4 : 3*

Explanation: $\lambda_m = 3.6 \times 10^{-7}$M, $\lambda_m' = 4.8 \times 10^{7}$M

According to Wein's displacement law

$$\lambda_m T = \lambda'_m T'$$

Where, T and T' be the temperature of the two stars

$$\frac{T}{T'}=\frac{\lambda_m'}{\lambda_m}=\frac{4.8\times10^{-7}M}{3.6\times10^{-7}M}=\frac{4}{3}$$

Related Theory

➥ *Though when the universe was created 10^{10} years ago. Its temperature was about 10^{32}K which at present is about 3 K. The highest laboratory temperature is about 10^8K (In a fusion test reactor) while this lowest was 10^{10}K (achieved in 1999 through nuclear spin cooling). Theory has established that zero Kelvin temperature can never be achieved practically.*

4. **A liquid with a coefficient of cubical expansion γ is contained in a vessel having a coefficient of linear expansion $\frac{\gamma}{3}$. When heated, what will happen to the level of the liquid in the vessel?**

(a) It falls

(b) It rises

(c) It may rise or fall depending upon the nature of the container

(d) Remains unchanged

Ans. *(d) Remains unchanged*

Explanation: If linear expansion is α,

Then $\gamma = 3\alpha$

Here, $\alpha = \frac{\gamma}{3}$

So, $\gamma = 3\alpha$

Thus, $\gamma' = \gamma$

Hence, volume expansion remains unchanged.

5. **A beaker is completely filled with water at 4°C. It will overflow.**

(a) when heated but not when cooled

(b) when cooled but not when heated

(c) both when heated or cooled

(d) neither when heated nor cooled [Diksha]

Ans. *(c) both when heated or cooled*

Explanation: Volume of water is minimum at 4°C. It will overflow if both heated and cooled above and below 4°C respectively.

Related Theory

Water equivalent = heat capacity of a body
= mass × specific heat
$W = mc$

6. The length of rod of aluminium is 1 m and its area of cross-section is 5×10^4 m². Its one end is kept at 25°C and the other end is at 50°C. The heat that will flow in the rod in 5 minutes when K for aluminium is 2×10^{-1} kilo-Joule/metre-second will be:
(a) 1435.5 cal (b) 1345.5 cal
(c) 1385.5 cal (d) 1240.5 cal [Diksha]

Ans. *(a) 1435.5 cal*

Explanation: As $Q = KA\frac{(T_1 - T_2)t}{L}$

$$= \frac{200 \times 5 \times 10^{-4} \times 200 \times 300}{1.0}$$

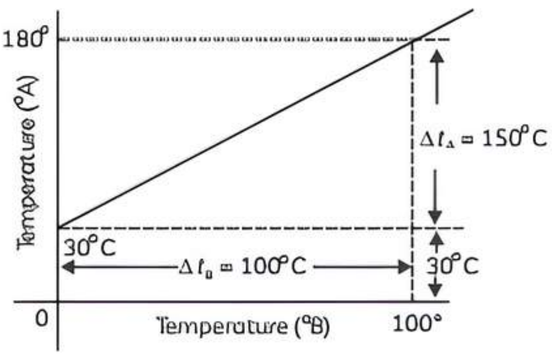
$$= 6000\,J = \frac{6000}{4.18} = 1435.4\,cal$$

7. A bimetallic strip is made of aluminium and steel ($\alpha_{Al} > \alpha_{Steel}$) on heating, the strip will:
(a) remain straight
(b) get twisted
(c) bend with aluminium on concave side
(d) bend with steel on concave side
[NCERT Exemplar]

Ans. *(d) bend with steel on concave side*

Explanation: Both strips of *Al* and *Steel* are fixed together initially in bimetallic strip. When both are heated then expansion in steel will be smaller than in aluminium. So *Al* strip will be convex side and steel on concave side verifies the last option.

8. The graph between the two temperature scales A and B is shown in the figure. Between the upper fixed point and lower fixed point, there are 150 equal divisions on scale A and 100 on scale B. The relationship for conversion between the two scales is given by:



(a) $\frac{t_A - 180}{100} = \frac{t_B}{150}$ (b) $\frac{t_A - 30}{150} = \frac{t_B}{100}$

(c) $\frac{t_B - 180}{150} = \frac{t_B}{100}$ (d) $\frac{t_B - 40}{100} = \frac{t_A}{180}$

[NCERT Exemplar]

Ans. *(b)* $\frac{t_A - 30}{150} = \frac{t_B}{100}$

Explanation: It is clear from the graph in t_A scale that the lower fixed point (LFP) is 30° and upper fixed point (UFP) is 180°.
Similarly in scale °B,
UFP = 100° and LFP = 0°.

Hence, $\frac{t_A - (LFP)_A}{(UFP)_A - (LFP)_A} = \frac{t_B - (LFP)_B}{(UFP)_B - (LFP)_B}$

$$\frac{t_A - 30}{180 - 30} = \frac{t_B - 0}{100 - 0}$$

$$\frac{t_A - 30}{150} = \frac{t_B}{100}$$

Assertion-Reason 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 A and R are true and R is the correct explanation of A.
(b) Both A and R are true and R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false and R is also false.

9. Assertion (A): When a solid iron ball is heated, the percentage increase in volume is the greatest.
Reason (R): The coefficient of superficial expansion is twice the coefficient of linear expansion, whereas the coefficient of volume expansion is three times the coefficient of linear expansion.

Ans. *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: As $\beta = 2\alpha$ and $\gamma = 3\alpha$, *i.e.*, coefficient of volume expansion of solid is three times the coefficient of linear expansion and 1.5 times the coefficient of superficial expansion, on heating a solid iron ball, percentage increase in its volume is largest.

10. Assertion (A): The formation of land and sea breezes is caused by specific heat capacity.
Reason (R): The specific heat of water is more than land.

Ans. (a) *Both A and R are true and R is the correct explanation of A.*

Explanation: The temperature of land rises rapidly as compared to sea because the specific heat of land is five times less than that of seawater. Thus, the air above the land becomes hot and light rises up because of pressure drops over land. To compensate for the drop of pressure, the cooler air from the sea starts blowing towards land, so, setting up the sea breeze. During night land as well, the sea radiates heat energy. The temperature of landfalls is more rapid as compared to seawater, as seawater consists of a higher specific heat capacity. The air above seawater being warm and light rises up and to take its place the cold air from land starts blowing towards sea and so sets up a breeze.

11. Assertion (A): **A body's specific heat is always greater than its thermal capacity.**

Reason (R): **Thermal capacity is the amount of energy required to raise the temperature of a unit mass of the body by one degree.**

Ans. (d) *A is false and R is also false.*

Explanation: Specific heat of a body is the amount of heat required to raise the temperature of a unit mass of the body through unit degree. When the mass of a body is less than unity, then its thermal capacity is less than its specific heat and *vice-versa*.

CASE BASED Questions (CBQs)

[**4** & **5** marks]

Read the following passages and answer the questions that follow:

12. *Even in its solid form, glass exhibits the molecular structure of a stiff liquid. For this reason, glass at room temperature is sometimes referred to as a supercooled liquid. As it is heated, glass gradually begins to behave more and more like a liquid until, at temperatures above 2000°F (1093°C), it will flow easily, with a consistency similar to honey. The temperatures at which glass is worked in a kiln are usually between 1000–1700°F (538–927°C). Within this range, a wide variety of effects may be achieved by using a variety of processes.*

(A) **Boiling water is used to dip a centigrade and a Fahrenheit thermometer. The temperature of the water is reduced until the thermometer reads 140°F. What is the temperature drop as measured according to the centigrade thermometer?**

(B) **Why do the ends of a glass tube become rounded on heating?**

(C) **The coolant used in a nuclear plant should have high specific heat. Why?**

Ans. (A) Here, F = 140°

Using,

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

$$\frac{140-32}{9}=\frac{C}{5}$$

$$C = 60°C$$

So, fall in temperature in °C is,

$$100 - 60 = 40°C$$

(B) When glass is heated, it melts. The surface of this liquid tends to have a minimum area. For a given volume, the surface area is minimum for a sphere. This is why the ends of a glass tube become rounded on heating.

(C) So that, it absorbs more heat with a comparatively small change in temperature and extracts a large amount of heat.

13. *Many solids are made up of crystals, regular shapes composed of molecules joined to one another as though on springs. A spring that is pulled back, just before it is released, is an example of potential energy, or the energy that an object possesses by virtue of its position. For a crystalline solid at room temperature, potential energy and spacing between molecules are relatively low. But as temperature increases and the solid expands, the space between molecules increases, as does the potential energy in the solid.*

(A) The length of a copper rod of 88 cm and an aluminium rod of unknown length increases independently of temperature increase. Aluminium rod has a length of ($\alpha_{Cu} \doteq 1.7 \times 10^{-5}$ K^{-1}, $\alpha_{Al} = 2.2 \times 10^{-5}$ K^{-1}):

(a) 68 cm (b) 6.8 cm

(c) 113.9 cm (d) 88 cm

(B) The linear expansion coefficients of brass and steel rods are α_1 and α_2, respectively. Brass and steel rods have lengths of l_1 and l_2, respectively. Which of the following relationships holds true if $(l_2 - l_1)$ remains constant at all temperatures?

(a) $\alpha_1^2 l_2 = \alpha_2^2 l_1$ (b) $\alpha_1 l_1 = \alpha_2 l_2$

(c) $\alpha_1 l_2 = \alpha_2 l_1$ (d) $\alpha_1 l_2^2 = \alpha_2 l_1^2$

(C) Glycerin has a coefficient of volume expansion of 5×10^{-4} K^{-1}. The fractional change in density of glycerin for a temperature increase of 40°C is:

(a) 0.025 (b) 0.010

(c) 0.015 (d) 0.020

(D) Water has a density of 998 kg/m^3 at 20°C and 992 kg/m^3 at 40°C, water's coefficient of volume expansion is:

(a) 3×10^{-4} /°C (b) 5×10^{-4}/°C

(c) 7×10^{-4}/°C (d) 2×10^{-4}/°C

(E) A uniform metallic rod rotates about its perpendicular bisector with constant angular speed. If it is heated uniformly to raise, its temperature slightly:

(a) Its speed of rotation increases.

(b) Its speed of rotation decreases.

(c) Its speed of rotation remains the same.

