Question 11. 17. Answer the following questions based on the P - T phase diagram of $CO_2$ (Fig. of question 17 given above)

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

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

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

(d) $CO_2$ is heated to a temperature 70 °C and compressed isothermally. What changes in its properties do you expect to observe ?

Answer:

(a) No, the $CO_2$ does not go through the liquid phase. The point (1.00 atm, - 60°C) is to the lift of the triple-point O and below the sublimation curve OA. Therefore, when $CO_2$ is compressed at this point at constant temperature, the point moves perpendicular to the temperature-axis and enters the solid phase region. Hence, the $CO_2$ vapour condenses to solid directly without going through the liquid phase.

(b) $CO_2$ at 4.0 atm pressure and room temperature (say, 27 °C) is in vapour phase. This point (4.0 atm, 27°C) lies below the vaporation curve OC and to the right of the triple point O. Therefore, when $CO_2$ is cooled at this point at constant pressure, the point moves perpendicular to the pressure-axis and enters the solid phase region. Hence, the $CO_2$ vapour condenses directly to solid phase without going through the liquid phase.

(c) When the solid $CO_2$ at - 65 °C is heated at 10 atm pressure, it is first converted into liquid. A further increase in its temperature brings it into the vapour phase. If a horizontal line at P = 10 atm is drawn parallel to the T-axis, then the points of intersection of line with the fusion and vaporization curve give the fusion and boiling points at 10 atm.

(d) Above 31.1°C, the gas cannot be liquefied. Therefore, on being compressed isothermally at 70°C, there will be no transition to the liquid region. However, the gas will depart, more and more from its perfect gas behaviour with the increase in pressure.

Question 11. 18. 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 minutes, 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:

Decrease of temperature, $\Delta t$

$$= 101° \quad F - 98° \quad F = 3° \ F = 3 \times \frac{5}{9} °C = 1.67°C$$

specific heat of water $= 1000 \text{ cal kg}^{-1} \ °C^{-1}$

latent heat of vaporisation, $L = 580 \times 10^3 \text{ cal kg}^{-1}$

heat lost

$$= 30 \text{ kg} \times 1000 \text{ cal kg}^{-1} \ °C^{-1} \times 1.67 \ °C = 50100 \text{ cal}$$

If $m'$ be the mass of water evaporated, then

$$m' = \frac{50100 \text{ cal}}{580 \times 10^3 \text{ cal kg}^{-1}} = 0.086 \text{ kg}$$

This much water has taken 20 minutes to evaporate.

$$\text{So, rate of evaporation} = \frac{0.086 \text{ kg}}{20 \text{ min}} = \frac{86 \text{ g}}{20 \text{ min}}$$

$$= \mathbf{4.3 \ g \ min^{-1}}.$$

Question 11. 19. A 'thermacole' icebox is a cheap and efficient method for storing small quantities of cooked food in summer in particular. A cubical icebox of side 30 cm has a thickness of 5.0 cm. If 4.0 kg of ice is put in the box, estimate the amount of ice remaining after 6 h. The outside temperature is 45°C, and coefficient of thermal conductivity of thermacole is 0.01 $Js^{-1} \ m^{-1} \ °C^{-1}$ [Heat of fusion of water = 335 x $10^3$ J $kg^{-1}$ ].

Answer: Each side of the cubical box (having 6 faces) is 30 cm = 0.30 m. Therefore, the total surface area' of the icebox exposed to outside air is A = 6 x $(0.30 \text{ m})^2 = 0.54 \text{ m}^2$. The thickness of the icebox is d = 5.0 cm = 0.05 m, time of exposure t = 6h = 6 x 3600 s and temperature difference $T_1 - T_2$ = 45°C - 0°C = 45°C.

∴ Total heat entering the icebox in 6 h is given by

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

$$= \frac{0.01 \text{ Js}^{-1} \text{ m}^{-1} \text{ C}^{-1} \times 0.54 \text{ m}^2 \times 45°C \times (6 \times 3600 \text{ s})}{0.05 \text{ m}}$$

$$= 1.05 \times 10^5 \text{ J}$$

Suppose a mass $m$ of ice melts with this heat. Then $Q = mL$, where $L$ is tatent heat of fusion of water. Thus,

$$1.05 \times 10^5 \text{ J} = m \ (335 \times 10^3) \text{ Jkg}^{-1}$$

or

$$m = \frac{1.05 \times 10^5 \text{ J}}{335 \times 10^3 \text{ J kg}^{-1}} = 0.313 \text{ kg}$$

