

CHAPTER 4

Respiratory System

PERFORMANCE OBJECTIVES

At the end of this chapter, students should be able to:

- describe the different types of respiratory systems.
- list the characteristics of a respiratory surface.
- draw and label some of the respiratory organs of some mammals.
- explain the various mechanisms of respiration in animals, e.g., mammals.
- describe the mechanism of exchange of gases through the stomata of plants.

INTRODUCTION

Respiration is one of the characteristics of living organisms. During this process, oxygen is taken in and carbon (IV) oxide is released. The oxygen is used to release energy stored in the food taken by the organism.

Two basic types of respiration have been identified in living organisms, namely aerobic and anaerobic respiration. The respiratory system of an organism includes all the organs in its body and every living cell in each of these organs because the organs in which respiration occurs contain mitochondria, which are found in every living cell.

Respiration can be defined simply as a biochemical process in which energy is liberated from food substances (mainly simple sugars) in the mitochondria of living cells with the aid of enzymes in the absence or presence of oxygen.

The production of water, carbon (IV) oxide, alcohol or other organic substances is just incidental to the basic process. Respiration is achieved through the mouth, nose, trachea, lungs and diaphragm.

The primary function of the respiratory system is to obtain oxygen for use by the body cells and to eliminate carbon (IV) oxide. The respiratory system works in conjunction with the circulatory system and is made up of organs in our body that helps us to breathe. The human respiratory system delivers oxygen to all parts of the body. Plant respiration is limited to the process of diffusion through the stomata.

TYPES OF RESPIRATORY SYSTEM

The respiratory system consists basically of organs, tissues and other structures, which facilitate the exchange of gases in organisms. These vary with size of organism and the environment where it lives.

In animals, the structures associated with respiration include the following organs:

- (i) Body Surface (ii) Gills
- (iii) Tracheae (iv) Lungs

In plants, the stomata are the main respiratory structures for gas exchange by diffusion. Gas exchange in animals depends on their respiratory medium (whether it is air or water) and the nature of their respiratory surfaces. For aquatic animals, the respiratory medium is water, whereas for terrestrial animals, the respiratory medium is air. Amphibians and

some fishes use both air and water as their respiratory media.

The exchange of gases with the respiratory medium by animals is called breathing. The respiratory surface provides a boundary between the body and the respiratory medium. The cells in this surface are epithelial in nature (have thin wall) and have large surface area. This enhances diffusion.

BODY SURFACE RESPIRATION

This is the simplest type of respiration found mainly in unicellular organisms and some multicellular organisms such as Annelids (earthworms), platyhelminthes (flatworms), sponges, toads and frogs.

Respiration occurs by diffusion. In unicellular organisms, the small nature of the cell makes it easy. Exchange of gases takes place at the respiratory surfaces. The gases are usually dissolved in water before they can diffuse across cell membranes.

Other organisms that respire through their body surface have moist skin. Many fairly large organisms such as arthropods and vertebrates develop elaborated respiratory systems. These quicken the rate at which they exchange gases by breathing.

Breathing is a visible, mechanical, muscular action, which enables an animal to quicken the rate of gas exchange between itself and its environment.

GILLS

The gill is found in large aquatic organisms such as tadpole, aquatic snails and fishes. Gills are highly branched and vascularised, i.e., they are richly supplied with blood capillaries. Gills may be external or enclosed. External gills are found in sea slugs and amphibian larvae, whereas enclosed gills are found in water snails and crustaceans.

TRACHEAL SYSTEM

These are found in insects and other arthropods. The tracheal system ends up in tiny holes in the cuticle called spiracles. The spiracles open and close by muscular action. The tracheae branch repeatedly into fine branches called tracheoles, which are equivalent to the air sacs in the lung. The tracheoles contain fluid in which oxygen dissolves before actually getting to the individual cells of the body.

LUNG

The lung is the main respiratory organ in terrestrial vertebrates especially mammals. The lungs are closely linked with the circulatory system. Lungs are found in amphibians, birds and mammals. The mammalian respiratory system consists of the nostrils, pharynx, larynx, lungs and diaphragm.

TABLE 4.1 Gas exchange organ of some organisms

1.	Unicellular organisms, e.g., amoeba and euglena	Entire body surface
2.	Multicellular organisms (aquatic organism), e.g., sponges, hydra, flatworms and roundworms	Entire body surface
3.	Earthworm	Moist skin
4.	Insects	Tracheae
5.	Fish, e.g., tilapia	Gills
6.	Tadpoles	Gills
7.	Reptiles, birds and mammals	Lungs
8.	Flowering plants	Leaves (i.e., through stomata), lenticels in stems and root cells
9.	Toad and frog	Mouth, moist skin and lungs

A summary of structures associated with respiration in living organisms is shown in Table 4.1.

SUGGESTED PRACTICALS

ACTIVITY 1

1. (i) Teacher should provide specimens of respiratory organs as well as prepared slides showing features of these organs for organisms such as earthworm, tilapia, toad, grasshopper and rats.
2. (ii) Display the gills removed from a freshly killed tilapia for students to observe.
3. (iii) Prepare a stencil of stomata from the under surface of a leaf, using nail hardener (clear nail varnish or cutex). The stencil is then mounted on the microscope for observation by students.

