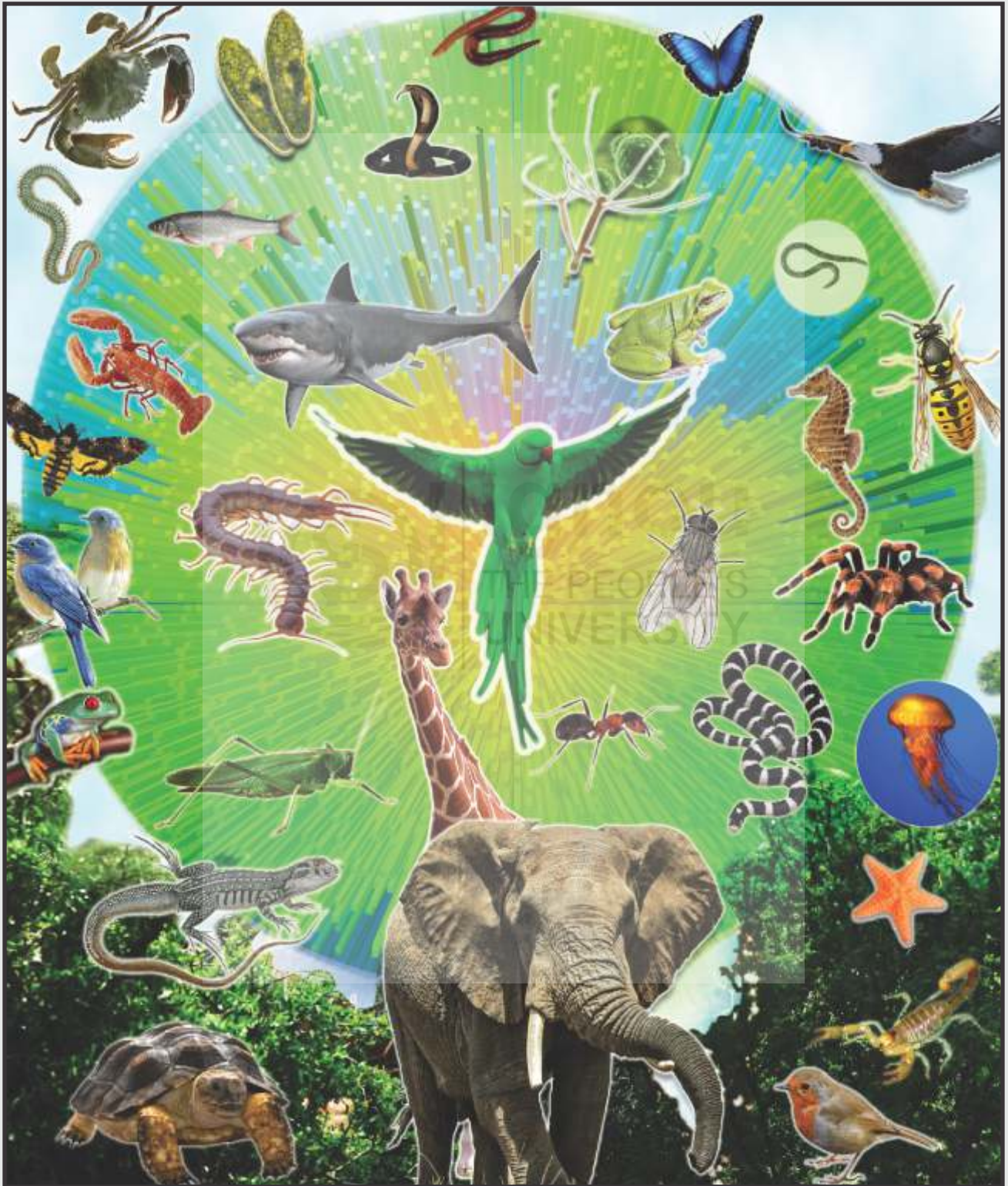




“शिक्षा मानव को बन्धनों से मुक्त करती है और आज के युग में तो यह लोकतंत्र की भावना का आधार भी है। जन्म तथा अन्य कारणों से उत्पन्न जाति एवं वर्गगत विषमताओं को दूर करते हुए मनुष्य को इन सबसे ऊपर उठाती है।”

— इन्दिरा गांधी



“Education is a liberating force, and in our age it is also a democratising force, cutting across the barriers of caste and class, smoothing out inequalities imposed by birth and other circumstances.”

— Indira Gandhi

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BLOCK 3 : ANAMNIOTES

The living chordates show enormous structural and functional diversity and are adapted to varied environments and modes of life. Yet they all share certain characteristic features that are the result of their common ancestry and these have undergone progressive modifications during evolution. In this block we have four units that present an overview of the classification of chordates, which is also a method of understanding their evolution.

Unit 11 **Protochordates** explores the relationship between the living chordates and other animal groups. We have described the primitive chordate groups that are possible ancestors of vertebrates and have listed important features that are necessary to identify the chordate. You will learn that all chordates possess, atleast during the embryonic stages a flexible notochord, a dorsal nerve cord, paired gill slits and pharyngeal pouches; and most are markedly cephalised i.e., the major sense organs tend to concentrate in the anterior part of the body. In this unit we also discuss the various hypotheses relating to the origin of vertebrates as no clear fossils have been found to link them to an invertebrate ancestral type.

Unit 12 **Agnatha** discusses the salient characters and classification of the anamniote groups of vertebrates – the jawless fishes. You will learn that jawless fishes are ancestral to fishes and can be regarded as the earliest vertebrates. Jawless fish differ from other vertebrates mainly in the absence of jaws. The major differences between Agnatha and other fish are absence of jaws and of true paired fins. They also lack internal ossification and scales.

Unit 13 **Pisces** deals with the chordate group that have a cartilaginous or bony endoskeleton, the anterior portion of which forms a cranium housing the brain and a vertebral column through which the nerve cord passes. Fishes are exclusively aquatic and have mastered the aquatic environment. A great variety of forms exist in fishes and because of the numerous structural adaptations they have evolved, fishes occupy a variety of niches in the aquatic environment including the ocean's abyssal depths.

Unit 14 **Amphibia** describes about how amphibians were the first group of vertebrates to leave the water for a life on land – a major evolutionary step, though they still spend a part of their life in water. This process led to a series of changes in the vertebrate body plan to suit a terrestrial existence. Amphibians on the other hand, have switched over to land, but have not completely forgotten their ancestral home. The transition in habitat from water to land was a slow evolutionary process that spanned over a million years. The process led to a series of alterations in vertebrate body plan that fitted these organisms to life on land.

Objectives

After studying this block you, should be able to:

- list the characteristic features possessed by all chordate groups;
- identify the characters that separate the vertebrates from the primitive protochordates;
- list the salient features and affinities of Agnatha;
- describe the characters of cartilaginous and bony fishes and distinguish between them;

- group the cartilaginous and bony fishes into specific subclasses;
- discuss the causes and mode of transition of amphibians from water to land;
- list the characters of Amphibia in general as well as the characters of its three orders; and
- discuss adaptations of fishes and amphibians to their respective habitat.



UNIT 11

PROTOCHORDATES

Structure

11.1	Introduction	11.5	Classification of Phylum Chordata
	Objectives		Subphylum Urochordata (Tunicata)
11.2	Phylogenetic Position and Classification of Chordates		Subphylum Cephalochordata
11.3	Five Chordate Hallmarks		Subphylum Vertebrata (Craniata)
11.4	Ancestry and Evolution	11.6	Summary
		11.7	Terminal Questions
		11.8	Answers

11.1 INTRODUCTION

Chordates occupy a greater variety of habitats and show more complicated mechanisms of self-maintenance than any other group in the whole animal kingdom. Chordates, and the arthropods and the pulmonate molluscs have fully solved the problem of life on the land which they now dominate.

Through all their variety of structure, the chordates show a considerable uniformity of general plan, and there can be no doubt that they have all evolved from a common ancestor of what might be called a 'fish-like' habit. In the very earliest stages only the larva was fish-like, and the life-history probably also included a sessile adult stage, such as the tunicates still show today.

This bottom-living phase was then eliminated by paedomorphosis, the larvae becoming the adults. Therefore the essential organisation of a chordate is that of a long-bodied, free-swimming creature. All the other types can be derived from such an ancestor, though in some cases only by what is often called degeneration. In the present unit we will study about evolution of chordates, their characteristics and classification.

Objectives

After studying this unit, you should be able to:

- ❖ explain general features of protochordates i.e. urochordates and cephalochordates;
- ❖ describe phylogeny of protochordates;

- ❖ discuss origin of chordates; and
- ❖ explain classification of chordates.

11.2 PHYLOGENETIC POSITION AND CLASSIFICATION OF CHORDATES

The structural plan of chordates shares features of many nonchordate invertebrates, such as bilateral symmetry, anteroposterior axis, coelom, tube-within-a-tube arrangement, metamerism, and cephalisation. However, the exact phylogenetic position of chordates within the animal kingdom is unclear. Two possible lines of descent have been proposed. Earlier speculations focused on the arthropod-annelid-mollusc group (Protostomia branch). But they are not being favoured now. Only members of the echinoderm-hemichordate assemblage (Deuterostomia branch) deserve serious concern as the chordate sister group. Chordates share with other deuterostomes several important characteristics viz: radial cleavage, an anus derived from the first embryonic opening (blastopore), a mouth derived from an opening of secondary origin, and a coelom formed by fusion of enterocoelus pouches (although in most vertebrates coelom formation is schizocoelus, but independently derived from that of protostomes, as an accommodation for their large yolks).

Phylum Chordata shows a more fundamental unity of organs and organ systems than do other phyla. Ecologically, chordates are among the most adaptable of organic forms and are able to occupy most kinds of habitats. They illustrate perhaps better than any other animal group the basic evolutionary processes of origin of new structures, adaptive strategies, and adaptive diversification.

Traditional and Cladistic Classification of Chordates

Traditional Linnaean classification of chordates provides a convenient way to indicate the taxa included in each major group. But, in cladistic usage, some of the traditional taxa, such as Agnatha and Reptilia, are no longer recognised. Such taxa do not satisfy the requirement of cladistics that only **monophyletic** groups, (those groups that contain all known descendants of a single common ancestor), are taxonomically valid. The reptiles, for example, are considered **paraphyletic**, because this group does not contain all of the descendants of their most recent common ancestor. The common ancestor of reptiles as traditionally recognised is also an ancestor of birds. As shown in the cladogram (Fig. 11.1), reptiles, birds, and mammals compose a monophyletic group called Amniota, (so named because all develop from an egg having an extraembryonic membrane called an amnion). Therefore according to cladistics, “reptiles” can be used only as a term of convenience to refer to amniotes that are not birds or mammals; there are no derived characters that unite “reptiles” to the exclusion of birds and mammals.

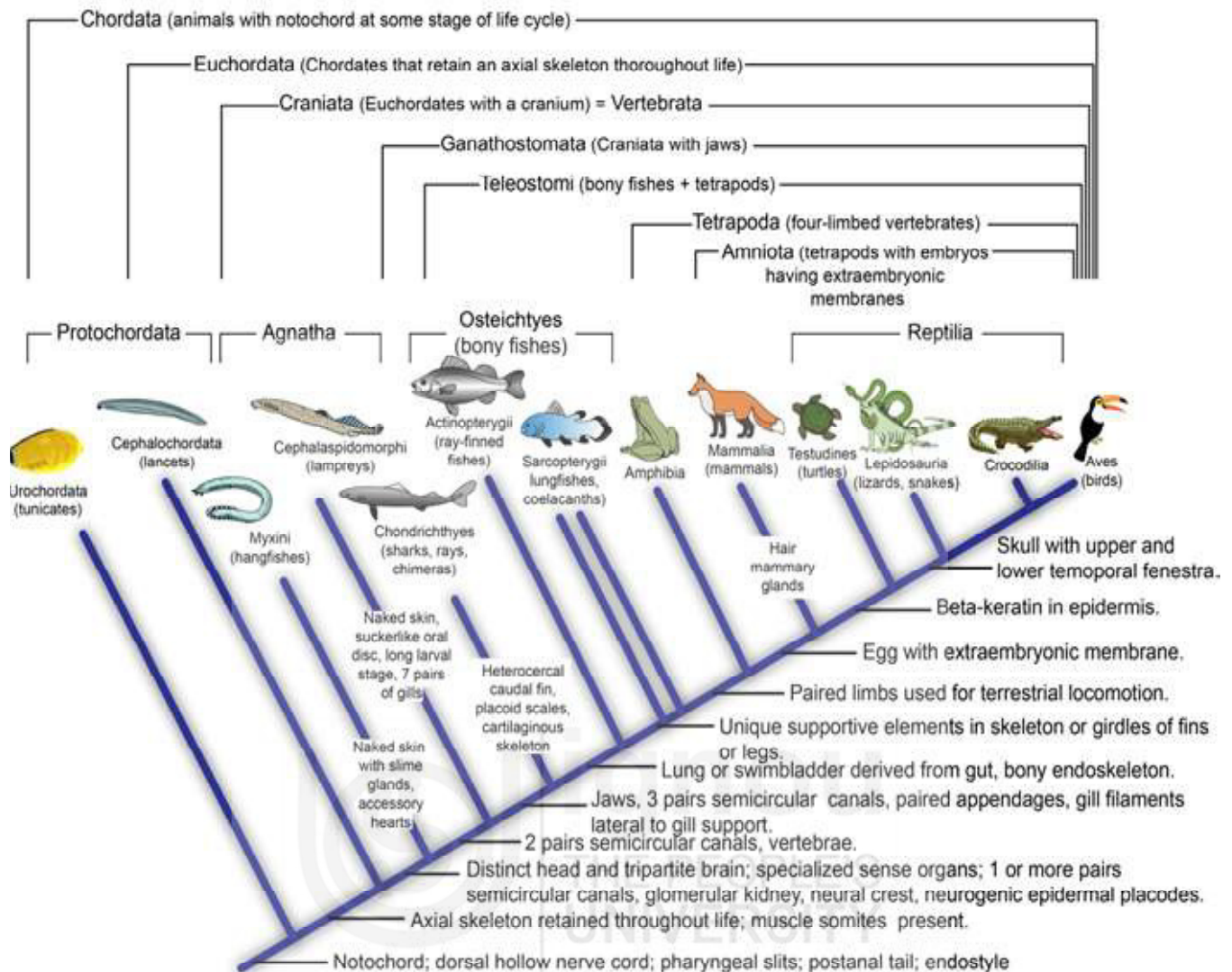


Fig. 11.1: Cladogram of Phylum Chordata showing probable relationships of monophyletic groups composing the phylum. Each branch in the cladogram represents a monophyletic group. Some derived character states that identify branching are shown to the right of the branch points. Nesting brackets across the top of the cladogram identify monophyletic groupings within the phylum. The term Craniata, although commonly equated with Vertebrata, is preferred by many authorities because it recognises that some jawless vertebrates have a cranium but no vertebrae. The lower set of brackets identify the traditional groupings Protochordata, Agnatha, Osteichthyes, and Reptilia. These groups are paraphyletic and not recognised in cladistic treatments, but are shown because of their widespread use.

The cladogram of chordates (Fig. 11.2) shows a nested hierarchy of taxa that are grouped by their shared derived characters. Their characters may be morphological, physiological, embryological, behavioural, chromosomal, or molecular. In contrast, the branches of a phylogenetic tree are intended to represent real lineages that occurred in the evolutionary past. Geological information regarding ages of lineages is added to information from the cladogram to generate a phylogenetic tree for the same taxa.

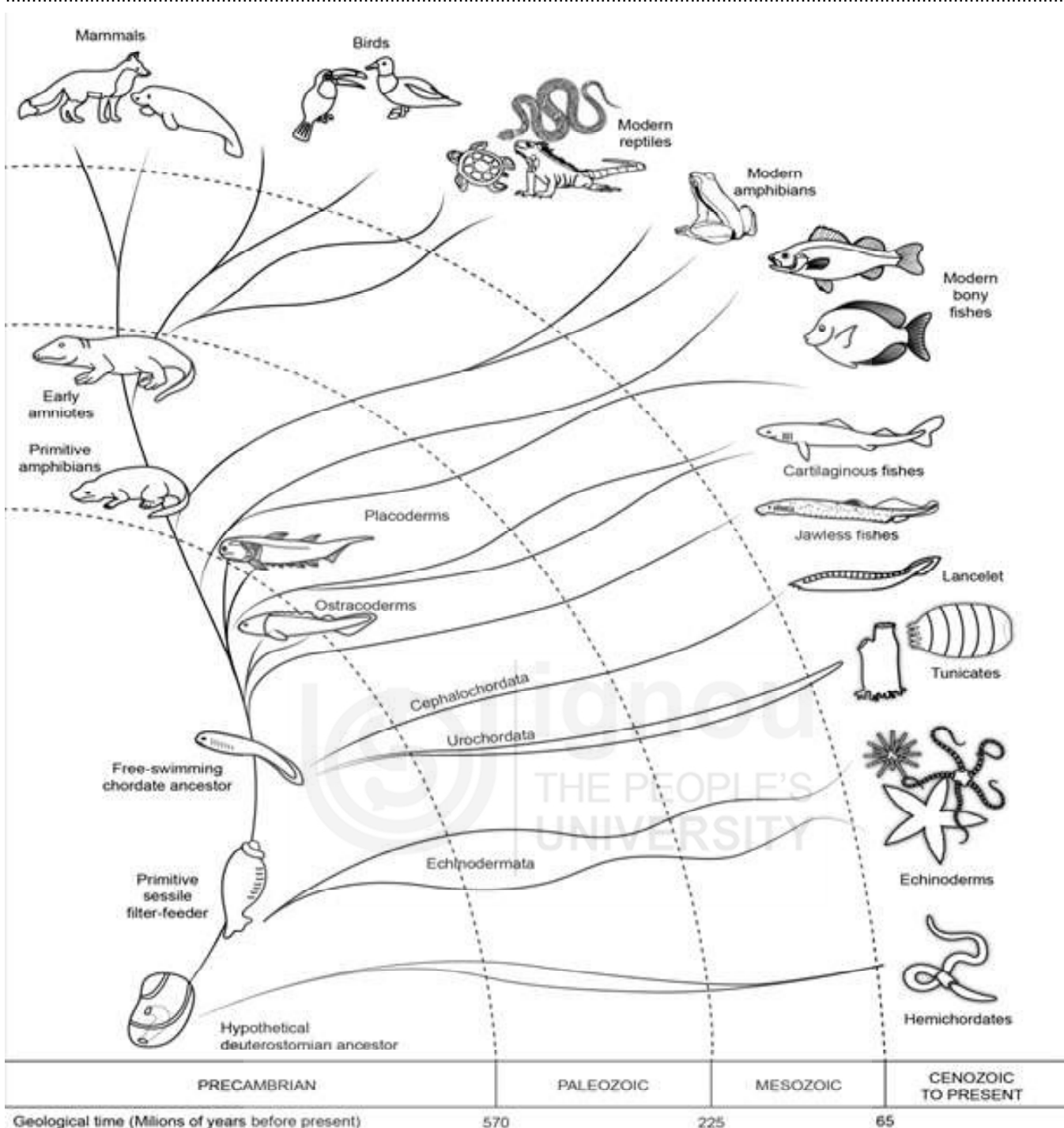


Fig.11.2: Phylogenetic tree of the chordates, suggesting probable origin and relationships. Other schemes have been suggested and are possible. The relative abundance in numbers of species of each group through geological time, as indicated by the fossil record, is suggested by the bulging and thinning of that group's line of descent.

Several traditional divisions of Phylum Chordata used in Linnaean classifications are shown in Table 11.1. A fundamental separation is Protochordata from Vertebrata. All vertebrates have a skull enclosing the brain and are called Craniata. You can note that some cladistic classifications exclude Myxini (hagfishes) from Vertebrata because they lack vertebrae, but retain them in Craniata because they have a cranium.

Table 11.1: Traditional Divisions of the Phylum Chordata

Cephalo- chordata (lancelets)	Urochor- data (tunicates)	Myxini (hag fishes)	Petromy- zontida (lampreys)	Chondrich- thyes (sharks)	Osteicht- hyes (bony fishes)	Amphibia (amphibi- ans)	Reptilia (amphi- bians)	Aves (birds)	Mammali-a (mammals)
← Chordata →									
← Protochordata →				← Vertebrata →					
← Agnatha →					← Craniata →				
						← Pisces →	← Tetrapoda →		
← Anamniota →							← Amniota →		

The vertebrates (craniates) may be variously subdivided into groups based on shared characteristics. Two such subdivisions shown in Table 11.1 are as follows:

1. Agnatha, vertebrates lacking jaws (hagfishes and lampreys), and Gnathostomata, vertebrates having jaws (all other vertebrates); and
2. Amniota, vertebrates whose embryos develop within a fluid-filled sac, the amnion (nonavian reptiles, birds, and mammals), and Anamniota, vertebrates lacking this adaptation (fishes and amphibians).
Gnathostomata in turn can be subdivided into Pisces, (jawed vertebrates with appendages, if any, in the form of fins); and Tetrapoda (jawed vertebrates with appendages, if any, the form of limbs). Several of these groupings are paraphyletic (Protochordata, Agnatha, Anamniota, Pisces) and consequently are not accepted in cladistic classifications.

Before moving further, try to attempt the following SAQ.

SAQ 1

How would you explain the phylogenetic position of chordates?

11.3 FIVE CHORDATE HALLMARKS

Five distinctive characteristics that, set chordates apart from all other phyla are **notochord**, **dorsal tubular nerve cord**, **pharyngeal pouches** or **slits**, **endostyle**, and **postanal tail**. These characteristics are always found at some embryonic stage, although they may change or disappear in later stages of life.

Notochord

The notochord is a flexible, rodlike structure, extending the length of the body. It is the first part of the endoskeleton to appear in an embryo. The notochord is a hydrostatic organ. Muscles attach to the notochord, and as it can bend laterally without shortening, it permits undulatory movements of the body.

Box 11.1 Characteristics of Phylum Chordata

1. **Postanal tail; notochord; endostyle or thyroid gland; bone and cartilage** in vertebrates.
2. Living in marine, freshwater, and terrestrial habitats; many capable of flight.
3. Free-living, but few fishes are ectoparasitic.
4. Bilateral symmetry; segmented, but segmentation inconspicuous in many.
5. Triploblastic.
6. **Coelom well-developed.**
7. Epidermis present in all; dermis in vertebrates; keratinised or bony structures often present in vertebrate integument; glands often diverse and abundant in vertebrates.
8. Digestive system complete; muscular gut in vertebrates; **pharyngeal pouches** present early in development, erupting to outside as gill slits in aquatic forms.
9. Smooth, skeletal, and cardiac muscle tissue present; segmented myomeres in fishes and amphibians.
10. **Nerve cord hollow and dorsal; distinct, three-lobed brain** present in vertebrates.
11. Protochordates with simple, unpaired photoreceptors and statocysts; vertebrates with well-developed paired sensory organs for vision, chemoreception, hearing, balance, electroreception, and vibration sensitivity.
12. Asexual reproduction by parthenogenesis in some fishes, amphibians, and lizards.
13. Sexes usually separate; hermaphroditism in sea squirts and some fishes; fertilization internal or external; oviparous or viviparous; distinct larval stage in some; crocodilians, birds, mammals, and some fishes and amphibians with parental care of young.
14. Paired, glomerular kidneys and ducts in vertebrates.
15. Respiration primarily via gills, lungs and skin; swim bladder present in many fishes.
16. Closed circulation; **chambered hearts** and red blood cells in vertebrates; distinct aortic arches in all except sea squirts.

In *Amphioxus* and in jawless vertebrates, the notochord persists throughout life (Fig. 11.3). In all vertebrates, except hagfishes a series of cartilaginous or bony vertebrae are formed from mesenchymal cells derived from blocks of mesodermal cells (**somites**) lateral to the notochord. In most vertebrates, the notochord is replaced by vertebrae, although remnants of the notochord may persist between or within the vertebrae.

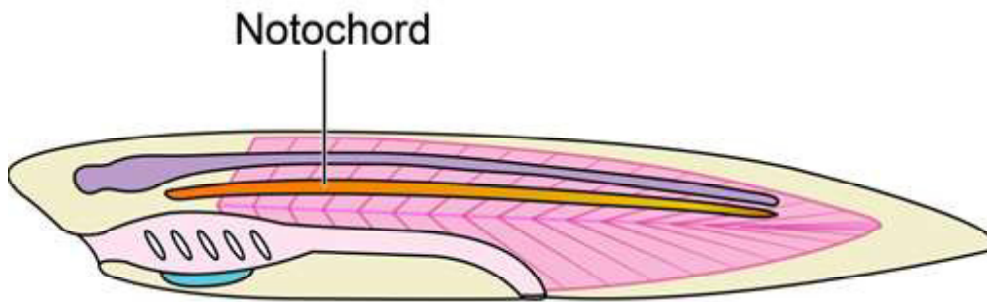


Fig. 11.3: Notochord.

Dorsal Tubular Nerve Cord

In most invertebrate phyla that have a nerve cord, it is ventral to the digestive tract and is solid, but in chordates the single cord is dorsal to the digestive tract and is a tube (although the hollow center will be diminished during growth). The anterior end becomes enlarged to form the brain in vertebrates (Fig. 11.4). The hollow cord is produced in the embryo by infolding of ectodermal cells on the dorsal side of the body above the notochord. Among vertebrates, the dorsal side of the protective neural arches of the vertebrae, and the brain is surrounded by a bony or cartilaginous cranium.

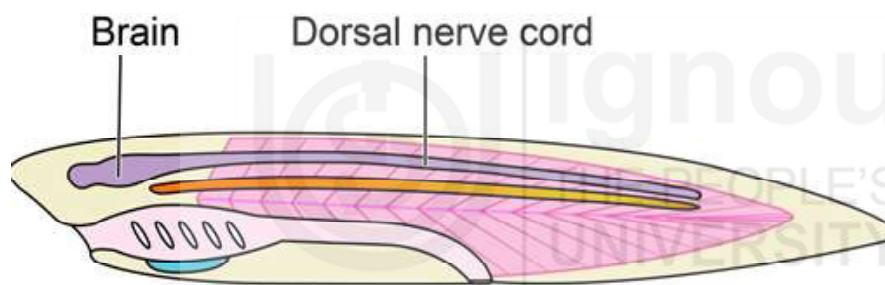


Fig. 11.4: Dorsal Tubular Nerve Cord.

Pharyngeal Pouches and Slits

Pharyngeal slits are openings that lead from the pharyngeal cavity to the outside. They are formed by in-pocketing of the outside ectoderm (pharyngeal grooves) and evagination, of the endodermal lining of the pharynx (pharyngeal pouches). In aquatic chordates, the two pockets break through the pharyngeal cavity where they meet to form the pharyngeal slit (Fig. 11.5). In tetrapod (terrestrial) vertebrates the pharyngeal pouches give rise to several different structures, including the Eustachian tube, middle ear cavity, tonsils, and parathyroid glands.

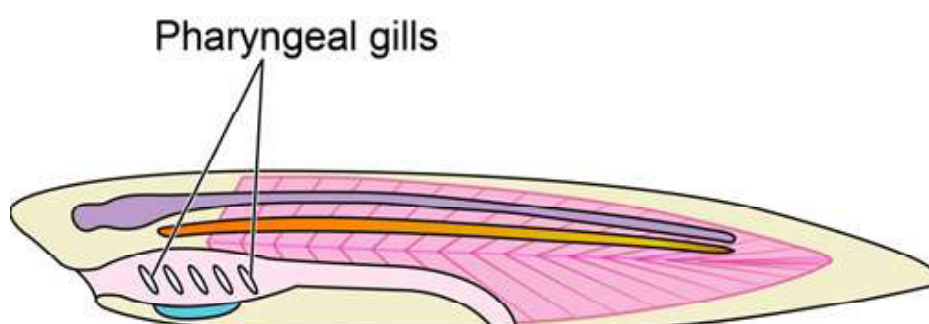


Fig. 11.5: Pharyngeal Pouches and Slits.

The perforated pharynx evolved as a filter-feeding apparatus and is used as such in protochordates. Water with suspended food particles is drawn by ciliary action through the mouth and flows out through pharyngeal slits where food is trapped in mucous. In vertebrates, ciliary action is replaced by muscular pharyngeal contractions that drive water through the pharynx. In protochordates these are simple vessels surrounded by connective tissue. Early fishes added a capillary network having only thin, gas-permeable walls, thus improving efficiency of gas transfer between blood and the water outside. These adaptations led to the evolution of **internal gills**, completing conversion of the pharynx from a filter-feeding apparatus in protochordates to a respiratory organ in aquatic vertebrates.

Endostyle or Thyroid Gland

Until recently, the endostyle was not recognised as a chordate character. However, endostyle or it the thyroid gland, occur in all chordates but in no other animals. The endostyle, in the pharyngeal floor, secretes mucous that traps small food particles brought into the pharyngeal cavity (Fig. 11.6). An endostyle occurs in protochordates and lamprey larvae. Some cells in the endostyle secrete iodinated proteins.

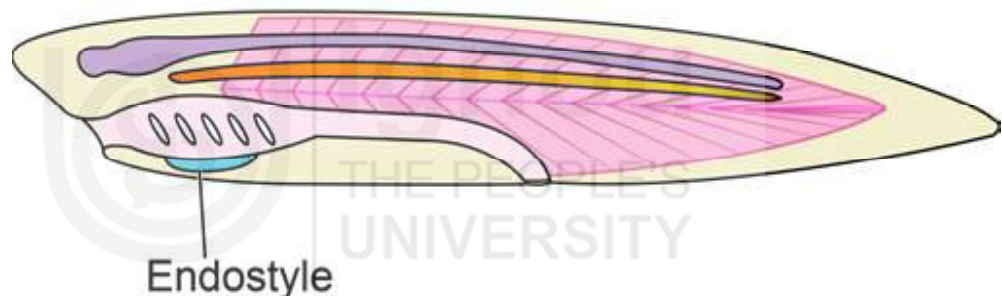


Fig. 11.6: Endostyle or Thyroid Gland.

Postanal Tail

A postanal tail, together with somatic musculature and the stiffening notochord, provides the motility that larval tunicates and *Amphioxus* need for their free-swimming existence. As a structure added to the body behind the end of the digestive tract, the tail clearly has evolved specifically for propulsion in water (Fig. 11.7). Its efficiency is later increased in fishes with the addition of fins. The tail is evident in humans only as a vestigial organ, but most other mammals have a waggable tail as adults.

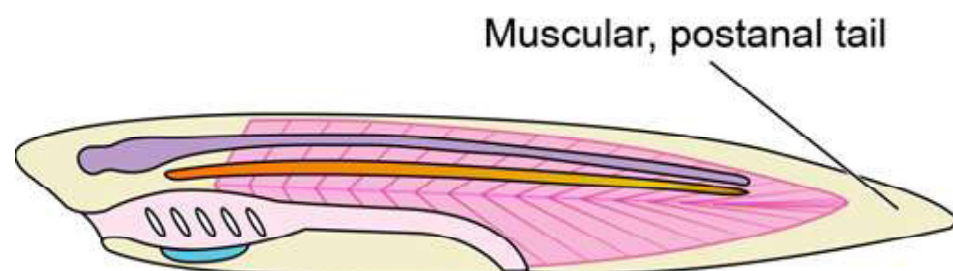


Fig. 11.7: Postanal Tail.

SAQ 2

What are the three most important characteristics of chordates that differ it from invertebrates?

