TOPIC

4

Heat

4.1. INTRODUCTION

We all have common-sense notions of heat and temperature. Temperature is a measure of 'hotness' of a body. A kettle with boiling water is hotter than a box containing ice. In physics, we need to define the notion of heat, temperature, etc., more carefully. In this chapter, you will learn what heat is and how it is measured. You will also learn what happens when water boils or freezes, and its temperature does not change during these processes even though a great deal of heat is flowing into or out of it.

4.2. TEMPERATURE AND HEAT

Temperature is a relative measure, or indication, of hotness or coldness. A hot utensil is said to have a high temperature, and ice cube to have a low temperature. An object that has a higher temperature than another object is said to be hotter. Note that hot and cold are relative terms, like tall and short. We can perceive temperature by touch. However, this temperature sense is somewhat unreliable and its range is too limited to be useful for scientific purposes.

We know from experience that a glass of ice-cold water left on a table on a hot summer day eventually warms up whereas a cup of hot tea on the same table cools down. It means that when the temperature of body, ice-cold water or hot tea in this case, and its surrounding medium are different, heat is exchanged between the system and the surrounding medium, until the body and the surrounding medium are

at the same temperature. We also know that in the case of cold water, heat flows from the environment to the glass tumbler whereas in the case of hot tea, it flows from the cup of hot tea to the environment. *Heat is the form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference.*

The SI unit of heat energy transferred is expressed in joule (J). SI unit of temperature is kelvin (K). The commonly used unit of temperature is °C.

The cgs or practical unit of heat is a calorie. *One calorie is the amount of heat required to raise the temperature of 1 gram of water from 14.5°C to 15.5°C.*

$$1 \text{ calorie} = 4.186 \text{ joule} ; 4.2 \text{ joule}$$

4.3. MEASUREMENT OF TEMPERATURE

Thermometer is an instrument which is used to measure the temperature of a body.

Many physical properties of materials change sufficiently with temperature to be used as the basis for constructing thermometers. The commonly used property is variation of the volume of a liquid with temperature. Mercury and alcohol are the liquids used in most liquid-in-glass thermometers.

Thermometers are calibrated so that a numerical value may be assigned to a given temperature. For the definition of any standard scale, two fixed reference points are needed. The ice point and the steam point of water are two convenient fixed points and are known as the freezing and boiling points. These two points are the temperature at which pure water freezes and boils under standard pressure.

The two familiar temperature scales are the Fahrenheit temperature scale and the Celsius temperature scale. The ice and steam point have values 32°F and 212°F respectively, on the Fahrenheit scale and that of 0°C and 100°C on the Celsius scale. On the Fahrenheit scale, there are 180 equal intervals between two reference points, and on the Celsius scale, there are 100.

A relationship for converting between the two scales may be obtained from a graph of Fahrenheit temperature (t_F) versus Celsius temperature (t_C) in a straight line (Fig. 4.1), whose equation is

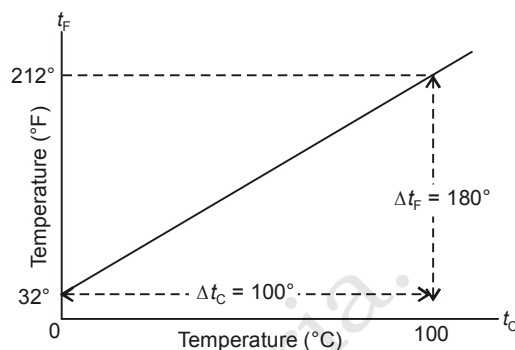$$\frac{t_F - 32}{180} = \frac{t_C}{100}$$

Fig. 4.1. A plot of Fahrenheit temperature (t_F) versus Celsius temperature (t_C)

Example 1. *What is the temperature at which we get the same reading on both the centigrade and Fahrenheit scales?*

Solution. If t is the required temperature, then

$$\frac{t}{100} = \frac{t - 32}{180}$$

On simplification, $t = -40$

So, the required temperature is **– 40°C** or **– 40°F.**

4.4. IDEAL GAS EQUATION AND ABSOLUTE SCALE OF TEMPERATURE

Liquid-in-glass thermometers show different readings for temperatures other than the fixed points because of differing expansion properties. A thermometer that uses a gas, however, gives the same readings regardless of which gas is used. The variables that describe the behaviour of a given quantity (mass) of gas are pressure, volume, and temperature (P, V and T) (where T = t + 273.15; t is the temperature in °C). When temperature is held constant, the pressure and volume of a quantity of gas are related as PV = constant. This relationship is known as Boyle's law, after Robert Boyle (1627–1691) the English Chemist who discovered it. When the pressure is held constant, the volume of a quantity of the gas is related to the temperature as V/T = constant. This relationship is known as Charles' law, after the French scientist Jacques Charles (1747–1823). Low density gases obey these laws, which may be combined into a single relationship.

Notice that since PV = constant and V/T = constant for a given quantity of gas, then PV/T should also be a constant. This relationship is known as ideal gas law. It can be written in a more general form that applies not just to a given quantity of a single gas but to any quantity of any dilute gas and is known as **ideal-gas equation :**

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

or $\hspace{3cm}$ PV = μRT $\hspace{5cm}$ ...(1)

where μ is the number of moles in the sample of gas and R is called universal gas constant :

$$R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$$

In Eq. (1), we have learnt that the pressure and volume are directly proportional to temperature : PV ∝ T. This relationship allows a gas to be used to measure temperature in a constant volume gas thermometer. Holding the volume of a gas constant, it gives P ∝ T. Thus, with a constant volume gas thermometer, temperature is read in terms of pressure. A plot of pressure versus temperature gives a straight line in this case, as shown in Fig. 4.2.
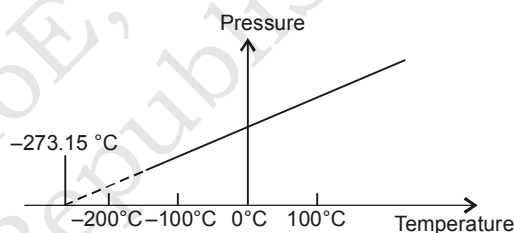
Fig. 4.2 Pressure versus temperature of a low density gas kept at constant volume

However, measurements on real gases deviate from the values predicted by the ideal gas law at low temperature. But the relationship is linear over a large temperature range, and it looks as though the pressure might reach zero with decreasing temperature if the gas continued to be a gas. The absolute minimum temperature for an ideal gas, therefore, inferred by extrapolating the straight line to the axis, as in Fig. 4.3. This temperature
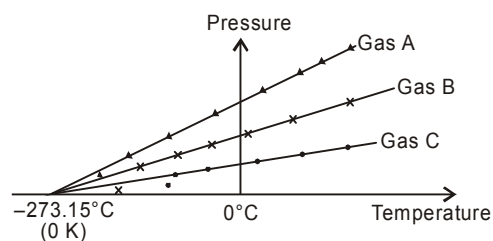
Fig. 4.3. A plot of pressure versus temperature and extrapolation of lines for low density gases indicates the same absolute zero temperature

is found to be – 273.15°C and is designated as **absolute zero.** Absolute zero is the foundation of the Kelvin temperature scale or absolute scale temperature named after the British scientist Lord Kelvin (1824–1907). The unit of temperature on this scale is written as K. On this scale, – 273.15°C is taken as the zero point, that is 0 K (Fig. 4.4).

