UNIT 7 RESPIRATORY SYSTEM

Structure

7.1 INTRODUCTION

Every living cell in a living organism consumes oxygen. Oxidation of substances within the cells results in the liberation of heat and energy and in the production of carbon dioxide. Carbon dioxide, the end product of respiratory metabolism is continuously removed from the body. The exchange of oxygen and carbon dioxide between an organism and its environment is known as respiration.

In vertebrates blood serves to transport oxygen and carbon dioxide. Haemoglobin, the respiratory pigment present in the blood of all vertebrates binds to oxygen and transports it from the respiratory structures to the cells and tissues. In vertebrates, haemoglobin is confined to the red blood corpuscles (RBC) or erythrocytes. RBCs and blood plasma play important role in the transport of the carbon dioxide. The process by which oxygen is obtained from the environment by the respiratory structures and its subsequent transport to the cells and tissues can be referred to as **external respiration**. The utilization of oxygen for oxidation of nutrients in cells and tissues may be termed as **internal respiration**. Internal respiration has been treated extensively in LSE-01 (Cell Biology) and LSE-05 (Physiology) courses. In this unit you will study respiratory structures that facilitate external respiration.

Objectives

After reading this unit you should be able to :

- describe the various water and air breathing respiratory structures of vertebrates,
- explain the mechanisms involved in the exchange of gases,
- describe accessory respiratory organs for air breathing in fishes and buccal respiration in frog,
- describe the functions of pharynx, trachea, bronchi and alveoli.

7.2 RESPIRATORY SYSTEM OF AQUATIC VERTEBRATES

External respiration is facilitated by the respiratory organs, the gills or lungs and in some cases the skin. For the respiratory organs to function efficiently they must have :

1. a large surface area provided with ample capillary network that has an access to the environment.

2. a thin and moist membrance surface that facilitates passage of gases.
3. a provision for renewing the supply of oxygen-containing medium, namely, air or water that comes in contact with respiratory surface and for removing carbon dioxide that is released from the surface.

With a few exceptions organs of respiration in vertebrates are formed in association with pharynx. However, a certain fish, the loach has developed a peculiar habit of swallowing air, passing the air bubble through the intestine, voiding it at the anus. Oxygen is absorbed en route by blood vessels in the richly vascular intestine.

In water breathing animals gills are the main respiratory organs. Gills are composed of numerous gill filaments or gill lamellae, which are thin walled extensions of epithelial surface. Each gill contains a vascular network. Blood is brought extremely close to the surface, thus facilitating ready exchange of gases.

Gills are of two types : (i) external gills and (ii) internal gills.

External gills (Fig.7.1) develop from the integument covering the outer surfaces of visceral arches. They are usually branched; filamentous structures derived from ecotoderm. Internal gills (Fig.7.2) are composed of a series of parallel gill lamellae although in some forms they may be filamentous. They may be borne on both sides of the interbranchial septa but in some cases are present on one side alone. A series of lamellae on one side of an interbranchial septum is termed a half-gill or **hemibranch**. Two hemibranchs are jointed with interbranchial septum to form a complete gill or **holobranch**. It is generally assumed that internal gills are derived from endoderm, although the exact origin is not clear. In some animals both external and internal gills are present.

The functioning of external gills poses no problem since the filaments are in direct contact with water containing dissolved oxygen. When internal gills are used in respiration, water containing dissolved oxygen enters through the mouth and passes through the internal gill slits into the gill clefts. As the water passes over the gill lamellae, oxygen is taken from the water and carbon dioxide is released. The water then passes through the external gills slits to the outside.

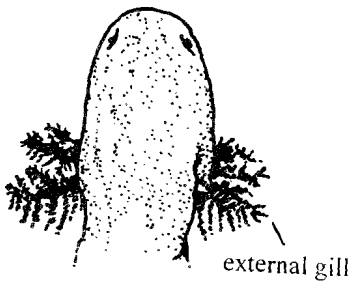

Fig.7.1: External gills of a salamander larva.

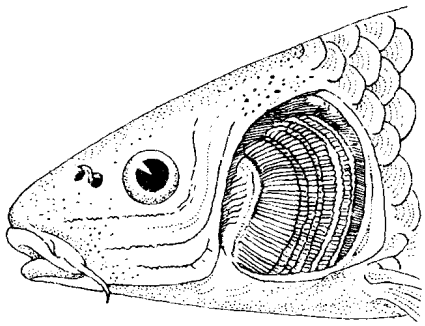

Fig. 7.2 : Operculum of a bony fish removed to show internal gills.