(d) Its speed increases because its moment of inertia increases

Ans. (A) *(a) 68 cm*

Explanation: As $\alpha_{cu} l_{cu} = \alpha_{Al} l_{Al}$

$$1.7 \times 10^{-5} \times 88 \text{ cm} = 2.2 \times 10^{-5} \times l_{Al}$$

$$l_{Al} = \frac{1.7 \times 88}{2.2}$$

$$= 68 \text{ cm}$$

(B) *(b)* $\alpha_1 l_1 = \alpha_2 l_2$

Explanation:

Linear expansion of brass $= \alpha_1$

Linear expansion of steel $= \alpha_2$

Length of brass rod $= l_1$

Length of steel rod $= l_2$

On increasing the temperature of the rods by ΔT, new lengths would be,

$$l'_1 = l_1(1 + \alpha_1 \Delta T)$$

$$l'_2 = l_2(1 + \alpha_2 \Delta T)$$

On subtracting the above both equations,

$$l'_2 - l'_1 = (l_2 - l_1)(l_2\alpha_2 - l_1\alpha_1)\Delta T$$

$$l'_2 - l'_1 = l_2 - l_1$$

For all temperatures

$$(l'_2\alpha_2 - l'_1\alpha_1) = 0$$

or, $$l_1\alpha_1 = l_2\alpha_2$$

(C) *(d) 0.020*

Explanation: Let ρ_0 and ρ_T be densities of glycerin at 0°C and T°C respectively. Then

$$P_T = P_0 (1 - \gamma\Delta T)$$

where, γ is the coefficient of volume expansion of glycerin and ΔT is a rise in temperature.

$$\frac{\rho_T}{\rho_0} = 1 - \gamma\Delta T$$

or $$\gamma\Delta T = 1 - \frac{\rho_T}{\rho_0}$$

Thus, $$\frac{\rho_0 - \rho_T}{\rho_0} = \gamma\Delta T$$

Here, $\gamma = 5 \times 10^{-4}$ K^{-1} and $\Delta T = 40$°C

The fractional change in the density of glycerin,

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

$$= (5 \times 10^{-4})(40K) = 0.020$$

(D) *(a) 3×10^{-4}/°C*

Explanation: Here,

$$\rho_{T_2} = \frac{\rho_{T_1}}{(1+\gamma\Delta T)} = \frac{\rho_{T_1}}{(1+\gamma(T_2 - T_1))}$$

Here, $T_1 = 20$°C, $T_2 = 40$°C

$\rho_{20°C} = 998 \text{kg/m}^3$, $\rho_{40°C} = 992$ kg/m^3

$$992 = \frac{998}{1+\gamma(40-20)}$$

$$992 = \frac{998}{1+20\gamma}$$

$$992(1 + 20\gamma) = 998$$

$$1 + 20\gamma = \frac{998}{992}$$

$$20\gamma = \frac{998}{992} - 1 = \frac{6}{992}$$

$$\gamma = \frac{6}{992} \times \frac{1}{20} = 3 \times 10^{-4} /°C$$

(E) *(b) its speed of rotation decreases.*

Explanation: On heating a uniform metallic rod, its length will increase, so moment of inertia of rod increased from I_1 to I_2

Now, from the law of conservation of angular momentum,

$$I_1\omega_1 = I_2\omega_2$$

As $I_1 < I_2$, $\omega_1 > \omega_2$,

So, angular speed decreased.

VERY SHORT ANSWER Type Questions (VSA)

[1 mark]

14. A long cylindrical vessel with a linear coefficient of expansion is filled to a certain level with liquid. It is observed that the level of liquid in the cylinder remains constant when heated. What is the liquid's volume coefficient of expansion?

Ans. As the level of the liquid remains the same, therefore the volume coefficient of the liquid is the same as that of the volume coefficient of expansion of the cylinder. Since the volume coefficient of expansion is 3 times the linear coefficient of expansion 'α'. Then the volume coefficient of expansion of the liquid is 3 α.

15. A plank of wood floats on water at 0°C with a volume X above the water's surface. Water temperature is gradually increased from 0°C to 8°C. How does the volume X change as the temperature changes?

Ans. As the density of water increases and volume of water decreases when heated from 0°C to 4°C, so the volume X of the wooden block will increase till the temperature of water becomes 4°C. As the temperature increases from 4°C to 8°C, the density of water decreases and its volume increases above 4°C, therefore the volume X of the block will also decrease.

16. A person weighing 60 kg takes in 2000 kcal diet in a day. If this energy were to be used in heating the person without any losses, what would be his rise in temperature? The specific heat of the human body is 0.83 calg^{-1}°C^{-1}. **[Diksha]**

Ans. Here

$$m = 60 \text{ kg} = 60 \times 10^3 \text{ g}$$

$$\Delta Q = 2000 \text{ kcal} = 2 \times 10^6 \text{ cal}$$

$$s = 0.83 \text{ cal g}^{-1}{}^\circ\text{C}^{-1}$$

$$\Delta Q = ms\Delta T$$

$$2 \times 10^6 = 60 \times 10^3 \times 0.83 \times \Delta T$$

$$\Delta T = 4.016^\circ\text{C}$$

17. Is the bulb of the thermometer made of diathermic walls or adiabatic walls? **[NCERT Exemplar]**

Ans. Adiabatic walls do not allow heat to pass into the mercury of the bulb and diathermic allows it to conduct heat through it. So, in the bulb of the thermometer, diathermic walls are used.

SHORT ANSWER Type-I Questions (SA-I)

[2 marks]

18. At the same temperature, there are two spheres of the same radius and material, but one is solid and the other is hollow. Which of the following spheres will expand more if,

(A) they are heated to the same temperature?

(B) Each of them receives the same amount of heat.

Ans. (A) The hollow sphere may have air or a fluid inside it, which will result in increased pressure by heating, so as to bulge more than the solid sphere. So, the hollow sphere will expand more. But if there is no air then $\Delta V = V\gamma\Delta T$, the both will expand the same.

(B) If the same amount of heat is given to the two spheres, then due to lesser mass, the rise in temperature of the hollow sphere will be more (as $\Delta T = \frac{Q}{Mc}$) and hence, the expansion will be more as

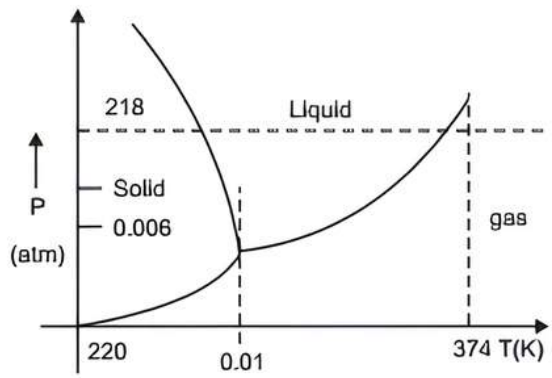
$$\Delta V = \gamma V \Delta T.$$

19. In which you can cool the water faster by keeping it in the tumbler at room temperature (i) by putting the ice in the tumbler and allowing the ice to float naturally or (ii) by putting the ice in the tumbler and then pushing it to the bottom and holding it here? Explain. **[Diksha]**

Ans. When the ice melts, the water in the vicinity is cooled and hence, becomes denser. If the ice is allowed to float naturally in the water *i.e.*, at top, the denser water goes down and the warmer water rises up to replace it. This mixture causes water to cool quickly. If the ice is made to stay at the bottom of the tumbler, the colder water would remain there. As a result, the cooling will be slowed.

20. During summers in India, one of the common practices to keep cool is to make ice balls of crushed ice, dip them them in flavoured sugar syrup and sip it. For this, a stick is inserted into crushed ice and is squeezed in the palm to make into the ball. Equivalently in winter in those areas where it snows, people make snowballs and throw them around. Explain the formation of a ball out of crushed ice or snow in the light of P–T diagram of water. [NCERT Exemplar]

Ans.



From the P–T graph or diagram of water and double headed arrow. Increasing pressure at 0°C and 1 atm takes ice into the liquid state and decreasing pressure in the liquid state at 0°C and 1 atm takes water to the ice state.

When crushed ice is squeezed, some of its parts melt into water at 0°C and fill up the gaps between the ice flakes. During squeezing the ice flakes, the m.p. increased and water at between the flakes also freezes into ice and binds all ice flakes making the ball more stable.

SHORT ANSWER Type-II Questions (SA-II)

[3 marks]

21. A jeweller wishes to harden a sample of pure gold by mixing it with some silver so that the mixture contains 5.0% silver by weight. The jeweller melts some pure gold and then adds the correct weight of silver. The initial temperature of the silver is 27°C. Use the data given below to calculate the initial temperature of pure gold, so that the final mixture is at the melting point of pure gold.

Melting point of gold and silver =1340 K and 1240 K respectively.

Specific heat of gold and silver = 129 $Jkg^{-1}K^{-1}$ and 235 $J\ kg^{-1}K^{-1}$ respectively.

Specific latent heat of fusion of gold and silver = 628 $kJ\ kg^{-1}$ and 105 $kJ\ kg^{-1}$ respectively.

Ans. Let T_1 be the initial temperature of pure gold (liquid) and M be the mass of gold and silver mixture.

Then, mass of the gold in the mixture = 0.95 M

Mass of the silver in the mixture = 0.05 M

Here, specific heat capacity of gold,

$$c_1 = 129\ J\ kg^{-1}K^{-1}$$

specific heat capacity of silver,

$$c_2 = 235\ J\ kg^{-1}K^{-1}$$

Specific latent heat of fusion silver,

$$L_2 = 105\ kJ\ kg^{-1} = 105 \times 10^3 J\ kg^{-1}$$

Initial temperature of pure silver,

$$T_2 = 27 + 273 = 300\ K$$

Final temperature of the mixture,

$$T = 1340\ K$$

Heat lost by gold

$$= 0.95\ M \times c_1 \times (T_1 - T)$$
$$= 122.55\ M \times (T_1 - 1340)$$

Heat lost by silver,

$$= 0.05\ M \times L_2 + 0.05\ M \times c_2 \times (T - T_2)$$
$$= 5{,}250\ M + 12{,}220 = 17{,}470$$

According to the principle of calorimetry,

$$122.55\ M \times (T_1 - 1340) = 17{,}470$$
$$T_1 = 1{,}482.6K$$

22. One day in the morning, Ramesh filled up $\frac{1}{3}$ bucket of hot water from a geyser, to take a bath. Remaining $\frac{2}{3}$ was to be filled by cold water (at room temperature) to bring the mixture to a comfortable temperature. Suddenly Ramesh had to attend to something which would take some time say 5 to 10 minutes before he could take a bath. Now he had two options: (a) fill the remaining bucket completely by cold water and then attend

to the work, (b) first attend to the work and fill the remaining bucket just before taking a bath. Which option do you think would have kept water warmer? Explain.

[NCERT Exemplar]

Ans. By Newton's law of cooling, we know that rate of cooling or loss of heat energy is directly proportional to the difference in the temperature of the body and surroundings.

Hence, First option would be to keep water warmer because the difference between the temperature of the surrounding water and particles of water is small. So, less amount of loss of heat energy in the (a) option. In the (b) option the difference between water and surrounding is large, so a larger amount of heat energy is lost.

23. **Find out the increase in moment of inertia, I of a uniform rod. (Coefficient of linear expansion, α) about its perpendicular bisector when its temperature is slightly increased by ΔT.**

[Diksha]

Ans. Moment of inertia of rod about its axis along perpendicular bisector $= \frac{1}{12}\int ML^2$

$$\Delta L = \alpha L \Delta T$$

$$I' = \frac{1}{12}M[L^2 + \Delta L^2 + 2L\Delta L]$$

$$I' = \frac{M}{12}[L^2 + 2L\Delta L]$$

$$= \frac{ML^2}{12} + \frac{ML\Delta L}{6} \times \frac{2L}{2L}$$

$$I' = \frac{ML^2}{12} + \frac{ML^2}{12} \cdot \frac{2\Delta L}{L}$$

$$= I + I\frac{2\alpha L\Delta T}{L}$$

$$I' = I + I(2\alpha L\Delta T)$$

LONG ANSWER Type Questions (LA)

[4 & 5 marks]

24. **A metallic bob weighs 50 g in air. If it is immersed in a liquid at a temperature of 25°C, it weight 45 g. When the temperature of the liquid is raised to 100°C, it weight 45.1 g. Calculate the coefficient of cubical expansion of the liquid, assuming the linear expansion of the metal to be 12 × 10^{-6} °C^{-1}.**

Ans. Loss in weight in liquid at 25°C = (50 – 45) = 5 gm

Weight of liquid displaced at 25°C = $V_{25}\rho_{25}g$

$$5 = V_{25}\,\rho_{25}\,g \quad \text{... (i)}$$

Similarly,

$$V_{100}\,\rho_{100}\,g = 50 - 45.1 = 4.9 \text{ g} \quad \text{...(ii)}$$

From equations (i) and (ii),

We get,

$$\frac{5}{4.9} = \frac{V_{25}}{V_{100}} \cdot \frac{\rho_{25}}{\rho_{100}}$$

Now,

$$V_{100} = V_{25}(1 + \gamma_{metal} \times 75)$$
$$= V_{25}(1 + 3\alpha_{metal} \times 75)$$
$$= V_{25}(1 + 3 \times 12 \times 10^{-6} \times 75)$$
$$V_{100} = V_{25}(1 + 0.0027)$$
$$V_{100} = V_{25} \times 1.0027$$

Also, $\rho_{25} = \rho_{100}(1 + \gamma \times 75)$

Where, γ = Required coefficient of expansion of the liquid

$$\frac{5}{4.9} = \frac{V_{25}}{V_{25} \times 1.0027} \times \frac{\rho_{100}(1+75\gamma)}{\rho_{100}}$$

$$= \frac{1+75\gamma}{1.0027}$$

$$\gamma = 3.1 \times 10^{-4} (°C)^{-1}$$

25. **(A) 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 lengths are at 40.0°C? Is there thermal stress developed at the junction? The ends of the rod are free to expand.**

(Coefficient of linear expansion of brass = 2 × 10^{-5}°C^{-1}, and that of steel = 1.2 × 10^{-5}°C^{-1}).

