Characteristics of Living Beings:

1. Growth:

- All living organisms grow in size and number.
- Growth of living beings comes from inside.
- A continuous process of cell division makes this growth possible.
- Most of the plants show growth in size throughout their life.
- But animals grow to a certain limit. After this the cell division facilitates repair in the organism.

2. Reproduction:

- All living beings reproduce their progeny.
- Progeny are more or less similar to their parents.
- Reproduction can be sexual or asexual.
- Most of the unicellular and less complex organisms reproduce by asexual methods.
- Multicellular and complex organisms reproduce by sexual methods.
- Reproduction by sexual method involves formation of male and female gametes and fusion of those gametes results in formation of zygotes, which ultimately give birth to the new progeny.

3. Metabolism:

- Metabolism can be classified in two types:
- Anabolism: The process which results in synthesis of something is called anabolism. Photosynthesis is a good example of anabolism as it involves synthesis of carbohydrates.
- Catabolism: The process which results in breaking down of a compound is called catabolism. Respiration is a good example of catabolism as it involves breaking down of carbohydrates into carbon-dioxide and water.

4.Consciousness and Response to Stimuli:

- All living organisms show a response to outside stimulus.
- These stimuli can be light, heat, other organisms or chemicals.
- For example all green plants grow in the direction from which sunlight comes.
- All animals are sensitive to heat.

Diversity in the Living World

Biodiversity: The variety and variability of living beings found in a given geographical area is called biodiversity of that area.

Nomenclature and Identification: Because of the huge diversity present in the living world it became necessary to develop a system to classify and name all plants and animals. International Code for Botanical Nomenclature has developed a system for identification and classification of plants. International Code of Zoological Nomenclature has developed a system for identifying and classifying the animals.

This system gives a unique name to each species. The name is called biological name and usually represented by two words. The first word always starts with a capital letter and the second word always starts with a small letter. Example;

Mangifera indica is the biological name of mango. The word Mangifera indicates the genus and indica indicates the species.

Following are the general rules for nomenclature:

1. Biological names are generally in Latin and written in italics. They are Latinised or derived from Latin irrespective of their origin.
2. The first word in a biological name represents the genus while the second component denotes the specific epithet.
3. Both the words in a biological name, when handwritten, are separately underlined, or printed in italics to indicate their Latin origin.
4. The first word denoting the genus starts with a capital letter while the specific epithet starts with a small letter.

Taxonomic Categories

Classification is not a single step process but involves hierarchy of steps in which each step represents a rank or category. Since the category is a part of overall taxonomic arrangement, it is called the taxonomic category and all categories together constitute the taxonomic hierarchy. Each category, referred to as a unit of classification, in fact, represents a rank and is commonly termed as taxon (pl.: taxa).

Taxonomical studies of all known organisms have led to the development of common categories such as kingdom, phylum or division (for plants), class, order, family, genus and species. All organisms, including those in the plant and animal kingdoms have species as the lowest category.

Species

Taxonomic studies consider a group of individual organisms with fundamental similarities as a species. One should be able to distinguish one species from the other closely related species based on the distinct morphological differences. Let us consider Mangifera indica, Solanum tuberosum (potato) and Panthera leo (lion). All the three names, indica, tuberosum and leo, represent the specific epithets, while the first words Mangifera, Solanum and Panthera are genera and represents another higher level of taxon or category. Each genus may have one or more than one specific epithets representing different organisms, but having morphological similarities. For example, Panthera has another specific epithet called tigris and Solanum includes species like nigrum and melongena. Human beings belong to the species sapiens which is grouped in genus Homo. The scientific name thus, for human being, is written as Homo sapiens.

Genus

Genus comprises a group of related species which has more characters in common in comparison to species of other genera. We can say that genera are aggregates of closely related species. For example, potato, tomato and brinjal are three different species but all belong to the genus Solanum. Lion (Panthera leo), leopard (P. pardus) and tiger (P. tigris) with several common features, are all species of the genus Panthera. This genus differs from another genus Felis which includes cats.

Family

The next category, Family, has a group of related genera with still less number of similarities as compared to genus and species. Families are characterised on the basis of both vegetative and reproductive features of plant species. Among plants for example, three different genera Solanum, Petunia and Datura are placed in the family Solanaceae. Among animals for example, genus Panthera, comprising lion, tiger, leopard is put along with genus, Felis (cats) in the family Felidae. Similarly, if you observe the features of a cat and a dog, you will find some similarities and some differences as well. They are separated into two different families – Felidae and Cancidae, respectively.

Order

Generally, order and other higher taxonomic categories are identified based on the aggregates of characters. Order being a higher category, is the assemblage of families which exhibit a few similar characters. The similar characters are less in number as compared to different genera included in a family. Plant families like Convolvulaceae, Solanaceae are included in the order Polymoniales mainly based on the floral characters. The animal order, Carnivora, includes families like Felidae and Cancidae.

Class

This category includes related orders. For example, order Primata comprising monkey, gorilla and gibbon is placed in class Mammalia along with order Carnivora that includes animals like tiger, cat and dog. Class Mammalia has other orders also.

Phylum

Classes comprising animals like fishes, amphibians, reptiles, birds along with mammals constitute the next higher category called Phylum. All these, based on the common features like presence of notochord and dorsal hollow neural system, are included in phylum Chordata. In case of plants, classes with a few similar characters are assigned to a higher category called Division.

Kingdom

All animals belonging to various phyla are assigned to the highest category called Kingdom Animalia in the classification system of animals. The Kingdom Plantae, on the other hand, is distinct, and comprises all plants from various divisions.

Animal Kingdom

Levels of Organisation

1. Cellular Level: In unicellular animals and some multicellular animals like sponges , the cell is responsible for all the metabolic activities in the animal body. This type of organization of function is termed as cellular level of organization.
2. Tissue Level: In certain animals like Coelenterates. cells performing the same function are arranged in a group.
3. Organ Level: Some animals like flatworms form specialized organs for specific functions.
4. Organ System Level: In higher and complex animals various organs group to form a complex organ system to perform specific function.

Symmetry

- Assymetric animals like Sponges cannot be divided in to two equal halves.
- Radial Symmetric animals: When any plane passing through the central axis of the body divides the organism into two identical halves, it is called radial symmetry. Coelenterates, ctenophores and echinoderms have this kind of body plan.
- Bilateral Symmetry: Animals like annelids, arthropods, etc., where the body can be divided into identical left and right halves in only one plane, exhibit bilateral symmetry.

- Diploblastic anmals:Animals in which the cells are arranged in two egerm layers, an external ectoderm and an internal endoderm, are called diploblastic animals, e.g., coelenterates. An undifferentiated layer, mesoglea, is present in between the ectoderm and the endoderm.

- Triploblastivc animals:Animals in which the developing embryo has a third germinal layer, mesoderm, in between the ectoderm and endoderm, are called triploblastic animals .Eg all animals from platyhelminthes to chordates.

Coelom

The body cavity present in between gut and body wall, which is lined by mesoderm is called coelom.

Acoelomates: The animals in which the body cavity is absent are called acoelomates, e.g., platyhelminthes.

Segmentation

Pseudoceolomates: In some animals, the body cavity is not lined by mesoderm, instead, the mesoderm is present as scattered pouches in between the ectoderm and endoderm. Such a body cavity is called pseudocoelom and the animals possessing them are called pseudocoelomates, e.g., aschelminthes.

Coelomates:Animals possessing coelom are called coelomates, e.g., annelids, molluscs, arthropods, echinoderms, hemichordates and chordates.

Metamerism

In some animals, the body is externally and internally divided into segments with a serial repetition of at least some organs. For example, in annelids, the body shows this pattern called metameric segmentation and the phenomenon is known as metamerism.

Notochord

Notochord is a mesodermally derived rod-like structure formed on the dorsal side during embryonic development in some animals. Animals with notochord are called chordates and those animals which do not form this structure are called non-chordates, e.g., porifera to echinoderms.

CLASSIFICATION OF ANIMALS

Phylum – Porifera

1. Members of this phylum are commonly known as sponges.
2. They are generally marine and mostly asymmetrical animals.
3. These are primitive multicellular animals and have cellular level of organisation.
4. Water Transport System in Sponges: Sponges have a water transport or canal system. Water enters through minute pores (ostia) in the body wall into a central cavity, spongocoel, from where it goes out through the osculum. This pathway of water transport is helpful in food gathering, respiratory exchange and removal of waste. Choanocytes or collar cells line the spongocoel and the canals.
5. Digestion is intracellular.
6. The body is supported by a skeleton made up of spicules or sponging fibres.
7. Reproduction: Sponges are hermaphrodite animals. Sexes are not separate, i.e., eggs and sperms are produced by the same individual.
8. Sponges reproduce asexually by fragmentation and sexually by formation of gametes.
9. Fertilisation is internal and development is indirect having a larval stage which is morphologically distinct from the adult.

Phylum – Coelenterata (Cnidaria)

1. They are aquatic, mostly marine, sessile or free-swimming,
2. radially symmetrical animals.
3. The name cnidaria is derived from the nidoblasts or cnidocytes (which contain the stinging capsules or nematocytes) present on the tentacles and the body. Cnidoblasts are used for anchorage, defense and for the capture of prey.
4. Cnidarians exhibit tissue level of organisation and are diploblastic.
5. They have a central gastro-vascular cavity with a single opening, hypostome.
6. Digestion is extracellular and intracellular.
7. Some of the cnidarians, e.g., corals have a skeleton composed of calcium carbonate.
8. Cnidarians exhibit two basic body forms called polyp and medusa. Polyp is a sessile and cylindrical form like Hydra, Adamsia, etc. whereas, medussa is umbrella-shaped and free-swimming like Aurelia or jelly fish. Those cnidarians which exist in both forms exhibit alternation of generation (Metagenesis), i.e., polyps produce medusae asexually and medusae form the polyps sexually (e.g., Obelia).

Examples:

- Physalia (Portuguese man-of-war)
- Adamsia (Sea anemone)
- Pennatula (Sea-pen)
- Gorgonia (Sea-fan)
- Meandrina (Brain coral)

Phylum – Ctenophora

1. Ctenophores, commonly known as sea walnuts or comb jellies
2. are exclusively marine, radially symmetrical, diploblastic organisms with tissue level of organisation.
3. The body bears eight external rows of ciliated comb plates, which help in locomotion.

4. Digestion is both extracellular and intracellular.
5. Bioluminescence (the property of a living organism to emit light) is well-marked in ctenophores.
6. Sexes are not separate.
7. Reproduction takes place only by sexual means.
8. Fertilisation is external
9. indirect development.

Examples:

- Pleurobrachia
- Ctenoplana.

Phylum – Platyhelminthes

1. They have dorso-ventrally flattened body, hence are called flatworms.
2. These are mostly endoparasites found in animals including human beings.
3. Flatworms are bilaterally symmetrical, triploblastic and acoelomate animals with organ level of organisation. Hooks and suckers are present in the parasitic forms
4. . Some of them absorb nutrients from the host directly through their body surface.
5. Specialised cells called flame cells help in osmoregulation and excretion.
6. Sexes are not separate.
7. Fertilisation is internal and development is through many larval stages.
8. Some members like Planaria possess high regeneration capacity.

Examples:

- Taenia (Tapeworm),
- Fasciola (Liver fluke).

Phylum – Aschelminthes

1. The body of the aschelminthes is circular in cross-section, hence, the name roundworms.
2. They may be freeliving, aquatic and terrestrial or parasitic in plants and animals.
3. Roundworms have organ-system level of body organisation.
4. They are bilaterally symmetrical, triploblastic and pseudocoelomate animals.
5. Digestive System: Alimentary canal is complete with a well developed muscular pharynx.
6. An excretory tube removes body wastes from the body cavity through the excretory pore.
7. Sexes are separate (dioecious), i.e., males and females are distinct.
8. Reproduction: Often females are longer than males.
9. Fertilisation is internal and development may be direct (the young ones resemble the adult) or indirect.

Examples:

- Ascaris (Round Worm),
- Wuchereria (Filaria worm),
- Ancylostoma (Hookworm).

Phylum – Annelida

1. They may be aquatic (marine and fresh water) or terrestrial; free-living, and sometimes parasitic. T
2. hey exhibit organ-system level of body organisation and bilateral symmetry.
3. They are triploblastic, metamerically segmented and coelomate animals.
4. Their body surface is distinctly marked out into segments or metameres (Latin, annulus : little ring) and, hence, the phylum name Annelida.
5. They possess longitudinal and circular muscles which help in locomotion.
6. Aquatic annelids like Nereis possess lateral appendages, parapodia, which help in swimming.
7. A closed circulatory system is present.
8. Nephridia (sing. nephridium) help in osmoregulation and excretion.
9. Neural system consists of paired ganglia (sing. ganglion) connected by lateral nerves to a double ventral nerve cord.
10. Nereis, an aquatic form, is dioecious, but earthworms and leeches are monoecious.
11. Reproduction is sexual.

Examples:

- Nereis,
- Pheretima (Earthworm)
- Hirudinaria (Blood sucking leech

Phylum – Arthropoda

1. This is the largest phylum of Animalia which includes insects.
2. Over two-thirds of all named species on earth are arthropods.

3. They have organ-system level of organisation.
4. They are bilaterally symmetrical, triploblastic, segmented and coelomate animals.
5. Structure: The body of arthropods is covered by chitinous exoskeleton.
6. The body consists of head, thorax and abdomen.
7. They have jointed appendages (arthros-joint, poda-appendages).
8. Respiratory organs are gills, book gills, book lungs or tracheal system.
9. Circulatory system is of open type.
10. Sensory organs like antennae, eyes (compound and simple), statocysts or balance organs are present.
11. Excretion takes place through malpighian tubules.
12. They are mostly dioecious. Fertilisation is usually internal.
13. They are mostly oviparous. Development may be direct or indirect.

- Examples:
- Economically important insects – Apis (Honey bee), Bombyx (Silkworm), Laccifer (Lac insect)
- Vectors – Anopheles, Culex Aedes (Mosquitoes)
- Gregarious pest – Locusta (Locust)
- Living fossil – Limulus (King crab).

Phylum – Mollusca

1. This is the second largest animal phylum.
2. Molluscs are terrestrial or aquatic (marine or fresh water) having an organ-system level of organisation.
3. They are bilaterally symmetrical, triploblastic and coelomate animals.
4. Structure: Body is covered by a calcareous shell and is unsegmented with a distinct head, muscular foot and visceral hump.
5. A soft and spongy layer of skin forms a mantle over the visceral hump.
6. The space between the hump and the mantle is called the mantle cavity in which feather like gills are present. They have respiratory and excretory functions.
7. The anterior head region has sensory tentacles.
8. The mouth contains a file-like rasping organ for feeding, called radula.
9. They are usually dioecious and oviparous with indirect development.

Examples:

- Pila (Apple snail),
- Pinctada (Pearl oyster),
- Sepia (Cuttlefish),
- Loligo (Squid),
- Octopus (Devil fish),
- Aplysia (Seahare),
- Dentalium (Tusk shell)
- Chaetopleura (Chiton).

Phylum – Echinodermata

1. These animals have an endoskeleton of calcareous ossicles and, hence, the name Echinodermata (Spiny bodied). All are marine with organ-system level of organisation.
2. The adult echinoderms are radially symmetrical but larvae are bilaterally symmetrical.
3. They are triploblastic and coelomate animals.
4. Digestive system is complete with mouth on the lower (ventral) side and anus on the upper (dorsal) side.
5. The most distinctive feature of echinoderms is the presence of water vascular system which helps in locomotion, capture and transport of food and respiration.
6. An excretory system is absent.
7. Sexes are separate. Reproduction is sexual.
8. Fertilisation is usually external.
9. Development is indirect with free-swimming larva.

Examples:

- Asterias (Star fish),
- Echinus (Sea urchin),
- Antedon (Sea lily),
- Cucumaria (Sea cucumber)
- Ophiura (Brittle star).

Phylum – Hemichordata

1. This phylum consists of a small group of worm-like marine animals with organ-system level of organisation.
2. They are bilaterally symmetrical, triploblastic and coelomate animals.
3. The body is cylindrical and is composed of an anterior proboscis, a collar and a long trunk.

4. Circulatory system is of open type.
5. Respiration takes place through gills.
6. Excretory organ is proboscis gland.
7. Sexes are separate.
8. Fertilisation is external.
9. Development is indirect.

Examples:

- Balanoglossus
- Saccoglossus.

Phylum – Chordata

1. Animals belonging to phylum Chordata are fundamentally characterised by the
2. Presence of a notochord,
3. Adorsal hollow nerve cord and
4. Paired pharyngeal gill slits.
5. These are bilaterally symmetrical,Triploblastic,
6. coelomate with organ-system level of organisation.
7. They possess a post anal tail and a closed circulatory system.

Phylum Chordata is divided into three subphyla:

Urochordata or Tunicata, In Urochordata, notochord is present only in larval tail

Examples:

- Ascidia,
- Salpa,
- Doliolum;

2. Cephalochordata : in Cephalochordata, it extends from head to tail region and is persistent throughout their life

Eg.

- Branchiostoma (Amphioxus or Lancelet).

3. Vertebrata. Vertebrata possess notochord during the embryonic period.

1. The notochord is replaced by a cartilaginous or bony vertebral column in the adult. Thus all vertebrates are chordates but all chordates are not vertebrates.
2. Besides the basic chordate characters,
3. Vertebrates have a ventral muscular heart with two, three or four chambers,
4. Kidneys for excretion and osmoregulation and
5. Paired appendages which may be fins or limbs.

Subphyla Urochordata and Cephalochordata are often referred to as protochordates and are exclusively marine.,

Comparison of Chordates and Non-chordates

Class – Cyclostomata

1. All living members of the class Cyclostomata are ectoparasites on some fishes.
2. They have an elongated body bearing 6-15 pairs of gill slits for respiration.
3. Cyclostomes have a sucking and circular mouth without jaws.
4. Their body is devoid of scales and paired fins.
5. Cranium and vertebral column are cartilaginous.
6. Circulation is of closed type.
7. Cyclostomes are marine but migrate for spawning to fresh water.
8. After spawning, within a few days, they die. Their larvae, after metamorphosis, return to the ocean.

Examples:

- Petromyzon (Lamprey)
- Myxine (Hagfish).

Class – Chondrichthyes

1. They are marine animals with streamlined body and have cartilaginous endoskeleton.
2. Mouth is located ventrally. Notochord is persistent throughout life.
3. Gill slits are separate and without operculum (gill cover).
4. The skin is tough, containing minute placoid scales. Teeth are modified placoid scales which are backwardly directed.
5. Their jaws are very powerful.
6. These animals are predaceous.
7. *Due to the absence of air bladder, they have to swim constantly to avoid sinking.*
8. Heart is two-chambered (one auricle and one ventricle).
9. Some of them have electric organs (e.g., Torpedo) and some possess poison sting (e.g., Trygon).

