Physics

Heat

09

9.1 Temperature

Daily weather report transmitted through television channels may be familiar to you. Do you remember hearing that the lowest temperature was reported from Nuwaraeliya while the highest temperature was reported from Trincomalee on a particular day?

Can you remember that it is difficult to dry washed clothes on rainy days and that they dry fast on warm sunny days?

Figure 9.1

Try to recall the coolness experienced in eating an ice-cream and the warmness felt in drinking a hot cup of tea.

The physical quantity that describes each of the instances above is the temperature.

Temperature can be specified as a fundamental property of any material object. An ice cube has a very low temperature. Temperature of warm water is higher than the temperature of cold water.

Our body too has a temperature. Therefore we can say whether the temperature of a certain object is higher than or lower than the temperature of our body by touching the object.

Temperature is measure of the mean kinetic energy possessed by the particles that form an object.

9.1.1 Measuring temperature

By touching various objects we can get a rough idea about their temperature. However, since the temperature felt by touching is not so accurate and cannot be expressed as a numerical value, it is not a suitable method for measuring temperature. Therefore, the scientists in the past had realized the necessity for constructing a device for measuring temperature.

• Thermometers

The device employed to measure temperature is known as the thermometer. World's first thermometer was invented by Galileo Galilei around 1600 A.D.

Figure 9.2 -Thermometer constructed by Galileo

Figure 9.3- Galileo Galilei

Various types of thermometers are in use at present. We will only be focusing on the glass - mercury thermometer and the glass-alcohol thermometer in this chapter.

Glass-mercury Thermometer

The glass – mercury thermometer is constructed by connecting a narrow glass tube to a bulb containing mercury. When the temperature rises, the mercury in the bulb expands and moves up along the narrow tube. The temperature can be read from the scale marked on the tube according to the length of the mercury column.

Although the volume expansion due to a small temperature difference is small, the length of the mercury column rises up by a clearly visible amount as the diameter of the narrow tube containing mercury is very small. A glass – mercury thermometer is shown in Figure 9.4.

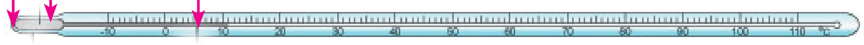


Figure 9.4 – A glass-mercury thermometer

Mercury is commonly used in thermometers as it has a uniform expansion over a broad range of temperatures, is a good thermal conductor and is a liquid over a broad range of temperatures (from - 39 °C to 357 °C). However, due to the toxicity of mercury, use of glass-mercury thermometers is on the decline.

Glass-Alcohol Thermometer

Glass-alcohol thermometer is constructed in the same manner as the glass - mercury thermometer, but replacing mercury by ethyl alcohol (ethanol). Since the melting point of ethanol is -115 °C, it is suitable for measuring low temperatures much below 0 °C. Ethanol is a suitable liquid for thermometers as it has a high expansion relative to most other liquids and as the expansion increases uniformly with temperature. Since purified ethanol is a colorless liquid, it is colored with a coloring material in order to see the alcohol column clearly.

Digital Thermometer

In addition the thermometers mentioned above, digital thermometers from which the temperature can be read directly are also commonly used today. In constructing digital thermometers, an electrical property such as the resistance which depends on the temperature is used instead of the expansion caused by an increase in temperature.

Figure 9.5 - A Digital thermometer

9.1.2 Temperature Scales

There are three temperature scales widely used for temperature measurements. They are the Celsius, Fahrenheit and the Kelvin scales.

- ### Celsius Scale

The Celsius scale has been formed by taking the temperature at which pure ice melts into liquid water under the pressure of one atmosphere as the zero temperature (0 °C) and the temperature at which water vaporizes into steam under the same pressure as 100 °C.

These two temperatures have been chosen for the Celsius scale as the temperature at which ice melts into water and the temperature at which water boils can be easily obtained and as these temperatures have fixed values apart from the variation with pressure.

The definite temperatures used in forming a temperature scale are known as **fixed points**. For the Celsius scale, these two fixed points are divided into 100 divisions.

- ### Fahrenheit Scale

For the Fahrenheit scale too, the melting point of ice and the boiling point of water are used as the two fixed points. However, here the melting point of ice is taken as 32 ^{o}F and the temperature range between the two fixed points are divided into 180 divisions. Accordingly, the boiling point of water is 212 ^{o}F.

- ### Kelvin Scale

The zero values of the Celsius and the Fahrenheit scales have been chosen according to the wishes of the people who introduced them. However, the British scientist Lord Kelvin later showed that there is a minimum value to the temperature that any object can reach. This temperature is known as the **absolute zero** temperature.

The temperature of an object is a measure of the mean kinetic energy of the particles that constitute the object. The temperature of the object decreases when the kinetic energy of the particles decreases. When the kinetic energy of all the particles become zero, the temperature of the object reaches the absolute zero. Its temperature cannot be decreased below this value. This temperature has been found to be - 273.15 ^{o}C according to the Celsius scale.

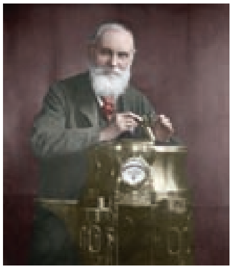


Figure 9.6 -Lord Kelvin

The Kelvin scale is defined so that its zero (0 K) is at the absolute zero temperature. However, in this scale, a temperature difference equal to 1 K is chosen to be equal to a temperature difference of 1 ^{o}C.

Accordingly, the melting temperature of ice is 273.15 K and the boiling temperature of water is 373.15 K. These temperatures are approximately taken as 273 K and 373 K respectively.

The international unit of measuring temperatures is the Kelvin (K).

For extra knowledge

- Celsius scale was introduced by Anderse Celsius (1701 – 1744).
- Fahrenheit scale was introduced by Gabriel Fahrenheit (1686 – 1736).
- Kelvin scale was introduced by Lord Kelvin (1824 – 1907).
- Clinical thermometer was constructed by Clifford Olbert (1836 - 1925).

9.1.3 Relationship between Celsius and Kelvin scales

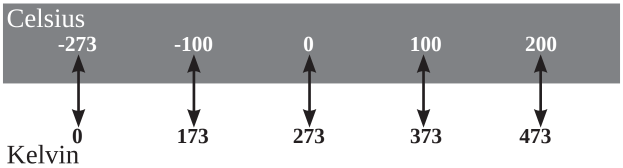


Figure 9.7 - Celsius and Kelvin scales

Since the difference between the Kelvin and Celsius scales lies only in the temperature chosen for their zero values, in order to convert a temperature measured in Celsius into the Kelvin scale one only needs to add 273. In order to convert a temperature measured in Kelvin into the Celsius scale one has to subtract 273.

Example 1

(i) How many divisions in the Kelvin scale are equal to one division in the Celsius scale?
(ii) What has to be done in order to convert a temperature value given in Celsius into Kelvin?
(iii) Indicate the temperature 50 ^{o}C in Kelvin.
(iv) What has to be done in order to convert a temperature value given in Kelvin into a value in Celsius?
(v) Indicate the temperature 373 K in degrees Celsius.

Solution

(i) 100 Celsius divisions = 100 Kelvin divisions
1 Celsius division = 1 Kelvin division

(ii) 273 Has to be added to the given value.

