CHAPTER-III

THERMAL PROPERTIES OF MATTER

2 MARK QUESTIONS

1.What is the reason the brake drum of an automobile gets heated up when the automobile moves down a hill at constant speed?

Ans.

The reason for this brake drum is since the speed is constant so there is no change in **kinetic energy.** The loss in gravitational potential energy is partially the gain in the heat energy of the brake drum.

2. What is thermal conduction?

Ans.

Thermal conduction is the process of the transfer of heat energy from one part of a solid to another part at a lower temperature without the actual motion of the molecules. It is also known as the conduction of heat.

3. A woolen blanket keeps the body warm. The same blanket if wrapped around ice would keep ice cold. Explain this in detail.

Ans.

As we know the blanket is an insulator that traps the heat released by our body and it makes us warm and in the case of ice, it does not release heat so, there is nothing to trap. The woolen blanket keeps us warm by preventing the heat of the human body from flowing outside and hence our body remains warm. In the case of ice, the heat from outsiders is prevented from flowing inside and thus ice remains cold.

4. Let us take some Wooden charcoal and a metal piece of the same dimension

that are heated in the same oven to the same temperature and then removed in the dark. Which will shine more and why?

Ans.

The charcoal will shine more as it is a good absorber and emitter of heat, so it will emit more energy and this is the only reason that charcoal will shine.

5. **What is the coefficient of thermal conductivity of a material?**

Ans. Thermal conductivity of a material is the quantity of heat flowing per second across the opposite faces of a unit cube made of that material when the opposite faces are maintained at a temperature difference of 1K or 1°C.

6. **What happens to the size of the hole if the metal disc is heated and there is a hole in a metal disc?**

Ans. The size of the hole increases on heating the metal disc according to the thermal properties of matter.

4 MARK QUESTIONS

1.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.

ANSWER:

Kelvin and Celsius scales are related as:

$T_C = T_K - 273.15$ … (*i*)

Celsius and Fahrenheit scales are related as:

$T_F = \frac{9}{5}T_C + 32$ … (*ii*)

<u>For neon:</u>

$T_K = 24.57$ K

$\therefore T_C = 24.57 - 273.15 = -248.58°C$

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

$$= \frac{9}{5}(-248.58) + 32$$

$$= 415.44°F$$

<u>For carbon dioxide:</u>

$T_K = 216.55$ K

$\therefore T_C = 216.55 - 273.15 = -56.60°C$

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

$$= \frac{9}{5}(-56.60) + 32$$

$$= -69.88°C$$

2.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?

ANSWER:

Triple point of water on absolute scaleA, T_1 = 200 A

Triple point of water on absolute scale B, T_2 = 350 B

Triple point of water on Kelvin scale, T_K = 273.15 K

The temperature 273.15 K on Kelvin scale is equivalent to 200 A on absolute scale A.

$T_1 = T_K$

200 A = 273.15 K

$$\therefore A = \frac{273.15}{200}$$

The temperature 273.15 K on Kelvin scale is equivalent to 350 B on absolute scale B.

$T_2 = T_K$

350 B = 273.15

$$\therefore B = \frac{273.15}{350}$$

T_A is triple point of water on scale A.

T_B is triple point of water on scale B.

$$\therefore \frac{273.15}{200} \times T_A = \frac{273.15}{350} \times T_B$$

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

Therefore, the ratio $T_A : T_B$ is given as 4 : 7.

3.A hole is drilled in a copper sheet. The diameter of the hole is 4.24 cm at 27.0 °C. What is the change in the diameter of the hole when the sheet is heated to 227 °C? Coefficient of linear expansion of copper = 1.70 × 10^{-5} K^{-1}.

ANSWER:

Initial temperature, T_1 = 27.0°C

Diameter of the hole at T_1, d_1 = 4.24 cm

Final temperature, T_2 = 227°C

Diameter of the hole at $T_2 = d_2$

Co-efficient of linear expansion of copper, α_{Cu}= 1.70 × 10^{-5} K^{-1}

For co-efficient of superficial expansion β,and change in temperature ΔT, we have the relation:

$$\frac{\text{Change in area }(\Delta A)}{\text{Original area }(A)} = \beta\Delta T$$

$$\frac{\left(\pi\frac{d_2^2}{4} - \pi\frac{d_1^2}{4}\right)}{\left(\pi\frac{d_1^2}{4}\right)} = \frac{\Delta A}{A}$$

$$\therefore \frac{\Delta A}{A} = \frac{d_2^2 - d_1^2}{d_1^2}$$

But $\beta = 2\alpha$

$$\therefore \frac{d_2^2 - d_1^2}{d_1^2} = 2\alpha\Delta T$$

$$\frac{d_2^2}{d_1^2} - 1 = 2\alpha(T_2 - T_1)$$

$$\frac{d_2^2}{(4.24)^2} = 2 \times 1.7 \times 10^{-5}(227 - 27) + 1$$

$$d_2^2 = 17.98 \times 1.0068 = 18.1$$

$$\therefore d_2 = 4.2544 \text{ cm}$$

Change in diameter = $d_2 - d_1$ = 4.2544 – 4.24 = 0.0144 cm

Hence, the diameter increases by 1.44 × 10^{-2} cm.