CHARACTERISTICS OF RESPIRATORY SURFACES

The following characteristics have been identified in gas exchange structures or organs (respiratory surfaces).

- (i) They are epithelial in nature.
- (ii) They have very thin walls, which shorten the diffusion distance and increase diffusion rate.

- (iii) They are often moist because gases diffuse in solution through them.
- (iv) They have delicate cells.
- (v) They possess a large surface area to volume ratio, which ensures exchange of large quantities of gases at every given time.
- (vi) They are permeable, thus allowing the gases pass easily in and out of them.
- (vii) They are supplied with a well-developed transport system, e.g., blood capillaries in many animals and vascular tissues in vascular plants

MECHANISMS OF RESPIRATORY SYSTEMS

Respiration in plants and animals is through basic gas exchange facilitated by organs such as stomata, lungs, gills and skin.

In lower animals, diffusion occurs through membranes. In higher animals, the internal organs are away from the environment. In vertebrate, exchange of gases occurs by inhalation and exhalation. This is also known as breathing in and breathing out.

RESPIRATION IN HIGHER ANIMALS

Respiration in higher animals takes place through the lungs. All mammals have a pair of lungs. The lungs are adaptations that allow animals to invade the terrestrial environment. These are found in some fishes and amphibians, reptiles, birds and mammals. All lungs are located internally.

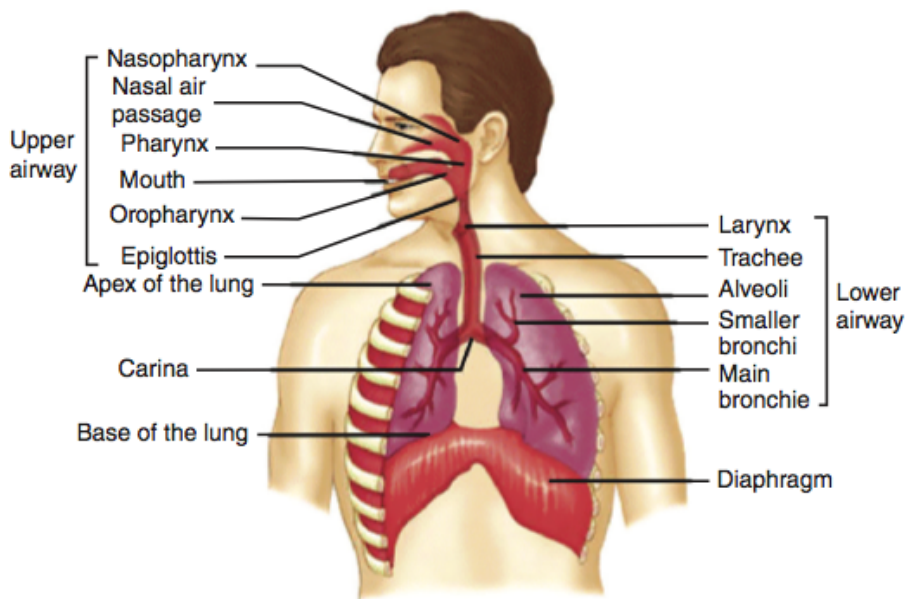
In mammals, the breathing system comprises the air passages (nostrils, pharynx, larynx and trachea), lungs and diaphragm (Figure 4.1). Air enters the nasal passages through the nostrils into the nasal cavity where it is moistened and kept warm. The nasal cavity has lining cells, which secrete mucus that traps most of the dust and microorganisms present in the air before it diffuses into the lungs.

The nasal cavity leads into the pharynx and then into the trachea (wind pipe), which divides into two bronchi (bronchus – singular) before it enters the lungs; the cartilages support the walls of the trachea and bronchus to prevent them from collapsing when the air pressure in them is reduced.

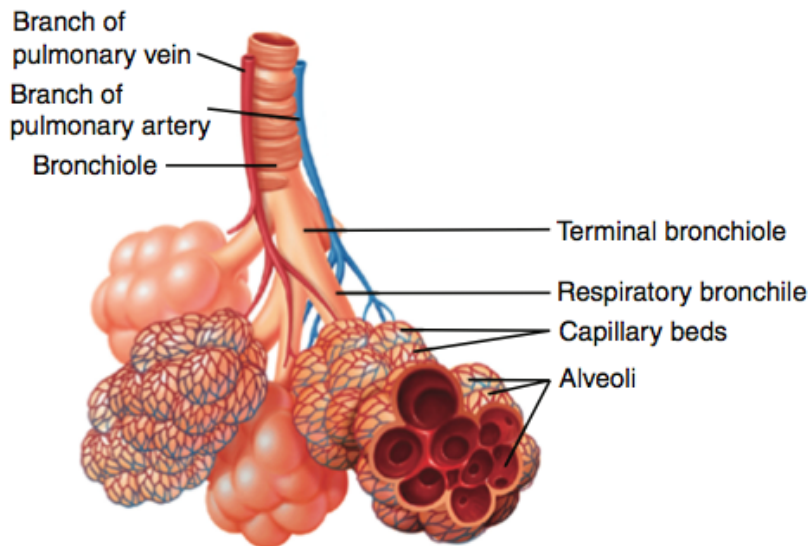
Within each lung, the bronchus divides repeatedly and becomes progressively narrower forming numerous tiny tubules called bronchioles, which end in pockets of air sacs called alveoli (alveolus – singular).

