CHAPTER 11

Thermal Properties of Matter

EXAM DRILL

ANSWERS

1. **(c) :** Let T_F be temperature on Fahrenheit scale corresponding to 60°C on Celsius scale. Then

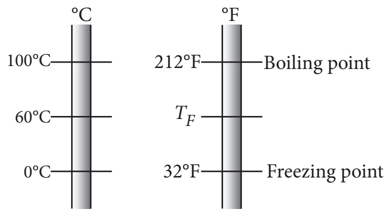
$$\frac{60-0}{100-0}=\frac{T_F-32}{212-32}$$

or $\frac{3}{5}=\frac{T_F-32}{180}$

or $5T_F - 160 = 540$

or $5T_F = 700$

or $T_F = \frac{700}{5}$ °F = 140° F



2. **(b) :** The change in length $\Delta L = \alpha L dT$

$L_T = L[1 + \alpha(T_2 - T_1)]$

$L_T = L[1 + \alpha T]$

Young's modulus of the metal rod

$$Y=\frac{F}{A}\frac{L_T}{\Delta L} \Rightarrow F=\frac{YA\Delta L}{L_T}=\frac{YA\alpha LT}{L[1+\alpha T]}$$

$$F=\frac{YA\alpha T}{(1+\alpha T)}$$

3. **(c) :** Length of the wire at temperature T_2 is

$$L_t=L\left(1+\frac{1}{100}\right) \quad \therefore \quad 2L_t^2=2L^2\left(1+\frac{1}{100}\right)^2$$

Now $2L_t^2$ = area of the plate at temperature T_2 and $2L^2$ = area of the plate at temperature T_1.

$$\therefore \quad A_t=A\left(1+\frac{1}{100}\right)^2=A\left(1+\frac{2}{100}\right)=\frac{102A}{100}$$

Thus, the area increases by 2%.

4. **(a) :** Here, $r_1 = 1.5 r_2 = \frac{3}{2} r_2$

Quantity of heat required to raise the temperature of copper sphere of radius r_1 through 1 K is

$$Q_1 = m_1 s_{Copper}\Delta T=\left(\frac{4}{3}\pi r_1^3 \rho_{Copper}\right)\times s_{Copper}\times 1$$

$$=\frac{4}{3}\pi r_1^3 \rho_{Copper} s_{Copper} \quad \text{...(i)}$$

Quantity of heat required to raise the temperature of copper sphere of radius r_2 through 1 K is

$$Q_2 = m_2 s_{Copper}\Delta T=\frac{4}{3}\pi r_2^3 \rho_{Copper}\times s_{Copper}\times 1$$

$$=\frac{4}{3}\pi r_2^3 \rho_{Copper} s_{Copper} \quad \text{...(ii)}$$

Divide (i) by (ii), we get $\frac{Q_1}{Q_2}=\left(\frac{r_1}{r_2}\right)^3=\left(\frac{3}{2}\right)^3=\frac{27}{8}$

5. **(b) :** Given,

Mass of water at 90°C = 100 gm = 100 × 10^{-3} kg

Mass of water at 20°C = 600 gm = 600 × 10^{-3} kg

From calorimetery

$m_1 s_1 T_1 + m_2 s_2 T_2 = (m_1 + m_2) sT$

$100 \times 10^{-3} \times 1 \times 90 + 600 \times 10^{-3} \times 1 \times 20$

$= (100 + 600) \times 10^{-3} \times 1 \times T$

$$T=\frac{100\times 10^{-3}\times 90+600\times 10^{-3}\times 20}{700\times 10^{-3}}$$

$$T=\frac{21000}{700}=30°C$$

6. **(c) :** With rise of altitude, pressure decreases and boiling point decreases.

7. **(c) :** According to Wien's displacement law

$\lambda_m T$ = constant

$$\therefore \quad \frac{\lambda_{m_A}}{\lambda_{m_B}}=\frac{T_B}{T_A} \text{ or } \frac{T_A}{T_B}=\frac{\lambda_{m_B}}{\lambda_{m_A}}=\frac{480\text{ nm}}{360\text{ nm}}=\frac{4}{3}$$

8. **(c)**

9. **(d) :** According to Wien's displacement law if λ is the wavelength at maximum intensity λT = constant.