The initial mass of ice in the box is 4.0 kg. Therefore,the ice remaining in the box after 6 h is

$$= (4.0 - 0.313) \text{ kg}$$

$$= 3.687 \text{ kg}.$$

Question 11. 20. A brass boiler has a base area 0.15 $m^2$ 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 = $10^9 \ Js^{-1} \ m^{-1} \ K^{-1}$. (Heat of vaporization of water = 2256 x $10^3$ J $kg^{-1}$ )

Answer:

Here, $K = 109 \text{ Js}^{-1} \text{ m}^{-1} \text{ K}^{-1}$

$A = 0.15 \text{ m}^2$

$d = 1.0 \text{ cm} = 10^{-2} \text{ m}$

$T_2 = 100° \text{ C}$

Let $T_1$ = temperature of the part of the boiler in contact with the stove.

If $Q$ be the amount of heat flowing per second through the base of the boiler, then

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

or
$$Q = \frac{109 \times 0.15 \times (T_1 - 100)}{10^{-2}}$$

$$= 1635 (T_1 - 100) \text{ Js}^{-1} \quad ...(i)$$

Also heat of vaporisation of water

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

Rate of boiling of water in the boiler,

$$M = 6.0 \text{ kg min}^{-1} = \frac{6.0}{60} = 0.1 \text{ kg}^{-1} \text{ s.}$$

$\therefore$ Heat received by water per second, $Q = ML$

$$\Rightarrow \quad Q = 0.1 \times 2256 \times 10^3 \text{ Js}^{-1} \quad ...(ii)$$

$\therefore$ From eqn. (*i*) and (*ii*), we get

$$1635 (T_1 - 100) = 2256 \times 10^2$$

or
$$T_1 - 100 = \frac{2256 \times 10^2}{1635} = 138$$

$$T_1 = 138 + 100 = 238°\text{C.}$$

Question 11. 21. 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 the furnace.
(d) the earth without its atmosphere would be inhospitably cold.
(e) heat systems based on circulation of steam are more efficient in warming a building than those based on circulation of hot water.
Answer: (a) According to Kirchh off's law of black body radiations, good emitters are good absorbers and bad emitters are bad absorbers. A body with large reflectivity is a poor absorber of heat and consequently, it is also a poor emitter.
(b) Brass is a good conductor of heat, while wood is a bad conductor. When we touch the brass tumbler on a chilly day, heat starts flowing from our body to the tumbler and we feel it cold. However, when the wooden tray is touched, heat does not flow from our hands to the tray and we do not feel cold.
(c) An optical pyrometer is based on the principle that the brightness of a glowing surface of a body depends upon its temperature. Therefore, if the temperature of the body is less than 600°C, the image formed by the optical pyrometer is not brilliant and we do not get the reliable result. It is for this reason that the pyrometer gives a very low value for the temperature of red hot iron in the open.
(d) The lower layers of earth's atmosphere reflect infrared radiations from earth back to the surface of earth. Thus the heat radiation received by the earth from the sun during the day are kept trapped by the atmosphere. If atmosphere of earth were not there, its surface would become too cold to live.
(e) Steam at 100°C possesses more heat than the same mass of water at 100°C. One gram of steam at 100°C possesses 540 calories of heat more than that possessed by 1 gm of water at 100°C. That is why heating systems based on circulation of steam are more efficient than those based on circulation of hot water.

Question 11. 22. 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, the rate of cooling is proportional to the difference in temperature.
Here average of 80 °C and 50 °C = 65 °C
Temperature of surroundings = 20°C

$\therefore$ Difference = 65 – 20 = 45 °C

Under these conditions, the body cools 30°C in time 5 minutes

$$\therefore \quad \frac{\text{Change in temp.}}{\text{Time}} = K \Delta T$$

$$\text{or} \quad \frac{30}{5} = K \times 45° \qquad ...(i)$$

The average of 60°C and 30°C is 45°C which is 25°C (45 – 20) above the room temperature and the body cools by 30°C (60 – 30) in a time $t$ (say)

$$\therefore \quad \frac{30}{t} = K \times 25 \qquad ...(ii)$$

where $K$ is same for this situation as for the original.
Dividing eqn. (*i*) by (*ii*), we get

$$\frac{30/5}{30/t} = \frac{K \times 45}{K \times 25}$$

$$\text{or} \quad \frac{t}{5} = \frac{9}{5}$$

$$\Rightarrow \quad t = 9 \text{ min.}$$

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