(B) A metal plate 16 mm thick has a temperature difference of 32°C between its opposite faces. It transmits 400 Kcal in 2 hours through an area of 5 cm². Calculate the coefficient of thermal conductivity.

(C) Explain why a beaker filled with water at 4°C overflows, if the temperature is decreased or increased.

Ans. (A) Here, L_B = 50 cm, L_s = 50 cm

$$\Delta T = 250 - 40 = 210°C$$

$\alpha_b = 2 \times 10^{-5}\,°C^{-1}$,

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

Let $L = L_B = L_S$

Total change in length is

$$\Delta L = \Delta L_B + \Delta L_S$$
$$= L_B\alpha_b\Delta T + L_S\alpha_s\Delta T$$
$$= L(\alpha_b + \alpha_s)\Delta T$$
$$= 50\,(2 \times 10^{-5} + 1.2 \times 10^{-5}) \times 210$$
$$= 0.336 \text{ cm}$$

(B) Here, $L = 16 \text{ mm} = 16 \times 10^{-3}$ m

$\theta_1 - \theta_2 = 32°C$

$Q = 400 \times 10^3 \times 4.2$ J

$t = 2 \times 60 \times 60$ sec.

$A = 5 \times 10^{-4}\ m^2$

From formula

$$Q_1 = \frac{KA(Q_1 - Q_2)}{L}.$$

$$K = \frac{Q_1}{A(Q_1 - Q_2)t}$$

$$K = \frac{400 \times 10^3 \times 4.2 \times 16 \times 10^{-3}}{5 \times 10^{-4} \times 32°C \times 60 \times 60}$$

$$= 233.3\ Wm^{-1}\,°C^{-1}$$

(C) The reason is the anomalous expansion of water. The maximum density of water occurs at 4°C. So, the water expands whether it is heated above 4°C or cooled below 4°C.

26. Calculate the stress developed inside a tooth cavity filled with copper, when hot tea at a temperature of 57°C is drunk. You can take body (tooth) temperature to be 37°C and α_{cu} = 1.7 × 10^{-5}/K. Bulk modulus for copper β_{cu} = 140 × 10^9 N/m². [NCERT Exemplar]

Ans. Change in temperature, $\Delta T = 57 - 37 = 20°C$

Linear expansion of (tooth) body, $\alpha = 1.7 \times 10^{-5}$/K

Cubical expansion,

$$\gamma = 3\alpha$$
$$= 3 \times 1.7 \times 10^{-5}$$
$$= 5.1 \times 10^{-5}\ K^{-1}$$

Let the volume of the cavity be V and its volume increased by ΔV due to an increase in temperature ΔT.

$$\Delta V = \gamma V \cdot \Delta T$$

$$\frac{\Delta V}{V} = \gamma\Delta T$$

Thermal stress produced = B × Volumetric strain

$$= B.\ \frac{\Delta V}{V} = B.\gamma\Delta T$$

Thermal stress

$$= 140 \times 10^9 \times 5.1 \times 10^{-5} \times 20$$
$$= 14280 \times 10^4$$
$$= 1.428 \times 10^8\ Nm^{-2}$$

This stress is about 10^3 times of atmospheric pressure (*i.e.*, $1.01 \times 10^5\ Nm^{-2}$).

NUMERICAL Type Questions

27. A 4 mm thick metal plate has a temperature difference of 32°C between its faces. It transmits 200 kcal/h over a 5 cm² area. Determine the thermal conductivity of the plate's material. (2m)

Ans. Given: $\Delta x = 4 \text{ mm} = 4 \times 10^{-3}$ m.

$\Delta T = 32°C$,

$$\frac{\Delta Q}{\Delta T} = 200 \text{ kcal/h}$$

$$\frac{\Delta Q}{\Delta T} = \frac{200 \times 1000 \times 4.2}{60 \times 60} \text{ J/s}$$

$$= 233.33 \text{ J/s}$$

$A = 5\ cm^2 = 5 \times 10^{-4}\ m^2$.

K = ?

$$\frac{\Delta Q}{\Delta T} = KA\frac{\Delta T}{\Delta x}$$

$$\frac{\Delta Q}{\Delta T} = K = \frac{\frac{\Delta Q}{\Delta T}}{A\left(\frac{\Delta T}{\Delta x}\right)} = \frac{233.33 \times 4 \times 10^{-3}}{5 \times 10^{-4} \times 32}$$

$$= \frac{233.33 \times 4 \times 10^{-3}}{5 \times 10^{-4} \times 32}$$

$$= 58.33\ W/m°C$$

28. Calculate the temperature difference between two sides of a 20 mm thick iron plate when heat is conducted at a rate of 6 × 10⁵ cal/min m².
(The metal's K is 0.2 cal/s cm °C.) (2m)

Ans. According to the question,

$$\Delta x = 20 \text{ mm}$$
$$= 20 \times 10^{-3} \text{ m}.$$

$$\frac{\Delta Q}{\Delta T} = 6 \times 10^5 \text{ cal. min } m^2$$

$K = 0.2$ cal/s cm °C

$$= \frac{0.2 \times 4.2}{10^{-2}} \text{ J/s/m/°C}$$

$\Delta T = ?$

$$\frac{\Delta T}{\Delta x} = \frac{\frac{\Delta Q}{\Delta T}}{KA}$$

$$\Delta T = \frac{\left(\frac{\Delta Q}{\Delta T}\right)\Delta x}{KA}$$

$$\Delta T = \frac{6 \times 10^5 \times 4.2 \times 20 \times 10^{-3} \times 10^{-2}}{60 \times 0.2 \times 4.2}$$

$\Delta T = 10°C$

29. **The coefficient of volume expansion of mercury is 5.4×10^{-4} °C^{-1}. What is the fractional change in its density for a 80°C rise in temperature?** [Diksha] (2 m)

Ans. Here, $\gamma = 5.4 \times 10^{-4}$ °C, $\Delta T = 80°C$

Let there be *m* grams of mercury and its initial volume be V. Suppose that the volume of the mercury becomes V' after a rise of temperature of 80°C.

Then,

$$V' = V(1 + \gamma \Delta T)$$

$$V = (1 + 5.4 \times 10^{-4} \times 80)$$

$$V' = 1.0432 \text{ V}$$

Initial density of the mercury, $\rho = \frac{m}{V}$

Final density of the mercury,

$$\rho' = \frac{m}{V'} = \frac{m}{1.0432 \text{ V}} = \frac{\rho}{1.0432}$$

$$= 0.9586 \rho$$

Therefore, fractional change in the value of density of mercury,

$$\frac{\rho - \rho'}{\rho} = \frac{\rho - 0.9586\rho}{\rho}$$

$$= 0.0414$$

MODES OF HEAT TRANSFER 2

TOPIC 1

CALORIMETRY

As per the theory of Calorimetry, "When two systems at different temperatures are linked together, heat flows from the higher temperature to the lower temperature until their temperatures become the same".

Calorimetry is the branch of physics concerned with the measurement of heat. The term calorimeter refers to a device that can measure heat. When a hot body comes into contact with a cold body, the former becomes colder and the latter becomes warmer. It is natural to conclude from this observation that some heat has passed from the hot body to the cold one.

Calorimeter Principle

The principle of calorimetry states that "Heat lost by a body at a higher temperature equals heat gained by a body at a lower temperature, ignoring heat loss to surroundings".

Heat gained = Heat lost

When heat is applied to anybody, either its temperature or its state changes.

Example 2.1: The coefficient of volume expansion of glycerin is 49 × 10^{-5} K^{-1}. What is the fractional change in its density for a 30°C rise in temperature? [NCERT]

Ans. Given, $\gamma = 49 \times 10^{-5}/°C$, $\Delta T = 30°C$

$$V_2 = V_1 + \Delta V$$
$$= V_1 (1 + \gamma \Delta T)$$
$$V_2 = V_1 (1 + 49 \times 10^{-5} \times 30)$$
$$= 1.0147 V_1$$

$$\rho_1 = \frac{M}{V_1}$$

and $$\rho_2 = \frac{M}{V_2}$$
$$= \frac{M}{1.0147 V_1}$$
$$= 0.9855 \rho_1$$

Fractional change in density

$$\Delta\rho = \frac{\rho_1 - \rho_2}{\rho_1}$$
$$= \frac{\rho_1 - 0.98551\rho_1}{\rho_1}$$
$$= 0.0145$$

Example 2.2: 5 g of ice at 0°C is dropped in a beaker containing 20 g of water at 40°C. What will be the final temperature? [NCERT]

Ans. It is known that for water and ice mixing

$$\theta_{mix} = \frac{m_w \theta_w - \frac{m_l L_l}{c_w}}{m_l + m_w}$$

$$\theta_{final} = \frac{20 \times 40 - \frac{5 \times 80}{1}}{5 + 20}$$
$$= 16°C$$

TOPIC 2

CHANGE OF STATE

Any substance's state (solid/liquid/gas) can be changed by heating or cooling. A change of state is the transition of a substance from one state to another.

Some Changes in States of Matter

Melting

When heat is applied to a solid substance, it transforms into a liquid, this change in state is referred as melting. The temperature at which the substance's solid and liquid states are in thermal equilibrium with each other is referred as its melting point.

Freezing

When heat is released, a liquid changes into a solid, this change of state is referred as freezing.

Condensation

When a vapour is cooled, it transforms into a liquid, this transition is referred as condensation.

Evaporation

The conversion of a liquid into a gaseous state at any temperature is referred as evaporation or boiling.

The temperature at which a substance's liquid and vapour states coexist in thermal equilibrium is referred as its boiling point.

It's a phenomenon that happens on the surface of liquids. The rate of evaporation increases as the temperature rises. At a given temperature, the heat required to convert a unit mass of liquid into vapour is referred as the heat of evaporation at that temperature.

Sublimation

Sublimation is the direct conversion of a solid into vapours.

Sublimation occurs when the boiling point is lower than the melting point. For example, because of the moon's extremely low pressure, a block of ice sublimates into vapours on its surface. At a given temperature, the heat required to convert a unit mass of solid directly into vapours is referred as the heat of sublimation at that temperature.

Regelation

The phenomenon in which ice-melts when pressure is increased and again freezes when pressure is removed is called regelation.

Example 2.3: The construction of the two thermometers is identical, with the exception that one has a spherical bulb and the other has an elongated cylindrical bulb. Which of these will react quickly to temperature changes?

Ans. The thermometer with a cylindrical bulb will respond quickly to temperature changes because the surface area of the cylindrical bulb is greater than that of a spherical bulb.

Example 2.4: How do you explain, when a body is heated to its melting point, the temperature remains constant?

Ans. When a body is being heated below the melting point, the heat supplied increases the potential as well as the kinetic energy of the molecules. Due to the increase in the kinetic energy of the molecules, the temperature increases. But at melting point, heat goes to increase only the potential energy of molecules and hence, the temperature remains the same.

