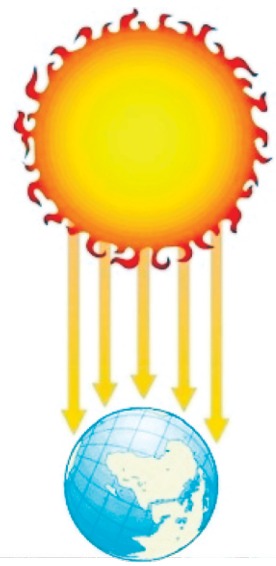
Unit 9

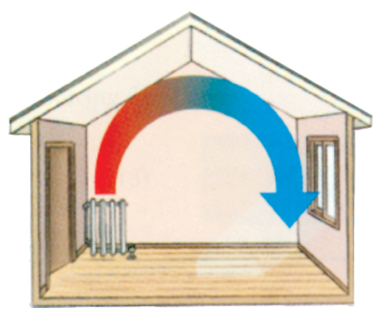
Transfer of Heat

STUDENT'S LEARNING OUTCOMES

After studying this unit, the students will be able to:

- recall that thermal energy is transferred from a region of higher temperature to a region of lower temperature.
- describe in terms of molecules and electrons , how heat transfer occurs in solids.
- state the factors affecting the transfer of heat through solid conductors and hence, define the term Thermal Conductivity.
- solve problems based on thermal conductivity of solid conductors.
- write examples of good and bad conductors of heat and describe their uses.
- explain the convection currents in fluids due to difference in density.
- state some examples of heat transfer by convection in everyday life.
- explain that insulation reduces energy transfer by conduction.
- describe the process of radiation from all objects.
- explain that energy transfer of a body by radiation does not require a material medium and rate of energy transfer is affected by:
  - colour and texture of the surface
  - surface temperature
  - surface area





Conceptual Linkage.

This unit is built on

Modes of heat transfer

- Science-VII

This unit leads to:

Thermodynamics

- Physics-XI

Major Concepts

9.1 The three process of heat transfer
9.2 Conduction
9.3 Convection
9.4 Radiation
9.5 Consequences and everyday applications of heat transfer

INVESTIGATION SKILLS

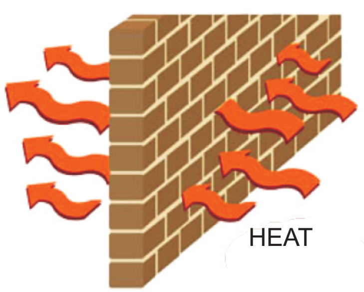
The students will be able to:

- describe convection in water heating by putting a few pinky crystals in a round bottom flask.
- explain that water is a poor conductor of heat.
- investigate the absorption of radiation by a black surface and silvery surfaces using Leslie cube.
- investigate the emission of radiation by a black surface and silvery surfaces using Leslie cube.

SCIENCE, TECHNOLOGY AND SOCIETY CONNECTION

The students will be able to:

- describe the use of cooking utensils, electric kettle, air conditioner, refrigerator cavity wall insulation, vacuum flask and household hot-water system as a consequence of heat transmission Processes.
- explain convection in seawater to support marine life.
- describe the role of land breeze and sea breeze for moderate coastal climate.
- describe the role of convection in space heating.
- identify and explain some of the everyday applications and consequences of heat transfer by conduction, convection and radiation.
- explain how the birds are able to fly for hours without flapping their wings and glider is able to rise by riding on thermal currents which are streams of hot air rising in the sky.
- explain the consequence of heat radiation in greenhouse effect and its effect in global warming.



Heat is an important form of energy. It is necessary for our survival. We need it to cook our food and to maintain our body temperature. Heat is also needed in various industrial processes. How to protect ourselves from high as well as low temperature, needs knowledge of how heat travels. In this unit, we will study various ways of heat transfer.