11.4 ANCESTRY AND EVOLUTION

Phylogeny of Protochordates and Chordate Evolution

- a) Chordate evolution has taken two paths, one leading to the sedentary urochordates, and the other to the active, mobile cephalochordates and vertebrates. In 1928 Walter Garstang of England postulated that the ancestral chordate was a sedentary filter feeder, like adult ascidian tunicates. Garstang hypothesised that the ancestral life cycle of chordates resembled that of tunicates, and that an ancestor of vertebrates lost the ability to metamorphose into a sessile adult, instead developing gonads and reproducing while retaining an otherwise larval morphology. This form, now free-swimming as an adult, would have been the ancestor of cephalochordates and vertebrates. Continued evolution, emphasising cephalisation, would have produced the first vertebrates (Fig. 11.8). Garstang called this process **paedomorphosis** (a term describing the evolutionary retention of juvenile or larval traits in the adult body). Paedomorphosis is a well-known phenomenon in several different animal groups.

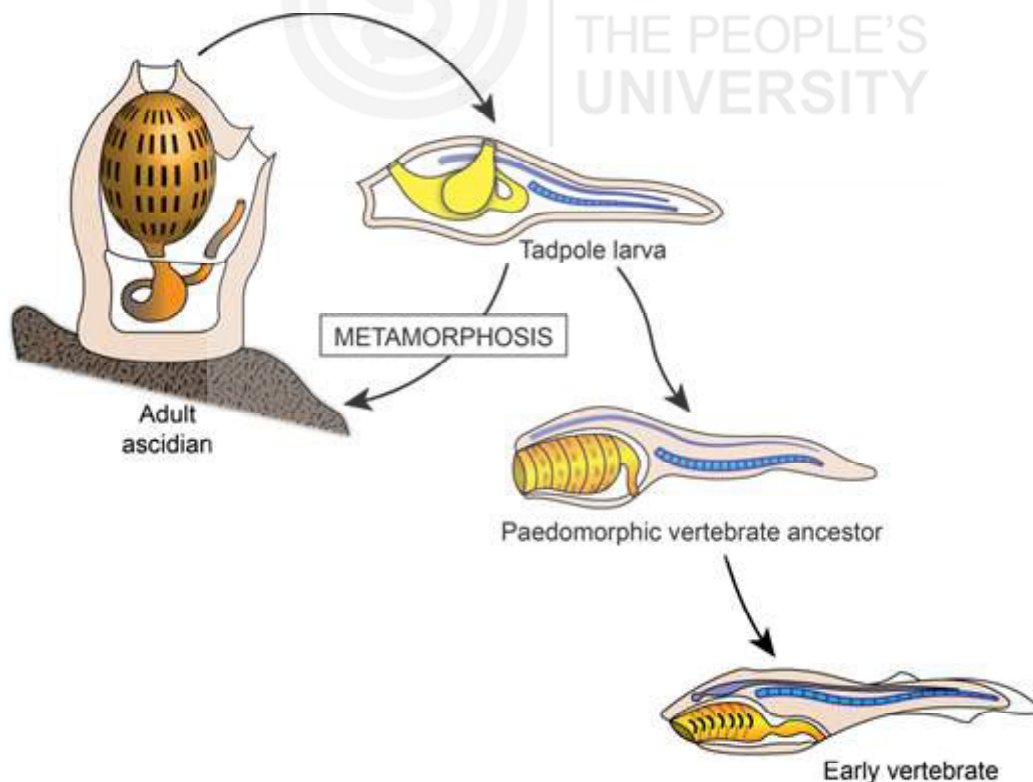


Fig. 11.8: Garstang's hypothesis of larval evolution. According to this hypothesis (now rejected), the ancestral chordate was a sedentary feeder, like most adult tunicates. More than 540 million years ago some larvae became paedomorphic, attaining reproductive maturity in the larval body form. These became cephalised, evolving to become the first vertebrates.

Paedomorphosis, the displacement of ancestral larval or juvenile feature into a descendant adult, can be produced by three different evolutionary-developmental processes: **neoteny**, **progenesis**, and **postdisplacement**. In **neoteny**, the growth rate of body form is slowed so that the animal does not attain the ancestral adult form when it reaches maturity. **Progenesis** is a precocious maturation of gonads in a larval (or juvenile) body that then stops growing and never attains the ancestral body form. In post displacement, the onset of a developmental process is delayed relative to reproductive maturation so that the ancestral adult form is not attained by the time of reproductive maturation. Neoteny, progenesis, and postdisplacement thus describe different ways in which paedomorphosis can happen.

Recently collected genetic and developmental evidence allows testing of Garstang's hypothesis. Numerous phylogenetic reconstructions, along with fossil evidence, place cephalochordates as the sister taxon to a clade consisting of urochordates plus vertebrates, suggesting that cephalochordates and vertebrates retain the ancestral chordate condition and that the sessile ascidians represent a derived condition. In addition, incipient neural crest tissue recently has been identified in urochordates, supporting a sister-group relationship with vertebrates. Thus, currently Garstang's hypothesis is rejected by many zoologists and the ancestral chordate as free-swimming creature (Refer Fig. 11.2) perhaps similar to the modern amphioxus is envisioned.

Although urochordates are now considered the closest living relative of vertebrates, their sessile body form evolved in a lineage ancestral only to urochordates and not in vertebrate ancestry. *Amphioxus* is viewed as retaining much of the prevertebrate and ancestral chordate body structure. Cephalochordates share several characteristics with vertebrates that are absent from tunicates, including segmented myomeres, dorsal and ventral aortas, branchial or aortic arches, and podocytes, specialised excretory cells. *Amphioxus* is unlike the most recent common ancestor of vertebrates because it lacks the tripartite brain, chambered heart, special sensory organs, muscular gut and pharynx, and neural crest tissue which was present in that ancestor.

- b) It has been difficult to reconstruct the evolutionary history of the earliest chordates because they were probably soft-bodied creatures that had little chance of being preserved as fossils. Although more Cambrian chordates recently have been discovered the fossil record does not show much. Consequently, such reconstructions largely come from the study of living organism, especially from an analysis of early developmental stages, which often tend to be more evolutionarily conserved than the differentiated adult forms they become.

Zoologists at first speculated that chordates evolved within the protostome clade (annelids and arthropods) but rejected such ideas when they realised that supposed morphological similarities were not homologous. Early in the twentieth century, further theorising became rooted in developmental patterns of animals, and it became apparent that the chordates are

deuterostomes. Deuterostomia, a group that includes the echinoderms, hemichordates, and chordates, has several important embryological features, as well as gene sequences, that clearly separate it from Protostomia and establish its monophyly. Thus, deuterostomes are almost certainly a natural grouping of interrelated animals that have their common origin in ancient Precambrian seas. Several lines of anatomical, developmental, and molecular evidence suggest that somewhat later, at the base of the Cambrian period some 540 million years ago, the first distinctive chordates arose from a lineage related to echinoderms and hemichordates.

SAQ 3

Explain the phylogeny of protochordates and evolution of chordates.

11.5 CLASSIFICATION OF PHYLUM CHORDATA

Phylum chordata is classified into three subphyla i.e. Urochordata, Cephalochordate and Vertebrata. Let us study about them in the following sub-sections.

11.5.1 Subphylum Urochordata (Tunicata)

The urochordats (tail-chordates), more commonly called tunicates, include about 1600 species. They live in all seas from near shoreline to great depths. Most are sessile as adults, although some are free-living. The name “tunicate” describes the usually tough, nonliving **tunic** that surrounds the animal and contains cellulose (Fig. 11.9). As adults, tunicates are highly

Most early efforts to identify chordate relationships were based on similarities due to analogy rather than homology. Analogous structures perform similar functions but have different origins (such as wings of birds and butterflies). Homologous structures, on the other hand, share a common origin but can look different (at least superficially) and perform different functions. For example, all vertebrate forelimbs are homologous because they are derived from a pentadactyl limb of the same ancestor, even though they may be modified as differently as a human's arm and a bird's wing.

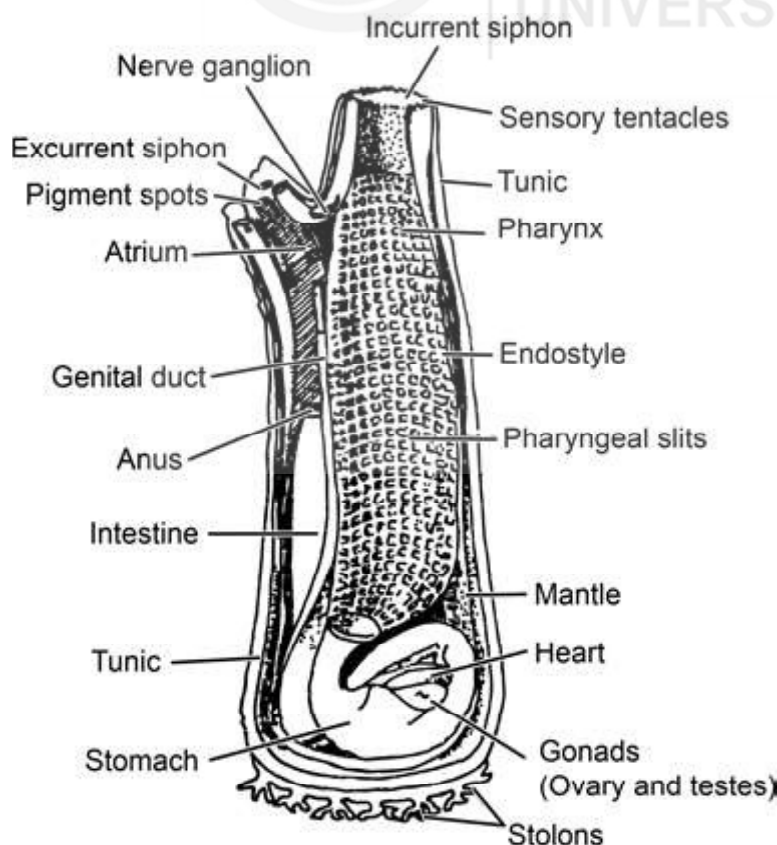


Fig. 11.9: Structure of common tunicate, *Ciona* sp.

specialised chordates, because in most species only the larval form, which resembles a microscopic tadpole, bears all the chordate hallmarks. During adult metamorphosis, the notochord (which, in the larva, is restricted to the tail, hence the group name Urochordata) and tail disappear, while the dorsal nerve cord becomes reduced to a single ganglion.

Urochordata is divided into three classes: **Ascidacea**, **Appendicularia** and **Thaliacea**. Members of Ascidacea are by far the most common, diverse, and best known. They are often called “sea squirts” because some species forcefully discharge a jet of water from the excurrent siphon when irritated. All but a few ascidian species are sessile animals, attached to rocky or other hard substrates such as pilings or bottoms of ships. In many areas, they are among the most abundant of intertidal animals.

Ascidians may be solitary, colonial, or compound. Each of the solitary and colonial forms has its own test, but among compound forms many individuals may share the same tunic. In some compound ascidians each member has its own incurrent siphon, but the excurrent opening is common to the group.

Solitary ascidians (Fig. 11.10) are usually spherical or cylindrical forms. Lining the tunic is an inner membrane, the **mantle**.

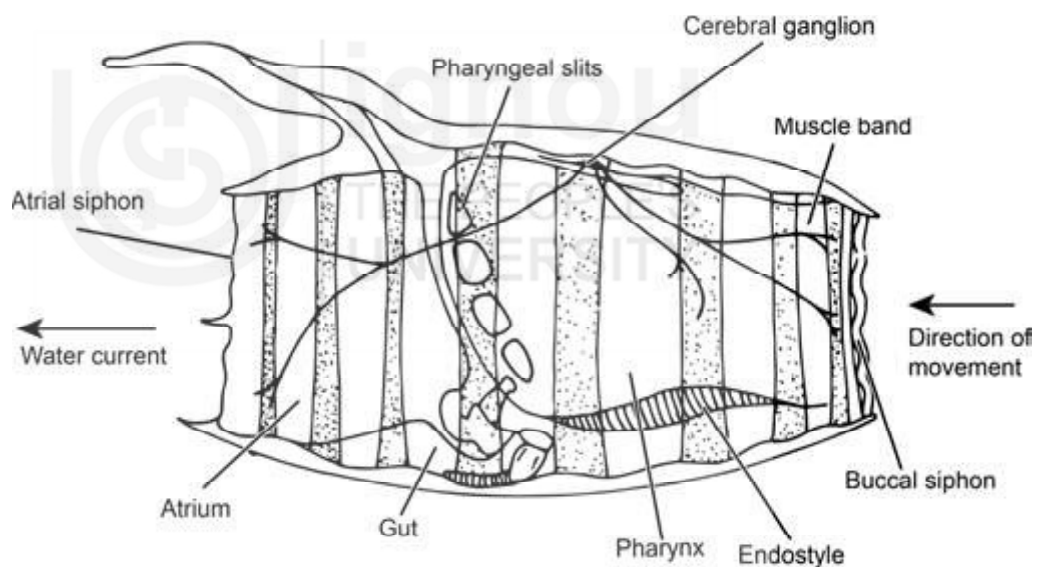


Fig. 11.10: Solitary Thaliacean *Doilolum*.

On the outside there are two projections: an **incurrent siphon**, on oral siphon which corresponds to the anterior end of the body, and an excurrent siphon, or atrial siphon that marks the dorsal side. Water enters the incurrent siphon and passes into a ciliated **pharynx** that is minutely perforated by slits to form an elaborate basketwork. Water passes through the slits into an atrial cavity and out through the excurrent siphon.

Feeding depends on formation of a mucous net that is secreted by a glandular groove, the **endostyle**, located along the midventral side of the pharynx. Cilia on bars of the pharynx pull the mucous into a sheet that spreads dorsally across the inner face of the pharynx. Food particles brought in the incurrent opening are trapped on the mucous net, which is then worked into a rope and carried posteriorly by cilia into the oesophagus.

Nutrients are absorbed in the midgut and indigestible wastes are discharged from the anus, located near the excurrent siphon.

Feeding depends on formation of a mucous net that is secreted by a glandular groove, the **endostyle**, located along the midventral side of the pharynx. Cilia on bars of the pharynx pull the mucous into a sheet that spreads dorsally across the inner face of the pharynx. Food particles brought in the incurrent opening are trapped on the mucous net, which is then worked into a rope and carried posteriorly by cilia into the oesophagus. Nutrients are absorbed in the midgut and indigestible wastes are discharged from the anus, located near the excurrent siphon.

The circulatory system consists of a ventral heart and two large vessels, one on either side of the heart; these vessels connect to a diffuse system of smaller vessels and space serving the pharyngeal basket (where respiratory exchange occurs), the digestive organs, gonads, and other structures. An odd feature, found in no other chordates, is that the heart drives the blood first in one direction for a few beats, then pauses, reverses its action, and drives the blood in the opposite direction for a few beats. Another remarkable feature is the presence of strikingly high amounts of rare elements in the blood, such as vanadium and niobium. The vanadium concentration in the sea squirt *Ciona* may reach 2 million times its concentration in seawater.

The nervous system is restricted to a **nerve ganglion** and plexus of nerves that lie on the dorsal side of the pharynx. Beneath the nerve ganglion is located the **subneural gland**, connected by a duct to the pharynx.

Sea squirts are hermaphroditic, with usually a single ovary and a single testis in the same animal. Gametes are carried by ducts into the atrial cavity, and then into the surrounding water where fertilization occurs.

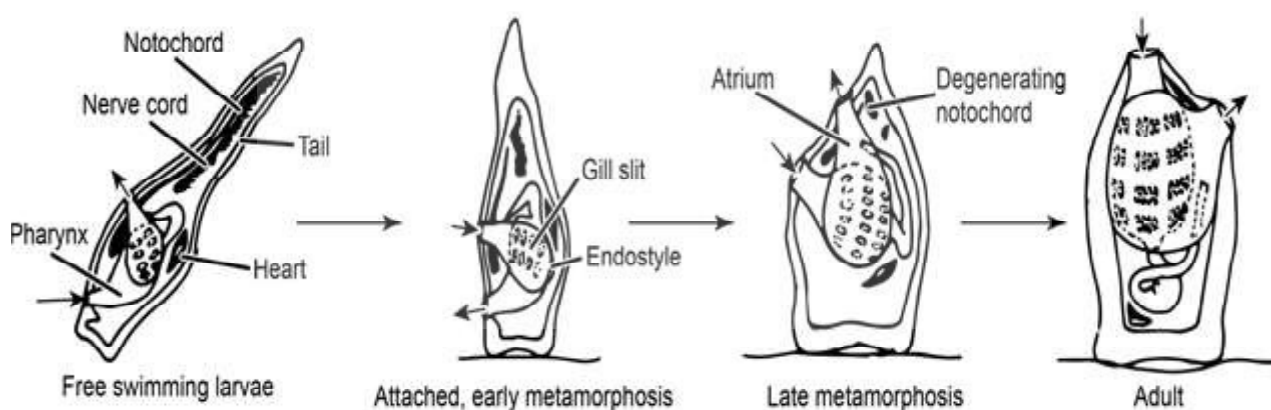


Fig. 11.11: Metamorphosis of a solitary ascidian from a free-swimming larval stage.

Of the five chief characteristics of chordates, adult sea squirts have only two: pharyngeal slits and endostyle. However, the larval form reveals the secret of their true relationship. The “tadpole” larva (Fig. 11.11) is an elongate, transparent form with all five chordate characteristics: notochord, hollow dorsal nerve cord, propulsive postanal tail, and large pharynx with endostyle and pharyngeal slits. The larva does not feed but swims for several hours or

days before fastening itself vertically by adhesive papillae to a solid object. It then undergoes a dramatic metamorphosis (Fig. 11.11) to become a sessile adult, so modified as to become almost unrecognisable as a chordate.

Tunicates of class Thaliacea, the thaliaceans or salpas, are barrel-or lemon-shaped pelagic forms with transparent, gelatinous bodies that, despite the considerable size that some species reach, are nearly invisible in sunlit surface waters. They occur singly or in colonial chains that may reach several meters in length (Fig. 11.12). The cylindrical thaliacean body is typically surrounded by bands of circular muscles, with incurrent and excurrent siphons at opposite ends.



Fig. 11.12: Salpas. The transparent individuals of this delicate, planktonic species are grouped in a chain. Visible within each individual is an opaque gonad, an opaque gut, and a long serrated gill bar. Class Thaliacea.

Water pumped through the body by muscular contraction (rather than by cilia as in ascidians) is used for locomotion by a sort of jet propulsion, for respiration and as a source of particulate food that is filtered on mucous surface. Many are provided with luminous organs which give brilliant light at night. Most of the body is hollow, with the viscera forming a compact mass on the ventral side.

The life histories of thaliaceans are often complex and are adapted to respond to sudden increase in their food supply. The appearance of a phytoplankton bloom, for example, is met by an explosive population increase leading to extremely high density of thaliaceans. Common forms include *Doliolum* and *Salpa*, both of which reproduce by an alternation of sexual and asexual generation.

The third tunicate class, the Appendicularia (Larvacea in some classification) contains tiny, pelagic creatures shaped like a bent tadpole. The name Larvacea refers to their resemblance to the larval stages of other tunicates. They feed by a method unique in the animal world. Each builds a delicate house, transparent hollow sphere of mucous interlaced with filters and passages through which water enters (Fig. 11.13). Tiny phytoplankton and bacteria trapped on feeding filter inside the house are drawn into the animal's mouth through a strawlike tube. When the filters become clogged with waste, which happens about every hours, the appendicularian abandons

its house and builds a new house, a process that takes only a few minutes. Like thaliaceans, appendicularians can quickly build dense populations when food is abundant.

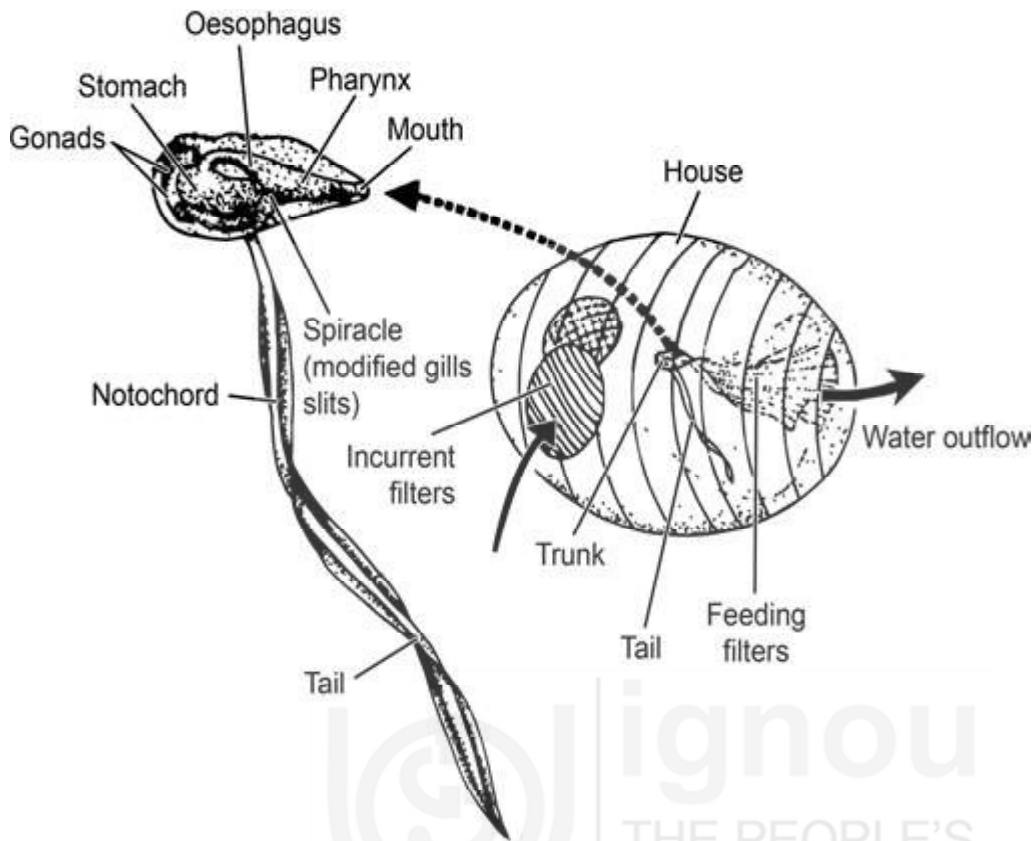


Fig. 11.13: Appendicularian (larvacean) adult (left) and as it appears within its transparent house (right), which is about the size of a walnut. When the feeding filters become clogged with food, the tunicate abandons its house and builds a new one.

11.5.2 Subphylum Cephalochordata

Cephalochordates are lancelets: slender, laterally compressed translucent animals about 3 to 7 cm in length (Fig. 11.14) inhabit the sandy sediments of coastal water around the world. Lancelets bore the generic name *Amphioxus*, later surrendered by priority to *Branchiostoma*. *Amphioxus* is still used, however, as a convenient common name for all approximately 29 species in this subphylum.

Amphioxus is especially interesting because it has the five characteristics of chordates in simple form. Water enters the mouth, driven by cilia in the buccal cavity and then passes through numerous pharyngeal slits where food is trapped in mucous and is then moved by cilia into the gut. Here the food particles are separated from the mucous and passed into hepatic cecum where they are phagocytized and digested intracellularly.

The closed circulatory system is complex for so simple a chordate. The flow pattern is remarkably similar to that of fishes, although there is no heart. Blood is pumped forward in the **ventral aorta** by peristaltic like contractions of the vessel wall and then passes upward through arteries (aortic arches) in

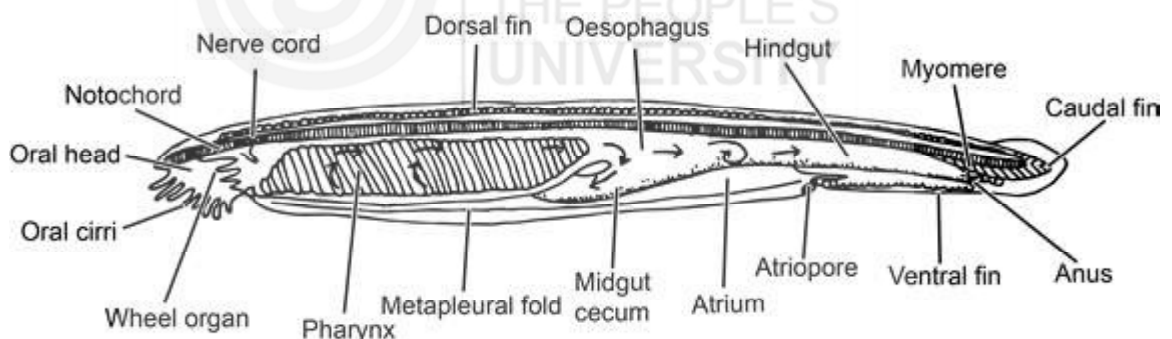
the pharyngeal bars to paired dorsal arteries which join posteriorly to become a single dorsal aorta. From here blood is distributed to body tissues by microcirculation and then is in veins, which return it to the ventral aorta. Blood is colourless lacking both erythrocytes and haemoglobin.

The nervous system is centred around a hollow nerve cord lying above the notochord. Sense organs are simple. The “brain” is a simple vesicle at the anterior end of the nerve cord.

Sexes are separate. Gametes are released in the atrium, then pass through the atriopore to the outside where fertilization occurs. The larvae hatch soon after eggs are fertilized and gradually assume the shape of adults.



(a)



(b)

Fig. 11.14: *Amphioxus*. This bottom-dwelling cephalochoradate illustrates the five distinctive chordate characteristics (notochord, dorsal nerve cord, pharyngeal slits, endostyle, and postanal tail). This body plan is considered ancestral for chordates. a) Living *Amphioxus* in typical position for filter-feeding. Note the oral hood with tentacles surrounding the mouth; b) Internal structure.

No other chordate shows the basic diagnostic chordate characteristics clearly as does *Amphioxus*. In addition to the five chordate anatomical hallmarks, *Amphioxus* possesses several structural features that resemble the vertebrate plan. Among these are a hepatic cecum, a diverticulum that resembles the vertebrate pancreas in secreting digestive enzymes and the liver in storing glycogen, segmented trunk musculature, and the basic circulatory plan of vertebrates.

11.5.3 Subphylum Vertebrata (Craniata)

The third subphylum of chordates is large and diverse Vertebrata. This monophyletic group shares the basic chordate characteristics with the other two subphyla, but in addition it exhibits a number of novel characters that the others do not share. The alternative name of the subphylum, Craniata, more accurately describes the group because all have a cranium (body or cartilaginous braincase) but some jawless fishes lack vertebrae.

Adaptations that have guided early vertebrate evolution

The earliest vertebrates were substantially larger and considerably more active than the protochordates. Modifications of skeletal structures and muscles permitted increased speed and mobility. The higher activity level and size of vertebrates also required structures specialised in the location, capture, and digestion of food and adaptations designed to support a high metabolic rate.

Musculoskeletal Modifications

Most vertebrates possess both an exoskeleton and an endoskeleton of cartilage or bone. The endoskeleton permits an almost unlimited body size with much greater economy of building materials than does the exoskeleton of arthropods. Some vertebrates have become the most massive organisms on earth. In most vertebrates, disclike centra replace the notochord, and dorsal projections called **neural spines** are present, providing more area for attachment of segmented muscles. The segmented body muscles (myomeres) changed from the V-shaped muscles of ancestral chordates to the W-shaped muscles of vertebrates. This increased complexity of folding in the myomeres provides powerful control over an extended length of the body. Also unique to vertebrates are fin rays of dermal origin, supporting fins used in swimming.

The endoskeleton probably was composed initially of cartilage and later of bone. Cartilage, with its fast growth and flexibility, is ideal for constructing the first skeletal framework of all vertebrate embryos. The endoskeleton of living hagfishes, lampreys, and sharks and even some “bony” fishes, such as sturgeons, is mostly cartilage. Bone may have been adaptive in early vertebrates in several ways. Plates of bone in the skin of ostracoderms and other ancient fishes certainly provided protection from predators, although there are more important benefits. The structural strength of bone is superior to that of cartilage, making it ideal for muscle attachment in areas of high mechanical stress. One of the most interesting ideas is that bone’s original function was mineral storage and homeostasis. Phosphorus and calcium are used for many physiological processes and are in particularly high demand in organisms with high metabolic rates.

Most vertebrates possess an extensive exoskeleton (one that develops from the skin), although it is highly modified in many forms. Some of the earliest fishes, including ostracoderms and placoderms (Figs. 11.15 and 11.16), were partly covered in a bony, dermal armor. This armor is modified as

scales in later fishes. Most vertebrates are further protected with keratinised structures derived from the epidermis, such as reptilian scales, hair, feathers, claws, and horns.

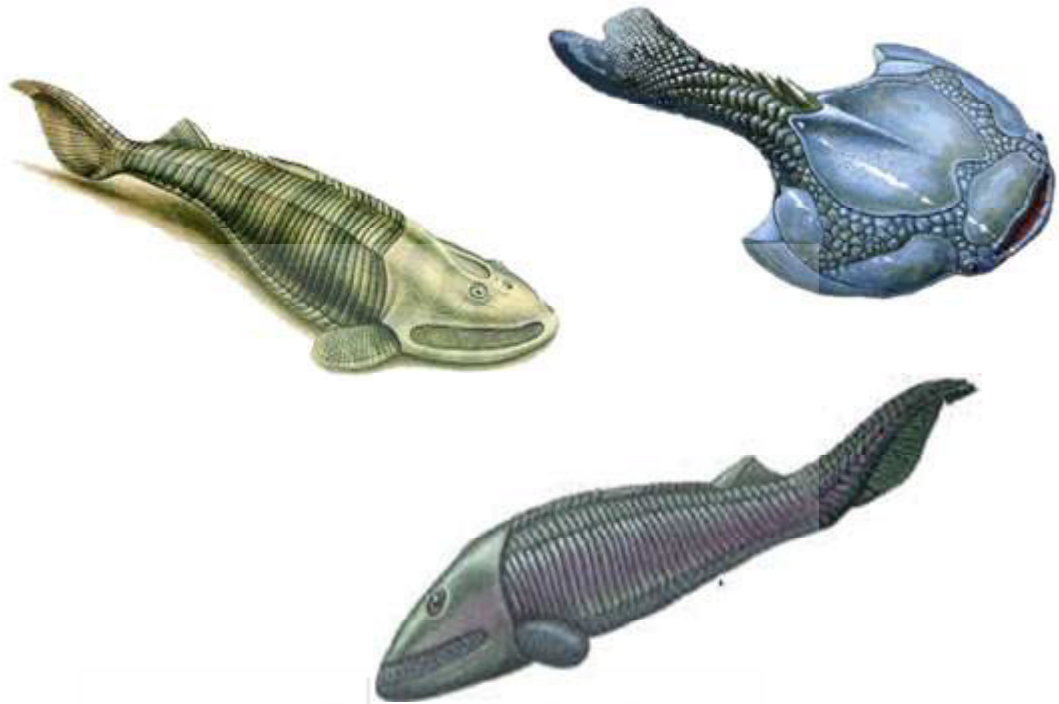


Fig. 11.15: Three ostracoderms, jawless fishes of Silurian and Devonian times. They are shown as they might have appeared while searching for food on the floor of a Devonian sea. They employed a strong pharyngeal pump to circulate water rather than the much more limiting mode of ciliary action used by their protochordate ancestors (presumably resembling *Amphioxus* in this way).



