

NCERT SOLUTIONS

CLASS-XI PHYSICS

CHAPTER-11

THERMAL PROPERTIES OF MATTER

Q.1: The triple points of carbon dioxide and neon are 216.55 K and 24.5K respectively. State these temperatures on the scales of Fahrenheit and Celsius.

Ans:

Given: Kelvin and Celsius scales are related as:

$$T_C = T_K - 273.15 \dots\dots\dots (1)$$

We know :

$$T_F = \left(\frac{9}{5}\right) T_C + 32 \dots\dots\dots (2)$$

For neon:

$$T_K = 24.57 \text{ K}$$

$$\Rightarrow T_C = 24.57 - 273.15 = -248.58^\circ \text{ C}$$

$$T_F = \left(\frac{9}{5}\right) T_C + 32 = \left(\frac{9}{5}\right) \times (-248.58) + 32 = -415.44^\circ \text{ F}$$

For carbon dioxide

$$T_K = 216.55 \text{ K}$$

$$\Rightarrow T_C = 216.55 - 273.15 = -56.60^\circ \text{ C}$$

$$T_F = \left(\frac{9}{5}\right) T_C + 32 = \left(\frac{9}{5}\right) \times (-56.60) + 32 = -69.88^\circ \text{ F}$$

Q.2: Absolute scales A and B have triple points of water at 200A and 350B. Find the relation between T_A and T_B .

Ans:

Given:

Triple point of water on absolute scale B, $T_2 = 400 \text{ B}$

Triple point of water on absolute scale A, $T_1 = 200 \text{ A}$

Triple point of water on Kelvin scale, $T_K = 273.15 \text{ K}$

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

$$\Rightarrow T_1 = T_K$$

$$200 \text{ A} = 273.15 \text{ K}$$

$$\text{Thus, } A = \frac{273.15}{200}$$

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

$$\Rightarrow T_2 = T_K$$

$$350 \text{ B} = 273.15 \text{ K}$$

$$\text{Thus, } B = \frac{273.15}{350}$$

Let, T_A and T_B be the triple point of water on scale A and B respectively.

Thus, we have

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

$$\text{Therefore, } T_A : T_B = 4 : 7$$

Q.3: A thermometer's electrical resistance varies with temperature in accordance to the law $R = R_0 [1 + \alpha(T - T_0)]$. For the triple point of water (273.16 K) the thermometer's resistance is 101.6Ω and for the melting point of lead (600.5 K) its resistance is 165.5Ω . Calculate the temperature at a resistance value of 100Ω .

Ans:

Given:

$$R = R_0 [1 + \alpha(T - T_0)] \dots\dots\dots (1)$$

Here, R_0 and T_0 are the initial resistance and temperature respectively while R and T are the final resistance and temperature respectively.

$$R_0 = 101.6 \Omega$$

$$T = 273.16 \text{ K}$$

$$t_0 = 273.15 \text{ K}$$

Melting point of lead, $T = 600.5 \text{ K}$

Resistance of lead, $R = 165.5 \Omega$

Using these values in equation (1):

$$165.5 = 101.6 [1 + \alpha (600.5 - 165.5)]$$

$$1.629 = 1 + \alpha (327.35)$$

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

Now, at $R = 100 \Omega$

$$100 = 101.6 [(1 + 1.92) \times 10^{-3} (T - 273.15)]$$

$$0.984 = 1 + 1.92 \times 10^{-3} (T - 273.15)$$

$$-8.3 = T - 273.15$$

Therefore, $T = 264.85 \text{ K}$

Q.4: Provide answers to the following:

(i) In modern thermometry the triple point of water is the standard fixed point. Why aren't the melting and boiling points of water considered as the standard fixed points?

(ii) There are two fixed points on the Celsius scale viz 0°C and 100°C . On the absolute scale however, the first fixed point is equal to 273.16 K of the Kelvin scale, which is the triple point of water. Find the upper fixed point of this scale.

(iii) The relation between the absolute temperature T (kelvin scale) and a temperature t_C on the Celsius scale is :

$$t_C = T - 273.15. \text{ Why is } 273.15 \text{ used instead of } 273.16?$$

(iv) Calculate the triple point temperature of water on an absolute scale that has the same unit interval size as that of the Fahrenheit scale.