∴ Shorter the wavelength of the peak, greater the temperature for intensity versus λ graph.

(λ_{max} is not maximum wavelength but λ at maximum intensity)

Thus, $T_1 > T_3 > T_2$

10. **(a) :** Initially, the black body absorbs all the radiant energy incident on it. So it is the darkest body. When the temperature of black body becomes equal to the temperature of the furnace, the black body will radiate maximum energy. Therefore, it will appear brightest of all.

11. (i) (d) : The change from solid state to vapour state without passing through the liquid state is called sublimation and the substance is said to sublime *e.g.* dry ice (solid CO_2), iodine etc.

(ii) **(a) :** In the given *P*-*T* diagram,

Region I - Liquid

Region II - Solid

Region III - Vapour

(iii) (a)

12. (a)

13. (d) : Coefficient of thermal conductivity depends only on nature of material of the rod and the length of rod is inversely proportional to the amount of heat conducted.

$$\Delta Q \propto \frac{1}{\Delta x}$$

14. The values of triple point of water on the centigrade, Fahrenheit and Absolute scales of temperature are 0.01°C, 32.018°F and 273.16 K respectively.

15. The branch of physics that deals with the measurement of high temperature is called pyrometry or radiation thermometry.

16. The two bodies may have different masses and different materials *i.e.*, they may have different thermal capacities. In case of two bodies have equal thermal capacities they would settle at the mean temperature $(T_1 + T_2)/2$.

OR

Yes, if the tube is held vertically, the position of the pellet will change with any change in the temperature of the surrounding air. This can be used as a thermometer.

17. The amount of heat flowing through the slab is

$$Q = \frac{kA(\theta_1 - \theta_2)t}{x}$$

According to the conditions of the problem, $Q = mL$.

$$\therefore \quad mL = \frac{kA(\theta_1 - \theta_2)t}{x}$$

Here $m = 4.8$ kg; $L = 80$ kCal/kg; $A = 0.36$ m^2

$\theta_1 - \theta_2 = 100 - 0 = 100$°C ;

$t = 1$ hour $= 3600$ s ; $x = 0.1$ m ; $k = ?$

$$4.8 \times 80 = \frac{k \times 0.36 \times 100 \times 3600}{0.1}$$

or Thermal conductivity, $k = \dfrac{4.8 \times 80 \times 0.1}{0.36 \times 100 \times 3600}$

$= 3 \times 10^{-4}$ k cal s^{-1} m^{-1}°C^{-1}

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

Rate of cooling of an object ∝ Temperature between the object and surroundings

19. The energy radiated per sec by a body is given by ;

$$P = \varepsilon \sigma A (T^4 - T_0^4) = \varepsilon \sigma A T^4 \qquad (\text{If } T_0 << T)$$

Here, $\varepsilon = 1$ (black body) ; $\sigma = 5.7 \times 10^{-8}$ W m^{-2} K^{-4}

$T = 127$°C $= 400$ K ; $A = 200$ cm^2 $= 200 \times 10^{-4}$ m^2

$P = 1 \times 5.7 \times 10^{-8} \times 200 \times 10^{-4} \times (400)^4 = 29.184$ J/s

Energy radiated in one minute (= 60 s)

$= 29.184 \times 60 = 1751$ J

20. A cooking utensils should have

(i) high conductivity, so that it can conduct heat through itself and transfer it to the contents quickly.

(ii) low specific heat, so that it immediately attains the temperature of the source.

21. (i) When the body is heated, the distance between any of its two points increases. Hence, the diameters of the holes *AB* and *CD* in a metal sheet increases.

(ii) When the metal sheet is heated, it expands a whole. Therefore, the holes increases in diameter as well as move outwards. So, the distance *BC* between the two holes decreases.

OR

Two merits of gas thermometer over those of mercury thermometers are following :

(i) A gas thermometer is more sensitive than a mercury thermometer.