9.1 TRANSFER OF HEAT

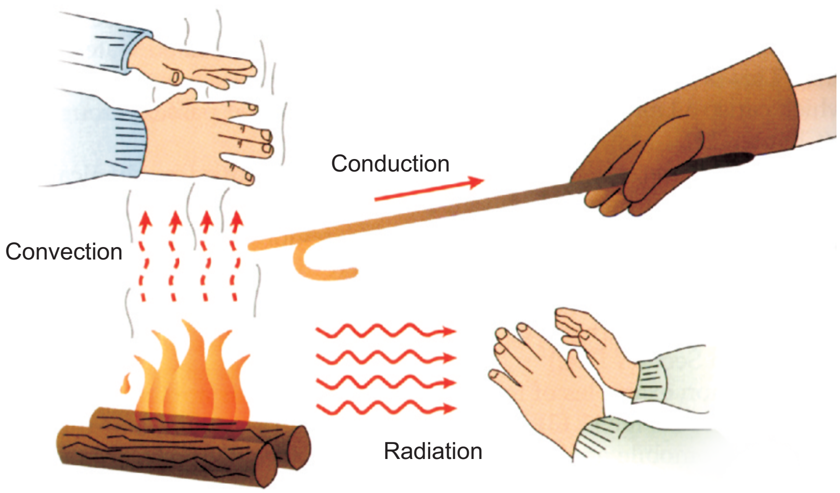


Figure 9.1: Three ways of heat transfer

Recall what happens when two bodies at different temperature are in thermal contact with each other. Thermal energy from a hot body flows to a cold body in the form of heat. This is called as transfer of heat. Transfer of heat is a natural process. It continues all the time as long as the bodies in thermal contact are at different temperature. There are three ways by which transfer of heat takes place. These are:

- conduction
- convection
- radiation

QUICK QUIZ

Think of objects around us getting heat or giving out heat.

9.2 CONDUCTION

The handle of metal spoon held in hot water soon gets warm. But in case of a wooden spoon, the handle does not get warm. Both the materials behave differently regarding the transfer of heat. Both metals and non-metals conduct heat. Metal are generally better conductors than non-metals.

In solids, atoms and molecules are packed close together as shown in figure 9.2. They continue to vibrate about their mean position. What happens when one of its ends is heated? The atoms or molecules

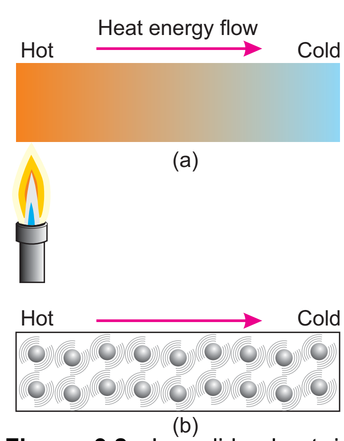


Figure 9.2: In solids, heat is transferred from one part to other parts from atoms to atoms or molecules to molecules due to collisions.

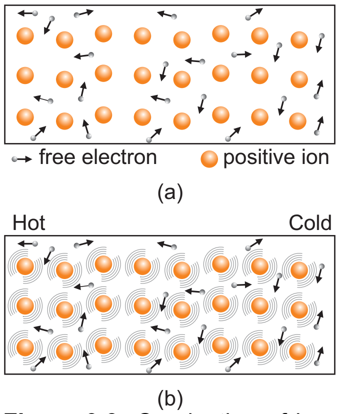


Figure 9.3: Conduction of heat in metals.

present at that end begin to vibrate more rapidly. They also collide with their neighbouring atoms or molecules. In doing so, they pass some of their energy to neighbouring atoms or molecules during collisions with them with the increase in their vibrations. These atoms or molecules in turn pass on a part of the energy to their neighbouring particles. In this way some heat reaches the other parts of the solids. This is a slow process and very small transfer of heat takes place from hot to cold parts in solids.

How does then heat flow from hot to cold parts in metals so rapidly than non-metals? Metals have free electrons as shown in figure 9.3. These free electrons move with very high velocities within the metal objects. They carry energy at a very fast rate from hot to cold parts of the object as they move. Thus, heat reaches the cold parts of the metal objects from its hot part much more quickly than non-metals.

The mode of transfer of heat by vibrating atoms and free electrons in solids from hot to cold parts of a body is called conduction of heat.

DO YOU KNOW?

Why Styrofoam boxes are used to keep food hot or ice cream cold for a long time? Styrofoam is a bad conductor of heat. It does not allow heat to leave or enter the box easily.

All metals are good conductors of heat. The substances through which heat does not conduct easily are called bad conductors or insulators. Wood, cork, cotton, wool, glass, rubber, etc. are bad conductors or insulators.

THERMAL CONDUCTIVITY

Conduction of heat occurs at different rates in different materials. In metals, heat flows rapidly as compared to insulators such as wood or rubber. Consider a solid block as shown in figure 9.4. One of its two opposite faces each of cross-sectional area A is heated to a temperature T_1. Heat Q flows along its length L to opposite face at temperature T_2 in t seconds.

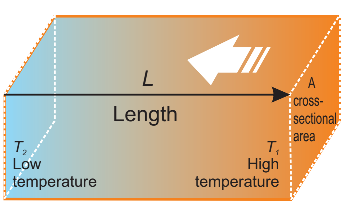


Figure 9.4: Rate at which heat conducts through different solids depends upon various factors.