Ans:

(i) Melting and boiling points of water aren't considered as the standard fixed points because they vary with

change in pressure, the temperature of triple point of water is unique and it does not vary with pressure.

(ii) On the Kelvin's scale there is only a lower fixed point which is 273.16 K , the upper fixed point is not there.

(iii) The relation is such because 273.15 K on the Kelvin's scale corresponds to the melting point of ice while 273.16 K is the triple point of water.

(iv) We know,

Relation between the Fahrenheit scale and Absolute scale :

$$\text{i.e. } \frac{T_F - 32}{180} = \frac{T_K - 273}{100} \dots\dots\dots (1)$$

For another set of T'_F and T'_K

$$\frac{T'_F - 32}{180} = \frac{T'_K - 273}{100} \dots\dots\dots (2)$$

Subtracting Equation (1) and (2):

$$\frac{T'_F - T_F}{180} = \frac{T'_K - T_K}{100}$$

$$\text{Therefore, } T'_F - T_F = 1.8(T'_K - T_K)$$

$$\text{For, } T'_K - T_K = 1\text{K}$$

$$T'_F - T_F = 1.8$$

$$\Rightarrow \text{For the triple point temperature} = 273.16 \text{ K, the temperature on the new scale} = 1.8 \times 273.16 =$$

$$491.688 \text{ Units}$$

Q.5: X and Y are ideal gas thermometers that use hydrogen and oxygen respectively. They made the following observations:

Temperature	Pressure Thermometer X	Pressure thermometer Y
Triple point of water	$0.200 \times 10^5 \text{ Pa}$	$1.250 \times 10^5 \text{ Pa}$
Melting point of sulfur	$0.287 \times 10^5 \text{ Pa}$	$1.797 \times 10^5 \text{ Pa}$

(a) Calculate the absolute temperature of melting temperature of sulfur as observed by thermometers X and Y.

(b) Give an explanation for the slight difference in the values you got from thermometers X and Y. What can be done to further reduce the difference between the two values?

Ans. (a)

Given:

At the triple point of water i.e., 273.16 K

Pressure in thermometer X, $P_X = 0.200 \times 10^5 \text{ Pa}$

Let the melting point of sulfur be T_1

At T_1 pressure in X, $P_1 = 0.287 \times 10^5 \text{ Pa}$

Using Charles' Law :

$$\frac{P_x}{T} = \frac{P_1}{T_1}$$

$$\text{Thus, } T_1 = T \left(\frac{P_1}{P_x} \right)$$

$$\Rightarrow T_1 = \frac{0.287 \times 10^5 \times 273.16}{0.2 \times 10^5} = 391.98 \text{ K}$$

Now for thermometer Y,

At the triple point of water i.e., 273.16 K

Pressure in thermometer Y, $P_Y = 1.250 \times 10^5 \text{ Pa}$

Let, the melting point of sulfur be T_1

At T_1 pressure in Y, $P_1 = 1.797 \times 10^5 \text{ Pa}$

Using Charles' Law :

$$\frac{P_x}{T} = \frac{P_1}{T_1}$$

$$\text{Thus, } T_1 = T \left(\frac{P_1}{P_x} \right)$$

$$\Rightarrow T_1 = \frac{1.737 \times 10^5 \times 273.16}{1.250 \times 10^5} = 392.69 \text{ K}$$

(b). The slight difference in the readings of the two thermometers is because the two gases being used in these thermometers, oxygen and hydrogen are not ideal gases.

To reduce the difference in the values the reading should be taken under lower pressure conditions. This way these gases behave more like ideal gases.

Q.6: A metallic measuring tape is correctly calibrated for 25°C. At 45°C this tape measures a steel rod to be 60 cm. Find the actual length of the steel rod. Also find the length of the steel rod at 25 °C. (Coefficient of linear expansion of this steel = $1.20 \times 10^{-5} \text{ K}^{-1}$)

Ans.