SAQ 1

Indicate whether the following statements are true or false :

1. External respiration would mean utilisation of oxygen for oxidation of nutrients in cells and tissues. T/F
2. One of the criteria for efficient functioning of the respiratory organs is that the respiratory surface should be thin and moist to facilitate exchange of gases. T/F
3. Internal gills develop from the integument covering the outer surface of visceral arches. T/F
4. Holobranch refers to a series of lamellae on one side of an interbranchial septum. T/F

Among hagfishes in *Myxine* six pairs of internal gills slits and gill pouches are present. However, only a single pair of external openings exists. A series of long tubes coming from the gill pouches unite to form a common duct on each side that opens to the exterior (Fig.7.5).

The external aperture is located near the midventral line at some distance from the anterior end. This may be of advantage to the animal when it is feeding, or boring its way into the body of a fish in order to devour the soft internal organs. In myxines, an oesophageo-cutaneous duct connects the oesophagus with the common duct on the left side. It lies posterior to the last gill pouch on that side and is similar to a gill cleft but lacks gills. In hagfish of the genus *Bdellostoma* the number of gill clefts varies from 6-7 upto 13-14 pairs. The gills clefts connect internally with pharynx and not with a blind pouch of the type found in the lamprey; and externally they open separately.

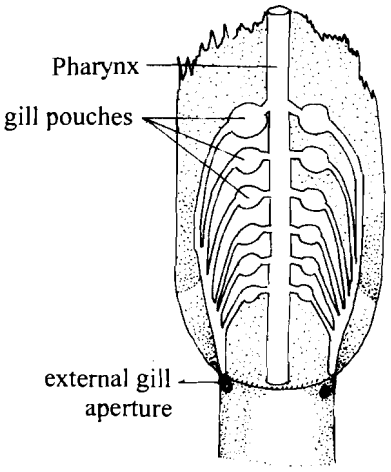

Fig. 7.5 : Diagram showing the relation of gill pouches of the hagfish to the pharynx and to the single pair of gill apertures.

7.2.3 Respiration in Fishes

A series of skeletogenous visceral arches encircles the pharynx of fishes and of tetrapods. In fishes these arches primarily support the gills. They are located between the gill clefts, one behind the other at the bases of the interbranchial septa. The first arch is called mandibular arch; and the second, hyoid arch. The remaining visceral arches are referred to by numbers (3,4,5,6, etc.). The first gill pouch or cleft lies between mandibular and hyoid arches and is often referred to as the hyomandibular cleft. In fishes it is either modified to form a spiracle or is closed altogether. The arrangement of gill arches and gills in elasmobranchs and bony fishes is shown in Fig. 7.6.

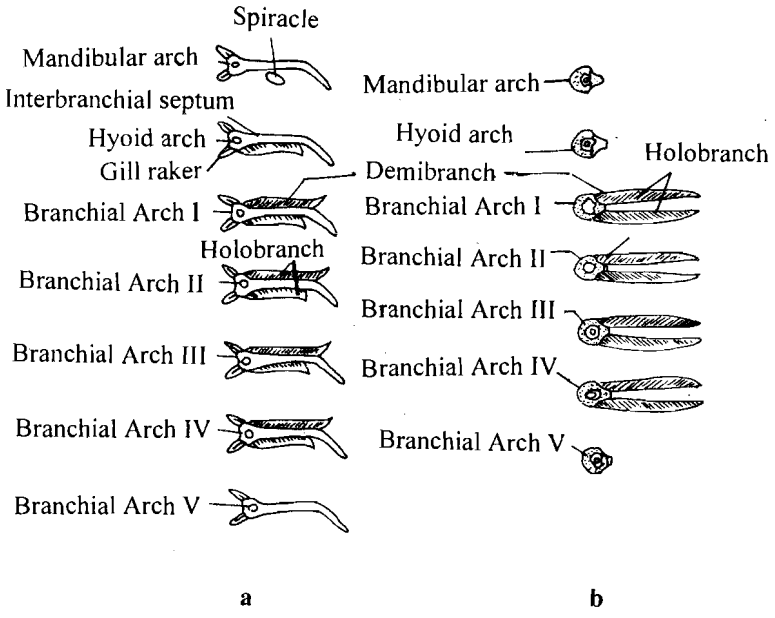

Fig. 7.6 : Arrangement of gill arches and gills in (a) an elasmorbranch and (b) a teleost.

Gills develop in close association with paired lateral pouches of pharynx, extend towards the surface of the body and open to the exterior. Each gill pouch thus has an internal branchial aperture that opens into pharynx and an external branchial aperture that opens to the outside. The relationship between the pharynx and branchial chamber is shown in Fig.7.7. The successive gill pouches are separated by interbranchial septa. Branchial filaments containing blood vessels line gill pouches. The water passing through the gill chamber bathes the vascularised filaments facilitating respiratory exchange of gases.

elongation of the hyoid arch, protects the gills in the branchial chamber which thus opens to the outside through a single gill aperture. In fishes having an operculum, a branchiostegal membrane supported by bony branchiostegal rays usually extends for the inner surface of the operculum to the body wall. Raising the opercula and closing the branchiostegal folds bring about gill respiration in these fishes. As the water passes over the gills emerging through the opercular slit oxygen is taken up and carbon dioxide is liberated. Respiration in fishes thus involves a series of muscular contractions in the wall of pharynx and mouth, bringing about a flow of water. The act of inspiration causes water to enter the mouth and pharynx, and expiration results in its expulsion.