TOPIC 3

LATENT HEAT OR HIDDEN HEAT

When a body's state changes, the change occurs at a constant temperature and the heat released or absorbed is given by Q = mL, where L is latent heat.

If a solid convert to a liquid or a liquid converts to vapours, heat is absorbed, and heat is released if a liquid converts to a solid or vapours convert to liquid.

$$\text{Latent heat, } L = \frac{Q}{m}$$

Types of Latent Heat

Latent heat of Fusion

The latent heat of fusion (L_f) is the amount of heat required per unit mass to convert a substance from solid to liquid at the same temperature and pressure.

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

Latent heat of vaporisation

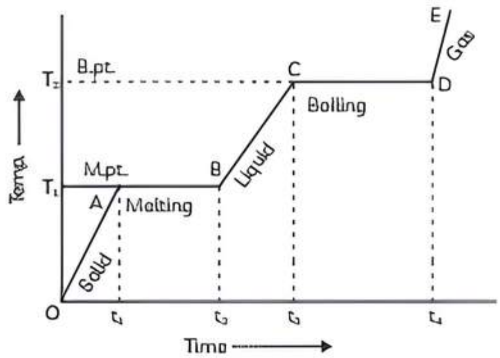
The latent heat of evaporation (L_v) is the amount of heat required per unit mass to convert a substance from liquid to vapour without changing the temperature or pressure.

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

Heating Curve

If heat is supplied at a constant rate to a given mass (m) of a solid and a graph between temperature and time is plotted, the graph is as shown in the figure and is known as a heating curve.

The curve is:



(1) In the region OA, temperature of solid is changing with time.

So, $Q = mc_s\Delta T$

But as $\frac{\Delta T}{\Delta t}$ is the slope of $\frac{\text{temp}}{\text{time}}$ curve.

$$c_s \propto \left(\frac{1}{\text{slope}} \text{ of line OA}\right)$$

i.e., specific heat (or thermal capacity) is inversely proportional to the slope of the $\frac{\text{temp}}{\text{time}}$ curve.

(2) In the region AB, temperature is constant, so it represents a change of state, *i.e.*, melting of solid with melting point T_1. At A melting starts and at B, all solids are converted into liquid. So, between A and B the substance is partly solid and partly liquid. If L_f is the latent heat of fusion

or $Q = mL_f$

or $L_f \propto$ length of line AB

i.e., Latent heat of fusion is proportional to the length of the line of zero slope.

(3) In the region BC, temperature of liquid increases so specific heat (or thermal capacity) of liquid will be inversely proportional to the slope of line BC.

i.e., $c_L \propto \left(\frac{1}{\text{slope}} \text{of line BC}\right)$

(4) In the region CD, temperature is constant, so it represents a change of state, *i.e.*, boiling with boiling point T_2. At C all substance is in a liquid state while at D is a vapour state and between C and D partly liquid and partly gas. The length of line CD is proportional to latent heat of evapouration.

i.e., $L_v \propto$ length of line CD.

(5) The line DE, represents gaseous state of substance with its temperature increasing linearly with time. The reciprocal of slope of line will be proportional to specific heat or thermal capacity of substance in vapour state.

Example 2.5: **A child running a temperature of 101°F is given an antipyrine (*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 the 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]**

Ans. Decrease in temperature

$= 101 - 98 = 3°F$

$= 3 \times \frac{5}{9} = \frac{5}{3}°C.$

Mass of child, $m = 30$ kg

Specific heat of water

= specific heat of human body

$c = 1000$ cal/kg/°C

Heat lost by the child $= mc\Delta T$

$= 30 \times 1000 \times \frac{5}{3}$

$= 5000$ Cal

Let m' be the mass of water evaporated then

$m'L = mc\Delta T$

Or $m' = \frac{5000}{580} = 8.620$

Average rate of extra evaporation

$= \frac{8.62}{20}$

$= 0.431$ g/min

TOPIC 4

HEAT TRANSFER

Heat can be transferred from one location to another using one of three methods: conduction, convection or radiation. Conduction occurs in solids, convection in liquids and gases and radiation occurs without the use of a medium.

Conduction

Conduction is the mechanism by which heat is transferred between two adjacent parts of a body due to temperature differences. Except for mercury, it usually occurs in solids.

Thermal Conduction

Thermal conduction is the process by which thermal energy is transferred from the hotter to the colder part of a body or from a hot body to a cold body in contact with it without the transfer of material particles.

At a steady state, the rate of heat energy flowing through the rod becomes constant.

This is rate $Q = KA\frac{(T_C - T_D)}{L}$ ...(i)

(for uniform cross-section rods)

Where, Q = Rate of heat energy flow (J/s or W)

A = Area of cross-section (m^2)

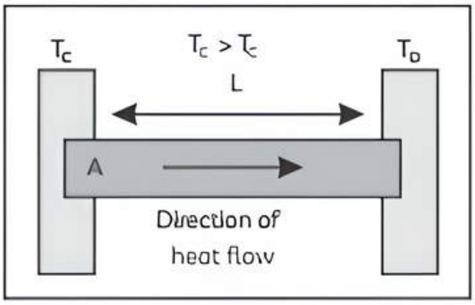
T_C and T_D = Temperature of hot end and cold end respectively (°C or K)

L = Length of the rod (M)

K = Coefficient of thermal conductivity

When a solid rod is heated, the molecules in a specific cross-section of the rod that is receiving heat begin vibrating more vigorously after gaining energy. As a result, they collide with the molecules in the next cross-section, transferring energy to them. As a result, the temperature of this cross-section of the rod begins to rise, resulting in the variable state.

After a while, the temperature of each cross-section becomes the same because there is no longer any heat absorption. The heat that reaches a specific cross-section is completely transmitted to the molecules of the next cross-section with only a small amount lost due to radiation. This is referred as a steady state.



Thermal Conductivity (K)

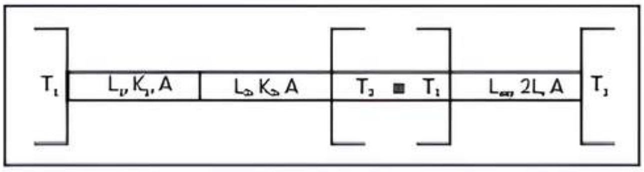
$$= \frac{\text{Rate of conduction of heat}}{\text{Area of cross-section} \times \text{temperature gradient}}$$

The SI unit of K is watt/mK.

Metals are generally good conductors of heat and non-metals are poor conductors of heat.

The concept of equivalent thermal conductivity of the composite rod for combinations of rods between two ends kept at different temperatures.

For example,



Where, K_{eq} for equivalent thermal conductivity of the compositive.

The term $\frac{(T_C - T_D)}{L}$ in the above equation (i) is called temperature gradient.

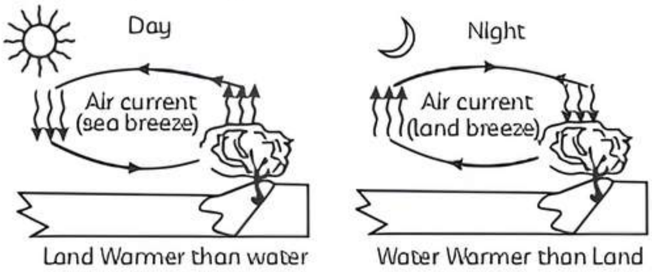
Convection

Maxwell defines convection as the flow of heat caused by the motion of a hot body carrying its own heat.

Thermal convection is the process by which heat is transferred from one point to another by the actual movement of heated material particles from a higher temperature location to a lower temperature location.

Forced convection occurs when the medium is forced to move by means of a fan or a pump.

Natural or free convection occurs when a material moves as a result of differences in the density of the medium. Circulatory system, cooling system and heat connector of an automobile. Examples of natural convection are trade winds, Sea Breeze/Land Breeze, Monsoons, Burning of Tea.



Radiation

It is a method of heat transmission in which heat travels directly from one location to another without the use of an intermediary medium. This radiation of heat energy takes the form of EM waves. These radiators are emitted as a result of their temperature, similar to how a red-hot iron or a filament lamp emits light.

All bodies radiate and absorb energy from their surroundings. The amount of energy absorbed is proportional to the colour of the body. Radiation is the fastest mode of transmission of heat, the same as the speed of light, $c = 3 \times 10^8$ m/s.

Thermal Radiations

The electromagnetic radiations emitted by a body because of its temperature are called thermal radiations.

Properties of thermal radiations:

(1) It travels in a straight line at the speed of light.

(2) It doesn't need a medium for propagation.

(3) It doesn't heat the intervening medium.

(4) It obeys the inverse square law.

(5) It obeys the laws of reflection and refraction of light.

(6) It shows interference, diffraction and polarisation like light.

Blackbody Radiations

Emissive Power

The amount of heat energy radiated per unit area of a body's surface, per unit time, and per unit wavelength range is constant, and this is referred to as the emissive power (e_λ) of the given surface, at a given temperature and wavelength.

It's S.I. unit is J s^{-1} m^{-2}.

Absorptive Power

When any radiation is incident over a surface of a body, a part of it gets reflected, a part of it gets refracted and the rest of it is absorbed by that surface. Therefore, the 'absorptive power' of a surface at a given temperature and for a given wavelength is the ratio of the heat energy absorbed by a surface to the total energy incident on it at a certain time. It is represented by (ε_λ). It has no unit as it is a ratio.

Perfect Black Body

A body is said to be a perfect black body if its absorptivity is greater than one. It neither reflects nor transmits thermal radiation, but instead absorbs all thermal radiations incident on it, regardless of wavelength.

Wien's Displacement Law

This law states that as the temperature increases, the maximum value of the radiant energy emitted by the black body, moves towards shorter wavelengths.

Wein found that "The product of the peak wavelength (λ_m) and the Kelvin temperature (T) of the black body should remain constant." $\lambda_m \times T = b$.

Where b is constant, known as Wein's constant.

Its value is 2.898×10^{-3} mK.

Stefan's Law

This law states that the thermal radiations energy emitted per second from the surface of a black body is directly proportional to its surface area A and to the fourth power of its absolute temperature T. Emission coefficient or degree of blackness of a body is represented by a dimensionless quantity ε.

$$0 < \varepsilon < 1.$$

If ε = 1, then the body is a perfect black body. Hence, for a body, which is a perfect black body.

Radiator, the energy emitted per unit time (H) is given by,

$$H = A\sigma T^4$$

Where, A is the area and T is the absolute temperature of the body. This relation was obtained experimentally by Stefan and later proved theoretically by Boltzmann is known as Stefan- Boltzmann law and the constant s is called Stefan-Boltzmann constant.

Its value in SI units is 5.67×10^{-8} $Wm^{-2}K^{-4}$.

Example 2.6: A brass boiler has a base area of 0.15 m² and thickness 1.0 cm. It boils water at the rate of 6.0 kg/min, 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 J s⁻¹ m⁻¹ k⁻¹, Heat of evapouration of water = 2256 × 10³ J k/g⁻¹) [NCERT]

Ans. Given, A = 0.15 m², Δx = 1 cm = 0.01 m

$$\text{Transfer of heat, } \frac{Q}{t} = 6 \text{ kg/min.}$$

$$= \frac{1}{10} \text{ kg/s}$$

$$\frac{\Delta Q}{\Delta t} = KA\left(\frac{\Delta T}{\Delta x}\right)$$

$$\frac{2256 \times 10^3}{10} = 6.09 \times 0.15 \times \frac{t-100}{0.01}$$

$$t - 100 = \frac{2256}{6.09 \times 0.15} = 24.7$$

$$t = 24.7 + 100$$

$$t = 124.7°C$$

Example 2.7: Explain, why:

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

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

(C) An optical pyrometer (for measuring high temperatures), 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 a furnace.

(D) The Earth without its atmosphere would be inhospitably cold.