(ii) The working of a gas thermometers are independent of the nature of the gas, they almost give the same value on different types of gas used.

22. (i) When the temperature difference between body and surroundings is small, (less than 30°C), then rate of cooling is obeyed by Newton's law of cooling.

(ii) When the temperature difference between body and surroundings is large, then rate of cooling is obeyed by Stefan's law.

23. When two thin blankets are hold together, a layer of air is trapped in between them which is a bad conductor. So it prevents heat from our body to outside. It means it provides better insulation than a single blanket of double the size.

24. The steam at 100°C carries 22.6×10^5 J kg^{-1} more heat than water at boiling point 100°C. That is why, the burns from the steam are generally more serious than those from boiling water.

OR

Bulk modulus of elasticity,

$$K = \frac{P}{\Delta V/V} \quad \text{or} \quad \frac{\Delta V}{V} = \frac{P}{K}$$

But $\dfrac{\Delta V}{V} = \gamma \Delta T$

or $\Delta T = \dfrac{\Delta V}{V} \times \dfrac{1}{\gamma} = \dfrac{P}{K} \times \dfrac{1}{\gamma} = \dfrac{P}{K \times 3\alpha}$

25. According to Joule, whenever a given amount of work (*W*) is converted into heat, always the same amount of heat (*Q*) is produced.

$$W \propto Q \ \text{ or } \ W = jQ \ \text{ or } \ j = \frac{W}{Q}$$

When $Q = 1$, then $j = W$, where j is the proportionality constant called Joule's mechanical equivalent of heat *i.e.*, $j = 4.186$ J cal^{-1}.

26. The electromagnetic radiation emitted by a body by virtue of its temperature is called thermal radiation or radiant energy.

All bodies having temperature above 0 K emit thermal radiation continuously.

For example, the radiation emitted by red-hot iron or light from a filament bulb is thermal radiation.

Properties of thermal radiation :

(i) Thermal radiation travel in straight line, with the speed of light.

(ii) They show the phenomenon of interference diffraction and polarisation.

27. (i) Both boiling point and freezing point of CO_2 decreases with pressure decrease.

(ii) Absorptive power : The absorptive power of a body for a given wavelength λ is defined as the ratio of amount of heat energy absorbed in a certain time to the total heat energy incident on it in the same time within a unit wavelength range around wavelength λ.

It is denoted by a_λ. A perfect black body absorbs all the heat radiations incident upon it, so its absorptive power is unity.

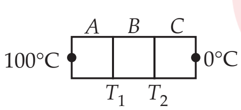
OR

Natural convection : Natural convection arises due to uneven heating of fluid. The more heated and less dense fluids rises up and are replaced by the cooler fluids. Also, natural convection is responsible for the origin of different types of winds in the atmosphere.

Forced convection : When the heated material is forced to move by an agency like a pump or a blower, the process of heat transfer is called forced convection.

Air conditioning, heating a liquid by brisk stirring are the examples of forced convection.

28. Here, $K_A = K$, $K_B = 2K$, $K_C = \frac{K}{2}$



Let L be the length and A be area of cross-section of each conductor respectively. Let T_1 and T_2 be temperatures of A–B and B–C junctions respectively.

At the steady state, $H_A = H_B = H_C$

$$\therefore \quad \frac{K_A A(100-T_1)}{L} = \frac{K_B A(T_1-T_2)}{L} = \frac{K_C A(T_2-0)}{L}$$

$$\text{or} \quad \frac{KA(100-T_1)}{L} = \frac{2KA(T_1-T_2)}{L} = \frac{\frac{K}{2}A(T_2-0)}{L}$$

$\therefore$ $(100 - T_1) = 2(T_1 - T_2)$ or $100 - T_1 = 2T_1 - 2T_2$

or $2T_2 = 3T_1 - 100$ or $T_2 = \frac{3}{2}T_1 - 50$ ...(i)

and $2(T_1 - T_2) = \frac{1}{2}T_2$ ...(ii)