10. They are cold-blooded (poikilothermous) animals, i.e., they lack the capacity to regulate their body temperature. Sexes are separate.
11. In males pelvic fins bear claspers.
12. They have internal fertilisation and many of them are viviparous.

Examples:

- Scoliodon (Dog fish),
- Pristis (Saw fish),
- Carcharodon (Great white shark),
- Trygon (Sting ray).

Class – Osteichthyes

1. It includes both marine and fresh water fishes with bony endoskeleton.
2. Their body is streamlined. Mouth is mostly terminal.
3. They have four pairs of gills which are covered by an operculum on each side.
4. Skin is covered with cycloid/ctenoid scales.
5. Air bladder is present which regulates buoyancy.
6. Heart is two-chambered (one auricle and one ventricle).
7. They are cold-blooded animals. Sexes are separate.
8. Fertilisation is usually external.
9. They are mostly oviparous and development is direct.

Examples:

- Marine – Exocoetus (Flying fish), Hippocampus (Sea horse);
- Freshwater – Labeo (Rohu), Catla (Katla), Clarias (Magur);
- Aquarium – Betta (Fighting fish), Pterophyllum (Angel fish).

Class – Amphibia

1. Amphibians can live in aquatic as well as terrestrial habitats.
2. Most of them have two pairs of limbs.
3. Body is divisible into head and trunk.
4. Tail may be present in some.
5. The amphibian skin is moist (without scales).
6. The eyes have eyelids.
7. A tympanum represents the ear.
8. Alimentary canal, urinary and reproductive tracts open into a common chamber called cloaca which opens to the exterior.
9. Respiration is by gills, lungs and through skin.
10. The heart is threechambered (two auricles and one ventricle).
11. These are cold-blooded animals. Sexes are separate.
12. Fertilisation is external.
13. They are oviparous and development is direct or indirect.

Examples:

- Bufo (Toad),
- Rana (Frog),
- Hyla (Tree frog),
- Salamandra (Salamander),
- Ichthyophis (Limbless amphibia).

Class – Reptilia

1. The class name refers to their creeping or crawling mode of locomotion
2. They are mostly terrestrial animals and their body is covered by dry and cornified skin, epidermal scales or scutes. They do not have external ear openings.
3. Tympanum represents ear.
4. Limbs, when present, are two pairs.
5. Heart is usually three-chambered, but four-chambered in crocodiles.
6. Reptiles are poikilotherms
7. Snakes and lizards shed their scales as skin cast.
8. Sexes are separate.
9. Fertilisation is internal.
10. They are oviparous and development is direct.

Examples:

- Chelone (Turtle),
- Testudo (Tortoise),
- Chameleon (Tree lizard),

- Calotes (Garden lizard),
- Crocodilus (Crocodile),
- Alligator (Alligator).
- Hemidactylus (Wall lizard),

Poisonous snakes – Naja (Cobra), Bangarus (Krait), Vipera (Viper).

Class – Aves

1. The characteristic features of Aves (birds) are the presence of feathers and most of them can fly except flightless birds (e.g., Ostrich).
2. They possess beak.
3. The forelimbs are modified into wings.
4. The hind limbs generally have scales and are modified for walking, swimming or clasping the tree branches.
5. Skin is dry without glands except the oil gland at the base of the tail.
6. Endoskeleton is fully ossified (bony) and the long bones are hollow with air cavities (pneumatic).
7. The digestive tract of birds has additional chambers, the crop and gizard.
8. Endoskeleton is fully ossified (bony) and the long bones are hollow with air cavities (pneumatic).
9. The digestive tract of birds has additional chambers, the crop and gizard.
10. Heart is completely fourchambered.
11. They are warm-blooded (homoiothermous) animals, i.e., they are able to maintain a constant body temperature. Respiration is by lungs. Air sacs connected to lungs supplement respiration. Sexes are separate.
12. Fertilisation is internal.
13. They are oviparous and development is direct.

Examples:

- Corvus (Crow),
- Columba (Pigeon),
- Psittacula (Parrot),
- Struthio (Ostrich),
- Pavo (Peacock),
- Aptenodytes (Penguin),
- Neophron (Vulture).

Class – Mammalia

1. The most unique mammalian characteristic is the presence of milk producing glands (mammary glands) by which the young ones are nourished.
2. They have two pairs of limbs, adapted for walking, running, climbing, burrowing, swimming or flying.
3. The skin of mammals is unique in possessing hair.
4. External ears or pinnae are present. Different types of teeth are present in the jaw.
5. Heart is four-chambered.
6. They are homoiothermous.
7. Respiration is by lungs.
8. Sexes are separate and fertilisation is internal.
9. They are viviparous with few exceptions and development is direct.

Examples:

- Oviparous-Ornithorhynchus (Platypus);
- Viviparous - Macropus (Kangaroo), Pteropus (Flying fox), Camelus (Camel), Macaca(Monkey), Rattus (Rat), Canis (Dog), Felis (Cat), Elephas (Elephant), Equus (Horse), Delphinus (Common dolphin), Balaenoptera (Blue whale), Panthera tigris (Tiger), Panthera leo (Lion).

Structural Organization In Animals

Tissues: Tissues are group of cells which is made to carry out specific task in a multicellular animal.
Group of different tissues make an organ, which in turn make an organ system. Thus this is a gradual step towards division of labour in multicellular organisms. A particular organ is meant to do a specific task and a particular organ system is responsible for a complex set of tasks.

ANIMAL TISSUES

Based on structure tissues are different and are broadly classified into four types :

(i) Epithelial,
(ii) Connective,
(iii) Muscular and
(iv) Neural.

Epithelial Tissue

Epithelial tissues provide covering to the inner and outer lining of various organs. The cells of epithelial tissues are compactly packed with little intercellular matrix.
There are two types of epithelial tissues:
(a) Simple Epithelium: Simple epithelium is composed of a single layer of cells and functions as a lining for body cavities, ducts, and tubes.
(b) Compound Epithelium: The compound epithelium consists of two or more cell layers and has protective function as it does in our skin. They cover the dry surface of the skin, the moist surface of buccal cavity, pharynx, inner lining of ducts of salivary glands and of pancreatic ducts.
On the basis of structural modification of the cells, simple epithelium is further divided into three types. These are:

(a) Squamous: The squamous epithelium is made of a single thin layer of flattened cells with irregular boundaries. They are found in the walls of blood vessels and air sacs of lungs and are involved in a functions like forming a diffusion boundary.
(b) Cuboidal: The cuboidal epithelium is composed of a single layer of cube-like cells. This is commonly found in ducts of glands and tubular parts of nephrons in kidneys and its main functions are secretion and absorption. The epithelium of proximal convoluted tubule (PCT) of nephron in the kidney has microvilli.
(c) Columnar: The columnar epithelium is composed of a single layer of tall and slender cells. Their nuclei are located at the base. Free surface may have microvilli. They are found in the lining of stomach and intestine and help in secretion and absorption. If the columnar or cuboidal cells bear cilia on their free surface they are called ciliated epithelium. Their function is to move particles or mucus in a specific direction over the epithelium. They are mainly present in the inner surface of hollow organs like bronchioles and fallopian tubes.
Connective Tissue
Connective tissues are most abundant and widely distributed in the body of complex animals. Function of connective tissues is linking and supporting other tissues/organs of the body. In all connective tissues except blood, the cells secrete fibres of structural proteins called collagen or elastin. The fibres provide strength, elasticity and flexibility to the tissue. These cells also secrete modified polysaccharides, which accumulate between cells and fibres and act as matrix (ground substance).
Connective tissues are classified into three types:

1. Loose Connective Tissue: Loose connective tissue has cells and fibres loosely arranged in a semi-fluid ground substance, for example, areolar tissue present beneath the skin. Often it serves as a support framework for epithelium. It contains fibroblasts (cells that produce and secrete fibres), macrophages and mast cells. Adipose tissue is another type of loose connective tissue located mainly beneath the skin. The cells of this tissue are specialised to store fats. The excess of nutrients which are not used immediately are converted into fats and are stored in this tissue.
2. Dense Connective Tissue: Fibres and fibroblasts are compactly packed in the dense connective tissues. Orientation of fibres show a regular or irregular pattern and are called dense regular and dense irregular tissues. In the dense regular connective tissues, the collagen fibres are present in rows between many parallel bundles of fibres. Tendons, which attach skeletal muscles to bones and ligaments which attach one bone to another are examples of this tissue. Dense irregular connective tissue has fibroblasts and many fibres (mostly collagen) that are oriented differently. This tissue is present in the skin.
3. Specialised Connective Tissue: Cartilage, bones and blood are various types of specialized connective tissues.
Cartilage: The intercellular material of cartilage is solid and pliable and resists compression. Cells of this tissue (chondrocytes) are enclosed in small cavities within the matrix secreted by them. Most of the cartilages in vertebrate embryos are replaced by bones in adults. Cartilage is present in the tip of nose, outer ear joints, between adjacent bones of the vertebral column, limbs and hands in adults.
Bones: Bones have a hard and non-pliable ground substance rich in calcium salts and collagen fibres which give bone its strength. It is the main tissue that provides structural frame to the body. Bones support and protect softer tissues and organs. The bone cells (osteocytes) are present in the spaces called lacunae. Limb bones, such as the long bones of the legs, serve weight-bearing functions. They also interact with skeletal muscles attached to them to bring about movements. The bone marrow in some bones is the site of production of blood cells.
Blood: Blood is a fluid connective tissue containing plasma, red blood cells (RBC), white blood cells (WBC) and platelets. It is the main circulating fluid that helps in the transport of various substances.
Muscle Tissue
Muscle: Each muscle is made of many long, cylindrical fibres arranged in parallel arrays. These fibres are composed of numerous fine fibrils, called myofibrils. Muscle fibres contract (shorten) in response to stimulation, then relax (lengthen) and return to their uncontracted state in a coordinated fashion. Their action moves the body to adjust to the changes in the environment and to maintain the positions of the various parts of the body. In general, muscles play an active role in all the movements of the body.
Muscles are of three types:
1. Skeletal,

2. Smooth, and
3. Cardiac.

Skeletal Muscle: Skeletal muscle tissue is closely attached to skeletal bones. In a typical muscle such as the biceps, striated (striped) skeletal muscle fibres are bundled together in a parallel fashion. A sheath of tough connective tissue encloses several bundles of muscle fibres.

Smooth Muscle: The smooth muscle fibres taper at both ends (fusiform) and do not show striations. Cell junctions hold them together and they are bundled together in a connective tissue sheath. The wall of internal organs such as the blood vessels, stomach and intestine contains this type of muscle tissue. Smooth muscles are 'involuntary' as their functioning cannot be directly controlled.

Cardiac Muscle: Cardiac muscle tissue is a contractile tissue present only in the heart. Cell junctions fuse the plasma membranes of cardiac muscle cells and make them stick together. Communication junctions (intercalated discs) at some fusion points allow the cells to contract as a unit, i.e., when one cell receives a signal to contract, its neighbours are also stimulated to contract.

Neural Tissue

Neurons, the unit of neural system are excitable cells. The neuroglial cell which constitute the rest of the neural system protect and support neurons. Neuroglia make up more than onehalf the volume of neural tissue in our body. When a neuron is suitably stimulated, an electrical disturbance is generated which swiftly travels along its plasma membrane. Arrival of the disturbance at the neuron's endings, or output zone, triggers events that may cause stimulation or inhibition of adjacent neurons and other cells and thereby transmitting neural signals to different parts of the body.

ORGAN AND ORGAN SYSTEM

The basic tissues mentioned above organise to form organs which in turn associate to form organ systems in the multicellular organisms. Such an organisation is essential for more efficient and better coordinated activities of millions of cells constituting an organism. Each organ in our body is made of one or more type of tissues. For example, our heart consists of all the four types of tissues, i.e., epithelial, connective, muscular and neural.

EARTHWORM

Earthworm is a reddish brown terrestrial invertebrate that inhabits the upper layer of the moist soil. During day time, they live in burrows made by boring and swallowing the soil. In the gardens, they can be traced by their faecal deposits known as worm castings. The common Indian earthworms are Pheretima and Lumbricus.

Morphology

Earthworms have long cylindrical body. The body is divided into more than hundred short segments which are similar (metameres about 100-120 in number).

Dorsal Surface: The dorsal surface of the body is marked by a dark median mid dorsal line (dorsal blood vessel) along the longitudinal axis of the body.

Ventral Surface: The ventral surface is distinguished by the presence of genital openings (pores).

Segments: Anterior end consists of the mouth and the prostomium, a lobe which serves as a covering for the mouth and as a wedge to force open cracks in the soil into which the earthworm may crawl. The prostomium is sensory in function. The first body segment is called the peristomium (buccal segment) which contains the mouth. In a mature worm, segments 14-16 are covered by a prominent dark band of glandular tissue called clitellum. Thus the body is divisible into three prominent regions – preclitellar, clitellar and postclitellar segments.

Genital Openings: Four pairs of spermathecal apertures are situated on the ventro-lateral sides of the intersegmental grooves, i.e., 5th -9th segments. A single female genital pore is present in the mid-ventral line of 14th segment. A pair of male genital pores are present on the ventro-lateral sides of the 18th segment.

Locomotion: In each body segment, except the first, last and clitellum, there are rows of S-shaped setae, embedded in the epidermal pits in the middle of each segment. Setae can be extended or retracted. Their principal role is in locomotion.

Anatomy

Body Wall: The body wall of the earthworm is covered externally by a thin non-cellular cuticle below which is the epidermis, two muscle layers (circular and longitudinal) and an innermost coelomic epithelium. The epidermis is made up of a single layer of columnar epithelial cells which contain secretory gland cells.

Alimentary Canal: The alimentary canal is a straight tube and runs between first to last segment of the body. A terminal mouth opens into the buccal cavity (1-3 segments) which leads into muscular pharynx. A small narrow tube, oesophagus (5-7 segments), continues into a muscular gizzard (8-9 segments). It helps in grinding the soil particles and decaying leaves, etc. The stomach extends from 9-14 segments.

The food of the earthworm is decaying leaves and organic matter mixed with soil. Calciferous glands, present in the stomach, neutralise the humic acid present in humus. Intestine starts from the 15th segment onwards and continues till the last segment. A pair of short and conical intestinal caecae project from the intestine on the 26th segment. The characteristic feature of the intestine between 26-35 segments is the presence of internal median fold of dorsal wall called typhlosole. This increases the effective area of absorption in the intestine.

The alimentary canal opens to the exterior by a small rounded aperture called anus. The ingested organic rich soil passes through the digestive tract where digestive enzymes breakdown complex food into smaller absorbable units. These simpler molecules are absorbed through intestinal membranes and are utilised.

Blood Vascular System: Pheretima exhibits a closed type of blood vascular system, consisting of blood vessels, capillaries and heart. Due to closed circulatory system, blood is confined to the heart and blood vessels. Contractions keep blood circulating in one direction. Smaller blood vessels supply the gut, nerve cord, and the body wall. Blood glands are present on the 4th, 5th and 6th segments. They produce blood cells and haemoglobin which is dissolved in blood plasma. Blood cells are phagocytic in nature. Earthworms lack specialised breathing devices. Respiratory exchange occurs through moist body surface into their blood stream.

Excretory System: The excretory organs occur as segmentally arranged coiled tubules called nephridia (sing.: nephridium). They are of three types:

(i) septal nephridia, present on both the sides of intersegmental septa of segment 15 to the last that open into intestine,
(ii) integumentary nephridia, attached to lining of the body wall of segment 3 to the last that open on the body surface and
(iii) pharyngeal nephridia, present as three paired tufts in the 4th, 5th and 6th segments.

These different types of nephridia are basically similar in structure. Nephridia regulate the volume and composition of the body fluids. A nephridium starts out as a funnel that collects excess fluid from coelomic chamber. The funnel connects with a tubular part of the nephridium which delivers the wastes through a pore to the surface in the body wall into the digestive tube.

Nervous System: Nervous system is basically represented by ganglia arranged segmentwise on the ventral paired nerve cord. The nerve cord in the anterior region (3rd and 4th segments) bifurcates, laterally encircling the pharynx and joins the cerebral ganglia dorsally to form a nerve ring. The cerebral ganglia alongwith other nerves in the ring integrate sensory input as well as command muscular responses of the body.

Sensory System: Sensory system does not have eyes but does possess light and touch sensitive organs (receptor cells) to distinguish the light intensities and to feel the vibrations in the ground. Worms have specialised chemoreceptors (taste receptors) which react to chemical stimuli. These sense organs are located on the anterior part of the worm.

Reproductive System: Earthworm is hermaphrodite (bisexual), i.e., testes and ovaries are present in the same individual. There are two pairs of testes present in the 10th and 11th segments. Their vasa deferentia run up to the 18th segment where they join the prostatic duct. Two pairs of accessory glands are present one pair each in the 17th and 19th segments. The common prostrate and spermatic duct (vary differential) opens to the exterior by a pair of male genital pores on the ventro-lateral side of the 18th segment. Four pairs of spermathecae are located in 6th-9th segments (one pair in each segment).

They receive and store spermatozoa during copulation. One pair of ovaries is attached at the inter-segmental septum of the 12th and 13th segments. Ovarian funnels are present beneath the ovaries which continue into oviduct, join together and open on the ventral side as a single median female genital pore on the 14th segment.

Fertilization & Development: A mutual exchange of sperm occurs between two worms during mating. One worm has to find another worm and they mate juxtaposing opposite gonadal openings exchanging packets of sperms called spermatophores. Mature sperm and egg cells and nutritive fluid are deposited in cocoons produced by the gland cells of clitellum. Fertilisation and development occur within the cocoons which are deposited in soil. The ova (eggs) are fertilised by the sperm cells within the cocoon which then slips off the worm and is deposited in or on the soil. The cocoon holds the worm embryos. After about 3 weeks, each cocoon produces two to twenty baby worms with an average of four. Earthworms development is direct, i.e., there is no larva formed.

Economic Importance: Earthworms are known as ‘friends of farmers’ because they make burrows in the soil and make it porous which helps in respiration and penetration of the developing plant roots. The process of increasing fertility of soil by the earthworms is called vermicomposting. They are also used as bait in game fishing.

Cockroach

Cockroaches are brown or black bodied animals that are included in class Insecta of Phylum Arthropoda. Bright yellow, red and green coloured cockroaches have also been reported in tropical regions. Their size ranges from ¼ inches to 3 inches (0.6-7.6 cm) and have long antenna, legs and flat extension of the upper body wall that conceals head. They are nocturnal omnivores that live in damp places throughout the world. They have become residents of human homes and thus are serious pests and vectors of several diseases.

Morphology

The adults of the common species of cockroach, Periplaneta Americana are about 34-53 mm long with wings that extend beyond the tip of the abdomen in males. The body of the cockroach is segmented and divisible into three distinct regions – head, thorax and abdomen.