(iii) 50 ^{o}C = 50 + 273 K
= 323 K

(iv) 273 Has to be subtracted from the given value.

(v) 373 K = 373 – 273 ^{o}C
= 100 ^{o}C

Exercise 9.1

(1) Convert the temperatures given in degrees Celsius below into Kelvin.

(i) 10 °C (ii) 27 °C (iii) 87 °C (iv) 127 °C (v) 100 °C

(2) Convert the temperatures given in Kelvin below into degrees Celsius.

(i) 0 K (ii) 100 K (iii) 273 K (iv) 373 K (v) 400 K

9.2 Heat

Let us put equal volumes of water into two identical vessels at room temperature. Next let us insert two thermometers and arrange the set up above two bunson burners as shown in the Figure 9.8. Now let us light up the bunson burner in Figure 9.8(b) while leaving that in Figure 9.8(a) as it is.

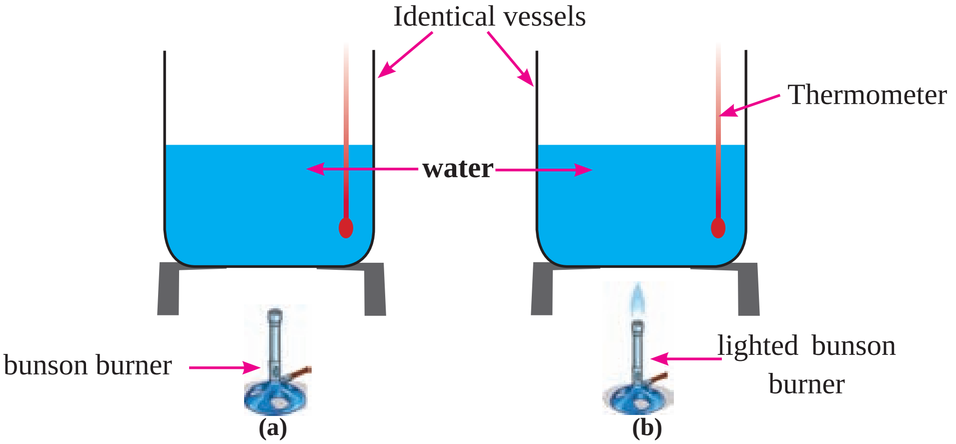


Figure 9.8

The temperature of the water in Figure 9.8(a) remains unchanged. The temperature of the water in Figure 9.8(b) can be seen to increase gradually.

Only the bunson burner in Figure 9.8(b) has been lighted. Therefore the temperature of water in that vessel has increased. From this it is clear that something has transferred from the candle flame to the water and that the temperature of the water has risen as a result of it. Here, heat has transferred to the water.

Therefore, the energy transfers from one object to another as a result of the temperature difference existing between the two objects is known as the **heat**.

For extra knowledge

American national Benjemin Thompson (Count Ramford) (1753 – 1814)has first described heat as a form of energy. In 1798, he experimentally showed that heat is a form of energy and thereafter it was a scientist named James Joule, who experimentally investigated about heat in 1840.

9.2.1 Heat Transfer

Let us investigate what happens when we put a heated piece of iron into a cold water vessel.

Activity 9.1

Apparatus required: A heated block of iron, A thermometer, A stirrer, A vessel with water at room temperature.

- Put a heated piece of iron into a cold water vessel.
- Observe the temperature of the water.

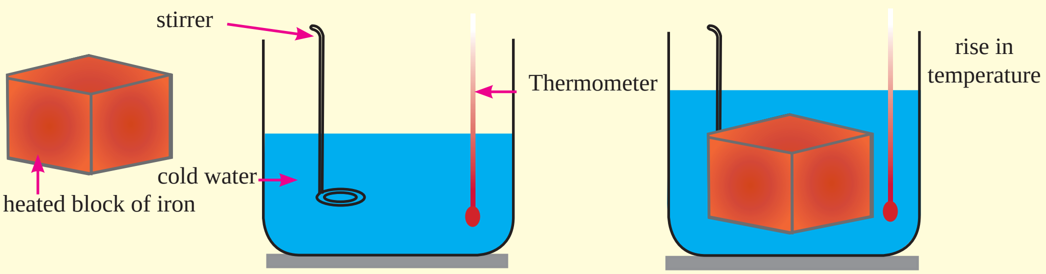


Figure 9.9

You will observe that the temperature of the water rises.

What happens here is the flow of heat from the iron which is at a higher temperature into the water which is at a lower temperature.

As the temperature of the water increases, the vessel also heats up as a result of absorbing heat. As heat flows out from the iron block, its temperature gradually decreases. After a while, the temperatures of the water and the iron block become equal. After reaching this common temperature, heat does not flow to the water from the iron block or to the iron block from the water. This state is known as **thermal equilibrium**. Just as water flows from a higher level to a lower level, heat also flows from a body at a higher temperature to a body at a lower temperature.

Therefore,
- Heat transfers from a body at a higher temperature to a body at a lower temperature.
- Then the temperature of the body at the lower temperature increases.
- At the same time, the temperature of the body at the higher temperature decreases.

Since heat is a form of energy, heat can be measured in Joules (J). The international unit for measuring heat is the Joule. In addition to this, the unit known as the Calorie is also frequently used to measure heat (thermal energy).

9.2.2 Heat Capacity of an Object

Activity 9.2

Apparatus required : Three identical beakers, Water, Coconut oil, Three thermometers, Three bunson burners a stirrer

- Obtain three identical beakers and pour a measured volume of water into one of them.
- Pour an equal volume of coconut oil into another beaker.
- Pour water with a volume equal to twice the initial volume into the third beaker.
- Measure the temperatures of the liquids in all three beakers.
- Now place all three beakers on three identical stands and heat them up for an equal time interval (about 5 minutes) using three identical candles.
- At the end of the time interval measure the temperatures of the liquids.

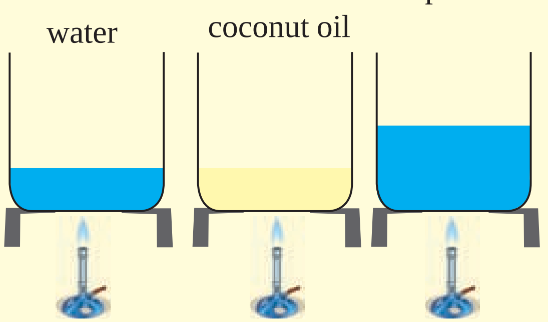


Figure 9.10

Even though there could be minor differences in the candles, we could assume that approximately the same amount of heat was supplied to each of the three beakers. However you will observe that the temperature rise in the three beakers are different.

You will understand from this activity that when the same amount of heat is supplied to different quantities of the same substance or the same quantities of different substances, their temperatures rise in different amounts.

Since the temperature rise in the three beakers of the above activity were not equal although the same amount of heat was supplied to all three beakers, we can conclude that the heat capacities of the substances in the three beakers are different.

The amount of heat required to increase the temperature of an object by one unit is known as the **heat capacity** of the object.

- The international unit for measuring heat capacity is Joules per Kelvin (J K^{-1}).
- Heat capacity can also be expressed in Joules per degree Celsius (J $^{o}C^{-1}$).