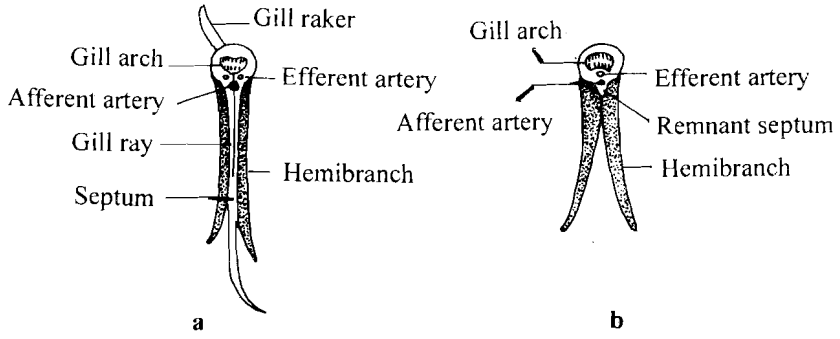

Fig. 7.9 : Types of gill in fishes (a) elasmobranch (b) teleost.

In most elasmobranchs and in a few other fishes (*Acipenser*, *Polydon*, *Polypterus*), the first gill pouch has become modified and opens to the outside by means of a spiracle. Rudimentary gill lamellae may be located on the anterior wall of the spiracle. Since blood supply to these lamellae consists of oxygenated blood, they do not perform a respiratory function and the term false gill or **pseudobranch** is applied to them. The spiracles generally open on the top of the head and in some species they are provided with valves.

In most bony fishes, a true hemibranch, receiving non-oxygenated blood is lacking on the posterior side of the hyoid arch. Instead a modified opercular gill or a pseudobranch, receiving oxygenated blood may be present. Opercular gills of this type are found in *Amia*, the Dipnoi and many teleosts. The lamellae of pseudobranch are shown to contain many receptors and ionocytes (chloride secreting cells). The receptors respond to changes in blood including partial pressures of oxygen and carbon dioxide, pH and osmotic pressure. The organ, thus, is comparable to the carotid body of mammals. Most elasmobranchs have five pairs of clefts in addition to the spiracles. One form, *Hexanchus*, has six and another *Heptanchus* has seven clefts. *Heptanchus* also has the largest number of gill clefts of any gnathostome, Chimaeras have four pairs of clefts but the spiracle is absent and the last cleft is closed. *Polypterus*, *Acipenser* and *Polydon* like most elasmobranchs have five pairs of clefts. Dipnoi which lack spiracles, also show variation in the number of clefts. *Neoceratodus* and *Protopterus* have five pairs of clefts, but *Lepidosiren* have only four.

The presence of external gills is rare among fishes. In *Polypterus* a single pair of external integumentary gills is present in the region of the hyoid arch. Larval Dipnoi possess four pairs of external cutaneous gills located on the visceral arches. Most fishes die soon after being exposed to air, even though their gills are kept moist. Lack of water in the branchial chambers as well as the accumulation of mucus causes the gills to stick to each other. With the result the exposed respiratory surface is decreased and the exchange of gases is no longer adequate. Fresh-water fishes face the problem of their environment getting dried up and to overcome this problem, in addition to gills, they have evolved accessory organs for breathing air. In the following subsection you will briefly learn about the accessory respiratory structures of certain fresh water fishes.

SAQ 2

Fill in the blanks with suitable words.

1. _____ is the major respiratory organ of *Amphioxus*.
2. The number of pairs of gill pouches present in lampreys is _____ and in myxines is _____

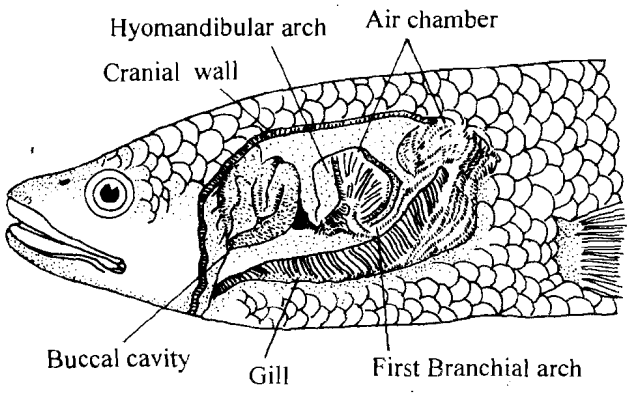

Fig. 7.11 : The accessory respiratory organ of *Ophiocephalus*.