(E) Heating systems based on circulation of steam are more efficient in warming a building than those based on circulation of hot water.

[NCERT]

Ans. **(A)** A body with large reflectivity will absorb very less heat, so it will be a poor emitter too.

(B) When we touch a brass tray on a chilly day heat flows from our body to the tray very fast as brass is a good conductor of heat, so, it appears colder, whereas wood is a bad conductor of heat, so, heat does not flow to wood from our body and we feel it warm.

(C) By Stefan's law, energy radiated when the hot iron piece is in the open is

$$E = \sigma T^4$$

Energy radiated by the hot iron when it is in the surroundings of temperature T_0 is,

$$E' = \sigma(T^4 - T_0^4)$$

(i) Pyrometer works on the principle that the brightness of a surface depends on its temperature.

(ii) It gives a low value for the temperature, of iron in the open.

(D) The infrared radiation received by the earth during the day from the sun is trapped by the atmosphere. The lower layers of the atmosphere reflect the infrared radiation back to the surface of the earth. So, if the atmosphere is not there, the earth will be too cold to live in.

(E) Steam at 100°C contains more heat than water at 100°C as latent heat is given to water to convert it to steam. So, heating systems based on circulation of steam are more efficient than systems based on circulation of water.

TOPIC 5

NEWTON'S LAW OF COOLING

Newton's law of cooling states that "the rate of cooling (or rate of loss of heat) of a body is directly proportional to the temperature difference between the body and its surroundings provided the temperature difference is small".

Mathematical expressions for Newton's law of cooling. Consider a hot body at temperature T. Let T_0 be the temperature of its surroundings. According to Newton's law of cooling.

Rate of loss of heat ∝ Temperature difference between the body and its surroundings.

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

or $$-\frac{dQ}{dt} = k(T - T_0)$$

Where, k is a proportionality constant depending upon the area and nature of the surface of the body.

Let m be the mass and c the specific heat of the body at temperature T. If the temperature of the body falls by small amount dT in time dt, then the amount of heat lost is

$$dQ = mc\,dT$$

Rate of loss of heat is given by,

$$\frac{dQ}{dt} = mc\frac{dT}{dt}$$

Combining the above equations,

We get,

$$-mc\frac{dT}{dt} = k(T - T_0)$$

Where, $K = \frac{k}{mc}$ is another constant. The negative sign indicates that as the time passes, the temperature of the body decreases.

The above equation can be written as,

$$\frac{dT}{T - T_0} = -k dT$$

On integrating both sides,

we get, $$\int \frac{1}{T - T_0} dT = -k\int dt$$

Or $\log_e (T - T_0) = -Kt + c$ ...(i)

Or $T - T_0 = e - Kt + c$ ...(ii)

Or $T = T_0 + e^c e^{-Kt}$ ...(iii)

Or $T = T_0 + C\,e^{-Kt}$ ...(iv)

Where, c is a constant of integration and $C = e^c$.

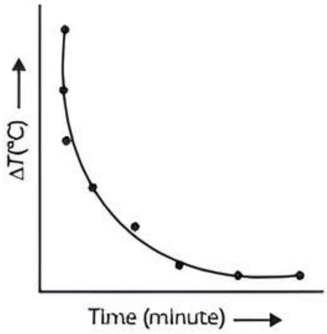
Equations (i), (ii), (iii) and (iv) are the different mathematical representations for Newton's law of cooling. Using equation (iv), one can calculate the time of cooling of a body through a particular range of temperature.

If we plot a graph by taking different values of temperature difference

$$\Delta T = T - T_0$$

along y-axis and the corresponding values of t along x-axis,

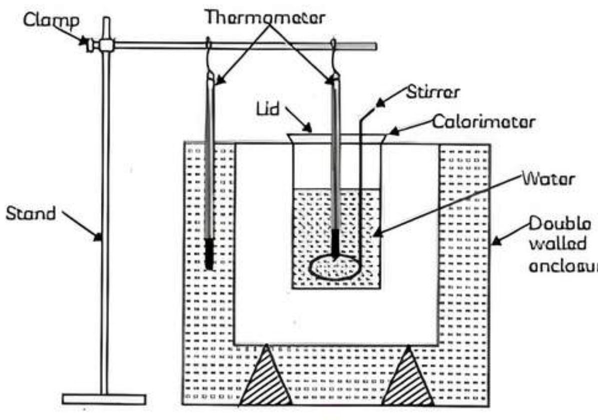
We get a curve of the form shown in figure, it clearly shows that the rate of cooling is initially higher and then decreases as the temperature of the body falls.



Experimental verification of Newton's law of cooling

Newton's law of cooling has been experimentally validated. The experimental setup used to validate Newton's law of cooling is depicted in the figure. The apparatus consists of a double-walled vessel (V) with water between the two walls. Inside the double-walled vessel is a copper calorimeter (C) filled with hot water. Two thermometers inserted through the corks are used to record the temperatures T of hot water in the calorimeter and T_0 of water between the double walls.

The temperature of hot water in the calorimeter is measured at regular intervals, such as every one minute of gently stirring the water with a stirrer.



Newton's law of cooling apparatus

Continue to record its temperature until it reaches a temperature that is about 5°C higher than the ambient temperature. Make a graph of log $e(T - T_0)$ versus time (t). As shown in the figure., the nature of the graph is a straight line with a negative slope. This demonstrates Newton's law of cooling.

Example 2.8: A body cools from 80°C to 50°C in 5 minutes. Calculate the time it takes to cool from 60°C to 30°C. The temperature of the surroundings is 20°C. [NCERT]

Ans. From Newton's law of cooling

$$\frac{dT}{dt} = -k(T - T_0).$$

where, T and T_0 are the temperatures of the body and the surrounding respectively

If the temperature of the body decreases from T_1 to T_2 in time t.

$$\int_{T_1}^{T_2} \frac{dT}{T - T_0} = -\int_0^t kdt$$

$$\log(T - T_0)_{T_1}^{T_2} = -kt$$

$$-\log_e \frac{T_2 - T_0}{T_1 - T_0} = -kt$$

$$2.303\log_{10} \frac{T_2 - T_0}{T_1 - T_0} = -kt$$

$$2.303\log_{10} \frac{T_1 - T_0}{T_2 - T_0} = kt$$

$$t = \frac{2.303}{k}\log_{10}\frac{T_1 - T_0}{T_2 - T_0}$$

Here, $T_1 = 80°C,$

$T_2 = 50°C,$

$T_0 = 20°C$

$t = 5 \text{ min} = 5 \times 60 = 300 \text{ sec}$

$$5 \times 60 = \frac{2.303}{k}\log_{10}\frac{80 - 20}{50 - 20}$$

$$= \frac{2.303}{k}\log_{10}(2)$$

Also, $T_1 = 60°C,$

$T_2 = 30°C,$

$T_0 = 20°C$

$$t = \frac{2.303}{k}\log_{10}\frac{60 - 20}{30 - 20}$$

$$= \frac{2.303}{k}\log_{10}(4)$$

$$\frac{t}{5 \times 60} = \frac{\log_{10}(4)}{\log_{10}(2)}$$

$$= \frac{0.6012}{0.3010} = 2$$

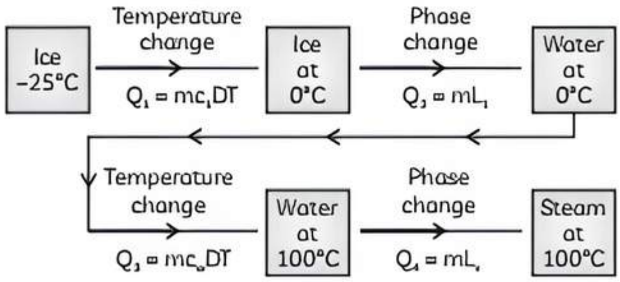
$$t = 5 \times 60 \times 2$$

$$= 600 \text{ sec.}$$

$$= 10 \text{ min.}$$

Example 2.9: Case Based:

A heating curve depicts the phase transitions that a substance goes through as heat is applied to it. The phase changes are indicated by the curve's plateaus. During these phase transitions, the temperature remains constant. Because of the strong hydrogen bonds that exist between water molecules, water has a high boiling point; it is both a strong hydrogen bond donor and acceptor. Melting is the first phase change, during which the temperature remains constant while water melts. The second phase change is boiling, which occurs when the temperature remains constant during the transition to gas.



(A) Find the quantity of heat required to convert 40 g of ice at −20°C into water at 20°C.

Given, $L_T = 0.336 \times 10^6$ J/kg,

specific heat of ice = 2100 J/kg-K,

specific heat of water = 4200 J/kg-K

(B) Steam at 100°C is passed into 1.1 kg of water contained in a calorimeter of water equivalent 0.02 kg at 15°C till the temperature of the calorimeter and its content rises to 80°C. What is the mass of steam condensed?

Latent heat of steam = 536 cal/g.

(C) Assertion (A): A room can be cooled by opening the door of a refrigerator in closed room.

Reason (R): Heat flows from lower temperature (refrigerator) to higher temperature (room).

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true and R is not correct explanation of A.

(c) A is true but R is false.

(d) A is false and R is also false.

[Delhi Gov. QB 2022]

(D) Equal masses of three different liquids A, B and C, have temperatures of 10°C, 15°C and 20°C, respectively. When A and B are combined, the temperature is 13°C, and when B and C are combined, the temperature is 16°C. When A and C are combined, what temperature will result?

(a) 20.01°C
(b) 20.26°C
(c) 10.01°C
(d) 22.01°C

(E) 5 kg of steam at 100°C is mixed with 10 kg of ice at 0°C. Choose an incorrect alternative.
(Given, S_{water} = 1 cal/g°C, L_f = 80 cal/g, L_v = 540 cal/g)

(a) Equilibrium temperature of mixture is 160°C.
(b) Equilibrium temperature of mixture is 100°C.
(c) At Equilibrium, mixture contains $13\frac{1}{3}$ kg of water
(d) At Equilibrium, mixture contains $1\frac{2}{3}$ kg of steam

Ans. (A) Heat required to raise the temperature of ice from –20°C to 20°C,

= 0.04 × 2100 × 20
= 1680 J

Heat required to convert the ice into water at 0°C = 0.04 × 0.336 × 10^6
= 13440 J

Heat required to heat water from 0°C to 20°C
= 0.04 × 4200 × 20
= 3360 J

Total Heat required
= 1680 + 13440 + 3360
= 18480 J

(B) Heat required by (calorimeter + water),

$Q = (m_1c_1 + m_2c_2)\,\Delta\theta$
= (0.02 + 1.1 × 1) (80–15)
= 72.8 kcal

If m is mass of steam condensed, then heat given by steam

$Q = mL + mc\Delta\theta$
$= m \times 536 + m \times 1 \times (100\text{-}80)$

$\therefore\ 556m = 72.8$

$$m = \frac{72.8}{556} = 0.130 \text{ kg}$$

(C) (d) *A is false and R is also false.*

Explanation: The heat that the refrigerator rejects to the room while the door is open will be more than the heat that the refrigerator absorbs from the room (by an amount equal to work done by the compressor). As a result, the room's temperature will rise, gradually warming it.

(D) (b) *20.26°C*

Explanation: Let m be the mass of each liquid and S_A, S_B, S_C be specific heats of liquids A, B and C respectively. When A and B are mixed.

The final temperature is 16°C.

∴ Heat gained by A = heat lost by B

i.e., $mS_A(16-12) = mS_B(19-16)$

i.e., $S_B = \frac{4}{3}$ ...(i)

When B and C are mixed.

Heat gained by B = Heat lost by C

i.e., $mS_B(23-19) = mS_C(28-23)$

i.e., $S_c = \frac{4}{5}S_B$ ...(ii)

From eqs. (i) and (ii)

$$S_c = \frac{4}{5}\times\frac{4}{3}S_A = \frac{16}{15}S_A$$

When A and C are mixed.