The entire body is covered by a hard chitinous exoskeleton (brown in colour). In each segment, exoskeleton has hardened plates called sclerites (tergites dorsally and sternites ventrally) that are joined to each other by a thin and flexible articular membrane (arthrodial membrane).

Head: Head is triangular in shape and lies anteriorly at right angles to the longitudinal body axis. It is formed by the fusion of six segments and shows great mobility in all directions due to flexible neck. The head capsule bears a pair of compound eyes. A pair of thread like antennae arise from membranous sockets lying in front of eyes. Antennae have sensory receptors that help in monitoring the environment.
Mouth Parts: Anterior end of the head bears appendages forming biting and chewing type of mouth parts. The mouthparts consisting of a labrum (upper lip), a pair of mandibles, a pair of maxillae and a labium (lower lip). A median flexible lobe, acting as tongue (hypopharynx), lies within the cavity enclosed by the mouthparts.

Thorax: Thorax consists of three parts – prothorax, mesothorax and metathorax. The head is connected with thorax by a short extension of the prothorax known as the neck. Each thoracic segment bears a pair of walking legs. The first pair of wings arises from mesothorax and the second pair from metathorax. Forewings (mesothoracic) called tegmina are opaque dark and leathery and cover the hind wings when at rest. The hind wings are transparent, membranous and are used in flight.
Abdomen: The abdomen in both males and females consists of 10 segments. In females, the 7th sternum is boat shaped and together with the 8th and 9th sterna forms a brood or genital pouch whose anterior part contains female gonopore, spermathecal pores and collateral glands. In males, genital pouch or chamber lies at the hind end of abdomen bounded dorsally by 9th and 10th terga and ventrally by the 9th sternum. It contains dorsal anus, ventral male genital pore and gonapophysis. Males bear a pair of short, threadlike anal styles which are absent in females. In both sexes, the 10th segment bears a pair of jointed filamentous structures called anal cerci.
Anatomy
Alimentary Canal: The alimentary canal present in the body cavity is divided into three regions: foregut, midgut and hindgut. The mouth opens into a short tubular pharynx, leading to a narrow tubular passage called oesophagus. This in turn opens into a sac like structure called crop used for storing of food. The crop is followed by gizzard or proventriculus. It has an outer layer of thick circular muscles and thick inner culicle forming six highly chitinous plate called teeth. Gizzard helps in grinding the food particles. The entire foregut is lined by cuticle. A ring of 6-8 blind tubules called hepatic or gastric caecae is present at the junction of foregut and midgut, which secrete digestive juice. The hindgut is broader than midgut and is differentiated into ileum, colon and rectum. The rectum opens out through anus.

Blood Vascular System: Blood vascular system of cockroach is an open type. Blood vessels are poorly developed and open into space (haemocoel). Visceral organs located in the haemocoel are bathed in blood (haemolymph). The haemolymph is composed of colourless plasma and haemocytes. Heart of cockroach consists of elongated muscular tube lying along mid dorsal line of thorax and abdomen. It is differentiated into funnel shaped chambers with ostia on either side. Blood from sinuses enter heart through ostia and is pumped anteriorly to sinuses again.

Respiratory System: The respiratory system consists of a network of trachea, that open through 10 pairs of small holes called spiracles present on the lateral side of the body. Thin branching tubes (tracheal tubes subdivided into tracheoles) carry oxygen from the air to all the parts. The opening of the spiracles is regulated by the sphincters. Exchange of gases take place at the tracheoles by diffusion.
Excretory System: Excretion is performed by Malpighian tubules. Each tubule is lined by glandular and ciliated cells. They absorb nitrogenous waste products and convert them into uric acid which is excreted out through the hindgut. Therefore, this insect is called uricotelic. In addition, the fat body, nephrocytes and urecose glands also help in excretion.
Nervous System: The nervous system of cockroach consists of a series of fused, segmentally arranged ganglia joined by paired longitudinal connectives on the ventral side. Three ganglia lie in the thorax, and six in the abdomen. The nervous system of cockroach is spread throughout the body. The head holds a bit of a nervous system while the rest is situated along the ventral (belly-side) part of its body. So, now you understand that if the head of a cockroach is cut off, it will still live for as long as one week. In the head region, the brain is represented by supra-oesophageal ganglion which supplies nerves to antennae and compound eyes.
Sense Organs: In cockroach, the sense organs are antennae, eyes, maxillary palps, labial palps, anal cerci, etc. The compound eyes are situated at the dorsal surface of the head. Each eye consists of about 2000 hexagonal ommatidia (sing.: ommatidium). With the help of several ommatidia, a cockroach can receive several images of an object. This kind of vision is known as mosaic vision with more sensitivity but less resolution, being common during night (hence called nocturnal vision).
Reproductive System: Cockroaches are dioecious and both sexes have well developed reproductive organs.

Male Reproductive System: Male reproductive system consists of a pair of testes lying one on each lateral side in the 4th - 6th abdominal segments. From each testis arises a thin vas deferens, which opens into ejaculatory duct through seminal vesicle. The ejaculatory duct opens into male gonopore situated ventral to anus. A characteristic mushroomshaped gland is present in the 6th-7th abdominal segments which functions as an accessory reproductive gland. The external genitalia are represented by male gonapophysis or phallomere (chitinous asymmetrical structures, surrounding the male

gonopore). The sperms are stored in the seminal vesicles and are glued together in the form of bundles called spermatophores which are discharged during copulation.
Female Reproductive System: The female reproductive sysytem consists of two large ovaries, lying laterally in the 2nd – 6th abdominal segments. Each ovary is formed of a group of eight ovarian tubules or ovarioles, containing a chain of developing ova. Oviducts of each ovary unite into a single median oviduct (also called vagina) which opens into the genital chamber. A pair of spermatheca is present in the 6th segment which opens into the genital chamber.
Fertilization: Sperms are transferred through spermatophores. Their fertilised eggs are encased in capsules called oothecae. Ootheca is a dark reddish to blackish brown capsule, about 3/8" (8 mm) long. They are dropped or glued to a suitable surface, usually in a crack or crevice of high relative humidity near a food source. On an average, females produce 9-10 oothecae, each containing 14-16 eggs. The development of P. Americana is paurometabolous, meaning there is development through nymphal stage. The nymphs look very much like adults. The nymph grows by moulting about 13 times to reach the adult form. The next to last nymphal stage has wing pads but only adult cockroaches have wings.
Significance for Human: Many species of cockroaches are wild and are of no economic importance. A few species thrive in and around human habitat. They are pests because they destroy food and contaminate it with their smelly excreta. They can transmit a variety of bacterial diseases by contaminating food material.

Frog

Frogs can live both on land and in freshwater and belong to class Amphibia of phylum Chordata. The most common species of frog found in India is Rana tigrina. They do not have constant body temperature i.e., their body temperature varies with the temperature of the environment. Such animals are called cold blooded or poikilotherms. They have the ability to change the colour to hide them from their enemies (camouflage). This protective coloration is called mimicry. Frogs are not seen during peak summer and winter. During this period they take shelter in deep burrows to protect them from extreme heat and cold. This is called as summer sleep (aestivation) and winter sleep (hibernation).

Morphology
The skin is smooth and slippery due to the presence of mucus. The skin is always maintained in a moist condition. The colour of dorsal side of body is generally olive green with dark irregular spots. On the ventral side the skin is uniformly pale yellow. The frog never drinks water but absorb it through the skin.
Body of a frog is divisible into head and trunk. A neck and tail are absent. Above the mouth, a pair of nostrils is present. Eyes are bulged and covered by a nictitating membrane that protects them while in water. On either side of eyes a membranous tympanum (ear) receives sound signals. The forelimbs and hind limbs help in swimming, walking, leaping and burrowing. The hind limbs end in five digits and they are larger and muscular than fore limbs that end in four digits. Feet have webbed digits that help in swimming. Frogs exhibit sexual dimorphism. Male frogs can be distinguished by the presence of sound producing vocal sacs and also a copulatory pad on the first digit of the fore limbs which are absent in female frogs.
Anatomy
Digestive System: The alimentary canal is short because frogs are carnivores and hence the length of intestine is reduced. The mouth opens into the buccal cavity that leads to the oesophagus through pharynx. Oesophagus is a short tube that opens into the stomach which in turn continues as the intestine, rectum and finally opens outside by the cloaca. Liver secretes bile that is stored in the gall bladder. Pancreas, a digestive gland produces pancreatic juice containing digestive enzymes. Food is captured by the bilobed tongue.
Digestion: Digestion of food takes place by the action of HCl and gastric juices secreted from the walls of the stomach. Partially digested food called chyme is passed from stomach to the first part of the intestine, the duodenum. The duodenum receives bile from gall bladder and pancreatic juices from the pancreas through a common bile duct. Bile emulsifies fat and pancreatic juices digest carbohydrates and proteins. Final digestion takes place in the intestine.
Absorption: Digested food is absorbed by the numerous finger-like folds in the inner wall of intestine called villi and microvilli. The undigested solid waste moves into the rectum and passes out through cloaca.
Respiration: Frogs respire on land and in the water by two different methods. In water, skin acts as aquatic respiratory organ (cutaneous respiration). Dissolved oxygen in the water is exchanged through the skin by diffusion. On land, the buccal cavity, skin and lungs act as the respiratory organs. The respiration by lungs is called pulmonary respiration. The lungs are a pair of elongated, pink coloured sac-like structures present in the upper part of the trunk region (thorax). Air enters through the nostrils into the buccal cavity and then to lungs. During aestivation and hibernation gaseous exchange takes place through skin.
Blood Vascular System: The vascular system of frog is well-developed closed type. Frogs have a lymphatic system also. The blood vascular system involves heart, blood vessels and blood. The lymphatic system consists of lymph, lymph channels and lymph nodes.
Heart: Heart is a muscular structure situated in the upper part of the body cavity. It has three chambers, two atria and one ventricle and is covered by a membrane called pericardium. A triangular structure called sinus venosus joins the right

atrium. It receives blood through the major veins called vena cava. The ventricle opens into a saclike conus arteriosus on the ventral side of the heart.
Arteries & Veins: The blood from the heart is carried to all parts of the body by the arteries (arterial system). The veins collect blood from different parts of body to the heart and form the venous system. Special venous connection between liver and intestine as well as the kidney and lower parts of the body are present in frogs. The former is called hepatic portal system and the latter is called renal portal system.
Blood: The blood is composed of plasma and cells. The blood cells are RBC (red blood cells) or erythrocytes, WBC (white blood cells) or leucocytes and platelets. RBC's are nucleated and contain red coloured pigment namely haemoglobin. The lymph is different from blood. It lacks few proteins and RBCs. The blood carries nutrients, gases and water to the respective sites during the circulation. The circulation of blood is achieved by the pumping action of the muscular heart.
Excretory System: The excretory system consists of a pair of kidneys, ureters, cloaca and urinary bladder. These are compact, dark red and bean like structures situated a little posteriorly in the body cavity on both sides of vertebral column. Each kidney is composed of several structural and functional units called uriniferous tubules or nephrons. Two ureters emerge from the kidneys in the male frogs. The ureters act as urinogenital duct which opens into the cloaca. In females the ureters and oviduct open seperately in the cloaca. The thin-walled urinary bladder is present ventral to the rectum which also opens in the cloaca. The frog excretes urea and thus is a ureotelic animal. Excretory wastes are carried by blood into the kidney where it is separated and excreted.
Control & Coordination: The system for control and coordination is highly evolved in the frog. It includes both neural system and endocrine glands.
Coordination By Hormones: The chemical coordination of various organs of the body is achieved by hormones which are secreted by the endocrine glands. The prominent endocrine glands found in frog are pituitary, thyroid, parathyroid, thymus, pineal body, pancreatic islets, adrenals and gonads.
Nervous System: The nervous system is organized into following:
1. Central Nervous System (brain and spinal cord),
2. Peripheral Nervous System (cranial and spinal nerves)
3. Autonomic Nervous System (sympathetic and parasympathetic).
Central Nervous System: There are ten pairs of cranial nerves arising from the brain. Brain is enclosed in a bony structure called brain box (cranium). The brain is divided into fore-brain, mid-brain and hind-brain. Forebrain includes olfactory lobes, paired cerebral hemispheres and unpaired diencephalon. The midbrain is characterised by a pair of optic lobes. Hind-brain consists of cerebellum and medulla oblongata. The medulla oblongata passes out through the foramen magnum and continues into spinal cord, which is enclosed in the vertebral column.

Sense Organs: Frog has different types of sense organs, namely organs of touch (sensory papillae), taste (taste buds), smell (nasal epithelium), vision (eyes) and hearing (tympanum with internal ears). Out of these, eyes and internal ears are well-organised structures and the rest are cellular aggregations around nerve endings. Eyes in a frog are a pair of spherical structures situated in the orbit in skull. These are simple eyes (possessing only one unit). External ear is absent in frogs and only tympanum can be seen externally. The ear is an organ of hearing as well as balancing (equilibrium).
Reproductive System: Frogs have well organised male and female reproductive systems.
Male Reproductive Organs: Male reproductive organs consist of a pair of yellowish ovoid testes, which are found adhered to the upper part of kidneys by a double fold of peritoneum called mesorchium. Vasa efferentia are 10-12 in number that arise from testes. They enter the kidneys on their side and open into Bidder's canal. Finally it communicates with the urinogenital duct that comes out of the kidneys and opens into the cloaca. The cloaca is a small, median chamber that is used to pass faecal matter, urine and sperms to the exterior.
Female Reproductive Organs: The female reproductive organs include a pair of ovaries. The ovaries are situated near kidneys and there is no functional connection with kidneys. A pair of oviduct arising from the ovaries opens into the cloaca separately. A mature female can lay 2500 to 3000 ova at a time.
Fertilization: Fertilisation is external and takes place in water. Development involves a larval stage called tadpole. Tadpole undergoes metamorphosis to form the adult.
Significance for Humans: Frogs are beneficial for mankind because they eat insects and protect the crop. Frogs maintain ecological balance because these serve as an important link of food chain and food web in the ecosystem. In some countries the muscular legs of frog are used as food by man.

Biomolecules

Analysis Of Chemical Composition
To do this one extracts the compounds, then subjects the extract to various separation techniques till one has separated a compound from all other compounds. In other words, one isolates and purifies a compound. Analytical techniques, when applied to the compound give us an idea of the molecular formula and the probable structure of the compound. All the carbon compounds that we get from living tissues can be called 'biomolecules'.
Analysis of Inorganic Compounds

A slightly different but destructive experiment has to be done. One weighs a small amount of a living tissue (say a leaf or liver and this is called wet weight) and dry it. All the water, evaporates. The remaining material gives dry weight. Now if the tissue is fully burnt, all the carbon compounds are oxidised to gaseous form (CO_2, water vapour) and are removed. What is remaining is called 'ash'. This ash contains inorganic elements (like calcium, magnesium etc). Inorganic compounds like sulphate, phosphate, etc., are also seen in the acid-soluble fraction. Therefore elemental analysis gives elemental composition of living tissues in the form of hydrogen, oxygen, chlorine, carbon etc. while analysis for compounds gives an idea of the kind of organic and inorganic constituents present in living tissues. From a chemistry point of view, one can identify functional groups like aldehydes, ketones, aromatic compounds, etc. But from a biological point of view, we shall classify them into amino acids, nucleotide bases, fatty acids etc.

Amino Acids:

Amino acids are organic compounds containing an amino group and an acidic group as substituents on the same carbon i.e., the α-carbon. Hence, they are called α-amino acids. They are substituted methanes. There are four substituent groups occupying the four valency positions. These are hydrogen, carboxyl group, amino group and a variable group designated as R group. Based on the nature of R group there are many amino acids. However, those which occur in proteins are only of twenty one types. The R group in these proteinaceous amino acids could be a hydrogen (the amino acid is called glycine), a methyl group (alanine), hydroxyl methyl (serine), etc. The chemical and physical properties of amino acids are essentially of the amino, carboxyl and the R functional groups. Based on number of amino and carboxyl groups, there are acidic (e.g., glutamic acid), basic (lysine) and neutral (valine) amino acids. Similarly, there are aromatic amino acids (tyrosine, phenylalanine, tryptophan). A particular property of amino acids is the ionizable nature of $–NH_2$ and $–COOH$ groups. Hence in solutions of different pHs, the structure of amino acids changes.

Lipids:

Lipids are generally water insoluble. They could be simple fatty acids. A fatty acid has a carboxyl group attached to an R group. The R group could be a methyl ($–CH_3$), or ethyl ($–C_2H_5$) or higher number of $–CH_2$ groups (1 carbon to 19 carbons). For example, palmitic acid has 16 carbons including carboxyl carbon. Arachidonic acid has 20 carbon atoms including the carboxyl carbon. Fatty acids could be saturated (without double bond) or unsaturated (with one or more C=C double bonds). Another simple lipid is glycerol which is trihydroxy propane. Many lipids have both glycerol and fatty acids. Here the fatty acids are found esterified with glycerol. They can be then monoglycerides, diglycerides and triglycerides. These are also called fats and oils based on melting point. Oils have lower melting point (e.g., gingely oil) and hence remain as oil in winters.

Some lipids have phosphorous and a phosphorylated organic compound in them. These are phospholipids. They are found in cell membrane. Lecithin is one example. Some tissues especially the neural tissues have lipids with more complex structures.

Living organisms have a number of carbon compounds in which heterocyclic rings can be found. Some of these are nitrogen bases – adenine, guanine, cytosine, uracil, and thymine. When found attached to a sugar, they are called nucleosides. If a phosphate group is also found esterified to the sugar they are called nucleotides. Adenosine, guanosine, thymidine, uridine and cytidine are nucleosides. Adenylic acid, thymidylic acid, guanylic acid, uridylic acid and cytidylic acid are nucleotides. Nucleic acids like DNA and RNA consist of nucleotides only. DNA and RNA function as genetic material.

PRIMARY AND SECONDARY METABOLITES

Primary metabolites have identifiable functions and play known roles in normal physiologial processes, we do not at the moment, understand the role or functions of all the 'secondary metabolites' in host organisms. However, many of them are useful to 'human welfare' (e.g., rubber, drugs, spices, scents and pigments). Some secondary metabolites have ecological importance.

BIOMACROMOLECULES

Chemical compounds found in living organisms are of two types. One, those which have molecular weights less than one thousand dalton and are usually referred to as micromolecules or simply biomolecules while those which are found in the acid insoluble fraction are called macromolecules or biomacromolecules. The molecules in the insoluble fraction with the exception of lipids are polymeric substances.

Average Composition of Cells

The acid soluble pool represents roughly the cytoplasmic composition. The macromolecules from cytoplasm and organelles become the acid insoluble fraction. Together they represent the entire chemical composition of living tissues or organisms.