In *Clarias*, the catfish, the highly branched and vascularised paired accessory respiratory organs are the outgrowths of the gill cavity. The arboriform or dendriform organs (Fig.7.12) as they are called, are more specifically derived from the upper parts of the second and fourth branchial arches.

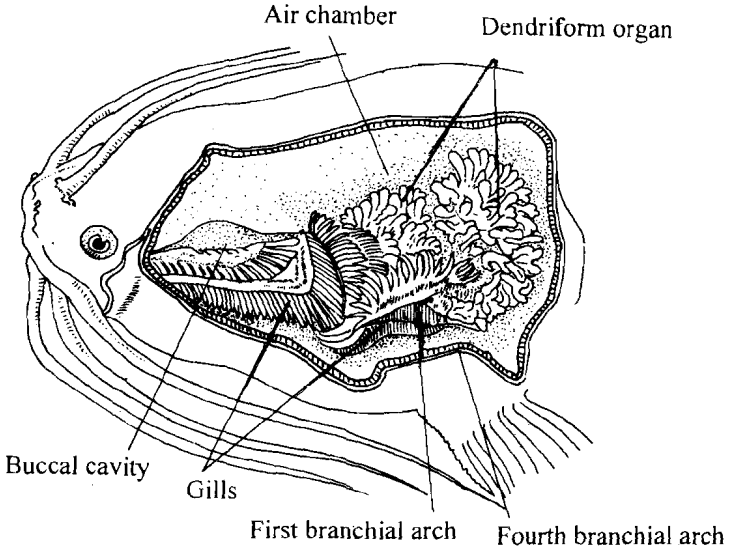

Fig. 7.12 : The arboriform accessory respiratory organ of *Clarias*.

In *Amphinous* the air chambers (Fig.7.13) arise as saccular outgrowths of dorsal wall of the pharynx extending as far as the third branchial arch. The walls of the sacs are folded and vascular. The sacs communicate with pharynx by an opening through which air is drawn in. The air exits through the gill slits and opercular opening. The gill filaments of the first gill arches are highly reduced.

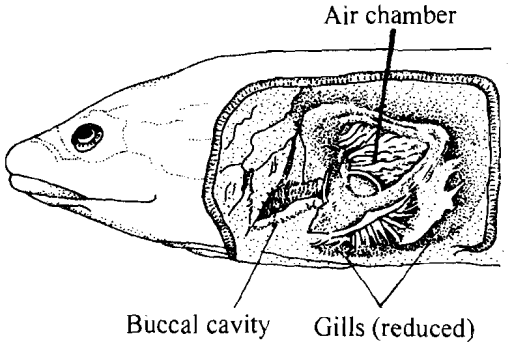

Fig. 7.13 : The air chamber in *Amphipnous*.

In *Saccobranchus* there is a pair of tubular sacs that arise as outgrowths of gill chambers extending upto the middle of the tail region (Fig.7.14). The folds in these tubes form a sort of air chamber that communicates with the buccal cavity by a slit.

The first and the last are not perforated and only 2, 3, 4 actually connect to the outside. In certain urodeles all the gill slits persist throughout adult life. In *Siren* (7.15a) all the three clefts remain functional. *Necturus* (7.15b), *Typhlomolge* and *Proteus* possess only two pairs of clefts. In *Amphiuma* only one pair persists. In hellbender, *Cryptobranchus alleganiensis*, when the external gills disappear, the edges of the operculum fuse to the throat except on the dorsal side, leaving an opening on either side.

Structures analogous to gills may develop in reptiles, birds and mammals. In reptiles five pairs of pharyngeal pouches are formed during embryonic life and in birds and mammals only four develop. In the latter groups a fifth one may also develop, but it remains rudimentary and attached to the fourth pair. The pouches do not break through to the outside, but very occasionally, they may do so. If the pharyngeal pouches fail to become obliterated in the normal manner, they may lead to the formation of branchial cysts and fistulae.

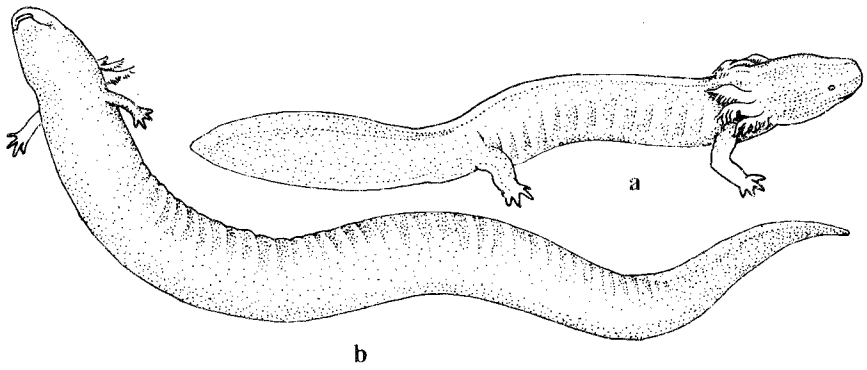

Fig. 7.15 : a. *Siren* and b. *Necturus* with external gills.