Let the final temperature be θ

$\therefore\ mS_A(\theta-12) = mS_C(28-\theta)$

i.e., $\theta - 12 = \frac{16}{15}(28-\theta)$

By solving, we get,

$$\theta = \frac{628}{31} = 20.26°C$$

(E) (a) *Equilibrium temperature of mixture is 160°C*

Explanation:

Required heat	Available heat
10 kg ice (0°C)	5 kg steam (100°C)
↓ (800 cal)	↓ (2700 Kcal)
10 kg water (0°C)	5 kg water (100°C)
↓ (1000 kcal)	
10 kg water (100°C)	

So, available heat is more than required heat.

Therefore, final temperature will be 100.

Mass of heat condensed

$$= \frac{800+1000}{540}$$

$$= \frac{10}{3} \text{ kg}$$

Total mass of water $= 10 + \frac{10}{3} = \frac{40}{3}$

$$= 13\frac{1}{3} \text{ kg}$$

Total mass of steam $= 5 - \frac{10}{3} = \frac{5}{3} = 1\frac{2}{3}$ kg

OBJECTIVE Type Questions

[1 mark]

Multiple Choice Questions

1. A piece of ice (heat capacity = 2100 J kg^{-1}°C^{-1} and latent heat = 3.36 × 10^5 J kg^{-1}) of mass *m* grams is at –5°C at atmospheric pressure. It is given 420 J of heat so that the ice starts melting. Finally, when the ice-water mixture is in equilibrium, it is found that 1 g of ice has melted. Assuming there is no other heat exchange in the process, the value of *m* is:
   (a) 40 g (b) 8 g
   (c) 16 g (d) 24

Ans. *(b) 8 g*

Explanation: As we know,

$$420\text{ J} = ms\Delta T + mL$$

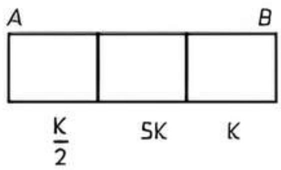
$$m \times \frac{1}{2} \times 5 + 1 \times 80 = \frac{420}{4.2}\text{ cal}$$

$$m = 8\text{ g}$$

Related Theory

➥ *The molar heat capacities for most elemental solids are about 25 $\frac{J}{mol}$ K. This is known as the rule of Dulong and Petit (for its discoverers). This means the heat required for a given temperature increase depends only on how many atoms the sample contains and not on the mass of an individual atom.*

2. As shown in the figure, a reinforced rod is made up of three rods of equal length and cross-section. The thermal conductivities of the rods materials are $\frac{K}{2}$, 5K and K respectively. The temperatures at ends A and B are constant. There is no heat loss from the sides of the bar because all heat entering the face A exits through the end B. The bar's effective thermal conductivity:



   (a) $\frac{15K}{16}$ (b) $\frac{6K}{13}$
   (c) $\frac{5K}{16}$ (d) $\frac{2K}{13}$

Ans. *(a) $\frac{15K}{16}$*

Explanation: Here, $R_{eq} = R_1 + R_2 + R_3$

$$\frac{3L}{AK_{eq}} = \frac{L}{\frac{KA}{2}} + \frac{L}{5KA} + \frac{L}{KA}$$

$$\Rightarrow \frac{3L}{K_{eq}} = \frac{10L + L + 5L}{5K} = \frac{16L}{5K}$$

$$K_{eq} = \frac{15}{16}K$$

3. The glass of a kitchen window has a surface area of 11 m^2 and a thickness of 1 mm. The outside and inside temperatures are 40°C and 20°C, respectively. Because the thermal conductivity of the glass in the MKS system is 0.2, the amount of heat flowing in the room per second be:
   (a) 2 × 10^4 joules (b) 3 × 10^4 Joules
   (c) 11 × 10^3 joules (d) 45 joules

Ans. *(c) 11 × 10^3 joules*

Explanation: Given, K = 0.2, A = 10, θ_1 = 40; θ_2 = 20,

$$T = 1\text{ sec}; l = 0.002$$

Heat flowing in the room per second will be,

$$Q = KA\frac{dT}{dx}$$

$$Q = \frac{0.2 \times 0.11 \times 20 \times 1}{0.002}$$

$$= 11000\text{ J.}$$

Related Theory

➥ *Thermal conductivity is a measure of a solid's ability to conduct heat.*

➥ *Coefficient of thermal conductivity of a solid is defined as the rate of heat flow per unit area per unit temperature gradient across the solid. It is determined by the nature of the solid.*

4. Melting point of ice:
   (a) increases with increasing pressure
   (b) decreases with increasing pressure
   (c) is independent of pressure
   (d) is independent of characteristics of the substance

Ans. *(b) decreases with increasing pressure*

Explanation: The melting rate of ice reduces as pressure increases.

The melting point of most solids rises as pressure rises. If the pressure on ice is raised, the ice water system will strive to decrease it again. It can accomplish this by shrinking itself. However, because water covers a smaller volume when liquid rather than solid, it will reduce its melting point, allowing more solid to become liquid.

5. At 127°C, the rectangular surface of 8 cm × 4 cm black body emits energy at the rate of E. If the length and width of the surface are reduced to half of their initial values and the temperature is raised to 327°C, the rate of energy emission will be:

(a) $\frac{3}{8}E$ (b) $\frac{81}{16}E$

(c) $\frac{9}{16}E$ (d) $\frac{81}{64}E$

Ans. *(d)* $\frac{81}{64}E$

Explanation: As $E \propto AT^4$

Let, $E = KAT^4$

$$E = K(8 \times 4)(400)^4$$
$$= 8192 \times 10^8$$
$$E_1 = K\left(\frac{8}{2} \times \frac{4}{2}\right)(600)^4$$
$$= 10368 \times 10^8$$
$$\frac{E_1}{E} = \frac{10368}{8192}$$
$$\frac{E_1}{E} = \frac{81}{64}$$

Related Theory

➥ *Whether the radiating body is hollow or solid it is the outer surface area only which comes into the formula. $H = \sigma AT^4$.*

6. According to the principle of calorimetry, Heat loss = Heat gain. Then:

(a) It is necessary that the fall in temperature of one substance should be equal to the rise of temperature of the other.

(b) It does not necessitate that the fall in temperature of one substance should be equal to the rise of temperature of the other.

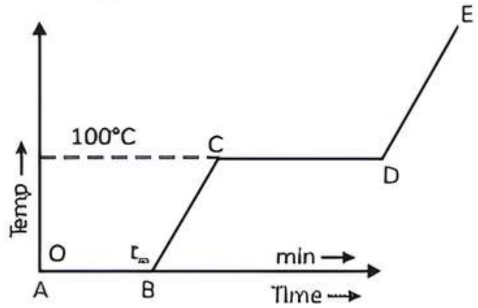
(c) Both (a) and (b) are correct

(d) None of these [Diksha]

Ans. *(a) It is necessary that the fall in temperature of one substance should be equal to the rise in temperature of the other.*

Explanation: According to the law of calorimetry or the principle of calorimetry states that "if there is no heat loss in the surrounding, then the heat lost by the body is equal to the heat gained by the body." When two bodies of different temperatures (preferably a solid and a liquid) are placed in physical contact with each other, the heat is transferred from the body with higher temperatures to the body with lower temperatures until thermal equilibrium is attained between them. The body at higher temperature releases heat while the body at lower temperature absorbs heat. The principle of calorimetry indicates the law of conservation energy, *i.e.*, the total heat lost by the hot body is equal to the total heat gained by the cold body.

7. Refer to the plot of temperature versus time (figure). Showing the changes in the state of ice on heating (not to scale). Which of the following is correct?



(a) The region AB represents ice and water in thermal equilibrium.

(b) At B water starts boiling.

(c) At C all the water gets converted into steam.

(d) C to D represents water and steam in equilibrium at normal temperature.

[NCERT Exemplar]

Ans. *(a) The region AB represents ice and water in thermal equilibrium.*

(d) C to D represents water and steam in equilibrium at normal temperature.

Explanation: When a substance heats continuously but its temperature does not change, then its state (solid, liquid or gas) changes.

So, AB (0°C) and CD (100°C) represent the conversion of solid into liquid and liquid to gas respectively. So, part AB contains ice and water both upto B, and part CD represents water and steam.

8. A glass full of hot milk is poured on the table the heat from hot milk spread on the table is transferred to the surroundings by conduction, convection and radiation. According to Newton's law of cooling the temperature of milk falls exponentially with time. It begins to cool gradually. Now under what conditions the below statements justified the same conditions?

(a) The temperature of milk falls off exponentially with time.

(b) While cooling, there is a flow of heat from milk to the surrounding as well as from surrounding to the milk but the net flow of heat is from milk to the surrounding and that's why it cools.

(c) The rate of cooling is constant till milk attains the temperature of the surrounding.

(d) All three phenomena, conduction, convection and radiation are responsible for the loss of heat from milk to the atmosphere.

Ans. (c) *The rate of cooling is constant till milk attains the temperature of the surrounding.*

Explanation: When hot milk spreads on the table it transfers heat to the surrounding by conduction, convection and radiation.

By Newton's law of cooling the heat of milk falls exponentially.

Loss of heat is directly proportional to the temperature difference between the surrounding and body. So as milk cools, temperature difference decreases so rate of cooling decreases with time.

While cooling a very small amount of heat also flows from surrounding to milk as compared to heat lost by milk to surrounding.

⚠ Caution

➥ *Students must know that for heat propagation via natural convection, temperature gradient exists in vertical direction, not in horizontal direction. Most of the heat transfer, is taking place on Earth, by convection, the contribution due to conduction and radiation is very small.*

9. During melting process, the heat given to the body is utilised in:

(a) increasing the temperature

(b) increasing the density of the material

(c) increasing the average distance between the molecules

(d) decreasing the mass of the body

[Diksha]

Ans. (c) *increasing the average distance between the molecules*

Explanation: Heat applied to a substance during the melting process is used to increase the average distance between molecules by lowering the intermolecular force of attraction.

Assertion-Reason 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:

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true and R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false and R is also false.

10. Assertion (A): Blue and white stars have higher surface temperatures than orange and red stars. The temperature in the center depends more on the mass, so the red giant Betelgeuse has a lower surface temperature but a higher core temperature than the Sun.

Reason (R): According to Wein's displacement law $m = \frac{b}{T}$ where symbols have their usual meanings.

Ans. (a) *Both A and R are true and R is the correct explanation of A.*

Explanation: From Wein's displacement law, temperature, $T \propto \left(\frac{1}{\lambda_m}\right)$

(where λ_m is the maximum wavelength).

Thus, the temperature of a body is inversely proportional to the wavelength. Since the blue star has a smaller wavelength and the red star has a maximum wavelength, therefore the blue star is at a higher temperature than the red star.

11. Assertion (A): According to Kirchhoff's law at a given wavelength the absorptivity of a body is equal to its emissivity. Also, a body, which is a good radiator, is also a good absorber of radiation or a poor reflector.

Reason (R): Kirchhoff's law states that for an arbitrary body emitting and absorbing thermal radiation in thermodynamic equilibrium, the emissivity is equal to the absorptivity.

Ans. (a) *Both A and R are true and R is the correct explanation of A.*

Explanation: According to Kirchhoff's law, the ratio of the emissive power to the absorptive power for radiation of a given wavelength is the same for all bodies at the same temperature and is equal to the emissive power of a perfectly black body at that temperature. A conclusion from Kirchhoff's law is that, if the surface is a good absorber of a particular wavelength of radiation it is also a good emitter of that wavelength of radiation.

12. Assertion (A): A material will have only one specific heat, if and only if its coefficient of thermal expansion is equal to zero.

Reason (R): An ideal gas has two specific heats (C_V and C_P) only.