Proteins

Each protein is a polymer of amino acids. As there are 21 types of amino acids (e.g., alanine, cysteine, proline, tryptophan, lysine, etc.), a protein is a heteropolymer and not a homopolymer. A homopolymer has only one type of monomer repeating 'n' number of times.

Certain amino acids are essential for our health and they have to be supplied through our diet. Hence, dietary proteins are the source of essential amino acids. Therefore, amino acids can be essential or non-essential. The latter are those which

our body can make, while we get essential amino acids through our diet/food. Proteins carry out many functions in living organisms, some transport nutrients across cell membrane, some fight infectious organisms, some are hormones, some are enzymes, Collagen is the most abundant protein in animal world and Ribulose bisphosphate Carboxylase-Oxygenase (RUBISCO) is the most abundant protein in the whole of the biosphere.
Some Proteins And Their Functions

POLYSACCHARIDES
Polysaccharides are long chains of sugars. They are threads containing different monosaccharides as building blocks. For example cellulose is a polymeric polysaccharide consisting of only one type of monosaccharide i.e., glucose. Cellulose is a homopolymer. Starch is a variant of this but present as a store house of energy in plant tissues. Animals have another variant called glycogen. Inulin is a polymer of fructose.

Three-D Structure of Cellulose
In a polysaccharide chain (say glycogen), the right end is called the reducing end and the left end is called the non-reducing end. Starch forms helical secondary structures. In fact, starch can hold I_2 molecules in the helical portion. Cellulose does not contain complex helices and hence cannot hold I_2. Plant cell walls are made of cellulose. Paper made from plant pulp is cellulose. Cotton fibre is cellulose.
There are more complex polysaccharides in nature. They have as building blocks, amino-sugars and chemically modified sugars (e.g., glucosamine, N-acetyl galactosamine, etc.). Exoskeletons of arthropods, for example, have a complex polysaccharide called chitin. These complex polysaccharides are heteropolymers.
NUCLEIC ACIDS
For nucleic acids, the building block is a nucleotide. A nucleotide has three chemically distinct components. One is a heterocyclic compound, the second is a monosaccharide and the third a phosphoric acid or phosphate.
The heterocyclic compounds in nucleic acids are the nitrogenous bases named adenine, guanine, uracil, cytosine, and thymine. Adenine and Guanine are substituted purines while the rest are substituted pyrimidines.
The skeletal heterocyclic ring is called as purine and pyrimidine respectively. The sugar found in polynucleotides is either ribose (a monosaccharide pentose) or 2’ deoxyribose. A nucleic acid containing deoxyribose is called deoxyribonucleic acid (DNA) while that which contains ribose is called ribonucleic acid (RNA).
STRUCTURE OF PROTEINS
Primary Structure: The sequence of amino acids i.e., the positional information in a protein – which is the first amino acid, which is second, and so on – is called the primary structure of a protein. A protein is imagined as a line, the left end represented by the first amino acid and the right end represented by the last amino acid. The first aminoacid is also called as N-terminal amino acid. The last amino acid is called the C-terminal amino acid. A protein thread does not exist throughout as an extended rigid rod.
Secondary Structure: Regularly repeating local structures stabilized by hydrogen bonds. The most common examples are the alpha helix, beta sheet and turns. Because secondary structures are local, many regions of different secondary structure can be present in the same protein molecule.
Tertiary structure: The overall shape of a single protein molecule; the spatial relationship of the secondary structures to one another. Tertiary structure is generally stabilized by nonlocal interactions, most commonly the formation of a hydrophobic core, but also through salt bridges, hydrogen bonds, disulfide bonds, and even post-translational modifications. The term "tertiary structure" is often used as synonymous with the term fold. The Tertiary structure is what controls the basic function of the protein.
Quaternary Structure: Some proteins are an assembly of more than one polypeptide or subunits. The manner in which these individual folded polypeptides or subunits are arranged with respect to each other (e.g. linear string of spheres, spheres arranged one upon each other in the form of a cube or plate etc.) is the architecture of a protein otherwise called the quaternary structure of a protein.
NATURE OF BOND LINKING MONOMERS IN A POLYMER
Glycosidic Bond: A glycosidic bond is a certain type of functional group that joins a carbohydrate (sugar) molecule to another group, which may or may not be another carbohydrate.

Peptide Bond: A peptide bond (amide bond) is a chemical bond formed between two molecules when the carboxyl group of one molecule reacts with the amine group of the other molecule, thereby releasing a molecule of water (H_2O). This is a dehydration synthesis reaction (also known as a condensation reaction), and usually occurs between amino acids. The resulting CO-NH bond is called a peptide bond, and the resulting molecule is an amide. The four-atom functional group -C(=O)NH- is called an amide group or (in the context of proteins) a peptide group. Polypeptides and proteins are chains of amino acids held together by peptide bonds, as is the backbone of PNA. Polyamides, such as nylons and aramids, are synthetic molecules (polymers) that possess peptide bonds.

Phospho-diester Bond: A phospho-diester bond is a group of strong covalent bonds between a phosphate group and two other molecules over two ester bonds. Phosphodiester bonds are central to all life on Earth, as they make up the backbone of the strands of DNA. In DNA and RNA, the phosphodiester bond is the linkage between the 3' carbon atom of one sugar molecule and the 5' carbon of another, deoxyribose in DNA and ribose in RNA.

DYNAMIC STATE OF BODY CONSTITUENTS – CONCEPT OF METABOLISM

One of the greatest discoveries ever made was the observation that all these biomolecules have a turn over. This means that they are constantly being changed into some other biomolecules and also made from some other biomolecules. This breaking and making is through chemical reactions constantly occurring in living organisms. Together all these chemical reactions are called metabolism. Each of the metabolic reactions results in the transformation of biomolecules. A few examples for such metabolic transformations are: removal of CO2 from amino acids making an amino acid into an amine, removal of amino group in a nucleotide base; hydrolysis of a glycosidic bond in a disaccharide, etc.

Majority of these metabolic reactions do not occur in isolation but are always linked to some other reactions. In other words, metabolites are converted into each other in a series of linked reactions called metabolic pathways.

These pathways are either linear or circular. These pathways crisscross each other, i.e., there are traffic junctions. Flow of metabolites through metabolic pathway has a definite rate and direction like automobile traffic. This metabolite flow is called the dynamic state of body constituents. What is most important is that this interlinked metabolic traffic is very smooth and without a single reported mishap for healthy conditions. Another feature of these metabolic reactions is that every chemical reaction is a catalysed reaction. There is no uncatalysed metabolic conversion in living systems.

The catalysts which hasten the rate of a given metabolic conversation are also proteins. These proteins with catalytic power are named enzymes.

METABOLIC BASIS FOR LIVING

Anabolic Pathways: Anabolic pathways convert simpler structure molecules to complex molecules. Anabolic pathways consume energy to synthesize something.

Catabolic Pathways: Catabolic pathways convert complex molecules into simple molecules. Catabolic pathways release energy while breaking down molecules. Living organisms have learnt to trap this energy liberated during degradation and store it in the form of chemical bonds. As and when needed, this bond energy is utilized for biosynthetic, osmotic and mechanical work that we perform. The most important form of energy currency in living systems is the bond energy in a chemical called adenosine triphosphate (ATP).

THE LIVING STATE

The most important fact of biological systems is that all living organisms exist in a steady-state characterised by concentrations of each of these biomolecules. These biomolecules are in a metabolic flux. Any chemical or physical process moves spontaneously to equilibrium. The steady state is a non-equilibirium state.

As living organisms work continuously, they cannot afford to reach equilibrium. Hence the living state is a non-equilibrium steady-state to be able to perform work; living process is a constant effort to prevent falling into equilibrium. This is achieved by energy input. Metabolism provides a mechanism for the production of energy. Hence the living state and metabolism are synonymous. Without metabolism there cannot be a living state.

ENZYMES

Almost all enzymes are proteins. An enzyme like any protein has a primary structure, i.e., amino acid sequence of the protein. An enzyme like any protein has the secondary and the tertiary structure.

"Lock and Key" Model:

Enzymes are very specific, and it was suggested by Emil Fischer in 1894 that this was because both the enzyme and the substrate possess specific complementary geometric shapes that fit exactly into one another. This is often referred to as "the lock and key" model. However, while this model explains enzyme specificity, it fails to explain the stabilization of the transition state that enzymes achieve. The "lock and key" model has proven inaccurate, and the induced fit model is the most currently accepted enzyme-substrate-coenzyme figure.

(ref: http://en.wikipedia.org/wiki/File:Induced_fit_diagram.svg accessed on 9th Oct 2009)

Induced Fit Model

Diagrams to show the induced fit hypothesis of enzyme action.In 1958, Daniel Koshland suggested a modification to the lock and key model: since enzymes are rather flexible structures, the active site is continually reshaped by interactions with the substrate as the substrate interacts with the enzyme. As a result, the substrate does not simply bind to a rigid active site; the amino acid side chains which make up the active site are molded into the precise positions that enable the enzyme to perform its catalytic function. In some cases, such as glycosidases, the substrate molecule also changes shape slightly as it enters the active site. The active site continues to change until the substrate is completely bound, at which point the final shape and charge is determined.

Enzyme catalysts differ from inorganic catalysts in many ways, but one major difference needs mention. Inorganic catalysts work efficiently at high temperatures and high pressures, while enzymes get damaged at high temperatures (say above 40°C). However, enzymes isolated from organisms who normally live under extremely high temperatures (e.g., hot vents and sulphur springs), are stable and retain their catalytic power even at high temperatures (upto 80°-90°C). Thermal stability is thus an important quality of such enzymes isolated from thermophilic organisms.

Mechanisms of Enzymatic Actions

• Lowering the activation energy by creating an environment in which the transition state is stabilized (e.g. straining the shape of a substrate—by binding the transition-state conformation of the substrate/product molecules, the enzyme distorts the bound substrate(s) into their transition state form, thereby reducing the amount of energy required to complete the transition).
• Lowering the energy of the transition state, but without distorting the substrate, by creating an environment with the opposite charge distribution to that of the transition state.
• Providing an alternative pathway: For example, temporarily reacting with the substrate to form an intermediate ES complex, which would be impossible in the absence of the enzyme.
• Reducing the reaction entropy change by bringing substrates together in the correct orientation to react. Considering $\Delta H^{\ddagger}$ alone overlooks this effect.
• Increases in temperatures speed up reactions. Thus, temperature increases help the enzyme function and develop the end product even faster. However, if heated too much, the enzyme's shape deteriorates and only when the temperature comes back to normal does the enzyme regain its shape. Some enzymes like thermolabile enzymes work best at low temperatures.

The catalytic cycle of an enzyme action can be described in the following steps:
1. First, the substrate binds to the active site of the enzyme, fitting into the active site.
2. The binding of the substrate induces the enzyme to alter its shape, fitting more tightly around the substrate.
3. The active site of the enzyme, now in close proximity of the substrate breaks the chemical bonds of the substrate and the new enzyme- product complex is formed.
4. The enzyme releases the products of the reaction and the free enzyme is ready to bind to another molecule of the substrate and run through the catalytic cycle once again.

Factors Affecting Enzyme Activity

Temperature and pH: Enzymes generally function in a narrow range of temperature and pH. Each enzyme shows its highest activity at a particular temperature and pH called the optimum temperature and optimum pH. Activity declines both below and above the optimum value. Low temperature preserves the enzyme in a temporarily inactive state whereas high temperature destroys enzymatic activity because proteins are denatured by heat.

Concentration of Substrate: With the increase in substrate concentration, the velocity of the enzymatic reaction rises at first. The reaction ultimately reaches a maximum velocity (Vmax) which is not exceeded by any further rise in concentration of the substrate. This is because the enzyme molecules are fewer than the substrate molecules and after saturation of these molecules, there are no free enzyme molecules to bind with the additional substrate molecules.

Effect of Inhibitor: The activity of an enzyme is also sensitive to the presence of specific chemicals that bind to the enzyme. When the binding of the chemical shuts off enzyme activity, the process is called inhibition and the chemical is called an inhibitor. When the inhibitor closely resembles the substrate in its molecular structure and inhibits the activity of the enzyme, it is known as competitive inhibitor. Due to its close structural similarity with the substrate, the inhibitor competes with the substrate for the substratebinding site of the enzyme. Consequently, the substrate cannot bind and as a result, the enzyme action declines, e.g., inhibition of succinic dehydrogenase by malonate which closely resembles the substrate succinate in structure. Such competitive inhibitors are often used in the control of bacterial pathogens.

Classification and Nomenclature of Enzymes

Thousands of enzymes have been discovered, isolated and studied. Most of these enzymes have been classified into different groups based on the type of reactions they catalyse. Enzymes are divided into 6 classes each with 4-13 subclasses and named accordingly by a four-digit number.

Oxidoreductases/dehydrogenases: Enzymes which catalyse oxidoreduction between two substrates S and S'.
Transferases: Enzymes catalysing a transfer of a group, G (other than hydrogen) between a pair of substrate S and S'.
Hydrolases: Enzymes catalysing hydrolysis of ester, ether, peptide, glycosidic, C-C, C-halide or P-N bonds.
Lyases: Enzymes that catalyse removal of groups from substrates by mechanisms other than hydrolysis leaving double bonds.
Isomerases: Includes all enzymes catalysing inter-conversion of optical, geometric or positional isomers.
Ligases: Enzymes catalysing the linking together of 2 compounds, e.g., enzymes which catalyse joining of C-O, C-S, C-N, P-O etc. bonds.

Co-factors

Enzymes are composed of one or several polypeptide chains. However, there are a number of cases in which non-protein constituents called cofactors are bound to the the enzyme to make the enzyme catalytically active. In these instances, the protein portion of the enzymes is called the apoenzyme. Three kinds of cofactors may be identified: prosthetic groups, co-enzymes and metal ions.

Prosthetic Groups: Prosthetic groups are organic compounds and are distinguished from other cofactors in that they are tightly bound to the apoenzyme. For example, in peroxidase and catalase, which catalyze the breakdown of hydrogen peroxide to water and oxygen, haem is the prosthetic group and it is a part of the active site of the enzyme.

Co-enzymes: Co-enzymes are also organic compounds but their association with the apoenzyme is only transient, usually occurring during the course of catalysis. Furthermore, co-enzymes serve as co-factors in a number of different enzyme

catalyzed reactions. The essential chemical components of many coenzymes are vitamins, e.g., coenzyme nicotinamide adenine dinucleotide (NAD) and NADP contain the vitamin niacin.
Metal Ions: A number of enzymes require metal ions for their activity which form coordination bonds with side chains at the active site and at the same time form one or more cordination bonds with the substrate, e.g., zinc is a cofactor for the proteolytic enzyme carboxypeptidase. Catalytic activity is lost when the co-factor is removed from the enzyme which testifies that they play a crucial role in the catalytic activity of the enzyme.

Digestion And Absorption

Digestive System
Food is one of the basic requirements of all living organisms. The major components of our food are carbohydrates, proteins and fats. Vitamins and minerals are also required in small quantities. Food provides energy and organic materials for growth and repair of tissues. The water we take in, plays an important role in metabolic processes and also prevents dehydration of the body. Bio-macromolecules in food cannot be utilized by our body in their original form. They have to be broken down and converted into simple substances in the digestive system. This process of conversion of complex food substances to simple absorbable forms is called digestion and is carried out by our digestive system by mechanical and biochemical methods.

The human digestive system consists of the alimentary canal and the associated glands.
Alimentary Canal: The alimentary canal begins with an anterior opening – the mouth, and it opens out posteriorly through the anus. The mouth leads to the buccal cavity or oral cavity. The oral cavity has a number of teeth and a muscular tongue. Each tooth is embedded in a socket of jaw bone. This type of attachment is called thecodont.
Dentition: Majority of mammals including human being forms two sets of teeth during their life, a set of temporary milk or deciduous teeth replaced by a set of permanent or adult teeth. This type of dentition is called diphyodont. An adult human has 32 permanent teeth which are of four different types (Heterodont dentition), namely, incisors (I), canine (C), premolars (PM) and molars (M). Arrangement of teeth in each half of the upper and lower jaw in the order I, C, PM, M is represented by a dental formula which in human is 2123/2123 . The hard chewing surface of the teeth, made up of enamel, helps in the mastication of food.
The tongue is a freely movable muscular organ attached to the floor of the oral cavity by the frenulum. The upper surface of the tongue has small projections called papillae, some of which bear taste buds. The oral cavity leads into a short pharynx which serves as a common passage for food and air.
Oesophagus: The oesophagus and the trachea (wind pipe) open into the pharynx. A cartilaginous flap called epiglottis prevents the entry of food into the glottis – opening of the wind pipe – during swallowing. The oesophagus is a thin, long tube which extends posteriorly passing through the neck, thorax and diaphragm and leads to a 'J' shaped bag like structure called stomach. A muscular sphincter (gastro-oesophageal) regulates the opening of oesophagus into the stomach.

Stomach: The stomach, located in the upper left portion of the abdominal cavity, has three major parts – a cardiac portion into which the oesophagus opens, a fundic region and a pyloric portion which opens into the first part of small intestine
Small Intestine: Small intestine is distinguishable into three regions, a 'U' shaped duodenum, a long coiled middle portion jejunum and a highly coiled ileum. The opening of the stomach into the duodenum is guarded by the pyloric sphincter.
Large Intestine: Ileum opens into the large intestine. It consists of caecum, colon and rectum. Caecum is a small blind sac which hosts some symbiotic micro-organisms.
Appendix: A narrow finger-like tubular projection, the vermiform appendix which is a vestigial organ, arises from the caecum.
Colon: The caecum opens into the colon. The colon is divided into three parts – an ascending, a transverse and a descending part. The descending part opens into the rectum which opens out through the anus. The wall of alimentary canal from oesophagus to rectum possesses four layers; namely serosa, muscularis, sub-mucosa and mucosa. Serosa is the outermost layer and is made up of a thin mesothelium (epithelium of visceral organs) with some connective tissues. Muscularis is formed by smooth muscles usually arranged into an inner circular and an outer longitudinal layer. An oblique muscle layer may be present in some regions. The submucosal layer is formed of loose connective tissues.
Digestive Glands
Salivary Glands: Saliva is mainly produced by three pairs of salivary glands, the parotids (cheek), the sub-maxillary/sub-mandibular (lower jaw) and the sublinguals (below the tongue). These glands situated just outside the buccal cavity secrete salivary juice into the buccal cavity.
Liver: Liver is the largest gland of the body weighing about 1.2 to 1.5 kg in an adult human. It is situated in the abdominal cavity, just below the diaphragm and has two lobes. The hepatic lobules are the structural and functional units of liver containing hepatic cells arranged in the form of cords. Each lobule is covered by a thin connective tissue sheath called the Glisson's capsule. The bile secreted by the hepatic cells passes through the hepatic ducts and is stored and concentrated in a thin muscular sac called the gall bladder. The duct of gall bladder (cystic duct) along with the hepatic duct from the liver forms the common bile duct.