The alveoli are surrounded by a dense network of capillaries, which enhance gas exchange. The alveoli give the lungs a very large surface

area for gas exchange (Figure 4.2). The lungs are located in the thorax or thoracic cavity, which comprises the breast bone or sternum in front and the back bone (vertebrae) at the back. At the sides are twelve pairs of ribs and intercostal muscles, which are attached to the spine and the sternum, thereby forming a bony cage. The diaphragm is a sheet of muscle at the floor of the thorax.



▲ **FIGURE 4.1** Human breathing system



▲ **FIGURE 4.2** Structures of alveoli and its blood supply

MECHANISM OF BREATHING IN MAMMALS

Breathing is controlled by centres in the medulla and pons, which form part of the brain stem. Breathing occurs in two phases called inhalation (breathing in) and exhalation (breathing out). The volume of air entering and leaving the lungs during inhalation and exhalation is called the tidal volume. This is usually higher in males than in females.

The maximum tidal volume is called the vital capacity. The amount of air remaining in the lungs after each forceful exhalation is known as the residual volume of the lungs.

INHALATION

- (i) The intercostal muscles contract, while the ribs move upwards and outwards.
- (ii) The diaphragm contracts and flattens out.

(iii) The thoracic cavity volume increases, while its air pressure decreases.

(iv) Air is then forced from outside into the lungs through the air passage.

EXHALATION

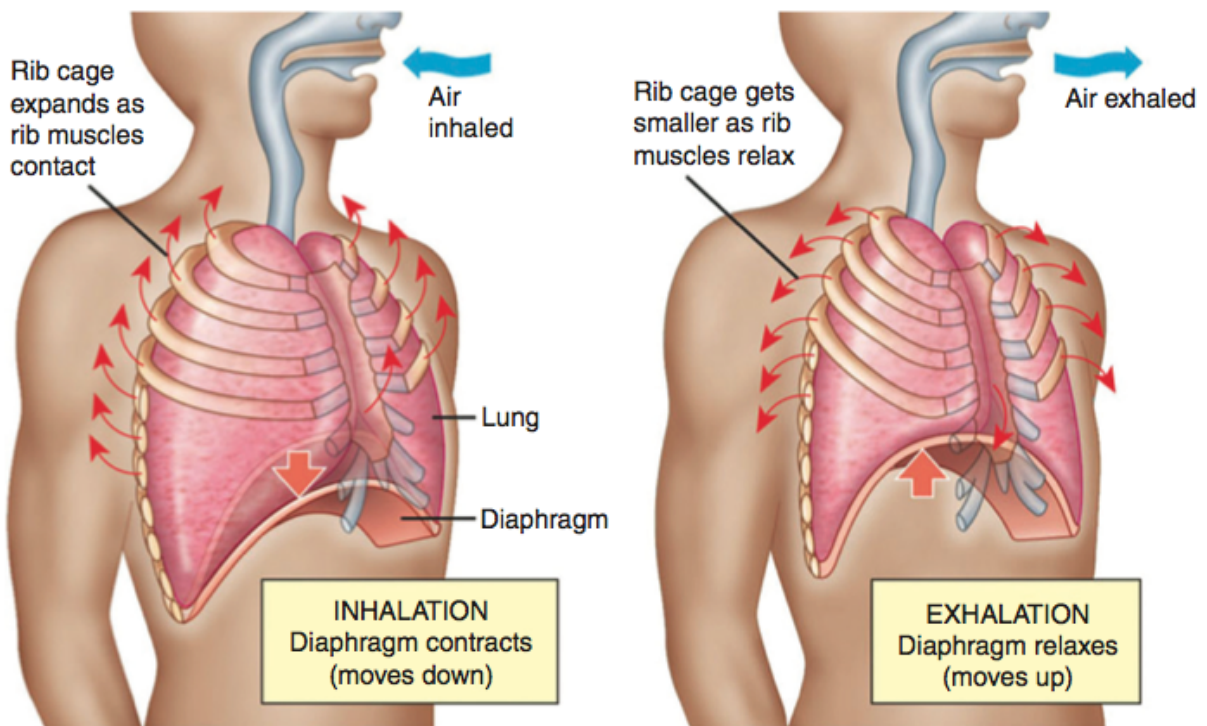
(i) The intercostal muscles relax, while the ribs cage is lowered.

(ii) The diaphragm relaxes and returns to its original dome-shaped position.