4.A child running a temperature of 101°F is given an antipyrin (i.e. a medicine that

lowers fever) which causes an increase in the rate of evaporation of sweat from his body. If the fever is brought down to 98 °F in 20 min, what is the average rate of extra evaporation caused, by the drug? Assume the evaporation mechanism to be the only way by which heat is lost. The mass of the child is 30 kg. The specific heat of human body is approximately the same as that of water, and latent heat of evaporation of water at that temperature is about 580 cal g^{-1}.

ANSWER:

Initial temperature of the body of the child, T_1 = 101°F

Final temperature of the body of the child, T_2 = 98°F

Change in temperature, $\Delta T = \left[(101-98)\times\frac{5}{9}\right]$ °C

Time taken to reduce the temperature, t = 20 min

Mass of the child, m = 30 kg = 30 × 10^3 g

Specific heat of the human body = Specific heat of water = c

= 1000 cal/kg/ °C

Latent heat of evaporation of water, L = 580 cal g^{-1} The heat

lost by the child is given as:

$$\Delta\theta = mc\Delta T$$
$$= 30\times 1000\times(101-98)\times\frac{5}{9}$$
$$= 50000 \text{ cal}$$

Let m_1 be the mass of the water evaporated from the child's body in 20 min.

Loss of heat through water is given by:

$$\Delta\theta = m_1 L$$

$$\therefore m_1 = \frac{\Delta\theta}{L}$$

$$= \frac{50000}{580} = 86.2 \text{ g}$$

∴Average rate of extra evaporation caused by the drug $= \frac{m_1}{t}$

$$= \frac{86.2}{200} = 4.3 \text{ g/min}$$

5.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.

ANSWER:

According to Newton's law of cooling, we have:

$$-\frac{dT}{dt} = K\left(T - T_0\right)$$

$$\frac{dT}{K\left(T - T_0\right)} = -Kdt \qquad \dots (i)$$

Where,

Temperature of the body = T

Temperature of the surroundings = T_0 = 20°C

K is a constant

Temperature of the body falls from 80°C to 50°C in time, t = 5 min = 300 s Integrating equation (i), we get:

$$\int_{50}^{80} \frac{dT}{K(T - T_0)} = -\int_{0}^{300} K dt$$

$$\left[\log_e (T - T_0)\right]_{50}^{80} = -K[t]_0^{300}$$

$$\frac{2.3026}{K} \log_{10} \frac{80 - 20}{50 - 20} = -300$$

$$\frac{2.3026}{K} \log_{10} 2 = -300$$

$$\frac{-2.3026}{300} \log_{10} 2 = K \qquad ...(ii)$$

The temperature of the body falls from 60°C to 30°C in time = t'

Hence, we get:

$$\frac{2.3026}{K} \log_{10} \frac{60 - 20}{30 - 20} = -t'$$

$$\frac{-2.3026}{t'} \log_{10} 4 = K \qquad ...(iii)$$

Equating equations (ii) and (iii), we get:

$$\frac{-2.3026}{t'} \log_{10} 4 = \frac{-2.3026}{300} \log_{10} 2$$

$$\therefore t' = 300 \times 2 = 600 \text{ s} = 10 \text{ min}$$

Therefore, the time taken to cool the body from 60°C to 30°C is 10 minutes.

8 MARK QUESTIONS

1.The electrical resistance in ohms of a certain thermometer varies with temperature according to the approximate law:

$R = R_o [1 + \alpha (T - T_o)]$

The resistance is 101.6 Ω at the triple-point of water 273.16 K, and 165.5 Ω at the normal melting point of lead (600.5 K). What is the temperature when the resistance is 123.4 Ω?