The bile duct and the pancreatic duct open together into the duodenum as the common hepato-pancreatic duct which is guarded by a sphincter called the sphincter of Oddi.

Pancreas: The pancreas is a compound (both exocrine and endocrine) elongated organ situated between the limbs of the 'U' shaped duodenum. The exocrine portion secretes an alkaline pancreatic juice containing enzymes and the endocrine portion secretes hormones, insulin and glucagon.

DIGESTION OF FOOD

The process of digestion is accomplished by mechanical and chemical processes.

Digestion Process in Mouth: The buccal cavity performs two major functions, mastication of food and facilitation of swallowing. The teeth and the tongue with the help of saliva masticate and mix up the food thoroughly. Mucus in saliva helps in lubricating and adhering the masticated food particles into a bolus.

Action of Saliva: The saliva secreted into the oral cavity contains electrolytes (Na^+, K^+, Cl^-, HCO^-) and enzymes, salivary amylase and lysozyme. The chemical process of digestion is initiated in the oral cavity by the hydrolytic action of the carbohydrate splitting enzyme, the salivary amylase. About 30 per cent of starch is hydrolysed here by this enzyme (optimum pH 6.8) into a disaccharide – maltose. Lysozyme present in saliva acts as an antibacterial agent that prevents infections.

The bolus is then conveyed into the pharynx and then into the oesophagus by swallowing or deglutition. The bolus further passes down through the oesophagus by successive waves of muscular contractions called peristalsis. The gastro-oesophageal sphincter controls the passage of food into the stomach.

Gastric Glands: The mucosa of stomach has gastric glands. Gastric glands have three major types of cells namely -

(i) mucus neck cells which secrete mucus;

(ii) peptic or chief cells which secrete the proenzyme pepsinogen; and

(iii) parietal or oxyntic cells which secrete HCl and intrinsic factor (factor essential for absorption of vitamin B12).

Digestion in Stomach: The stomach stores the food for 4-5 hours. The food mixes thoroughly with the acidic gastric juice of the stomach by the churning movements of its muscular wall and is called the chyme. The proenzyme pepsinogen, on exposure to hydrochloric acid gets converted into the active enzyme pepsin, the proteolytic enzyme of the stomach. Pepsin converts proteins into proteoses and peptones (peptides).

• The mucus and bicarbonates present in the gastric juice play an important role in lubrication and protection of the mucosal epithelium from excoriation by the highly concentrated hydrochloric acid.

• HCl provides the acidic pH (pH 1.8) optimal for pepsins. Rennin is a proteolytic enzyme found in gastric juice of infants which helps in the digestion of milk proteins. Small amounts of lipases are also secreted by gastric glands.

Digestion in Small Intestine: Various types of movements are generated by the muscularis layer of the small intestine. These movements help in a thorough mixing up of the food with various secretions in the intestine and thereby facilitate digestion. The bile, pancreatic juice and the intestinal juice are the secretions released into the small intestine. Pancreatic juice and bile are released through the hepato-pancreatic duct.

The pancreatic juice contains inactive enzymes – trypsinogen, chymotrypsinogen, procarboxypeptidases, amylases, lipases and nucleases. Trypsinogen is activated by an enzyme, enterokinase, secreted by the intestinal mucosa into active trypsin, which in turn activates the other enzymes in the pancreatic juice.

The bile released into the duodenum contains bile pigments (bilirubin and bili-verdin), bile salts, cholesterol and phospholipids but no enzymes. Bile helps in emulsification of fats, i.e., breaking down of the fats into very small micelles. Bile also activates lipases.

The intestinal mucosal epithelium has goblet cells which secrete mucus. The secretions of the brush border cells of the mucosa alongwith the secretions of the goblet cells constitute the intestinal juice or succus entericus. This juice contains a variety of enzymes like disaccharidases (e.g., maltase), dipeptidases, lipases, nucleosidases, etc. The mucus alongwith the bicarbonates from the pancreas protects the intestinal mucosa from acid as well as provide an alkaline medium (pH 7.8) for enzymatic activities. Sub-mucosal glands (Brunner's glands) also help in this.

• Proteins, proteoses and peptones (partially hydrolysed proteins) in the chyme reaching the intestine are acted upon by the proteolytic enzymes of pancreatic juice as given below:

• Carbohydrates in the chime are hydrolysed by pancreatic amylase into disaccharides:

• Fats are broken down by lipases with the help of bile into di- and monoglycerides:

• Nucleases in the pancreatic juice acts on nucleic acids to form nucleotides and nucleosides:

• The enzymes in the succus entericus act on the end products of the above reactions to form the respective simple absorbable forms. These final steps in digestion occur very close to the mucosal epithelial cells of the intestine.

ABSORPTION

Absorption: The breakdown of bio-macromolecules mentioned above occurs in the duodenum region of the small intestine. The simple substances thus formed are absorbed in the jejunum and ileum regions of the small intestine. The undigested and unabsorbed substances are passed on to the large intestine. No significant digestive activity occurs in the large intestine. The functions of large intestine are:
(i) absorption of some water, minerals and certain drugs;
(ii) secretion of mucus which helps in adhering the waste (undigested) particles together and lubricating it for an easy passage.
The undigested, unabsorbed substances called faeces enters into the caecum of the large intestine through ileo-caecal valve, which prevents the back flow of the faecal matter. It is temporarily stored in the rectum till defaecation.
Transport of water depends upon the osmotic gradient. Active transport occurs against the concentration gradient and hence requires energy. Various nutrients like amino acids, monosacharides like glucose, electrolytes like Na+ are absorbed into the blood by this mechanism. Fatty acids and glycerol being insoluble, cannot be absorbed into the blood. They are first incorporated into small droplets called micelles which move into the intestinal mucosa. They are re-formed into very small protein coated fat globules called the chylomicrons which are transported into the lymph vessels (lacteals) in the villi. These lymph vessels ultimately release the absorbed substances into the blood stream. Absorption of substances takes place in different parts of the alimentary canal, like mouth, stomach, small intestine and large intestine. However, maximum absorption occurs in the small intestine.

Assimilation: The absorbed substances finally reach the tissues which utilise them for their activities. This process is called assimilation. The digestive wastes, solidified into coherent faeces in the rectum initiate a neural reflex causing an urge or desire for its removal. The egestion of faeces to the outside through the anal opening (defaecation) is a voluntary process and is carried out by a mass peristaltic movement.
The Summary of Absorption in Different Parts of Digestive System

VIDEO
DISORDERS OF DIGESTIVE SYSTEM
The inflammation of the intestinal tract is the most common ailment due to bacterial or viral infections. The infections are also caused by the parasites of the intestine like tape worm, round worm, thread worm, hook worm, pin worm, etc.
Jaundice: The liver is affected, skin and eyes turn yellow due to the deposit of bile pigments.
Vomiting: It is the ejection of stomach contents through the mouth. This reflex action is controlled by the vomit centre in the medulla. A feeling of nausea precedes vomiting.
Diarrhoea: The abnormal frequency of bowel movement and increased liquidity of the faecal discharge is known as diarrhoea. It reduces the absorption of food.
Constipation: In constipation, the faeces are retained within the rectum as the bowel movements occur irregularly.
Indigestion: In this condition, the food is not properly digested leading to a feeling of fullness. The causes of indigestion are inadequate enzyme secretion, anxiety, food poisoning, over eating, and spicy food.

Breathing And Exchange of Gases

Respiration: The process of exchange of O_2 from the atmosphere with CO_2produced by the cells is called breathing, commonly known as respiration.
Respiratory Organs:
• Mechanisms of breathing vary among different groups of animals depending mainly on their habitats and levels of organisation.
• Lower invertebrates like sponges, coelenterates, flatworms, etc., exchange O_2 with CO_2 by simple diffusion over their entire body surface.
• Earthworms use their moist cuticle and insects have a network of tubes (tracheal tubes) to transport atmospheric air within the body.
• Special vascularised structures called gills are used by most of the aquatic arthropods and mollusks.
• Vascularised bags called lungs are used by the terrestrial forms for the exchange of gases. Among vertebrates, fishes use gills whereas reptiles, birds and mammals respire through lungs. Amphibians like frogs can respire through their moist skin also. Mammals have a well developed respiratory system.

Human Respiratory System
Pharynx: We have a pair of external nostrils opening out above the upper lips. It leads to a nasal chamber through the nasal passage. The nasal chamber opens into nasopharynx, which is a portion of pharynx, the common passage for food and air.
Larynx: Nasopharynx opens through glottis of the larynx region into the trachea. Larynx is a cartilaginous box which helps in sound production and hence called the sound box. During swallowing glottis can be covered by a thin elastic cartilaginous flap called epiglottis to prevent the entry of food into the larynx.

Trachea: Trachea is a straight tube extending up to the mid-thoracic cavity, which divides at the level of 5th thoracic vertebra into a right and left primary bronchi.
Bronchi: Each bronchi undergoes repeated divisions to form the secondary and tertiary bronchi and bronchioles ending up in very thin terminal bronchioles. The tracheae, primary, secondary and tertiary bronchi, and initial bronchioles are supported by incomplete cartilaginous rings. Each terminal bronchiole gives rise to a number of very thin, irregularwalled and vascularised bag-like structures called alveoli.
Lungs: The branching network of bronchi, bronchioles and alveoli comprise the lungs. We have two lungs which are covered by a double layered pleura. Pleura is filled with pleural fluid. It reduces friction on the lungsurface. The outer pleural membrane is in close contact with the thoracic lining whereas the inner pleural membrane is in contact with the lung surface.
Conducting Part of Respiratory System: The part of respiratory system, starting with the external nostrils up to the terminal bronchioles constitutes the conducting part. The conducting part transports the atmospheric air to the alveoli, clears it from foreign particles, humidifies and also brings the air to body temperature.
Exchange Part of Respiratory System: The alveoli and their ducts form the respiratory or exchange part of the respiratory system. Exchange part is the site of actual diffusion of O_2 and CO_2 between blood and atmospheric air.
Thoracic Chamber: The lungs are situated in the thoracic chamber which is anatomically an air-tight chamber. The thoracic chamber is formed dorsally by the vertebral column, ventrally by the sternum, laterally by the ribs and on the lower side by the dome-shaped diaphragm. The anatomical setup of lungs in thorax is such that any change in the volume of the thoracic cavity will be reflected in the lung (pulmonary) cavity. Such an arrangement is essential for breathing, as we cannot directly alter the pulmonary volume.

MECHANISM OF BREATHING

Breathing involves two stages, viz., inspiration during which atmospheric air is drawn in and expiration by which the alveolar air is released out. The movement of air into and out of the lungs is carried out by creating a pressure gradient between the lungs and the atmosphere. Inspiration can occur if the pressure within the lungs (intra-pulmonary pressure) is less than the atmospheric pressure, i.e., there is a negative pressure in the lungs with respect to atmospheric pressure. Similarly, expiration takes place when the intra-pulmonary pressure is higher than the atmospheric pressure.
The diaphragm and a specialised set of muscles – external and internal intercostals between the ribs, help in generation of such gradients. Inspiration is initiated by the contraction of diaphragm which increases the volume of thoracic chamber in the antero-posterior axis. The contraction of external inter-costal muscles lifts up the ribs and the sternum causing an increase in the volume of the thoracic chamber in the dorso-ventral axis. The overall increase in the thoracic volume causes a similar increase in pulmonary volume. An increase in pulmonary volume decreases the intra-pulmonary pressure to less than the atmospheric pressure which forces the air from outside to move into the lungs, i.e., inspiration. Relaxation of the diaphragm and the inter-costal muscles returns the diaphragm and sternum to their normal positions and reduce the thoracic volume and thereby the pulmonary volume. This leads to an increase in intra-pulmonary pressure to slightly above the atmospheric pressure causing the expulsion of air from the lungs, i.e., expiration.
We have the ability to increase the strength of inspiration and expiration with the help of additional muscles in the abdomen. On an average, a healthy human breathes 12-16 times/minute. The volume of air involved in breathing movements can be estimated by using a spirometer which helps in clinical assessment of pulmonary functions.

EXCHANGE OF GASES

Alveoli are the primary sites of exchange of gases. Exchange of gases also occur between blood and tissues. O_2 and CO_2 are exchanged in these sites by simple diffusion mainly based on pressure/concentration gradient. Solubility of the gases as well as the thickness of the membranes involved in diffusion are also some of the important factors that can affect the rate of diffusion. Pressure contributed by an individual gas in a mixture of gases is called partial pressure and is represented as pO_2 for oxygen and pCO_2 for carbon dioxide.

TRANSPORT OF GASES

Blood is the medium of transport for O_2 and CO_2. About 97 per cent of O_2 is transported by RBCs in the blood. The remaining 3 per cent of O_2 is carried in a dissolved state through the plasma. Nearly 20-25 per cent of CO_2 is transported by RBCs whereas 70 per cent of it is carried as bicarbonate. About 7 per cent of CO_2 is carried in a dissolved state through plasma.

Transport of Oxygen

Haemoglobin is a red coloured iron containing pigment present in the RBCs. O_2 can bind with haemoglobin in a reversible manner to form oxyhaemoglobin. Each haemoglobin molecule can carry a maximum of four molecules of O_2. Binding of oxygen with haemoglobin is primarily related to partial pressure of O_2. Partial pressure of CO_2, hydrogen ion concentration and temperature are the other factors which can interfere with this binding. A sigmoid curve is obtained when percentage saturation of haemoglobin with O_2 is plotted against the pO_2. This curve is called the Oxygen dissociation curve and is highly useful in studying the effect of factors like pCO_2, H^+concentration, etc., on binding of O_2 with haemoglobin.

Transport of Carbon dioxide

CO_2 is carried by haemoglobin as carbamino-haemoglobin (about 20-25 per cent). This binding is related to the partial pressure of CO_2.

pO_2 is a major factor which could affect this binding. When pCO_2 is high and pO_2 is low as in the tissues, more binding of carbon dioxide occurs whereas, when the pCO_2 is low and pO_2 is high as in the alveoli, dissociation of $CO_2$from carbamino-haemoglobin takes place, i.e., CO_2 which is bound to haemoglobin from the tissues is delivered at the alveoli. RBCs contain a very high concentration of the enzyme, carbonic anhydrase and minute quantities of the same is present in the plasma too. This enzyme facilitates the following reaction in both directions.

At the tissue site where partial pressure of CO_2 is high due to catabolism, CO_2 diffuses into blood (RBCs and plasma) and forms HCO_3 –and H+,. At the alveolar site where pCO_2 is low, the reaction proceeds in the opposite direction leading to the formation of CO_2 and H_2O. Thus, CO_2 trapped as bicarbonate at the tissue level and transported to the alveoli is released out as CO_2 . Every 100 ml of deoxygenated blood delivers approximately 4 ml of CO_2 to the alveoli.

REGULATION OF RESPIRATION

Human beings have a significant ability to maintain and moderate the respiratory rhythm to suit the demands of the body tissues. This is done by the neural system. A specialised centre present in the medulla region of the brain called respiratory rhythm centre is primarily responsible for this regulation. Another centre present in the pons region of the brain called pneumotaxic centre can moderate the functions of the respiratory rhythm centre. Neural signal from this centre can reduce the duration of inspiration and thereby alter the respiratory rate. A chemosensitive area is situated adjacent to the rhythm centre which is highly sensitive to CO2 and hydrogen ions. Increase in these substances can activate this centre, which in turn can signal the rhythm centre to make necessary adjustments in the respiratory process by which these substances can be eliminated. Receptors associated with aortic arch and carotid artery also can recognize changes in CO2 and H+ concentration and send necessary signals to the rhythm centre for remedial actions. The role of oxygen in the regulation of respiratory rhythm is quite insignificant.

DISORDERS OF RESPIRATORY SYSTEM

Asthma is a difficulty in breathing causing wheezing due to inflammation of bronchi and bronchioles.

Emphysema is a chronic disorder in which alveolar walls are damaged due to which respiratory surface is decreased. One of the major causes of this is cigarette smoking.

BODY FLUIDS AND CIRCULATION

Circulation: Blood is the most commonly used body fluid by most of the higher organisms including humans for this purpose. Another body fluid, lymph, also helps in the transport of certain substances.

Blood

Blood is a special connective tissue consisting of a fluid matrix, plasma, and formed elements.

Plasma

Plasma is a straw coloured, viscous fluid constituting nearly 55 per cent of the blood. 90-92 per cent of plasma is water and proteins contribute 6-8 per cent of it. Fibrinogen, globulins and albumins are the major proteins. Fibrinogens are needed for clotting or coagulation of blood. Globulins primarily are involved in defense mechanisms of the body and the albumins help in osmotic balance. Plasma also contains small amounts of minerals like Na^+, Ca^{++}, Mg^{++}, $HCO3^-$, Cl^-, etc. Glucose, amino acids, lipids, etc., are also present in the plasma as they are always in transit in the body. Factors for coagulation or clotting of blood are also present in the plasma in an inactive form. Plasma without the clotting factors is called serum.

Formed Elements

Erythrocytes, leucocytes and platelets are collectively called formed elements and they constitute nearly 45 per cent of the blood.

Erythrocytes: They are also known as Red Blood Cells (RBC). They are the most abundant of all the cells in blood. A healthy adult man has, on an average, 5 millions to 5.5 millions of RBCs mm^{-3} of blood. RBCs are formed in the red bone marrow in the adults. RBCs are devoid of nucleus in most of the mammals and are biconcave in shape. They have a red coloured, iron containing complex protein called haemoglobin, hence the colour and name of these cells. A healthy individual has 12-16 gms of haemoglobin in every 100 ml of blood. These molecules play a significant role in transport of respiratory gases. RBCs have an average life span of 120 days after which they are destroyed in the spleen. Hence, spleen is also known as the graveyard of RBCs.

Leucocytes: They are also known as White Blood Cells (WBC) as they are colourless due to the lack of haemoglobin. They are nucleated and are relatively lesser in number which averages 6000-8000 mm^{-3} of blood. Leucocytes are generally short lived.

There are two main categories of WBCs:

1. Granulocytes , e.g., neutrophils, eosinophils and basophils
2. Agranulocytes. e.g., Lymphocytes and monocytes.

• Neutrophils are the most abundant cells (60-65 per cent) of the total WBCs and basophils are the least (0.5-1 per cent) among them. Neutrophils and monocytes (6-8 per cent) are phagocytic cells which destroy foreign organisms entering the body.

• Basophils secrete histamine, serotonin, heparin, etc., and are involved in inflammatory reactions.
• Eosinophils (2-3 per cent) resist infections and are also associated with allergic reactions.
• Lymphocytes (20-25 per cent) are of two major types – 'B' and 'T' forms. Both B and T lymphocytes are responsible for immune responses of the body.