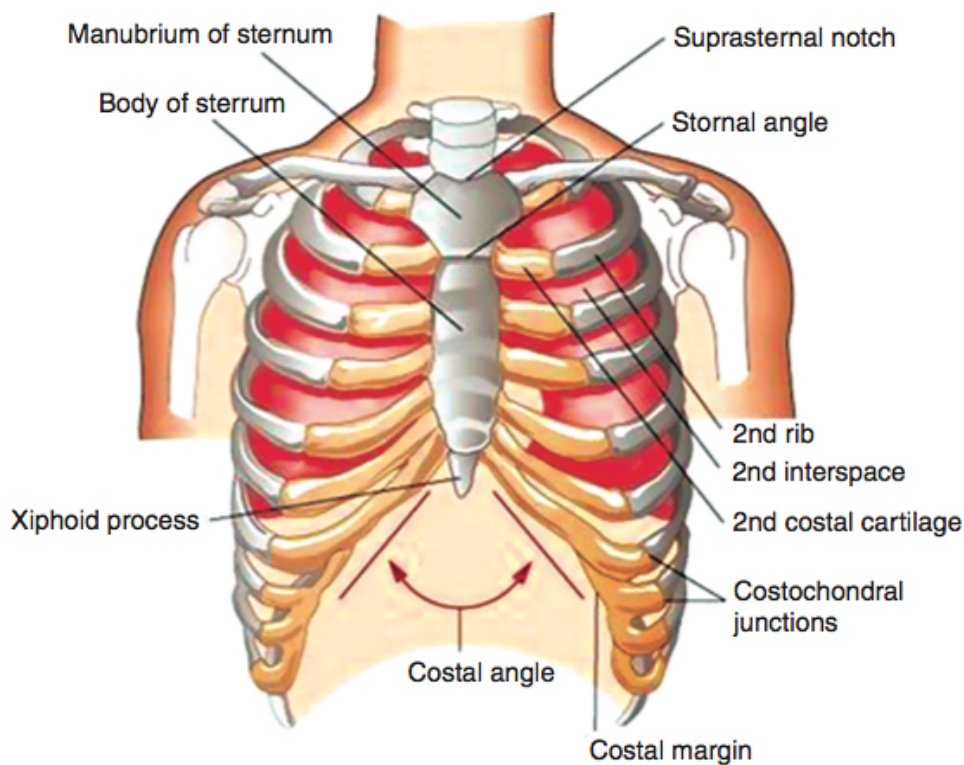
(iii) The thoracic cavity volume decreases, while the lungs shrink.

(iv) The lung air pressure increases, and a lot of air is expelled from the lungs through the air passage.

A film of moisture covers the lining of each alveolus (Figure 4.5). The oxygen concentration in the blood capillaries of the alveoli is less than that in the cavity of the alveoli. As a result, oxygen in the air spaces of the alveoli dissolves in the film of moisture and diffuses through the capillary walls into the red blood corpuscles where it readily combines with the haemoglobin. The capillaries form the pulmonary veins, which return the oxygenated blood to the left auricle of the heart. From here, it is transported round the body. The oxygen is used in the body cells for respiration, whereas carbon (IV) oxide, energy and water are produced.

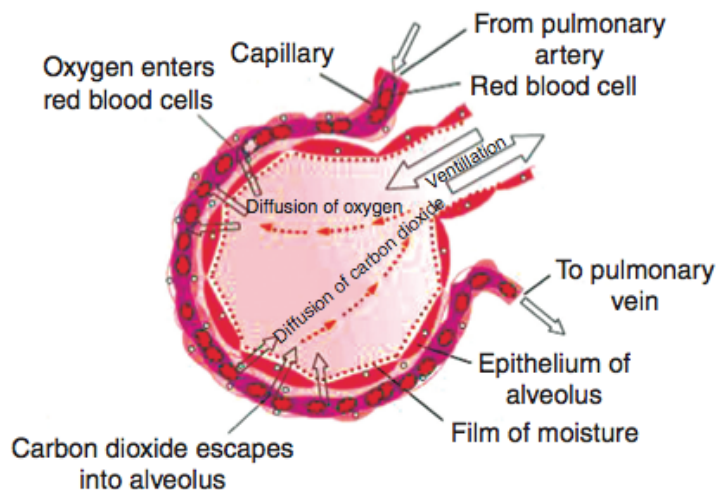


▲ **FIGURE 4.3** Movement of the ribcage during breathing



▲ **FIGURE 4.4** Human thorax showing the stages that mark the mechanism of breathing

The carbon (IV) oxide concentration of the air in the blood capillaries of the alveoli is, therefore, very high compared with that of within the alveoli. As a result, the carbon (IV) oxide in the capillaries diffuses into the cavities of the alveoli from where it is expelled during exhalation. A lot of water (in vapour form) produced in the body cells as a result of respiration is expelled with other gases including some oxygen (Table 4.2). Gas exchange occurs when the gas diffuses from an area of higher concentration to an area of lower concentration.



▲ **FIGURE 4.5** Gaseous exchange in alveolus

TABLE 4.2 Percentage of gases in inhaled and exhaled air

GAS	% INHALED	% EXHALED
Oxygen	21	16
Carbon (IV) oxide	0.04	4
Nitrogen	79	79
Water vapour	Variable	Saturated

The quantity of various gases inhaled is different from that exhaled as could be seen from the table above.

MECHANISM OF BREATHING IN FISH

Gaseous exchange takes place in fishes across the gill surfaces. All gills possess a very high surface area-to-volume ratio. More oxygen is made available to animals that breathe by gills than in animals that breathe in and out using lungs.

TO BREATHE

- (i) The fish opens its mouth, and water passes over the gill surface inside the opercula, which are then closed.
- (ii) As water flows over the gills, the dissolved oxygen in water diffuses into the thin walled blood capillaries of the gills. At the same time, carbon (IV) oxide in the blood diffuses into the water.
- (iii) The alternate opening and closing of the mouth and operculum allow a constant flow of water over the gills.
- (iv) Oxygen is transported by the blood into every living cell where it is used for aerobic respiration. Hence, the gills are used for gas exchange (breathing), and not just for respiration.