Given:

Length of the metallic tape at temperature $T = 25^\circ\text{C}$, $l = 1 \text{ m} = 100 \text{ cm}$

At temperature $T_1 = 45^\circ\text{C}$

The length of the steel rod, $l_1 = 60 \text{ cm}$

Coefficient of linear expansion of the metal (measuring tape), $\alpha = 1.20 \times 10^{-5} \text{ K}^{-1}$

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

$$\text{i.e. } l' = l + \alpha(l - T)$$

$$\Rightarrow l' = 100 + 1.20 \times 10^{-5} \times 100(45 - 25) = 100.024 \text{ cm}$$

Thus the real length of the steel measured by the tape is :

$$l_2 = 60 \times \frac{100.024}{100}$$

$$= 60.0144 \text{ cm}$$

And at 25 °C length of the rod is 60cm.

Q.7: A steel disc is to be attached to a steel rod. At 27°C the outer diameter of the rod is 8cm and the central hole in the disc is of radius 7.99 cm. The rod is then cooled, at what temperature will the rod fit in the disc? (Consider the linear expansion of steel to be constant, $\alpha = 1.20 \times 10^{-5} \text{ K}^{-1}$)

Ans:

Given:

Temperature, $T = 27^\circ\text{C}$

$$\Rightarrow 27 + 273 = 300 \text{ K}$$

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

At temperature T:

Outer diameter of the steel rod $d_1 = 8 \text{ cm}$

Diameter of the central hole in the disc, $d_2 = 7.99 \text{ cm}$

Let the temperature be cooled to T_1 at which the rod will be able to fit in the central hole:

$$\text{i.e., } \Delta d = 7.99 - 8.00 = -0.01 \text{ cm}$$

Now, we know:

$$\Delta d = d_1 \alpha (T_1 - T) = 8 \times 1.20 \times 10^{-5} (T_1 - 300)$$

$$\Rightarrow (T_1 - 300) = -104.16$$

Therefore, $T_1 = 195.63 \text{ K}$

$$= 195.63 - 273.16 = -77.53^\circ\text{C}$$

Hence, the rod will fit into the disc's central hole when its temperature is -77.53°C

Q.8: A 4cm hole is drilled in a copper sheet at 27°C . Find the diameter of this hole if the sheet is heated to 227°C . (Coefficient of linear expansion of copper $= 1.70 \times 10^{-5} \text{ K}^{-1}$).

Ans:

Given:

Initial temperature, $T_1 = 27.0^\circ\text{C}$

Diameter of the hole at T_1 , $d_1 = 4.00 \text{ cm}$

At T_1 area of the hole, $A_1 = \pi \left(\frac{d_1^2}{4} \right)$

Final temperature, $T_2 = 227^\circ\text{C}$

Let, the diameter of the hole at T_2 be d_2

At T_2 area of the hole, $A_2 = \pi \left(\frac{d_2^2}{4} \right)$

Co-efficient of linear expansion of copper, $\alpha = 1.70 \times 10^{-5} \text{ K}^{-1}$

We know, co-efficient of superficial expansion $\beta = 2\alpha = 3.4 \times 10^{-5}$

Also, increase in area $= A_2 - A_1 = \beta A_1 \Delta T$

Or, $A_2 = \beta A_1 \Delta T + A_1$

$$\frac{\pi d_2^2}{4} = \frac{\pi (4)^2}{4} [1 + 3.4 \times 10^{-5} (228 - 27)]$$

$$d_2^2 = 4^2 \times 1.0068$$

$$\Rightarrow d_2 = 4.0136$$

Thus the change in diameter is $= 4.013 - 4 = 0.0136 \text{ cm}$.

Q.9: A 2m long brass wire with a diameter of 2.5mm is held stiffly between two rigid supports with minimum tension. This wire is then cooled to 39°C , find the tension produced in the wire.

(Co-efficient of linear expansion of brass $= 2.0 \times 10^{-5} \text{ K}^{-1}$; Young's modulus of brass $= 0.91 \times 10^{11} \text{ Pa}$.)