The amount of heat that flows in unit time is called the rate of flow of heat.

Thus Rate of flow of heat $= \frac{Q}{t}$ .... (9.1)

It is observed that the rate at which heat flows through a solid object depends upon various factors.

CROSS-SECTIONAL AREA OF THE SOLID

Larger cross-sectional area *A* of a solid contains larger number of molecules and free electrons on each layer parallel to its cross-sectional area and hence greater will be the rate of flow of heat through the solid. Thus

Rate of flow of heat $\frac{Q}{t} \propto A$

LENGTH OF THE SOLID

Larger is the length between the hot and cold ends of the solid, more time it will take to conduct heat to the colder end and smaller will be the rate of flow of heat. Thus

Rate of flow of heat $\frac{Q}{t} \propto \frac{1}{L}$

TEMPERATURE DIFFERENCE BETWEEN ENDS

Greater is the temperature difference $T_1 - T_2$ between hot and cold faces of the solid, greater will be the rate of flow of heat. Thus

Rate of flow of heat $\frac{Q}{t} \propto (T_1 - T_2)$

Combining the above factors, we get

$$\frac{Q}{t} \propto \frac{A\,(T_1 - T_2)}{L}$$

Rate of flow of heat $\frac{Q}{t} = \frac{k\,A\,(T_1 - T_2)}{L}$ ... ... (9.2)

Here k is the proportionality constant called thermal conductivity of the solid. Its value depends on the nature of the substance and is different for different materials. From equation (9.2), we find k as:

$$k = \frac{Q}{t} \times \frac{L}{A\,(T_1 - T_2)} \quad \ldots \quad \ldots \quad \ldots \quad (9.3)$$

Thus, thermal conductivity of a substance can be defined as:

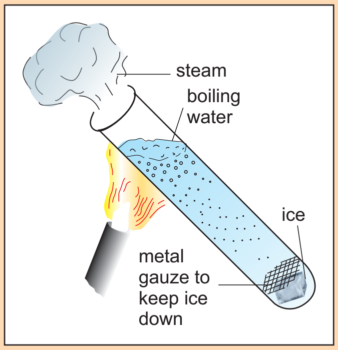
The rate of flow of heat across the opposite faces of a metre cube of a substance maintained at a temperature difference of one kelvin is called the thermal conductivity of that substance.

Thermal conductivities of some substances are given in the table.

Thermal conductivities of some common substances

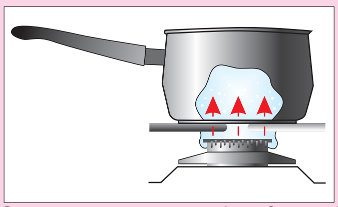
Substance	$Wm^{-1}K^{-1}$
Air (dry)	0.026
Aluminium	245
Brass	105
Brick	0.6
Copper	400
Glass	0.8
Ice	1.7
Iron	85
Lead	35
Plastic foam	0.03
Rubber	0.2
Silver	430
Water	0.59
Wood	0.08

FOR YOUR INFORMATION



Water is a poor conductor. Water at the top in the test tube starts boiling after getting heat from the burner without melting ice.

DO YOU KNOW?



Sauce-pans are made of metal for quick heat transfer.

Figure 9.5: Soft insulation board between external brick wall of a house.

USE OF CONDUCTORS AND NON-CONDUCTORS

In houses, good thermal insulation means lower consumption of fuel. For this, following measures may be taken to save energy.

- Hot water tanks are insulated by plastic or foam lagging.
- Wall cavities are filled with plastic foam or wool.
- Ceiling of rooms is covered by insulating materials (false ceiling).
- Double glazed window panes are used. These window panes have air between glass sheets that provides good insulation.

Good conductors are used when quick transfer of heat is required through a body. Thus cookers, cooking plate, boiler, radiators and condensers of refrigerators, etc. are made of metals such as aluminum or copper. Similarly, metal boxes are used for making ice, ice cream, etc.

Insulators or bad conductors are used in home utensils such as handles of sauce-pans, hot plates, spoons, etc. They are made up of wood or plastic. Air is one of the bad conductors or best insulator. That is why cavity walls i.e. two walls separated by an air space and double glazed windows keep the houses warm in winter and cool in summer. Materials which trap air i.e. wool, felt, fur, feathers, polystyrenes, fibre glass are also bad conductors. Some of these materials are used for laggings to insulate water pipes, hot water cylinders, ovens, refrigerators, walls and roofs of houses. Woollen cloth is used to make warm winter clothes.