MECHANISM OF BREATHING IN AMPHIBIANS

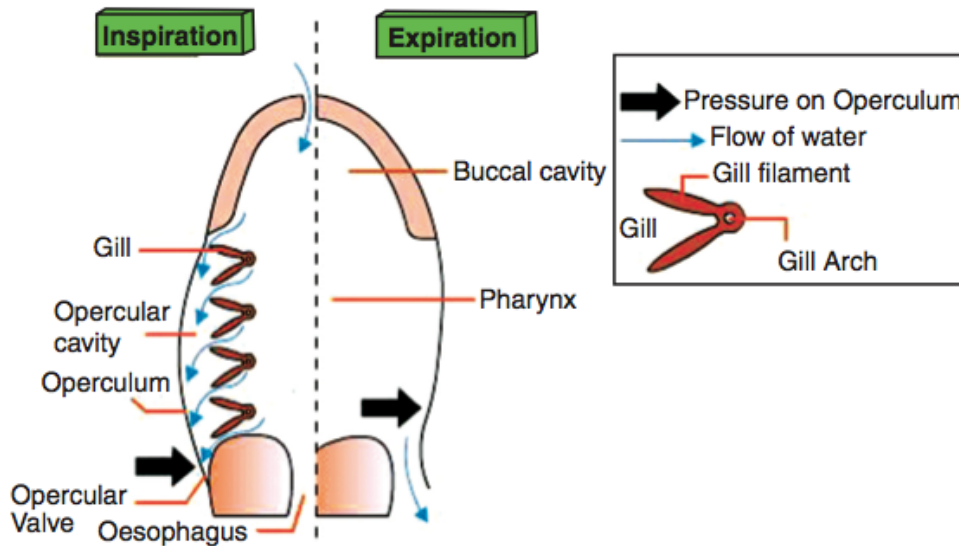
Adult amphibians (e.g., toads and frogs) breathe in three ways, namely:

- (i) Through their skin (cutaneous breathing);
- (ii) Through their mouth (buccal breathing);
- (iii) Through their lungs (pulmonary breathing).

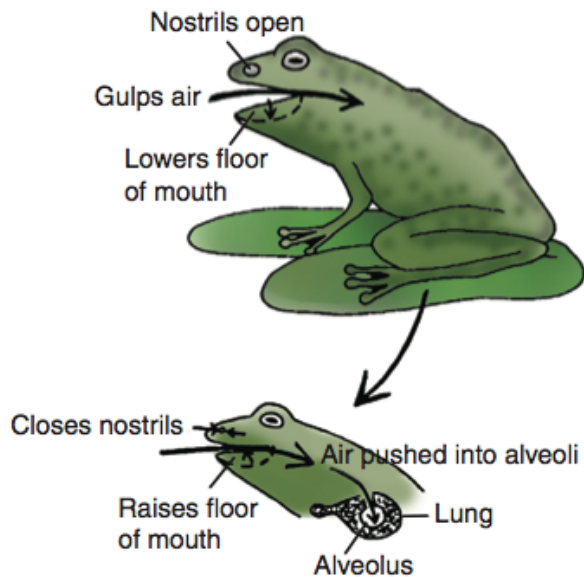
BREATHING THROUGH THE SKIN (CUTANEOUS BREATHING)

- (i) To serve as a breathing surface, the toad's skin is kept moist always so that gases could diffuse through it.
- (ii) The skin contains numerous glands, which secrete a watery slime (mucus) onto the surface.

(iii) The skin is also thin-walled and well supplied with blood vessels to quicken the rate of diffusion of gases in and out of it.



▲ FIGURE 4.6 Mechanism of breathing in fish



▲ FIGURE 4.7 Breathing parts in a Toad

BREATHING THROUGH MOUTH (BUCCAL BREATHING)

(i) To breathe with the mouth, the mouth is closed, the nostrils are opened and the buccal cavity floor is lowered by a muscular action.

(ii) The buccal cavity volume, therefore, increases; its air pressure decreases, and air is forced from outside into the buccal cavity through the nostrils.

(iii) Oxygen in the air diffuses into the lining of the buccal cavity, which is well supplied with blood capillaries, when the nostrils are closed.

(iv) In exchange, carbon (IV) oxide from the blood capillaries is given off by diffusion.

(v) The buccal cavity floor is raised; its air pressure increases, and air containing a lot of carbon (IV) oxide and water vapour is expelled through the nostrils.

BREATHING THROUGH LUNGS (PULMONARY BREATHING)

(i) The toad or frog breathes through the lungs while on land, only when it is very active and the demand for oxygen is high.

(ii) Air is drawn into the buccal cavity and the nostrils are closed.

(iii) The buccal cavity floor is raised and air is expelled through the larynx into the alveoli of the two lungs in which gas exchange occurs.

(iv) The alternate raising and lowering of the buccal cavity ensures that air is forced into and out of the lungs.

(v) Air is expelled through the nostrils when they open, whereas the contraction of the lungs also aids the sending out of air.