Fig. 4.4. Comparision of the Kelvin, Celsius and Fahrenheit temperature scales

The size of the unit for Kelvin temperature is the same Celsius degree, so temperature on these scales are related by

$$T = t_C + 273.15$$

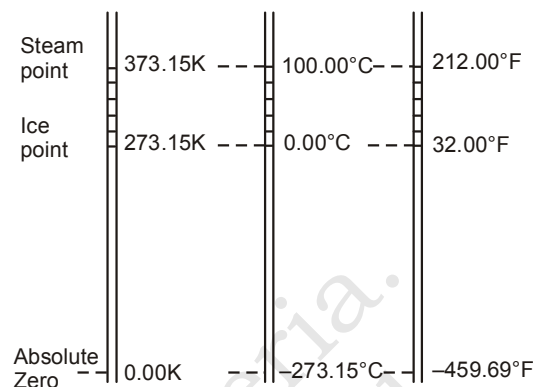## 4.5. SPECIFIC HEAT CAPACITY

(*i*) **Heat capacity.** The quantity of heat required to warm a given substance depends on its mass, m, the change in temperature, ΔT and the nature of substance. The change in temperature of a substance, when a given quantity of heat is absorbed or rejected by it, is characterised by a quantity called the **heat capacity** of that substance. We define heat capacity, S of a substance as

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

where ΔQ is the amount of heat supplied to the substance to change its temperature from T to T + ΔT.

(*ii*) **Specific heat capacity.** If equal amount of heat is added to equal masses of different substances, the resulting temperature changes will not be the same. It implies that every substance has a unique value for the amount of heat absorbed or rejected to change the temperature of unit mass of it by one unit. This quantity is referred to as the **specific heat capacity** of the substance.

If ΔQ stands for the amount of heat absorbed or rejected by a substance of mass m when it undergoes a temperature change ΔT, then the specific heat capacity, of that substance is given by

$$s = \frac{S}{m} = \frac{1}{m}\frac{\Delta Q}{\Delta T} \qquad \qquad \ldots(1)$$

The **specific heat capacity** is the property of the substance which determines the change in the temperature of the substance (undergoing no phase change) when a given quantity of heat is absorbed (or rejected) by it. **It is defined as the amount of heat per unit mass absorbed or rejected by the substance to change its temperature by one unit.** It depends on the nature of the substance and its temperature.

The specific heat of a material is not constant. It depends on the location of the temperature interval. Equation (1) gives only the average value of specific heat capacity in the temperature range of ΔT.

The SI unit of specific heat capacity is J kg^{-1} K^{-1}.

From equation (1), $\Delta Q = ms\,\Delta T$

In differential notation,

$$dQ = ms\,dT$$

The heat required to increase the temperature of a body of mass m from T_i to T_f is given by

$$Q = m\int_{T_i}^{T_f} s\,dT$$

Equation (1) does not define specific heat capacity uniquely. We must specify the conditions under which heat is supplied to the system.

(*iii*) **Molar specific heat capacity.** It is often convenient to use the mole to describe the amount of substance. By definition, one mole of any substance is a quantity of matter such that its mass in gram is numerically equal to the molecular mass M (often called molecular weight). To calculate the number μ of moles, we divide the mass m in gram by the molecular mass M.

So, $\qquad\qquad \mu = \dfrac{m}{M} \qquad$ or $\quad m = \mu M$

If the amount of substance is specified in terms of moles μ, instead of mass m in kg, we can define heat capacity per mole of the substance by,

$$C = \frac{S}{\mu} = \frac{1}{\mu}\frac{\Delta Q}{\Delta T}$$

where C is known as **molar specific heat capacity** of the substance. Like S, C also depends on the nature of the substance and its temperature. The SI unit of molar specific heat capacity is J mol^{-1} K^{-1}.

4.6. DULONG AND PETIT LAW (SPECIFIC HEAT OF SOLIDS)

In 1819, two French physicists Dulong and Petit observed that the average molar specific heat of all metals, except the very lightest, is approximately constant and equal to nearly 3R = 6 cal mol^{-1} K^{-1} = 25 J mol^{-1} °C^{-1}.

Although the law is only an approximate one, it conveys a very important idea. **Nearly the same amount of heat is required per molecule to raise the temperature of metals by a given amount.** Thus, the heat required to raise the temperature of a sample of metal depends only on how many molecules the sample contains, and not on the mass of an individual molecule. One mole of each metal contains same number of atoms (= Avogadro's number). So, the molar specific heat of all metals at room temperature is nearly constant. This is a property of matter which is directly related to its molecular structure.

4.7. VARIATION OF SPECIFIC HEAT OF SOLIDS WITH TEMPERATURE

According to Dulong and Petit's law, the molar specific heat of every solid *must* come out to be equal to 6 cal. But the result is very nearly 6 cal and not exactly 6 cal. Also when we perform the experiment at various temperatures, we note that the specific heat is not constant quantity. Instead, it varies with temperature as shown in Fig. 4.5. At T = 0 K, C_v tends to be zero. With rise in

Fig. 4.5. Variation of C_v with T

temperature, C_v increases. At a specific temperature depending upon the nature of the material, C_v becomes constant (= 3R).
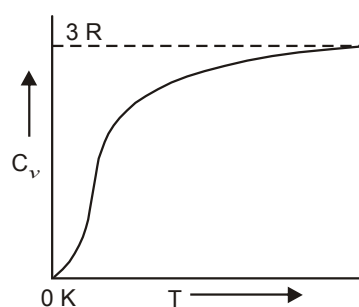
4.8. VARIATION OF SPECIFIC HEAT OF WATER

Specific heat of water is the amount of heat energy required to raise the temperature of unit mass of water through 1°C or 1K.

Specific heat of water,

c = 1 cal g^{-1} °C^{-1} = 1 cal g^{-1} K^{-1}

= 4.2 J g^{-1} K^{-1} = 4200 J kg^{-1} K^{-1}

The specific heat of every liquid varies with temperature. However, water shows a peculiar variation. Considerable variations in the specific heat of water were first observed by Rowland.

The specific heat of water as a function of temperature from 0° to 100°C has been plotted in Fig. 4.6.
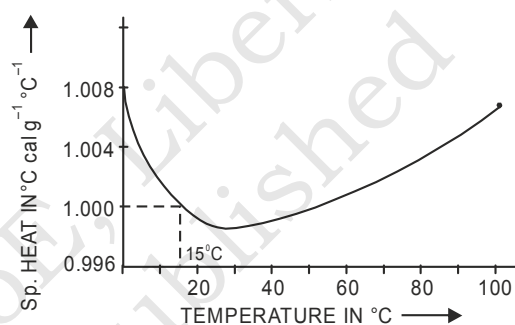

Fig. 4.6. Variation of specific heat of water with temperature

4.9. SPECIFIC HEATS OF A GAS

*The **specific heat** of a substance is the amount of heat required to increase the temperature of a unit mass of it through a unit temperature change.* Its unit in cgs system is cal g^{-1}°C^{-1}. In mks system, it is measured in kilocal kg^{-1}°C^{-1}. The SI unit is J kg^{-1} K^{-1}.