Platelets: Platelets are also called thrombocytes, are cell fragments produced from megakaryocytes (special cells in the bone marrow). Blood normally contains 1,500,00-3,500,00 platelets mm^{-3}. Platelets can release a variety of substances most of which are involved in the coagulation or clotting of blood. A reduction in their number can lead to clotting disorders which will lead to excessive loss of blood from the body.

Blood Groups

Two such groupings – the ABO and Rh – are widely used all over the world.

ABO Grouping

ABO grouping is based on the presence or absence of two surface antigens (chemicals that can induce immune response) on the RBCs namely A and B. Similarly, the plasma of different individuals contain two natural antibodies (proteins produced in response to antigens).

Importance of Blood Group: During blood transfusion, any blood cannot be used; the blood of a donor has to be carefully matched with the blood of a recipient before any blood transfusion to avoid severe problems of clumping (destruction of RBC).

Blood Groups and Donor Compatibility

From the above mentioned table it is evident that group 'O' blood can be donated to persons with any other blood group and hence 'O' group individuals are called 'universal donors'. Persons with 'AB' group can accept blood from persons with AB as well as the other groups of blood. Therefore, such persons are called 'universal recipients'.

Rh Grouping

Another antigen, the Rh antigen similar to one present in Rhesus monkeys (hence Rh), is also observed on the surface of RBCs of majority (nearly 80 per cent) of humans. Such individuals are called Rh positive (Rh +ve) and those in whom this antigen is absent are called Rh negative (Rh -ve).

Significance of Rh Group: An Rh -ve person, if exposed to Rh +ve blood, will form specific antibodies against the Rh antigens. Therefore, Rh group should also be matched before transfusions.

Rh Incompatibility of Foetus and Mother: A special case of Rh incompatibility (mismatching) has been observed between the Rh -ve blood of a pregnant mother with Rh +ve blood of the foetus. Rh antigens of the foetus do not get exposed to the Rh -ve blood of the mother in the first pregnancy as the two bloods are well separated by the placenta. However, during the delivery of the first child, there is a possibility of exposure of the maternal blood to small amounts of the Rh +ve blood from the foetus. In such cases, the mother starts preparing antibodies against Rh in her blood. In case of her subsequent pregnancies, the Rh antibodies from the mother (Rh -ve) can leak into the blood of the foetus (Rh +ve) and destroy the foetal RBCs. This could be fatal to the foetus or could cause severe anaemia and jaundice to the baby. This condition is called erythroblastosis foetalis. This can be avoided by administering anti-Rh antibodies to the mother immediately after the delivery of the first child.

Coagulation of Blood

Blood exhibits coagulation or clotting in response to an injury or trauma. This is a mechanism to prevent excessive loss of blood from the body. A dark reddish brown scum is formed at the site of a cut or an injury over a period of time. It is a clot or coagulam formed mainly of a network of threads called fibrins in which dead and damaged formed elements of blood are trapped. Fibrins are formed by the conversion of inactive fibrinogens in the plasma by the enzyme thrombin. Thrombins, in turn are formed from another inactive substance present in the plasma called prothrombin. An enzyme complex, thrombokinase, is required for the above reaction. This complex is formed by a series of linked enzymic reactions (cascade process) involving a number of factors present in the plasma in an inactive state. An injury or a trauma stimulates the platelets in the blood to release certain factors which activate the mechanism of coagulation. Certain factors released by the tissues at the site of injury also can initiate coagulation. Calcium ions play a very important role in clotting.

Hemophilia: The clotting disorder which prevents blood from clotting is called haemophilia. The person suffering from haemophilia is always at a risk of excessive blood loss in case of injury. The blood loss can prove fatal.

LYMPH (TISSUE FLUID)

As the blood passes through the capillaries in tissues, some water along with many small water soluble substances move out into the spaces between the cells of tissues leaving the larger proteins and most of the formed elements in the blood vessels. This fluid released out is called the interstitial fluid or tissue fluid. It has the same mineral distribution as that in plasma. Exchange of nutrients, gases, etc., between the blood and the cells always occur through this fluid. An elaborate network of vessels called the lymphatic system collects this fluid and drains it back to the major veins. The fluid present in the lymphatic system is called the lymph. Lymph is a colourless fluid containing specialised lymphocytes which are responsible for the immune responses of the body. Lymph is also an important carrier for nutrients, hormones, etc. Fats are absorbed through lymph in the lacteals present in the intestinal villi.

CIRCULATORY PATHWAYS

The circulatory patterns are of two types – open or closed.
Open Circulatory System: In open circulatory system blood pumped by the heart passes through large vessels into open spaces or body cavities called sinuses. Arthodpodas and Molluscs have this type of circulatory system.
Closed Circulatory System: In closed circulatory system blood pumped by the heart is always circulated through a closed network of blood vessels. This pattern is considered to be more advantageous as the flow of fluid can be more precisely regulated. Annelids and chordates have this type of system.
Chambered Heart: All vertebrates possess a muscular chambered heart. Fishes have a 2-chambered heart with an atrium and a ventricle. Amphibians and the reptiles (except crocodiles) have a 3-chambered heart with two atria and a single ventricle, whereas crocodiles, birds and mammals possess a 4-chambered heart with two atria and two ventricles.
Single Circulation: In fishes the heart pumps out deoxygenated blood which is oxygenated by the gills and supplied to the body parts from where deoxygenated blood is returned to the heart.
Incomplete Double Circulation: In amphibians and reptiles, the left atrium receives oxygenated blood from the gills/lungs/skin and the right atrium gets the deoxygenated blood from other body parts. However, they get mixed up in the single ventricle which pumps out mixed blood.
Complete Double Circulation: In birds and mammals, oxygenated and deoxygenated blood received by the left and right atria respectively passes on to the ventricles of the same sides. The ventricles pump it out without any mixing up, i.e., two separate circulatory pathways are present in these organisms, hence, these animals have double circulation.
Human Circulatory System
Human circulatory system, also called the blood vascular system consists of a muscular chambered heart, a network of closed branching blood vessels and blood, the fluid which is circulated.
Heart:
Location and Size: Heart, the mesodermally derived organ, is situated in the thoracic cavity, in between the two lungs, slightly tilted to the left. It has the size of a clenched fist.

Structure: The heart is protected by a double walled membranous bag, pericardium, enclosing the pericardial fluid.
Heart has four chambers:
(a) Two relatively small upper chambers called atria and
(b) two larger lower chambers called ventricles.
A thin, muscular wall called the interatrial septum separates the right and the left atria, whereas a thick-walled, the inter-ventricular septum, separates the left and the right ventricles The atrium and the ventricle of the same side are also separated by a thick fibrous tissue called the atrio-ventricular septum. However, each of these septa are provided with an opening through which the two chambers of the same side are connected.
The opening between the right atrium and the right ventricle is guarded by a valve formed of three muscular flaps or cusps, the tricuspid valve, whereas a bicuspid or mitral valve guards the opening between the left atrium and the left ventricle. The openings of the right and the left ventricles into the pulmonary artery and the aorta respectively are provided with the semilunar valves. The valves in the heart allows the flow of blood only in one direction, i.e., from the atria to the ventricles and from the ventricles to the pulmonary artery or aorta. These valves prevent any backward flow.
Conduction of Heart Beat:
The entire heart is made of cardiac muscles. The walls of ventricles are much thicker than that of the atria. A specialised cardiac musculature called the nodal tissue is also distributed in the heart .

SA Node: A patch of this tissue is present in the right upper corner of the right atrium called the sino-atrial node (SAN).
AV Node: Another mass of this tissue is seen in the lower left corner of the right atrium close to the atrio-ventricular septum called the atrio-ventricular node (AVN).
Bundle of His: A bundle of nodal fibres, atrioventricular bundle (AV bundle) continues from the AVN which passes through the atrio-ventricular septa to emerge on the top of the interventricular septum and immediately divides into a right and left bundle. These branches give rise to minute fibres throughout the ventricular musculature of the respective sides and are called purkinje fibres. These fibres alongwith right and left bundles are known as bundle of HIS.
Generation of Heart Beat: The nodal musculature has the ability to generate action potentials without any external stimuli, i.e., it is autoexcitable. However, the number of action potentials that could be generated in a minute vary at different parts of the nodal system. The SA Node can generate the maximum number of action potentials, i.e., 70-75 min–1, and is responsible for initiating and maintaining the rhythmic contractile activity or beating of the heart. Therefore, it is called the pacemaker. Our heart normally beats 70-75 times in a minute (average 72 beats per minute).
Cardiac Cycle
• To begin with, all the four chambers of heart are in a relaxed state, i.e., they are in joint diastole. As the tricuspid and bicuspid valves are open, blood from the pulmonary veins and vena cava flows into the left and the right ventricle respectively through the left and right atria. The semilunar valves are closed at this stage.
• The SA Node now generates an action potential or impulse which stimulates both the atria to undergo a simultaneous contraction – the atrial systole. This increases the flow of blood into the ventricles by about 30 per cent.

• The action potential is conducted to the ventricular side by the AV Node and AV bundle from where the bundle of HIS transmits it through the entire ventricular musculature. This causes the ventricular muscles to contract, (ventricular systole), the atria undergoes relaxation (diastole), coinciding with the ventricular systole.
• Ventricular systole increases the ventricular pressure causing the closure of tricuspid and bicuspid valves due to attempted backflow of blood into the atria. As the ventricular pressure increases further, the semilunar valves guarding the pulmonary artery (right side) and the aorta (left side) are forced open, allowing the blood in the ventricles to flow through these vessels into the circulatory pathways.
• The ventricles now relax (ventricular diastole) and the ventricular pressure falls causing the closure of semilunar valves which prevents the backflow of blood into the ventricles. As the ventricular pressure declines further, the tricuspid and bicuspid valves are pushed open by the pressure in the atria exerted by the blood which was being emptied into them by the veins. The blood now once again moves freely to the ventricles. The ventricles and atria are now again in a relaxed (joint diastole) state, as earlier.
• Soon the SA Node generates a new action potential and the events described above are repeated in that sequence and the process continues. This sequential event in the heart which is cyclically repeated is called the cardiac cycle and it consists of systole and diastole of both the atria and ventricles.

Stroke Volume & Cardiac Output: As mentioned earlier, the heart beats 72 times per minute, i.e., that many cardiac cycles are performed per minute. From this it could be deduced that the duration of a cardiac cycle or beat is 0.8 seconds. During a cardiac cycle, each ventricle pumps out approximately 70 mL of blood which is called the stroke volume. The stroke volume multiplied by the heart rate (no. of beats per min.) gives the cardiac output. Therefore, the cardiac output can be defined as the volume of blood pumped out by each ventricle per minute and averages 5000 mL or 5 litres in a healthy individual. The body has the ability to alter the stroke volume as well as the heart rate and thereby the cardiac output. For example, the cardiac output of an athlete will be much higher than that of an ordinary man. During each cardiac cycle two prominent sounds are produced which can be easily heard through a stethoscope. The first heart sound (lub) is associated with the closure of the tricuspid and bicuspid valves whereas the second heart sound (dub) is associated with the closure of the semilunar valves. These sounds are of clinical diagnostic significance.

Electrocardiograph (ECG)

ECG is a graphical representation of the electrical activity of the heart during a cardiac cycle. A patient is connected to the machine with three electrical leads (one to each wrist and to the left ankle) that continuously monitor the heart activity. For a detailed evaluation of the heart's function, multiple leads are attached to the chest region.

Each peak in the ECG is identified with a letter from P to T that corresponds to a specific electrical activity of the heart. The P-wave represents the electrical excitation (or depolarisation) of the atria, which leads to the contraction of both the atria. The QRS complex represents the depolarisation of the ventricles, which initiates the ventricular contraction. The contraction starts shortly after Q and marks the beginning of the systole. The T-wave represents the return of the ventricles from excited to normal state (repolarisation). The end of the T-wave marks the end of systole. Obviously, by counting the number of QRS complexes that occur in a given time period, one can determine the heart beat rate of an individual. Since the ECGs obtained from different individuals have roughly the same shape for a given lead configuration, any deviation from this shape indicates a possible abnormality or disease. Hence, it is of a great clinical significance.

DOUBLE CIRCULATION

Systemic Circulation: The blood pumped by the right ventricle enters the pulmonary artery, whereas the left ventricle pumps blood into the aorta. The deoxygenated blood pumped into the pulmonary artery is passed on to the lungs from where the oxygenated blood is carried by the pulmonary veins into the left atrium. This pathway constitutes the pulmonary circulation. The oxygenated blood entering the aorta is carried by a network of arteries, arterioles and capillaries to the tissues from where the deoxygenated blood is collected by a system of venules, veins and vena cava and emptied into the right atrium. This is the systemic circulation. The systemic circulation provides nutrients, O_2 and other essential substances to the tissues and takes CO_2 and other harmful substances away for elimination.

Hepatic Portal Circulation: A unique vascular connection exists between the digestive tract and liver called hepatic portal system. The hepatic portal vein carries blood from intestine to the liver before it is delivered to the systemic circulation. A special coronary system of blood vessels is present in our body exclusively for the circulation of blood to and from the cardiac musculature.

REGULATION OF CARDIAC ACTIVITY

Normal activities of the heart are regulated intrinsically, i.e., auto regulated by specialised muscles (nodal tissue), hence the heart is called myogenic. A special neural centre in the medulla oblangata can moderate the cardiac function through autonomic nervous system (ANS). Neural signals through the sympathetic nerves (part of ANS) can increase the rate of heart beat, the strength of ventricular contraction and thereby the cardiac output. On the other hand, parasympathetic neural signals (another component of ANS) decrease the rate of heart beat, speed of conduction of action potential and thereby the cardiac output. Adrenal medullary hormones can also increase the cardiac output.

DISORDERS OF CIRCULATORY SYSTEM

High Blood Pressure (Hypertension): Hypertension is the term for blood pressure that is higher than normal (120/80). In this measurement 120 mm Hg (millimeters of mercury pressure) is the systolic, or pumping, pressure and 80 mm Hg is

the diastolic, or resting, pressure. If repeated checks of blood pressure of an individual is 140/90 (140 over 90) or higher, it shows hypertension. High blood pressure leads to heart diseases and also affects vital organs like brain and kidney.
Blood Pressure: This is the resistance offered by the lumen of the artery to the flow of blood.

EXCRETION

Animals accumulate ammonia, urea, uric acid, carbon dioxide, water and ions like Na^+, K^+, Cl^-, phosphate, sulphate, etc., either by metabolic activities or by other means like excess ingestion. These substances have to be removed totally or partially. The process of removal of these harmful substances is called excretion.

Ammonotelism: Ammonia is the most toxic form and requires large amount of water for its elimination. The process of excreting ammonia is Ammonotelism. Many bony fishes, aquatic amphibians and aquatic insects are ammonotelic in nature. Ammonia, as it is readily soluble, is generally excreted by diffusion across body surfaces or through gill surfaces (in fish) as ammonium ions. Kidneys do not play any significant role in its removal.

Ureotelic: Terrestrial adaptation necessitated the production of lesser toxic nitrogenous wastes like urea nd uric acid for onservation of water. Mammals, many terrestrial mphibians and marine fishes mainly xcrete urea and are called ureotelic animals. Ammonia produced by metabolism is converted into urea in the liver of these animals and released into the blood which is filtered an excreted out by the kidneys. Some amount of urea may be retained in the kidney matrix of some of these animals to maintain a desired osmolarity.

Uricotelic: Reptiles, birds, land snails and insects excrete nitrogenous wastes as uric acid in the form of pellet or paste with a minimum loss of water and are called uricotelic animals.

Different Types of Excretory Organs in Animals:

• **Protonephridia** or flame cells are the excretory structures in Platyhelminthes (Flatworms, e.g., Planaria), rotifers, some annelids and the cephalochordate – Amphioxus. Protonephridia are primarily concerned with ionic and fluid volume regulation, i.e., osmoregulation.

• **Nephridia** are the tubular excretory structures of earthworms and other annelids. Nephridia help to remove nitrogenous wastes and maintain a fluid and ionic balance.

• **Malpighian tubules** are the excretory structures of most of the insects including cockroaches. Malpighian tubules help in the removal of nitrogenous wastes and osmoregulation.

• **Antennal glands** or green glands perform the excretory function in crustaceans like prawns.

HUMAN EXCRETORY SYSTEM

In humans, the excretory system consists of a pair of kidneys, one pair of ureters, a urinary bladder and a urethra .

Kidneys:

Shape & Size: Kidneys are reddish brown, bean shaped structures situated between the levels of last thoracic and third lumbar vertebra close to the dorsal inner wall of the abdominal cavity. Each kidney of an adult human measures 10-12 cm in length, 5-7 cm in width, 2-3 cm in thickness with an average weight of 120- 170 g.

Structure: Towards the centre of the inner concave surface of the kidney is a notch called hilum through which ureter, blood vessels and nerves enter.

Inner Structure: Inner to the hilum is a broad funnel shaped space called the renal pelvis with projections called calyces. The outer layer of kidney is a tough capsule. Inside the kidney, there are two zones, an outer cortex and an inner medulla. The medulla is divided into a few conical masses (medullary pyramids) projecting into the calyces (sing.: calyx). The cortex extends in between the medullary pyramids as renal columns called Columns of Bertini.

Nephrons: Each kidney has nearly one million complex tubular structures called nephrons, which are the functional units. Each nephron has two parts – the glomerulus and the renal tubule.

Glomerulus: Glomerulus is a tuft of capillaries formed by the afferent arteriole – a fine branch of renal artery. Blood from the glomerulus is carried away by an efferent arteriole. The renal tubule begins with a double walled cup-like structure called Bowman's capsule, which encloses the glomerulus. Glomerulus alongwith Bowman's capsule, is called the malpighian body or renal corpuscle.

Tubules: The tubule continues further to form a highly coiled network – proximal convoluted tubule (PCT). A hairpin shaped Henle's loop is the next part of the tubule which has a descending and an ascending limb. The ascending limb continues as another highly coiled tubular region called distal convoluted tubule (DCT). The DCTs of many nephrons open into a straight tube called collecting duct, many of which converge and open into the renal pelvis through medullary pyramids in the calyces. The Malpighian corpuscle, PCT and DCT of the nephron are situated in the cortical region of the kidney whereas the loop of Henle dips into the medulla.

Cortical Nephrons: In majority of nephrons, the loop of Henle is too short and extends only very little into the medulla. Such nephrons are called cortical nephrons.

Medullary Nephrons: In some of the nephrons, the loop of Henle is very long and runs deep into the medulla. These nephrons are called juxta medullary nephrons.

Vasa Recta: The efferent arteriole emerging from the glomerulus forms a fine capillary network around the renal tubule called the peritubular capillaries. A minute vessel of this network runs parallel to the Henle's loop forming a 'U' shaped vasa recta. Vasa recta is absent or highly reduced in cortical nephrons.

URINE FORMATION

Urine formation involves three main processes namely:
1. Glomerular Filtration,
2. Reabsorption and
3. Secretion.