Fig. 11.16: Early jawed fishes of the Devonian period, 400 million years ago. Jaws and gill supports from which the jaws evolved develop from neural crest cells, a nearly diagnostic character of vertebrates. Most placoderms were dwellers that fed on benthic animals, although some were active predators. Acanthodians carried less armor than placoderms and had large, anteriorly placed eyes and prominent spines on paired fins. Most were marine but several species lived in freshwater.

Physiology Upgrade

Vertebrate digestive, respiratory, circulatory, and excretory systems are modified to meet in increased metabolic demand. The perforated pharynx

evolved as a filter-feeding device in early chordates, using cilia and mucous to move water and to trap small suspended food particles. In vertebrates, the addition of muscles to the pharynx created a powerful pump for moving water. With the origin of highly vascularised gills, the function of the pharynx shifted primarily to gas exchange. Early chordates moved food in the gut with cilia, but vertebrates move food in the gut with muscles. This shift, along with addition of two distinct digestive glands, the liver and pancreas, enabled vertebrates to manage the increased amount of food ingested. A ventral, three-chambered heart consisting of a sinus venosus, atrium and ventricle, and erythrocytes with haemoglobin-enhanced transportation of nutrients, gases, and other substances. Protochordates have no distinct kidneys, but vertebrates possess paired, glomerular kidneys that remove metabolic waste products and regulate body fluids and ions.

New Head, Brain, and Sensory Systems

When vertebrate ancestors shifted from filter-feeding to active predation, new sensory, motor, and integrative controls became essential for locating and capturing larger prey. The anterior end of the nerve cord became enlarged as a **tripartite brain** (forebrain, midbrain, and hindbrain) and protected by a cartilaginous or bony cranium. Paired special sense organs designed for distance reception evolved. These included eyes with lenses and inverted retinas; pressure receptors, such as paired inner ears designed for equilibrium and sound reception; chemical receptors including taste and exquisitely sensitive olfactory organs; receptors for detecting water vibrations; and electroreceptors for detecting electrical currents that single prey.

Neural Crest, Ectodermal Placodes, and Hox Genes

Development of the vertebrate head and special sense organs was largely the result of two embryonic innovations present only in vertebrates; **neural crest** and **ectodermal placodes**. The neural crest, contributes to the formation of many different structures, including most of the cranium, the pharyngeal skeleton, tooth dentine, some cranial nerves, ganglia, some endocrine glands, and Schwann cells. In addition, the neural crest regulates the development of adjacent tissue, such as tooth enamel and pharyngeal muscles. Ectodermal placodes are platelike ectodermal thickenings that appear on either side of the neural tube. These give rise to the olfactory epithelium, lens of the eye, inner ear epithelium, some ganglia and cranial nerves, lateral-line mechanoreceptors, and electroreceptors. Thus the vertebrate head, with its sensory structures located adjacent to the mouth (later equipped with prey-capturing jaws), stemmed from new embryonic tissues.

Studies of the distribution of homeobox (*Hox*) genes that control the body plan of chordate embryos suggest that *Hox* genes were duplicated at about the time of the origin of vertebrates. *Amphioxus* and invertebrates have only one copy of *Hox* genes, whereas most living gnathostomes have four copies. These additional copies of *Hox* genes could be responsible for the evolution of many vertebrate characters.

SAQ 4

- i) Explain the mode of feeding adopted by a larvacean.
- ii) Fill in the blanks with appropriate words.
 - a) The tough nonliving covering of urochordates is called
 - b) The three classes of Urochordata are and
 - c) In ascidians the food particles are trapped in the secreted by
 - d) spends most of the time buried tail down in the sand.
 - e) Excretion is by means of in *Branchiostoma*.
 - f) In lancelets are separate and is external.
 - g) Digestion is in *Branchiostoma*.

11.6 SUMMARY

Let us summarise whatever you have learnt so far:

- Phylum Chordata is named for the rodlike notochord that forms a stiffening body axis at some stage in the life cycle of every chordate.
- All chordates share five distinctive hallmarks that set them apart from all other phyla: notochord, dorsal tubular nerve cord, pharyngeal pouches, endostyle, and postanal tail.
- Two of the three chordate subphyla are invertebrates and lack a well-developed head. They are Urochordata (tunicates), most of which are sessile as adults, but all of which have a free-swimming larval stage; and cephalochordate (lancelets), fishlike forms that include the famous amphioxus.
- Chordates have evolutionary affinities to hemichordates, but the precise evolutionary origin of chordates is not yet known. Taken as a whole, chordates have a greater fundamental unity of organ systems and body plan than have many invertebrate phyla.
- Subphylum Vertebrata includes the back-boned members of the animal kingdom (hag-fishes actually lack vertebrae but are included with the Vertebrata by tradition because they share numerous homologies with vertebrates).

11.7 TERMINAL QUESTIONS

1. Name five hallmarks shared by all chordates, and explain the function of each.
2. Give a description of an adult tunicate that would identify it as a chordate, yet distinguish it from any other chordate group.

3. Both sea squirts (urochordates) and lancelets (cephalochordates) are suspension-feeding organisms. Describe the suspension-feeding apparatus of a sea squirt and explain in what ways its mode of feeding is similar to, and different from, that of amphioxus.
4. List three groups of adaptations that explain how each contributed to the success of vertebrates.
5. In 1928 Walter Garstang hypothesised that tunicates resemble the ancestral stock of the vertebrates. Explain this hypothesis.

11.8 ANSWERS

Self-Assessment Questions

1. Refer to Section 11.2.
2. Refer to Section 11.3.
3. Refer to Section 11.4.
4. i) The food particles coming along with water are trapped on the feeding filter in the house. The filtered food is then drawn into the animal's mouth through a straw like tube. After about four hours when filter is clogged with waste, the animal leaves the house and builds a new one.
ii) a) tunic b) Ascidiacea, Larvacea, Thaliacea c) mucous, endostyle
d) *Amphioxus* e) nephridia f) sexes, fertilization g) intracellular

Terminal Questions

1. Refer to Section 11.3.
2. Refer to Sub-section 11.5.1.
3. Refer to Sub-section 11.5.2.
4. Refer to Sub-section 11.5.3.
5. Refer to Section 11.4.

AGNATHA–JAWLESS FISHES|

Structure

12.1	Introduction Objectives	12.3	Living Jawless Fishes General Characters Classification
12.2	Ancestry and Affinities of Agnatha	12.4	Summary
		12.5	Terminal Questions
		12.6	Answers

12.1 INTRODUCTION

In the last unit you were introduced to phylum Chordata. You learnt about the five salient features of the phylum that set them apart from all other phyla. These are the notochord, dorsal hollow nerve cord, pharyngeal gill slits or pouches, endostyle and a postanal tail; and these features are found always at some embryonic stage of life, even though they may not be seen as such in the adult chordates. You also learnt about the primitive subphyla of Chordata i.e. Urochordata and Cephalochordata (collectively known as protochordates), that are really invertebrates more closely related to vertebrates than to other invertebrates and represent a transition between invertebrate and vertebrate animals. About half a million years ago in the Cambrian period, a branch of chordates gave rise to the vertebrates. With a skeletal system and a more complex nervous system with sense organs they became more successful in finding food and avoiding becoming food for other animals. In this unit you will begin the study of two primitive groups of subphylum Vertebrata- the hagfishes and the lampreys, which are the only living vertebrates that lack jaws and are therefore placed in **superclass Agnatha** (=jawless).

We begin our unit by giving a brief description of the evolution of jawless fishes along with their affinities with other fishes. Next we describe the general characters of the first vertebrates – the jawless fishes and their two living groups – hagfishes and lampreys.

Objectives

After studying this unit, you should be able to:

- ❖ discuss the affinities of Agnatha with major groups of fishes;
- ❖ describe the characteristic features of Agnatha;

- ❖ discuss the distinguishing features of hagfishes and lampreys; and
- ❖ describe the life cycle of lamprey.

12.2 ANCESTRY AND AFFINITIES OF AGNATHA

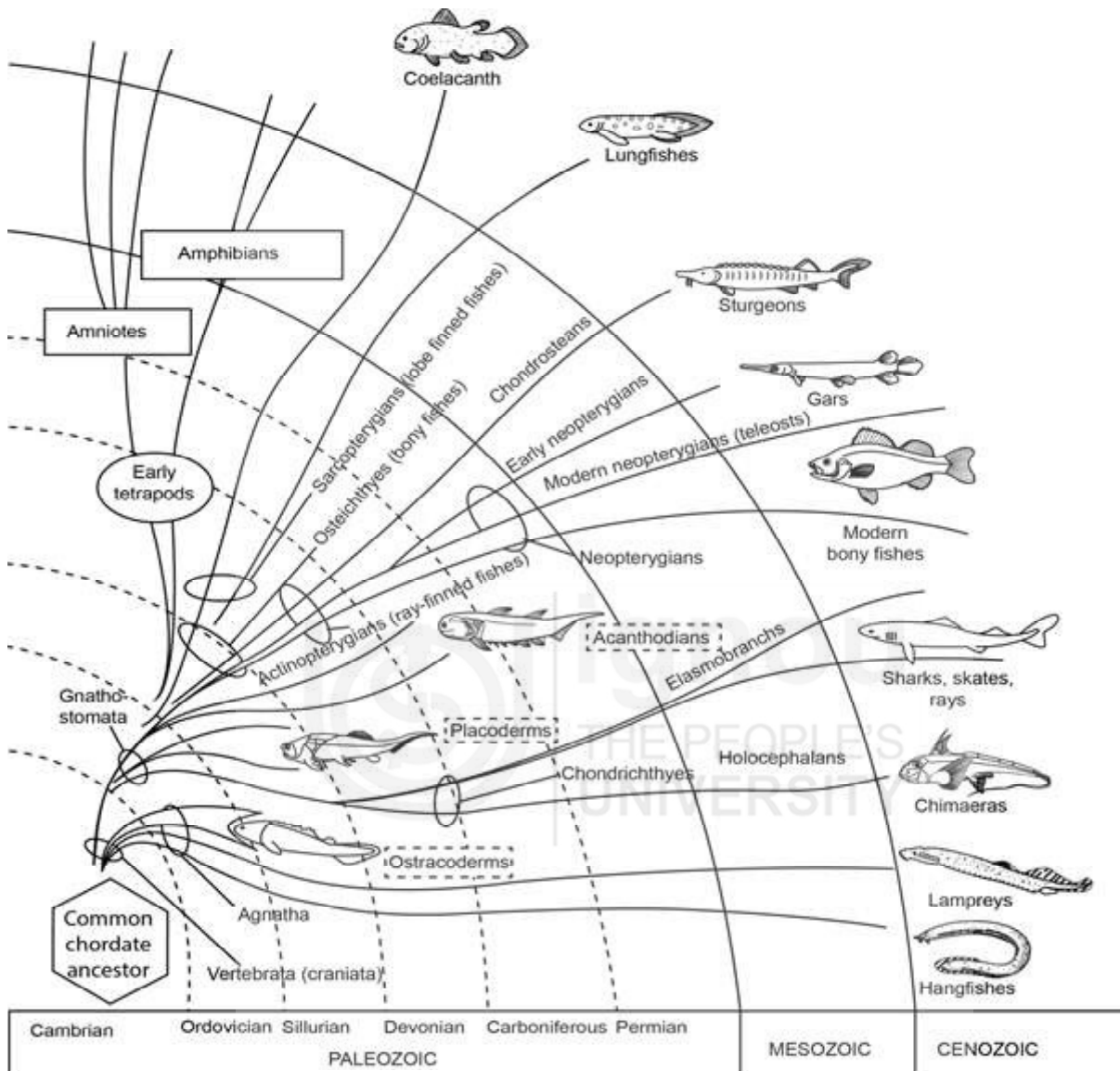


Fig.12.1: Probable relationship of jawless fishes and Gnathostomata. The extinct lineages of fishes are shown in broken line boxes.

The most ancient vertebrates living today are the diverse groups of fishes that make up five out of the nine classes in subphylum Vertebrata. It is supposed that fishes have descended from an ancient free swimming protochordate ancestor about 550 million years ago. One of the early vertebrates were the armoured jawless fishes, the **ostracoderms** that became extinct in the **Paleozoic era by the end of Devonian period** (Fig. 12.1). The living jawless fishes along with the extinct ostracoderms are placed in a Superclass Agnatha because they lack jaws and two sets of paired fins. However, the ancestry of living agnathans is not very clear; they do not bear much resemblance to the extinct ostracoderms, but they are considered to have been derived from a common ancestor. One group of ostracoderms gave rise to jawed fishes which along with the tetrapods are

placed in a superclass – **Gnathostomata**. However, no intermediate forms between the agnathans and gnathostomes appear in fossil records. The oldest fossils of jawless fishes appear in the Cambrian period and two groups survive till date. The living agnathans are represented by hagfishes and lampreys. Although hagfishes have no vertebrae and lampreys have only rudimentary vertebrae, they are still placed under subphylum Vertebrata because they have a cranium and other vertebrate homologies (similarity of structure that indicates a common origin).

12.3 LIVING JAWLESS FISHES

The living agnathans (hagfishes and lampreys) are represented by approximately 110 species placed in two different classes as mentioned above. They lack jaws, internal ossification, scales and paired fins and have porelike gill openings and eel like body form (Fig.12.2). Because of their morphological similarities, hagfishes and lampreys were formerly placed in one group – Cyclostomata. However, lampreys bear enough derived morphological characters which place them phylogenetically closer to the jawed fishes rather than to hagfishes. Therefore they have been placed in two different classes **Myxini** (hagfishes) and **Petromyzontida** (lampreys).

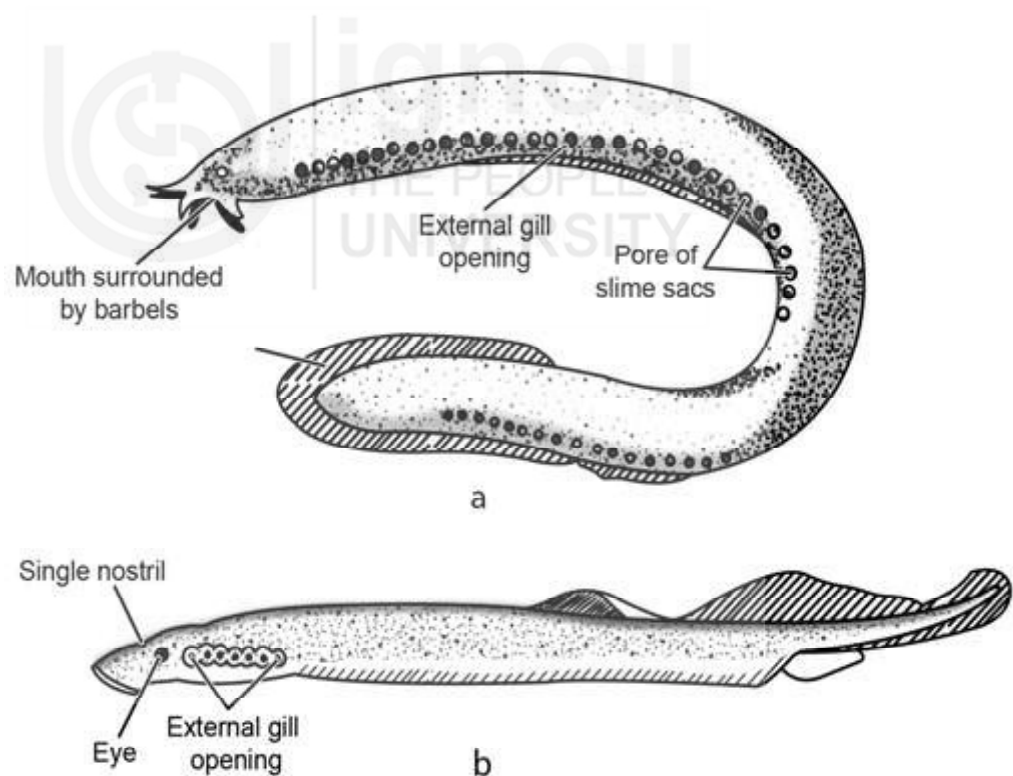


Fig. 12.2: a) Hagfish; b) Lamprey.

12.3.1 General Characters

1. Absence of jaw and paired appendages.
2. The body of both hagfishes and lampreys are cylindrical, elongated and in general resemble those of eels. Though there are no paired appendages, but they do have median fins that are supported by cartilaginous fin rays.

3. The skin is naked i.e., scales are absent. The skin is soft because of the presence of mucous glands in it.
4. The skeleton is not ossified, rather it is fibrous and cartilaginous; notochord is persistent; vertebrae are reduced or absent.
5. Lampreys have a sucker like oral disc with well developed keratinised teeth. Hagfishes possess a biting mouth that has two rows of eversible keratinised teeth on the tongue.
6. The digestive system lacks a distinct stomach. Mouth directly opens into intestine. In lampreys intestine has a spiral fold provided with cilia. In hagfishes, the fold is present but cilia are absent.
7. Heart with a sinus venosus, atrium and a ventricle. Single circulation; the gills are supplied with blood by aortic arches arising from the heart. Blood has erythrocytes and leukocytes.
8. The number of gills in the hagfish and lamprey vary. There are seven pairs of gills in lampreys and five to sixteen pairs of gills in hagfishes.
9. Brain small but distinct; nerve cord and 10 pairs of cranial nerves present.
10. Sense organs for perceiving location, taste and hearing are present. Eyes poorly developed in hagfishes and moderately developed in lamprey; one pair or two pairs of semicircular canals present.
11. Sexes are separate in Agnatha. Gonads are unpaired and gonadoducts are absent. Fertilization is external. Development does not include a larval stage in hagfishes but includes ammocoetes larval stage in lampreys.
12. Hagfishes have pronephric kidneys located anteriorly and mesonephric kidneys located posteriorly, while opisthonephric kidney is found in lamprey. Ammonia is the main nitrogenous waste.

12.3.2 Classification

In the classification discussed here, only the living groups are given. The extinct group agnathans known only from fossils i.e., ostracoderms is not included.

Superclass Agnatha: Craniate chordates, with pouchlike gills and lacking jaws. Ordovician Period to present. This superclass has two extant classes:

I) Class Myxini (Hagfishes)

Nostril at tip of snout, eyes vestigial, tongue with 2 rows of horny teeth, mouth surrounded by barbels, slime glands along body, 1–16 pairs of gills, single fin extending around posterior end of body; Pennsylvanian Subperiod to present. Only one order present.

Order Myxiniiformes: Examples are *Bdellostoma*, *Myxine* and *Eptatretus indrambaryai* (found in the Indian ocean and seas near Anadaman islands).

II) Class: Petromyzontida (Lampreys)

7 pairs of gills opening through pores, laterally placed eyes, single nostril dorsal, horny teeth on an oral sucker, horny teeth on tongue. 1 or 2 dorsal fins. 10 genera, 43 species. Pennsylvanian *Subperiod* to present.

Order Petromyzontiformes: *Petromyzon*, *Lampetra*.

Now let study about these classes in detail:

Class Myxini

Class Myxini includes the hagfishes. They belong to the single order **Myxiniformes**. There are about 70 described species of hagfishes, most of which live in the cold waters of Atlantic and Pacific oceans. *Bdellostoma*, *Myxine* and *Eptatretus* are some of the common genera. The hagfishes are exclusively marine predators and scavengers of the sea. They feed on dead or dying fishes, molluscs, crustaceans and annelids. Hagfishes usually live buried in mud and sand. A hagfish enters the body of the dead or dying animal either through an orifice or by digging a hole into the body. Around the mouth is an array of barbels or sensory tentacles, the tongue has two plates of keratinised teeth that can fold over and act like pincers to rasp bits of flesh (Fig. 12.3 a). For attaching more firmly on its prey, the hagfish often ties a knot in its tail which then moves along the length of the body until it presses firmly against the body of the prey (Fig. 12.3 b)

A whale that dies and falls to the ocean bottom attracts thousand of hagfishes that will feed on it for years!!

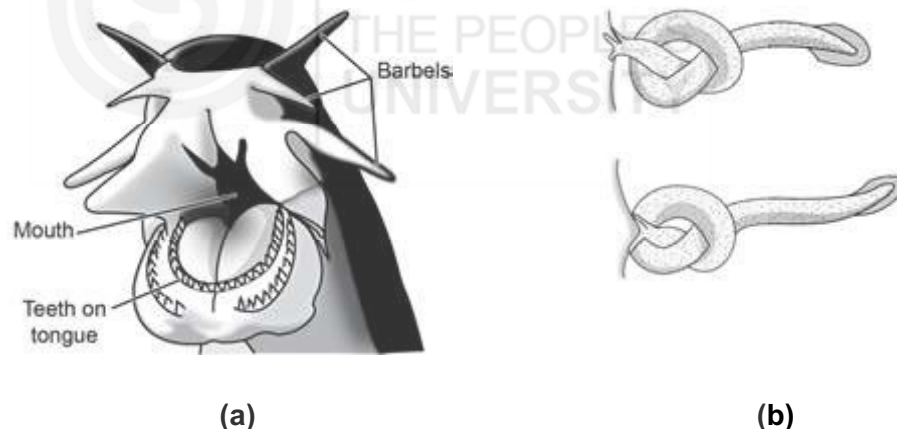


Fig. 12.3: a) Retractable tongue that has two plates of keratinised teeth; b) hagfish knots its tail to attach securely to the body of the prey.

Hagfishes are the only living vertebrates that have a cranium but no vertebral column; skeleton is cartilaginous. Evidence from 18S ribosomal sequence has shown that the vertebrae have been lost secondarily and that they are more closely related to lampreys than as thought previously. They are almost completely blind but have a keen sense of smell and touch which leads them to their food.

Gills are modified into pouches and vary in number between 6 and 14. These open into the pharynx as well as to the exterior by small tubes. In genus *Myxine* all tubes after joining together open to the exterior by a single aperture on each side (Fig. 12.2 a) forming the external gill opening. Water enters through the nostril and is pumped inside the water into the gill chambers. Skin also functions as an organ of gas exchange.

Hagfishes have other anatomical and physiological peculiarities; they have a low-pressure circulatory system with three accessory hearts besides the main heart that lies behind the gills. Unlike other vertebrates the body fluid of hagfishes is isoosmotic to sea water.

Around the bile duct there are insulin B cells that resemble those of vertebrates. Pituitary appears as a primitive organ.

Hagfishes secrete large amounts of sticky mucous or slime from the mucous glands positioned along its body. When disturbed or handled roughly a hagfish exudes a milky secretion that in contact with seawater forms a slippery slime that makes it impossible to hold the animal. Mucous is useful in protection of the animal as well as in feeding.

Reproduction in hagfishes is not well documented. Some hagfishes were thought to be hermaphrodites since in certain individuals, one end of the gonad contains large yolk eggs and the other resembles testis. Since mature sperms are not found in testis, they are not considered as functional testis. In vertebrates, gonads pass through a hermaphrodite stage during development. Hagfish gonad represents a stage in which the intermediate stage still persists. There is no larval stage; the young hatch as completely formed small hagfishes.

Hagfish slime contains hundreds and thousands of thin protein threads. When stretched and dried out the slime resembles spider silk. Potentially it could be used for preparing material with the strength of nylon or plastic, which could have several applications.

SAQ 1

List four characters that are unique to hagfishes.

Class Petromyzontida

Lampreys belong to class **Petromyzontida**. The group's name refers to the stone sucking habit of lampreys (Petros: stone; myzons: sucking) (Fig. 12.4). These animals have the habit of grasping a stone with the mouth to remain stable and not get washed away in a current. There are about 41 species of lampreys worldwide. Lampreys are found in temperate waters of both northern and southern hemispheres and reach upto a length of one meter. There are both parasitic and non parasitic species, those that are parasitic attach themselves by their sucker like mouth to a fish and using their sharp keratinised teeth pull out the flesh to suck the body fluids.



Fig. 12.4: River Lamprey attached to a stone to prevent being washed with the current.

Petromyzon, *Lampetra* and *Ichthyomyzon* are some of the common genera. The body wall of lampreys consists of an epidermis, dermis and a

bunch of collagen-elastin fibers arranged in a circle. The dermis contains pigment cells or chromatophores that impart colour to the skin. The head of lamprey bears a pair of eyes and a conspicuous round sucker. There is an unpaired nasal opening and seven pairs of round gill openings on the body. Paired fins are absent but the tail has a median fin which extends anteriorly as a dorsal fin (Fig.12.2).

There are numerous teeth in the sucker of lamprey. These teeth are horny epidermal thickenings supported by cartilaginous pads (Fig. 12.5 a). The small mouth opens into a large buccal cavity which at its hind end divides into two passages, a dorsal oesophagus and a ventral respiratory tube. The respiratory tube leads into gill pouches and closes behind. At the opening of respiratory tube a series of tentacles known as **velar tentacles** serve to separate the oesophagus and respiratory tube while the animal is feeding. The secretions from the paired salivary glands prevent coagulation of blood on which lampreys feed. Once the lamprey is attached to a fish, it remains so for several days and the fish often dies (Fig. 12.5 b).



Fig. 12.5: a) Buccal funnel of lamprey with the keratinised teeth; b) Parasitic sea lamprey attached to a trout.

Since a stomach is absent, oesophagus leads directly into the intestine. Liver, gall bladder and bile duct appear as in other vertebrates and pancreas is absent. Heart is S shaped and is three chambered. Haemoglobin is the respiratory pigment present in blood corpuscles that are spherical and nucleated. The brain of lamprey is small and is built on vertebrate body plan consisting of forebrain, midbrain and hindbrain (Fig.12.6).

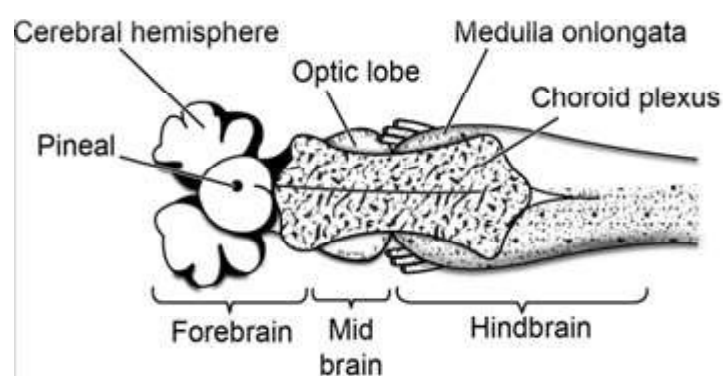


Fig. 12.6: Brain of lamprey showing the typical divisions of forebrain, mid and hindbrain.

Sense organs include a pair of eyes and **lateral line receptors** found along certain lines on the head and trunk. These receptors are helpful in detecting the movement of water relative to fish. There is another specialised sense organ called **labyrinth** which is a part of the lateral line system. Labyrinth responds to vibrations in water and records the position of the head and its angular movements. Besides the usual pair of eyes, lampreys also have a well-developed third eye or pineal organ. It is believed that the pineal organ is concerned with the regulation of daily rhythm of change in colour of animals – dark during day time and pale during night. Pineal organ also appears to influence reproduction and the metamorphosis of the animal.

Excretion is carried out by mesonephric tubules in adult lampreys. Sexes are separate in lampreys. Ovum is released into the coelom. Sperms develop in testicular follicles and are also released into the coelom. Both in males and females, short channels arise from the coelom, and open at the posterior end of the mesonephric duct. Gametes find their way to the water through the mesonephric duct. Fertilization is external. The modification of cloaca ensures fertilization and deposition of eggs.

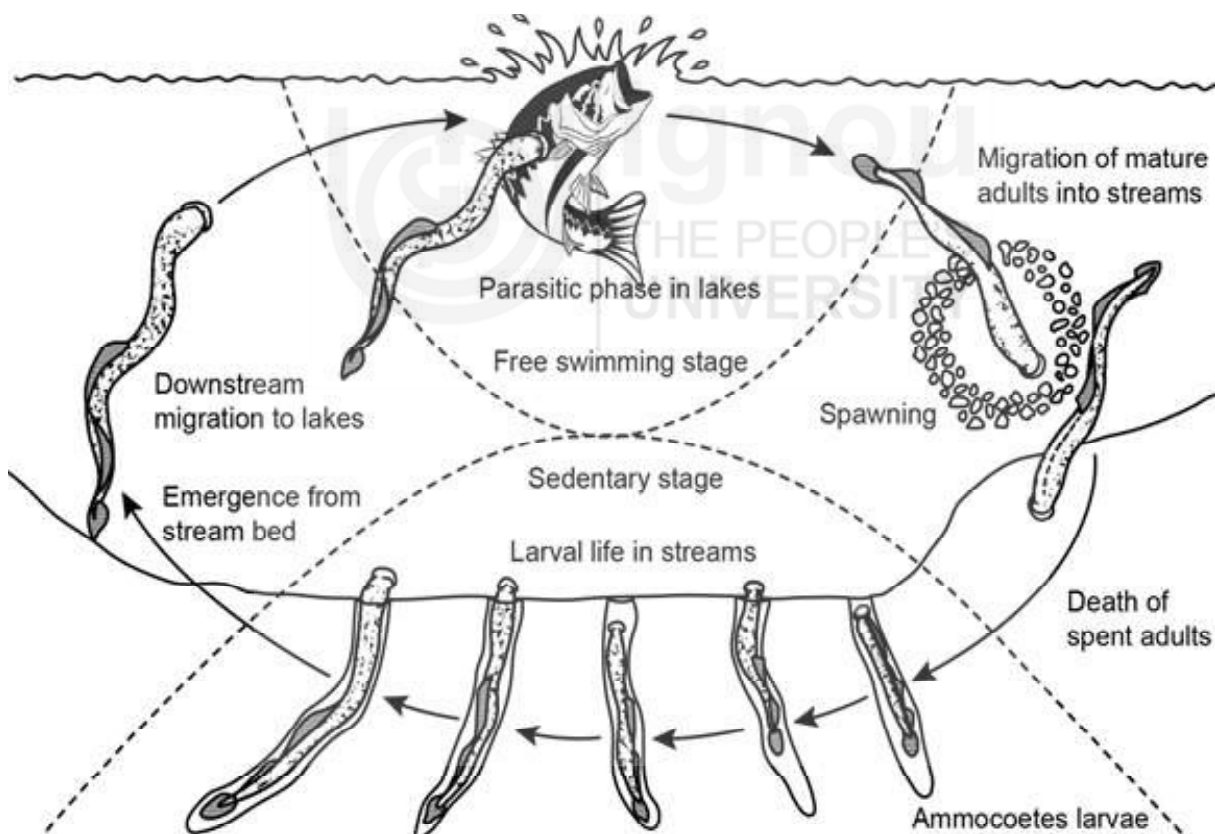


Fig.12.7: Life cycle of marine lamprey *Petromyzon marinus*.

Some species live their entire life in fresh water, others like the sea lamprey (*Petromyzon marinus*) are **anadromous**, that is, they are hatched in fresh water, migrate to the sea to live their adult life and leave the sea and return to spawn in fresh water bodies such as rivers and streams. For spawning, lampreys migrate thousands of kilometers and reach fresh waters (anadromous migration). Spawning is preceded by a form of nest building.