The above definition is based on the assumption that the heat supplied to the substance causes only a rise in the temperature of the substance. This assumption is valid only if the substance is heated at constant volume. But a substance generally expands when heated. In that case, the heat supplied is utilised in two ways. A part of the heat supplied is used in doing mechanical work in moving the molecules apart against forces of attraction between them and also in expanding against atmospheric pressure. The rest of the heat supplied increases the temperature of the substance.

In the case of solids and liquids, the coefficient is very small. So, the heat supplied is assumed to increase only the temperature. But the coefficient of expansion is very large in the case of gases. Thus, if a

gas is heated, the heat energy will be required not only to increase the temperature of the gas but also to do mechanical work in overcoming external pressure during expansion. In the case of gases, only a negligible amount of mechanical work is required to pull the molecules apart because the intermolecular forces are extremely weak.

4.10. LIMITS OF SPECIFIC HEAT OF A GAS

Consider mass m of a gas. Let ΔQ units of heat raise the temperature of the gas through ΔT. Then the specific heat of the gas is given by

$$c = \frac{\Delta Q}{m \, \Delta T} \qquad\qquad [\because \ \Delta Q = m \, c \, \Delta T]$$

Consider a gas enclosed in a cylinder fitted with an air-tight and frictionless piston.

(*i*) Let the gas be suddenly compressed. In this case, no heat is supplied to the gas. But there is an increase in the temperature of the gas.

$$c = \frac{\Delta Q}{m \, \Delta T} = 0 \qquad\qquad [\because \ \Delta Q = 0]$$

(*ii*) Let the gas be heated and allowed to expand. Suppose the 'fall in temperature due to expansion' is equal to the 'rise in temperature due to heat supplied'.

$$\therefore \qquad c = \frac{\Delta Q}{m \times 0} = \infty \qquad\qquad [\because \ \Delta T = 0]$$

(*iii*) Let the gas be heated and allowed to expand. Suppose, in this case, the 'fall in temperature due to expansion' is less than the 'rise in temperature due to heat supplied'. The net effect will be a rise in the temperature of the gas. So, ΔT is positive. Thus $c = \left(\dfrac{\Delta Q}{m \, \Delta T} \right)$ is positive.

(*iv*) Let the gas be heated and allowed to expand such that the 'fall in temperature due to expansion' is more than the 'rise in temperature due to heat supplied'. The net effect will be a decrease in the temperature of the gas. So, ΔT is negative. Thus, $c = \left(\dfrac{\Delta Q}{m \, \Delta T} \right)$ is negative.

CONCLUSION

We can conclude from the above examples that a gas does not possess a unique or a single specific heat. The specific heat of a gas may have any positive or negative value ranging from zero to infinity. The specific heat of a gas depends upon the manner in which it is being heated. Thus, it is meaningless to talk about the specific heat of a gas unless the conditions under which it is being heated are mentioned.

4.11. HEAT TRANSFER

We have seen that heat is energy transfer from one system to another or from one part of a system to another part, arising due to temperature difference. What are the different ways by which this energy transfer takes place? There are three distinct modes of heat transfer: conduction, convection and radiation (Fig. 4.7).
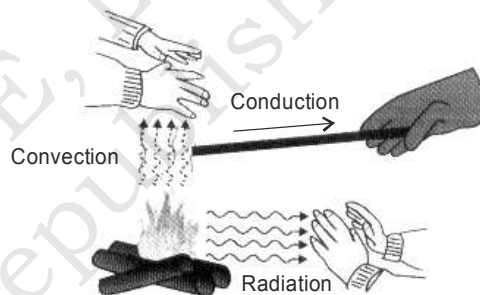

Fig. 4.7. Heating by conduction, convection and radiation

4.12. CONDUCTION

(*i*) *Conduction is the mechanism of transfer of heat between two adjacent parts of a body because of their temperature difference, without the actual movement of the particles from their equilibrium positions.*

Suppose one end of a metallic rod is put in a flame. The other end of the rod will soon feel so hot that you cannot hold it by your bare hands. Here heat transfer takes place by conduction from the hot end of the rod through its different parts to the other end.

The ability to conduct heat differs widely from substance to substance. Gases are poor thermal conductors. Liquids have conductivities intermediate between solids and gases.

(*ii*) **Quantitative description of heat flow.** Consider a metal rod of uniform cross-sectional area A with its two ends maintained at

temperatures T_1 and T_2 such that $T_1 > T_2$. Let L be the length of the rod between the hot reservoir (at temperature T_1) and cold reservoir (at temperature T_2).

Fig. 4.8. Steady state heat flow by conduction in a bar with its two ends maintained at temperatures T_1 and T_2

It has been experimentally observed that in the steady state, the rate of flow of heat (or heat current) is

(*a*) directly proportional to the cross-sectional area A

$$H \propto A \qquad ...(1)$$

(*b*) directly proportional to the temperature difference $(T_1 - T_2)$ between the hot and cold faces

$$H \propto (T_1 - T_2) \qquad ...(2)$$

(*c*) inversely proportional to the distance L between the hot and cold reservoirs.

$$H \propto \frac{1}{L} \qquad ...(3)$$

Combining factors (1), (2) and (3), we get

$$H \propto \frac{A (T_1 - T_2)}{L}$$

or

$$\boxed{H = \frac{KA(T_1 - T_2)}{L}}$$

Here, K is a constant of proportionality called coefficient of thermal conductivity of the material of the block. Its value depends upon the nature of material of the block.

Total amount of heat Q flowing from hot to cold reservoir is the product of heat current H and time *t*.

$$\therefore \qquad Q = Ht$$

or

$$Q = \frac{KA(T_1 - T_2)t}{L} \qquad ...(4)$$

(*iii*) **Coefficient of thermal conductivity.** If A = 1, L = 1, *t* = 1 and $(T_1 - T_2) = 1$, then from equation (4), K = Q.
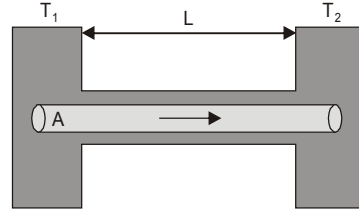
This leads us to the following definition of coefficient of thermal conductivity.

The coefficient of thermal conductivity of a material is defined as the quantity of heat flowing per second through a rod (or slab or block) of that material having unit length and unit cross-sectional area in the steady state when the difference of temperature between two ends of the rod (or slab or block) is 1°C or 1K and the flow of heat is perpendicular to the end-faces of the rod (or slab or block).

The coefficient of thermal conductivity may also be defined in terms of 'unit cube'.

The coefficient of 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 1°C or 1K.

(*iv*) **Concept of temperature gradient.** *Temperature gradient is defined as the rate of change of temperature with distance between two isothermal surfaces.*

In equation (4), $\dfrac{T_1 - T_2}{L}$ gives the rate of change of temperature with distance. It is called temperature gradient. Let it be denoted by '$-\dfrac{dT}{dL}$'. Here negative sign indicates the decrease of temperature with distance.