The heat capacity of an object depends on the substance that the object is made of and it's mass. Two objects made out of the same substance but with different masses have different heat capacities. Even though the masses are the same, two objects made out of different substances can have different heat capacities. The heat capacity of a substance is indicated by the symbol *C*.

Specific Heat Capacity

It can be experimentally shown that the heat capacity of different masses of the same substance is proportional to the mass. This means that the heat capacity doubles when the mass is doubled. However the heat capacity of a unit mass of a given substance or the amount of heat required to increase the temperature of a unit mass of the substance by one degree is a property that depends on the substance.

The amount of heat required to increase the temperature of a unit mass of a given substance by one degree is known as the **specific heat capacity** of the substance.

Since the specific heat capacity is the amount of heat that should be supplied to increase the temperature of a unit mass of a given substance by one degree, it can also be described as the heat capacity of a unit mass. Therefore, the heat capacity of an object can be obtained by multiplying the specific heat capacity of an object by its mass.

Heat capacity = Mass × Specific heat capacity

$$C = mc$$

Units of specific heat capacity is J kg^{-1} K^{-1} (Joules per kilogramme per Kelvin) or J kg^{-1} $^{o}C^{-1}$ (Joules per kilogramme per degree Celsius).

The specific heat capacity of a substance is indicated by the symbol *c*.

Specific heat capacities of some substances are given in table 9.1.

Table 9.1 - Specific heat capacities of some substances.

Substance	Specific heat capacity $J\ kg^{-1}\ K^{-1}$	Substance	Specific heat capacity $J\ kg^{-1}\ K^{-1}$
Water	4200	Concrete	3000
Ice	2100	Iron	460
Kerosene oil	2140	Asbestos	820
Coconut oil	2200	Copper	400
Alcohol	2500	Zinc	380
Rubber	1700	Mercury	140
Aluminium	900	Lead	130

• Finding the Quantity of Heat

When a substance absorbs or releases heat its temperature changes. In order to find the quantity of heat flow, the following relation can be established.

If the specific heat capacity of a substance is c,

- Quantity of heat required to increase the temperature of 1 kg by 1 ^oC = c
- Quantity of heat required to increase the temperature of m kg by 1 ^oC = mc
- Quantity of heat required to increase the temperature of m kg by θ ^oC = $mc\theta$

If the quantity of heat is Q,

Quantity of heat (Q) = mass (m) × specific heat capacity (c) × temperature change (θ)

$$Q = mc\theta$$

Q – quantity of heat (J)
m – mass (kg)
c – specific heat capacity ($J\ kg^{-1}\ K^{-1}$ or $J\ kg^{-1}\ {}^oC^{-1}$)
θ – temperature difference (K or ^oC)

This means that the amount of heat required to increase the temperature of a given mass of a substance by a certain amount is equal to the product between the increase in temperature and the heat capacity.

In terms of magnitude, one Kelvin and one degree of Celsius are the same. Therefore, when we consider a temperature range, we can specify it in Celsius instead of using Kelvin, without making any change in the value.

Let us find the amount of heat required to increase the temperature of 6 kg of copper by 20 K. Specific heat capacity of copper is 400 $J\ kg^{-1}\ K^{-1}$.

Heat required to increase the temperature of 1 kg of copper by 1 K $= 400$ J
Heat required to increase the temperature of 6 kg of copper by 1 K $= 6 \times 400$ J
Heat required to increase the temperature of 6 kg of copper by 20 K $= 6 \times 400 \times 20$ J
$= 48\,000$ J

Example 1

Find the amount of heat required to increase the temperature of 2 kg of water by 10 K. Specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

The amount of heat required $= mc\theta$,
$= 2 \times 4200 \times 10$ J
$= 84\,000$ J

Example 2

The mass of a block of aluminium is 500 g. Find the amount of heat required to increase the temperature of the block from 30 °C to 50 °C. Specific heat capacity of aluminium is 900 J kg^{-1} $°C^{-1}$.

The amount of heat required $= mc\theta$
$= 0.5 \times 900 \times (50 - 30)$ J
$= 9000$ J

Example 3

If 20 000 J of heat is transferred to 2 kg of copper at a temperature of 30 °C, what is the final temperature? (Specific heat capacity of copper is 400 J kg^{-1} K^{-1}).

If the change of temperature is θ,

$$Q = mc\theta$$
$$20\,000 = 2 \times 400 \times \theta$$
$$\theta = \frac{20\,000}{2 \times 400}\ °C$$
$$\theta = 25\ °C$$

$\therefore$ Final temperature of copper $= 30\ °C + 25\ °C$
$= 55\ °C$

Example 4

A copper vessel contains 1 kg of water. Mass of the vessel with water is 1.6 kg. The temperature of the water is 25 °C. Find the amount of heat required to heat the water until it boils.

(Specific heat capacity of water is 4200 J kg^{-1} K^{-1}; specific heat capacity of copper is 400 J kg^{-1} K^{-1}.)

Since both the vessel and the water heats up in this case,

Required total quantity of heat = heat absorbed by the vessel + heat absorbed by water

The mass of the copper vessel = total mass – the mass of water

$= 1.6\ \text{kg} - 1.0\ \text{kg} = 0.6\ \text{kg}$

Heat absorbed by the vessel $= mc\theta$

$= 0.6 \times 400 \times (100 - 25)\ \text{J}$

$= 0.6 \times 400 \times 75\ \text{J}$

$= 18\ 000\ \text{J}$

Heat absorbed by the water $= mc\theta$

$= 1 \times 4200 \times (100 - 25)\ \text{J}$

$= 315\ 000\ \text{J}$

Required total quantity of heat $= 18\ 000\ \text{J} + 315\ 000\ \text{J}$

$= 333\ 000\ \text{J}$

Exercise 9.2

(1) Specific heat capacity of iron is 460 J $kg^{-1}\ K^{-1}$. Find the quantity of heat required to increase the temperature of 2 kg of iron at a temperature of 25 °C up to 65 °C?

(2) Find the temperature of 0.8 kg of aluminium at a temperature 30 °C when 14 400 J of heat is transferred to it?
(Specific heat capacity of aluminium is 900 J $kg^{-1}\ K^{-1}$.)

(3) The mass of a glass vessel is 500 g. It contains 400 g of water at 25 °C temperature. Find the quantity of heat required to boil the water.(Specific heat capacity of glass is 840 J $kg^{-1}\ K^{-1}$, specific heat capacity of water is 4200 J $kg^{-1}\ {}^{\circ}C^{-1}$.)

9.3 Change of State of Matter

You have learnt before that there are three states of matter known as solid, liquid and gas. As an example, when it is being heated ice melts into water and water converts into vapor. By absorbing or releasing heat, water changes from one state to another state.

Figure 9.11

The conversion of the state of a substance from solid, liquid or gas into another state is known as a **change of state**. **Condensation** of a gas, **melting** of a solid, **solidification** of a liquid, **boiling** of a liquid are examples of changes of state.

Melting Point

The temperature at which a solid substance that is being heated changes state from the solid state to the liquid state is known as its **melting point**. The melting point of a given substance depends of the pressure.

Freezing Point

The temperature at which a liquid substance that is being cooled changes state from the liquid state to the solid state is known as its **freezing point**. The freezing point of a given substance depends of the pressure.

The melting point and the freezing point of a given substance have the same value.

Melting points of some solids are given in table 9.2.