In the latter condition, there is an opening in the neck region, which communicates with pharynx. In such cases perforated gill clefts have failed to disappear. In fact, gills do not develop in association with the pharyngeal pouches of reptiles, birds and mammals. Some transitory structures that appear for a short time during development as outgrowths of gill pouches in chick embryos and the embryos of certain turtles may possibly be homologous gills. It is certain that they have no respiratory function.

SAQ 4

Choose the correct answer from the alternatives provided.

1. Most larval amphibians have external gills/internal gills of integumentary type.
2. The internal gills appear appear/disappear at the time of metamorphosis.
3. In a few taillesss amphibians/urodeles, gills persist throughout adult life.
4. In *Proteus* only two/three gills clefts remain functional.
5. Gills develop/do not develop in association with the pharyngeal pouches of reptiles, birds and mammals.

7.3 RESPIRATORY SYSTEM IN TERRESTRIAL VERTEBRATES

In air breathing animals the main respiratory organ is lung. Embryologically, the diverticulum that grows out ventrally from the floor of the pharynx posterior to the last gill pouch develops into lungs. The diverticulum divides into two halves, the lung buds, which are destined to give rise to the bronchi, and the lungs proper. The lung buds grow posteriorly, invested by an envelope of mesoderm, until they reach their final destination in the body. They may branch to varying degrees, depending upon the species. The original unpaired duct, which connects the lungs to the pharynx, serves to carry air back and forth and is known, in most cases, as windpipe or trachea. In most salientian amphibians the duct is so short as to be practically nonexistent. The trachea at its lower end divides into two bronchi which lead directly to the lungs.

like cricoid, a pair of small arytenoids and a pair of small prearytenoids. This chamber corresponds to the larynx and the trachea of the human body; but the two regions are short and are not differentiated in frog. The laryngo-tracheal chamber opens in front into the buccal cavity through glottis. The buccal cavity itself communicates to the exterior by the mouth as well as the external nostrils. The air passes in and out of the buccal cavity via the external nostrils.

There are two processes involved in pulmonary respiration. One, the drawing in of the air into lungs – the inspiration and two, the forcing out of air from lungs – the expiration. Inspiration occurs in two stages (Fig.7.18). In the first stage, the external nostrils are kept open and the mouth is tightly kept closed. The lowering of the floor of the buccal cavity causes an increase in buccal space. This in turn leads to the rushing of air from outside into buccal space through external nostrils. The buccal cavity thus functions as a suction pump. Essentially in the first stage the air is drawn into the buccal cavity from outside. In the second stage, the valvular external nostrils as well as the mouth are kept closed. The floor of the buccal cavity is raised. The air in the buccal cavity is under pressure; but the pressure is insufficient to open the mouth or the pharynx. The air enters the laryngo-tracheal chamber through the glottis. The elastic wall of the lungs causes the dilation of lungs allowing the entry of air. Exchange of gases takes place in the alveoli of the lungs. During expiration, the elastic wall of the lungs recoil expelling the air contained in them. The air arrives at the buccal cavity and from there moves outside through the external nostrils.

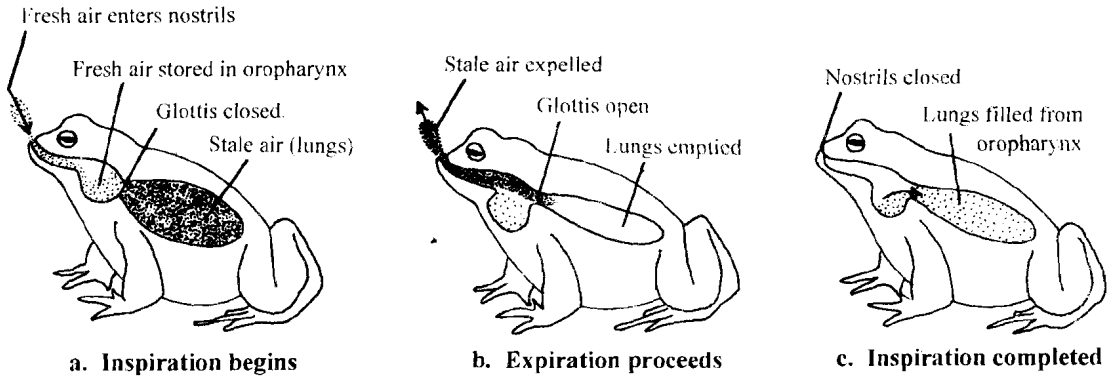

Fig. 7.18 : Stages in inspiration of frog (a) first stage (c) second stage (b) expiration.