Substituting the value of T_2 from eqn. (i) in eqn. (ii), we get

$$2\left(T_1 - \left(\frac{3}{2}T_1 - 50\right)\right) = \frac{1}{2}\left(\frac{3}{2}T_1 - 50\right)$$

$$\text{or} \quad 2\left(\frac{2T_1 - 3T_1 + 100}{2}\right) = \frac{3T_1 - 100}{4}$$

or $-T_1 + 100 = \frac{3T_1 - 100}{4}$ or $-4T_1 + 400 = 3T_1 - 100$

or $7T_1 = 500$ or $T_1 = \frac{500}{7}\,°C \approx 71°C$

29. Let m_1 and m_2 be the masses of ice melted in same time t(= 1 min) in vessels A and B respectively. Then, the amount of heat flowed into the two vessels will be

$$Q_1 = \frac{K_1 A(T_1 - T_2)t}{x} = m_1 L \quad ...(i)$$

$$\text{and} \quad Q_2 = \frac{K_2 A(T_1 - T_2)t}{x} = m_2 L \quad ...(ii)$$

From eqns. (i) and (ii), we get

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

30. In conduction, heat flows from particle to particle from one end of a solid body to another but the material particle do not leave their positions. In convection, heat is transferred by the actual motion of the heated particles from one place to other in a medium.

In radiation, heat is transferred from one medium to other without affecting the intervening medium and without any actual motion of the material particles.

In convection, heat flows from one point to on other due to actual bodily movement of the heated particles of substance.

Conduction and convection require some material medium for transfer of heat, whereas radiation does not require any material medium for transfer of heat.

Conduction is generally possible in solids, convection in liquid and gases, whereas radiation is possible in vacuum.

Radiation is the quickest mode of transfer of heat as compared to conduction and convection.

31. Here, $\lambda_m = 2.16 \times 10^{-5}$ cm

E = ?; T_0 = 13°C = 13 + 273 = 286 K

b = 0.288 cm K,

$\sigma = 5.77 \times 10^{-5}$ erg s^{-1} cm^{-2} K^{-4}

From Wien's displacement law,

$$T = \frac{b}{\lambda_m} = \frac{0.288}{2.16 \times 10^{-5}} = 13333.3 \text{ K}$$

As, $E = \sigma(T^4 - T_0^4)$

$\therefore \quad E = 5.77 \times 10^{-5}[(13333.3)^4 - (286)^4]$ erg s^{-1} cm^{-2}
$= 18.24 \times 10^8$ J s^{-1} m^{-2}

32. As, $\frac{dQ}{dt} = KA\frac{d\theta}{dx}$ or $\frac{d}{dt}(ms\,\theta) = KA\frac{d\theta}{dx}$

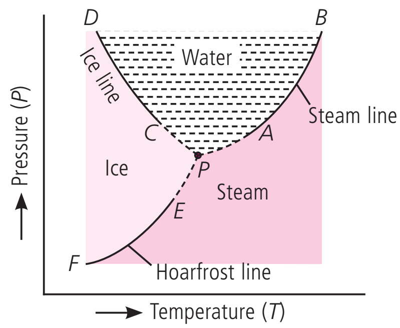
or $\quad ms\frac{d\theta}{dt} = KA\frac{d\theta}{dx}$ or $\frac{d\theta}{dt} = \frac{KA}{ms}\frac{d\theta}{dx}$

or $\quad \frac{d\theta}{dt} \propto \frac{A}{ms}$ $\quad \left[\because K\frac{d\theta}{dx} \text{ is constant as per question}\right]$

Since, $A \propto r^2$ and $m \propto r^3\rho$,

We can write, $\frac{d\theta}{dt} \propto \frac{r^2}{r^3\rho s}$ or $\frac{d\theta}{dt} \propto \frac{1}{r\rho s}$

33.



(i) Vaporisaiton line AB : It represents the variation of boiling point of the substance (in liquid state) with the pressure.

At any point on the vaporisation line, the temperature and pressure values are such that the substance co-exists in equilibrium in liquid and vapour phase.