EXAMPLE 9.1

The exterior brick wall of a house of thickness 25 cm has an area 20 m^2. The temperature inside the house is 15°C and outside is 35°C. Find the rate at which thermal energy will be conducted through the wall, the value of k for bricks is 0.6 $Wm^{-1}K^{-1}$.

SOLUTION

Here $A = 20\ m^2$

L = 25 cm = 0.25 m

T_1 = 35 + 273 = 308 K

T_2 = 15 + 273 = 288 K

$\Delta T = T_1 - T_2$

= 308 K – 288 K = 20 K

k = 0.6 $Wm^{-1}K^{-1}$.

Using equation 9.2, rate of conduction of thermal energy is

$$= \frac{k A (T_1 - T_2)}{L}$$

$$= \frac{0.6\ Wm^{-1}K^{-1} \times 20\ m^2 \times 20\ K}{0.25\ m}$$

= 960 watt or 960 Js^{-1}

Thus, the rate of flow of thermal energy across the wall will be 960 joules per second.

DO YOU KNOW?

Feathers give good thermal insulation especially when fluffed up.

9.3 CONVECTION

Liquids and gases are poor conductors of heat. However, heat is transferred through **fluids** (liquids or gases) easily by another method called convection.

Why a balloon inflated with hot air as shown in figure. 9.6 rises up? A liquid or a gas becomes lighter (less dense) as it expands on heating. Hot liquid or gas rises up above the heated area. The cooler liquid or gas from the surroundings fills the place which in turns is heated up. In this way, all the fluid is heated up. Therefore, transfer of heat through fluids takes place by the actual movement of heated molecules from hot to cold parts of the fluid.

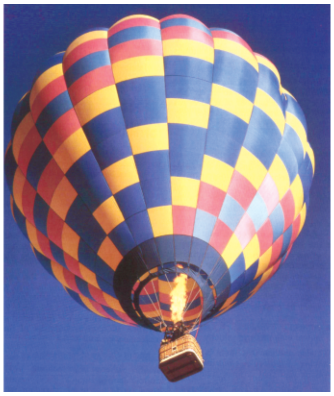


Figure 9.6: Balloons inflated with hot air rise up. Air becomes lighter on heating.

Transfer of heat by actual movement of molecules from hot place to a cold place is known as convection.

EXPERIMENT 9.1

Take a beaker and fill two-third of it with water. Heat the beaker by keeping a burner below it. Drop two or three crystals of potassium permanganate in the water. It will be seen that coloured streaks of water formed by the crystals move upwards above the flame

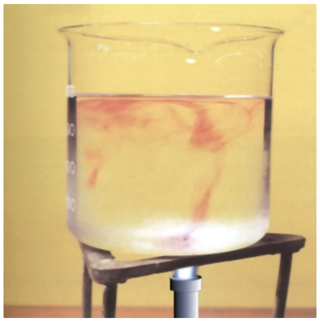


Figure 9.7: Crystals of potassium permanganate are used to show the movement of water on heating.

and then move downwards from side ways as shown in the figure 9.7. These coloured streaks show the path of currents in the liquid. Why the liquid currents stop on removing the burner under the beaker? When the water at the bottom of the beaker gets hot, it expands, becomes lighter and rises up. While the cold but denser water moves downward to take its place.

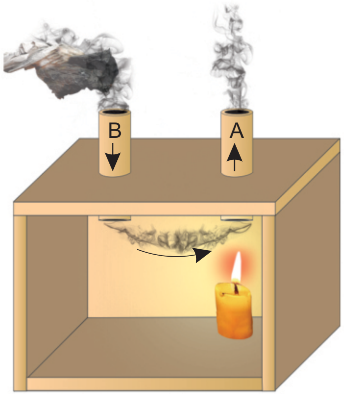


Figure 9.8: Smoke showing the path of the convection.

CONVECTION CURRENTS IN AIR

Gases also expand on heating, thus convection currents are easily set up due to the differences in the densities of air at various parts in the atmosphere. This can be observed by a simple experimental set up as shown in figure 9.8. Can you explain it?

USE OF CONVECTION CURRENTS

Convection currents set up by electric, gas or coal heaters help to warm our homes and offices. Central heating systems in buildings work on the same principle by convection. Convection currents occur on a large scale in nature. The day–to–day temperature changes in the atmosphere result from the circulation of warm or cold air that travels across the region. Land and sea breezes are also the examples of convection currents.