Ans:

Given:

Initial temperature, $T_1 = 27^\circ\text{C}$

At T_1 :

length of the brass wire, $l = 2 \text{ m}$

Diameter of the wire, $d = 2.5 \text{ mm} = 2.5 \times 10^{-3} \text{ m}$

Final temperature, $T_2 = 39^\circ\text{C}$

Let the tension developed in the wire $= F$

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

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

We know, Young's modulus $= \text{Stress} / \text{Strain} = \frac{F \times L}{A \times \Delta L}$

$$\text{Or, } \Delta L = \frac{F \times L}{A \times Y} \dots \dots \dots (1)$$

$$\text{Where, } \Delta L = \alpha L (T_2 - T_1) \dots \dots \dots (2)$$

Using equation (2) in (1) we have:

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

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

$$F = 2 \times 10^{-5} \times (-39 - 27) \times 3.14 \times 0.91 \times 10^{11} \times \left(\frac{2.5 \times 10^{-3}}{2} \right)^2$$

Therefore the tension, $F = -5.893 \times 10^2 \text{ N}$ [The negative sign indicates that the tension is directed inwards]

Q.10: A 80 cm long brass wire with a diameter of 2mm is connected to a steel rod of equal dimensions. At 250°C what will the change in the length of the combined rod be, considering them to have original lengths at 40°C ? If the rods are free to expand from their ends will there be thermal stress at the joint? [Co-efficient of linear expansion of brass $= 2.0 \times 10^{-5} \text{ K}^{-1}$, steel $= 1.2 \times 10^{-5} \text{ K}^{-1}$]

Ans:

Given:

Initial temperature, $T_1 = 40^\circ\text{C}$

Final temperature, $T_2 = 250^\circ\text{C}$

Change in temperature, $\Delta T = T_2 - T_1 = 210^\circ\text{C}$

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

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

At T_1 length of the brass rod, $l_B = 80 \text{ cm} = l_S$, length of steel rod

At T_1 diameter of the brass rod, $d_B = 2.0 \text{ mm} = d_S$, diameter of brass rod.

Now, change in the length of the brass rod $\Delta l_B = \alpha_B \times l_B \times \Delta T = 2.0 \times 10^{-5} \times 80 \times 210 = 0.36 \text{ m}$

Now, change in the length of the steel rod $\Delta l_S = \alpha_S \times l_S \times \Delta T = 1.2 \times 10^{-5} \times 210 \times 80 = 0.2016 \text{ m}$

Therefore total change in the length of the rod $= 0.36 + 0.2016 = 0.5616 \text{ cm}$

As the rods are free to expand from their ends, no thermal stress is developed in the junction.

Q-11: Calculate the fractional change in the density of glycerin for a temperature rise of 30°C if the coefficient of volume expansion of glycerin is $49 \times 10^{-5} \text{ K}^{-1}$.

Ans:

Given:

Coefficient of volume expansion of glycerin, $\alpha_V = 49 \times 10^{-5} \text{ K}^{-1}$

Rise in temperature, $\Delta T = 30^\circ\text{C}$

Fractional change in volume $= \frac{\Delta V}{V}$

We know:

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

$$\text{Or, } V_{T_2} - V_{T_1} = V_{T_1} \alpha_V \Delta T$$

$$\text{Or, } \frac{m}{\rho_{T_2}} - \frac{m}{\rho_{T_1}} = \frac{m}{\rho_{T_1}} \alpha_V \Delta T$$

Where, m = mass of glycerin

ρ_{T_2} = Final density at T_2

ρ_{T_1} = Initial density at T_1

$$\Rightarrow \frac{\rho_{T_1} - \rho_{T_2}}{\rho_{T_2}} = \text{Fractional change in density}$$

Therefore, Fractional change in density $= 1.47 \times 10^{-2}$

Q.12: A drilling machine with a power rating of 20 kW is drilling a hole in a 10 kg aluminum block . What is the increase in temperature of the block in 2.5 minutes, considering that 50% of the power is lost in heating the machine itself and lost to the environment. (Specific heat of aluminum $= 0.91 \text{ J g}^{-1} \text{ K}^{-1}$)

Ans:

Given:

Power of the drilling machine, $P = 20 \text{ kW} = 20 \times 10^3 \text{ W}$

Mass of the aluminum block, $m = 10 \text{ kg} = 10 \times 10^3 \text{ g}$

Time for which the machine is used, $t = 2.5 \text{ min} = 2.5 \times 60 = 150 \text{ s}$

Specific heat of aluminum, $c = 0.91 \text{ J g}^{-1} \text{ K}^{-1}$

Let , the rise in the temperature $= \Delta T$

Total energy of the drilling machine $= \text{Power} \times \text{Time} = 20 \times 10^3 \times 150 \text{ J} = 3 \times 10^6 \text{ J}$

As 50% of energy is lost

Therefore, Useful energy, $\delta Q = \frac{50}{100} \times 3 \times 10^6$

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

Since, $\delta Q = m c \Delta T$

Therefore the increase in temperature is, $\Delta T = \frac{\delta Q}{mc}$

$$\Delta T = \frac{1.5 \times 10^6}{10 \times 10^3 \times 0.91}$$

Therefore, $\Delta T = 164.8^\circ\text{C}$

Q.13: A block of copper having a mass of 3 kg is heated to 500°C and then kept on ice block. Find the total amount of ice that melts. [Heat of fusion of water, $L = 335 \text{ J g}^{-1}$, Specific heat of copper $= 0.39 \text{ J g}^{-1} \text{ K}^{-1}$].

Ans:

Given:

Mass of the copper block, $m = 3 \text{ kg} = 3000 \text{ g}$

Rise in the temperature of the copper block, $\Delta \theta = 500^\circ\text{C}$

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

The maximum heat the copper block can lose, $Q = m C \Delta \theta = 3000 \times 0.39 \times 500 = 5.85 \times 10^5 \text{ J}$

Let, m_1 be the total amount of ice melted by the hot block of copper.

Heat gained by molten ice, $Q = m_1 L$

$$\text{Therefore, } m_1 = \frac{Q}{L} = \frac{585000}{335} = 1746.26 \text{ g}$$

Q.14: A metal block of mass 0.10 kg at 160°C is immersed in a copper calorimeter having 150 cm³ of water at 27°C. If the temperature of the metal drops to a final value of 50°C, what is the specific heat of the metal? If heat is lost to the environment, is your answer lesser or greater than the real value of the specific heat of the metal? [Copper calorimeter is water equivalent to 0.025 kg].

Ans:

Given;

Mass of the metal, $m = 0.10 \text{ kg} = 100 \text{ g}$

Initial temperature of the metal, $T_1 = 160^\circ\text{C}$

Final temperature of the metal, $T_2 = 50^\circ\text{C}$

Calorimeter has a water equivalent mass, $w = 0.025 \text{ kg} = 25 \text{ g}$

Volume (V) of water = 150 cm³

At temperature $T = 27^\circ\text{C}$

Mass of water, $M = 150 \times 1 = 150 \text{ g}$

Fall in the temperature of the metal: $\Delta T = T_1 - T_2 = 160 - 50 = 110^\circ\text{C}$

Specific heat of water, $C_W = 4.186 \text{ J/g/K}$

Let, the specific heat of the metal = C

Heat lost by the metal, $\theta = m C \Delta T$ (1)

Increase in the temperature of the calorimeter and water:

$$\Delta T' = 50 - 27 = 23^\circ\text{C}$$

Heat gained by the calorimeter and water ;

$$\Delta \theta' = m C_W \Delta T' = (M + w) C_W \Delta T' \text{ (2)}$$

We know:

Heat lost by the metal = Heat gained by the calorimeter and water

$$\Rightarrow m C \Delta T = (M + w) C_W \Delta T'$$

$$100 \times C \times 110 = (150 + 25) \times 4.186 \times 23$$

Therefore, specific heat $C = 1.53 \text{ J/g/K}$

If heat is lost to the environment then the actual value of the specific heat of this metal will be less than what we have arrived at i.e., 1.53 J/g/K

Q.15: Presented below are molar specific heat readings of a few common gases at room temperature.