RESPIRATION IN LOWER ANIMALS

In the single-celled organisms and some multicellular organisms, which live in aquatic habitats, gas exchange is by simple diffusion. Oxygen diffuses into the cell, and carbon (IV) oxide diffuses out into the water, e.g., amoeba and earthworm.

The earthworm lives in damp places and uses its moist outer skin as a respiratory organ. The skin is effective as an organ for gas exchange in small animals with a high surface area to volume ratio.

BREATHING IN INSECTS

i) The insect breathes through a tracheal system. Insects have impermeable cuticle, but at intervals along the sides of the body, and have about ten tiny openings called spiracles (Figure 4.8) through which air enters and leaves the tracheae.

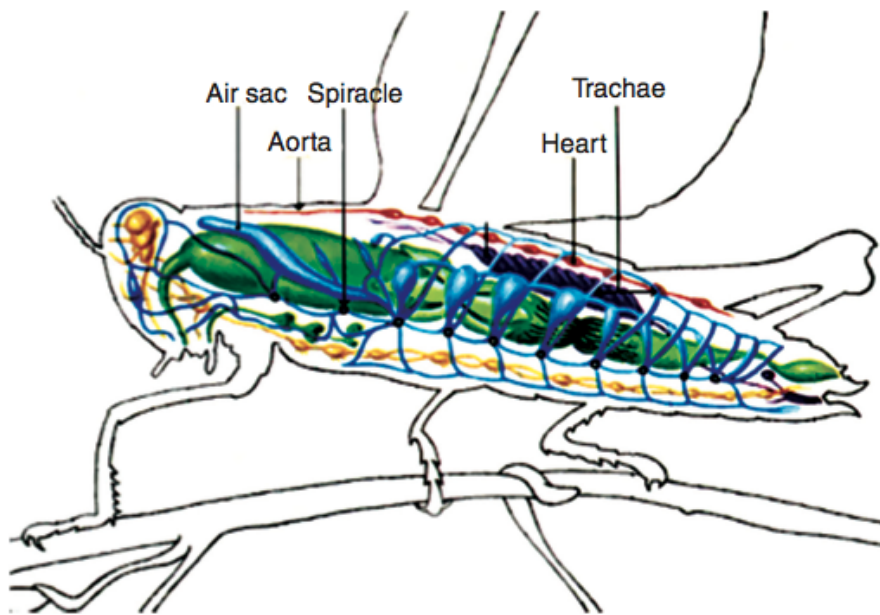
(ii) The tracheae end in tiny hair-like structures called tracheoles, which are fluid filled and also close to every cell of the body.

(iii) As the body wall of an insect contracts and expands, oxygen in the air diffuses through the spiracles into the tracheae and tracheoles. It then diffuses into the body cells where it is used for aerobic respiration.

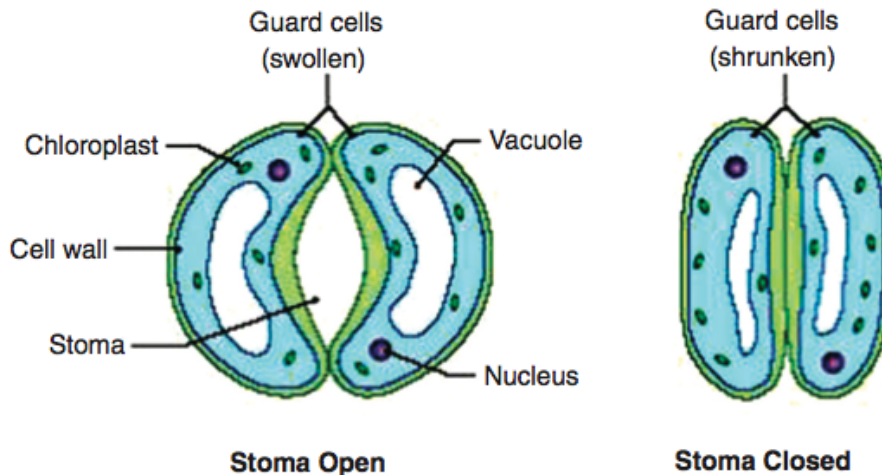
(iv) Carbon (IV) oxide and water (in vapour form) produced diffuse out of the body through the spiracles.

(v) The spiracles have valves, which are opened only when the carbon (IV) oxide concentration in the tissues is above a specific level.

(vi) The spiracles are closed for most of the time, when an insect is inactive, to reduce water loss.



▲ **FIGURE 4.8** Respiratory system of insect



▲ **FIGURE 4.9** Opening and closing of stoma

MECHANISMS OF GASEOUS EXCHANGE THROUGH THE STOMATA OF PLANTS

Gaseous exchange in plants is by stomata on the leaves and lenticels, which are found on roots and woody stems. In many annual plants, the stems are green and almost as important for photosynthesis as the leaves. These stems use stomata rather than leaves for gaseous exchange. During photosynthesis, green plants use carbon (IV) oxide and release oxygen. On the other hand, plants need oxygen for cellular respiration during which they release carbon (IV) oxide. Each part of the plant, therefore, takes care of its gaseous exchange needs, and hence, there are no specialised organs for gaseous exchange as found in animals. In other words, the plants do not have lungs, gills or tracheal systems for gaseous exchange. Completely submerged aquatic plants like algae and floating aquatic plants like water lettuce exchange gases by diffusion all over their body surface or through the stomata in their leaves.