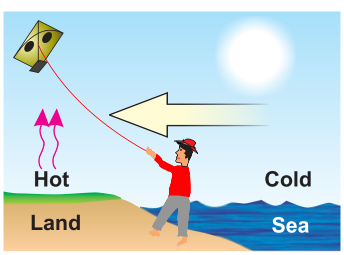


Figure 9.9: Sea breeze blows from sea to land in daytime.

LAND AND SEA BREEZES

Why does sea breeze blow during the day? Why does land breeze blow in the night?

Land and sea breezes are the result of convection. On a hot day, the temperature of the land increases more quickly than the sea. It is because the specific heat of land is much smaller as compared to water. The air above land gets hot and rises up. Cold air from the sea begins to move towards the land as illustrated in figure 9.9. It is called sea breeze.

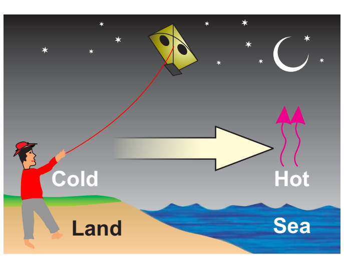


Figure 9.10: Land breeze blows from land to sea during night.

At night, the land cools faster than the sea. Therefore, air above the sea is warmer, rises up and the cold air from the land begins to move towards the sea as illustrated in figure 9.10. It is called land breeze.

How do the land and sea breezes help to keep the temperature moderate in coastal areas?

GLIDING

What causes a glider to remain in air?

A glider such as shown in figure 9.11 looks like a small aeroplane without engine. Glider pilots use upward movement of hot air currents due to convection of heat. These rising currents of hot air are called **thermals.** Gliders ride over these thermals. The upward movement of air currents in thermals help them to stay in air for a long period.

Figure 9.11: A glider

How do thermals help birds to fly for hours without flapping their wings?

The birds stretch out their wings and circle in these thermals. The upward movement of air helps birds to climb up with it. Eagles, hawks and vultures are expert **thermal climbers.** After getting a free lift, birds are able to fly for hours without flapping their wings. They glide from one thermal to another and thus travel through large distances and hardly need to flap their wings.

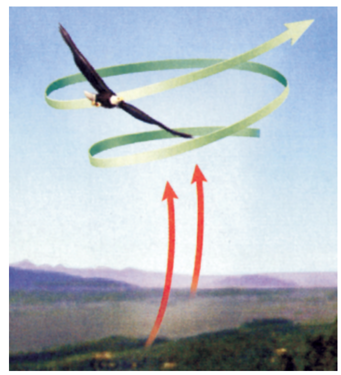


Figure 9.12: Birds fly taking the advantage of thermal air currents.

9.4 RADIATION

Our Sun is the major source of heat energy. But how does this heat energy reach the Earth? It reaches us neither by conduction nor by convection, because the space between the Sun and the Earth's atmosphere is empty. There is a third mode called radiation by which heat travels from one place to another. It is through radiation that heat reaches us from the Sun.

Radiation is the mode of transfer of heat from one place to another in the form of waves called electromagnetic waves.

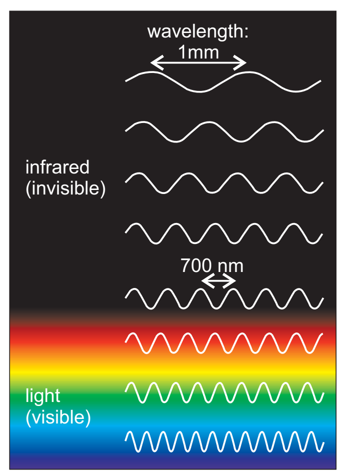


Figure 9.13: Thermal radiations and visible light spectrum.

How does this heat reach us directly from a fireplace? Figure 9.14 shows a fireplace such as used for room heating. Heat does not reach us by conduction through air from a fireplace because air is a poor conductor of heat. Heat does not reach us by

Figure 9.14: Heat from the fireplace reaches us by radiation.

convection because the air getting heat from the fireplace does not move in all directions. Hot air moves upward from the fireplace. Heat from the fireplace reaches us directly by a different process in the form of waves called radiation. A sheet of paper or cardboard kept in the path of radiations stop these waves to reach us.

Radiations are emitted by all bodies. The rate at which radiations are emitted depends upon various factors such as

- Colour and texture of the surface
- Surface temperature
- Surface area

Why does a cup of hot tea become cold after sometime? Why does a glass of chilled water become hot after sometime?