The male builds the nest in shallow waters where the bottom is both stony and sandy. The animals drag the stones by mouth to create a small depression in which the eggs are laid and fertilized externally. Lamprey eggs hatch into the **ammocoetes** larva that is so unlike the adult that biologists once considered them to be a separate species! The larva which resembles *Amphioxus* leaves the nest and burrows into a sandy, low current area for nearly 3 to 7 years, before it metamorphoses into an adult, hence it is called **sand sleeper**. It feeds on microorganisms. The life cycle of lamprey is shown in Fig.12.7. The adults die soon after spawning.

SAQ 2

State whether the following statements are Right or Wrong. Correct the wrong statement:

- Lampreys and hagfishes are exclusively marine in their habitat.
 - All lampreys are hermaphrodites.
 - Lampreys migrate from marine environment to fresh water bodies for breeding.
 - The release of gametes in lampreys is directly into the mesonephric duct.
 - Pineal organ in lampreys is concerned with the regulation of colour change in animals.
 - Ammocoete larvae metamorphose into adults in 3 to 7 days.
-

12.4 SUMMARY

In this unit you have learnt that:

- The most ancient living vertebrates are the jawless fishes grouped as Agnatha. They are the hagfishes and the lampreys. General characters of these fishes are – cartilaginous endoskeleton, no paired fins/appendages; jaws absent, notochord that persists throughout life, no distinct stomach, eyes poorly developed, chambered heart, single circulation, ammonia is their chief excretory product.
- Hagfishes are grouped in class Myxini with a single order Myxiniiformes. They are all marine predators and scavengers. Mouth with four pairs of tentacles; no vertebral canal; 1-16 pairs of gill openings; body fluids isoosmotic with sea water; exude large amounts of slime when disturbed.
- Lampreys are grouped in class Petromyzontida in a single order Petromyzontiformes. Lampreys can be free living or parasitic on other fish, where they attach to live fish sucking their body fluids. Their mouth is surrounded by keratinised teeth but no barbels; 7 pairs of gill openings. Lampreys have rudimentary vertebrae and their brain is typically divided into a fore, mid and hind brain. Some species are exclusively freshwater but some are anadromous, returning from the sea

to the freshwater habitats for spawning. They have small eggs that hatch into a long living ammocoete larva that looks very different than the adult.

12.5 TERMINAL QUESTIONS

1. Correct the given statements.
 - a) Presence of cranium and paired appendages is a characteristic feature of Agnatha.
 - b) In jawless fishes heart is a single chambered structure.
 - c) Development in hagfishes includes a larval stage called ammocoetes.
 - d) Special mucous glands are present in *Petromyzon*.
2. Describe the common morphological features of hagfishes and lampreys. How do they differ from each other?
3. Describe the life cycle of *Petromyzon marinus*.
4. Why are hagfishes and lampreys considered to be more closely related than as thought before?

12.6 ANSWERS

Self-Assessment Questions

1.
 - i) No vertebral column.
 - ii) Production of copious slime.
 - iii) Four barbels surrounding the mouth.
 - iv) They have a low-pressure circulatory system with three accessory hearts besides the main heart that lies behind the gills.
2.
 - a) F
Correct statement: Hagfishes are exclusively marine; lampreys can inhabit marine as well as freshwater.
 - b) F
Correct statement: Sexes are separate in lampreys.
 - c) T
 - d) F
Correct statement: The gametes are released into the coelom and then into the posterior part of the mesonephric duct via a channel.
 - e) T
 - f) F
Correct statement: Ammocoete larvae metamorphose into adults in 3 to 7 months.

Terminal Questions

1.
 - i) Presence of cranium and unpaired appendages is a characteristic feature of Agnatha.
 - ii) In jawless fishes heart is a three chambered structure.
 - iii) Development in lamprey includes a larval stage called ammocoetes.
 - iv) Special mucous glands are present in Myxine.
2. Common features: Elongated rounded body; presence of cranium and unpaired fins; lack jaws and stomach; pore like gill openings; cartilaginous internal skeleton, no ossification.

Differences

Hagfishes: 5-16 pairs of external gill pores; scavengers or predators; almost completely blind; body fluids iso-osmotic with marine water; low pressure circulatory system three accessory hearts in addition to main heart slime glands; no vertebrae. Large yolky eggs and no larval stage during development.

Lampreys: rudimentary vertebrae; exclusively parasitic; mouth with keratinised teeth adapted for sucking body fluids of host. They can be marine or freshwater; migrate from marine to freshwater for spawning, small eggs with long larval stage (ammocoete); 7 pairs of external gill openings, no accessory hearts.

3. Refer to Fig. 12.7.
4. Molecular analysis data suggests that lack of vertebrae in hagfishes is a derived character, their common ancestor had vertebral column and hagfishes and lampreys are monophyletic as they share many characters.

UNIT 13

PISCES|

Structure

13.1 Introduction Objectives	13.4 Bony Fish – Osteichthyes Class Actinopterygii Class Sarcopterygii
13.2 General Characters and Classification	13.5 Osmoregulation in Fish Osmoregulation in Freshwater Fish Osmoregulation in Marine Fish
13.3 Cartilaginous Fish - Chondrichthyes Subclass Elasmobranchii Subclass Holocephali	13.6 Summary 13.7 Terminal Questions 13.8 Answers

13.1 INTRODUCTION

In the previous unit you learned about **agathans** or the jawless fish that along with the extinct **ostracoderms** are the earliest vertebrates. One group of ostracoderms gave rise to the jawed **gnathostomes** (animals with biting jaws). This large assemblage of animals includes a very diverse and large group of jawed fish – superclass Pisces and other jawed animals like amphibians, reptiles, birds and mammals. Out of these groups, fish are exclusively aquatic and have mastered the aquatic environment. A great variety of forms exist in fish and because of the numerous structural adaptations, fish occupy a variety of niches in rivers, freshwater bodies and marine waters including the abyssal depths of the ocean floor.

Living jawed fish belong to either of two classes, **Chondrichthyes** (cartilaginous fish) or **Osteichthyes** (bony fish). Two groups of jawed fish have become **extinct**; those belonging to class **Placodermi** and class **Acanthodii**. When we use the term “fish” we generally include the hagfish and lampreys along with the cartilaginous and bony fish to define any non-tetrapod chordate which has gills throughout its lifetime and appendages, if present, in the form of fins. Thus “fish” are considered a *paraphyletic* group where not all the descendents of a common ancestor are included (had fish been considered *monophyletic* then we would have to include the tetrapods in their group because fish and tetrapods have common ancestors). Recent studies show that there are about 33,000 known species of fish, majority of which are bony fish; about 970 species are sharks, rays and chimaeras; and 108 species are jawless fish. In this unit we will refer to jawed fish only.

Various workers have provided different schemes of their classification. However, no classification had been universally accepted because of the confusion due to staggering numbers of fish and great diversity in their shape, size, habits and habitat.

In this unit we will study the general characters common to all jawed fish and will learn to distinguish between the various classes and orders in which the fish are classified because of their specific characteristics.

Fish inhabit both **freshwaters** and **marine** waters. Since they live and breathe in water, they must maintain ionic balance between their body fluids and their surrounding watery habitat through a process of osmoregulation. We will learn about their **osmoregulatory** process and its importance in allowing the fish to survive and adapt in their environment.

Objectives

After studying this unit, you will be able to:

- ❖ describe the characteristic features of superclass Pisces;
- ❖ distinguish between the cartilaginous and bony fish;
- ❖ classify living fish according to their specific characters up to orders; and
- ❖ explain the process of osmoregulation in fish.

13.2 GENERAL CHARACTERS AND CLASSIFICATION

- Fish are gill bearing non-tetrapod aquatic animals that have a vertebral column and paired appendages in the form of fins.
- The body of a fish is streamlined for movement in water which is a medium 800 times as dense as air (Fig. 13.1).
- It has two sets of paired fins and one or two dorsal fins and a tail fin. Pectoral fins of fish are paired appendages usually just behind the head and the paired pelvic fins are located ventrally and posteriorly.
- Fish are mostly ectothermic and use gills or accessory breathing organs for obtaining oxygen from the water for respiration. Oxygen rich water is drawn through the mouth, passes over the gill surface which is richly supplied with blood capillaries; gas exchange is very efficient in the gills and the water that leaves the gills contains only a fifth of the oxygen initially present in it.
- The skin of fish is usually covered by scales that are dermal derivatives.
- Most fish are carnivorous though there are herbivorous species as well.
- Fish reproductive organs are paired ovaries and testes; there may also be a range of secondary organs that increase reproductive fitness.
- Fish typically have quite small brains relative to body size compared with other vertebrates; however, they have well-developed sense organs.

- Most fish have sensitive receptors that form the lateral line system which detects gentle currents and vibrations, and senses the motion of nearby fish and prey.

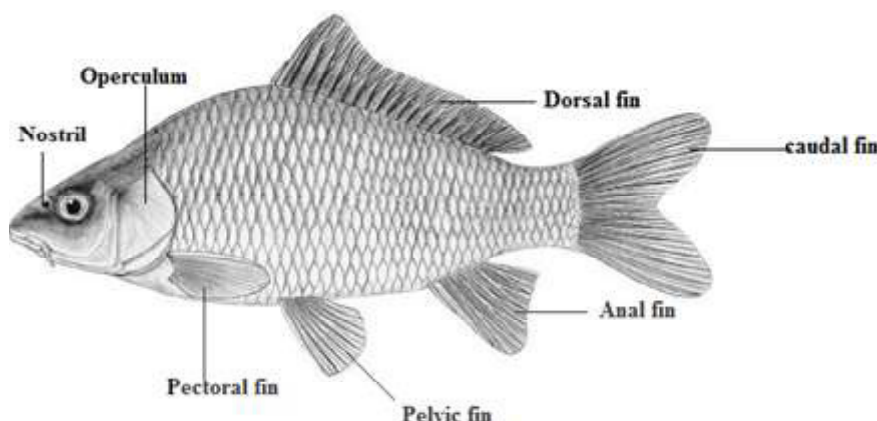


Fig.13.1: Common carp: a typical bony fish.

Let us now become familiar with the classification of fish.

The first fish appeared in the fossil records from the **Silurian** period (see Appendix 1 for the geological time table), however no forms are found that lie between the agnathans and the gnathostomes. In the **Devonian** period which is also known as the **age of fish**, several distinct groups of jawed fish were present. One of these groups; the **placoderms**, became **extinct** in the **Carboniferous** period leaving no descendants.

Another group of fish belonging to the class **Chondrichthyes**, lost the heavy dermal plates of early jawed fish, developed a cartilaginous **endoskeleton** and became the active **predators** of the seas, these have survived almost unchanged over the ages. The other two groups of **gnathostome** fish- **Acanthodii** and bony fish were abundant in the Devonian period and of these the bony fish have diversified and survived till the present. The fish grouped in class **Acanthodii** became **extinct** in the lower **Permian** period and are represented by fossils.

An outline classification of the major fish taxa is given below.

Before starting classification, please understand one thing clearly, that different scientists have classified animals in a different way, here we follow the classification proposed by Nelson (2006). While reading other books, you may come across variations in classification.

Phylum: Chordata

Group: Vertebrata

Superclass: Gnathostomata: Jaws and paired appendages present; appendages may be lost secondarily in some groups; three pairs of semicircular canals; notochord partially or completely replaced by centrum in the vertebrae in the vertebral column.

1. **Class Placodermi:** Extinct armoured fish; primitive jaws with teeth fused to jaw; large predatory forms; considered basal to all gnathosomes.

2. **Class Chondrichthyes:** Skeleton cartilaginous; teeth not fused to the jaws but replaced usually; no swim bladder; intestine with spiral valve; claspers present in males.
 - i) **Subclass Elasmobranchii:** Placoid scales or derivatives present; five to seven gill arches and gill slits in separate clefts on either side along pharynx; upper jaw not fused to cranium. Includes sharks, rays and skates; mostly marine: includes 13 orders.
 - ii) **Subclass Holocephali:** Scales absent; 4 gill slits covered by cartilaginous operculum; jaws do not have teeth but jaw plates; upper jaw fused with the cranium; addition claspers present.
3. **Class Acanthodii:** Extinct group of fish that are so named because of the presence of stout spines anterior to their dorsal, anal and paired fins. They lived from the late Ordovician to late Permian period.
4. **Class Actinopterygii:** Ray-finned fish; skeleton bony; gills covered by bony operculum; paired fins supported by dermal rays; swim bladder functions in buoyancy; atrium and ventricle not divided; teeth covered by enamel.
 - i) **Subclass Cladistia:** (Bichirs) rhomboid ganoid scales; lungs and spiracles present; dorsal fin consisting of 5-18 finlets; e.g., *Polypterus* (16 species)
 - ii) **Subclass Chondrostei:** (Paddlefish and sturgeons), skeleton primarily cartilaginous; caudal fin heterocercal; more fin ray numbers than their support; ganoid scales or large scutes; spiracles present; e.g., *Polydon*, *Acipenser* (26 species, freshwater and anadromous).
 - iii) **Subclass Neopterygii:** (gars, bowfins and teleosts) skeleton bony; caudal fin primarily homocercal; scales are cycloid or ctenoid or absent, very rarely ganoid; in the dorsal and anal fins the fin ray number is equal to their support; examples – *Amia*, *Lepistosteus* and most of the world's bony fish (about 27000 species).
5. **Class Sarcopterygii:** Lobe-finned fish; skeleton bony; gills covered by bony operculum; paired fins thick with internal skeleton and musculature to support; diphyccercal tail; intestine with spiral valve; atrium and ventricle partially divided; usually lungs present; teeth with enamel covering; examples are *Latimaria*, *Neoceratodus*, *Lepidosiren*, *Propterus* (in all 8 species, marine or freshwater).

SAQ 1

From the information given in the section above, construct a flow chart showing the broad classification of fish.

13.3 CARTILAGINOUS FISH - CHONDRICHTHYES

Class **Chondrichthys** includes all the cartilaginous fish. There are about 970 living species placed in this class. Except for 28 species that live in

freshwater, all are marine. They have a combination of specialised characters that ensure their success in the aquatic habitat. Their distinctive characters are:

1. Body **fusiform** or spindle shaped; mouth is ventral; caudal fin in sharks and rays is **heterocercal** that is, the vertebral column turns upwards and extends into the dorsal lobe of the caudal fin (Fig. 13.2 a) and **diphycercal** in **chimaeras** that is, a tail that tapers to a point and vertebral column extends to the tip without upturning (Fig. 13.2 b); paired pectoral and pelvic fins.
2. All have a **cartilaginous** endoskeleton, though extensively calcified; however, bone is absent from the entire class. Absence of bone is a derived character as Chondrichthyes descended from bony ancestors. However, **phosphatised** tissue is found in teeth, scales and spines.
3. Skin has **placoid** scales or may be naked. Notochord present but reduced, vertebrae present and separate from the notochord; jaws with **polyphyodont** teeth (teeth that are replaced several times as they wear out), these teeth are modified placoid scales. Placoid scales have dentine core covered by enamel.
4. Stomach large J shaped, spiral valve in intestine, liver large and oil filled.
5. **Opisthonephric** kidney (See Box 13.1); high concentration of urea and trimethylamine in the blood; rectal gland present.
6. Brain well-developed with 10 pairs of **cranial nerves**; sense of smell, vibration reception, vision and electroreception well-developed; three pairs of semicircular canals present.
7. **Sexes separate**, fertilization **internal**, males have pelvic fins with **claspers** to assist in fertilization; oviparous or viviparous; no larval stage.
8. Five to seven pairs of gills leading to exposed **gill slits**, **no operculum**; no swim bladder or lungs; heart two chambered with **sinus venosus**, atrium, ventricle and **conus arteriorus**; single circulation.

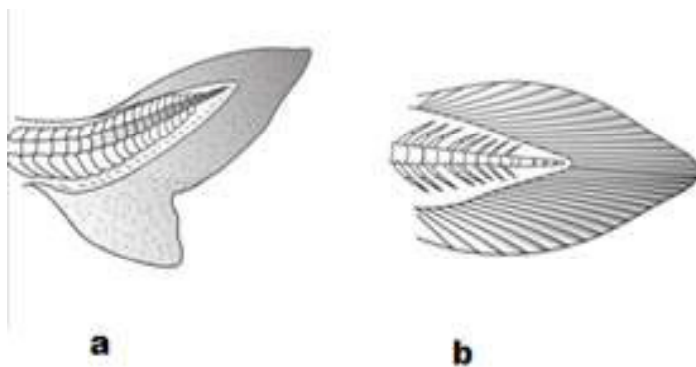


Fig. 13.2: a) Heterocercal tail in Shark; b) Diphycercal tail in Chimaera.

Box 13.1

Kidneys in vertebrates develop in three stages: pronephros which is the functional kidney in adult hagfish, a few bony fish and embryonic form in

other fish and amphibians; mesonephros the transient form in embryonic lampreys, fish and other vertebrates; metanephros which is the functional kidney in adult reptiles, birds and mammals. In all vertebrates some but not all stages are found during development. Fish and amphibians have a mixture of meso and metanephros which is known as opisthonephros. You will learn more about the evolutionary stages in kidneys in later courses.

Class Chondrichthyes is broadly divided into two subclasses

Elasmobranchii and **Holocephali**. Most of the species in this class are elasmobranchs grouped in 12 orders. Holocephali consists of only one order with around 40 extant species.

13.3.1 Subclass Elasmobranchii

There are about 937 species of living **sharks**, **skates** and **rays** grouped in 3 superorders and 13 orders of subclass Elasmobranchii. They inhabit the widest ranges of habitats including the Arctic and Antarctic oceans. Most of the sharks live in shallow tropical waters, however, they are highly adaptable to their environment and can live in varying temperatures. All sharks have gracefully streamlined bodies. Fig. 13.3 shows the structure of spiny dogfish shark (*Squalus acanthias*). You can see that there are paired pectoral and pelvic fins supported by appendicular skeletons; pelvic fin in males is modified to include claspers; two dorsal fins and a caudal fin are present. In *Squalus* each dorsal fin is accompanied with a spine. There is also an anal fin in most sharks (though not present in *Squalus*).

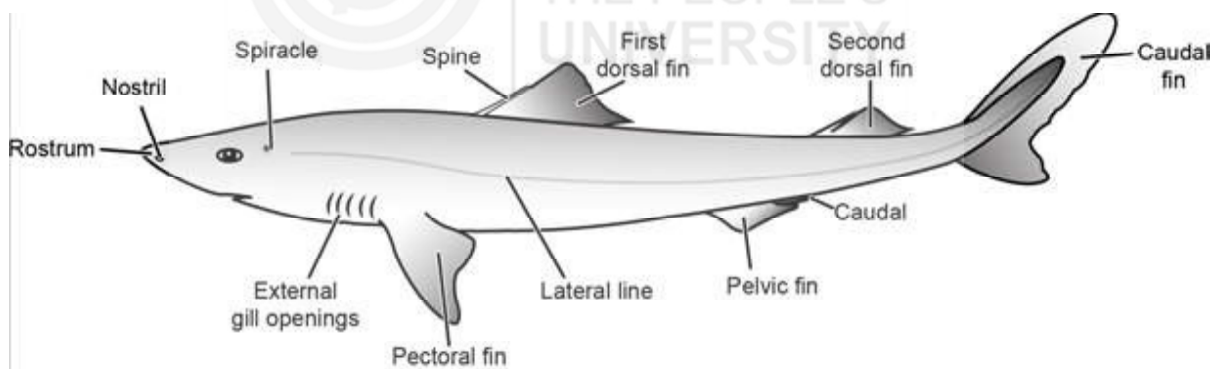


Fig.13.3: *Squalus acanthias* female.

1. The tail is heterocercal, lobes unequal in length and this provides thrust and lift as it moves back and forth while swimming.
2. The lateral eyes are lidless and the remnant of the first gill slit is present as a spiracle behind each eye; paired nostrils are associated with sense of smell.
3. Five gill slits are present anterior to the pectoral fin on each side (in some sharks there are 6 or 7 gill slits).
4. The skin is covered by placoid scales (Fig. 13.4 a) that are composed of a vascular inner core of pulp, a middle layer of dentine and a hard enamel-like outer layer of vitrodentine (Fig. 13.4 b).

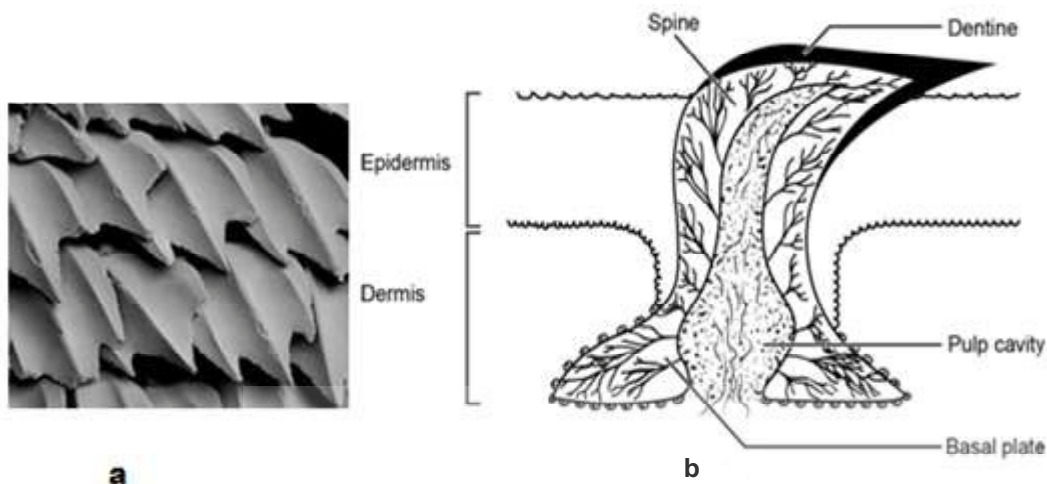


Fig.13.4: a) SEM of placoid scales of white shark *Carcharodon*; b) inside of a placoid scale.

5. The mouth is located ventrally; both lower and upper jaws of sharks have sharp teeth. The front row of functional teeth are followed by back teeth that replace the front teeth regularly as they get worn out.
6. The mouth opens into the large pharynx which has openings for the separate gill slits and spiracles. The pharynx leads to the wide oesophagus followed by a J shaped stomach and short straight intestine with a spiral valve which slows the passage of food and increases the absorptive surface (Fig.13.5). The rectum is short and has a rectal gland attached to it which secretes a colourless fluid containing a high concentration of sodium chloride. This gland is unique to all cartilaginous fish. The rectal gland along with opisthonephric kidney regulates the water and salt concentration in the blood you will learn about their role in regulating the salt and water balance in cartilaginous fish later in Section 13.5.

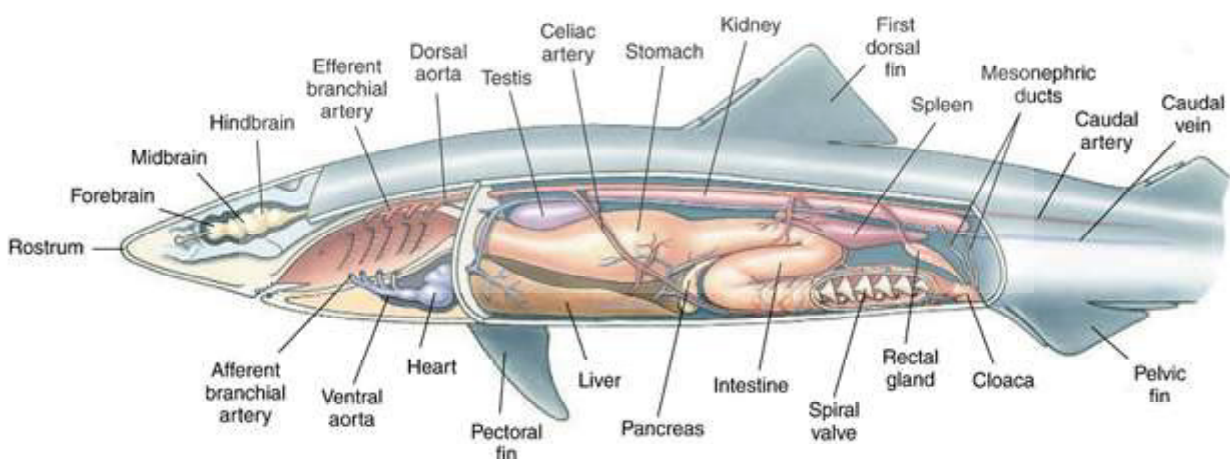


Fig. 13.5: Internal anatomy of dogfish shark.

7. There is internal fertilization, sharks may be oviparous laying large yolky eggs soon after fertilization; some may be ovoviviparous that is, the young are nourished by the yolk but inside the mother, still others are truly viviparous. In these the embryo receives nourishment from the

blood stream through a placenta or nutritious secretions from the uterine milk of the mother. However, all parental care ends once the young sharks are born.

8. Marine elasmobranchs retain nitrogenous compounds especially urea and trimethylamine oxide (TMO) in their extracellular fluids which helps in osmoregulation.
9. Sharks have a sensitive sensory system that enables them to track their prey. Initially they may track their prey from over a kilometer by their large olfactory organs, prey can also be sensed from a distance by the mechanoreceptors in the lateral line system. This system is made up of special receptor organs made up of **neuromast cells** in interconnected tubes and pores arranged on the head and along the sides of the body. Neuromasts are sensitive to disturbances in water enabling the sharks to detect nearby objects by reflected waves in the water. At close range, sharks use their vision for tracking prey. During an attack the sharks are guided by electroreceptors **the ampullae of Lorenzini** that are mainly located on the shark's head and can be seen by the naked eye (Fig. 13.6).

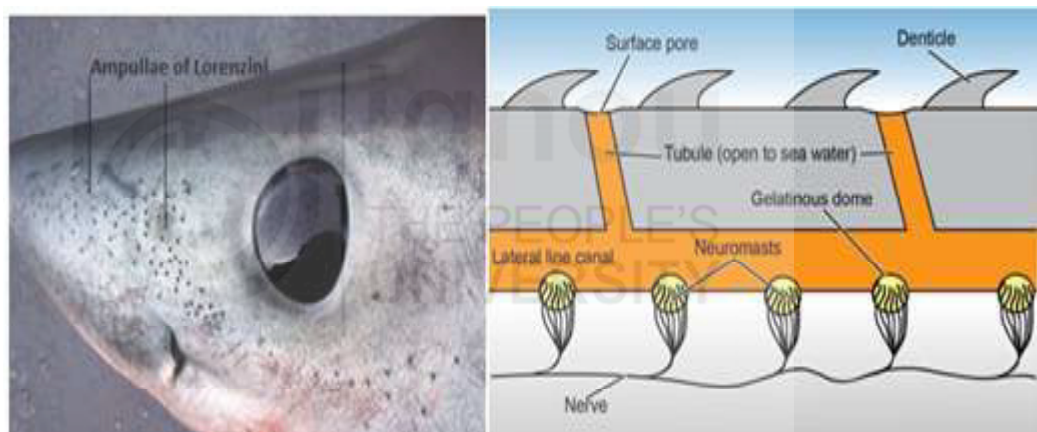


Fig.13.6: Lateral line system with neuromasts and ampullae of Lorenzini; the electro receptors that help in tracking the prey in sharks.

More than half of all elasmobranchs are the rays and skates that are included in superorder Batoidea. This group includes the electric rays, sawfish, stingrays and manta rays.

1. Skates and rays are specialised for bottom dwelling and have a dorsoventrally flattened body and greatly enlarged pectoral fins. Their movement is wavelike by undulating their wing-like pectoral fins which propels them (Fig. 13.7). Differences between skates and rays are summarised in Table 13.1.
2. The gill openings are on the underside of the head and the large spiracles are on the top (Fig. 13.7 b). Water enters through the spiracles which prevents clogging of the gills as the mouth is often buried in sand. Teeth are plate like adapted for crushing prey (molluscs, crustaceans and small fish).

3. Stingrays have a slender whip-like tail with venom glands; wounds from the spines containing venom gland are very painful and often heal very slowly.
4. Electric rays are sluggish with paired electric organs on the head (Fig. 13.8) which can produce severe electric shocks to stun their prey. Each electric organ is made up of numerous vertical stacks of disc like cells that are connected in parallel and can discharge together to produce a high amperage current that flows in the surrounding water.

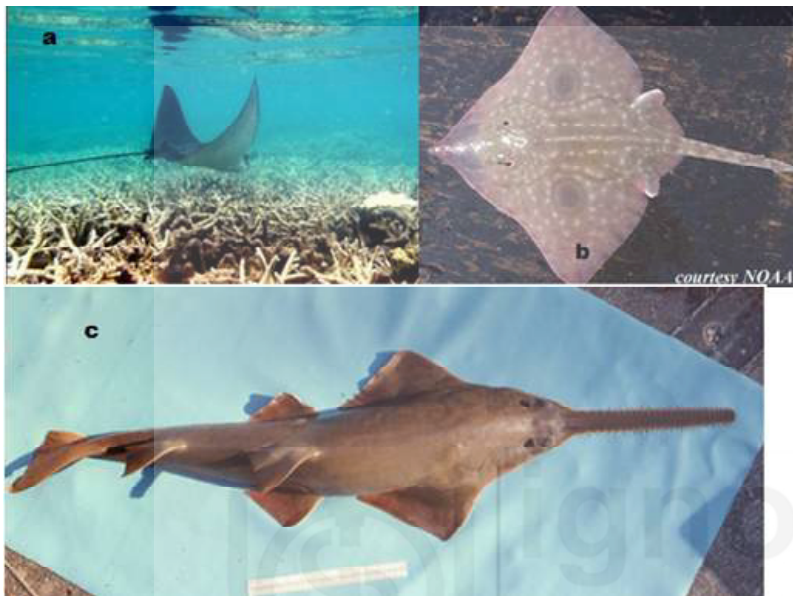


Fig. 13.7: Skates and ray are very well adapted for a life on the ocean floor a) *Myliobatis* one of the largest rays. Observe the fusion of pectoral fins with the head to form wing like structures that are used for swimming. Note the whip-like long tail which carries spines. b) *Raja binoculata* (big skate) lives in the cold waters of northeastern pacific and can grow up to 8 feet long. See the spiracles on the dorsal surface. c) Smalltooth sawfish (*Pristis pectinata*) is a modified ray.

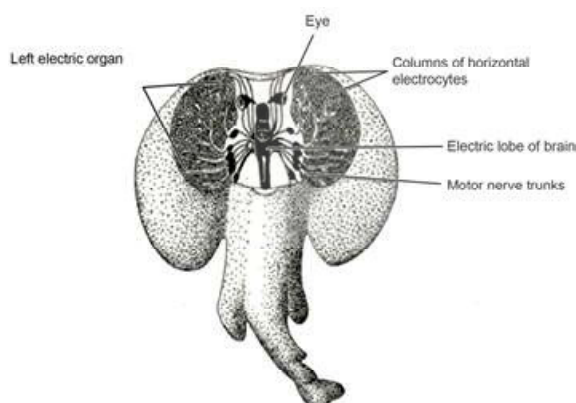


Fig. 13.8: *Torpedo*; the electric ray with paired electric organs exposed. The cells that make up the organs are known as electrocytes. These cells discharge simultaneously to give an output of up to 1Kv depending on the species. The large cerebellum of the brain processes the electrosensory information.

Table 13.1: Differences between skates and rays.

SKATES	RAYS
i) Oviparous; releasing their eggs in hard cases called “mermaid’s purse”	Viviparous
ii) Dorsal fin present and prominent	Dorsal fin reduced or absent
iii) Fleshy tails that lack spines; have thorny projections on the back and tail for protection.	Thin whip-like tails that have one or more stinging spines which are poisonous.
iv) Small teeth present.	Plate like teeth present that are adapted for crushing prey.