Gas	Molar Specific Heat C_V (cal mol ⁻¹ K ⁻¹)
Chlorine	6.17
Oxygen	5.02
Carbon monoxide	5.01
Nitric oxide	4.99
Nitrogen	4.97
Hydrogen	4.87

Generally the specific heat of a mono atomic gas is $2.92 \text{ cal (mol K)}^{-1}$, which is significantly lower from the specific heat of the above gases. Explain.

It can be observed that chlorine has little larger value of specific heat, what could be the reason?

Ans:

The gases in the above list are all diatomic and a diatomic molecule has translational, vibrational and rotational motion. Whereas, a **monoatomic gas** only has translational motion. So to increase the temperature of one mole of a diatomic gas by 1°C, heat needs to be supplied to increase translational, rotational and vibrational energy. Thus the above gases have significantly higher specific heats than mono atomic gases

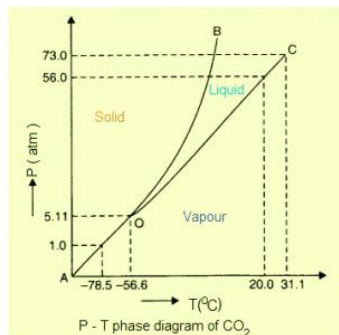
Chlorine has little larger **specific heat** as compared to the others in list because it possesses **vibrational motion** as well while the rest only have **rotational and translational motions**.

Q.16: Provide answers to the following referring to the P-T phase diagram of CO₂ given below.

(a). What is the temperature where the solid, liquid and vapour states of carbon dioxide co-exist in equilibrium?

equilibrium :

- (b). How will decreased pressure affect the boiling and fusion point of CO_2 ?
 (c). State the significance and value of the critical pressure and temperature of carbon dioxide .
 (d). Identify the physical state [solid, liquid and vapor] of CO_2 at (i) -72°C under 1 atm, (ii) 61°C under 10 atm, (iii) 14°C under 55 atm.



Ans:

- (a). At the triple point temperature = 56.6°C and pressure = **5.11 atm**
 (b). Decreased pressure will **decrease** the fusion and boiling point of CO_2 .
 (c). The **critical pressure and temperature** of carbon dioxide is 73 atm and 31.1°C respectively. Beyond this temperature carbon dioxide will not be able to **liquefy** no matter how much pressure is exerted.
 (d).
 (i) At -72°C and 1 atm CO_2 will be in **the vapor state**.
 (ii) At -61°C and 10 atm CO_2 will be **in the solid state**.
 (iii) At 14°C and 55 atm CO_2 will be **in the liquid state**.

Q.17: Provide answers to the following questions referring to the P-T phase diagram of CO_2 above.

- (i). Carbon dioxide at -61°C and 1 atm pressure is isothermally compressed.
 (ii). If carbon dioxide at 4.5 atm pressure is cooled at a constant pressure from the room temperature, what will happen to it?
 (iii). State qualitatively the changes in a block of solid carbon dioxide at -60°C and 10 atm pressure as it is heated up to room temperature at a constant pressure.
 (iv). What are the possible changes in the properties of CO_2 when it is isothermally compressed and heated up to 70°C ?

Ans:

- (a). As -61°C lies to the left of 56.6°C on the graph i.e., it lies in the vapor and solid state, so CO_2 will directly condense to solid without changing into liquid.
 (b). As 4.5 atm is less than 5.11 atm, CO_2 will directly condense into solid without changing into liquid.
 (c). When the temperature of the solid block of CO_2 [at 10 atm and -65°C] is increased, it changes to liquid and then to vapor. If a line parallel to the temperature axis is drawn at 10 atm. The fusion and boiling points of carbon dioxide at 10 atm are given by the points where this parallel line cuts the fusion and vaporization curves.
 (d). As 70°C is **higher than the critical temperature**, CO_2 cannot liquefy on being isothermally compressed at this temperature. However with the increase in pressure the gas will drift further away from its ideal behavior.

Q.18: An elderly lady of 60 kg is suffering from a 102°F fever. She is then given a tablet that lowers fever by increasing the rate of evaporation of sweat from the body. Within 20 minutes her body temperature was lowered to 98°F . Find the average rate of extra evaporation caused by the tablet assuming that sweat evaporation is the only way for the body to lose heat. Also, the specific heat of a human body is almost the same as that of water, and water's latent heat of evaporation at this temperature is approximately 580 cal /g.