Table 9.2 - Melting points of some solids (under the pressure of 1 atmosphere)

Substance	Melting point °C
Ice	0
Paraffin	54
Naphthalene	80
Sulphur	114
Lead	330

Substance	Melting point °C
Zinc	410
Aluminium	660
Gold	1063
Tungsten	5385
Iron	1535

Boiling Point

The temperature at which a liquid starts to boil (i.e. the temperature at which the liquid turns to vapour by forming bubbles inside the liquid) is known as its **boiling point.**

The temperature at which changes of states of matter occur depend on the pressure. Normally, the boiling points and melting points of materials are specified as the temperatures at which boiling or melting occur under the pressure of 1 atmosphere.

Boiling points of some solids are given in table 9.3.

Table 9.3 - Boiling points of some solids (under the pressure of 1 atmosphere)

Substance	Water	Ethanol	Mercury	Zinc	Copper	Iron	Oxygen
Boiling point (°C)	100	78	357	907	2310	2750	-183

9.3.1 Latent Heat

The change of state of a substance takes place as a result of supplying heat to the substance or removing heat from it. Atoms of substances that exist as solids at room temperature possess some amount of kinetic energy. When heat is supplied, this kinetic energy increases gradually and along with it the temperature of the substance increases. When heat is continuously supplied, at a certain point the kinetic energy of the atoms becomes large enough to break the bonds between the atoms and allow the atoms to move freely. This is the point that the substance changes state from the solid state to the liquid state.

At the point that the change of state takes place, the heat supplied is spent on breaking the bonds between molecules and therefore, the temperature of the substance does not increase. When the change of state of all atoms is complete, the heat supplied is spent again on increasing the temperature of the system.

The heat absorbed by the system without changing its temperature while the change of state is taking place is known as the **latent heat**.

Consider an instance when heat is being supplied to a block of ice at a temperature slightly below 0 °C.

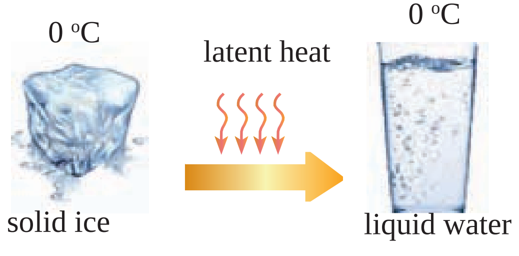


Figure 9.12

At first, its temperature would increase gradually up to 0 °C. Since 0 °C is the melting point of ice, the heat supplied thereafter is spent on doing work against the intermolecular attractive forces between the water molecules and the ice at 0 °C becomes water at 0 °C. If heat is supplied further after the block of ice has completely melted into water, then the heat supplied will be spent on increasing the temperature of the water again.

Conversion of a solid into a liquid is known as **fusion** and the heat absorbed in the conversion of ice at 0 °C into water at 0 °C is known as the **latent heat of fusion**.

Any solid substance that undergoes fusion absorbs latent heat, not only ice. If the fused substance is cooled, it solidifies again, releasing the same amount of heat that it absorbed during fusion. Therefore, when the water mass at 0 °C is cooled, the same quantity of latent heat is released and the water becomes ice.

Now let us consider an instance where heat is supplied to water at 100 °C.

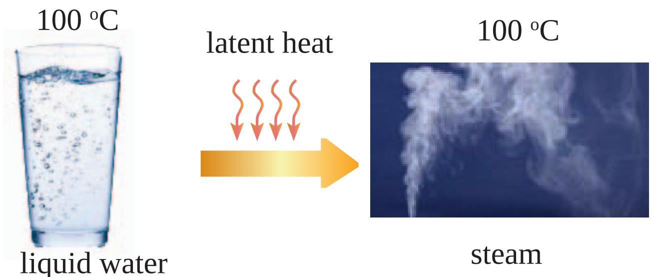


Figure 9.13

Since water is at its boiling point, here too a change of state takes place. Here again, work has to be performed against the intermolecular attractive forces. Therefore, the heat supplied is first spent on doing work against the intermolecular attractive forces and the temperature does not change until all the water at 100 °C becomes steam. The latent heat absorbed in this instance is known as the **latent heat of vaporization**.

Any liquid that vaporizes absorbs latent heat while this vapor releases the same amount of latent heat upon condensation back into the liquid.

- **Specific Latent Heat of Fusion**

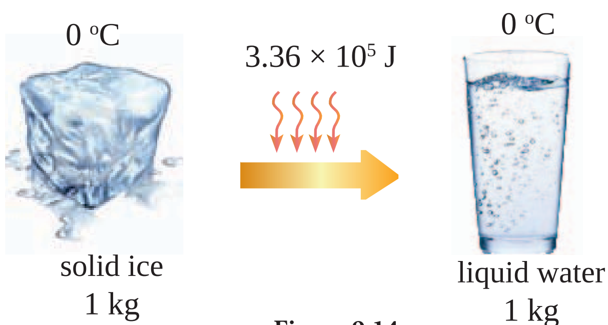


Figure 9.14

The amount of latent heat that has to be supplied in order to convert 1 kg of ice at 0 °C into liquid water at the same temperature is 3.36×10^5 J. This quantity of heat is known as the specific latent heat of fusion of ice.

The amount of heat required to change the state of a unit mass of a solid substance at its melting point into the liquid state is known as the **specific latent heat of fusion** of the substance.

- ## Specific Latent Heat of Vaporization

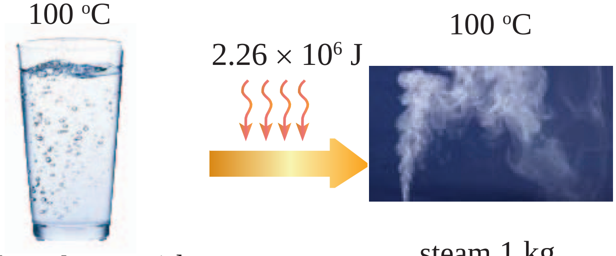


Figure 9.15

The amount of latent heat required in order to convert 1 kg of water at 100 °C into steam at the same temperature is 2.26×10^6 J. This quantity of heat is known as the specific latent heat of vaporization of water.

The amount of heat required to change the state of a unit mass of a solid substance at its boiling point into the gas state is known as the **specific latent heat of vaporization** of the substance.

Evaporation and Vaporization

The conversion of a liquid into a gaseous state is called **vaporization**. Liquid into a gaseous can happen in one of two ways. One is the **boiling** that takes place at the boiling point of a liquid when further heat is supplied. The other is the conversion of the liquid into a gas gradually at temperatures below the boiling point. The conversion of a liquid at a temperature below the boiling point is known as **evaporation**.

In vaporization due to either of the processes boiling and evaporation, latent heat is absorbed. Generally, evaporation takes place only at the surface of a liquid exposed to air. However in boiling vaporization takes place even below the liquid surface. This is why bubbles are formed in a boiling liquid.

In drying clothes and in perspiring to regulate our body temperature, evaporation is the process that plays an important role. Since the specific latent heat of vaporization has a fairly large value, in the evaporation of water through the process of perspiration taking place from our skin, a large amount of heat is removed from our body.