Rewriting equation (4) in terms of temperature gradient, we get

$$Q = -KA\frac{dT}{dL}t$$

If $A = 1$, $-\dfrac{dT}{dL} = 1$ and $t = 1$, then $K = Q$.

*The **coefficient of thermal conductivity** of a material is the rate of flow of heat energy through a rod, made of that material, of unit cross-section area under a unit temperature gradient, the flow of heat being normal to the cross-sectional area.*

(*v*) **Units of K.** We know that

$$Q = \frac{KA(T_1 - T_2)t}{L} \quad \text{or} \quad K = \frac{QL}{A(T_1 - T_2)t}$$

In cgs system, Q, L, A, $(T_1 - T_2)$ and t are measured in cal, cm, cm^2, °C and s respectively. So, the cgs unit of K is cal cm^{-1}°C^{-1} s^{-1}.

In SI, Q, L, A, $(T_1 - T_2)$ and t are measured in joule, m, m^2, K and s respectively.

So, the SI unit of K is J m^{-1} K^{-1} s^{-1} or W m^{-1} K^{-1}.

(vi) Dimensional formula of K.

$$[K] = \frac{[Q]\,[L]}{[A]\,[T_1 - T_2]\,[t]}$$

$$= \frac{[ML^2T^{-2}]\,[L]}{[L^2]\,[K]\,[T]} = [ML\,T^{-3}\,K^{-1}]$$

(vii) Values of K. The thermal conductivities of various substances are listed in Table 4.1. These values vary slightly with temperature, but can be considered to be constant over a normal temperature range.

You may have noticed that some cooking pots have copper coating on the bottom. Being a good conductor of heat, copper promotes the distribution of heat over the bottom of a pot for uniform cooking. Plastic foams, on the other hand, are good insulators, mainly because they contain pockets of air. Recall that gases are poor conductors, and note the low thermal conductivity of air in the Table 4.1. Heat retention and transfer are important in many other applications. Houses made of concrete roofs get very hot during summer days, because thermal conductivity of concrete (though much smaller than that of a metal) is still not small enough. Therefore, people usually prefer to give

TABLE 4.1. Thermal Conductivities (K)

		$W\,m^{-1}\,K^{-1}$
Metals	Aluminium	205
	Brass	109
	Copper	385
	Lead	34.7
	Mercury	8.3
	Silver	406
	Steel	50.2
Non-metals	Body fat	0.20
	Insulating brick	0.15
	Red brick	0.6
	Concrete	0.8
	Cork	0.04
	Felt	0.04
	Glass	0.8
	Water	0.8
	Ice	1.6
	Glass wool	0.04
	Styrofoam	0.01
	Wood	0.12–0.04
Gases	Air	0.024
	Argon	0.016
	Helium	0.14
	Hydrogen	0.14
	Oxygen	0.023

a layer of earth or foam insulation on the ceiling so that heat transfer is prohibited and keeps the room cooler.

Generally, metals are good conductors of heat, silver being the best. Non-metals like wood, glass are poor conductors with low value of K.

4.13. APPLICATIONS OF THERMAL CONDUCTIVITY TO EVERYDAY LIFE

1. In winter, a brass knob appears colder than a wooden knob. It is due to the reason that the thermal conductivity of brass (K = 109 W m^{-1} K^{-1}) is more than that of wood (K = 0.12 Wm^{-1} K^{-1}). When the brass knob is touched, the heat energy is quickly conducted away from the hand. On the other hand, when the wooden knob is touched, the flow of heat energy from the hand is extremely slow. Thus, a brass knob appears colder than a wooden knob although both may be at the same temperature.

2. Woollen clothes keep us warm. This is because wool contains air in its pores. Air (K = 0.024 Wm^{-1} K^{-1}) is a bad conductor of heat. In-fact, wool (K = 0.01 Wm^{-1} K^{-1}) is also a bad conductor of heat. Both the air and the wool do not permit heat to be conducted away from the body. So, the woollen clothes keep us warm.

3. A new quilt is warmer than old quilt. This is because new quilt contains more air in its pores as compared to old quilt. Since air is a bad conductor of heat therefore the heat is not conducted away from the body.

4. Cooking utensils are provided with wooden handles. This is because wood is a bad conductor of heat. So, the wooden handle would not permit heat to be conducted from hot utensil to hand. Thus, the hot cooking utensil can be easily held in hand through the wooden handle.

5. Cooking utensils are made of aluminium and brass. This is because aluminium and brass are good conductors of heat. They rapidly absorb heat from the fire and supply it to the food to be cooked.

6. Ice is covered in gunny bags to prevent melting of ice. This is because of the fact that gunny bags are bad conductors of heat. The pores of gunny bags contain air which is also a bad conductor of heat.

7. The double-walled houses of ice made by Eskimos are warm from inside. This is because the air within the walls does not allow heat to be conducted away to the outside air.

8. Two thin blankets are warmer than a single thick blanket. This is because the two thin blankets enclose a layer of air between them. Since air is a bad conductor of heat therefore the conduction of heat is prevented.

Example 2. *Two rods, one semi-circular and the other straight, of the same material and of same cross-sectional area are joined as shown in Fig. 4.9. The ends A and B are maintained at a constant temperature difference. Calculate the ratio of the heat conducted through a cross-section of a semi-circular rod to the heat conducted through a cross-section of the straight rod in a given time.*

Solution. We know that $Q = \dfrac{KA(T_1 - T_2)t}{L}$

In the given problem, $Q \propto \dfrac{1}{L}$

$\therefore \qquad \dfrac{Q_1}{Q_2} = \dfrac{2r}{\pi r} = \dfrac{2}{\pi}$

Fig. 4.9

Example 3. *One end of a 0.25 m long metal bar is in steam and the other in contact with ice. If 12×10^{-3} kg of ice melts per minute, what is the thermal conductivity of the metal? Given: cross-section of the bar = 5×10^{-4} m^2 and latent heat of ice is 80 kcal/kg.*

Solution. $\qquad L = 0.25$ m, $A = 5 \times 10^{-4}$ m^2,

$(T_1 - T_2) = (100 - 0)$ K = 100 K

$t = 1$ minute = 60 s

If Q is the amount of heat required to melt 12×10^{-3} kg of ice, then

$Q = 12 \times 10^{-3} \times 80 \times 1000$ cal

$Q = K\dfrac{A(T_1 - T_2)}{L}t \quad$ or $\quad K = \dfrac{QL}{A(T_1 - T_2)t}$

or $\qquad K = \dfrac{12 \times 10^{-3} \times 80 \times 1000 \times 0.25}{5 \times 10^{-4} \times 100 \times 60}$ cal s^{-1} m^{-1} K^{-1}

$= \textbf{80 cal s}^{-1}\ \textbf{m}^{-1}\ \textbf{K}^{-1}$

4.14. CALORIMETRY

(*i*) **Isolated System.** *A system is said to be isolated if there is no transfer of heat between the system and its surroundings.* When different parts of an isolated system are at different temperatures, a quantity of heat transfers from the part at higher temperature to the part at lower temperature. The heat lost by the part at higher temperature is equal to the heat gained by the part at lower temperature.

(*ii*) **Principle of Calorimetry.** Calorimetry means measurement of heat. According to the principle of calorimetry, when a body at higher temperature is brought in contact with another body at lower temperature, the heat lost by the hot body is equal to the heat gained by the colder body, provided no heat is allowed to escape to the surroundings.