Ans:

Given:

Initial body temperature of the lady, $T_1 = 102^\circ\text{F}$

Final body temperature of the lady, $T_2 = 98^\circ\text{F}$

Final body temperature of the lady, $t_2 = 38^\circ\text{C}$

Change in temperature, $\Delta T = 102 - 98 = 4^\circ\text{F}$

$$\Rightarrow \Delta T = 4 \times (5/9) = 2.22^\circ\text{C}$$

Time taken for the change in temperature, $t = 20 \text{ min}$

Mass of the child, $m = 60 \text{ kg} = 60 \times 10^3 \text{ g}$

Specific heat of the human body = Specific heat of water = $c = 1000 \text{ cal/kg/}^\circ\text{C}$

Latent heat of evaporation of water, $L = 580 \text{ cal/g}$

The heat lost by the lady :

$$\Delta \theta = m c \Delta T = 60 \times 1000 \times 2.22 = 133200 \text{ cal}$$

Let m' be the mass of water that has evaporated from the lady's body in 20 min.

Loss of heat through water :

$$\Delta \theta = m' L$$

$$m' = \frac{\Delta \theta}{L} = \frac{133200}{580} = 229.6 \text{ g}$$

Therefore, Average rate of evaporation = $\frac{m'}{t}$

$$\Rightarrow \frac{229.6}{20} = 11.48 \text{ g/min}$$

Q.19: There is a cubical thermacole ice box of side 20 cm and thickness 4 cm. If 5 kg of ice is kept inside the box, what will be the amount of ice left in the box after 6 h?

[Outside temperature = 45°C , co-efficient of thermal conductivity of thermacole = $0.01 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$

and heat of fusion of water = $335 \times 10^3 \text{ J kg}^{-1}$]

Ans:

Given:

Side of the cubical ice box, $s = 20 \text{ cm} = 0.2 \text{ m}$

Thickness of the ice box, $l = 4.0 \text{ cm} = 0.04 \text{ m}$

Mass of ice kept inside the ice box, $m = 5 \text{ kg}$

Time gap, $t = 6 \text{ h} = 6 \times 60 \times 60 \text{ s} = 21600 \text{ s}$

Outside temperature, $T = 45^\circ\text{C}$

Coefficient of thermal conductivity of thermacole, $K = 0.01 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$

Heat of fusion of water, $L = 335 \times 10^3 \text{ J kg}^{-1}$

Let m' be the total amount of ice that melts in 6 h.

The amount of heat lost by the food kept inside the ice box, $\Theta = \frac{KA(T - 0)t}{l}$

Where,

$$A = \text{Surface area of the box} = 6s^2 = 6 \times 0.2^2 = 0.24 \text{ m}^2$$

$$\Rightarrow \Theta = \frac{0.01 \times 0.24(45 - 0)21600}{0.04} = 58320 \text{ J}$$

Also, we know; $\Theta = m' L$

$$\text{Therefore } m' = \frac{58320}{335 \times 10^3} = 0.174 \text{ kg}$$

Thus, the amount of unmolten ice in the box after 6 h = $5 - 0.174 = 4.825 \text{ kg}$

Q.20: A utensil made up of brass has a thickness of 0.5 cm and a base area 0.20 m^2 . Water can boil in it at the rate of 6 kg / min when placed over a flame. Calculate the temperature of the flame in contact with the utensil. (Thermal conductivity of brass = $109 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$, Heat of vaporization of water = $2256 \times 10^3 \text{ J kg}^{-1}$)

Ans:

Given:

Base area of the boiler, $A = 0.2 \text{ m}^2$

Thickness of the boiler, $l = 0.5 \text{ cm} = 0.005 \text{ m}$

Boiling rate of water, $R = 6.0 \text{ kg/min}$

Mass, $m = 6 \text{ kg}$

Time, $t = 1 \text{ min} = 60 \text{ s}$

Thermal conductivity of brass, $K = 109 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$