7.3.2 Respiration in Reptiles

In *Sphenodon* and snakes lungs remain as simple sacs. The posterior third of the lining of the snake lung is septate and is filled with stored air. In higher lizards, crocodilians and turtles, the septa are so constructed that there are numerous large chambers, each with a multitude of individual subchambers (Fig.7.19). The trachea bifurcates to form two bronchi, and from each bronchus arise numerous bronchioles, which lead to the air chambers. Lungs are spongy because of the numerous pockets of the trapped air. Volume of lungs is relatively larger than in mammals but the surface area is sometimes 100 times smaller in proportion to body weight. The purpose of the large volume is to provide a reservoir of air, useful in diving species for holding breath when startled and so remaining still. In aquatic forms lungs are often provided with smooth avascularised air sacs. They are useful for maintaining buoyancy.

The left lung in limbless lizards and in snakes is rudimentary or absent altogether except in occasional forms such as black snakes. In puffing adder an enormous diverticulum of the left lung extends into the neck region. Inflation of the diverticulum causes the neck to spread characteristically, and inflation of the lungs causes the body to swell. In the spotted king snake, the lung and its bronchus extend fully two-thirds the length of the body.

The oxygen requirement of reptiles is relatively low. Their standard metabolic rate is only 10 to 20 percent of that in homeotherms. Most reptiles are therefore incapable of sustained activity. Their movements are in short bursts during which their muscles

invade most parts of the body; (ii) the anastomosing of the air ducts within the lungs so that no passage terminates blindly within the lungs and (iii) the isolation of lungs in pleural cavities. The air sacs are blind thin walled, distensible diverticula of the lungs that invade most parts of the body (Fig.7.20).

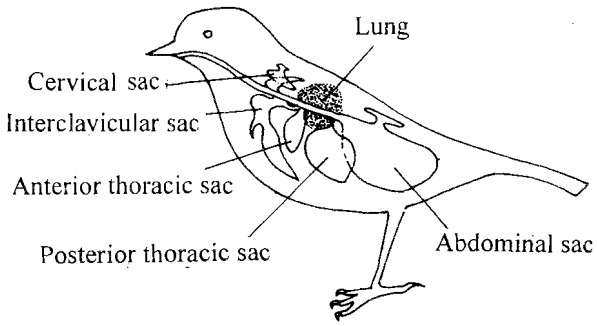

Fig. 7.20 : The lungs and air sacs of a bird. The main bronchus runs through the lung and has connections to air sacs and lung.

The glottis leads into the larynx, the walls of which are supported by paired arytenoid and cricoid cartilage. The larynx is followed by a long trachea, which is supported by complete rings formed of ossified cartilage. The trachea divides into two bronchi, which by a peculiar system of branching gives rise to lungs and air sacs. The primary bronchus of each side enters the medioventral side of the lung and is dilated into a vesicle. From there it continues as mesobronchus into the distal end of the lung (Fig. 7.21). The mesobronchus gives rise to secondary bronchi that are variously termed as ectobronchus, endobronchus, laterobronchus and dorsibronchus depending on their position. The secondary bronchi further branch and give rise to tertiary bronchi or parabronchi which divide and subdivide into a system of bronchioles. The bronchioles form a system of air capillaries that are surrounded by blood capilaries. These are the sites at which the exchange of gases takes place. The tertiary bronchi are connected with one another and are responsible for the circulation of pure air in the lungs. Structures known as 'recurrent bronchi', which arise as outgrowths of air sacs, connect the lungs with the air sacs.

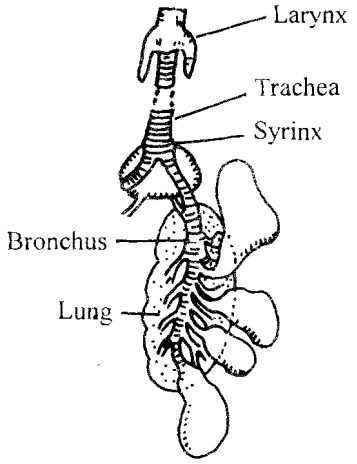

Fig. 7.21 : The respiratory system of a bird.

Lungs are small spongy inelastic organs. The thin walled air sacs are divided into two sets of chambers, the posterior inspiratory chambers and the anterior expiratory chambers. The abdominal and posterior thoracic air sacs constitute the posterior chambers and they are filled with air rushing into them through primary bronchus. The anterior thoracic, median interclavicular and cervical air sacs constitute the anterior set of air sacs. These air sacs continue as spaces in the bones. During inspiration some of the air passes directly to the posterior sacs. Another part passes into secondary and tertiary bronchi and into the air sacs indirectly. During expiration the air again passes through the tertiaries and secondaries and then into anterior sacs and trachea (Fig. 7.22). The posterior sacs contain 4% CO_2 and 17% O_2 and in the anterior sacs it is 7 and 14% respectively. The blood vessels are so arranged that the air richest in oxygen meets the blood just before it leaves the lungs. Thus a system of cross currents allows the blood to become fully oxygenated (Fig.7.23).