Glomerular Filtration: The glomerular capillary blood pressure causes filtration of blood through 3 layers, i.e., the endothelium of glomerular blood vessels, the epithelium of Bowman's capsule and a basement membrane between these two layers. The epithelial cells of Bowman's capsule called podocytes are arranged in an intricate manner so as to leave some minute spaces called filtration slits or slit pores. The diameter of efferent arteriole (arteriole bringing blood out of the glomerulus) is less than the diameter of afferent arteriole (arteriole taking blood inside the glomerulus). This difference in diameters creates a pressure which facilitates the filtration. Blood is filtered so finely through these membranes, that almost all the constituents of the plasma, except the proteins pass onto the lumen of the Bowman's capsule. Therefore, it is considered as a process of ultra filtration.

Glomerular Filtration Rate (GFR): The amount of the filtrate formed by the kidneys per minute is called glomerular filtration rate (GFR). GFR in a healthy individual is approximately 125 ml/minute, i.e., 180 litres per day. On an average, 1100-1200 ml of blood is filtered by the kidneys per minute which constitute roughly 1/5th of the blood pumped out by each ventricle of the heart in a minute.

Regulation of GFR: The kidneys have built-in mechanisms for the regulation of glomerular filtration rate. One such efficient mechanism is carried out by juxta glomerular apparatus (JGA). JGA is a special sensitive region formed by cellular modifications in the distal convoluted tubule and the afferent arteriole at the location of their contact. A fall in GFR can activate the JG cells to release renin which can stimulate the glomerular blood flow and thereby the GFR back to normal.

Reabsorption: A comparison of the volume of the filtrate formed per day (180 litres per day) with that of the urine released (1.5 litres), suggest that nearly 99 per cent of the filtrate has to be reabsorbed by the renal tubules. This process is called reabsorption. The tubular epithelial cells in different segments of nephron perform this either by active or passive mechanisms. For example, substances like glucose, amino acids, Na^+, etc., in the filtrate are reabsorbed actively whereas the nitrogenous wastes are absorbed by passive transport. Reabsorption of water also occurs passively in the initial segments of the nephron . During urine formation, the tubular cells secrete substances like H^+, K^+ and ammonia into the filtrate. Tubular secretion is also an important step in urine formation as it helps in the maintenance of ionic and acid base balance of body fluids.

FUNCTION OF THE TUBULES

Proximal Convoluted Tubule (PCT): PCT is lined by simple cuboidal brush border epithelium which increases the surface area for reabsorption. Nearly all of the essential nutrients, and 70-80 per cent of electrolytes and water are reabsorbed by this segment. PCT also helps to maintain the pH and ionic balance of the body fluids by selective secretion of hydrogen ions, ammonia and potassium ions into the filtrate and by absorption of HCO_3^- from it.

Henle's Loop: Reabsorption in this segment is minimum. However, this region plays a significant role in the maintenance of high osmolarity of medullary interstitial fluid. The descending limb of loop of Henle is permeable to water but almost impermeable to electrolytes. This concentrates the filtrate as it moves down. The ascending limb is impermeable to water but allows transport of electrolytes actively or passively. Therefore, as the concentrated filtrate pass upward, it gets diluted due to the passage of electrolytes to the medullary fluid.

Distal Convoluted Tubule (DCT): Conditional reabsorption of Na+ and water takes place in this segment. DCT is also capable of reabsorption of HCO and selective secretion of hydrogen and potassium ions and NH_3 to maintain the pH and sodium potassium balance in blood.

Collecting Duct: This long duct extends from the cortex of the kidney to the inner parts of the medulla. Large amounts of water could be reabsorbed from this region to produce concentrated urine. This segment allows passage of small amounts of urea into the medullary interstitium to keep up the osmolarity. It also plays a role in the maintenance of pH and ionic balance of blood by the selective secretion of H^+ and K^+ ions

MECHANISM OF CONCENTRATION OF THE FILTRATE

The Henle's loop and vasa recta play a significant role in this. The flow of filtrate in the two limbs of Henle's loop is in opposite directions and thus forms a counter current. The flow of blood through the two limbs of vasa recta is also in a counter current pattern. The proximity between the Henle's loop and vasa recta, as well as the counter current in them help in maintaining an increasing osmolarity towards the inner medullary interstitium, i.e., from 300 $mOsmolL^{-1}$ in the cortex to about 1200 $mOsmolL^{-1}$ in the inner medulla. This gradient is mainly caused by NaCl and urea. NaCl is transported by the ascending limb of Henle's loop which is exchanged with the descending limb of vasa recta. NaCl is returned to the interstitium by the ascending portion of vasa recta.

Similarly, small amounts of urea enter the thin segment of the ascending limb of Henle's loop which is transported back to the interstitium by the collecting tubule.

The above described transport of substances facilitated by the special arrangement of Henle's loop and vasa recta is called the counter current mechanism. This mechanism helps to maintain a concentration gradient in the medullary interstitium. Presence of such interstitial gradient helps in an easy passage of water from the collecting tubule thereby concentrating the filtrate (urine). Human kidneys can produce urine nearly four times concentrated than the initial filtrate formed.

REGULATION OF KIDNEY FUNCTION

The functioning of the kidneys is efficiently monitored and regulated by hormonal feedback mechanisms involving the hypothalamus, JGA and to a certain extent, the heart.

• Osmoreceptors in the body are activated by changes in blood volume, body fluid volume and ionic concentration. An excessive loss of fluid from the body can activate these receptors which stimulate the hypothalamus to release antidiuretic hormone (ADH) or vasopressin from the neurohypophysis. ADH facilitates water reabsorption from latter parts of the tubule, thereby preventing diuresis.

• An increase in body fluid volum can switch off the osmoreceptors and suppress the ADH release to complete the feedback. ADH can also affect the kidney function by its constrictory effects on blood vessels. This causes an increase in blood pressure. An increase in blood pressure can increase the glomerular blood flow and thereby the GFR.

• The JGA plays a complex regulatory role. A fall in glomerular blood flow/glomerular blood pressure/GFR can activate the JG cells to release renin which converts angiotensinogen in blood to angiotensin I and further to angiotensin II. Angiotensin II, being a powerful vasoconstrictor, increases the glomerular blood pressure and thereby GFR. Angiotensin II also activates the adrenal cortex to release Aldosterone. Aldosterone causes reabsorption of Na^+ and water from the distal parts of the tubule. This also leads to an increase in blood pressure and GFR. This complex mechanism is generally known as the Renin-Angiotensin mechanism.

• An increase in blood flow to the atria of the heart can cause the release of**Atrial Natriuretic Factor** (ANF). ANF can cause vasodilation (dilation of blood vessels) and thereby decrease the blood pressure. ANF mechanism, therefore, acts as a check on the rennin angiotensin mechanism.

MICTURITION

Urine formed by the nephrons is ultimately carried to the urinary bladder where it is stored till a voluntary signal is given by the central nervous system (CNS). This signal is initiated by the stretching of the urinary bladder as it gets filled with urine. In response, the stretch receptors on the walls of the bladder send signals to the CNS. The CNS passes on motor messages to initiate the contraction of smooth muscles of the bladder and simultaneous relaxation of the urethral sphincter causing the release of urine. The process of release of urine is called micturition and the neural mechanisms causing it is called the micturition reflex.

An adult human excretes, on an average, 1 to 1.5 litres of urine per day. The urine formed is a light yellow coloured watery fluid which is slightly acidic (pH-6.0) and has a characteristic odour. On an average, 25-30 gm of urea is excreted out per day. Various conditions can affect the characteristics of urine. Analysis of urine helps in clinical diagnosis of many metabolic discorders as well as malfunctioning of the kidney. For example, presence of glucose (Glycosuria) and ketone bodies (Ketonuria) in urine are indicative of diabetes mellitus.

ROLE OF OTHER ORGANS IN EXCRETION

Lungs: Lungs remove large amounts of CO_2 (18 litres/day) and also significant quantities of water every day.

Liver: Liver, the largest gland in our body, secretes bile containing substances like bilirubin, biliverdin, cholesterol, degraded steroid hormones, vitamins and drugs. Most of these substances ultimately pass out alongwith digestive wastes.

Skin: The sweat and sebaceous glands in the skin can eliminate certain substances through their secretions. Sweat produced by the sweat glands is a watery fluid containing NaCl, small amounts of urea, lactic acid, etc. Though the primary function of sweat is to facilitate a cooling effect on the body surface, it also helps in the removal of some of the wastes mentioned above. Sebaceous glands eliminate certain substances like sterols, hydrocarbons and waxes through sebum. This secretion provides a protective oily covering for the skin.

DISORDERS OF THE EXCRETORY SYSTEM

Kidney Failure: Malfunctioning of kidneys can lead to accumulation of urea in blood, a condition called uremia, which is highly harmful and may lead to kidney failure. In such patients, urea can be removed by a process called hemodialysis. Blood drained from a convenient artery is pumped into a dialysing unit after adding an anticoagulant like heparin. The unit contains a coiled cellophane tube surrounded by a fluid (dialyzing fluid) having the same composition as that of plasma except the nitrogenous wastes. The porous cellophane membrance of the tube allows the passage of molecules based on concentration gradient. As nitrogenous wastes are absent in the dialysis fluid , these substances freely move out, thereby clearing the blood. The blood is pumped back to the body through a vein after adding anti-heparin to it.

Renal Calculi: Stone or insoluble mass of crystallized salts (oxalates, etc.) formed within the kidney. These produce severe pain if they result in obstruction of urethra. Smaller sized calculi or stones are expelled by the body, while larger ones require surgical procedure to be expelled.

Locomotion and Movement

TYPES OF MOVEMENT

Cells of the human body exhibit three main types of movements, namely, amoeboid, ciliary and muscular.

Amoeboid Movement: Some specialised cells in our body like macrophages and leucocytes in blood exhibit amoeboid movement. It is effected by pseudopodia formed by the streaming of protoplasm (as in Amoeba). Cytoskeletal elements like microfilaments are also involved in amoeboid movement.

Ciliary Movement: Ciliary movement occurs in most of our internal tubular organs which are lined by ciliated epithelium. The coordinated movements of cilia in the trachea help us in removing dust particles and some of the foreign substances inhaled alongwith the atmospheric air. Passage of ova through the female reproductive tract is also facilitated by the ciliary movement.

Muscular Movement: Movement of our limbs, jaws, tongue, etc, require muscular movement. The contractile property of muscles are effectively used for locomotion and other movements by human beings and majority of multicellular organisms. Locomotion requires a perfect coordinated activity of muscular, skeletal and neural systems.

MUSCLE

Muscle is a specialised tissue of mesodermal origin. About 40-50 per cent of the body weight of a human adult is contributed by muscles. They have special properties like excitability, contractility, extensibility and elasticity. Muscles have been classified using different criteria, namely location, appearance and nature of regulation of their activities. Based on their location, three types of muscles are identified:

(i) Skeletal

(ii) Visceral

(iii) Cardiac.

Skeletal Muscles: Skeletal muscles are closely associated with the skeletal components of the body. They have a striped appearance under the microscope and hence are called striated muscles. As their activities are under the voluntary control of the nervous system, they are known as voluntary muscles too. They are primarily involved in locomotory actions and changes of body postures.

Visceral Muscles: Visceral muscles are located in the inner walls of hollow visceral organs of the body like the alimentary canal, reproductive tract, etc. They do not exhibit any striation and are smooth in appearance. Hence, they are called smooth muscles (nonstriated muscle). Their activities are not under the voluntary control of the nervous system and are therefore known as involuntary muscles. They assist, for example, in the transportation of food through the digestive tract and gametes through the genital tract.

Cardiac Muscles: As the name suggests, Cardiac muscles are the muscles of heart. Many cardiac muscle cells assemble in a branching pattern to form a cardiac muscle. Based on appearance, cardiac muscles are striated. They are involuntary in nature as the nervous system does not control their activities directly.

Structure of Skeletal Muscle:

Each organised skeletal muscle is made of a number of muscle bundles or fascicles held together by a common collagenous connective tissue layer called fascia. Each muscle bundle contains a number of muscle fibres.

Each muscle fibre is lined by the plasma membrane called sarcolemma enclosing the sarcoplasm. Muscle fibre is a syncitium as the sarcoplasm contains many nuclei. The endoplasmic reticulum, i.e., sarcoplasmic reticulum of the muscle fibres is the store house of calcium ions. A characteristic feature of the muscle fibre is the presence of a large number of parallelly arranged filaments in the sarcoplasm called myofilaments or myofibrils. Each myofibril has alternate dark and light bands on it. A detailed study of the myofibril has established that the striated appearance is due to the distribution pattern of two important proteins – Actin and Myosin. The light bands contain actin and is called I-band or Isotropic band, whereas the dark band called 'A' or Anisotropic band contains myosin. Both the proteins are arranged as rod-like structures, parallel to each other and also to the longitudinal axis of the myofibrils.

Actin filaments are thinner as compared to the myosin filaments, hence are commonly called thin and thick filaments respectively. In the centre of each 'I' band is an elastic fibre called 'Z' line which bisects it. The thin filaments are firmly attached to the 'Z' line. The thick filaments in the 'A' band are also held together in the middle of this band by a thin fibrous membrane called 'M' line. The 'A' and 'I' bands are arranged alternately throughout the length of the myofibrils. The portion of the myofibril between two successive 'Z' lines is considered as the functional unit of contraction and is called a sarcomere.

In a resting state, the edges of thin filaments on either side of the thick filaments partially overlap the free ends of the thick filaments leaving the central part of the thick filaments. This central part of thick filament, not overlapped by thin filaments is called the 'H' zone.

Structure of Contractile Proteins

Each actin (thin) filament is made of two 'F' (filamentous) actins helically wound to each other. Each 'F' actin is a polymer of monomeric 'G' (Globular) actins. Two filaments of another protein, tropomyosin also run close to the 'F' actins throughout its length. A complex protein Troponin is distributed at regular intervals on the tropomyosin. In the resting state a subunit of troponin masks the active binding sites for myosin on the actin filaments.

Each myosin (thick) filament is also a polymerised protein. Many monomeric proteins called Meromyosins constitute one thick filament. Each meromyosin has two important parts, a globular head with a short arm and a tail, the former being called the heavy meromyosin (HMM) and the latter, the light meromyosin (LMM). The HMM component, i.e.; the head and short arm projects outwards at regular distance and angle from each other from the surface of a polymerised myosin filament and is known as cross arm. The globular head is an active ATPase enzyme and has binding sites for ATP and active sites for actin.

Mechanism of Muscle Contraction

Mechanism of muscle contraction is best explained by the sliding filament theory which states that contraction of a muscle fibre takes place by the sliding of the thin filaments over the thick filaments.

Muscle contraction is initiated by a signal sent by the central nervous system (CNS) via a motor neuron. A motor neuron alongwith the muscle fibres connected to it constitute a motor unit. The junction between a motor neuron and the sarcolemma of the muscle fibre is called the neuromuscular junction or motor-end plate. A neural signal reaching this junction releases a neurotransmitter (Acetyl choline) which generates an action potential in the sarcolemma. This spreads through the muscle fibre and causes the release of calcium ions into the sarcoplasm. Increase in Ca^{++} level leads to the binding of calcium with a subunit of troponin on actin filaments and thereby remove the masking of active sites for myosin. Utilising the energy from ATP hydrolysis, the myosin head now binds to the exposed active sites on actin to form a cross bridge. This pulls the attached actin filaments towards the centre of 'A' band. The 'Z' line attached to these actins are also pulled inwards thereby causing a shortening of the sarcomere, i.e., contraction. It is clear from the above steps, that during shortening of the muscle, i.e., contraction, the 'I' bands get reduced, whereas the 'A' bands retain the length. The myosin, releasing the ADP and P1 goes back to its relaxed state. A new ATP binds and the cross-bridge is broken. The ATP is again hydrolysed by the myosin head and the cycle of cross bridge formation and breakage is repeated causing further sliding. The process continues till the Ca^{++} ions are pumped back to the sarcoplasmic cisternae resulting in the masking of actin filaments. This causes the return of 'Z' lines back to their original position, i.e., relaxation.

The reaction time of the fibres can vary in different muscles. Repeated activation of the muscles can lead to the accumulation of lactic acid due to anaerobic breakdown of glycogen in them, causing fatigue. Muscle contains a red coloured oxygen storing pigment called myoglobin. Myoglobin content is high in some of the muscles which gives a reddish appearance. Such muscles are called the Red fibres. These muscles also contain plenty of mitochondria which can utilise the large amount of oxygen stored in them for ATP production. These muscles, therefore, can also be called aerobic muscles.

On the other hand, some of the muscles possess very less quantity of myoglobin and therefore, appear pale or whitish. These are the White fibres. Number of mitochondria are also few in them, but the amount of sarcoplasmic reticulum is high. They depend on anaerobic process for energy.

SKELETAL SYSTEM

Skeletal system consists of a framework of bones and a few cartilages. This system has a significant role in movement shown by the body. Bone and cartilage are specialised connective tissues. The former has a very hard matrix due to calcium salts in it and the latter has slightly pliable matrix due to chondroitin salts. In human beings, this system is made up of 206 bones and a few cartilages. It is grouped into two principal divisions – the axial and the appendicular skeleton.

Axial Skeleton: Axial skeleton comprises 80 bones distributed along the main axis of the body. The skull, vertebral column, sternum and ribs constitute axial skeleton.

Skull: The skull is composed of two sets of bones – cranial and facial, that totals to 22 bones. Cranial bones are 8 in number. They form the hard protective outer covering, cranium for the brain. The facial region is made up of 14 skeletal elements which form the front part of the skull. A single U-shaped bone called hyoid is present at the base of the buccal cavity and it is also included in the skull. Each middle ear contains three tiny bones – Malleus, Incus and Stapes, collectively called Ear Ossicles. The skull region articulates with the superior region of the vertebral column with the help of two occipital condyles (dicondylic skull).

(ref: http://en.wikipedia.org/wiki/File:Human_skull_side_simplified_(bones).svg accessed on 14th Oct, 2009)

Vertebral Column: Our vertebral column is formed by 26 serially arranged units called vertebrae and is dorsally placed. It extends from the base of the skull and constitutes the main framework of the trunk. Each vertebra has a central hollow portion (neural canal) through which the spinal cord passes. First vertebra is the atlas and it articulates with the occipital condyles.