Heat of vaporization, $L = 2256 \times 10^3 \text{ J kg}^{-1}$

We know that the amount of heat flowing into water through the brass base is :

$$\Theta = \frac{KA(T - T')t}{l} \dots \dots \dots (1)$$

Where,

T = temperature of the flame in contact with the utensil

T' = boiling point of water = 100°C

$t = \text{boiling point of water} = 100^\circ\text{C}$

Heat needed for boiling water :

$\theta = \text{mL} \dots \dots \dots (2)$

Equating equation (1) and equation (2):

$$\text{mL} = \frac{KA(T - T')t}{l}$$

$$T - T' = \text{mL}/\text{Kat} = \frac{6 \times 2256 \times 10^3 \times 0.005}{109 \times 0.2 \times 60} = 151.743^\circ\text{C}$$

Thus the temperature of the flame in contact with utensil is 151.743°C

Q.21: Give reasons why:

- (a). A body having a large value of reflectivity is a bad emitter.
- (b). On a chilly day a brass spoon feels much colder than a wooden spoon.
- (c). The earth without an atmosphere would be extremely cold.
- (d). Heating systems using circulating steam are more efficient in heating a building than those using circulating water.
- (e). An optical pyrometer (measures high temperatures) calibrated for an ideal black body radiation produces low temperature readings for a red hot iron piece in the open. However, it gives a correct reading when the same piece is in a furnace.

Ans:

- (a). A body that is a good reflector is a bad absorber and thus a bad emitter. This is in accordance to Kirchhoff's Law of black body radiations that states poor emitters are poor absorbers and good emitters are good absorbers.
- (b). Brass being a better conductor of heat draws greater amount of heat from our hands when we touch it on a chilly day. Wood however does not draw that much amount of heat from us, hence a brass spoon is much colder to touch than a wooden one.
- (c). The atmosphere, especially the lower layers, is responsible for reflecting the infrared waves coming from earth back to the surface, thus trapping the heat received during the day. Without an atmosphere, all the heat would have been lost back to space causing our planet to freeze over.
- (d). Heating systems using steam are more efficient than those using hot water because at 100°C steam has more heat than the same mass of water at 100°C .
- (e). An optical pyrometer calibrated for an ideal black body radiation gives too low a value for temperature of a red hot iron piece kept in the open.

Black body radiation equation is given by:

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

Where,

E = energy radiation

T = temperature of the optical pyrometer

T_0 = Temperature of open space

σ = Constant

We can see that an increase in the temperature of the open space reduces the radiation thereby altering the reading.

However, the same piece of iron when placed in a furnace the radiation energy, $E = \sigma T^4$

Q.22: A hot ball cools from 90°C to 10°C in 5 minutes. If the surrounding temperature is 20°C , what is the time taken to cool from 60°C to 30°C ?

Ans:

Using Newton's law of cooling, the cooling rate is directly proportional to the difference in temperature.

Here, average of 90°C and $40^\circ\text{C} = 50^\circ\text{C}$

Surrounding temperature = 20°C

Difference = $50 - 20 = 30^\circ\text{C}$

Under the given conditions, the ball cools 80°C in 5 minutes

$$\text{Therefore, } \frac{\text{Change in temperature}}{\text{Time}} = k\Delta t$$

$$\Rightarrow \frac{30}{5} = K \times 30 \dots \dots \dots (1)$$

Where the value of K is a constant.

The average of 60°C and $30^\circ\text{C} = 45^\circ\text{C}$

$\Rightarrow 45^\circ\text{C} - 20^\circ\text{C} = 25^\circ\text{C}$ above the room temperature and the body cools by 30°C [$60^\circ\text{C} - 30^\circ\text{C}$] within time t (Assume)

$$\text{Therefore, } \frac{30}{t} = K \times 25 \dots \dots \dots (2)$$

Dividing equation (1) by (2), we have:

$$\frac{\frac{30}{5}}{t} = \frac{K \times 30}{K \times 25}$$

$$\Rightarrow \frac{t}{5} = 1.2$$

Therefore, $t = 6$ mins.