9.4 Thermal Expansion

You may have experienced that two glasses washed and one inserted inside the other (*A* inside *B*) are found to be stuck together when you examine them after a few days. At such an instance the two glasses can be separated by pouring cold water into the inner glass and inserting the outer glass in a vessel containing warm water.

Figure 9.16

In this case it becomes possible to separate the two glasses because the glass inserted in warm water expands slightly while the glass into which cold water was poured contracts slightly.

The increase in dimensions of a substance subjected to an increase in temperature is known as **thermal expansion**. That is, the increase in its length, area or volume is called expansion. Similarly, the decrease in dimensions of a substance subjected to a decrease in temperature is known as **contraction**. That is, the decrease in its length, area or volume is called contraction.

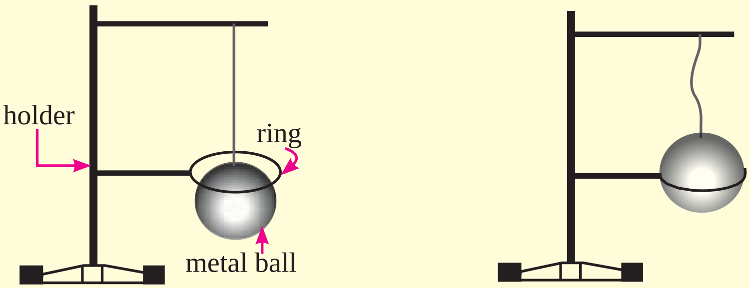
9.4.1 Expansion of Solids

Let us engage in activity 9.3 to demonstrate the expansion of solids.

Activity 9.3

Apparatus required: A metal ball, A holder, A ring through which the iron ball just passes.

- Obtain an iron ball and a ring through which the iron ball just passes.
- Heat up the ball and see if it can be passed through the ring.
- Also observe that the iron ball passes through the ring again after being cooled.



(a)
Before heating up the iron ball passes through the ring.

(b)
After heating up the iron ball cannot pass through the ring.

Figure 9.17 - Modelling expansion of solids

It will be clear from this activity that solids expand when they are heated up and they contract upon being cooled.

Influences and Applications of Expansion of Solids

- When fitting iron rims to wooden cart wheels, the diameter of the iron rim is chosen to be slightly less than that of the wooden wheel. Then the iron rim is heated and expanded until the wheel can be inserted into it. After inserting the wooden wheel into the iron rim, it is allowed to cool and thus contract, fitting it into the wheel securely.
- In railways, a small gap is left between two rails allowing them to expand when the temperature rises, thus preventing the rails from being deformed due to expansion.

Figure 9.18

- Telephone wires and cables carrying electricity are loosely fitted between posts in order to allow them to contract without breaking the wires when the environmental temperature drops.

Figure 9.19

- Tight fitting metallic bottle lids can be easily opened by heating them up to expand slightly.

  The reason for this is that the expansion of metals is larger than that of glass making the lid slightly larger than the bottle when they are heated up.

- In electrical appliances such as electric irons and rice cookers, bimetallic strips consisting of two different metals that have different expansions for a given temperature difference are used to regulate the temperature.

Figure 9.20(a) shows such a bimetallic strip. It consists of two metallic strips with inequal expansions rigidly riveted together. One of its ends is rigidly fixed to a piece of metal while the other end remains free. When the temperature of the bipolar strip is increased, one of the strips expands more than the other. Then the two strips bend as shown in figure 9.20(b).

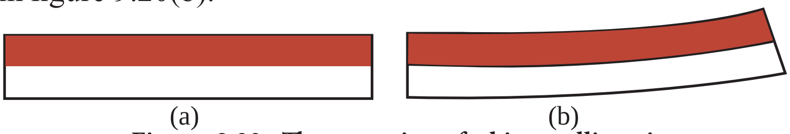


Figure 9.20 –The operation of a bi-metallic strip

By connecting the bipolar strip to an electric circuit as shown in the figure 9.21, power can be disconnected from the circuit when the temperature is increased by supplying power to the heater.

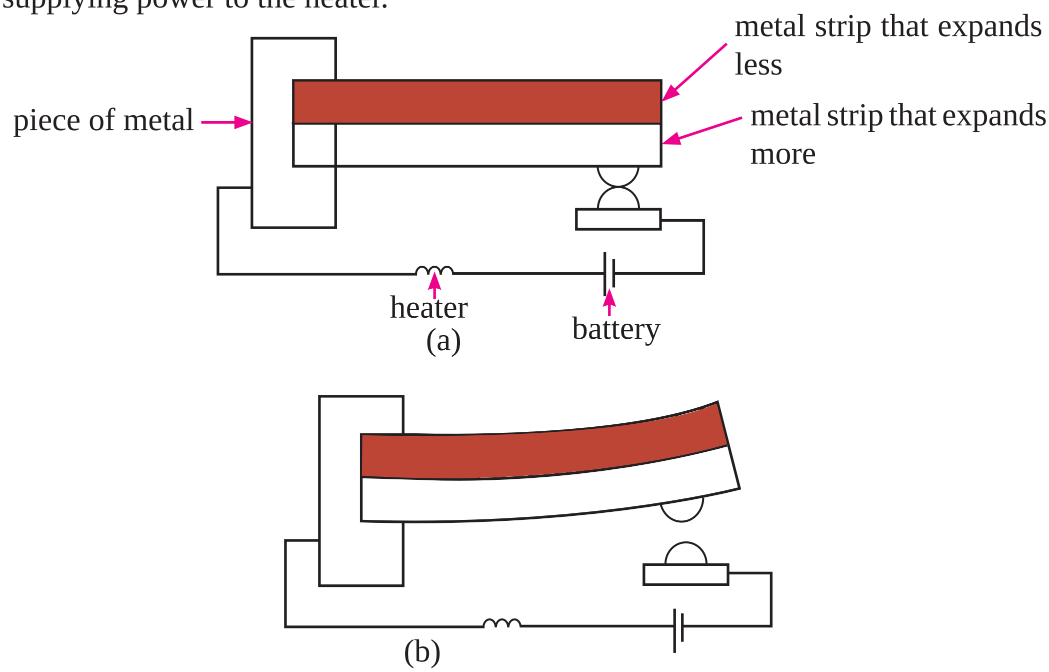


Figure 9.21 – Connecting a bimetallic strip to an electric circuit

Assignment 9.1

Explore other instances where expansion of solids are utilized and record your data.

9.4.2 Expansion of Liquids

Let us engage in activity 9.4 to illustrate the expansion of liquids.

Activity 9.4

Apparatus required: A test tube, Colored water

- Fill a test tube with colored water and fix a rubber stopper with a glass tube to the test tube as shown in the figure 9.22(a).
- Mark the water level on the glass tube
- Insert the glass tube in a warm water vessel for a few minutes and examine it.
- When heating up, the test tube expands and the liquid level goes down to *B* and when the liquid expands, the liquid level rises upto *C*.