Ans. (c) *A is true but R is false.*

Explanation: The coefficient of thermal expansion α_r

From the expression,

$$\frac{\Delta L}{L} = \alpha_r \Delta T.$$

the coefficient of thermal expansion measures the deforming capability of a material. This proves that the coefficient of thermal expansion has no relation with the specific heats. It is an independent quantity.

The specific heats of gases are given as C_P and C_V at constant pressure and constant volume respectively while solids and liquids are having only a single value for specific heat.

13. Assertion (A): **When a bottle of cold carbonate drink is opened. Then adiabatic expansion of gas evolved due to this temperature of gas decreasing. It condenses the water vapour, which forms a slight fog around the opening.**

Reason (R): **An adiabatic process is a type of thermodynamic process that occurs without transferring heat or mass between the thermodynamic system and its environment.**

Ans. *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: In cold carbonated drinks, gas is dissolved under pressure, when pressure is released expansion of gas occurs due to which gas cools down and temperature falls. Condensation of water vapour occurs. The process takes place very fast so we can assume it is an adiabatic process.

CASE BASED Questions (CBQs)

[**4** & **5** marks]

Read the following passages and answer the questions that follow:

14. *At high doses, radiation therapy kills cancer cells or slows their growth by damaging their DNA. Cancer cells whose DNA is damaged beyond repair stop dividing or die. When the damaged cells die, they are broken down and removed by the body. Radiation therapy does not kill cancer cells right away. It takes days or weeks of treatment before DNA is damaged enough for cancer cells to die. Then, cancer cells keep dying for weeks or months after radiation therapy ends.*

(A) Consider a physical body which absorbs all incident electromagnetic radiation and whose temperature is 57.60 K. The energy of radiation emitted by a body at wavelength 250 nm is λ_1, the energy at wavelength 500 nm is λ_2, and the energy at wavelength 1000 nm is λ_3, b = 2.88 × 10^6 nm K is Wien's constant. What's the link between λ_1 and λ_2?

(B) What is Fery's black body?

(C) Explain that different temperature causes variation in wavelength and intensity of blackbody radiation.

Ans. (A) Given Temperature, T_1 = 5760 K

Since its given that energy of radiation emitted by the body at wavelength 250 nm for λ_1, at wavelength 500 nm for λ_2 and that of 1000 nm for λ_3

According to Wein's law,

$$\lambda_m T = b$$

$$\lambda_m = \frac{b}{T}$$

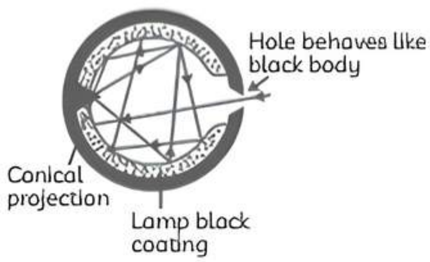
$$\lambda_m = \frac{2.88 \times 10^6}{5760 \text{ K}}$$

$$\lambda_m = 500 \text{ K}$$

λ_m is wavelength corresponding to maximum energy.

So, $\lambda_2 > \lambda_1$

(B) The radiation inside an enclosure whose.



Most of the energy entering through hole is absorbed (99%).

(C) At a certain temperature as wavelength increases, intensity corresponding to those wavelengths also increases, achieves a maximum value and again starts to decrease. It means at a given temperature; spectral emissive power is maximum for a particular wavelength. Spectrum of black body is a continuous spectrum. As temperature increases, wavelengths corresponding to maximum intensity shift towards lower wavelengths. Wavelength corresponding to maximum intensity is inversely proportional to absolute temperature.

15. *A body emits radiation at a given temperature and frequency exactly as well as it absorbs the same radiation. This was proved by Kirchhoff. the essential point is that if we suppose a particular body can absorb better than it emits, then in a room full of objects all at the same temperature, it will absorb radiation from the other bodies better than it radiates energy back to them. This means it will get hotter, and the rest of the room will grow colder, contradicting the second law of thermodynamics.*

(A) The temperature of boiler is 2324°C and the intensity of its radiation spectrum is near 12000. If the maximum intensity in a star's spectrum is near 4800, then the star's surface temperature is:

(a) 8400°C (b) 7200°C
(c) 6219.5°C (d) 5900°C

(B) A black body at 27°C emits 10 J of energy per second. If the temperature of the black body is raised to 327°C, the energy emitted per second will be:

(a) 20 J (b) 40 J
(c) 80 J (d) 160 J

(C) A black body's initial temperature is 727°C. The temperature at which the total radiant energy from this black body doubles is:

(a) 971 K (b) 1189 K
(c) 2001 K (d) 1458 K

(D) In one minute, a cup of coffee cools from 80°C to 60°C. The temperature outside is 30°C. How long will it take to cool from 60°C to 50°C?

(a) 60 sec (b) 48 sec
(c) 52 sec (d) 3 min

(E) A black body at 200 K emits the most energy at a wavelength of 14 m. When its temperature is raised to 1000 K, what wavelength emits the most energy?

(a) 2.8 μm (b) 2.4 μm
(c) 4.2 μm (d) 5.6 μm

Ans. (A) *(c) 6219.5°C*

Explanation: According to Wien's displacement law,

λ_{max} is inversely proportional to temperature (in Kelvin).

$$\frac{\lambda_1}{\lambda_2} = \frac{T_2}{T_1}$$

$$\frac{12000}{4800} = \frac{T_2}{(2324+273)}$$

$$T_2 = 6492.5K$$

So, $T_2 = 6492.5 - 273$

$= 6219.5°C$

$T_2 = 6219°C$

(B) *(d) 160 J*

Explanation: Given that:

Initial temperature,

$T_1 = 27°C$

$T_1 = 27 + 273$

$T_1 = 300$ K

Final temperature,

$T_2 = 327°C$

$T_2 = 327 + 273$

$T_2 = 600$ K

Initial energy radiated, $E_1 = 10$ J

Final energy emitted, $E_2 = ?$

By Applying Stefan's law

$E \propto T^4$

$E = KT^4$

$2\frac{1}{4} = K$ (constant)

$$\frac{E_1}{T_1^4} = \frac{E_2}{T_2^4}$$

$$\frac{100}{(300)^4} = \frac{E_2}{(600)^4}$$

$E_2 = 160$ J

(C) *(b) 1189 K*

Explanation: Radiant Energy = σT^2

Energy = $\sigma(1000)^4$

$E_2 = 2E_1$

Then, $\sigma T_2^4 = 2 \times \sigma(1000)^4$

$$T_2 = 2\frac{1}{4} \times 1000$$

$T_2 = 1189$ K

(D) *(b) 48 sec*

Explanation: As,

$$\frac{\Delta T}{\text{time}} = K\left(\frac{t_1+t_2}{2} - t_0\right)$$

$$\frac{80-60}{60} = K\left(\frac{80+60}{2} - 30\right)$$

$$\frac{1}{3} = K(40)$$

$$K = \frac{1}{120}$$

$$\frac{60-50}{\text{time}} = \frac{1}{120}\left(\frac{60+50}{2} - 30\right)$$

= 48 sec.

Time = 48 sec.

(E) *(a) 2.8 μm*

Explanation: From Wien's displacement law,

$\lambda \times T$ = Constant.

So, $1000 \times \lambda = 200 \times 14$

$$\Rightarrow \quad \lambda = \frac{200 \times 14}{1000}$$

= 2.8 μm

VERY SHORT ANSWER Type Questions (VSA)

[1 mark]

16. In the absence of the atmosphere, the earth would become so cold that life would be impossible. Why is this happen?

Ans. The atmosphere of the earth does not allow the whole heat received by the earth during day time to escape from it during the night. But if there is no atmosphere, then the whole heat radiated by the earth will leave its surface and it becomes too cold.

17. When a piece of paper wrapped tightly around a wooden rod is held over a flame, it chars much faster than a similar piece of paper wrapped around a brass rod. Why does this happen?

Ans. Wood is a bad conductor of heat and is unable to conduct away the heat. So, the paper quickly reaches its ignition temperature and is charred. On the other hand, brass is a good conductor of heat and conducts away the heat quickly. So, the paper does not reach its ignition point easily.

18. How is the heat utilised during the melting process? [Diksha]

Ans. When a solid is heated the particles gain energy and start to vibrate faster and faster. Initially, the structure is gradually weakened which has the effect of expanding the solid. Further heating provides more energy until the particles start to break free of the structure.

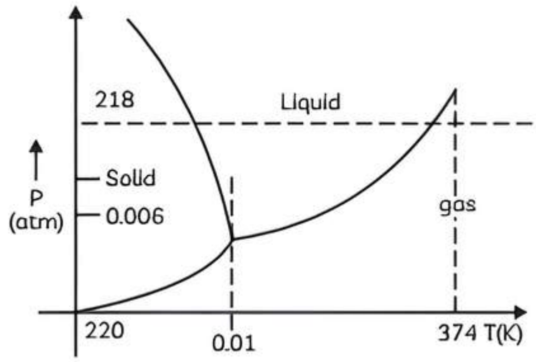
SHORT ANSWER Type-I Questions (SA-I)

[2 marks]

19. Suppose you had filled half of the bucket with very hot water from a geyser to take a bath. Suddenly somebody knocked at your door and you had to attend to that person for 10 minutes. What would you do, so that the water in the bucket may remain hot?

Ans. As the rate of loss of heat is directly proportional to the temperature difference between the body and its surrounding. If the temperature difference between the body and its surrounding is large, the body loses heat slowly if the temperature difference between the body and surrounding is small. Hence before leaving the bathroom to attend the person, the remaining part of the bucket has to be filled with cold water.

20. During the hot weather in India, one of the most common ways to stay cool is to make ice balls out of crushed ice, dip them in flavoured sugar syrup, and sip them. A stick is inserted into crushed ice and squeezed in the palm to form the ball. Similarly, in areas where it snows, people make snowballs and throw them around. Explain the formation of a ball from crushed ice or snow using the P–T diagram of water.



Ans. From the P–T graph or diagram of water and double-headed arrow. Increasing pressure at 0°C and 1 atm takes ice into liquid state and decreasing pressure in liquid state at 0°C and 1 atm takes water to ice state. When crushed ice is squeezed, some of its parts melt into water at 0°C and fill up the gaps between the ice flakes. During squeezing the ice flakes, the melting point increases and water at between the flakes also freeze into ice and binds all ice flakes making the ball more stable.

21. One day in the morning, Ramesh filled up $\frac{1}{3}$ rd a bucket of hot water from a geyser, to take a bath. Remaining $\frac{2}{3}$ rd was to be filled by cold water (at room temperature) to bring the mixture to a comfortable temperature. Suddenly Ramesh had to attend to something which would take some time say 5–10 minutes before he could take a bath. Now he had two options: (a) fill the

remaining bucket completely by cold water and then attend to the work, (b) first attend to the work and fill the remaining bucket just before taking a bath. Which option do you think would have kept water warmer? Explain.

[NCERT Exemplar]

Ans. By Newton's law of cooling, we know that rate of cooling or loss of heat energy is directly proportional to the difference in the temperature of the body and surroundings.

Hence First option would be to keep water warmer, because the difference between the temperature of the surrounding water and water is small. So, less heat energy in (a) option.

In (b) option, the difference between water and surrounding is large, so a larger amount of heat energy is lost.

22. **Why does a metal bar appear hotter than a wooden bar at the same temperature? Equivalently it also appears cooler than wooden bars if they are both colder than room temperature.** [NCERT Exemplar]

Ans. (1) It is due to the fact that the conductivity of metal bars is very high as that of wood. So, the rate of transferring the heat in metal is much larger than the wood.

(2) The specific heat of metal is very low as compared to wood, so metal requires very smaller quantities of heat than wood to change each degree of temperature. So due to larger conductivity and smaller specific heat, metals become more colder when placed in colder regions as compared to wood and become hotter when placed in hot regions.