All the objects, lying inside a room including the walls, roof and floor of the room are radiating heat. However, they are also absorbing heat at the same time. When temperature of an object is higher than its surroundings then it is radiating more heat than it is absorbing. As a result, its temperature goes on decreasing till it becomes equal to its surroundings. At this stage, the body is giving out the amount of heat equal to the amount of heat it is absorbing.

When temperature of an object is lower than its surroundings, then it is radiating less heat than it is absorbing. As a result, its temperature goes on increasing till it becomes equal to its surroundings. The rate at which various surfaces emit heat depends upon the nature of the surface. Various surfaces can be compared using Leslie's cube.

Emission and Absorption of Radiation

A Leslie cube is a metal box having faces of different nature as shown in figure 9.15. The four faces of Leslie's cube may be as follows:

- A shining silvered surface
- A dull black surface
- A white surface
- A coloured surface

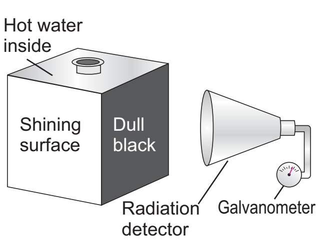


Figure 9.15: Radiations from Leslie's cube.

Hot water is filled in the Leslie's cube and is placed with one of its face towards a radiation detector. It is found that black dull surface is a good emitter of heat.

The rate at which various surfaces absorb heat also depends upon the nature of those surfaces. For example, take two surfaces, one is dull black and the other is a silver polished surface as shown in figure 9.16 with a candle at the middle of the surface. It is found that:

A dull black surface is a good absorber of heat as its temperature rises rapidly.

A polished surface is poor absorber of heat as its temperature rises very slowly. The observations made from the set up shown in figure 9.16 are shown in the table given below:

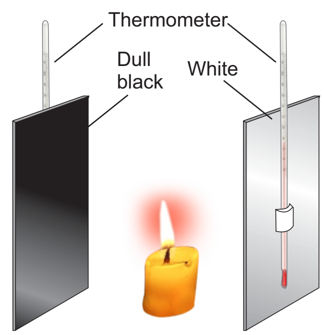


Figure 9.16: A comparison of absorption of radiation.

Surfaces	Emitter	Absorber	Reflector
dull black surface	best	best	worst
coloured surface	good	good	bad
White surface	bad	bad	good
shining silvered surface	worst	worst	best

It is also found that the transfer of heat by radiation is also affected by the surface area of the body emitting or absorbing heat. Larger is the area, greater will be the transfer of heat. It is due to this reason that large numbers of slots are made in radiators to increase their surface area.

GREENHOUSE EFFECT

How dos the temperature in a greenhouse can be maintained?

Light from the Sun contains thermal radiations (infrared) of long wavelengths as well as light and ultraviolet radiations of short wavelengths. Glass and transparent polythene sheets allow radiations of short wavelength to pass through easily but not long wavelengths of thermal radiations. Thus, a greenhouse becomes a heat trap. Radiations from the Sun pass easily through glass and warms up the objects in a greenhouse. These objects and plants such as shown in figure 9.17give out radiations of much longer wavelengths. Glass and transparent polythene sheets

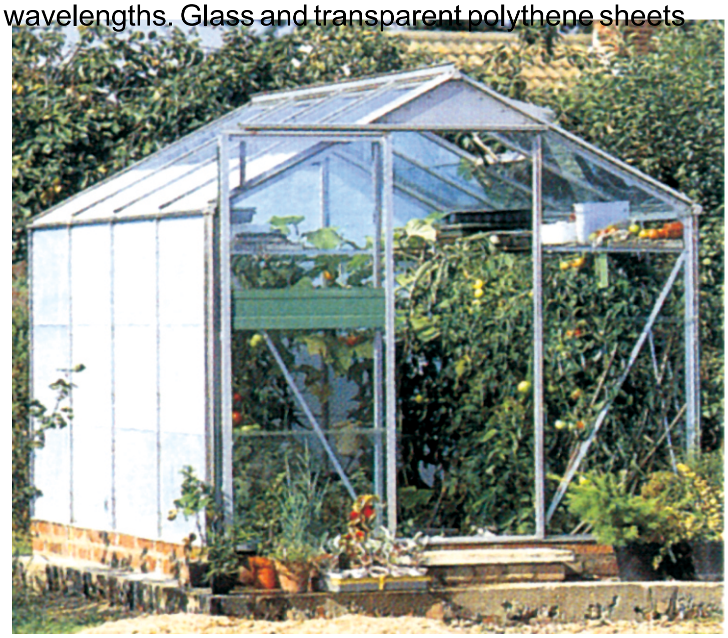


Figure 9.17: A greenhouse

do not allow them to escape out easily and are reflected back in the greenhouse. This maintains the inside temperature of the greenhouse. Greenhouse effect promises better growth of some plants.