13.3.2 Subclass Holocephali

These fish first appeared during Devonian times and flourished in the Cretaceous and early Tertiary periods. The subclass includes about 33 living species and includes rat fish, rabbit fish and elephant fish. The sweeping movements of pectoral fins aid in locomotion. Holocephali possess certain characters that resemble elasmobranchs such as the presence of conus arteriosus, separate urinary and spermatic ducts, urea in blood and the rectal gland. They have very large eyes typical of deep sea species, the head is large. However, they have certain unique features:

1. No spiracle present; gill slits are covered by a cartilaginous opercular flap creating a single external respiratory opening on either side. Gill filaments are free at the tip like in bony fish.
2. In front of the dorsal fin there is an erectile spine which in some forms is poisonous. The tail is thin and long almost rat tail like.
3. The mouth appears as a small opening between the lips. The upper jaw is fused with the skull and the type of jaw suspension is known as holostyly as against the hyostylic jaw suspension seen in elasmobranchs. For this reason this group is known as Holocephali.
4. The teeth appear as broad plates firmly attached to the jaws. These are bottom dwelling fish feeding on molluscs, echinoderms, crustaceans and fish which is a diverse diet considering they have a specialised dentition.
5. The oesophagus leads directly into a broad spiral intestine, the stomach being absent. The intestine in turn leads into a rectum.
6. Besides the pelvic claspers, as in elasmobranchs, male Holocephali have extra claspers in front of pelvic ones and an additional clasper in the head region – the cephalic clasper.
7. The notochord does not show constrictions and vertebrae are reduced to separate nodules. The open lateral line canals are found more on the underside of the snout, probably to detect food.
8. They lay large eggs considering their size; fertilization is internal. The eggs are enclosed in brown horny capsules that could be elliptical, spindle shaped.

Chimaera (Fig. 13.9), known as ratfish dates back to Cretaceous period of the Mesozoic era. But many extinct Holocephali were much older and could be traced to the Carboniferous period.

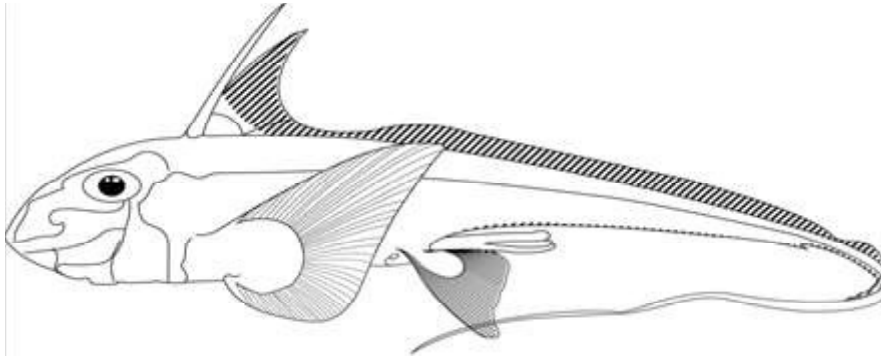


Fig. 13.9: Ratfish - *Chimaera* has a bizarre shape but has pearly iridescence.

The classification of Chondrichthyes is summarised below. You will study the characteristics that are typical of those orders in more detail when the specimens given in the laboratory course are described.

Class Chondrichthyes: Cartilaginous skeleton, bone present in the roots of teeth; 5-7 gill slits in most groups; dorsal fins, fin spines rigid and not erectile when present.

A) Subclass Elasmobranchii: 5-7 gill clefts not covered by a fold of skin but open separately to the exterior; heterocercal tail; body covered with placoid scales.

1. **Superorder Batoidea:** 5 gill slits on the underside; pectoral fins large, united with the head beyond the gill openings; differ from all other sharks by not having an upper free eyelid.

Order Rajiformes (skates and guitar fish): Flattened bodies with large wing like pectoral fins attached to the head that run the length of their bodies; caudal fin may be present or absent, no anal fin; tail long mouth ventral; water for respiration taken in by spiracles on the head, eyes present on the top of head; all have 5 gill slits except six gill stingray *Hexatrigon*; oviparous, eggs laid in egg cases often known as mermaid's purse. Examples: *Acanthobatis*, *Raja*, *Rhinobatos*.

Order Pristiformes (sawfish): Body flattened; long narrow rostrum or nose extension lined on both sides by sharp transverse denticles, rostrum has electrosensitive pores that enable it to detect slightest movement in water; bottom dwelling; euryhaline moving between freshwater and saltwater; critically endangered. E.g., *Pristis* (Fig.13.7 b).

Order Torpidiniformes (electric rays) have a unique electric organ on the head which is capable of emitting electric current from 8-220 volts depending on the species; sluggish bottom dwellers; body rounded with rounded pectoral fins and stout tail; no dermal denticles. E.g., *Torpedo* (Fig. 13.8 a), *Narcine*.

Order Myliobatiformes (stingrays, manta rays, devil rays, eagle rays): Bottom dwelling or pelagic; flat body, large triangular pectoral fins that look like wings; mouth ventral or at the front of head-like in Manta rays. Live in temperate, tropical or subtropical waters, some could be very large in size up to 363 kg (800 pounds). They are born fully formed.

2. **Superorder Squalomorphi:** Characterised by lack of anal fin, nictitating membrane

Order Hexanchiformes (frill sharks): Small order of ancient sharks; 1 dorsal fin, 6-7 gill slits; only 6 living species.

Order Squaliformes (dogfish shark, bramble sharks): Large ancient order, marine; 2 dorsal fins usually with spines, variable shape and size.

Order Squatiniformes (angel sharks): Flattened bodies; broad pectoral fins; benthic marine.

Order Pristiophoriformes (saw sharks): Unique sharks with long snout covered with teeth; 5-6 gill slits; a pair of barbels on the snout; deep benthic; only 8 species.

3. **Superorder Galeomorphi:** Includes all modern sharks except dogfish and relatives; usually 2 dorsal fins with or without spines; anal fin present, caudal fin heterocercal to diphycercal; 5 gill slits, spiracles may be present or absent.

Order Lamniformes (mackerel shark, basking shark): Includes the familiar great white and the unusual goblin shark; 2 dorsal fins and anal fin present.

Order Carcharhiniformes (cat shark, hammerhead shark): Eyes with nictitating membrane; 2 dorsal fins without spines; eyes lateral or dorsolateral.

Order Orectolobiformes (blind shark, zebra shark, whale shark): 5 gill slits present on the sides or dorsolaterally on the head; spiracles small to very large; 2 dorsal fins without spines; pelvic fin small and pectoral fin very large.

Order Heterodontiformes (horn shark, bull head shark): Basal modern sharks; all members relatively small bottom feeders, live in tropical sub-tropical waters; 9 species.

- B) **Subclass Holocephali:** These are bottom feeders; large pectoral fins, thin tail; dorsal fin with erectile spine which may be poisonous; no stomach; upper jaw completely fused with cranium.

Order Chimaeriformes (chimaeras, elephant fish,): Teeth in a single series of a few tooth plates along each jaw; pelvic fin claspers present; dermal armour often present on head; body covered with placoid scales (Fig.13.8).

SAQ 2

- a) Fill in the blanks with suitable words:
- The two sub-classes of Chondrichthyes are and
 - Elasmobranchs have a tail and scales.
 - In rays, the are enlarged and fused with the head.
 - In male sharks the pelvic fins are modified into
 - Elasmobranchs have a mouth.
 - In skates and rays the mouth and are ventral and spiracles are on the side.
- b) What are the unique features of Holocephali?
- c) What are the functions of ampullae of Lorenzini and the lateral line system in sharks?

Endochondral bone develops on and within a cartilage template. The template is entirely destroyed by calcification and subsequent resorption and is replaced by bone.

13.4 BONY FISH - OSTEICHTHYES

In the early Silurian period a lineage of jawed fish gave rise to the first bony fish ancestors. These ancestral forms also gave rise to a group of vertebrates that contain 96% of the living bony fish and the rest of the tetrapods. The bony fish form a large group called **Osteichthyes**. The common characteristic of bony fish and tetrapods is the presence of **endochondral** bone (bone tissue that replaces cartilage during development), presence of lungs or swim bladder that develops from the gut and several dental and cranial characters. They are the most successful aquatic vertebrates occupying all possible niches in fresh water, marine and brackish water.

Fossils of the earliest bony fish show that they shared many common features with that of acanthidians. It is presumed that they also shared a common ancestor.

The main adaptations of bony fish that lead to their wide diversity are:

- They have an **operculum** on either side composed of bony plates attached to muscles covering the gills. This feature increases the respiratory efficiency by rotating outwards, thus creating a negative pressure assisting the water to flow along with the mouth pump over the gills.
- A gas filled **diverticulum** of the oesophagus provides further means of gas exchange in oxygen deprived waters. In fish that use this gas filled diverticulum exclusively for breathing this diverticulum is called **lung** and in fish that use this gas filled chamber for buoyancy it is called **swim bladder**.
- Specialisation of jaw muscles and skeletal elements for feeding is another adaption found in bony fish. The mouth is terminal or subterminal; jaws usually with teeth.

4. Well-developed lateral line system(a system of sense organs to detect movement, vibrations, pressure gradient in surrounding water, internal ear with 3 semicircular canals in internal ear.

The bony fish diverged into two groups by the middle Devonian period:

- i) the ray-finned fish (class Actinopterygii) that include the modern bony fish and
- ii) the lobe-finned fish (class Sarcopterygii) that have only 2 living groups– the lungfish and coelacanths, and which include the ancestor for the sister group of land vertebrates.

Let us first look at the general features of Class Actinopterygii along with its classification.

13.4.1 Class Actinopterygii

Actinopterygii or the ray finned fish are the largest assemblage of bony fish that we are familiar with. The earliest actinopterygians found in fossil records known as palaeoniscids (ancient sea fish), were small fish with large eyes and covered with thick interlocking scales made of a kind of enamel **ganoin**. These fish had a single dorsal fin and numerous bony rays derived from scales and had a heterocercal tail-like the elasmobranchs. They were abundant in the Devonian period and shared the waters with lungfish and other lobe finned fish. From the earliest ray finned fish arose several clades or groups that gave rise to the modern day fish.

General Features of Actinopterygians

1. Actinopterygians or ray-finned fish have a skeleton with bone of endochondral origin.
2. Caudal fin is heterocercal in ancestral forms but homocercal in descendent forms (Fig. 13.10).
3. Skin with mucous glands; ganoid scales in ancestral forms but cycloid or ctenoid (see Fig. 13.11) or absent in derived forms. Scales grow throughout life.
4. Paired fins thin, broad without fleshy basal lobes but supported by long dermal rays, their movement is controlled by muscles in the body.
5. Double external nares are present; olfactory sacs do not open in the mouth.
6. Teeth with a covering of enamel; spiral valve present in stomach in ancestral forms but absent in derived forms.
7. Respiration by gills supported by gill arches and covered by a bony operculum. Swim bladder may or may not be connected to the oesophagus by a duct and usually functions in buoyancy of the fish.
8. Heart consists of sinus venosus, undivided atrium and ventricle; single circulation; 4 aortic arches, erythrocytes nucleated.
9. Excretory system consists of paired opisthonephric kidneys.
10. Sexes separate. Fertilization usually external; usually oviparous, rarely ovoviviparous or viviparous; larval forms very different from the adults.

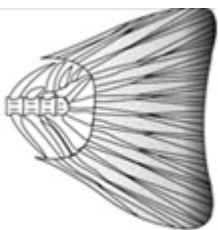


Fig. 13.10: Homocercal caudal fin in bony fish.

11. In the nervous system brain with a small cerebrum, optic lobes, cerebellum; ten pairs of cranial nerves; three semicircular canals.

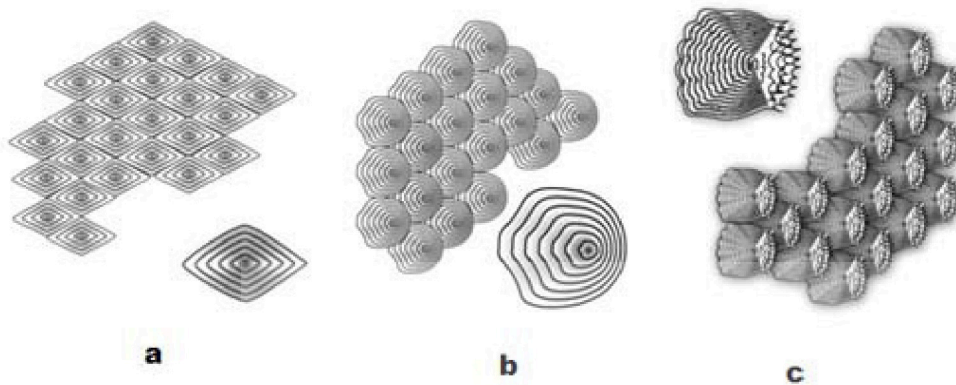


Fig. 13.11: Types of scales in bony fish. a) diamond shaped ganoid scales, present in early bony fish and living gars, these are covered by silvery enamel (ganoin) on the upper surface and bone on the lower; b) cycloid scales; c) ctenoid scales; both these types are thin and flexible and arranged in overlapping rows in teleost fish.

Classification of Actinopterygians

The living actinopterygians are placed in 3 subclasses made up of 44 orders and about 27,000 species. You will learn about the distinguishing features of some of the orders in the laboratory course as you study the specimens representing those orders.

- A) Subclass Cladista:** This class includes the most primitive of the actinopterygians that have heavy ganoid scales and lungs and other features similar to palaeoniscids. There is only one **order Polypteriformes** with one family consisting of 16 species of bichirs (Fig.13.12) found in the freshwaters of Africa.

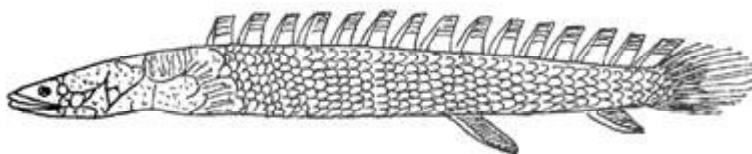


Fig. 13.12: The bichir *Polypterus* is found only in African freshwaters.

- B) Subclass Chondrostei:** Represented by 27 species of freshwater, anadromous sturgeons and paddle fish (Fig.13.13) placed in one **order Acipenseriformes**. Almost no internal ossification; scales large and arranged in isolated rows. Sturgeons may be as large as 20 feet and usually have a long life upto 60 years in some species.



Fig. 13.13: Siberian sturgeon *Acipenser baerii*.

- C) Subclass Neopterygii:** The third group that arose from the palaeoconscids were the neopterygians. These diversified in the Mesozoic era and one such group gave rise to the modern bony fish – the **teleosts**. Only three genera still survive from the early non teleost neopterygians, they are placed in two orders:
- i) **Order Lepisosteiformes** consists of two genera of gars – *Lepistosteus* and *Atractosteus* that are found in eastern and southern North America (Fig. 13.14). Gars are large predatory fish with elongated bodies and needle like teeth in their jaws. They are large fish that look lethargic but are sharp predators. Their vascularised swim bladders can function as lungs and they come up from the water to gulp air. They have large ganoid scales.
 - ii) **Order Amiiformes** includes the bowfin – *Amia* found in the weedy waters of Great Lakes and river basin of Mississippi in North America.



Fig. 13.14: a) spotted gar *Lepistosteus*; b) Bowfin *Amia calva*.

Division Teleostei: All remaining actinopterygians are placed in this group. These are the modern day fish representing about 96% of all living fish. Teleosts occupy all possible niches and display varied morphological diversity and adaptations that allowed them to flourish. Teleosts show a reduction in bony elements e.g. they have fewer bones in the skull and fewer vertebrae. The position of the paired fins changes in various groups of teleosts; dorsal fin position and functions also change in different groups and they have a more efficient feeding mechanism. Fig. 13.15 shows the anatomy of a common freshwater teleost.

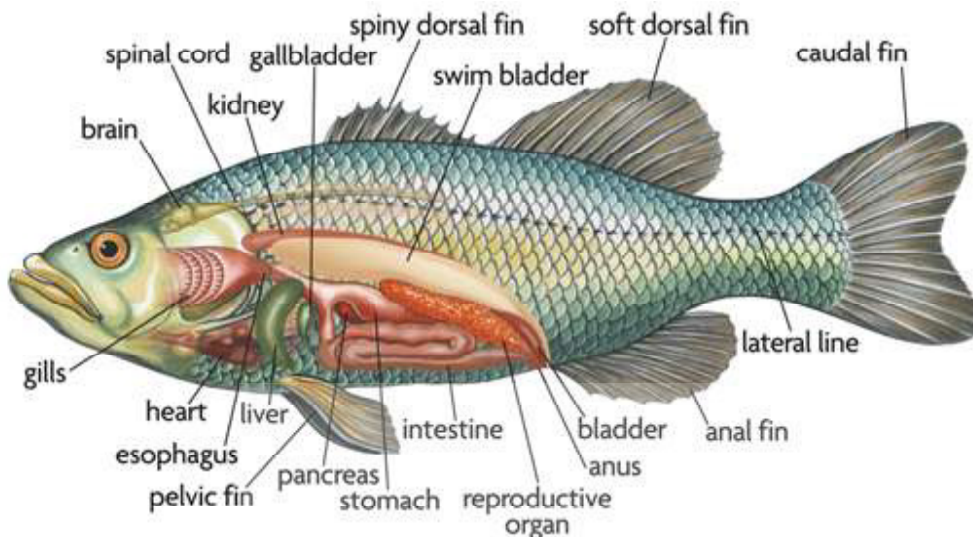


Fig.13.15: Anatomy of a yellow perch.

1. The modern teleosts have a streamlined body; the heavy armour of the primitive ray finned fish is replaced by lighter cycloid or ctenoid scales (Fig. 13.11) which are more flexible and allow greater speed in movement for predator avoidance or catching prey.
2. They have a fully homocercal caudal fin with equally sized lobes that extend from the end of the spine. With its attached musculature, this fin enables greater speed in movement. The elaborate paired fins are used in precise steering, camouflage, protection, attachment or social communication.
3. Changes in jaw suspension allowed greater suction which aids in respiration. They have highly mobile mouth parts; the bones of the upper jaw maxilla and premaxilla are movable which allows them to protrude their upper jaw forwards when they open their mouth. This enables them to catch prey and suck it inside the mouth swiftly.
4. Respiration by gills. The gills are composed of thin filaments covered by a very thin membrane that folds repeatedly to form plate-like lamellae (Fig.13.16). The lamellae are richly supplied with blood capillaries where gas exchange takes place as the oxygen rich water moves in through the mouth, flows over the gills and leaves through the single gill slit. The flow of water is in the opposite direction of the blood flow so that maximum oxygen is extracted from the water.
5. Most teleosts are carnivorous; the prey is seized by sharp pointed teeth present in the jaws and on the roof of the mouth and swallowed whole. Some fish are herbivorous, or scavengers or omnivorous. The mouth leads into the pharynx and short oesophagus, a sphincter prevents the water from entering the stomach from the respiratory system. The intestine is long and coiled and there is no spiral valve.

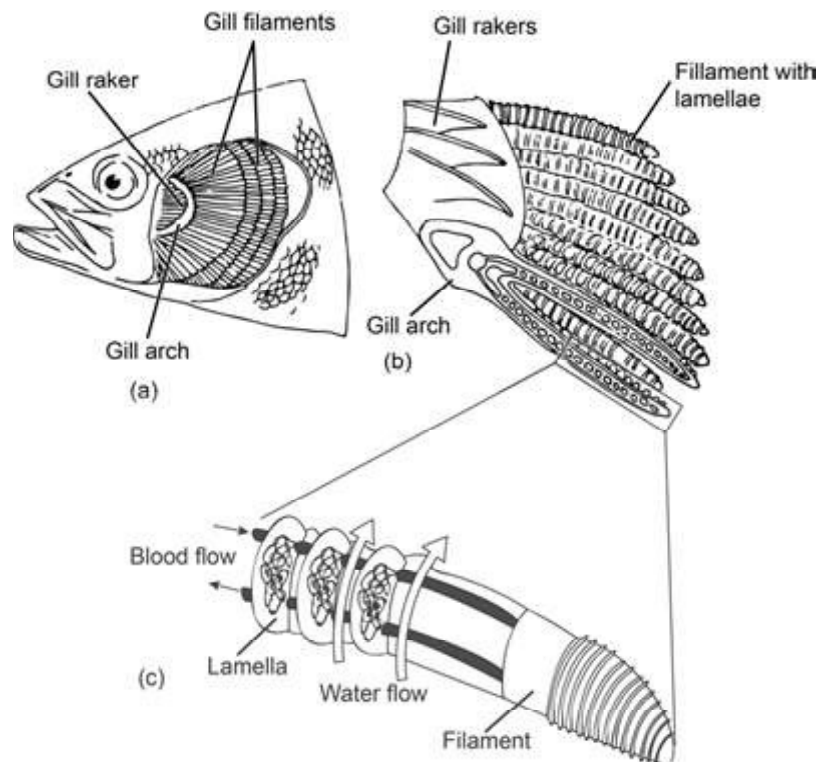


Fig. 13.16: a) Gills of fish with the operculum removed to show the branchial chamber with the gills. There are 4 gill arches on each side; b) shows the gill rakers that strain the debris and food and the gill filaments project to the rear; c) shows a single gill filament after dissection to show the plate like lamellae.

6. All fish are heavier than water. Teleosts have a floatation device the swim bladder, which (Fig.13.17 a and b) shows fine control in resorption and secretion of gases to improve control of buoyancy allowing the fish to remain at one depth or ascend or descend without much expenditure of energy. In primitive teleosts the swim bladder is attached to the oesophagus but in fish where the swim bladder is closed there is a network of capillaries that serves as countercurrent exchanger of gases between the swim bladder and the blood.

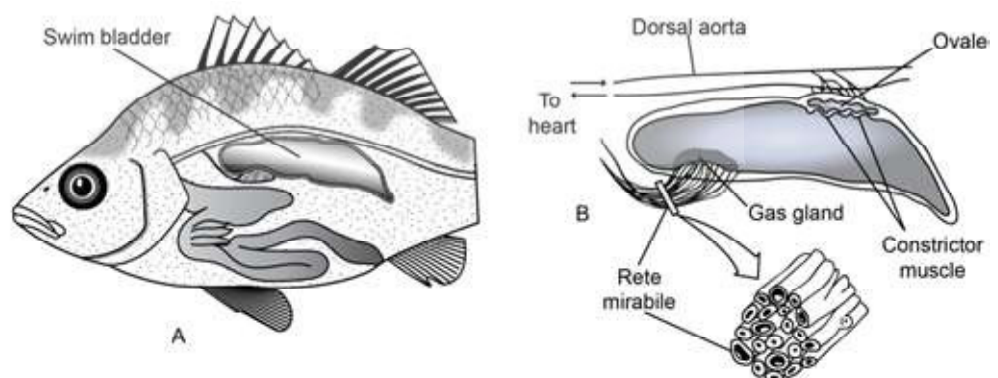


Fig. 13.17: a) swim bladder; and b) the arrangement for gas equilibrium through retae mirabile.

7. The heart contains three chambers in a series – sinus, atrium and ventricle. The muscular conus arteriosus found in elasmobranchs is absent.

8. Most teleosts have separate sexes with external fertilization and external development. The female lays eggs in batches that are then fertilized by the male, the larvae do not require further parental care. However, some teleosts are viviparous and some provide parental care with the male usually guarding the eggs and fanning them to provide increased oxygen. Many freshwater teleosts show elaborate courtship behaviour. Genital system and excretory system is entirely separated from each other in both sexes.

Now that you have learnt about the general characters of teleosts we will briefly study the classification of living fish placed in Division Teleostei. The modern teleosts are placed in 4 subdivisions each including several orders as given below. You are not expected to memorise the names of all orders but will be able to appreciate the immense diversity and numbers of modern day fish.

1. **Subdivision Ostoglossomorpha:** Probably the most primitive living bony fish with rudimentary caudal skeleton and lack of inter-muscular bones in the abdominal and caudal part of the body; contains 2 orders of freshwater species.
 - i. **Order Hiodontiformes:** The anal fin is long and the caudal fin is forked. Two living species are goldeye and mooneye.
 - ii. **Order Osteoglossiformes:** have toothed or bone tongues, include butterfly fish, and elephant fish.
2. **Subdivision Elopomorpha:** Consists four orders of mostly marine fish. Typically has a ribbon-like larva known as **leptocephalus** which is entirely unlike the adult. Swim bladder not connected to the ear.
 - i. **Order Elopiformes:** Body slender, usually compressed, gill opening wide and caudal fin deeply forked. (tarpons, ladyfish, tenpounders).
 - ii. **Order Albuliformes:** Bonefish.
 - iii. **Order Anguilliformes:** Different types of marine and freshwater eels, Morey eels, (Fig.13.19 a). Spagatti eels etc. Body elongated, dorsal, anal and caudal fins fused to form a single ribbon-like fin. Gill chamber modified. Do not have gill rakers. Pelvic fins and girdle absent, scales usually absent or if present are cycloid.
 - iv. **Order Saccopharygiformes:** Deep sea fish similar to eels but have significant differences in internal anatomy.
3. **Subdivision Ostarioclupeomorpha:** Consists of two superorders.
 1. **Superorder Clupeomorpha:** Includes only one order.
 - i) **Order Clupieformes:** Body compressed in most of its member fish. Internal connection between ear and swim bladder has a pair of extensions that extend into the skull; pneumatic duct connected to gut or stomach; includes some of the important food fish-like sardines, denticle herrings, anchovies, pilchards, shads mostly marine. Plankton feeders with many gill rakers.

2. **Superorder Ostariophysi:** This has five orders of mostly freshwater fish. All except the first order have modification in the first four vertebrae that connect the inner ear to the swim bladder forming an apparatus known as the **Weberian apparatus** used for amplifying sound transmission (Fig. 13.18).

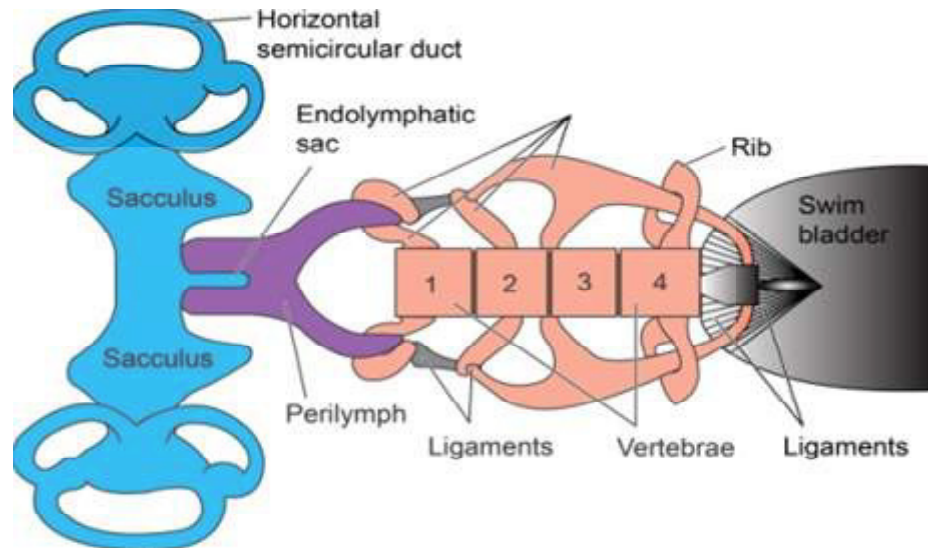


Fig.13.18: Weberian apparatus consists of four pairs of bones, called ossicles, derived from the vertebrae immediately following the skull. The bones link the swim bladder and inner ear and serve to enhance hearing by conducting pressure changes produced by externally originating sound waves from the swim bladder to the ear.

- i) **Order Gonorynchiformes** (milk fish, beaked salmons): These are important food source. Have a primitive Weberian apparatus.
- ii) **Order Cypriniformes:** All freshwater; one of the largest orders with about 400 families. Includes minnows (Fig.13.19 b), carps, loaches. Most diverse in South East Asian waters. Always toothless, head not covered by scales, barbels may or may not be present. Includes most food and ornamental fish; also includes the zebrafish which is important for genetic and developmental studies (Fig.13.19 i).
- iii) **Order Characiformes:** Teeth always present, almost always scaled; scales may be ctenoid; very diverse in morphology many popular aquarium fish. Includes characins, tetras, African tetras, hatchet fish, headstanders.
- iv) **Order Siluriformes:** Body naked or covered with bony plates; normally up to four pairs of barbels on head, one nasal, one maxillary, and two on chin. Spine, like rays often present at the front of the dorsal and pectoral fins that could be poisonous. Includes catfish (Fig. 13.19 c), mostly freshwater, few species marine.
- v) **Order Gymnotiformes:** American knifefish, eel-like body with electric organs, found in freshwater in southern Mexico, Central America, and South America. Pelvic girdle and pelvic fins absent; anal fin extremely long, caudal fin absent or reduced.

vi) **Subdivision Euteleostei:** Consists of nine superorders and 28 orders, both freshwater and marine fish.

1. **Superorder Protacanthopterygii:** Includes four orders

- i) **Order Argentiniformes:** Adipose fin may be present; caudal fin forked (argentines/marine smelts).
- ii) **Order Osmeriformes:** Freshwater smelts. Adipose fin may or may not be present; some may be marine, anadromous; always spawn in freshwater.
- iii) **Order Salmoniformes:** Salmonids, salmon and trouts (Fig.13.19 d). Freshwater and anadromous; food and game fish live in the Northern Hemisphere; adipose fin present; last three vertebrae upturned.
- iv) **Order Esociformes:** Elongated snouts, long, well-muscled torsos, forked tails, no adipose fin; dorsal and anal fins set well back and opposite each other for rapid acceleration along a straight line (pikes and pickerels).

2. **Superorder Stenopterygii:** Includes one order

- i) **Order Stomiiformes:** Dragonfish, hatchetfish. All marine, mostly deep sea, luminescent organs present.

3. **Superorder Ateleopodomorpha:** Includes one order

- i) **Order Ateleopodiformes:** Jellynose fish; caudal fin reduced and united with long anal fin; pelvic fin with single elongated ray on the throat in adult; snout bulbous.

4. **Superorder Cyclosquamata:** Includes one order

- i) **Order Aulopiformes:** All marine, deep sea fish; exception is lizardfish that lives in coral reefs, tripod fish. Gill arches specialised and unique to this order.

5. **Superorder Scopelomorpha:** Includes one order

- i) **Order Myctophiformes:** All marine, occur primarily in deep waters; lantern fish.

6. **Superorder Lampriomorpha:** Includes one order; all members are marine.

- i) **Order Lampriformes:** Includes velvetfish, the tube-eyes and ribbonfish.

7. **Superorder Polymixiomorpha:** Includes only one order; all members are marine.

- i) **Order Polymixiformes:** Includes the beardfish; barbels suspended from anterior part of gill arches.

8. **Superorder Paracanthopterygii:** Includes five orders

- i) **Order Percopsiformes:** Trout-perch; all freshwater, small in size, pelvic fins if present are always behind the pectorals.