ANSWER:

It is given that:

$R = R_0 [1 + \alpha (T - T_0)]$ … (*i*)

Where,

R_0 and T_0 are the initial resistance and temperature respectively R and T

are the final resistance and temperature respectively α is a constant

At the triple point of water, T_0 = 273.15 K

Resistance of lead, R_0 = 101.6 Ω

At normal melting point of lead, T = 600.5 K

Resistance of lead, R = 165.5 Ω

Substituting these values in equation (i), we get:

$$R = R_0\left[1 + \alpha\left(T - T_0\right)\right]$$
$$165.5 = 101.6\left[1 + \alpha\left(600.5 - 273.15\right)\right]$$
$$1.629 = 1 + \alpha\left(327.35\right)$$

$$\therefore \alpha = \frac{0.629}{327.35} = 1.92 \times 10^{-3}\ \text{K}^{-1}$$

For resistance, R_1 = 123.4 Ω

$$\text{R}_1 = \text{R}_0\left[1 + \alpha\left(\text{T} - \text{T}_0\right)\right]$$

Where, T is the temperature when the resistance of lead is 123.4 Ω

$$123.4 = 101.6\left[1 + 1.92 \times 10^{-3}\left(\text{T} - 273.15\right)\right]$$
$$1.214 = 1 + 1.92 \times 10^{-3}\left(\text{T} - 273.15\right)$$

$$\frac{0.214}{1.92 \times 10^{-3}} = \text{T} - 273.15$$

$$\therefore \text{T} = 384.61\ \text{K}$$

2.Answer the following:

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

(b) There were two fixed points in the original Celsius scale as mentioned above which were assigned the number 0 °C and 100 °C respectively. On the absolute scale, one of the fixed points is the triple-point of water, which on the Kelvin

absolute scale is assigned the number 273.16 K. What is the other fixed point on this (Kelvin) scale?

(c) The absolute temperature (Kelvin scale) T is related to the temperature t_c on the Celsius scale by

$$t_c = T - 273.15$$

Why do we have 273.15 in this relation, and not 273.16?

(d) What is the temperature of the triple-point of water on an absolute scale whose unit interval size is equal to that of the Fahrenheit scale?

ANSWER:

(a) The triple point of water has a unique value of 273.16 K. At particular values of volume and pressure, the triple point of water is always 273.16 K. The melting point of ice and boiling point of water do not have particular values because these points depend on pressure and temperature.

(b) The absolute zero or 0 K is the other fixed point on the Kelvin absolute scale.

(c) The temperature 273.16 K is the triple point of water. It is not the melting point of ice. The temperature 0°C on Celsius scale is the melting point of ice. Its corresponding value on Kelvin scale is 273.15 K.

Hence, absolute temperature (Kelvin scale) T, is related to temperature t_c, on Celsius scale as:

$$t_c = T - 273.15$$

(d) Let T_F be the temperature on Fahrenheit scale and T_K be the temperature on absolute scale. Both the temperatures can be related as:

$$\frac{T_F - 32}{180} = \frac{T_K - 273.15}{100} \qquad \ldots(i)$$

Let T_{F1} be the temperature on Fahrenheit scale and T_{K1} be the temperature on absolute scale. Both the temperatures can be related as:

$$\frac{T_{F1}-32}{180}=\frac{T_{K1}-273.15}{100} \qquad \dots(ii)$$

It is given that:

$T_{K1} - T_K = 1$ K

Subtracting equation (*i*) from equation (*ii*), we get:

$$\frac{T_{F1}-T_F}{180}=\frac{T_{K1}-T_K}{100}=\frac{1}{100}$$

$$T_{F1}-T_F=\frac{1\times 180}{100}=\frac{9}{5}$$

Triple point of water = 273.16 K

∴Triple point of water on absolute scale = $273.16\times\frac{9}{5}$ = 491.69

3.A steel tape 1m long is correctly calibrated for a temperature of 27.0 °C. The length of a steel rod measured by this tape is found to be 63.0 cm on a hot day when the temperature is 45.0 °C. What is the actual length of the steel rod on that day? What is the length of the same steel rod on a day when the temperature is 27.0 °C? Coefficient of linear expansion of steel = 1.20 × 10^{-5} K^{-1}.

ANSWER:

Length of the steel tape at temperature T = 27°C, l = 1 m = 100 cm

At temperature T_1 = 45°C, the length of the steel rod, l_1 = 63 cm

Coefficient of linear expansion of steel, α = 1.20 × 10^{-5} K^{-1}

Let l_2 be the actual length of the steel rod and l' be the length of the steel tape at 45°C.

$$l'=l+\alpha l(T_1-T)$$

$$\therefore l'=100+1.20\times10^{-5}\times100(45-27)$$
$$=100.0216 \text{ cm}$$

Hence, the actual length of the steel rod measured by the steel tape at 45°C can be calculated as:

$l_2 = \frac{100.0216}{100} \times 63$ = 63.0136 cm

Therefore, the actual length of the rod at 45.0°C is 63.0136 cm. Its length at 27.0°C is 63.0 cm.