Carbon dioxide and water also behave in a similar way to radiations as glass or polythene. Earth's atmosphere contains carbon dioxide and water vapours. It causes greenhouse effect as shown in figure 9.18 and thus maintains the temperature of the

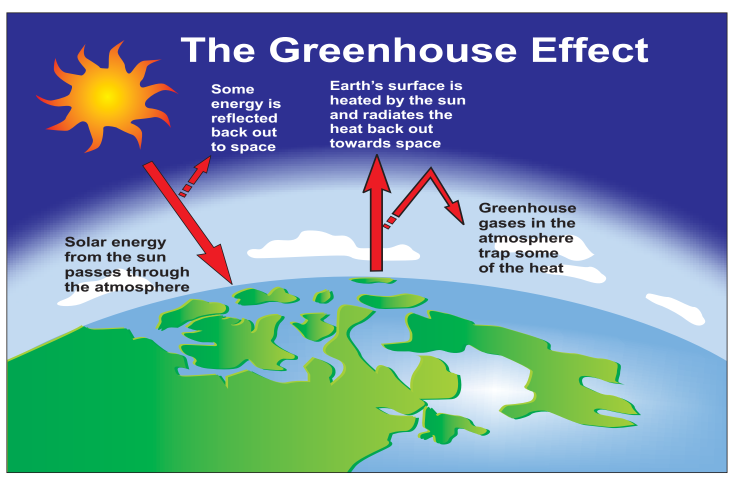


Figure 9.18: Greenhouse effect in global warming.

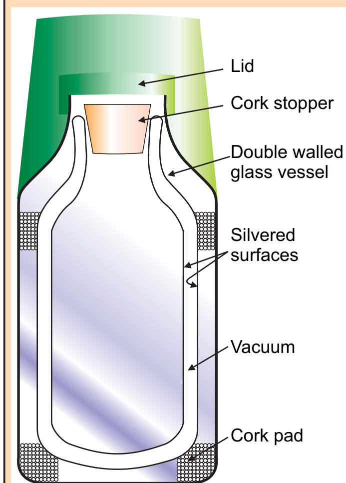
Earth. During the recent years, the percentage of carbon dioxide has been increased considerably. This has caused an increase in the average temperature of the Earth by trapping more heat due to greenhouse effect. This phenomenon is known as **global warming.** This has serious implications for the global climate.

9.5 APPLICATION AND CONSEQUENCES OF RADIATION

Different objects absorb different amounts of heat radiations falling upon them reflecting the remaining part. The amount of heat absorbed by a body depends upon the colour and nature of its surface. A black and rough surface absorbs more heat than a white or polished surface. Since good absorbers are also good radiators of heat. Thus, a black coloured body gets hot quickly absorbing heat reaching it during a sunny day and also cools down quickly by giving out its heat to its surroundings. The bottoms of cooking pots are made black to increase the absorption of heat from fire.

Like light rays, heat radiations also obey laws of reflection. The amount of heat reflected from an object depends upon its colour and nature of the surface. White surfaces reflect more than coloured or black surfaces. Similarly, polished surfaces are good reflectors than rough surfaces and reflection of heat radiations is greater from polished surfaces. Hence, we wear white or light coloured clothes in summer which reflect most of the heat radiation reaching us during the hot day. We polish the interior of the cooking and hot pots for reflecting back most of the heat radiation within them.

FOR YOUR INFORMATION



In a thermos flask, most of the heat is prevented to enter or leave the flask. This is done by suitable measures to reduce the transfer of heat due to conduction, convection and radiation. Thus, anything kept in it, maintains its temperature for a long time.

SUMMARY

- Heat flows from a body at higher temperature to a body at lower, temperature.
- There are three ways of heat transfer. These are conduction, convection and radiation.