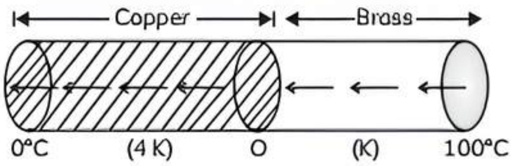
SHORT ANSWER Type-II Questions (SA-II)

[3 marks]

23. **Suppose that copper has four times the thermal conductivity of brass. End to end, two copper and brass rods of the same length and cross-section are joined. The copper rod's free end is kept at 0°C, while the brass rod's free end is kept at 100°C. Calculate the temperature at the equilibrium junction of the two rods. Ignore the effects of radiation.**

Ans. Let the thermal conductivity of brass be K.

Thermal conductivity of copper = 4K



Let the area of each rod = A

Let length of each rod = x

Let θ be the temperature of the junction of the two rods in equilibrium.

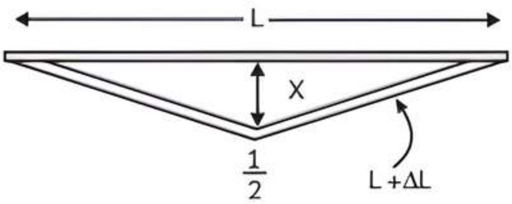
Rate of flow of heat energy through brass = rate of flow of heat energy through copper.

$$\frac{KA(100-\theta)}{x} = \frac{4KA(\theta-0)}{x}$$

$$100 - \theta = 4(\theta - 0)$$

$$\theta = 20°C$$

24. **Consider a steel track with a length of 10 m clamped at both ends of a railway line (Fig.). On a hot summer day, the temperature rises by 20°C, causing it to deform as shown in the figure. Calculate the displacement 'x'?**



Ans. Given,

$\alpha = 1.2 \times 10{-}5/°C$, $L_0 = 10$ m, $\Delta T = 20°C$

By Pythagoras' theorem,

$$x^2 = \left[(L+\Delta L)\frac{1}{2}\right]^2 - \left(\frac{L}{2}\right)^2$$

$$= \frac{1}{4}[L^2 + \Delta L^2 + 2L\Delta L] - \frac{L^2}{4}$$

$$x = \frac{L^2}{4} + \frac{\Delta L^2}{4} + \frac{2L\Delta L}{4} - \frac{L^2}{4}$$

($\Delta L^2 << L$, neglecting $-\Delta L^2$)

$$x^2 = \frac{2L\Delta L}{4}$$

$$x = \frac{1}{2}\sqrt{2L\Delta L}$$

$$\Delta L = L_c \alpha \Delta T = 10 \times 1.2 \times 10^{-5} \times 20$$

$$= 240.0 \times 10^{-5}$$

$$x = \frac{1}{2}\sqrt{2 \times 10 \times 240 \times 10^{-5}}$$

$$x = 10.8 \text{ cm}$$

25. **A thin rod having length, L_0 at 0°C and coefficient of linear expansion has its two ends maintained at temperatures θ_1 and θ_2 respectively. Find its new length.**

[NCERT Exemplar]

Ans. As the temperature of the rod varies from θ_1 and θ_2 from one end to another.

So, mean temperature of rod, $\theta = \frac{\theta_1+\theta_2}{2}$ at C.

So, the rate of flow of heat from A to C and C to B are equal.

$\therefore \quad \theta_1 > \theta > \theta_2$

$$\frac{d\theta}{dt} = \frac{KA(\theta_1-\theta)}{\frac{L_0}{2}} = \frac{KA(\theta-\theta_2)}{\frac{L_0}{2}}$$

K is the coefficient of thermal conductivity.

$\theta_1 - \theta = \theta - \theta_2$

$$\theta = \frac{\theta_1+\theta_2}{2}$$

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

$$= L_0\left[1+\alpha\left(\frac{\theta_1+\theta_2}{2}\right)\right]$$

26. In winter, why do road surfaces on bridges tend to be icier than the road surfaces on the land at either side?

Ans. Energy radiated by roads on land is partially replenished by heat conducted from the warmer ground below the pavement. But there's an absence of thermal contact between the road surfaces of bridges and the ground, so they receive very little if any replenishing energy conducted from the ground. This is why road surfaces on bridges get colder than roads on land, which increases the chance of ice formation. Understanding heat transfer can make you a safer driver.

LONG ANSWER Type Questions (LA)

[4 & 5 marks]

27. According to Stefan Boltzmann's law, the amount of radiation emitted per unit time from an area A of a black body at absolute temperature, T is directly proportional to the fourth power of the temperature and radiates energy, T^4 from its unit surface area every second where T is the surface temperature of the black body and $\sigma = 5.67\times 10^{-8}$ W/m^2/K^4 is known as Stefan's constant. A nuclear weapon may be thought of as a ball of radius 0.5 m. When detonated, it reaches a temperature of 10^6 K and can be treated as a physical body which absorbs all the radiation called a black body.

(A) How much power does a black body radiate?

(B) If the surrounding has water at 30°C, how much water can 10% of energy produced evaporate in 1 s?

(C) If all this energy U is in the form of radiation, corresponding momentum is $p' = \frac{U}{c}$. How much momentum per unit time does it impact on the unit area at a distance of 1 kilometre?

Ans. (A) $E = \sigma T^4$ per second per square meter.

Total E = radiated from all surface area A per sec will be power radiated by nuclear weapon

$P = \sigma A T^4 = 5.67 \times 10^{-8}$ W/m^2/K^4.

$R = 0.5$ m, $T = 10^6$ K

$P = 5.67 \times 10^{-8} \times (4 \times \pi R^2)(10^6)^4$

$= 5.67 \times 4 \times 3.14 \times 0.5 \times 0.5 \times 10^{-8} \times 10^{24}$

$= 5.67 \times 3.14 \times 10^{24-8} \times 1.00$

$P \equiv 18 \times 10^{16}$ Watt $= 1.8 \times 10^{17}$ J/s

(B) $P = 18 \times 10^{16}$ Watt

10% of this power is required to evaporate water

$$E = \frac{10}{100} \times 18 \times 10^{16} \text{ watt} = 1.8 \times 10^{16} \text{ J/s}$$

Energy required by m kg water at 30° C to evaporate 100°C. = E required to heat up water from 30°C to 100°C + E required to evapourate water into vapour

$= mS_w(T_2 - T_1) + mL$

$= m(S_w(T_2 - T_1) + L)\ 1.8 \times 10^{16}$

$= m[4180\ (100 - 30) + 22.6 \times 10^5]$

$= m[4186 \times 70 + 22.6 \times 10^5]$

$m(2.93020 \times 10^5 + 22.6 \times 10^5) = 1.8 \times 10^{16}$

$m(2.93020 + 22.6) \times 10^5 = 1.8 \times 10^{16}$

$m\ (25.5 \times 10^5) = 1.8 \times 10^{16}$

$$m = \frac{1.8\times10^{16}}{25.5\times10^5} \equiv 7\times10^9 \text{ kg}$$

(C) Momentum per unit time,

$$p' = \frac{U}{c} = \frac{1.8\times10^{17}}{3\times10^8}$$

$= 0.6 \times 10^9$

p per unit time per unit area at a distance,

$$1 \text{ km} = \frac{6\times10^8}{4\pi R^2}$$

$$p' = \frac{6\times10^8}{4\times3.14\times(10^3)^2}$$

$= 47.77$ kg ms^{-2}/m^2

p marked per sec at 1 km away on,

1m^2= 47.8 N/m^2.

28. A space is kept at 20°C by a heater with a resistance of 20 connected to 200 V-mains. The temperature is consistent throughout the room, and heat is transmitted through a 1 m^2 glass window with a thickness of 0.2 cm. Determine the temperature outside. Given that glass has a thermal conductivity of K = 0.2 cal $m^{-1}s^{-1}°C^{-1}$ and a mechanical equivalent of heat, J = 4.2 J cal^{-1}.

Ans. Given, J = 4.2Jcal^{-1}, T_1 = 20°C, d = 0.2 cm, A = 1 m^2, K = 0.2 cal $m^{-1}s^{-1}°C^{-1}$

Heat generated by the heater per second,

$$Q_1 = \frac{V^2}{R}$$

$$= \frac{(200)^2}{20} = 2{,}000 \text{ J}$$

Let, T_2 be the temperature outside the room. Heat conducted through the window per second.

$$Q_2 = \frac{KA(T_1 - T_2)}{d}$$

$$= \frac{0.2 \times 4.2 \times 1 \times (20 - T_2)}{2 \times 10^{-3}}$$

Since, the temperature of the room is maintained constant at 20°C.

$$Q_1 = Q_2$$

or

$$\frac{0.2 \times 4.2 \times 1 \times (20 - T_2)}{2 \times 10^{-3}} = 2{,}000$$

$$T_2 = 20 - 4.76$$

$$= 15.24°C$$

NUMERICAL Type Questions

29. A 100 g piece of iron is kept in a furnace for a long time before being placed in a calorimeter of water equivalent 10 g containing 240 g of water at 20°C. The temperature of the mixture at equilibrium is 60°C. Determine the furnace temperature. The specific heat capacity of iron is 470 J/kg/°C^{-1}. (2m)

Ans. Given: m_1 = 100 g, W = 10 g, m_2 = 240 g; T_1 = 20°C, T = 60°C, T_2 = Temp. of furnace = ?

∴ Heat gained by water and calorimeter = Heat lost by iron

∴ $(m_2 + W)(T - T_1) = m_1 c (T_2 - T)$

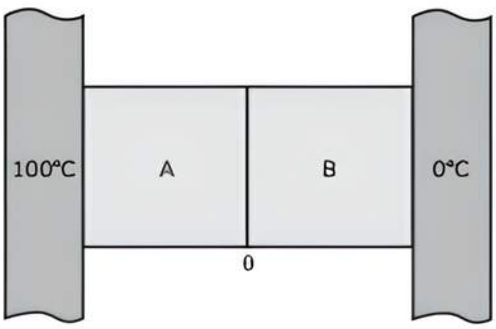
$$(240 + 10)(60 - 20) = 100 \times \frac{470(T_2 - 60)}{4.2 \times 10^3}$$

$$T_2 - 60 = \frac{250 \times 40 \times 4.2 \times 10^3}{100 \times 470}$$

$$= 893.6$$

$$T_2 = 893.6 + 60 = 953.6°C$$

30. Consider two alloys named A and B which are of the same size



Both the ends of the alloy are thermally insulated and the coefficient of thermal conductivity are 600 $Wm^{-1}°C^{-1}$ and 400 $Wm^{-1}°C^{-1}$ respectively. What will be the temperature (t) of the interface when the steady state is reached. (2m)

Ans. The heating temperature through A per second,

$$Q_1 = \frac{K_1 A(100 - t)}{l}$$

The heat transferred through B per second

$$Q_2 = \frac{K_2 A(t - 0)}{l}$$

At steady state,

$$\frac{K_1 A(100 - t)}{l} = \frac{K_2 A(t - 0)}{l}$$

$\Rightarrow$ $600(100 - t) = 400(t - 0)$

$\Rightarrow$ $t = 60°C$.

31. A person weighing 60 kg takes in 2000 kcal diet in a day. if this energy were to be used in heating the person without any losses, what would be his rise in temperature? Given specific heat of the human body is 0.83 cal g^{-1} °C^{-1}. [Diksha](2m)

Ans. Heat = $mc\Delta T$

c = specific heat = 0.83 cal/g °C

m = 60 kg = 60 × 10^3g

Heat = 200 × Kcal = 200 × 10^3 cal

∴ $200 \times 10^3 = 60 \times 10^3 \times 0.83 \times \Delta T$

∴ $$\Delta T = \frac{200}{60 \times 0.83} = 4.016°C.$$