- ii) **Order Gadiformes:** Includes the cods, grenadiers, hakes, pollocks, most of them marine except one species of freshwater burbot (*Lota lota*). Mostly found in temperate or cold waters. Major food fish belong to this order.
- iii) **Order Ophidiiformes:** Includes many deep sea tropical and subtropical freshwater and marine fish including *Abyssobrotula galathea* found in the deepest waters of the Puerto Rico trench. Includes cusk-eels and pearl fish. Have small heads and long slender bodies; smooth scales or no scales, long dorsal fin that runs into the caudal.
- iv) **Order Batrachoidiformes:** Includes only one family of toadfish that are benthic ambush predators, mostly marine except a few species that are found in fresh waters of South America.
- v) **Order Lophiiformes:** Includes anglerfish (Fig.13.19 e), many species with angling devices to attract prey, all marine.

The rest of the teleosts are known as acanthomorphs (spiny ray fish). Many members have true fin spines in the dorsal, pelvic and anal fins.

9. **Superorder Acanthopterygii:** These spiny fin fish make up a large assemblage of 13 orders. They are the most advanced and diverse fish. The fins are supported by sharp inflexible spines or rays; mouth highly protrusible. Divided into three series:

Series Mugilimorpha: Members mostly marine and anadromous; consisting of one order.

- i) **Order Mugiliformes:** Includes the mullets. They have two separate dorsal fins, small triangular mouth and absence of lateral line organs.

Series Atherinomorpha: Small surface oriented fish; primarily (about 75%) freshwater or brackish water. The only naturally occurring population of unisexual fish (all females) present in this group; varied methods of internal fertilization.

- ii) **Order Cyprinodontiformes:** Killifish. Caudal fin truncated or rounded. Aquarium fish usually brightly coloured.
- iii) **Order Beloniformes:** Needlefish, flying fish. Fixed non protrusible upper jaw (Fig.13.19 f).
- iv) **Order Atheriniformes:** Surfsilversides, rainbowfish, silverbacks. Usually two dorsal fins; anal fin preceded by spine, lateral line system weak.

Series Percomorpha: Perches or perch like fish. Pelvic fin with one spine and five rays or less; pelvic girdle connected to pectoral girdle by ligament; ctenoid scales; includes nine orders.

- v) **Order Stepanoberyciformes:** Body rounded; skull bones are extremely thin; marine. Whalefish generally deep sea with luminescent organs.

- vi) **Order Beryciformes:** Marine, mostly nocturnal; roughies, flashlight fish, lantern fish.
- vii) **Order Zeiformes:** Marine deep sea; commercially important fish; dories, tinseltail.
- viii) **Order Gasterosteiformes:** Marine and freshwater; snipefish, pipefish, seahorses (Fig. 13.9g), trumpetfish, sickleback one of the most studied fish for its courtship behaviour.
- ix) **Order Synbranchiformes:** Pharynx modified for air breathing; largely freshwater in tropics. Swamp eels, spiny eels.
- x) **Order Scorpaeniformes:** Velvetfish, flatheads, gurnards, horsefish, scupins; the world's most venomous fish are found in this order.
- xi) **Order Perciformes:** Largest number of species in the vertebrate group and among the fish 1/3 belong to this order; gobies, cichlids, wrasses, basses, perches, breams, snappers, butterflyfish (Fig. 13.19 h), pomfrets, snooks, angelfish and many other ornamental fish. Very varied in size and weight.
- xii) **Order Pleuronectiformes:** Mostly marine. Flounders, halibuts, hogchokers, soles. Both eyes on the same side of the head, skull twisted and asymmetrical.
- xiii) **Order Tetradontiformes:** Highly derived fish; spikefish, boxfish (Fig. 13.19 j), molas, pufferfish. Beak like snout, marine, occasionally freshwater, bottom dwellers.

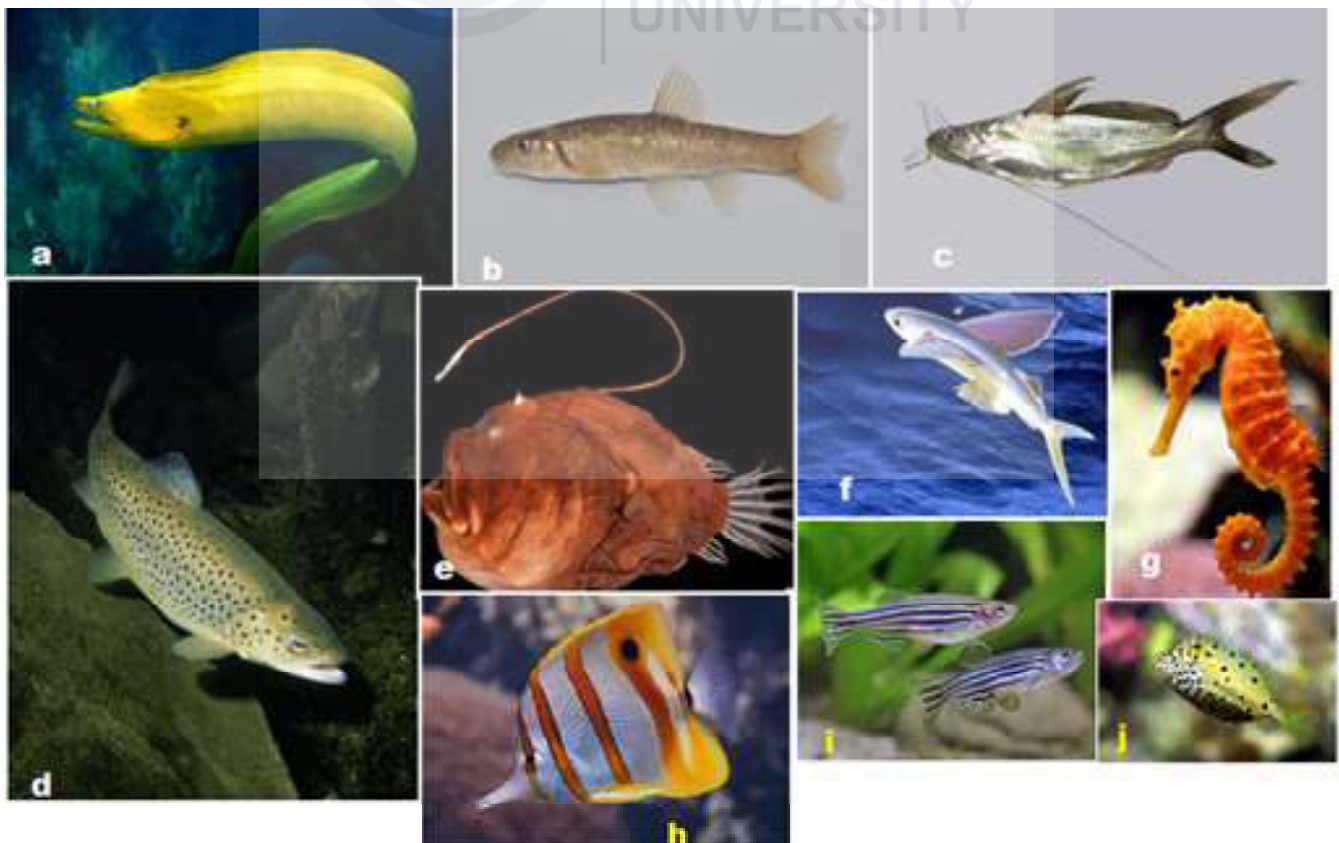


Fig. 13.19: Diversity in teleosts.

SAQ3

- Draw a flowchart to summarise the classification of bony fish up to superorders and give only the number of orders (names not required).
- Name the three living genera among the non teleosts in subclass Neopterygii.

13.4.2 Class Sarcopterygii

These are the lobe finned fish. The name Sarcopterygii earlier referred to only fish but it has become clear that the tetrapod ancestor was a sarcopterygian fish, therefore, the group has been enlarged to include the tetrapods as well.

The early lobed fin fish fossils appeared in the Devonian period in the fresh waters; they were large headed fish with fleshy fins; had both lungs and gills and a heterocercal tail. In the Paleozoic era the vertebral column's orientation changed and the tail became symmetrical diphyccercal type (Fig. 13.2 b). The sarcopterygians had powerful jaws, fleshy paired fins that may have been used like legs to crawl over the riverbeds. The extant sarcopterygians are represented by only 8 fish species placed in two orders.

General Characters of living Sarcopterygian fish

Caudal fin is diphyccercal; paired pectoral and pelvic fins present that are supported by stout bones and bony rays. Muscles control the movement of the fins. Gills covered by bony operculum; swim bladder is present and used for respiration in lung fish.

Heart with sinus venosus, atrium and partially divided ventricle and a conus arteriosus. Pulmonary and systemic circuits incompletely separated.

Skeleton ossified; skin covered by bony dermal scales (cosmoid) covered by cosmine which is a form of dentine. Jaws with polyphyodont teeth covered by true enamel. Intestine with spiral valve.

Brain small but well-developed; 10 pairs of cranial nerves; three pairs of semicircular canals.

Sexes separate; fertilization internal in coelacanth and external in lung fish.

Living sarcopterygians are placed in two orders:

Order Coelacanthiformes: Only one living genus *Latimaria* (Fig. 13.20). This genus was discovered off the coast of South Africa in 1938. Later more specimens were found off the coast of Comoro Islands. In 1998 another species was found from Sulawesi, Indonesia. Coelacanth is metallic blue in colour with irregular white or brassy spots. The swim bladders are not used for respiration but are filled with fat bodies. The young are born fully formed after hatching internally. They have lived almost unchanged for 380 million years! Their fins have ball and socket arrangement just like arms of the terrestrial vertebrates.

An interesting resource is found on youtube: "Coelacanth a Fish that Time Forgot" that gives the history of its discovery.



Fig. 13.20: Model of *Latimeria* the only surviving genus of coelacanth. These fish are blue in colour.

Order Ceratodontiformes: Consists of 3 living genera of lungfish (Fig. 13.21); the most primitive of these is the Australian lungfish *Neoceratodus* which may be as large as 1.5 meters, this fish unlike the other two genera cannot survive outside the water as it relies entirely on gills for respiration. The South American lungfish *Lepidosiren* and the African lungfish *Protopterus* can survive for a long time outside the water. Since African freshwater streams dry up regularly, *Protopterus* burrows in the riverbeds before the dry season arrives, secreting copious amounts of slime that forms a hard cocoon in which it survives during the dry period and gets its oxygen from the atmosphere using its lungs. The oxygen reaches all the tissues through the partially separated pulmonary and systemic circulation.

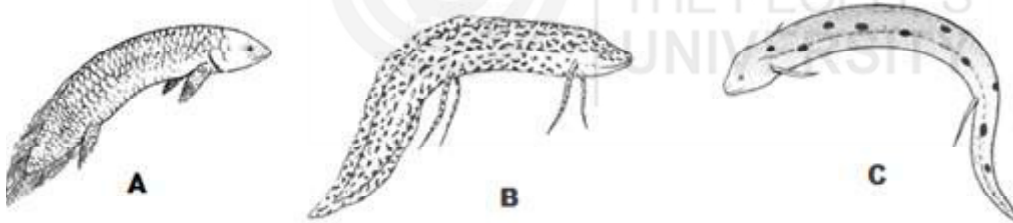


Fig. 13.21: The three species of lungfish a) *Neoceratodus* or the Australian lungfish resembles the primitive lungfish, it has paddle-like pectoral and pelvic fins; b) *Lepidosiren* (spotted African lung fish), it has long and thin pectoral and pelvic fins; and c) *Protopterus* which is the African lungfish and the most well adapted to survive in dry conditions.

SAQ 4

How are sarcopterygians different from actinopterygians?

In the next Section you will learn how fish cope with the osmotic stress by maintaining their water and electrolyte balance in their aquatic habitat.

13.5 OSMOREGULATION IN FISH

Any animal achieves water balance only if the input and output of water is equal. All cells in an animal's body need very precise concentrations of the essential electrolytes like Na^+ , K^+ , Cl^- and Ca^{2+} to function and the

electrolyte balance is also crucial for their survival. Since fish live in water it is important that their body fluids are regulated in terms of salts and water content in relation to the medium in which they live. The process by which living organisms control the concentration of water and salt balance in their bodies is known as **osmoregulation**. Fish are **osmoregulators** because they actively regulate the osmolarity (concentration of solutes) in their body fluids. In this Section we will see how freshwater and marine habitats pose different challenges to fish in maintaining their water and electrolyte balance in the body.

13.5.1 Osmoregulation in Freshwater Fish

Freshwater is a very dilute medium with a salt concentration of 0.001 to 0.005 gram moles /liter (M). This salt concentration is much lower than that found in the body of freshwater fish (0.2 to 0.3 M). Therefore, cells in the gills of freshwater fish are **hypertonic** relative to the surrounding. This means that the solution inside the cells have more solutes than the surrounding water; as a result water enters the cells of the epithelium by osmosis and moves from there to the other cells of the body and salt tends to move out of the cells by diffusion. However, ionic concentration of 0.2 to 0.3 M has to be maintained if the fish are to survive. Freshwater fish are therefore, **hyperosmotic regulators** and have different strategies to face this challenge.

1. They do not drink water.
2. They have opisthonephric kidneys that are capable of forming a very dilute urine by reabsorbing NaCl in the tubules.
3. Although the scales on the body and the mucous covering on the body make the body almost impervious to water, gills are in contact with the water constantly and, excess water is pumped out of the gills. There are special cells in the gill epithelium that absorb salt (Na^+ and Cl^-) actively from the water back into the blood. Along with this the food they eat brings back salt in the body (Fig. 13.22 a).

13.5.2 Osmoregulation in Marine Fish

Marine bony fish have tissues that are **hypotonic** to the saltwater in which they live that is, their body contains fewer solutes (0.3 to 0.4 M) than the solution outside (about 1M) and *they tend to lose water and gain salts*. This loss of water occurs mostly through the gill surfaces as they are directly in contact with seawater. Marine fish are thus **hypoosmotic regulators**. To prevent the water loss, marine bony fish drink seawater and the excess salts (Na^+ , Cl^- , and K^+) that enter the body are eliminated by special cells in the gill epithelium. The remaining ions, mainly Mg^{2+} , SO_4^{2-} , Ca^{2+} are thrown out of the body in the faeces or excreted by the kidneys via tubular secretion. Because marine teleosts secrete very little urine, the glomeruli in the kidneys have a very insignificant role to play, they are reduced in number or are lost completely (in pipefish and frogfish) and such kidneys are called **aglomerular**. Fig. 13.22 a and b show a diagrammatic representation of osmoregulation in freshwater and marine teleosts.

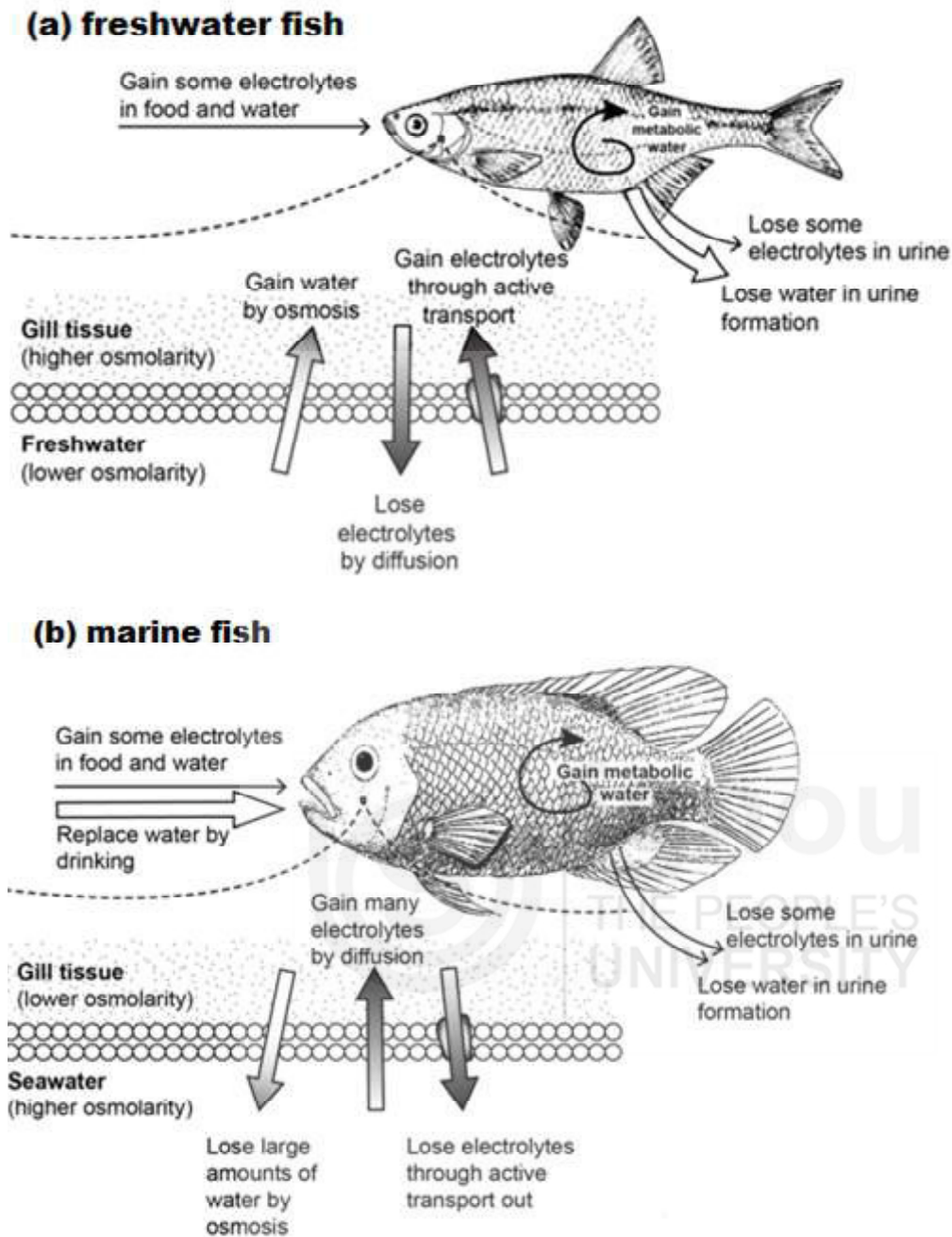


Fig.13.22: Water and salt regulation in freshwater and marine teleosts. a) Freshwater fish gain water by osmosis and lose salts by diffusion; b) Seawater fish lose water by osmosis and gain electrolytes by diffusion.

Elasmobranchs on the other hand are **isotonic** to the seawater and have different strategies for maintaining osmoregulation. To prevent water from being drawn out of their body elasmobranchs retain their nitrogenous products inside their body in the form of urea and trimethyl amine oxide (TMAO) in their extracellular fluid. This along with the salt content in the body increase the blood solute concentration more than the surrounding seawater so that a balance is maintained. Urea is retained in the body because gills have very low permeability to urea. Influx and efflux of water is minimised as the salt content of the body mimics that of the marine water. While studying shark anatomy biologists discovered an organ which secreted concentrated salt solution, which they called **rectal gland**. To study

its function researchers studied the function of this organ *in vitro* that is outside the body, by connecting dissected rectal gland with the blood vessel that supplies it with blood in the body. The dissected gland was immersed in a solution that had the composition of shark body fluids and a tube was connected to the rectal gland which brought out their secretions in the environment. They then introduced Na, K and Cl ions in the same concentration in which they occur in normal shark body fluids and found that the rectal gland secreted a concentrated solution of these ions. By adding ATP molecules to their preparation of the solution, they concluded that the ions were actively transported against the concentration gradient. Subsequent research found that this mechanism is found in other animals like marine teleost, birds and reptiles that have similar salt secreting cells in other locations in their body.

About 90% of bony fish are restricted to either freshwater or seawater habitats as they would not be able to exist in the wrong environment (stenohaline). However, 10% of the teleosts can move between freshwater and seawater habitats. Such fish are known as **euryhaline** fish. There are two types of euryhaline fish, those that live in estuaries or intertidal zones where salt content of water fluctuates according to tides and fish-like salmon, eels that spend part of their lifecycles in freshwater and part in seawater. Researchers found that anadromous salmon (the eggs are laid in fresh water and young migrate to the sea to live for several years and then migrate back to freshwater streams to breed) had two types of salt secreting cells in their gill epithelium. One kind of chloride cells, that are active when salmon is in seawater and excretes excess salt; the other kind that actively imports salt from the water. Similar mechanisms have been found in other euryhaline fish as well. However the exact mechanism in this switch over in the function of chloride cells in the gills is not very well understood.

13.6 SUMMARY

In this unit you have studied:

- Fish are the oldest jawed, aquatic, gill breathing vertebrates that have fins for appendages. They have originated from ancestors that lived in the Cambrian period and flourished in the Devonian.
- Fish are broadly classified in two groups viz. the Chondrichthyes and the Osteichthyes. Chondrichthyes have a cartilagenous skeleton, paired fins, well-developed sense organs, and are active and predaceous; these are mostly marine. They can be divided into two subclasses– Elasmobranchi (sharks rays and skates) and Holocephali (chimeras). Bony fish are divided into two classes the Actinopterygii or the ray finned fish which is a large diverse group of fish that includes most of the familiar fish that we see today; and Sarcopterygii or lobed finned fish represented by lung fish and coelacanths. Tetrapods have arisen from one branch of this group.
- Actinopterygians can be divided into 3 subclasses Cladistia which includes the bichirs; Chondrostei which includes the sturgeons and

paddle fish and the Neopterygii which includes the gars, bowfins and the modern bony fish i.e. the teleosts.

- Teleosts are a very large and diverse group of fish that live in marine and freshwater habitat. This group includes about 27000 species placed in more than 30 orders. They have diverse body forms and adaptations for buoyancy in the form of a gas filled swim bladder. Sensitivity to sound is increased by the presence of a set of bones forming the Weberian ossicles that transmit sound from the swim bladder to the inner ear.
- All fish have an efficient system of osmoregulation. Marine and freshwater fish have different solutions for maintaining their osmotic and ionic balance. Marine fish are hypoosmotic regulators. Marine bonyfish retain their water by excreting salts through chloride cells in the gill epithelium and drinking water, while freshwater fish are hyperosmotic regulators and excrete copious urine and have salt absorbing cells in their gill epithelium. Some teleosts are euryhaline and can live part of their lives in freshwater as well as saltwater. They adjust in these two differing environments by either secreting salts (when in seawater) and salt absorption (when living in freshwater). Elasmobranchs retain their nitrogenous compounds like trimethyl amine oxide and urea in their extracellular fluids and secrete salts through special cells in their rectal glands.

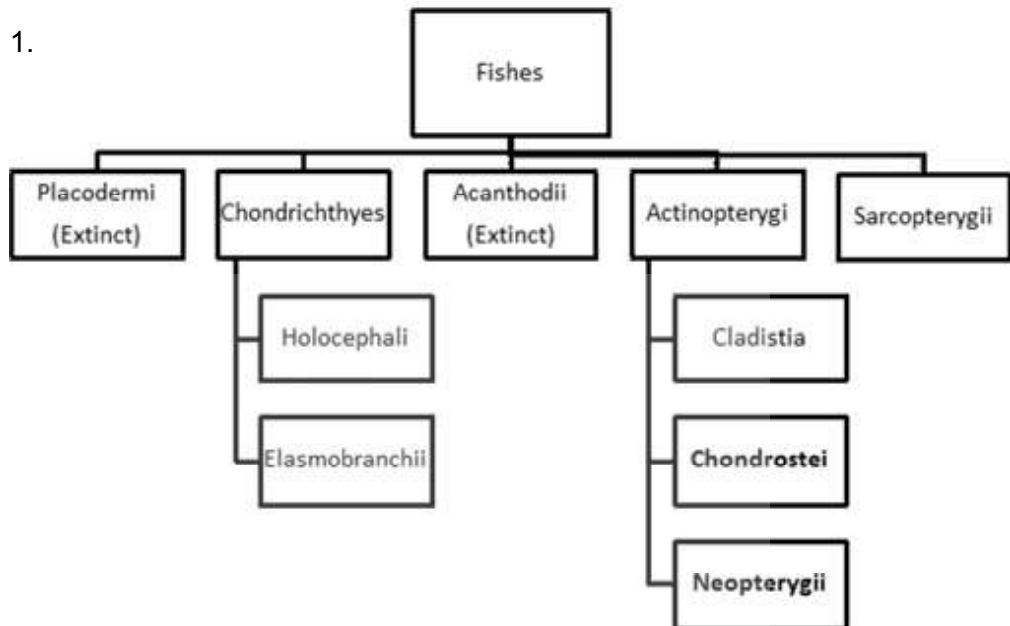
13.7 TERMINAL QUESTIONS

1. Give one word/short answer for the following:
 - i) Give one prominent difference between sharks and rays.
 - ii) What kind of tail characterises elasmobranchs?
 - iii) In what way are sharks well adapted for predatory life habit?
 - iv) What is the function of the lateral line system in elasmobranchs?
 - v) How is the Chimera different from sharks and rays?
2. If you are given two fish i.e. one perch and one dogfish, what external features would enable you to identify one of them as bony fish and the other as elasmobranch?
3. Make a flow chart to list the various superorders and orders that are placed in subclass – Elasmobranchii.
4. Explain the three most important adaptations found in bony fish that have made them successful in their aquatic environment.
5. Define the following terms:
 - a) stenohaline
 - b) euryhaline
 - c) hypoosmotic regulator
 - d) rectal glands in sharks
6.
 - a) Why do marine teleosts need to drink large amounts of seawater?
 - b) How do the freshwater teleosts overcome their osmoregulatory challenges?

13.8 ANSWERS

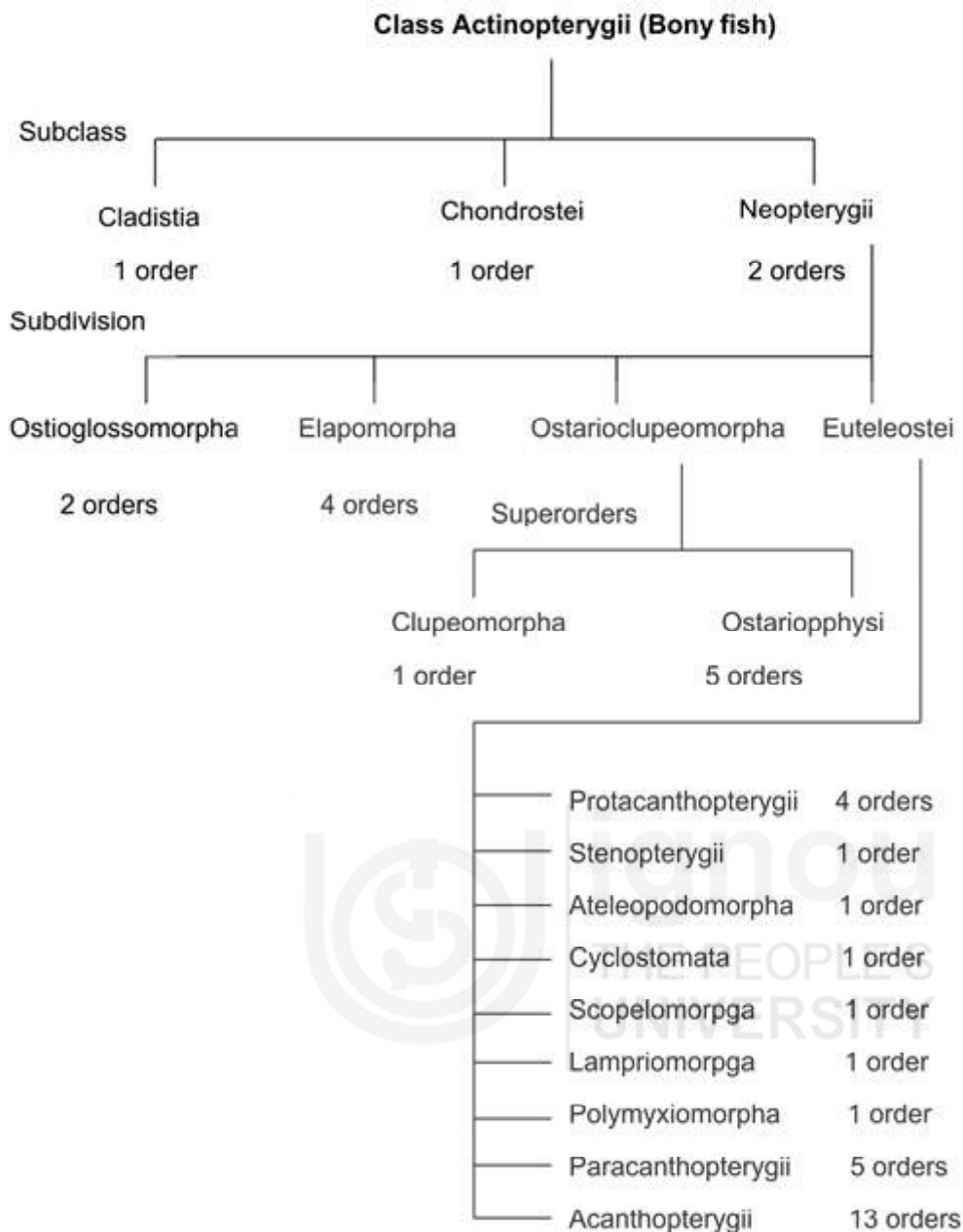
Self Assessment Questions

1.



2. a) i) Elasmobranchii and Holocephali; ii) heterocercal, placoid; iii) pectoral fin; iv) claspers; v) ventral mouth.
 b) No Spiracles; no stomach; jaw completely fused with cranium (holostylic); gill slits covered by cartilaginous operculum; teeth fused with the jaws forming plates.
 c) Electoreceptors that help in tracking prey. Lateral line is a system of pits and canals on the body of the fish that is made up of mechanoreceptors. These cells are able to detect disturbances in the water.
3. a) Refer to sub-section 13.4.1 and draw the flowchart.
 b) *Amia*, *Acipenser*, *Lepisosteus*.
4. Differences between Sarcopterygians and Actinopterygians:

Sarcopterygians	Actinopterygians
1. Tail diphyccercal	Tail homocercal
2. Paired pectoral and pelvic fins stout and fleshy with bone and bony rays	Paired pectoral and pelvic fins supported by bony rays
3. Muscles controlling movement of fins present in the fin	Muscles controlling movement of fins present in the trunk
4. Swim bladder used for respiration	Swim bladder used mainly for buoyancy
5. Heavy jaws and enameled scales	Ganoid, cycloid, ctenoid scales
6. Pulmonary and systemic circuits incompletely separated	Single circulation



Terminal Questions

1. i) Sharks have streamlined body; rays have dorsoventrally flattened body; Sharks have polydont sharp teeth while rays have plate-like teeth.
- ii) Hertrocercal.
- iii) They have a highly developed sensory system made up of large olfactory organs, lateral lines composed of neuromasts and electro receptors – ampullae of Lorenzini on the head; excellent vision; powerful jaws with both upper and lower jaw having many sharp teeth. Powerful musculature for swimming.
- iv) Detect low frequency vibrations with mechanoreceptors known as neuromasts placed in interconnected tubes and pores that extend along the sides of the body and over the head.