The lungs of birds are capable of little expansion, as they are attached to the ribs and thoracic vertebrae. The raising of the sternum when the animal is at rest, and lowering of the backbone when the animal is in flight diminishes the size of the body cavity, leading to the forcing of the air outside (expiration). Thus expiration is an active process in birds. Inspiration is a process, brought about by the rebounding of the muscles to their original size, causing an increase in the size of the body cavity.

7.3.2 Respiration in Mammals

Mammals have a pair of lungs enclosed in a thoracic cavity. The bony framework of the thoracic cavity is formed of thoracic vertebrae, ribs and sternum. The lungs of the mammals are multichambered and usually divided into lobes. Usually the right side has more lobes than the left side. Man has three right and two left lobes (Fig.7.24). Rabbits have three lobes on each side, but the right posterior lobe is subdivided. Cats have three left lobes and four right ones, and several are subdivided. The lungs of whales, sea cows, elephants, and perissodactyls lack lobes. In monotremes and rats only the right lung is lobed.

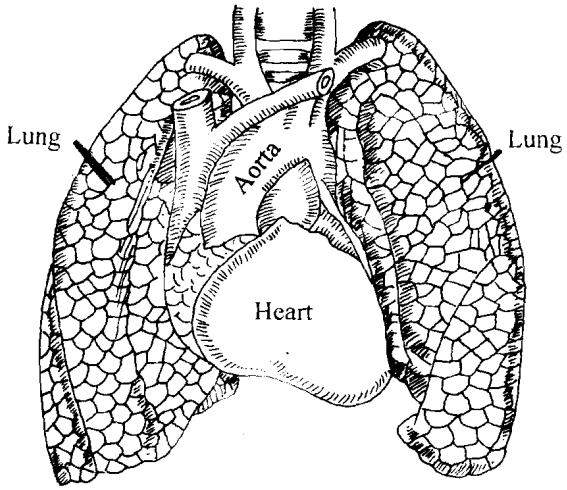

Fig.7.24 : The human lungs.

The air from outside passes through the external nostrils and nasal passages into pharynx. From the pharynx it passes through the glottis into trachea. The trachea is a long tube that traverses the neck and lies ventral to gullet. The anterior part of the terachea is enlarged to from the voice box or larynx. The larynx has its walls supported by four cartilagenous plates. The thyroid cartilage supports the ventral and lateral walls of cartilage; the lower part of the trachea is supported by the ring-like cricoid; and a pair of arytenoids supports the dorsal part. The vocal cords are located inside the larynx and the vibrations of the vocal cords results in the production of the sound. The trachea bifurcates into two primary bronchi. Each primary bronchus enters into lungs and branches into secondary and tertiary bronchi, and finally into bronchioles. Terminal bronchioles lead into thin walled delicate alveolar ducts, the walls of which are evaginated to form clusters of alveoli.

Each lung is enclosed in pleural cavity formed by two thin layers of walls. There is an outer parietal layer lining the cavity of the thorax and an inner visceral layer forming an investment to the lung. The parietal layer is reflected ventrally and is continuous with the visceral layer. The reflected layer of the parietal layer is continuous with pericardium (Fig. 7.25a and b). The cavity of thorax is thus divided into pleural cavities that enclose lungs and the pericardial cavity that contains heart. The space between the two lungs is the mediastinum.

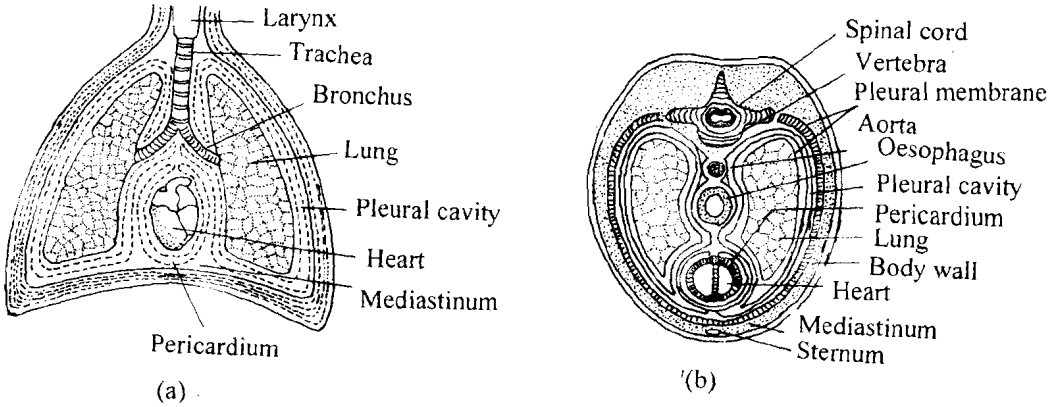

Fig. 7.25 : (a) The respiratory organs of a rabbit, (b) Transverse section through thorax.