Terrestrial plants exchange gases mainly through the stomata in their leaves, lenticels in their stems and through the roots (from the air spaces in the soil particles around the roots). Stomata are tiny pores found on the

lower surface of the epidermis of most leaves. They also occur in the stems of young herbaceous plants. A stoma (singular) is a tiny pore or opening enclosed by two bean-shaped guard cells. Unlike other epidermal cells, guard cells have chloroplasts. Each guard cell has a thick, relatively inelastic wall around the pore and a thin, elastic outer wall (Figure 4.9). Stomata have been observed to open during the day and close at night. Therefore, light intensity is seen as a major factor controlling stomatal movement (opening and closing of the stomata).

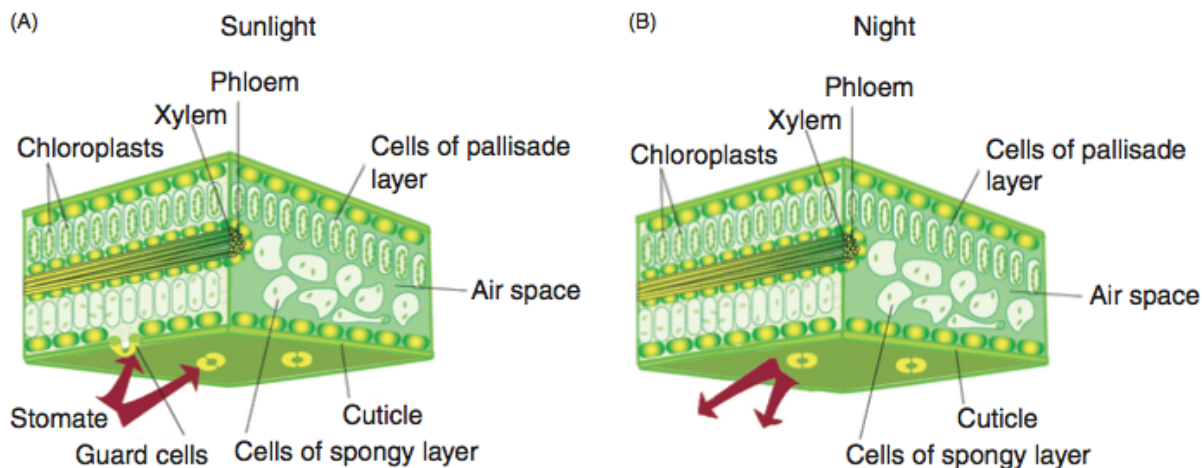
Other factors associated with stomatal movement are water balance of plants and concentration of carbon (IV) oxide in the surrounding air.

Wilting plants close their stomata: low concentration of carbon (IV) oxide causes stomata to open, whereas high concentration of carbon (IV) oxide causes the stomata to close. The osmotic pressure within the guard cells also plays a role in the opening and closing of the stomata. When the osmotic pressure is high, the guard cells become turgid as a result of which the stomatal pore opens. When the pressure is low, the guard cells become flaccid and the pore is closed. In general, the movement of gases and water vapour in and out of the leaves is controlled by the opening and closing of the stomata.

EFFECT OF LIGHT ON GASEOUS EXCHANGE IN THE LEAF

In all living cells, respiration occurs all the time. In sunlight, the rate of photosynthesis is usually greater than that of respiration in green plants. Part of the oxygen produced during photosynthesis is used in respiration but the excess diffuses out of the leaf. Likewise, the carbon (IV) oxide produced in respiratory cells is used in photosynthesis, whereas a lot of carbon (IV) oxide diffuses into the leaf mesophyll cells from outside. The diffusion distances from the inside of the leaf to the outside are short. Hence, gaseous molecules diffuse rapidly in and out of the leaf through the stomata (Figure 4.10A).

At night, photosynthesis stops, whereas respiration continues; some oxygen diffuses into the leaf from outside through the stomata and lenticels. The oxygen is used up in the respiring cells, whereas the carbon (IV) oxide produced diffuses out of the leaf and lenticels (Figure 4.10B).



▲ FIGURE 4.10 Gas exchange in a leaf

SUGGESTED PRACTICALS

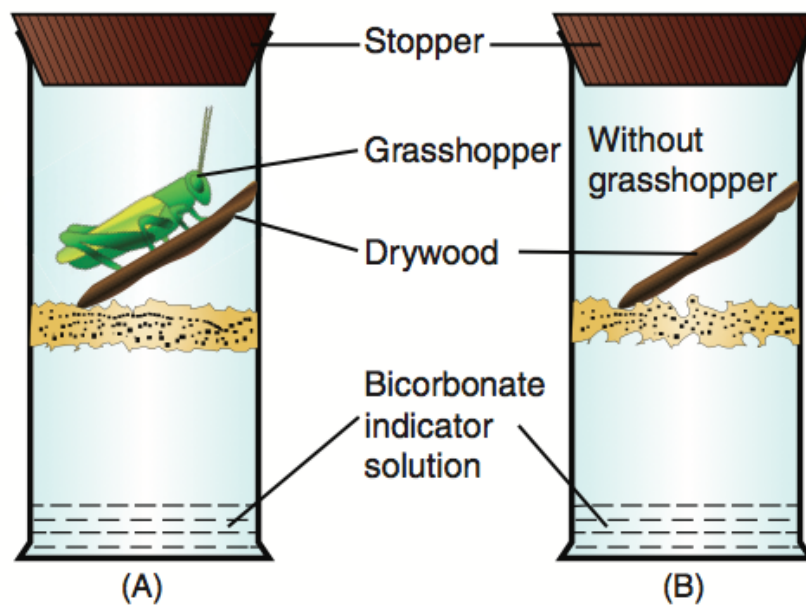
Teacher should obtain the lungs of a mammal (either sheep or goat) from butcher or dissect a rabbit and display the lungs for observation by the students.