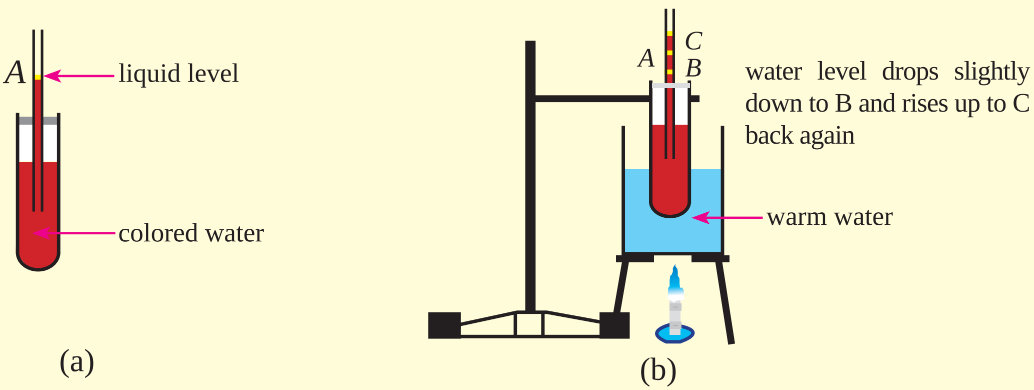


Figure 9.22 - Illustrating expansion of liquids

In this experiment, first the test tube expands when the temperature of the water increases. Then the liquid level drops down slightly. However when the liquid inside the test tubes heats up, the liquid also begins to expand. When the expansion of the liquid exceeds that of glass, the liquid level rises up again. When making thermometers, thermal expansion of liquids is commonly used. In mercury and alcohol thermometers, the expansion of liquid volume is used for measuring temperature.

9.4.3 Expansion of Gases

Let us engage in activity 9.5 to illustrate the expansion of gases.

Activity 9.5

Apparatus required: Ice, An empty plastic bottle, A balloon.

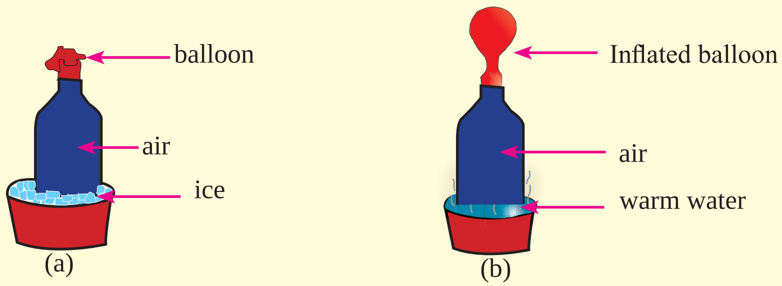


Figure 9.23 - Illustration of expansion of gases

- Place an empty plastic bottle without a lid vertically in a vessel containing ice and water for a short while.
- Then attach a balloon to the opening as shown in Figure 9.23(a).
- Next place the bottle in another empty vessel and pour hot water into the vessel as shown in Figure 9.23(b).
- Observe that the balloon inflates slightly.
- Also observe that the balloon shrinks when left outside for a while.

When the bottle is placed inside the ice vessel, the temperature of the air inside the bottle is close to 0 ^{o}C. When it is placed inside the warm water bottle the temperature of the cool air in the bottle increases close to the room temperature and the air expands. This air cannot leave the bottle because of the balloon attached to it. Instead, the balloon inflates. When the bottle is taken out, the air cools down to the room temperature shrinking again.

From this experiment it is clear that the air inside the bottle expands when it heats up and contracts when the air cools down.

9.5 Heat Transfer

If you touch the far end of a metal spoon inserted in a hot cup of tea you would feel that it gets warmer gradually. Similarly if you hold your hand above a burning fire, you would feel that the hand gets warmer. What has happened in these instances is that heat has transferred along the spoon in the first case and upwards away from the flame in the second. Heat passing from one place to another in this manner is known as **heat transfer**.

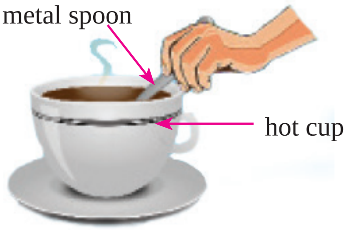


Figure 9.24

Figure 9.25

Heat transfer occurs from the place with the higher temperature to the place with the lower temperature. The energy known as thermal energy (heat) of an object is actually present as the kinetic energy resulting from the random motion of the particles that form the object. This energy can be the translational, rotational or vibrational kinetic energy of the particles. Heat transfer is the spreading of kinetic energy from a region with atoms having a high degree of random motion (with a high temperature) to a region of atoms having a low degree of random motion (with a low temperature).

There are three methods of transferring heat.

(1) Conduction
(2) Convection
(3) Radiation

Let us investigate these methods in a simple way.

9.5.1 Conduction

The handle of a metal spoon held in a hot water soon gets warm. Heat passes along the spoon by conduction.

Some examples where heat transfers by condition are given below.

- Heat flow along a metallic rod in contact with a flame.
- Heat flow from the bottom to the interior of a vessel placed on a cooker.

The main method of heat transfer through solids is conduction.

Since the atoms of a solid are tightly bound to one another, they cannot freely move throughout the volume of the solid. In such substances, heat exists as the vibrational kinetic energy of atoms. In metallic substances, part of the thermal energy exists as kinetic energy of freely moving electrons (free electrons) in addition to this. Conduction is the spreading of the kinetic energy of atoms and electrons throughout the substance due to collisions among these particles.

Substances that conduct heat efficiently are known as **good conductors** and substances that do not conduct heat efficiently are known as **insulators**.

Examples: good conductors – silver, copper, iron, mercury, aluminium

Insulators – wood, plastic, asbestos, clay, wool

Existence of free electrons in metals make metals good conductors.

In liquids, molecules are not very tightly bound. Therefore, conduction of current through liquids is very weak. Water is a very poor thermal conductor.

This Robbin has fluffed out its feathers to trap a layer of air. Air is a poor conductor of heat and so the bird manages to keep warm even in cold weather.

Figure 9.26 - Robbin bird

Seals, spend all of their lives in cold water. They are protected from losing heat by conduction by a very thick layer of fat (blubber) which surrounds their body.

• Conduction through a metal rod

The Figure 9.27 illustrates how heat is conducted through a metal rod that is heated from one end.

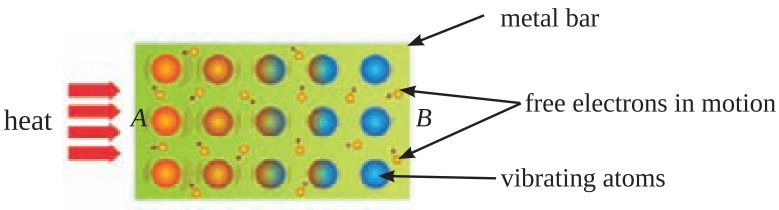


Figure 9.27 – Metal rod heated at one end

Suppose that the metallic rod shown in figure 9.27 is heated by a flame at the end *A*.

Then the atoms at that end begin to vibrate with a large amplitude by receiving thermal energy (heat) from the flame. In addition to this, the free electrons in random motion at that end gain kinetic energy from the flame. As a result of the increased kinetic energy, these atoms collide with adjacent atoms. Due to the collisions, energy transfers to one atom from another increasing the amplitude of vibrations. This process continues through the atoms in the rod from *A* to *B* in succession, transferring thermal energy along the rod. Thermal energy is also transferred by the free electrons in random motion in the rod by receiving thermal energy from the flame.