Many tetrapods are voiceless in a true sense. This is particularly true of salamanders and apodans among the amphibians and of the great majority of reptiles, although certain of these forms can make hissing or roaring noises by a violent expulsion of air through the glottis. In frogs, toads, a few lizards and notably mammals larynx is a vocal organ. Voice production is accomplished through the presence of a pair of vocal cords, ridges containing an elastic tissue, which are stretched across the larynx. The two cords can be set in vibration by the passage of a current of expired air between them.

In birds larynx is present, but lacks vocal cords, and voice production takes place in a special organ called the syrinx. This is strucutre somewhat comparable to the larynx, but situated farther down the air passage typically at the point on which the trachea divides into the two major bronchi.

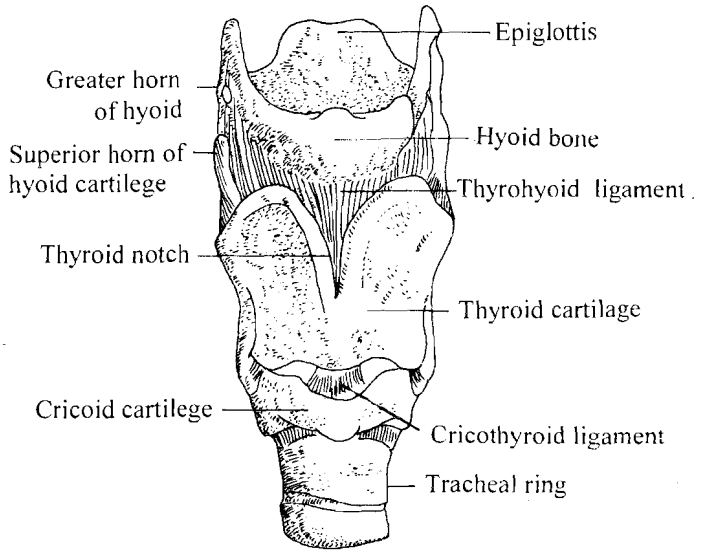

Fig. 7.26 : Human larynx-frontal view.

7.4.2 Syrinx

At the bronchial bifurcation is a small or large syrinx, a special voice box found only in birds (Fig. 7.27). There are three types of syrinx : bronchotracheal, tracheal, and broncheal. In the bronchotracheal type of syrinx the last several tracheal rings support the walls of an expanded resonating chamber (tympanus), into which project membranous folds of the lining of the syrinx. A bony structure bearing a semilunar membrance may be present within the chamber. When air is expelled from the lungs and the striated syringeal muscles are contracted, the membranes become taut and bird calls and songs are produced. The bronchotracheal syrinx may be median or asymmetrical.

The other two types of syringes are simpler. In the tracheal syrinx the lateral portions of the last several tracheal rings are absent and the resulting membranous wall vibrates and thereby produces the sound. In the broncheal syrinx, the membrane between two broncheal cartilages becomes folded into the lumen of the bronchus. When the cartilages are drawn together vibrations of the simple vocal cord produces sound.

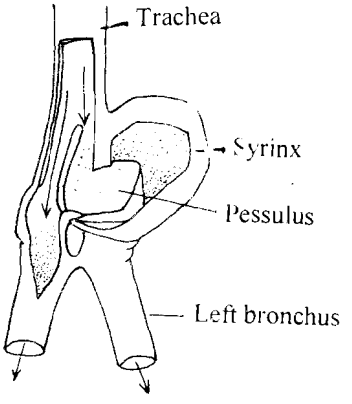

Fig. 7.27 : The voice box of a bird.

SAQ 6

Fill in the blanks with suitable words.

i) Larynx is an enlarged _____ at the beginning of trachea and it was is supported by _____.

ii) Among amphibians _____ and are _____voiceless.

iii) In birds larynx is present but lacks_____.

iv) Syrinx is situated at the _____ _____ and is found only in _____.

v) Vibration of _____ _____ produces sound.

- In vertebrates the main voice producing apparatus are the larynx and syrinx. Larynx is present in most amphibians, reptiles and mammals but the syrinx is present only in birds.

7.5 TERMINAL QUESTIONS

1) Define external and internal respiration.

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2) Describe the structure of the respiratory system of cartilagenous fishes and state how does it differ from that of bony fishes.

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3) Briefly discuss the mechanism of pulmonary respiration in frog.

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4) How is the respiratory system of birds modified to meet their high oxygen requirement ?

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7.6 ANSWERS

Self Assessment Questions

1. 1. F; 2. T; 3. F; 4. F.
2. 1. skin; 2. Seven, six; 3. passive, active 4. Seven, one; 5. mandibular, hyoid, 6. Counter current;