- (i) Students should feel the lungs by pressing on the lungs with their fingers.
- (ii) Students should look at the trachea and note how it is attached to the lungs.
- (iii) Students should squeeze the trachea with their finger and explain how it feels.

BREATHING IN INSECTS

- (i) Put a grasshopper in a sealed tube with lime water or bicarbonate indicator solution (Figure 4.11A)
- (ii) Get another sealed tube with limewater in which a dry wood is put without a grasshopper (Figure 4.11B)
- (iii) Observe what happens to the lime water or bicarbonate indicator solution in each tube.

How would you explain the difference observed?



BREATHING IN HUMANS

- (i) (a) Breathe out into a test tube containing lime water.
- (b) Record and explain what you observed.
- (ii) (a) Breathe out on a piece of clean glass or mirror.
- (b) Record and explain your observation.

CHAPTER SUMMARY

â- Respiration is a biochemical process in which energy is released from the food substances in the mitochondria of living cells with the aid of enzymes in the absence or presence of oxygen.

â- The respiratory system of an organism consists of all its living cells and every organ in

its body.

â- The mechanical taking in of air and the sending out of air by muscular contraction in many animals is called breathing.

â- Most living things exchange gases by taking in air from their surroundings and sending out air from their respiratory systems into their surroundings.

â- Flowering plants use their leaves and lenticels as gas exchange organs. Gills, lungs and trachea are gas exchange organs of fishes and tadpoles, vertebrates and insects, respectively.

â- Gas exchange or breathing occurs by simple diffusion in most organisms. But for efficient gas exchange, all gas exchange organs are thin walled, moist, permeable, have large surface area and well supplied with transport system.

â- In adult amphibians (toads and frogs), breathing occurs by three ways: through the

â- In mammals, breathing occurs in two stages: inhalation and exhalation.

â- During inhalation, the intercostal muscles contract; the ribs move upwards and outwards; the diaphragm contracts and flattens out; the thoracic cavity volume increases while its pressure decreases; and air is forced into the lungs from outside through the air passages.

â- During exhalation, the intercostal muscles relax; the rib cage is lowered; the diaphragm relaxes and becomes dome shaped; the thoracic cavity volume decreases while the lungs shrink; the lung air pressure increases, and air is expelled from the lungs through the air passages.

â- The guard cells of the stomata control their opening and closing. Hence, they control the movement of gases and water vapour in and out of leaves.

â- In the sunlight, carbon (IV) oxide diffuses into the leaf through the stomata and is used for photosynthesis in green plants. The carbon (IV) oxide released by the respiring cells are also used up.

â- Part of the oxygen produced during photosynthesis is used in respiration, whereas the excess diffuses out of the leaf through the stomata.

â- At night, oxygen diffuses into the leaf through the stomata (and lenticels) in the stems. The carbon (IV) oxide released from the respiring cells diffuses out through the stomata.

REVISION QUESTIONS

OBJECTIVE QUESTIONS

Choose the correct options to the following questions.

1. Which of the following terms has the same meaning as breathing?

a. Respiratory organs b. Respiratory surface c. Gas exchange d. Pulmonary respiration

2. Which of the following is not a feature of a gas exchange organ?

a. Semi-permeable b. Permeable c. Thin walled d. Richly supplied with a transport system

3. The gas exchange organ of an insect is the

a. spiracle. b. lung. c. lung book. d. tracheal system.

4. Which of the following statements about inhalation in mammals is false?

- a. The intercostals muscles contract.
- b. The ribs move up and outwards.
- c. The diaphragm contracts and flattens out.
- d. The thoracic cavity volume decreases

5. Which of these statements about a stoma is false?

- a. It is found only on the lower epidermis of leaves.
- b. It consists of two bean-shaped guard cells
- c. Each guard cell has inelastic inner walls and elastic outer walls.
- d. There are chloroplasts in the guard cells

ESSAY QUESTIONS

1. What do you understand by the following terms:

(a) respiration (b) respiratory system (c) breathing (d) gas exchange

2. (a) What are the characteristics of a gas exchange organ?

(b) Name the gas exchange organs of the following organisms

- 1. an insect
- 2. a bird
- 3. a lizard
- 4. a mosquito larva a tadpole
- 5. a cow

3. With the aid of well-labeled diagrams, explain how the following organisms breathe or exchange gases: (a) fish and (b) toad.

1.)With the aid of well-labeled diagrams, explain how a named mammal breathes.

2. Explain the process of respiration in plants.