9.5.2 Convection

The water is heated just under the purple crystal - the crystal colours the water as it dissolves. The heated water expands and becomes less dense than the colder surrounding water, so it floats up to the top of the beaker. Colder water sinks to take its place, and is then heated too.

Figure 9.28

When heat is supplied to liquids or gases they expand and decrease in density and move upwards. In order to fill these gaps, liquids or gases with lower temperatures move downwards. Due to this process, heat flows upwards from the region where heat is supplied. This is known as **convection**.

When a fire is lighted underneath a tree, branches and leaves above the fire tend to swing about and burn as a result of the upward motion of heated up air particles.

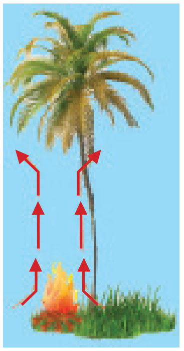


Figure 9.29

Upward motion of heated up particle streams is known as **convection currents**.

Consider the figures below showing an immersion heater used to heat up water.

Figure 9.30 - An immersion heater used to heat up water

Figure 9.30(a) shows a heater partially immersed in water. Here the water near the bottom of the jug warms up slowly but the water near the top warms up fast. This happens since convection currents do not flow downwards.

The immersion heater in Figure 9.30(b) is fully immersed inside the vessel. Then water warms up from bottom to top. Heated up water particles become lighter and move upwards and the water particles that are not heated up move down as their density is higher. When heated up they too move upwards. This process takes place continually heating up the whole jug of water.

- **Formation of Sea breeze and Land breeze**

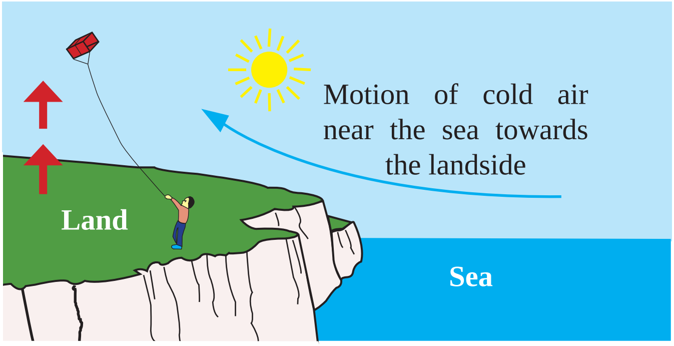


Figure 9.31 - Sea breeze

Specific heat capacity of the earth's surface in the land side is smaller than that of the sea water. Therefore during day time the land surface heats up faster from the sun's heat than the sea water. Then the air near the land surface warms up which decreases the density and the air moves upwards. This reduces the pressure near the ground. Then an air mass flows from the sea to the land side. This is known as **sea breeze.**

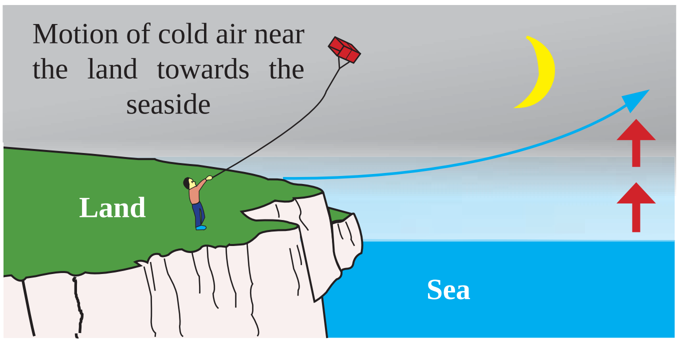


Figure 9.32 - Land breeze

During night time both the land and the sea cool down. The sea cools down slowly while the land cools down fast. Air near the sea water surface is warm while that above is cold. Therefore the air near the sea water moves upwards giving rise to a low pressure region just above the sea. Then wind blows from the land side towards the sea in order to equalize the pressure difference. This is known as **land breeze.**

Think........
How does a warm cup of tea cool down upon blowing on it?

9.5.3 Thermal Radiation

You will be able understand that it is not due to either conduction or convection that you feel the warmth near a burning fire. Then it must be through another means that heat has transferred. We feel the warmth when thermal rays travel through space in the form of rays (waves) from the flame and reach our bodies.

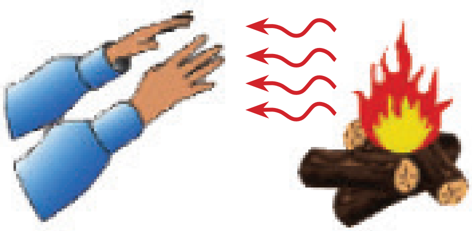


Figure 9.33

The propagation of heat in the form of electromagnetic radiation from a warm body without the aid of matter is known as **thermal radiation**. For heat transfer by radiation, a material medium is not required. However, for heat transfer by conduction or convection, particles of a medium are essential.

Heat from the sun reach the earth through a vacuum of about 150 million kilometres as thermal radiation. Any heated body emits heat as radiation.

• Absorption and Reflection of Thermal Radiation

When thermal radiation is incident on an object, part of the radiation is absorbed by the object while another part is reflected. The surface roughness or the smoothness and the colour of the surface of the object are the factors affecting the amount of thermal radiation absorbed or reflected.

Absorption of thermal radiation is high from darker surfaces and rough surfaces.

Reflection of thermal radiation is high from shining surfaces.

Reflection of heat radiation by polished surfaces and by white surfaces are very high.

Black surfaces absorb a high amount of heat while they reflect a very low amount of heat.

Assignment 9.6

Design an experiment to find out from which out of dark, white and shining surfaces that thermal radiation is most effectively absorbed. Write down the conclusions you can draw based on your observations.

• Situations where thermal radiation is important

When cricketers dress in white during the day time in the presence of sunlight, the absorption of thermal radiation is very low. Then warming up of the body is controlled.

Wearing dark colors inside homes by people in cold climates increase the absorption of thermal radiation. This helps to maintain the body temperature.

If the cooking utensils placed on cookers are black in color, they can absorb thermal radiation efficiently and transfer heat to the vessels fast.

The inner surfaces of thermos flasks are silvered to make them highly reflective. These surfaces reflect heat radiated by the contents inside the bottle or heat radiation coming from outside.

Summary

- Temperature is a measure of the mean kinetic energy of the atoms forming an object.
- The instrument that is used to measure temperature is the thermometer.
- The units used to measure temperature are degrees Celsius (^{o}C), degrees Fahrenheit (^{o}F) and Kelvin (K).
- The international unit of measuring temperature is the Kelvin.
- Heat is the energy transferred from one object to another object due to the temperature difference between them.
- If energy is absorbed by an object where no change of state occurs, then its temperature will definitely rise.
- If energy is released by an object where no change of state occurs, then its temperature will definitely drop.
- Heat capacity (C) of an object is the amount of heat required to increase its temperature by one temperature unit.
- Units of heat capacity are $J\ K^{-1}$ or $J\ ^{o}C^{-1}$.
- Specific heat capacity (c) of an object is the amount of heat required (or released) to increase (or decrease) the temperature of a unit mass of the object by one temperature unit.
- Units for measuring the specific heat capacity are $J\ kg^{-1}\ K^{-1}$ or $J\ kg^{-1}\ ^{o}C^{-1}$.
- Heat capacity $C = mc$
- Quantity of heat $Q = mc\theta$
- Latent heat is the amount of heat absorbed or released in a change of state of a substance without changing its temperature.
- Specific latent heat capacity of fusion is the heat required to convert a unit mass of a solid at its melting point into a liquid at the same temperature.