(*iii*) **Calorimeter.** *A device in which heat measurement can be made by utilising the principle of calorimetry is called a calorimeter.* It consists of a metallic vessel and stirrer of the same material like copper or aluminium. The vessel is kept inside a wooden jacket which contains heat insulating materials (glass, wool, etc.). The outer jacket acts as a heat shield and reduces the heat loss from the inner vessel. There is an opening in the outer jacket through which a mercury thermometer can be inserted into the calorimeter.

(*iv*) **Thermal Capacity or Heat Capacity.** *Thermal capacity of a body is the amount of heat required to raise the temperature of the body through 1°C or 1K.*

The amount of heat required to raise the temperature of a body of mass m through ΔT is,

$\Delta Q = ms\,\Delta T$, where s is the specific heat of the body under consideration.

If $\Delta T = 1$, then ΔQ = thermal capacity.

∴   Thermal capacity, $S = ms$ ...(1)

So, the thermal capacity of a body is the product of mass and specific heat of the body. The SI unit of thermal capacity is $J\ K^{-1}$.

(*v*) **Water Equivalent.** *Water equivalent of a body is defined as the mass of water in gram which absorbs or emits the same amount of heat as is done by the given body for the same rise or fall in temperature.*

It is denoted by w. Its SI unit is kg.

Now, $\Delta Q = w\,\Delta T = ms\,\Delta T$ or $w = ms$ ...(2)

It follows from equations (1) and (2) that the water equivalent and thermal capacity of a body are numerically equal. If water equivalent is measured in gram, the thermal capacity is measured in calorie/°C.

4.15. CHANGE OF STATE—LATENT HEAT CAPACITY

(*i*) **Change of state.** *A transition from one of the three states of matter to another is called a change of state.* Two common changes of states are solid to liquid and liquid to gas (and vice versa). These changes can occur when the exchange of heat takes place between the substance and its surroundings.

(*ii*) **Melting.** *The change of state from solid to liquid is called melting and from liquid to solid is called **fusion**.* It is observed that the temperature remains constant until the entire amount of the solid substance melts. Both the solid and liquid states of the substance coexist in thermal equilibrium during the change of state from solid to liquid. **The temperature at which the solid and the liquid states of the substance coexist in thermal equilibrium with each other is called its melting point.** It is characteristic of the substance. It also depends on pressure. The melting point of a substance at standard atmospheric pressure is called its **normal melting point.**

After the whole of ice gets converted into water and as we continue further heating, we shall see that temperature begins to rise. The temperature keeps on rising till it reaches nearly 100°C when it again becomes steady. The heat supplied is now being utilised to change water from liquid state to vapour or gaseous state.

(*iii*) **Vaporisation.** *The change of state from liquid to vapour (or gas) is called vaporisation.* It is observed that the temperature remains constant until the entire amount of the liquid is converted into vapour. Both the liquid
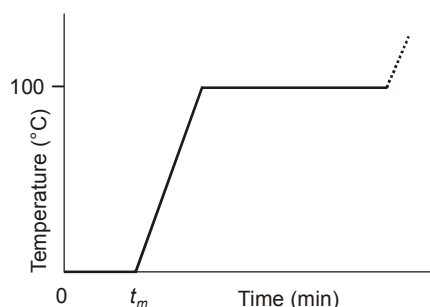
Fig. 4.10. A plot of temperature versus time showing the changes in the state of ice on heating (not to scale)

and vapour states of the substance coexist in thermal equilibrium, during the change of state from liquid to vapour. The temperature at which the liquid and the vapour states of the substance coexist is called its **boiling point.**

Boiling point decreases with decrease in pressure. This explains why cooking is difficult on hills. At high altitudes, atmospheric pressure is lower, reducing the boiling point of water as compared to that at sea-level. On the other hand, boiling point is increased inside a pressure cooker by increasing the pressure. Hence, cooking is faster. The boiling point of a substance at standard atmospheric pressure is called its **normal boiling point.**

(*iv*) **Sublimation.** All substances do not pass through the three states : solid-liquid-gas. There are certain substances which normally pass from the solid to the vapour state directly and vice versa. *The change from solid state to vapour state without passing through the liquid state is called **sublimation.*** The substance is said to sublime. Dry ice (solid CO_2) and iodine sublime. During the sublimation process, both the solid and vapour states of a substance coexist in thermal equilibrium.

(*v*) **Latent heat.** *The amount of heat per unit mass transferred during a change of state of the substance is called latent heat of transformation for the process.*

The heat required during a change of state depends upon the heat of transformation and the mass of the substance which completely undergoes a state change. Thus, if mass m of a substance undergoes a change from one state to the other completely, then the quantity of heat required is given by

$$Q = mL \quad \text{or} \quad L = Q/m$$

where L is known as latent heat. It is a characteristic of the substance. Its SI unit is J kg^{-1}. The value of L depends on the pressure at which it is measured. Its value at standard atmospheric pressure is usually quoted. The latent heat for a solid-liquid state change is called the **latent heat of fusion (L_f),** and that for a liquid-gas state change is called the **latent heat of vaporisation (L_v).** These are often referred to as simply the heat of fusion and the heat of vaporisation (v_p).

The variation of temperature with heat energy for a given quantity of water is shown in Fig. 4.11.

Fig. 4.11. Temperature versus heat for water (Not to scale)

The following facts are clear from the graph:

(*i*) When heat is added (or removed) during a change of state, the temperature remains constant.

(*ii*) The slopes of the phase lines are not all the same. This indicates that specific heats of the various states are not equal.

(*iii*) For water, the latent heats of fusion and vaporisation are L_f = 3.33 × 10^5 J kg^{-1} and L_v = 22.6 × 10^5 J kg^{-1} respectively. So, 3.33 × 10^5 J of heat is needed to melt 1 kg of ice at 0°C, and 22.6 × 10^5 J of heat is needed to convert 1 kg of water to steam at 100°C. So, steam at 100°C carries 540 cal/g more heat than water at 100°C. This is why burns from steam are usually more serious than those from boiling water.
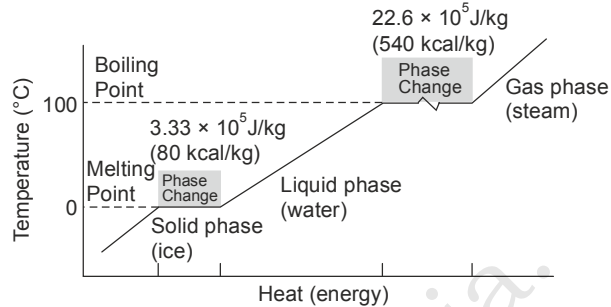
Example 4. *When 0.15 kg of ice of 0°C mixed with 0.30 kg of water at 50°C in a container, the resulting temperature is 6.7°C. Calculate the heat of fusion of ice. (s_{water} = 4186 J $kg^{-1}°C^{-1}$).*

Solution. Heat lost by water

= (0.30 kg) (4186 J $kg^{-1}°C^{-1}$) (50.0°C − 6.7°C)

= 54376.14 J

Heat to melt ice = (0.15 kg) L_f

Heat to raise temperature of ice water to final temperature

= (0.15 kg) (4186 J $kg^{-1}°C^{-1}$) (6.7°C − 0°C)

= 4206.93 J

Heat lost = heat gained

54376.14 = (0.15 kg) L_f + 4206.93 J

L_f = **3.34 × 10^5 J kg^{-1}**

Example 5. *How much heat energy is liberated when 100 g of copper in a vessel is cooled from 100°C to 50°C ? Given : specific heat capacity copper, $s_{Cu} = 385\ J\ kg^{-1}°C^{-1}$.*

Solution. Given, mass of the copper,

$$m = 100\ g = 0.1\ kg$$

Initial temperature of copper, $T_i = 100°C$,

Final temperature of copper, $T_f = 50°C$,

and specific heat capacity of copper, $s_{Cu} = 385\ J\ kg^{-1}°C^{-1}$.