At pressure and temperature corresponding to any point above the vaporisation line, the substance shall exist only in liquid phase. This is because at higher pressure all vapours will condense into liquid. Similarly, when pressure is decreased, liquid will evaporate into vapours *i.e.*, at all points below the vaporisation line, the substance shall exist only in the vapour state. The vaporisation line is called steam line in case of water.

(ii) Fusion line CD; It represents the variation of melting point of the substance (in solid state) with the pressure.

At every point on the fusion line, the temperature and pressure values are such that the substance co-exists in equilibrium in solid and the liquid phases.

When pressure is more than the pressure corresponding to a point on the fusion line, the solid will melt into the liquid. Hence, at all points above the fusion line, substance shall exist only in liquid phase. Similarly, at all points below the fusion line, the substance shall exist only in the solid phase.

The fusion line is called ice line in case of water.

(iii) Sublimation line EF : It represents the variation of pressure with temperature at which a solid changes directly into vapour state (without going into the liquid phase).

All points above the sublimation line, the substance shall exist only in solid state. Similarly, at all the points below this line, the substance shall exist only in the vapour state. The sublimation line is also called hoar-frost line for water. The three curves AB, CD and EF when extrapolated they meet at a point P is called triple point of the substance.

OR

(i) Temperature of liquid = $\frac{2}{5}$ of distance between lower and upper fixed points = $\frac{2}{5} \times 100 = 40°C$

On Kelvin scale, $T_K = 273.15 + 40 = 313.15$ K

(ii) As, $2 = 2\pi\sqrt{\frac{l_{20}}{g}}$ and $T' = 2\pi\sqrt{\frac{l_{40}}{g}}$

$\therefore \quad \frac{T'}{2} = \sqrt{\frac{l_{40}}{l_{20}}} = [1 + \alpha \times (40 - 20)]^{1/2}$

$= [1 + 12 \times 10^{-6} \times 20]^{1/2}$

$= 1 + \frac{1}{2} \times 12 \times 20 \times 10^{-6} = 1 + 0.000120$

$T' = 2(1 + 0.00012) = (2 + 2 \times 0.00012)$ s

Loss in 2 seconds = $(2 + 2 \times 0.00012) - 2 = 2 \times 0.00012$ s

Loss per day = $0.00012 \times (24 \times 60 \times 60) = 10.368$ s

34. Generally matter exist in three states : (i) solid (ii) liquid (iii) gas.

Any state of a matter can be changed into other by heating or cooling. The conversion of one of these states of matter to another is called the change of state.

The common changes of states are as follows :

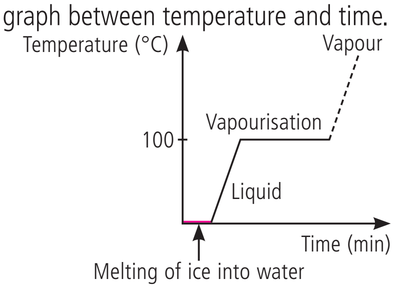
(i) Melting of a solid or conversion of solid to liquid, *e.g.*, ice to water.

(ii) Vaporization of a liquid or conversion of liquid to vapour, *e.g.*, water to steam.

(iii) Condensation of vapour, *e.g.*, steam to water.

(iv) Freezing of a liquid or conversion of liquid to solid, *e.g.*, water to ice.

Let us plot a graph between temperature and time.



The change of state from solid to liquid is called melting and from liquid to solid is called fusion. The solid and liquid states of the substance coexist in thermal equilibrium during the change of state from solid to liquid.

The change of state from liquid to vapour is called vapourisation. In this case the temperature remain constant until the entire amount of liquid is converted into vapour. Both the liquid and the vapour states coexist in thermal equilibrium.

Melting point : The temperature at which the solid and liquid states of matter coexist in thermal equilibrium is called its melting point. It depends on pressure. The melting point of a substance at standard atmospheric pressure is called normal melting point.

Boiling point : The temperature at which the liquid and vapour states of matter coexist in thermal equilibrium is called its boiling point.