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

ANSWER:

The given temperature, T = 27°C can be written in Kelvin as:

27 + 273 = 300 K

Outer diameter of the steel shaft at T, d_1 = 8.70 cm

Diameter of the central hole in the wheel at T, d_2 = 8.69 cm

Coefficient of linear expansion of steel, $\alpha_{steel} = 1.20 \times 10^{-5}\ K^{-1}$

After the shaft is cooled using 'dry ice', its temperature becomes T_1.

The wheel will slip on the shaft, if the change in diameter, Δd = 8.69 – 8.70

= – 0.01 cm

Temperature T_1, can be calculated from the relation:

$\Delta d = d_1 \alpha_{steel} (T_1 - T)$

$0.01 = 8.70 \times 1.20 \times 10^{-5} (T_1 - 300)$

$(T_1 - 300) = 95.78$

$\therefore T_1 = 204.21$ K

$= 204.21 - 273.16$

$= -68.95°C$

Therefore, the wheel will slip on the shaft when the temperature of the shaft is –69°C.

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

ANSWER:

Initial temperature, $T_1 = 27°C$

Length of the brass wire at T_1, $l = 1.8$ m

Final temperature, $T_2 = -39°C$

Diameter of the wire, $d = 2.0$ mm $= 2 \times 10^{-3}$ m

Tension developed in the wire = F

Coefficient of linear expansion of brass, $\alpha = 2.0 \times 10^{-5}$ K^{-1}

Young's modulus of brass, $Y = 0.91 \times 10^{11}$ Pa Young's

modulus is given by the relation:

$$Y = \frac{\text{Stress}}{\text{Strain}} = \frac{\frac{F}{A}}{\frac{\Delta L}{L}}$$

$$\Delta L = \frac{F \times L}{A \times Y} \qquad \ldots (i)$$

Where,

F = Tension developed in the wire

A = Area of cross-section of the wire.

ΔL = Change in the length, given by the relation:

$\Delta L = \alpha L(T_2 - T_1)$ … (*ii*)

Equating equations (*i*) and (*ii*), we get:

$$\alpha L(T_2 - T_1) = \frac{FL}{\pi\left(\frac{d}{2}\right)^2 \times Y}$$

$$F = \alpha(T_2 - T_1)\pi Y\left(\frac{d}{2}\right)^2$$

$$F = 2 \times 10^{-5} \times (-39 - 27) \times 3.14 \times 0.91 \times 10^{11} \times \left(\frac{2 \times 10^{-3}}{2}\right)^2$$

$$= -3.8 \times 10^2 \text{ N}$$

(The negative sign indicates that the tension is directed inward.)

Hence, the tension developed in the wire is 3.8×10^2 N.

6.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 junction? The ends of the rod are free to expand (Co-efficient of linear expansion of

brass = 2.0 × 10^{-5} K^{-1}, steel = 1.2 × 10^{-5} K^{-1}).

ANSWER:

Initial temperature, T_1 = 40°C

Final temperature, T_2 = 250°C

Change in temperature, $\Delta T = T_2 - T_1$ = 210°C

Length of the brass rod at T_1, l_1 = 50 cm

Diameter of the brass rod at T_1, d_1 = 3.0 mm

Length of the steel rod at T_2, l_2 = 50 cm

Diameter of the steel rod at T_2, d_2 = 3.0 mm

Coefficient of linear expansion of brass, $\alpha_1 = 2.0 \times 10^{-5} K^{-1}$

Coefficient of linear expansion of steel, $\alpha_2 = 1.2 \times 10^{-5} K^{-1}$ For the

expansion in the brass rod, we have:

$$\frac{\text{Change in length}(\Delta l_1)}{\text{Original length } (l_1)} = \alpha_1 \Delta T$$

$$\therefore \Delta l_1 = 50 \times \left(2.1 \times 10^{-5}\right) \times 210$$
$$= 0.2205 \text{ cm}$$

For the expansion in the steel rod, we have:

$$\frac{\text{Change in length}(\Delta l_2)}{\text{Original length}(l_2)} = \alpha_2 \Delta T$$

$$\therefore \Delta l_2 = 50 \times \left(1.2 \times 10^{-5}\right) \times 210$$
$$= 0.126 \text{ cm}$$

Total change in the lengths of brass and steel,

$\Delta l = \Delta l_1 + \Delta l_2$

$= 0.2205 + 0.126$

$= 0.346$ cm

Total change in the length of the combined rod = 0.346 cm Since the rod expands freely from both ends, no thermal stress is developed at the junction

SUMMARY

Thermal properties are those properties of a material which is related to its conductivity of heat. In other words, these are the properties that are exhibited by a material when the heat is passed through it. Thermal properties come under the broader topic of the physical properties of materials.