Thus, the quantity of heat energy exchanged is given by

$$\Delta Q = m\ s_{Cu}\ \Delta T$$
$$= (0.1\ kg)\ (385\ J\ kg^{-1}°C^{-1}) \times (50°C - 100°C)$$

i.e., $\qquad \Delta Q = (0.1\ kg)\ (385\ J\ kg^{-1}°C^{-1})\ (-50°C)$

or $\qquad \Delta Q = $ **– 1925 J**

The negative sign shows that heat is liberated.

4.16. CONVECTION

Convection is the process in which heat is transferred from one point to another by the actual motion of matter from a region of high temperature to a region of lower temperature.

Convection is possible only in fluids. Convection can be natural or forced. Natural convection is responsible for many familiar phenomena. In natural convection, gravity plays an important part. When a fluid is heated from below, the hot part expands and, therefore, becomes less dense. Because of buoyancy, it rises and the upper colder part replaces it. This again gets heated, rises up and is replaced by the colder part of the fluid. The process goes on. This mode of heat transfer is evidently different from conduction. Convection involves bulk transport of different parts of the fluid. In forced convection, material is forced to move by a pump or by some other physical means. The common examples of forced convection systems are forced-air heating systems in home, the human circulatory system, and the cooling system of an automobile engine. In the human body, the heart acts as the pump that circulates blood through different parts of the body, transferring heat by forced convection and maintaining it at a uniform temperature.

*If the material is forced to move by a blower or pump, the process is called **forced convection.** If the material flows due to difference in density (caused by thermal expansion), the process is called **natural** or **free convection.***

4.17. PHENOMENA BASED ON CONVECTION

(*i*) Land and Sea Breezes

It is an example of natural convection.

During the day, the ground heats up more quickly than large bodies of water do. This occurs both because the water has a greater specific heat and because mixing currents disperse the absorbed heat throughout the great volume of water. The air in contact with the warm ground is heated by conduction. It expands, becoming less dense than the surrounding cooler air. As a result, the warm air rises (air currents) and other air moves (winds) to fill the space-creating a **sea breeze** near a large body of water. Cooler air descends, and a thermal convection cycle is set up, which transfers heat away from the land. At night, the ground loses its heat more quickly, and the water surface is warmer than the land. As a result, the cycle is reversed and **land breeze** is there (Fig. 4.12).
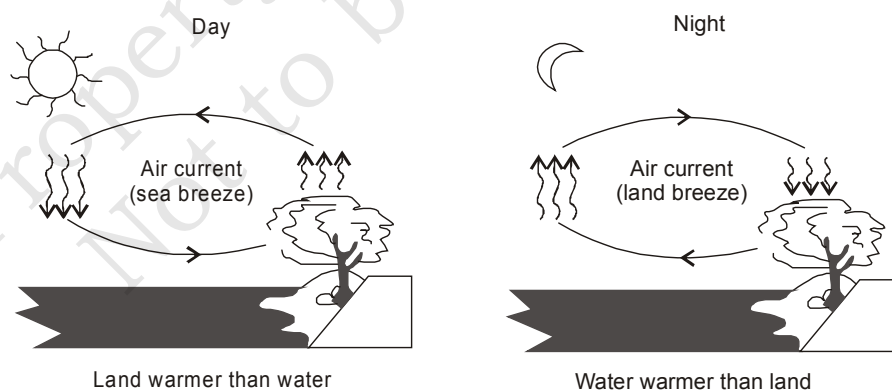
Fig. 4.12. Convection cycles

(*ii*) Formation of Trade Winds

*The steady wind blowing from north-east to equator, near the surface of Earth, is called **trade wind.*** It is an example of natural convection.

The equatorial and polar regions of the Earth receive unequal solar heat. Air at the Earth's surface near the equator is hot while the air in the upper atmosphere of the poles is cool. In the absence of any other factor, a convection current would be set up, with the air at the equatorial surface rising and moving out towards the poles, descending and streaming in towards the equator. The rotation of the Earth, however modifies this convection current.

(*iii*) To Regulate Temperature in the Human Body

Heat transfer in the human body involves a combination of mechanisms. These together maintain a remarkably uniform temperature in the human body inspite of large changes in environmental conditions.

The chief internal mechanism is forced convection. The heart serves as the pump and the blood as the circulating fluid.

4.18. RADIATION

The transfer of heat from one place to another in a straight line, with the speed of light, without heating the intervening medium is called radiation.

Conduction and convection require some material as a transport medium. These modes of heat transfer cannot operate between bodies separated by a certain distance in vacuum. The third mechanism for heat transfer needs no medium; it is called radiation. In radiation, the heat flows by means of electromagnetic waves. The energy so radiated in the form of electromagnetic waves is called radiant energy.

Electromagnetic waves do not require a material medium for propagation. These waves travel with a speed of 3×10^8 m s^{-1} in vacuum. This explains as to how heat transfer by radiation does not need any medium and why it is so fast. Heat from the Sun reaches the Earth by radiation. Similarly, we feel the warmth of nearby fire due to radiation.

4.19. NATURE OF THERMAL RADIATION

*The energy emitted by a body in the form of radiation by virtue of its temperature is called **thermal radiation.*** This energy is emitted by all

bodies above absolute zero and is also called radiant energy. The most powerful source of radiant energy is the Sun.

Thermal radiation belongs to the electromagnetic family *i.e.,* it resembles γ-rays, X-rays, ultraviolet light, visible light and radiowaves. It can travel through vacuum and other transparent media. Its speed is the same as that of light. Like other electromagnetic radiations, it exhibits the phenomena of reflection, refraction, interference, diffraction and polarisation.

The wavelength of thermal radiation is longer than that of visible light. The wavelength of thermal radiation ranges from 8×10^{-7} m to 3×10^{-4} m whereas the wavelength of visible light ranges from 4×10^{-7} m to 8×10^{-7} m.

4.20. PROPERTIES OF THERMAL RADIATION

Thermal radiation has got following properties:

(*i*) Thermal radiation can travel through vacuum.

(*ii*) Thermal radiation travels in straight lines.

(*iii*) Thermal radiation travels equally, in all directions, in a homogeneous medium.

(*iv*) Thermal radiation travels with the speed of light.

(*v*) Thermal radiation does not heat the medium through which it passes.