Sublimation : The process of transition of a matter from the solid state to vapour state without passing through liquid state is called sublimation. The substance which undergo through this process is called sublime substance.

During this process, the solid and vapour states of matter coexist in thermal equilibrium.

OR

(i) Natural convection : If materials moves due to difference in density, the process of heat transfer is called natural or free convection.

Natural convection arises due to uneven heating of fluid and gravity. The more heated and less dense fluids rises up and are replaced by the cooler fluids. Also natural convection is responsible for the origin of different types of winds in the atmosphere.

Some phenomenon based on natural thermal convections are following :

(a) Monsoon wind

(b) Land breeze and sea breeze

(c) Trade wind

(ii) During the day, the strong solar heat reaches to the ground and to the sea water on earth. Due to it, the ground is heated more quickly than water in sea, because the water has a great specific heat and the mixing currents disperse the absorbed heat throughout the great mass of sea water. The air in contact with the warm ground is heated by conduction. It expands and becomes lighter than the surrounding cooler air. As a result, the warm air rises, resulting the air-currents. The cooler air from above moves down to fill the space. This creates a see breeze near a large quantity of sea water. In this way, a thermal convection cycle is set up, which transfers heat away from the ground.

At night, the ground loses its heat more quickly than water of sea. Due to it, the water surface is warmer at night than that of ground. As a result of it, the land breeze is set up and the thermal convection cycle is reversed.

35. (i) A perfect black body is one which neither reflects nor transmits but absorbs the whole radiation incident on it. The absorptive power of a perfect black body is unity.

(ii) Kirchhoff's law : According to this law, the ratio of emissive power to the absorptive power corresponding to a particular wavelength and at any given temperature is always a constant for all bodies. This is equal to the emissive power of a perfectly black body at some temperature and some wavelength.

If e_λ and a_λ are the emissive and the absorptive powers of a body corresponding to wavelength λ, then

$$\frac{e_\lambda}{a_\lambda} = E_\lambda \text{ (constant)} \qquad \text{...(i)}$$

where, E_λ is the emissive power of perfect black body at the same temperature corresponding to the same wavelength.

As the emissivity ε of a body is defined as the ratio of its emissive power to that of the emissive power of a black body at the same temperature, so

$$\frac{e_\lambda}{E_\lambda} = \varepsilon \qquad \text{...(ii)}$$

From equation, (i) and (ii), we get

$$a_\lambda = \varepsilon$$

Thus, the absorptive power of a body is equal to its emissivity. This is another form of Kirchhoff's law.

Hence, a good absorber is a good emitter and poor reflector, so ability of a body to emit radiation is related oppositely to its ability to reflect.

The silvered surface of a thermos flask is a bad absorber. It does not absorb much heat from the surroundings. That is why ice inside the flask does not melt. Also, the silver surface is a bad emitter/radiator, therefore hot liquids inside the flask do not cool quickly.

OR

This law states that the rate of cooling or rate of loss of heat of a body is directly proportional to the small temperature difference between the body and its surrounding.

For example, a hot water bucket cools fast initially until it gets lukewarm, after this it remains lukewarm for a long time.

Let us consider a hot body at temperature T and T_0 be the temperature of its surrounding. So, according to the Newton's law of cooling,

Rate of loss of heat $\propto$ temperature difference between the body and its surrounding

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

$$\Rightarrow \quad -\frac{dQ}{dt} = K(T - T_0),$$

where K is proportionality constant depends on area of the surface and nature of the body.

As, $dQ = mcdT$,

$\therefore$ Rate of loss of heat is, $\frac{dQ}{dt} = mc\frac{dT}{dt}$

$$-mc\frac{dT}{dt} = K(T - T_0) \quad \text{or} \quad \frac{dT}{dt} = -\frac{k}{mc}(T - T_0) = -K(T - T_0)$$

or $$\frac{dT}{(T - T_0)} = -K\,dt,$$

where $K = \frac{k}{mc}$ is another constant and $\frac{dT}{dt}$ represents the rate of cooling.