- v) Do not have individual teeth but large flat plates that are fused to the jaws. Upper jaw completely fused to the cranium; Gills covered by cartilaginous operculum with single opening while sharks and rays have gill slits that open to the exterior.
- 2. **Hint:** You should look at the external features of a bony fish and a dogfish in terms of their body shape, type of scales, type of tail, number and position of fins, placement of mouth, presence or absence of operculum/gillslits etc.
- 3. Refer to Sub-section 13.3.1 and make flow chart.
- 4. Three most important adaptations of bony fish: i) Presence of bony operculum attached to muscles that increases respiratory efficiency; ii) a gas filled outgrowth of the oesophagus called swim bladder that provides additional way of respiratory gas exchange and helps in the buoyancy; iii) specialisation of jaw musculature and skeletal bones that helps in efficient catching of prey .
- 5. a) Stenohaline: aquatic organisms that have restricted tolerance to salt water.
b) euryhaline: able to live in both saltwater and freshwater.
c) hypoosmotic regulator: marine fish that are able to maintain lower salt content in their body cells relative to the surrounding seawater.
d) rectal glands in sharks: secrete concentrated salt solution from the body.
- 6. a) The cells of marine fish have $\frac{1}{3}^{\text{rd}}$ the concentration of salt than seawater therefore, water from their cells tend to diffuse out and salt enters in. To replace the lost water marine fish drink large quantities of seawater.
b) Freshwater teleosts lose salts as their cells have a higher concentration of solutes than the water surrounding them (flow is from a higher gradient to a lower one). At the same time they gain water by osmosis. If this excess water is not removed then the cells would burst, therefore freshwater teleosts excrete large amounts of dilute urine and do not drink water. To make up for the lost electrolytes they take in NaCl through the gill membranes through active transport and through tubular reabsorption in the kidneys.

UNIT 14

AMPHIBIA

Structure

14.1 Introduction Objectives	14.4 Parental Care in Class Amphibia Parental Care in Urodela Parental Care in Anura
14.2 Class Amphibia Salient Features of Amphibia General Organisation of Amphibia	14.5 Summary
14.3 Classification of Amphibia Order Anura (Salientia) Order Gymnophiona (Apoda) Order Caudata (Urodela)	14.6 Terminal Questions 14.7 Answers

14.1 INTRODUCTION

In the last unit you were introduced to phylum Chordata. You learnt about the salient features of the phylum and the classes included in it. You also learnt about primitive chordates, the protochordates, which represent a transition between invertebrate and vertebrate animals. In this unit you will begin the study of Vertebrata. You are aware that **Pisces** (Fishes), **Amphibia**, **Reptilia**, **Aves** and **Mammalia** are the five main groups of subphylum Vertebrata. Of these five groups, the first three include animals which are **poikilotherms** or cold blooded animals. The body temperature of cold blooded animals conforms to the ambient temperature or the temperature of the environment in which they live, and does not remain constant. Birds and mammals, on the other hand, have a constant body temperature and are classified as warm blooded animals or **homeotherms**. Also reptiles, birds and mammals are grouped under **amniota**, that is animals that develop an amnion during their embryonic life. Fishes and amphibians are anamniotes. In this unit you will study about the characters and classification of the organisms which live both in water and land, the amphibians.

Amnion is the inner most of the extra embryonic membranes forming a fluid filled sac around the embryo.

Amphibians include the only living vertebrates that have a transition from water to land in both their ontogeny and their phylogeny. Even after 350 million years of evolution, amphibians remain quasiterrestrial, hovering between aquatic and land environments. This double life is expressed in their name. Even the amphibians best adapted for a terrestrial existence cannot stray far from moist conditions. Many, however, have developed ways

to keep their eggs out of open water where their larvae would be exposed to enemies. Amphibians on the other hand, have switched over to land, but have not completely forgotten their ancestral home. The transition in habitat from water to land was a slow evolutionary process that spanned over a million years. The process led to a series of alterations in vertebrate body plan that fitted these organisms to life on land. Nearly 7667 species of amphibians have been described so far.

Objectives

After studying this unit, you should be able to:

- ❖ list the characters of class amphibia in general;
- ❖ describe the characteristics of its three orders;
- ❖ discuss adaptations of amphibians to their respective habitats; and
- ❖ explain parental care in amphibians.

14.2 CLASS AMPHIBIA

One of the most significant events to have occurred during the course of animal evolution is the movement of animals from water to land. The shift from aquatic to terrestrial environment required varied structural, functional and behavioural modifications in the organisms. In fact such changes required alterations in almost every system of the body. This also explains the basic similarities in the fundamental structural and functional pattern of all vertebrates. Although among the vertebrates, amphibians were the first one to make the transition to land, among the invertebrates insects had done it much earlier and plants were the earliest. But among all the organisms that made transition to land, amphibians can be regarded as an important group as their descendents are the most advanced animals on land. The organisational modifications that were required for switching over to life on land were:

- i) the ability of the organism to support its weight
- ii) resist drying and rapid temperature changes and
- iii) extract oxygen from air.

In the Devonian period, some 400 million years ago, the climate was characterised by alternating droughts and floods. The drought resulted in the drying up of fresh water bodies and those fishes that could not use atmospheric oxygen for respiration could not survive drought since their gills were unusable in such conditions. But many lobe finned and ray finned bony fishes did survive the drought periods because they had a lung developed as an outpocket of pharynx. With increased vascularisation and rich capillary network and a supply of arterial blood from the last pair of aortic arches, lungs became the primary organs of gas exchange in tetrapods. A pulmonary vein returned the blood to the heart that completed the pulmonary circuit. Thus the phenomenon of double circulation came to be established,

with the systemic circulation serving the body and the pulmonary circulation supplying the lungs.

The evolution of pentadactyl limbs occurred during the Devonian period. The drying up of ponds and pools forced the fishes to move to neighbouring pools that still contained water. The crossopterygians used their lobed fins as paddles to lever their way across the land in search of water. Essentially, therefore, the limbs did not develop for purposes of colonisation of land but rather to live like a fish. But both lung and limb development were the adaptations that were required for a successful life on land. Most amphibians have to return to water (become temporarily aquatic) for purpose of reproduction. This means that these organisms still maintain their connection with the aquatic environment; hence the name Amphibia.

We shall now briefly look into some of the salient features of class Amphibia before describing their general organisation.

14.2.1 Salient Features of Amphibia

Frogs, toads, salamanders and blind worms are examples of Amphibia. Amphibia lack an exoskeleton. The endoskeleton is bony. The number of vertebrae differ in different groups. Some forms have ribs while others do not. A notochord is absent.

Body may have an elongate trunk with a distinct head, neck and tail or it could be a depressed body with fused head and trunk and with no intervening neck. Skin appears smooth with many glands including some poison glands (Fig. 14.1), skin also contains pigment cells or chromatophores of different types. Generally scales are absent but in some, dermal scales may be present.

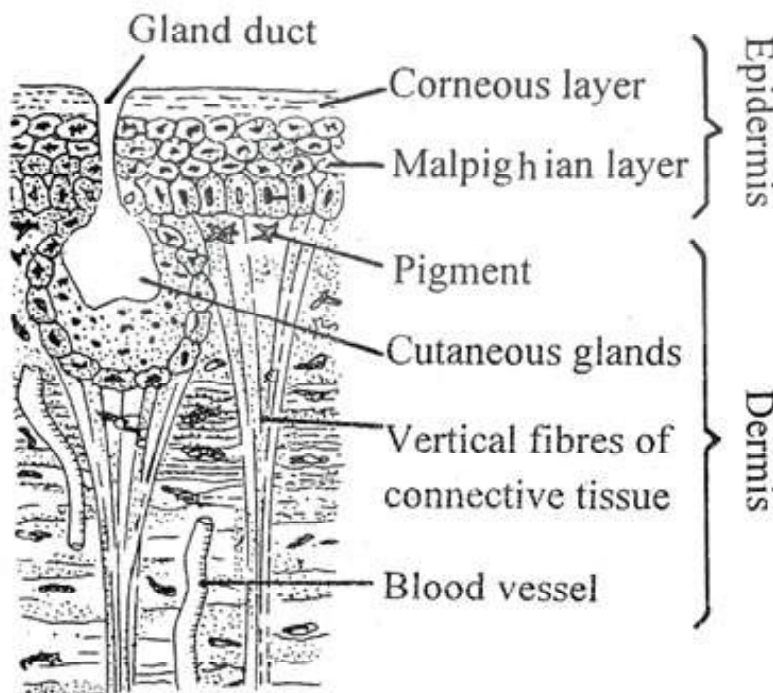


Fig. 14.1: A section through frog skin.

Most of the amphibians have four limbs, while some have secondarily lost the limbs. In some forms forelimbs are shorter than hindlimbs and in some others all limbs may be very small and inadequate to be used for locomotion. Many forms have web in their feet as an adaptation to aquatic life. Nails and claws are often absent.

Amphibians possess large mouth with small teeth present both in upper and lower jaws. A pair of nostrils located in the snout region open into the anterior part of the buccal cavity. Skin, buccal cavity and lungs are the routes of oxygen entry for respiration. Salamanders lack lungs. Larvae show external gills (Fig. 14.2). They are also present in adults of some amphibians.



Fig. 14.2: Larva of salamander with feather like external gills.

Heart is a three chambered structure consisting of two atria and one ventricle and there is a double circulation through the heart. Skin is richly supplied with blood vessels and is always kept moist by mucous glands. Paired mesonephric kidneys are present. Amphibians excrete urea. Ten pairs of cranial nerves are present. Sexes are separate. Fertilization is external in frogs and toads but internal in salamanders and blind worms. Amphibians are predominantly oviparous. A few ovoviviparous and viviparous forms are present. Larvae undergo metamorphic changes before becoming adults. Eggs are mesolecithal (moderately yolked eggs) with jelly like membrane covering. The above mentioned features can be regarded as characteristic of amphibians. You will now study the general organisation of amphibians and subsequently briefly about the classification of the group. Essentially Amphibia includes three living orders; order *Anura* includes frogs and toads; order *Urodela* includes newts and salamanders; and order *Apoda* includes blindworms.

14.2.2 General Organization of Amphibia

Among the amphibians frogs and toads can be regarded as the most successful organisms. Therefore, our study of the organisation of Amphibia will mostly centre around this group. Amphibians generally have a smooth and moist skin. Local thickenings of epidermis often occur in Amphibia. For instance, in the skin of toads that is often dry, epidermal thickenings appear as warts (Fig. 14.3). Frogs have various forms of claws and pads on the feet. Such feet may be used for digging insects from the mud as is done by the clawed aquatic toad *Xenopus*.



Fig. 14.3: A toad showing warts on its skin.

In *Leptodactylus* they may be used for burrowing. The horn teeth found in many amphibian larvae are also epidermal thickenings. The glands in the skin are of two types: the mucous and poisonous glands. Mucous serves to keep the skin moist. Skin is a respiratory organ and therefore the surface needs to be kept moist for exchange of gases. The secretions of the poison glands are alkaline in nature and may cause an irritation of the eye and nasal epithelium. Limbs and supporting girdles – pectoral and pelvic girdles are present. The basic pattern of structure of limbs and girdles found in amphibians are retained in all the higher tetrapods.

Skeletal and Muscular Systems

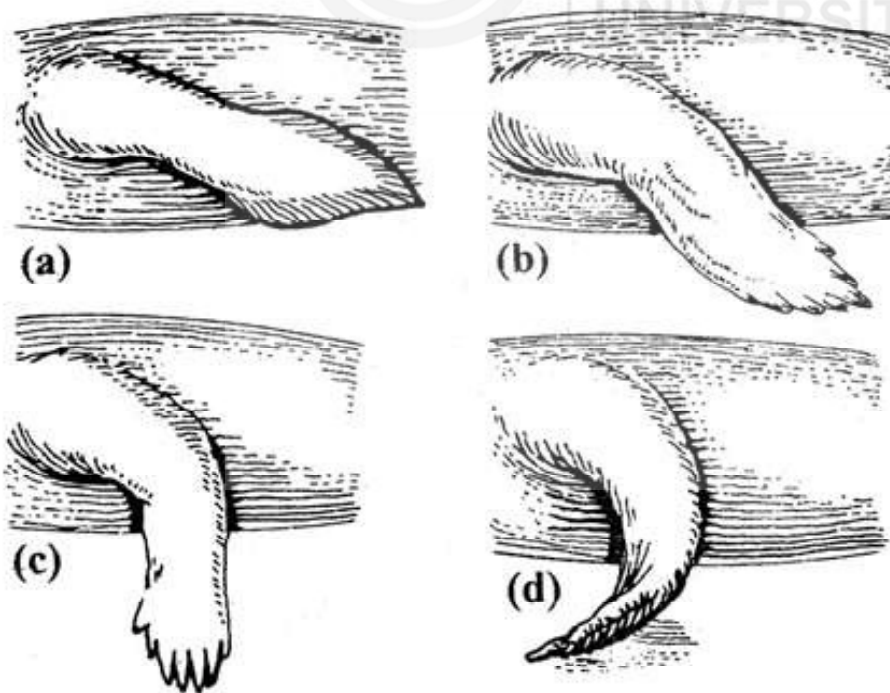


Fig. 14.4: Illustration showing the probable changes in position during the evolution of a tetrapod limb from a pelvic fin. a) pelvic fin; b) double bends to give knee and ankle joints, and the foot directed backwards; c) and (d) rotation of tarsus and digits that turns the foot forward.

In anurans (frogs and toads) both skeletal and muscular systems are specialised for swimming and jumping modes of locomotion. Frogs and toads are also capable of walking on land. Urodela that includes newts and salamanders that have a fish like body exhibit two types of locomotion. One is, they wriggle along the belly on the ground and thus can move fast especially when they are frightened. The second is the normal locomotion, when the animal raises its body on its legs and then propels it along as movable levers. It is believed that the tetrapod limbs should have arisen from the lobed fins of the crossopterygians. The lobed fins were used as levers “to swim on the land”. The contraction of the muscles of the limb would move the limbs forwards and backwards relative to the body and thus assist in locomotion. Slowly the elongation of limbs took place and subsequently they were turned away from the body. The limbs then showed distinct bends downwards at elbow and knee, and upwards at wrist and ankle. This enabled the tetrapods to have a firm application to the ground as well as to raise themselves off the ground. The transformation is completed by bringing the limbs to the side of the body by rotation so that the elbow is pointed backward and the knee forward (Fig.14.4).

Digestive System

Amphibians generally feed on invertebrates, mainly insects but may also eat worms, slugs, snails, spiders, centipedes and millipedes. The larval stage may be herbivorous or omnivorous. The tongue is an effective food capturing organ. In frogs and toads it is attached to the floor of the mouth anteriorly. The tongue is moist and sticky and is flicked outwards while catching the prey. Generally aquatic amphibians have a reduced tongue. In frogs and toads teeth are confined to upper jaw and they are useful in preventing the escape of the prey. Most urodeles have teeth in upper and lower jaws. The oesophagus of amphibians is short and the stomach is a simple tube. A pyloric sphincter is present between the stomach and intestine (Fig. 14.5). In adult amphibians intestine is a short tube and dilates into a large intestine that does the function of water absorption in terrestrial animals. Liver and pancreas are the digestive glands.

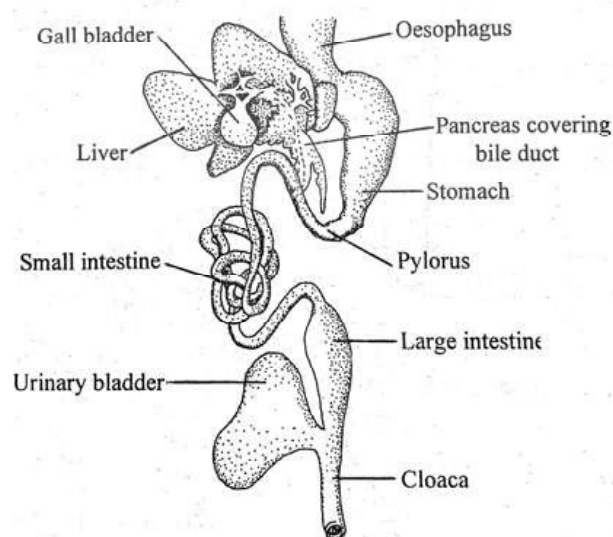


Fig. 14.5: Digestive system of a frog.

Respiratory System

Amphibians in general have varied means of respiration. Many amphibians, besides lungs use skin as an accessory respiratory organ. Lungs of frogs are paired sacs and open into a short laryngeal chamber. The laryngeal chamber communicates, with the pharynx by a slit like opening, the glottis. The richly vascularised skin as well as the buccal cavity play a significant part in exchange of gases.

In newts, lungs have a hydrostatic function serving to lift the animal from water. For this purpose the inner surface of lungs is quite simple. In stream living forms, lung is entirely lost. In forms which live in cold waters, since the activity of the animals is much reduced the entire oxygen need of the organism is fully met by cutaneous (skin) respiration. In these forms, skin is highly vascularised and lungs are much reduced. Gills are confined to amphibian larvae and neotenuous adult urodeles.

Circulatory System

In amphibians there is an incomplete separation of arterial and venous blood. In frogs, toads and salamanders the auricles are completely separated by an interauricular septum. The ventricle is a single chamber and is provided with spongy projection in the wall that prevents the mixing of oxygenated and deoxygenated blood to a large extent. The ventral aorta or the truncus arteriosus arises from the right side of the ventricle. From the truncus arteriosus three arches arise — the **carotid arch** that supplies blood to the anterior parts of the body, the **systemic arch** that supplies blood to the posterior parts of the body and the **pulmonary artery** that carries the blood to lungs.

The venous system consists of a posterior vena cava that collects blood from the posterior organs of the body and drains into the sinus venosus. Most of the blood from hind limbs passes through the renal portal system before it enters the posterior vena cava. Also there is an alternate route in which the blood from hind limbs passes through the pelvic vein, and a median anterior abdominal vein that breaks into capillaries in the liver. The blood from forelimbs, skin and other organs of the anterior part of the body is drained into a pair of anterior vena cava which in turn empties it into sinus venosus (Fig.14.6).

Frogs also have a lymphatic system that consists of a set of spaces that communicate with tissue spaces around the capillaries. Lymph spaces in tissues join to form larger channels and great sinuses that lie below the loose skin of the frog. Lymph hearts that are sacs of endothelium covered by striated muscle fibers keep circulating the lymph fluid by rhythmic contractions.

RBCs of Amphibia are generally larger than 20 μm . Generally, red cells are formed in spleen and kidney although in some species bone marrow is the site of RBC production. Spleen is also the site of destruction of RBC; the life

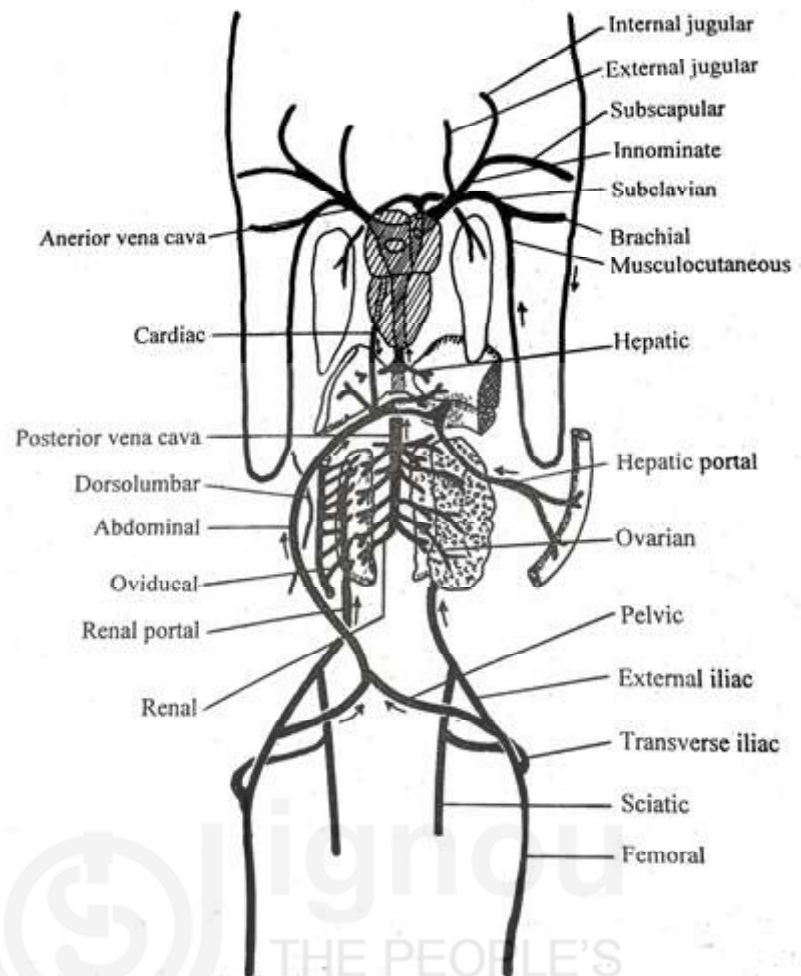


Fig. 14.6: Venous system of frog.

span of which is around 100 days. The haemoglobin of frogs has relatively less affinity for oxygen than is found in mammals. Lymphocytes, monocytes and polymorphogranulocytes are the three types of WBCs seen in blood. The polymorphogranulocytes may be neutrophils or acidophils or basophils. Thus there is a parallel between the mammalian leucocyte system and that of the amphibians. Frog's blood also carries platelets or thrombocytes that play a role in blood coagulation process.

Nervous System and Sense Organs

Nervous system consists of a brain (Fig.14.7) and spinal cord as found in Dipnoi fishes. Prosencephalon (forebrain) mesencephalon, (mid brain) and metencephalon (hindbrain) are the three regions of the brain. Olfactory lobes, large evaginated cerebral hemispheres and unpaired diencephalon, shorter in frogs and larger in urodeles constitute the forebrain. Midbrain is dominated by well developed optic lobes. Hypothalamus and pituitary are located ventrally in the mid brain. The cerebellum is a simple and small structure. Amphibian brain is capable of regeneration after injury, more completely in urodeles than in anurans.

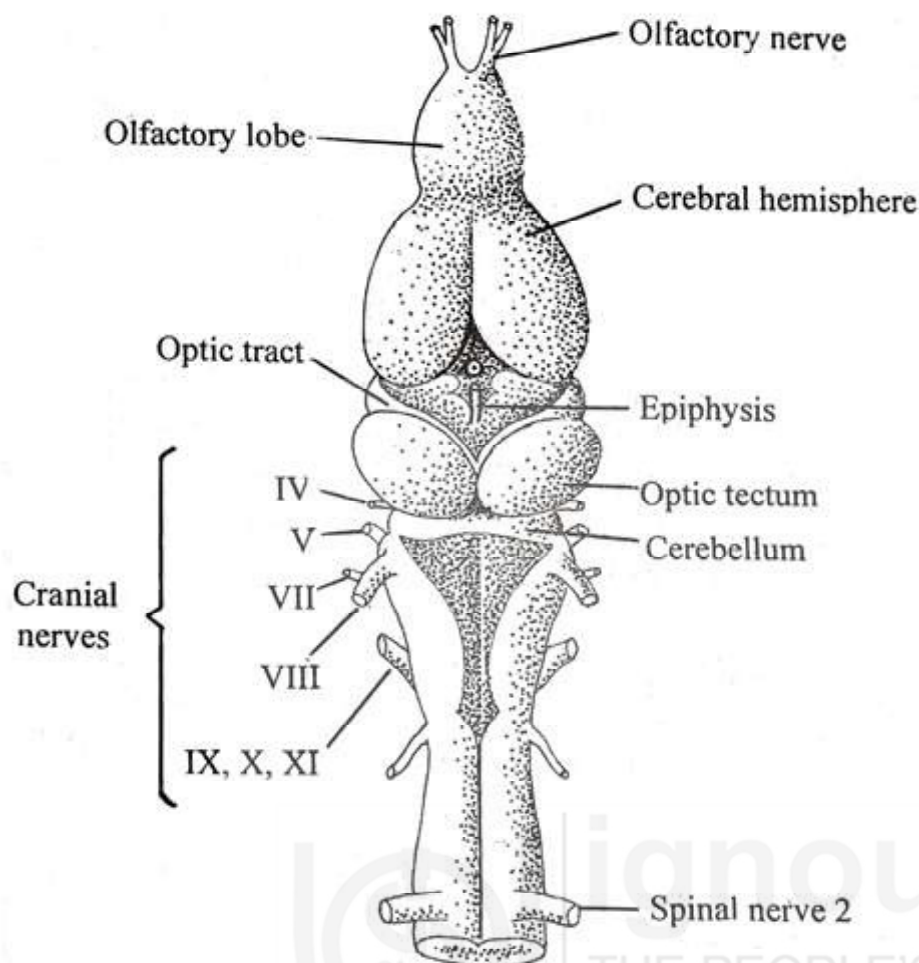


Fig. 14.7: Brain of frog: dorsal view.

Amphibians possess various endocrine glands usually seen in mammals. The three divisions of the pituitary are clearly seen. Pituitary produces various tropic hormones. Paired thyroids and parathyroids that are derived from pharyngeal pouches are present. Ultimobranchial bodies that secrete calcitonin develop from the floor of last pharyngeal pouch. Adrenal glands with ectodermal adrenaline secreting tissue and mesodermal steroid secreting tissues are developed for the first time in amphibians among vertebrates. In urodeles, adrenals are spread out tissue whereas in frog they are compact orange masses lying over the kidneys. Pancreas contains islets of Langerhans with both 'a' and 'b' cells that secrete glucagon and insulin respectively.

Eyes are generally well-developed in amphibians except in Gymnophiona and sight is the dominant sense in most species. To protect and to keep the eyes moist and free of particles, eye lids and lachrymal glands are well-developed. A fixed upper eye lid, a movable lower eye lid and a nictitating membrane that can be pulled across the surface of the eye are the protective devices of amphibian eye. Amphibians like reptiles and birds lack an external ear. The tympanum is a round structure within the cavity of which lies a single middle ear bone, the columella auris. The inner ear includes sacculus, utriculus and lagena, the semicircular canals and the two auditory structures — the basilar papilla and the amphibian papilla. The auditory structures of amphibians appear to be capable

of discriminating various types of signals, such as mating calls, territorial calls, release calls, rain calls, distress calls and warning calls.

All aquatic larvae and some aquatic adults possess lateral line sense organs for maintenance of balance and equilibrium in the body. The organs are of simple type consisting of a group of cells in an open pit. The skin contains tactile sense organs and is also sensitive to chemical stimuli as well as to temperature changes. Taste buds in tongue appear to respond only to two types of taste, namely salt and sour. The olfactory function is carried out by the olfactory epithelia lining the internal nostril. A diverticulum of olfactory chamber—the Jacobson's organ — serves to test the 'smell' of the food in the mouth. The organ is absent in aquatic amphibians. The sense of smell is most developed in Apoda, as these organisms are blind.

Anuran amphibians have vocal organs that enable them to make noise. Both sexes have vocal organs and those of males are larger. Male frogs use them for making calls to attract females. Certain urodeles also make noise; some by means of larynx and others by lips during inspiration.

Excretory System

Amphibians have mesonephric kidneys. Frogs and toads have relatively compact kidneys whereas those of urodeles are elongated. Ureter generally arises from the anterior margin of kidney. Frogs with their moist skin face the threat of being flooded with water osmotically while in the aquatic habitat and being desiccated while on land. The water content of the body is regulated by a complex control system located in the hypothalamus. While in water, flooding is prevented by the efficiently pumping glomerulus as they can filter water 1/3 of the weight of the body per day. While on land, a larger urinary bladder does the resorption of water as the resorbing segment in Henle's loop of nephric tubule is very short. Certain desert forms have no glomeruli altogether in order to conserve water.

Urinogenital System

The genital system consists of paired testes in males (Fig. 14.8) and sperms are discharged into the mesonephros by vasa efferentia. This is in contrast to what is seen in modern fishes which have acquired separate urinary and genital ducts. In the genus *Alytes* sperms do not pass through the kidney. Ovaries are sac like structures formed from peritoneal folds. Eggs are surrounded by follicle cells that appear to produce ovarian hormones. The nucleus of eggs of urodeles have large chromosomes with high DNA content and are known as lamp-brush chromosomes. Eggs leave the ovary and find their way to the mouth of oviducts — the Mullerian ducts, the walls of which are muscular and glandular, and secrete albumen. The oviducts are dilated at the lower end forming ovisacs in which eggs are stored until they are released.

Since many of the amphibians are not completely adapted to life on land, they return to water each year to breed. Some frogs migrate several

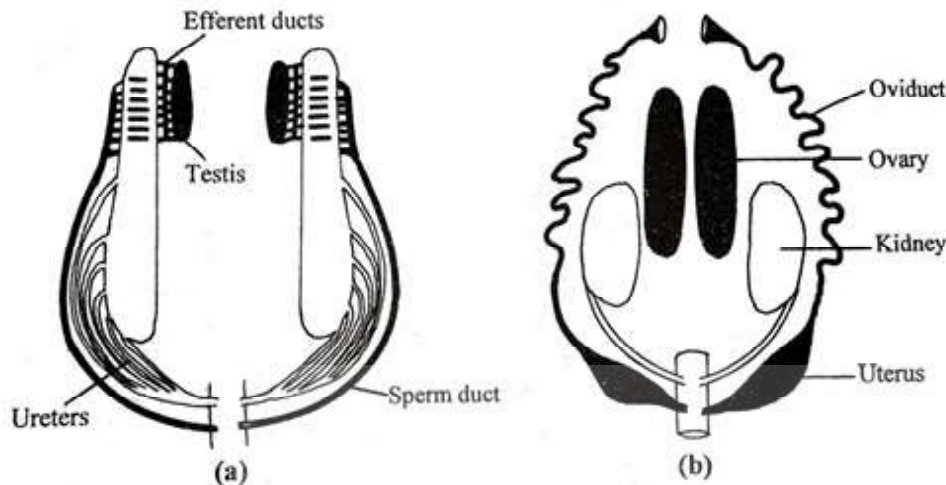


Fig. 14.8: Urinogenital system of frog (a) male; (b) female.



Fig. 14.9: Forelimb of male frog with nuptial pad.

kilometers to the breeding site and prefer to visit the same pond each year. Pronounced sexual dimorphism is seen in many amphibians. Male frogs attract females by making mating calls. The louder and larger calls are more attractive to females and more inhibitory to other males. In toads sexual activity and the calls alternate with each other. Rainfall is one of the influences that initiates mating calls in frogs. During copulation, male clings to the back of the female with the 'nuptial pad' developed as an extra digit in the forelimbs (Fig.14.9). Newts exhibit elaborate courtship behaviour before the actual mating. In newts sperms are bundled into spermatophores before they are transferred to females.

Thus far you have studied structure and organisation of amphibians. The characteristics of modern amphibians are summarised in Table 14.1.

Table 14.1: Features of modern amphibians

1. **Limbs usually four (quadrupedal)** in two pairs with associated shoulder/hip girdle, although some salamanders have forelimbs only and caecilians have no limbs; no true nails; feet often webbed; **forelimb usually with four digits** and hindlimb with five. **Skeleton mostly bony** with varying numbers of vertebrae; salamanders usually have distinct head, neck, trunk, and tail; adult frogs have a fused head and trunk and usually no tail; adult frogs have fused head and trunk and usually no tail; caecilians have an elongated trunk not strongly demarcated from the head and a terminal anus; **ectothermic**.
2. **Skin smooth, moist, and glandular**; integument modified for **cutaneous respiration**; pigment cells (chromatophores) common and varied; **granular glands** secrete defensive compounds.
3. Skull relatively lighter, less ossified, flattened in profile and with fewer bones than other vertebrates.
4. Mouth usually large with small teeth in upper or both jaws and on the vomer/palate.