(*vi*) Thermal radiation obeys inverse square law. The intensity of radiation at a point is inversely proportional to the square of the distance of the point from the source of radiation.

(*vii*) Thermal radiation obeys the laws of reflection.

(*viii*) Thermal radiation can be refracted.

4.21. BLACK BODY

A perfectly black body is one which absorbs completely the radiations of all wavelengths falling on it. Since a perfectly black body neither reflects nor transmits any radiation therefore its absorptance is unity. It is for the same reason that it appears black irrespective of the wavelength of incident radiation.

A perfectly black body cannot be *realised in practice. The nearest approach to a perfect black body* is a surface coated with lamp black or platinum black. Such a surface absorbs 96% to 98% of the incident radiation.

For accurate experimental work, the black body designed by Fery is generally used. **Fery black body** is a closed double-walled hollow sphere having small opening O and a conical projection P opposite to the

Fig. 4.13. Black body

opening. The projection will protect direct reflection of any radiation in the opening from the surface opposite it. It is painted black from inside. Radiation entering the opening O suffers multiple reflections at the inner walls. After a few reflections, almost the entire radiation gets absorbed. *As an example, let 80% of energy be reflected at each reflection, the remaining 20% being absorbed.* Then, at two reflections, 64% will be reflected and 36% will be absorbed. Thus, nearly 99% of the energy will be absorbed in 10 reflections.
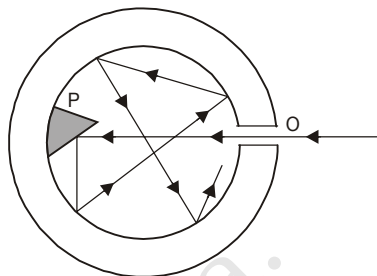
When the body is heated, it becomes a source of thermal radiation. The radiation from a constant temperature enclosure depends only on the temperature of the enclosure. It does not depend on the nature of the substance of which the enclosure is made.

4.22. STEFAN'S LAW OF BLACK BODY RADIATION

Statement. *The total amount of heat energy radiated per second per unit area of a perfect black body is directly proportional to the fourth power of the absolute temperature of the surface of the body.*

This law is also known as Stefan's fourth power law.

If E be the *energy radiated by a unit area of the surface of black body per second* at absolute temperature T, then

$$E \propto T^4 \quad \text{or} \quad E = \sigma T^4$$

where σ is a constant known as Stefan's constant. Its value in SI units is

$$5.67 \times 10^{-8} \text{ J m}^{-2} \text{ s}^{-1} \text{ K}^{-4} \quad \text{or} \quad \text{W m}^{-2} \text{ K}^{-4}$$

Stefan derived this law experimentally in 1879. In 1884, Boltzmann gave a theoretical proof of this law based on thermodynamical considerations. So, this law is also known as **Stefan-Boltzmann law.**

It may be pointed out that the above law is not a law of cooling. It does not refer to the net loss of heat by a body. *It merely deals with the amount of heat energy radiated by the body by virtue of its temperature,* irrespective of what it gains from the surroundings. Moreover, Stefan's law applies to the whole range of wavelengths, without being limited to any particular wavelength.

Stefan's law can be extended to represent the *net loss of heat* by a body.

Consider a black body at absolute temperature T sorrounded by another black body at absolute temperature T_0. A unit area of the 'inner' black body loses heat energy σT^4 per second. But it also gains heat energy σT_0^4 per second.

∴   Net loss of heat energy per unit area per unit time,

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

If the body is not a perfect black body, then $E = e\sigma (T^4 - T_0^4)$

where e is called the radiation emissivity or emissivity of the surface.

The value of e depends upon the nature of the surface.

4.23. DEDUCTION OF NEWTON'S LAW OF COOLING FROM STEFAN'S LAW

$$E = \sigma (T^4 - T_0^4)$$
$$= \sigma (T^2 - T_0^2) (T^2 + T_0^2)$$
$$= \sigma (T - T_0) (T + T_0) (T^2 + T_0^2)$$

If T is nearly equal to T_0, then

$$E = \sigma (T - T_0) (2T_0) (2T_0^2)$$
$$= \sigma (T - T_0) (4T_0^3) = 4\sigma T_0^3 (T - T_0)$$

If A be the total surface area, then loss of heat energy per unit time or rate of loss of heat

$$= 4 A\sigma T_0^3 (T - T_0).$$

∴   rate of loss of heat $\propto (T - T_0)$

So, *the rate of loss of heat is proportional to the difference of temperature between the body and surroundings.* This is Newton's law of cooling.

4.24. GREENHOUSE EFFECT

We can see the Sun and the stars clearly through the atmosphere because the atmosphere is transparent to visible radiation. However, most of the infrared radiation is absorbed by the atmosphere. So, most of the infrared radiation cannot pass through the atmosphere. Now, the energy from sunlight obviously heats the Earth, which like any other hot body, starts emitting radiation. However, the Earth is much cooler than the Sun so that, according to Planck's law, its radiation is mostly in the infrared region. This is unlike the solar radiation. The radiation from the Earth is unable to cross the lower atmosphere which reflects it right back. Thus, **the Earth's atmosphere is richer in infrared radiaton** which is sometimes called "heat radiation". This is because most materials absorb these radiations quickly 'heating' themselves up in the process. The clouds that are low also prevent infrared radiation from passing through. This helps to keep the Earth's surface warm at night. This phenomenon is popularly known as **"Greenhouse effect".**

Fig. 4.14 shows a Greenhouse effect. *The surface of the Earth absorbs solar radiation which passes through the atmosphere. In turn, the Earth radiates infrared waves. These waves are reflected back by clouds and gases in the lower atmosphere.*

The components of solar and other extra-terrestrial sources in the ultraviolet and lower wavelength domains are dangerous.

Fig. 4.14. Greenhouse effect

This is because they cause genetic damages to living cells. It is the ozone layer which blocks the passage of UV radiation and protects us from the harmful portions of solar radiation. Nearly all radiation of wavelength less than 3×10^{-7} m is absorbed by the ozone layer.
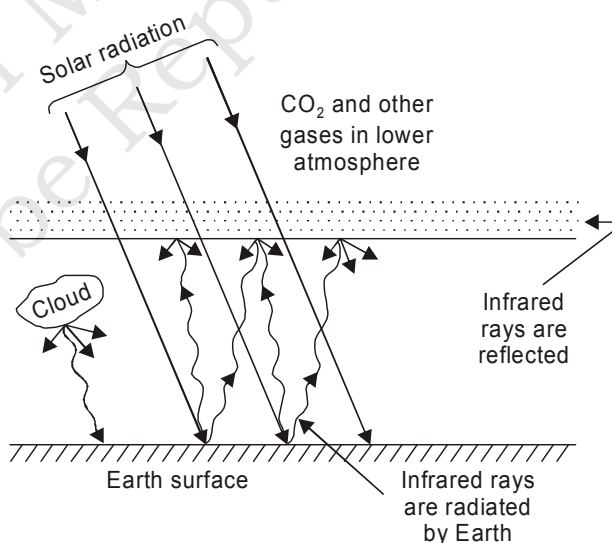
The Earth may be regarded as a huge Greenhouse where the glass of the artificial Greenhouse is replaced by atmosphere. The carbon dioxide and the water vapours present in the Earth's atmosphere are good absorbers of infrared radiation.