- Specific latent heat capacity of vaporization is the heat required to convert a unit mass of a liquid at its boiling point into a vapor at the same temperature.
- The unit of specific latent heat capacity is J kg^{-1}.
- The increase in length, area or volume taking place when an object is heated up is known as thermal expansion.
- Heat transfer is the flow of heat from a point at a higher temperature to a point at a lower temperature.
- The three methods of heat transfer are conduction, convection and radiation.
- Conduction is the forward flow of heat through any material by heating up of the constituent particles one by one in succession.
- Convection is the flow of heat by the upward motion of particles by decreasing the density when liquids or gases are heated up.
- Radiation is the flow of heat from a heated body in the form of electromagnetic waves without the aid of a material medium.

Exercise 9.3

(1) Fill in the blanks of the sentences given below.

(i) The international unit used to measure temperature is .... and the international unit used to measure the amount of heat is ....

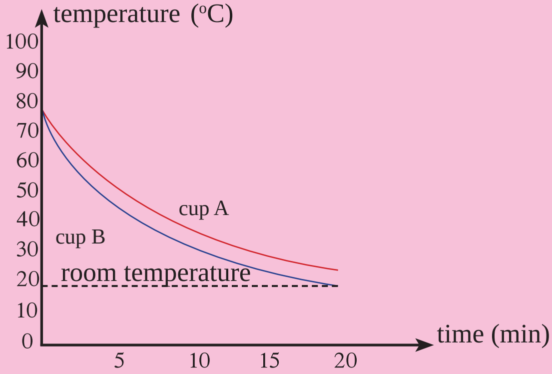
(ii) The absolute zero is equal to .... Celsius.

(iii) The .... does not change when absorbing latent heat while the .... changes.

(iv) The method of transferring heat without the influence of a medium is ....

(v) Bodies having low specific heat capacities increase their temperature ...., bodies with high specific heat capacities increase their temperature ....

(2) Two cups of the same size and shape made out of two different materials are filled with equal amounts of hot tea and are allowed to cool down. Cooling curves plotted by measuring the temperatures of the two cups at definite time intervals are shown below.



(i) What is the temperature of the tea in cup *A* after five minutes?
(ii) What is the time taken for the temperature of the tea in cup *B* to drop by 30 °C?
(iii) What is the difference in the temperatures of the tea in the two cups after 15 minutes?
(iv) Which cup is made out of the material with the lower heat conductivity?
(v) What is the reason for your answer above?
(vi) What is the ultimate temperature of the tea in the two cups?

(3) The figure below shows the cross-section of a thermos flask.

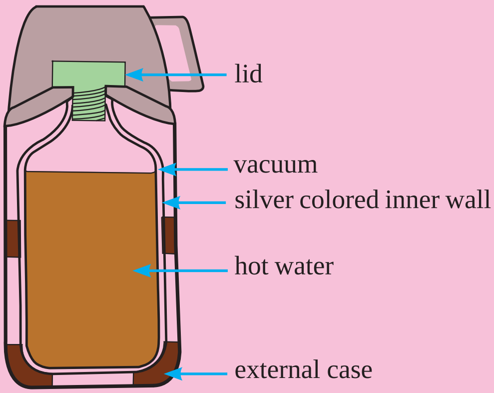


Figure 9.34

(i) There are two situations that a thermos flask can be used. What are they?
(ii) There are 500 ml of water at a temperature of 100 °C inside the flask. In order to keep the water at this temperature, heat loss has to be prevented. What are the techniques used here for this purpose?

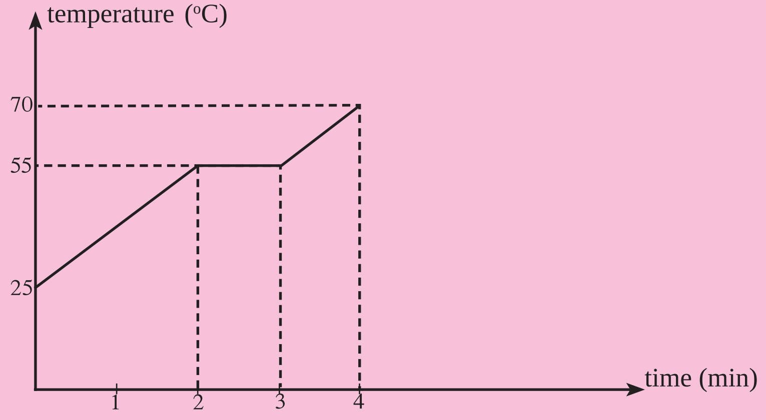
(iii) Calculate the amount of heat loss occurring when 500 ml of water at 100 °C cools down to the room temperature of 25 °C. (Specific heat capacity of water is 4200 J kg^{-1} K^{-1})

(iv) It is not appropriate to remove the hot water from a flask and fill it with cold water immediately. What is the reason for this?

(4) (i) Find the heat released in cooling 10 g of water at 100 °C down to 25 °C.

(ii) A burn caused by steam at 100 °C is more harmful than a burn caused by boiling water at 100 °C. Explain this.

(5) A piece of paraffin is at room temperature. Investigate the changes occurring in it when the temperature is gradually increased and temperature measurements were plotted against time, the following graph was obtained. Answer the questions given below using the graph.



(i) What is the room temperature?

(ii) What is the melting point of paraffin?

(iii) How long after commencing the experiment did the paraffin begin to melt?

(iv) What is the reason for the temperature to remain constant in the time interval between 2 min to 3 min?

(v) If supplying heat to paraffin was stopped at time 4 min, give a rough sketch to show the variation of the temperature of paraffin with time thereafter.

Technical terms

Temperature	- උෂ්ණත්වය	- வெப்பநிலை
Glass-mercury Thermometer	- වීදුරු රසදිය උෂ්ණත්වමානය	- கண்ணாடி இரச வெப்பமானி
Glass-Alcohol Thermometer	- වීදුරු මද්‍යසාර උෂ්ණත්වමානය	- கண்ணாடி அற்கசோல் வெப்பமானி
Heat Capacity	- තාප ධාරිතාව	- வெப்பக் கொள்ளளவு
Specific Heat Capacity	- විශිෂ්ට තාප ධාරිතාව	- தன்வெப்பக் கொள்ளளவு
Melting Point	- ද්‍රවාංකය	- உருகுநிலை
Freezing Point	- හිමාංකය	- உறைநிலை
Boiling Point	- තාපාංකය	- கொதிநிலை
Latent Heat	- ගුප්ත තාපය	- மறை வெப்பம்
Latent heat of fusion	- විලයනයේ ගුප්ත තාපය	- உருகலின் தன்மறை வெப்பம்
Latent heat of vaporization	- වාෂ්පීකරණයේ ගුප්ත තාපය	- ஆவியாதலின் தன்மறை வெப்பம்
Vaporization	- වාෂ්පීකරණය	- கொதித்து ஆவியாதல்
Evaporation	- වාෂ්පීභවනය	- ஆவியாதல்
Thermal Expansion	- තාප ප්‍රසාරණය	- வெப்பவிரிவு