- The mode of transfer of heat by vibrating atoms and free electrons in solids from hotter to colder part of a body is called conduction of heat.
- The amount of heat that flows in unit time is called the rate of flow of heat.
- The rate at which heat flows through solids depends on the cross-sectional area of the solid, length between hot and cold ends, temperature difference between hot and cold ends and nature of the material.
- The rate of flow of heat across the opposite faces of a metre cube maintained at a difference of 1 K is called the thermal conductivity of the material of the cube.
- Good conductors are used for quick transfer of heat. Thus cookers, cooking plate, boiler, radiators and condensers of refrigerators etc. are made of metals.
- Water is a poor conductor of heat.
- Materials which trap air are also bad conductors such as wool, felt, fur, feathers, polystyrenes and fibre glass.
- Transfer of heat by actual movement of molecules from hot place to a cold place is known as convection.
- Land and sea breezes are also the examples of convection.
- Gliders use upward movement of hot air currents due to convection of heat. Air currents help them to stay in air for a long period.
- Birds are able to fly for hours without flapping their wings due to the upward movement of air currents.
- The term radiation means the continual emission of energy from the surface of a body in the form of electromagnetic waves.
- Radiations are emitted by all bodies. The rate at which radiations are emitted depends on various factors such as colour and texture of the surface, temperature and surface area.
- A dull black surface is a good absorber of heat as its temperature rises rapidly.
- A polished surface is poor absorber of heat as its temperature rises very slowly.
- Radiations from the Sun pass easily through glass/polythene and warms up the materials inside a greenhouse. The radiations given out by them are of much longer wavelengths. Glass/polythene does not allow them to escape out and thus maintains the inside temperature of the greenhouse.
- Earth's atmosphere contains carbon dioxide and water vapours. It causes greenhouse effect and thus retains the temperature of the Earth.
- The bottoms of cooking pots are made black to increase the absorption of heat from fire.
- White surfaces reflect more heat than coloured or black surfaces. Similarly, polished surfaces are good reflectors than rough surfaces and reflection of heat radiations is

greater from polished surfaces. Therefore, We wear white or light coloured clothes in summer

- We polish the interior of the cooking pots for reflecting back most of the heat radiation inside the hot pots.
- A thermos flask consists of a double-walled glass vessel. It reduces the transfer of heat by conduction, convection and radiation.

QUESTIONS

9.1 Encircle the correct answer from the given choices:

i. In solids, heat is transferred by:
(a) radiation
(b) conduction
(c) convection
(d) absorption

ii. What happens to the thermal conductivity of a wall if its thickness is doubled?
(a) becomes double
(b) remains the same
(c) becomes half
(d) becomes one fourth

iii. Metals are good conductor of heat due to the:
(a) free electrons
(b) big size of their molecules
(c) small size of their molecules
(d) rapid vibrations of their atoms

iv. In gases, heat is mainly transferred by
(a) molecular collision
(b) conduction
(c) convection
(d) radiation

v. Convection of heat is the process of heat transfer due to the:
(a) random motion of molecules
(b) downward movement of molecules
(c) upward movement of molecules
(d) free movement of molecules

vi. False ceiling is done to
(a) lower the height of ceiling
(b) keep the roof clean
(c) cool the room
(d) insulate the ceiling

vii. Rooms are heated using gas heaters by
(a) Conduction only
(b) Convection and radiation
(c) Radiation only
(d) Convection only

viii. Land breeze blows from
(a) sea to land during night
(b) sea to land during the day
(c) land to sea during night
(d) land to sea during the day

ix. Which of the following is a good radiator of heat?

(a) a shining silvered surface
(b) a dull black surface
(c) a white surface
(d) green coloured surface

9.2 Why metals are good conductors of heat?

9.3 Explain why:

(a) a metal feels colder to touch than wood kept in a cold place?

(b) land breeze blows from land towards sea?

(c) double walled glass vessel is used in thermos flask?

(d) deserts soon get hot during the day and soon get cold after sunset?

9.4 Why conduction of heat does not take place in gases?

9.5 What measures do you suggest to conserve energy in houses?

9.6 Why transfer of heat in fluids takes place by convection?

9.7 What is meant by convection current?

9.8 Suggest a simple activity to show convection of heat in gases not given in the book.

9.9 How does heat reach us from the Sun?

9.10 How various surfaces can be compared by a Leslie cube?

9.11 What is greenhouse effect?

9.12 Explain the impact of greenhouse effect in global warming.

PROBLEMS

9.1 The concrete roof of a house of thickness 20 cm has an area 200 m^2. The temperature inside the house is 15 °C and outside is 35°C. Find the rate at which thermal energy will be conducted through the roof. The value of k for concrete is 0.65 $Wm^{-1}K^{-1}$. (13000 Js^{-1})

9.2 How much heat is lost in an hour through a glass window measuring 2.0 m by 2.5 m when inside temperature is 25 °C and that of outside is 5°C, the thickness of glass is 0.8 cm and the value of k for glass is 0.8$Wm^{-1}K^{-1}$? ($3.6x10^7$J)