REVIEW EXERCISES

Do the review exercises in your notebook.

A. Multiple Choice Questions

1. A metal cube of length 10.0 mm at 0°C (273 K) is heated to 200°C (473 K). Given : its coefficient of linear expansion is 2×10^{-5} K^{-1}. The per cent change of its volume is

(a) 0.1   (b) 0.2

(c) 0.4   (d) 1.2.

2. Which of following quantities must be determined so that the thermal capacity of a body may be calculated, when the specific heat of body is known?

(a) Emissivity   (b) Latent heat

(c) Mass   (d) Temperature.

3. The density of water at 20°C is 998 kg m^{-3} and at 40°C, it is 992 kg m^{-3}. The coefficient of cubical expansion of water is nearest to

(a) 2×10^{-4}/°C   (b) 4×10^{-4}/°C

(c) 6×10^{-4}/°C   (d) 3×10^{-4}/°C.

4. The density of water at 4°C is 1000.0 kg/m^3 and at 100°C it is 958.4 kg/m^3. The cubic expansivity of water between these temperatures is

(a) 4.5×10^{-3} K^{-1} (b) 5.4×10^{-5} K^{-1}

(c) 4.5×10^{-4} K^{-1} (d) 5.4×10^{-6} K^{-1}.

5. If C_p and C_v denote the specific heats of nitrogen per unit mass at constant pressure and constant volume respectively, then

(a) $C_p - C_v = 28R$ (b) $C_p - C_v = R/14$

(c) $C_p - C_v = R/28$ (d) $C_p - C_v = R$.

6. An ideal gas is expanding such that PT ^{2} = constant. The coefficient of volume expansion of the gas is

(*a*) $\dfrac{1}{T}$ (*b*) $\dfrac{2}{T}$

(*c*) $\dfrac{3}{T}$ (*d*) $\dfrac{4}{T}$.

7. Two uniform brass rods A and B of lengths 1 and 2l and radii 2r and r respectively are heated to the same temperature. The ratio of the increase in the volume of A to that of B is

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

(*c*) 2 : 1   (*d*) 1 : 4.

8. 0.1 m^3 of water at 80°C is mixed with 0.3 m^3 of water at 60°C. The final temperature of the mixture is

(*a*) 65°C   (*b*) 70°C

(*c*) 60°C   (*d*) 75°C.

9. The resistance of the wire in the platinum resistance thermometer at ice point is 5 Ω and at steam point is 5.25 Ω. When the thermometer is inserted in an unknown hot bath, its resistance is found to be 5.5 Ω. The temperature of the hot bath is

(*a*) 100°C   (*b*) 200°C

(*c*) 300°C   (*d*) 350°C.

10. 10 mole of an ideal monatomic gas at 10°C is mixed with 20 mole of another monatomic gas at 20°C. Then the temperature of the mixture is

(*a*) 15.5°C   (*b*) 15°C

(*c*) 16°C   (*d*) 16.6°C.

B. Fill in the Blanks

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 gram 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 _____ .

2. Certain amount of heat is given to 100 g of copper to increase its temperature by 21°C. If the same amount of heat is given to 50 g of water, then the rise in its temperature is _____ .

3. A thin copper rod rotates about an axis passing through its end and perpendicular to its length with an angular speed ω_0. The temperature of the copper rod is increased by 100°C. If the

coefficient of linear expansion of copper is $2 \times 10^{-5}/°C$, the percentage change in the angular speed of the rod is _____ .

4. A metal rod of Young's modulus Y and coefficient of thermal expansion α is held at its two ends such that its length remains invariant. If its temperature is raised by $t°C$, the linear stress developed in it is _____ .

5. An aluminium sphere of 20 cm diameter is heated from 0°C to 100°C. Its volume changes by _____ . (Given that coefficient of linear expansion for aluminium $\alpha_{Al} = 23 \times 10^{-6}/°C$)

6. A lead bullet strikes against a steel plate with a velocity 200 m s^{-1}. If the impact is perfectly inelastic and the heat produced is equally shared between the bullet and the target, then the rise in temperature of the bullet is _____ .

7. Two temperature scales A and B are related by $\dfrac{A - 42}{110} = \dfrac{B - 72}{220}$. At _____ temperature two scales have the same reading?

8. When the temperature of a rod increases from t to $t + \Delta t$, its moment of inertia increases from I to I + ΔI. If α be the coefficient of linear expansion of the rod, then the value of $\dfrac{\Delta I}{I}$ is _____ .

9. If an anisotropic solid has coefficients of linear expansion α_x, α_y and α_z for three mutually perpendicular directions in the solid, its coefficient of volume expansion will be _____ .

10. If the pressure and the volume of certain quantity of ideal gas are halved, then its temperature _____ .

C. Very Short Answer Questions

1. Is the bulb of a thermometer made of diathermic or adiabatic wall?

2. Why does a metal bar appear hotter than a wooden bar at the same temperature? Equivalently it also appears cooler than wooden bar if they are both colder than room temperature.

3. Calculate the temperature which has same numeral value on Celsius and Fahrenheit scale.

4. These days people use steel utensils with copper bottom. This is supposed to be good for uniform heating of food. Explain this effect using the fact that copper is the better conductor.

5. Calculate the stress developed inside a tooth cavity filled with copper when hot tea at temperature of 57°C is drunk. You can take body (tooth) temperature to be 37°C and $\alpha = 1.7 \times 10^{-5}/°C$, bulk modulus for copper = 140×10^9 N m^{-2}.

D. Short Answer Questions

1. 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.

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

3. 100 g of water is supercooled to – 10°C. At this point, due to some disturbance mechanised or otherwise some of it suddenly freezes to ice. What will be the temperature of the resultant mixture and how much mass would freeze?
   [S_w = 1 cal/g/°C and L^w_{Fusion} = 80 cal/g]

4. One day in the morning, Ramesh filled up 1/3 bucket of hot water from geyser, to take bath. Remaining 2/3 was to be filled by cold water (at room temperature) to bring 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 bath. Now he had two options: (*i*) fill the remaining bucket completely by cold water and then attend to the work, (*ii*) first attend to the work and fill the remaining bucket just before taking bath. Which option do you think would have kept water warmer? Explain.

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

E. Long Answer Questions

1. A geyser heats water flowing at the rate of 3.0 litre per minute from 27°C to 77°C. If the geyser operates on a gas burner, what is the rate of consumption of the fuel, if its heat of combustion is 4.0×10^4 J g^{-1} ?

2. Calculate the difference between two specific heats of 1 g of helium gas at NTP. Molecular weight of helium = 4 and J = 4.186×10^7 erg cal^{-1}.

3. How much heat energy is absorbed when 50 g ice cube melts at 0°C ? (Latent heat of fusion of ice, L_f = 3.35×10^5 J kg^{-1})

4. A small hole is made in a hollow sphere whose walls are at 723°C. Find the total energy radiated per second per cm^2.

5. Calculate the temperature in kelvin at which a perfect black body radiates at the rate of 5.67 W cm^{-2}. Stefan's constant is 5.67×10^{-5} erg s^{-1} cm^{-2} K^{-1}.