5. **Tripartite brain** includes forebrain (telencephalon) coordinating olfaction, midbrain (mesencephalon) coordinating vision, and hindbrain (rhombencephalon) coordinating hearing and balance; ten pairs of cranial nerves.
6. Ear with **tympanic membrane** (eardrum) and **stapes** (columella) for transmitting vibrations to inner ear; for vision in air, cornea rather than lens is principal refractive surface for bending light; **eyelids** and **lachrymal glands** protect and wash eyes; paired **internal nostrils** open into a nasal cavity lined with **olfactory epithelium** at anterior part of mouth cavity.
7. Separate sexes; fertilization mostly external in frogs and toads but internal via a spermatophore in most salamanders and caecilians; predominantly oviparous, but some ovoviviparous or viviparous.
8. **Eggs moderately yolky (mesolecithal) with jellylike member coverings**; aquatic larva often present with metamorphosis to a more terrestrial adult form.
9. Excretory system of paired mesonephric or opisthonephric kidneys; urea main nitrogenous waste.
10. Respiration by skin and some forms by gills and/or lungs; presence of gills and lungs varies among species and by developmental state of some species; form with aquatic larvae lose gills at metamorphosis in frogs; many salamanders retain gills and an aquatic habitat throughout life; paired nostrils enable breathing in lung-breathing forms; vocal cords present between lungs and vocal sacs, especially in frogs.
11. **Heart with a sinus venosus**, two atria, one ventricle, a conus arteriosus; **double circulation** through the heart in which pulmonary arteries and veins supply lungs (when present) and return oxygenated blood to heart; skin abundantly supplied with blood vessels.

You shall now study three major groups of living amphibia – the order Anura – the tailless Amphibians, order Caudata (Urodela) -the tailed Amphibians and order Gymnophiona (Apoda) – the limbless Amphibians. To date more than 3900 living amphibians have been described. The three orders of living amphibians are grouped into subclass Lissamphibia. We will begin the study with order Anura. But before you do so, attempt the following SAQ.

SAQ 1

- I. Answer the following questions briefly.
 - i) What were the basic organisational modifications required when the vertebrates switched over from an aquatic environment to a terrestrial environment?
 - ii) List any five salient features of class Amphibia.
-

SAQ 2

State whether the following statements are true or false:

- i) The pattern of structure of limbs and girdles found in amphibians is different from those found in higher tetrapods.
 - ii) Skeletal and muscular systems of urodeles are specialised for swimming and jumping modes of locomotion.
 - iii) The larval stages of amphibians are herbivorous or omnivorous.
 - iv) In frogs and toads teeth are present in both upper and lower jaws.
 - v) Many amphibians use skin besides lungs as an organ of gas exchange.
 - vi) Gills are used as respiratory organs in larvae of Anura and in adults of urodeles.
 - vii) The systemic arch that arises from truncus arteriosus supplies blood to the anterior parts of the body.
 - viii) The blood collected from the anterior and posterior venae cava are emptied into sinus venosus.
 - ix) The haemoglobin of amphibians has a higher affinity for oxygen than that found in mammals.
 - x) In case of injury, the regenerative capacity of urodele brain is greater than that of anurans.
 - xi) Among vertebrates, amphibians are the first group to develop adrenaline secreting ectodermal tissue and steroid secreting mesodermal tissue in the adrenal gland.
 - xii) While living on land the resorption of water in frogs is carried out by urinary bladder.
 - xiii) Absence of separate urinary and genital tracts and discharge of sperm into mesonephros through vasa efferentia are characteristic of male amphibians.
-

14.3 CLASSIFICATION OF AMPHIBIA

Class Amphibia has three orders namely **Anura**, **Apoda** and **Urodela**.

14.3.1 Order Anura (Salientia)

Anurans are the most familiar and successful amphibians. There are more than 3400 species of frogs and toads known. The term Anura would mean lack of tail. And in anurans tail persists during development and in the larval stages only. Because of the leaping mode of locomotion, the order is also known as Salientia. Anurans are one of the oldest groups of amphibians and their fossil history dates back to Jurassic period, some 150 million years ago. In spite of certain inherent constraints anurans have come to occupy a great variety of habitats. Such constraints relate to the compulsions of returning to

water for breeding, and ectothermy that bars them from occupying polar and subarctic habitats. Some of the salient features of anurans are absence of a visible neck, fusion of the caudal vertebrae into a structure called urostyle (coccyx), absence of ribs in most species and enlarged hind limbs for leaping locomotion.

Frogs and toads are divided into 21-families. The most common genera are *Bufo*, *Rana*, *Hyla*, *Pipa* and *Xenopus* (Fig.14.10). Genus *Rana* includes 260 species and is one of the most abundant and successful group of frogs that has a cosmopolitan distribution spread over temperate and tropical regions of the world. *Rana* is not found in New Zealand, in oceanic islands and southern South America. *R. hexadactyla*, and *R. tigrina*, *R. cyanophlictis* are some of the common species found in damp forest floors not far away from water.

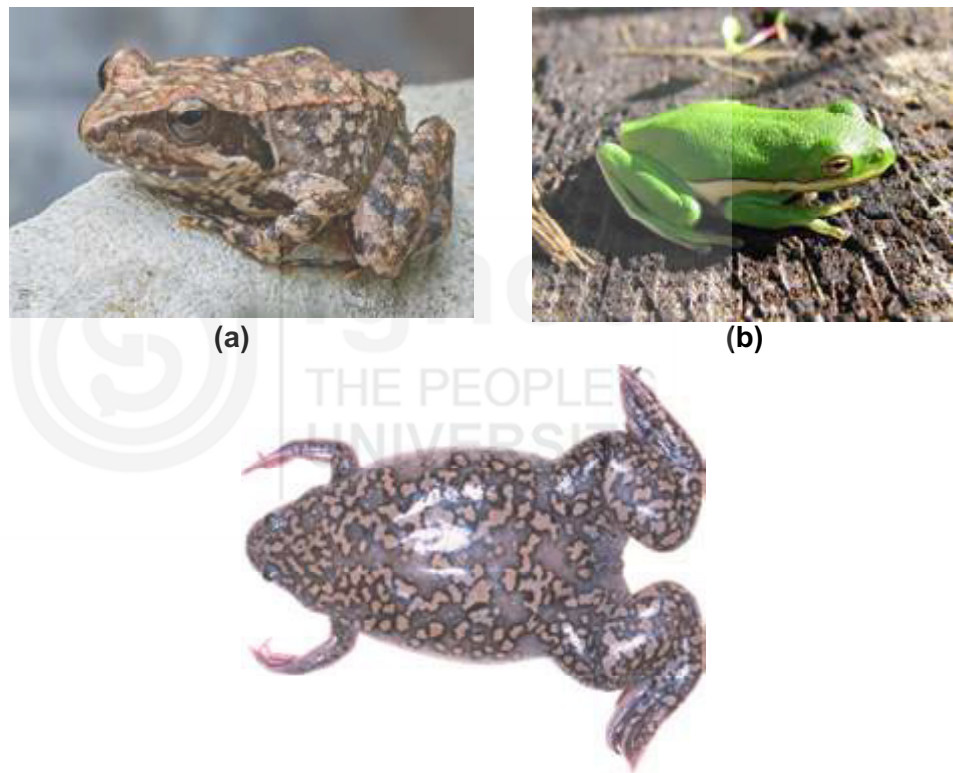


Fig. 14.10: Some common anurans; a) *Rana*; b) *Hyla*; c) *Xenopus*.

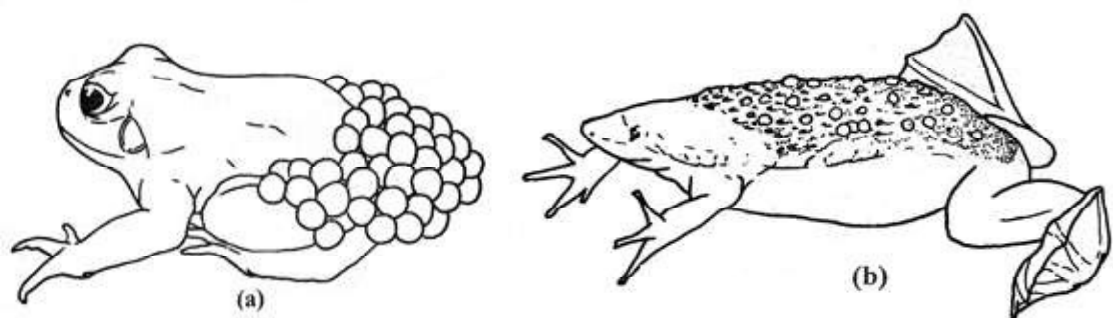


Fig. 14.11: a) *Alytes* midwife toad with eggs around his legs; b) *Pipa* female with eggs embedded in dorsum.

The bull frog *R. catesbiana* and the green frog *R. clamitans* are found near permanent waters or swampy regions. *K. pipiens* lives in a wide variety of habitats and is the most widespread in America. Among toads, the bufonid toads are the most successful group. They are well adapted to terrestrial mode of life, but return to waters to breed. *Bufo* is a common genus that has worldwide distribution except in Australia and Madagascar and is known for parental care. In *Alytes* (Fig. 14.11a), the midwife toad of Europe, eggs are carried by the male wrapped around its legs. *Pipa*, the South American aquatic frog has no tongue and has an elaborate arrangement by which the eggs are carried on the pits on the back (Fig. 14.11b). *Xenopus* is the African toad related to *Pipa* but does not exhibit parental care. Viviparity is not common among frogs and toads. A West African toad *Nectophrynoides* is the only genus to exhibit viviparity. Many frogs are tree living and well adapted to arboreal life. *Hyla* is a common tree living genus. The tree living frogs have developed pads in their toes. *Cacopus* and *Breviceps* are burrowing frogs which have a modified snout for burrowing purposes.

14.3.2 Order Gymnophiona (Apoda)

Gymnophiona are limbless amphibians, also known as caecilians or blind worms. The order is also known as **Apoda**. Nearly 160 species of Apoda are known. They have a long slender body with no limbs. Small scales may be present in the skin of some species. The animals have long ribs and many vertebrae. Their eyes are very small and reduced, and in some cases, totally blind. The subterranean burrowing mode of living apodans explains the absence of eyes in these forms. The organisms are however provided with special-sensory tentacles in the snout. They feed on subsoil insects and other small invertebrates. The skull is bony and solidly built to enable the organisms to burrow in soil. Fertilization is internal and males have a copulatory organ. Eggs are large and yolk. Cleavage is meroblastic. The eggs are laid on land and embryos have long plumed gills. *Ichthyophis* (Fig. 14.12) is a tropical apodan. *Typhlonectes* is a viviparous form.

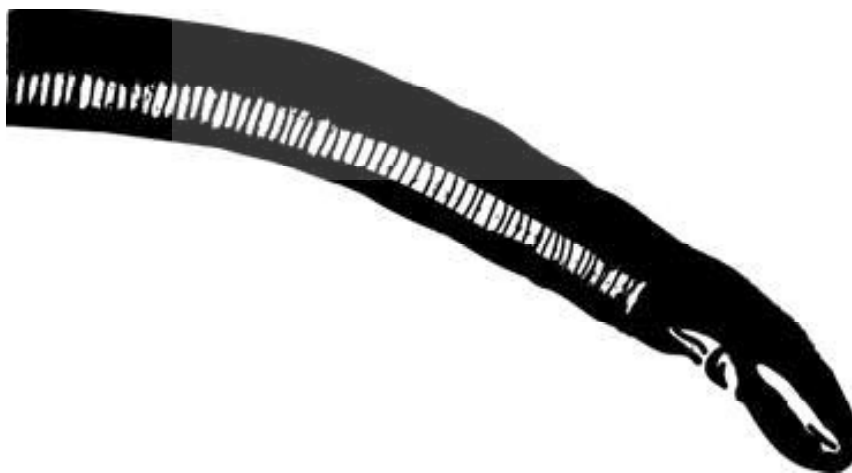


Fig. 14.12: *Ichthyophis*.

14.3.3 Order Caudata (Urodela)

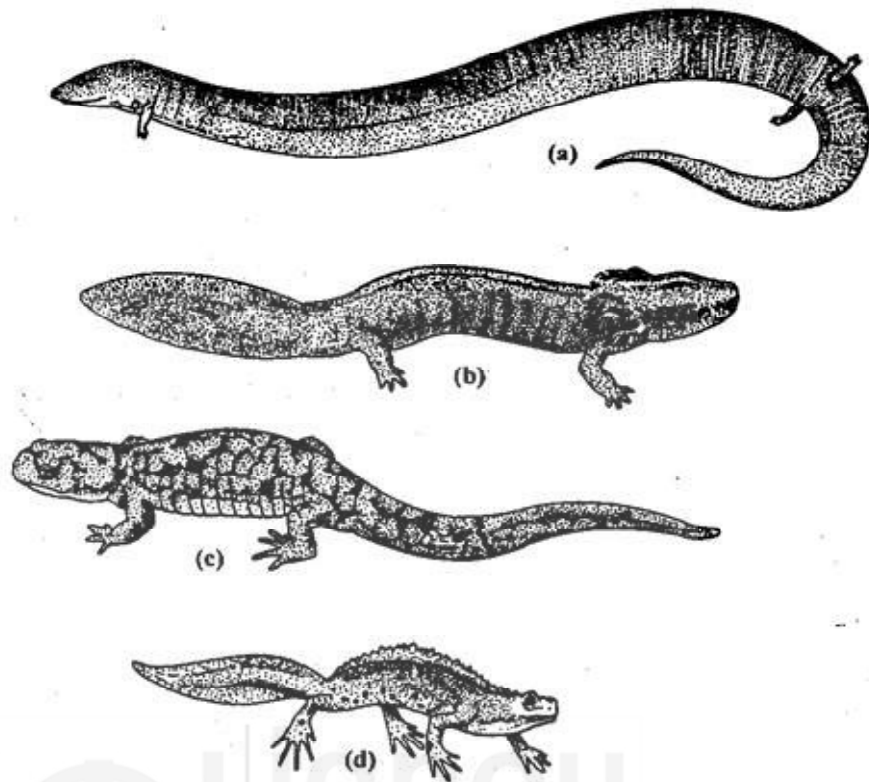


Fig. 14.13: Newts and Salamanders; a) *Amphiuma* (salamander); b) *Necturus* (salamander); c) *Triturus* (newt); d) *Ambystoma* (salamander).

Order Caudata or Urodela includes tailed amphibians, the salamanders (Fig.14.13) and newts. They have a worldwide distribution but most species occur in north America. Most of the salamanders are small measuring around 15 cm in length, although some aquatic forms are considerably larger. A Japanese giant salamander measures 1.5 m in length. Generally organisation and habitat occupation of urodeles are less specialised than that of the anurans. Adult urodeles do not differ much from the larval forms and the adults are well adapted to lead an aquatic life. In urodeles adaptations in different species range from life suited exclusively to terrestrial environments to a fully aquatic life. The European salamander *Salamandra maculosa* is a terrestrial form that exhibits viviparity. The mud puppy of North America *Necturus* is a fully aquatic form.

Limbs of salamander are quite primitive, are of equal size and lie at angles to the body. Most of them feed on moving objects. They are all carnivorous, preying on worms; small arthropods and molluscs.

The young ones that emerge from eggs have gills. Gills are usually lost during metamorphosis except in aquatic forms and in those that fail to undergo complete metamorphosis. Many forms do not possess lungs and in some lungs are much reduced. In all of them, skin is richly vascularised and serves as an organ of gas exchange. Cutaneous respiration is supplemented by pumping air in and out of mouth, across the vascularised membrane of the buccal cavity.

Fertilization in most salamanders is internal and sperm transfer is via spermatophores. Aquatic species lay eggs in clutches in water and terrestrial forms deposit them in small grape like clusters under logs or below the soft earth. Parental care of eggs is quite common among salamanders which are observed to guard the eggs. Larvae that hatch out of the eggs resemble their parents and undergo metamorphosis in the course of development.

An interesting aspect of urodele development is neoteny. Neoteny essentially refers to the attainment of sexual maturity in larval condition. Further there is retention of larval characters in the adulthood. Some neotenic forms remain permanently as larvae and their developing tissues fail to respond to thyroxine hormone that induces metamorphic events. This is a genetically imposed condition and known as obligate neoteny. *Necturus* is an example of obligate neoteny. The mud puppy lives in the bottom of ponds and lakes and retains external gills throughout life. Another genus *Amphiuma* is also an obligate neotenic form and has non-functional rudimentary legs. Some species of salamanders become sexually mature and breed as larvae but have the potential to metamorphose into adults if there are changes in environmental conditions. Such neoteny is called facultative neoteny. Genera *Ambystoma* and *Triturus* are examples of urodeles showing facultative neoteny. **Amgrinum** as an axolotl larval form is aquatic, possesses gills and is reproductively active. But with drying up of water, the organism metamorphoses into an adult, develops legs and becomes a typical adult salamander. Facultative neotenic forms can be induced to metamorphose by treatment with thyroxine.

SAQ 3

Match the subclasses of Amphibia given under A with their characters given under B.

A	B
I) Anura	a) tailed amphibians
	b) absence of visible neck
	c) presence of fused caudal vertebrae – coccyx.
II) Urodela	d) limbless amphibians
III) Apoda	e) presence of long ribs
	f) absence of eyes
	g) viviparity is common
	h) primitive limbs
	i) absence of tail
	j) presence of sensory tentacles in the snout
	k) occurrence of neoteny

- l) bony skull to enable burrowing in soil
- m) absence of ribs.

14.4 PARENTAL CARE IN CLASS AMPHIBIA

Amphibians include anurans, urodelans and apodans. In all these groups of amphibians we come across with a great deal of parental care. Amphibians show several mechanisms to protect their eggs and developing young ones.

Parents protect the eggs and early developmental stages in two ways.

1. They construct nests.
2. Direct Nursing.

Let us now discuss about parental care in orders Urodela and Anura in the following sub-sections.

14.4.1 Parental Care in Urodela

In some urodelans, the eggs are very small. They hatch and directly develop into larvae. In those organisms parental care is not required.

a) Protection by Nests

- i) *Salamandrella keyserlingi* constructs a gelatinous bag like structure. It is attached to a plant below the water. In this bag eggs are stored. Thus they are protected by the nest (Fig. 14.14).



Fig. 14.14: Eggs are stored in bag in *S. keyserlingi*.

- ii) *Autodax* lays eggs in a dry hole in the soil or in a hole on a tree. The parents also live in the hole and protect the egg and the larvae developed from them (Fig.14.15).



Fig. 14.15: Eggs laid in hole by *Autodax*.

b) Direct Nursing by Parents

- i) *Amphiuma*, (Congoeel): The mother coils around the eggs and protects them (Fig. 14.16).



Fig. 14.16: Coiling around eggs in *Amphiuma*.

- ii) *Desmognathus fuscus*, (the dusky salamander): The mother carries the eggs. They are attached around its neck (Fig.14.17).



Fig. 14.17: Eggs carried around neck in *D. fuscus*.

- iii) *Salamandra atra*, (the European fire salamander): The mother retains few eggs in its body. It liberates the larvae into water. They complete their development in the water.

- iv) *Salamandra atra*, (the European alpine salamander): The mother keeps the eggs in its uterus. It liberates only the young ones which have completed their metamorphosis.

14.4.2 Parental Care in Anura

The parental care has reached its peak in this group. Many organisms exhibit parental care.

a) Protection by Nests

Many frogs and toads build nests in which the eggs are laid and developed. This is a primitive method of parental care. In these organisms the larva comes out in a very early embryonic stage which requires some kind of protection in the very early stages of development, hence the parent will build nests.

- i) ***Hyla faber***: It is Brazilian tree frog. The female constructs the nest in the shallow waters of a pond. The female digs a hole of 8 to 10 cm depth. The mud which comes out of it is used by the female *Hyla* to construct a wall around the hole. This wall is raised above the level of water. Female *Hyla* will make the inner surface of this nursery smooth and even the female will lay eggs in this nursery. The eggs and larval forms are protected inside this structure.
- ii) ***Rhacophorus malabaricus***: It is called chunam frog. It lays eggs on the branches or leaves of a tree which will be hanging over a pond. These larvae after hatching from eggs fall into the pond water and undergo metamorphosis (Fig.14.18).



Fig. 14.18: Hanging eggs of *R. malabaricus*.

- iii) ***Rhacophorus schlegelii***: It is called Japan tree frog. Both male and female frogs make a burrow in the moist soil near a pond edge. This hole is filled with foam by female. Then female lays eggs in this foam. The male and female animals will make an exit tunnel into the pond from

the hole. The larvae developed from eggs will be carried by the liquid formed from the foam into the pond through these exit tunnels.

- iv) ***Hyla resinfectris***: It is a tree frog. It will make use of holes in the trees. It will line the hole of tree trunk with beewax brought from bee comb. Female animal lays eggs in this hole when filled with rain water.
- v) ***Leptodactylus mystacinus***: It digs a hole in the moist mud near a pond. This hole is filled with foam which is secreted by the oviducts of the female. Female lays eggs in it. These eggs hatch into larvae when the pond will get good amount of water from rain. Then these holes are also surrounded by the pond water. Then the larvae will enter the pond and grow.
- vi) ***Hyla nebulosa***: It lays its eggs in a nest. This nest is made by dry leaves. The eggs hatch and develop into small adults. Larval form is absent (Fig. 14.19).



Fig. 14.19: Eggs laid in nest by *Hyla nebulosa*.

- vii) ***Hylodes***: It is an American frog. It deposits its eggs in moist places or under the stones. The eggs hatch and give tiny adults perfect condition.

2) Direct Nursing by Parents

This method is more advanced than protecting the eggs and larvae by constructing nests.

- i) ***Alytes***: It is called Midwife-toad. When the eggs are laid by the female frog, the male frog winds the strings of eggs round his back and thighs. This male frog lives in a shallow pit of the moist soil. It will come out of the pit now and then for feeding and to make the eggs moist. When the eggs are ready to hatch the male frog moves to a nearby pond and the larvae are released (Fig. 14.20).



Fig. 14.20: *Alytes* (Mid-wife-toad).

- II) ***Gastrotheca***: It is called New World brooding (or) Marsupial frog. It has a special pouch in its skin. It opens out through an opening near the cloaca. Fertilized eggs are transferred into this pouch. The eggs are stored in this pouch where they undergo development and tadpoles are liberated out (Fig.14.21).



Fig. 14.21: Eggs laid in pouch in *Gastrotheca*.

- III) ***Pipa americana***: It is called Surinam toad. During breeding season the skin of the back of the female becomes soft and spongy. During copulation the oviducts will come out of the female. Because of the movements of male the eggs are forced out of the oviduct. Each egg sinks into a small pocket of the skin. It gets covered by an operculum. In the soft maternal tissue the young one can develop safely. The developing embryo has a tail and yolk sac. It has no gills. The tail may work like placental connection to draw nutrition from the mother. Nearly after 80 days small individuals may come out (Fig. 14.22).



Fig. 14.22: *Pipa americana*.

IV) ***Rhinoderma darwini***: It is called little South American frog. The fertilized eggs are transferred into its vocal sacs, the development takes place here. Then the completely developed young individual will jump out from the mouth of the male frog (Fig. 14.23).



Fig. 14.23: Eggs in vocal sacs of *R. darwini*.

SAQ 4

Explain parental care in anurans.

14.5 SUMMARY

In this unit you have learnt:

- Amphibians are poikilothermic tetrapod vertebrates and use glandular skin, gills and lungs for respiratory exchange of gases. The living, modern amphibians include three groups – Anura – the frogs and toads, Apoda – limbless, blind amphibians and Urodela – the tailed newts and salamanders. Of these three groups; frog and toads are largest group of amphibians having adapted to jumping mode of locomotion.
- As the name implies amphibians have a biphasic life cycle in which aquatic larva undergoes metamorphosis to produce a terrestrial adult

that returns to water to lay eggs. A few frogs, salamanders, caecilians have omitted an aquatic larval stage and undergo direct development. Some apodans have evolved viviparity. A few salamanders have acquired a permanent larval morphology and do not venture into the terrestrial environment. These forms are neotenuous.

- Life on land has led to the development of
 - i) tetrapod limb and the associated pectoral and pelvic girdles,
 - ii) respiratory structures that utilise atmospheric oxygen and
 - iii) sensory structures that facilitate sensory perception on land.
- There are various ways by which parental care is manifested in amphibians i.e. selection of site, frothing of water, defending eggs, formation of nest and carrying eggs on the body.

14.6 TERMINAL QUESTIONS

1. Describe the excretory system of amphibians.
2. Explain the mechanism of circulation in amphibians.
3. Describe parental care in amphibians.
4. Distinguish between anurans and urodeles.

14.7 ANSWERS

Self-Assessment Questions

1. i) a) Ability of the organism to support its weight on land
b) Ability to resist drying and rapid temperature changes
c) Ability to extract oxygen from air.
- ii. 1) Lack of an exoskeleton 2) Adapted to live both on land and water
3) Skin, buccal cavity and lungs are the respiratory organs 4)
Predominantly oviparous forms 5) Larvae undergo metamorphosis
before becoming adults.
2. i)-F; ii)-F; iii)-T; iv)-F; v)-T; vi)-T; vii)-F; viii)-T; ix)-F;
x)-T; xi)-T; xii)-T; xiii)-F.
3. I) b, c, m; II) a, e, h, k; III) d, f, g, j, i, l.
4. Refer to Section 14.4

Terminal Questions

1. Refer to Section 14.2.
2. Refer to Section 14.2.
3. Refer to Section 14.4.
4. Refer to Section 14.3.

GLOSSARY

Alveolus (plural, alveoli):	a small cavity such as the tiny air sac in the lung or sac of a compound gland, or the socket for a tooth.
Amnion	: the innermost extra embryonic membrane forming a fluid filled sac around the embryo in amniotes.
Anus	: the terminal opening of the gut.
Atrium	: any main chamber; the principal receiving chamber of the heart; the large cavity containing the pharynx in tunicates and cephalochordates.
Autostyly	: a type of jaw suspension in which hyomandibular is non functional as a supporting structure and the upper jaw region is entirely responsible for its own suspension, seen in Dipnoi.
Bipinnaria larva	: free swimming ciliated larva of the asteroid echinoderm.
Eocene	: the second epoch of the Tertiary period of the Cenozoic era.
Esophagus	: the part of the gut tube that lies between pharynx and stomach, oesophagus.
Heterocercal tail	: the type of tail fin found in cartilaginous fishes (sharks and rays) in which the lobes of the fin are asymmetrical; this is caused by the lengthening of some of the fin rays.
Holostyly	: a type of jaw suspension in which there is support both from hyomandibular and a direct articulation of upper jaw of braincase seen in Holocephali.
Homocercal tail	: the type of tail fin found in most living bony fishes. The two lobes of the tail are symmetrical and supported only by dermal fin rays.
Hyostyly	: a type of jaw suspension in which the upper jaw has no direct connection with the brain case and the jaw joint is braced entirely by hyomandibular bone. Seen in most modern fishes.
Genealogy	: account of descent from ancestor; investigation of pedigree; plants or animal's line of development from earlier forms.
Labyrinthodont	: One of a group of extinct amphibians derived from crossopterygians that have complexly infolded tooth dentine; of 'like' or pertaining to that group of amphibians.

Lateral line receptors	: a line of mechanical receptor cells lying along the sides of certain fishes and amphibians, and sensitive to sound and wave action in water.
Larynx	: a complex of cartilaginous elements, muscles, and fibers at the pharyngeal openings of the trachea that functions to protect the opening and in some forms permits vocalization, voice box especially in humans.
Lophophore	: ciliated tentacle used to collect food.
Monophyletic	: group of species having all been derived from a common ancestor or single parent stock.
Nocturnal	: of or pertaining to the night.
Polyphyletic	: derived from more than one ancestral source; opposed to monophyletic.
Poikilotherms	: cold blooded animals having a body temperature that varies with that of their surroundings
Taxonomic clade	: a taxon or other group consisting of a single species and all of its descendents forming a distinct branch on a phylogenetic tree.
Tornaria larva	: a free swimming larva of Enteropneusta that rotates as it swims.
Viviparity	: the condition of producing young of considerable development within the adult body.

SUGGESTED READING

- Ruppert and Barnes, R.D. (2006). *Invertebrate Zoology*, VIII Edition. Holt Saunders International Edition.
- Barnes, R.S.K., Calow, P., Olive, P.J.W., Golding, D.W. and Spicer, J.I. (2002). *The Invertebrates: A New Synthesis*, III Edition, Blackwell Science.
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UNIT 11 PROTOCHORDATES

- Fig. 11.12:** http://cifonauta.cebimar.usp.br/site_media/photos/aem_v3azXE.jpg
- Fig. 11.14:** <https://allyouneedisbiology.files.wordpress.com/2015/04/12014.jpg>; <http://www.phototem.com/moteur/zoom.asp?pre=122661&NumPhoto=122662&suiv=122663&motscles=fus#>
- Fig. 11.15:** a) <https://alchetron.com/cdn/ostracoderm-b563f443-f1bc-468a-93ac-481d21e6fea-resize-750.jpeg>;
b) <https://vignette.wikia.nocookie.net/cooldinofacts/images/5/51/Drepanaspis1.png/revision/latest/scale-to-width-down/326?cb=20120207132924>;
c) <http://people.eku.edu/ritchisong/ostracoderm.jpg>
- Fig. 11.16:** a) <https://alchetron.com/cdn/acanthodii-23bd4f20-7239-4f6a-b126-8f1b093bde0-resize-750.jpeg>
b) <https://www.ab-com.cz/content/images/product/original/633080.png>

UNIT 12 AGNATHA – JAWLESS FISHES

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UNIT 13 PISCES

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UNIT 14 AMPHIBIA

Fig. 14.10: a) https://img2.juzaphoto.com/002/shared_files/uploads/2366420_m.jpg

b) https://upload.wikimedia.org/wikipedia/commons/4/46/Hyla_cinerea2.jpg

c) <https://www.xenbase.org/anatomy/static/intro/laevis.png>

Fig. 14.14: https://www.researchgate.net/profile/Vladimir_Vershinin2/publication/319873165/figure/fig61/AS:613862080524288@1523367533127/Abnormal-clutches-of-Salamandrella-keyserlingii-left-eggs-arranged-in-strings-lacking_W840.webp

Fig. 14.15: <https://www.flickr.com/photos/davemedia/7461567424>

Fig. 14.16: http://lh4.ggpht.com/-bfDPoqeJsII/TrgEfdkW8cl/AAAAAAAAABpI/2zG6XoMVzaw/Amphiuma-congoeel-eggs_thumb%25255B4%25255D.jpg?imgmax=800

Fig. 14.20: [https://thumbs-prod.si-cdn.com/2xtT7x_oaLPsNNRclaKNAvAGB3c=/800x600/filters:no_upscale\(\)/https://public-media.smithsonianmag.com/filer/midwife-toad-520-300x200.jpg](https://thumbs-prod.si-cdn.com/2xtT7x_oaLPsNNRclaKNAvAGB3c=/800x600/filters:no_upscale()/https://public-media.smithsonianmag.com/filer/midwife-toad-520-300x200.jpg)

Fig. 14.21: <http://3.bp.blogspot.com/-jvNYjj8W2H0/Ud3HyCNZZhI/AAAAAAAAAZE/7wp0BvqtCcY/s1600/H.+fasciatus+with+eggs+%2528500%2529.JPG>

Fig. 14.22: <https://daviniasobservations.wordpress.com/tag/pipa-americana/>

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