The vertebral column is differentiated into following regions starting from the skull:

1. cervical (7),
2. thoracic (12),
3. lumbar (5),
4. sacral (1-fused) and

5. coccygeal (1-fused) regions
The number of cervical vertebrae are seven in almost all mammals including human beings. The vertebral column protects the spinal cord, supports the head and serves as the point of attachment for the ribs and musculature of the back. Sternum is a flat bone on the ventral midline of thorax.
Rib Cage: There are 12 pairs of ribs. Each rib is a thin flat bone connected dorsally to the vertebral column and ventrally to the sternum. It has two articulation surfaces on its dorsal end and is hence called bicephalic. First seven pairs of ribs are called true ribs. Dorsally, they are attached to the thoracic vertebrae and ventrally connected to the sternum with the help of hyaline cartilage. The 8th, 9th and 10th pairs of ribs do not articulate directly with the sternum but join the seventh rib with the help of hyaline cartilage. These are called vertebrochondral (false) ribs. Last 2 pairs (11th and 12th) of ribs are not connected ventrally and are therefore, called floating ribs. Thoracic vertebrae, ribs and sternum together form the rib cage.
Appendicular Skeleton: The bones of the limbs alongwith their girdles constitute the appendicular skeleton. Each limb is made of 30 bones.
• The bones of the hand (fore limb) are humerus, radius and ulna, carpals (wrist bones – 8 in number), metacarpals (palm bones – 5 in number) and phalanges (digits – 14 in number).
• Femur (thigh bone – the longest bone), tibia and fibula, tarsals (ankle bones – 7 in number), metatarsals (5 in number) and phalanges (digits – 14 in number) are the bones of the legs (hind limb). A cup shaped bone called patella cover the knee ventrally (knee cap).
Girdle Bones: Pectoral and Pelvic girdle bones help in the articulation of the upper and the lower limbs respectively with the axial skeleton. Each girdle is formed of two halves. Each half of pectoral girdle consists of a clavicle and a scapula. Scapula is a large triangular flat bone situated in the dorsal part of the thorax between the second and the seventh ribs. The dorsal, flat, triangular body of scapula has a slightly elevated ridge called the spine which projects as a flat, expanded process called the acromion. The clavicle articulates with this. Below the acromion is a depression called the glenoid cavity which articulates with the head of the humerus to form the shoulder joint. Each clavicle is a long slender bone with two curvatures. This bone is commonly called the collar bone.
Pelvic girdle consists of two coxal bones. Each coxal bone is formed by the fusion of three bones – ilium, ischium and pubis. At the point of fusion of the above bones is a cavity called acetabulum to which the thigh bone articulates. The two halves of the pelvic girdle meet ventrally to form the pubic symphysis containing fibrous cartilage.

(Ref: http://en.wikipedia.org/wiki/File:Human_skeleton_back_en.svg accessed on 14th Oct, 2009)
JOINTS
Joints are essential for all types of movements involving the bony parts of the body. Locomotory movements are no exception to this. Joints are points of contact between bones, or between bones and cartilages. Force generated by the muscles is used to carry out movement through joints, where the joint acts as a fulcrum. The movability at these joints vary depending on different factors. Joints have been classified into three major structural forms, namely, fibrous, cartilaginous and synovial.
Fibrous Joints: Fibrous joints do not allow any movement. This type of joint is shown by the flat skull bones which fuse end-to-end with the help of dense fibrous connective tissues in the form of sutures, to form the cranium.
Cartilaginous Joints: In cartilaginous joints, the bones involved are joined together with the help of cartilages. The joint between the adjacent vertebrae in the vertebral column is of this pattern and it permits limited movements.
Synovial Joints: Synovial joints are characterised by the presence of a fluid filled synovial cavity between the articulating surfaces of the two bones. Such an arrangement allows considerable movement. These joints help in locomotion and many other movements. Ball and socket joint (between humerus and pectoral girdle), Hinge joint (knee joint), Pivot joint (between atlas and axis), Gliding joint (between the carpals) and Saddle joint (between carpal and metacarpal of thumb) are some examples.
DISORDERS OF MUSCULAR AND SKELETAL SYSTEM
Myasthenia gravis: Auto immune disorder affecting neuromuscular junction leading to fatigue, weakening and paralysis of skeletal muscle.
Muscular dystrophy: Progressive degeneration of skeletal muscle mostly due to genetic disorder.
Tetany: Rapid spasms (wild contractions) in muscle due to low Ca^{++} in body fluid.
Arthritis: Inflammation of joints.
Osteoporosis: Age-related disorder characterised by decreased bone mass and increased chances of fractures. Decreased levels of estrogen is a common cause.
Gout: Inflammation of joints due to accumulation of uric acid crystals.

Nervous Control and Coordination

Nervous System

The nervous system of all animals is composed of highly specialised cells called neurons which can detect, receive and transmit different kinds of stimuli.

HUMAN NERVOUS SYSTEM

The human nervous system is divided into two parts:

(i) Central Nervous System (CNS)

(ii) Peripheral Nervous System (PNS)

The CNS includes the brain and the spinal cord and is the site of information processing and control. The PNS comprises of all the nerves of the body associated with the CNS (brain and spinal cord). The nerve fibres of the PNS are of two types:

(a) Afferent Fibres

(b) Efferent Fibres

The afferent nerve fibres transmit impulses from tissues/organs to the CNS and the efferent fibres transmit regulatory impulses from the CNS to the concerned peripheral tissues/organs.

The PNS is divided into two divisions called somatic nervous system and autonomic nervous system. The somatic nervous system relays impulses from the CNS to skeletal muscles while the autonomic nervous system transmits impulses from the CNS to the involuntary organs and smooth muscles of the body. The autonomic nervous system is further classified into sympathetic nervous system and parasympathetic nervous system.

NEURON AS STRUCTURAL AND FUNCTIONAL UNIT OF NERVOUS SYSTEM

A neuron is a microscopic structure composed of three major parts, namely, cell body, dendrites and axon.

Cell Body: The cell body contains cytoplasm with typical cell organelles and certain granular bodies called Nissl's granules.

Dendrites: Short fibres which branch repeatedly and project out of the cell body also contain Nissl's granules and are called dendrites. These fibres transmit impulses towards the cell body.

Axon: The axon is a long fibre, the distal end of which is branched. Each branch terminates as a bulb-like structure called synaptic knob which possess synaptic vesicles containing chemicals called neurotransmitters. The axons transmit nerve impulses away from the cell body to a synapse or to a neuro-muscular junction.

Based on the number of axon and dendrites, the neurons are divided into three types:

(a) Multipolar (with one axon and two or more dendrites; found in the cerebral cortex),

(b) Bipolar (with one axon and one dendrite, found in the retina of eye) and

(c) Unipolar (cell body with one axon only; found usually in the embryonic stage).

There are two types of axons, namely, myelinated and nonmyelinated. The myelinated nerve fibres are enveloped with Schwann cells, which form a myelin sheath around the axon. The gaps between two adjacent myelin sheaths are called nodes of Ranvier. Myelinated nerve fibres are found in spinal and cranial nerves. Unmyelinated nerve fibre is enclosed by a Schwann cell that does not form a myelin sheath around the axon, and is commonly found in autonomous and the somatic nervous systems.

Generation and Conduction of Nerve Impulse

Neurons are excitable cells because their membranes are in a polarized state. Different types of ion channels are present on the nervous membrane. These ion channels are selectively permeable to different ions. When a neuron is not conducting any impulse, i.e., resting, the axonal membrane is comparatively more permeable to potassium ions (K+) and nearly impermeable to sodium ions (Na+). Similarly, the membrane is impermeable to negatively charged proteins present in the axoplasm. Consequently, the axoplasm inside the axon contains high concentration of K+ and negatively charged proteins and low concentration of Na+.

In contrast, the fluid outside the axon contains a low concentration of K+, a high concentration of Na+ and thus forms a concentration gradient. These ionic gradieNeurons are excitable cells because their membranes are in a polarized state. Different types of ion channels are present on the nervous membrane. These ion channels are selectively permeable to different ions. When a neuron is not conducting any impulse, i.e., resting, the axonal membrane is comparatively more permeable to potassium ions (K^+) and nearly impermeable to sodium ions (Na^+). Similarly, the membrane is impermeable to negatively charged proteins present in the axoplasm. Consequently, the axoplasm inside the axon contains high concentration of K^+ and negatively charged proteins and low concentration of Na^+.

In contrast, the fluid outside the axon contains a low concentration of K^+, a high concentration of Na^+ and thus forms a concentration gradient. These ionic gradients across the resting membrane are maintained by the active transport of ions by the sodium-potassium pump which transports 3 Na^+outwards for 2 K^+ into the cell. As a result, the outer surface of the axonal membrane possesses a positive charge while its inner surface becomes negatively charged and therefore is polarised. The electrical potential difference across the resting plasma membrane is called as the resting potential.

Conduction of Nerve Impulse: site is reversed, and an action potential is generated at site B. Thus, the impulse (action potential) generated at site A arrives at site BWhen a stimulus is applied at a site on the polarised membrane, the membrane at the site A becomes freely permeable to Na^+. This leads to a rapid influx of Na^+ followed by the reversal of the polarity at that site, i.e., the outer surface of the membrane becomes negatively charged and the inner side becomes

positively charged. The polarity of the membrane at the site is thus reversed and hence depolarised. The electrical potential difference across the plasma membrane at the site A is called the action potential, which is in fact termed as a nerve impulse.
At sites immediately ahead, the axon (e.g., site B) membrane has a positive charge on the outer surface and a negative charge on its inner surface. As a result, a current flows on the inner surface from site A to site B. ptic neuron, which may or may not be separated by a gap called synaptic cleft. There are two types of synapses, namely, electrical synapses and chemical synapses. At electrical synapses, the membranes of pre- and post-synaptic neurons are in very close proximity. Electrical current can flow directly from one neuron into the other across these synapses. Transmission of an impulse across electrical synapses is very similar to impulse conduction along a single axon. Impulse transmission across an electrical synapse is always faster than that across a chemical synapse. Electrical synapses are rare in our system.
At a chemical synapse, the membranes of the pre- and post-synaptic neurons are separated by a fluid-filled space called synaptic The rise in the stimulus-induced permeability to Na^+ is extremely shortlived. It is quickly followed by a rise in permeability to K^+. Within a fraction of a second, K^+diffuses outside the membrane and restores the resting potential of the membrane at the site of excitation and the fibre becomes once more responsive to further stimulation.
Transmission of Impulses generate a new potential in the post-synaptic neuron. The new potential developed may be either excitatory or inhibitory.

(Image ref: http://en.wikipedia.org/wiki/File:Synapse_Illustration2_tweaked.svg accessed on 15th Oct, 2009)

CENTRAL NERVOUS SYSTEM

The brain is the central information processing organ of our body, and acts as the ‘command and control system’. It controls the voluntary movements, balance of the body, functioning of vital involuntary organs (e.g., lungs, heart, kidneys, etc.), thermoregulation, hunger and thirst, circadian (24-hour) rhythms of our body, activities of several endocrine glands and human behaviour. It is also the site for processing of vision, hearing, speech, memory, intelligence, emotions and thoughts.
The human brain is well protected by the skull. Inside the skull, the brain is covered by cranial meninges consisting of an outer layer called dura mater, a very thin middle layer called arachnoid and an inner layer (which is in contact with the brain tissue) called pia mater. The brain can be divided into three major parts:
(i) Forebrain,
(ii) Midbrain, and
(iii) Hindbrain

Forebrain

The forebrain consists of cerebrum, thalamus and hypothalamus. Cerebrum forms the major part of the human brain. A deep cleft divides the cerebrum longitudinally into two halves, which are termed as the left and right cerebral hemispheres. The hemispheres are connected by a tract of nerve fibres called corpus callosum.
The layer of cells which covers the cerebral hemisphere is called cerebral cortex and is thrown into prominent folds. The cerebral cortex is referred to as the grey matter due to its greyish appearance. The neuron cell bodies are concentrated here giving the colour.
The cerebral cortex contains motor areas, sensory areas and large regions that are neither clearly sensory nor motor in function. These regions called as the association areas are responsible for complex functions like intersensory associations, memory and communication.
Fibres of the tracts are covered with the myelin sheath, which constitute the inner part of cerebral hemisphere. They give an opaque white appearance to the layer and, hence, is called the white matter.
The cerebrum wraps around a structure called thalamus, which is a major coordinating centre for sensory and motor signaling. Another very important part of the brain called hypothalamus lies at the base of the thalamus. The hypothalamus contains a number of centres which control body temperature, urge for eating and drinking. It also contains several groups of neurosecretory cells, which secrete hormones called hypothalamic hormones.
The inner parts of cerebral hemispheres and a group of associated deep structures like amygdala, hippocampus, etc., form a complex structure called the limbic lobe or limbic system. Along with the hypothalamus, it is involved in the regulation of sexual behaviour, expression of emotional reactions (e.g., excitement, pleasure, rage and fear), and motivation.

Midbrain

The midbrain is located between the thalamus/hypothalamus of the forebrain and pons of the hindbrain. A canal called the cerebral aqueduct passess through the midbrain. The dorsal portion of the midbrain consists mainly of four round swellings (lobes) called corpora quadrigemina. Midbrain and hindbrain form the brain stem.

Hindbrain

The hindbrain comprises pons, cerebellum and medulla (also called the medulla oblongata). Pons consists of fibre tracts that interconnect different regions of the brain. Cerebellum has very convoluted surface in order to provide the additional space for many more neurons. The medulla of the brain is connected to the spinal cord. The medulla contains centres which control respiration, cardiovascular reflexes and gastric secretions.

REFLEX ACTION AND REFLEX ARC

You must have experienced a sudden withdrawal of a body part which comes in contact with objects that are extremely hot, cold pointed or animals that are scary or poisonous. The entire process of response to a peripheral nervous stimulation, that occurs involuntarily, i.e., without conscious effort or thought and requires the involvment of a part of the central nervous system is called a reflex action.

The reflex pathway comprises at least one afferent neuron (receptor) and one efferent (effector or excitor) neuron appropriately arranged in a series. The afferent neuron receives signal from a sensory organ and transmits the impulse via a dorsal nerve root into the CNS (at the level of spinal cord). The efferent nueuron then carries signals from CNS to the effector. The stimulus and response thus forms a reflex arc as shown below in the knee jerk reflex.

SENSORY RECEPTION AND PROCESSING

Eye

The adult human eye ball is nearly a spherical structure. The wall of the eye ball is composed of three layers.

The external layer is composed of a dense connective tissue and is called the sclera. The anterior portion of this layer is called the cornea.

The middle layer, choroid, contains many blood vessels and looks bluish in colour. The choroid layer is thin over the posterior two-thirds of the eye ball, but it becomes thick in the anterior part to form the ciliary body.

The ciliary body itself continues forward to form a pigmented and opaque structure called the iris which is the visible coloured portion of the eye.

The eye ball contains a transparent crystalline lens which is held in place by ligaments attached to the ciliary body. In front of the lens, the aperture surrounded by the iris is called the pupil. The diameter of the pupil is regulated by the muscle fibres of iris.

The inner layer is the retina and it contains three layers of cells – from inside to outside – ganglion cells, bipolar cells and photoreceptor cells.

There are two types of photoreceptor cells, namely, rods and cones. These cells contain the light-sensitive proteins called the photopigments. The daylight (photopic) vision and colour vision are functions of cones and the twilight (scotopic) vision is the function of the rods. The rods contain a purplish-red protein called the rhodopsin or visual purple, which contains a derivative of Vitamin A.

In the human eye, there are three types of cones which possess their own characteristic photopigments that respond to red, green and blue lights. The sensations of different colours are produced by various combinations of these cones and their photopigments. When these cones are stimulated equally, a sensation of white light is produced.

The optic nerves leave the eye and the retinal blood vessels enter it at a point medial to and slightly above the posterior pole of the eye ball. Photoreceptor cells are not present in that region and hence it is called he blind spot. At the posterior pole of the eye lateral to the blind spot, here is a yellowish pigmented spot called macula lutea with a central pit called the fovea. The fovea is a thinned-out portion of the retina where only the cones are densely packed. It is the point where the visual acuity (resolution) is the greatest.

The space between the cornea and the lens is called the aqueous chamber and contains a thin watery fluid called aqueous humor. The pace between the lens and the retina is called the vitreous chamber and is filled with a transparent gel called vitreous humor.

Mechanism of Vision

• The light rays in visible wavelength focussed on the retina through the ornea and lens generate potentials (impulses) in rods and cones.

• Light induces dissociation of the retinal from opsin resulting in changes in the structure of the opsin. This causes membrane permeability changes. As a result, potential differences are generated in he photoreceptor cells. This produces a signal that generates action potentials in the ganglion cells through the bipolar cells.

• These action potentials (impulses) are transmitted by the optic nerves to the visual cortex area of the brain, where the nervous impulses are analysed and the image formed on the retina is recognised based on earlier memory and experience.

The Ear

The ears perform two sensory functions, hearing and maintenance of body balance. Anatomically, the ear can be divided into three major sections called the outer ear, the middle ear and the inner ear.

Outer Ear: The outer ear consists of the pinna and external auditory meatus (canal). The pinna collects the vibrations in the air which produce sound. The external auditory meatus leads inwards and extends up to the tympanic membrane (the ear drum). There are very fine hairs and wax-secreting sebaceous glands in the skin of the pinna and the meatus. The tympanic membrane is composed of connective tissues covered with skin outside and with mucus membrane inside.

Middle Ear: The middle ear contains three ossicles called malleus, incus and stapes which are attached to one another in a chain-like fashion.

The malleus is attached to the tympanic membrane and the stapes is attached to the oval window of the cochlea. The ear ossicles increase the efficiency of transmission of sound waves to the inner ear.
An Eustachian tube connects the middle ear cavity with the pharynx. The Eustachian tube helps in equalising the pressures on either sides of the ear drum.
Inner Ear: The fluid-filled inner ear called labyrinth consists of two parts, the bony and the membranous labyrinths. The bony labyrinth is a series of channels. Inside these channels lies the membranous labyrinth, which is surrounded by a fluid called perilymph. The membranous labyrinth is filled with a fluid called endolymph. The coiled portion of the labyrinth is called cochlea.
The membranes constituting cochlea, the reissner's and basilar, divide the surounding perilymph filled bony labyrinth into an upper scala vestibuli and a lower scala tympani. The space within cochlea called scala media is filled with endolymph. At the base of the cochlea, the scala vestibuli ends at the oval window, while the scala tympani terminates at the round window which opens to the middle ear.

(Image ref: http://en.wikipedia.org/wiki/File:Anatomy_of_the_Human_Ear.svg accessed on 15th Oct, 2009)
The organ of corti is a structure located on the basilar membrane which contains hair cells that act as auditory receptors. The hair cells are present in rows on the internal side of the organ of corti. The basal end of the hair cell is in close contact with the afferent nerve fibres. A large number of processes called stereo cilia are projected from the apical part of each hair cell. Above the rows of the hair cells is a thin elastic membrane called tectorial membrane.
The inner ear also contains a complex system called vestibular apparatus, located above the cochlea. The vestibular apparatus is composed of three semi-circular canals and the otolith organ consisting of the saccule and utricle. Each semi-circular canal lies in a different plane at right angles to each other. The membranous canals are suspended in the perilymph of the bony canals. The base of canals is swollen and is called ampulla, which contains a projecting ridge called crista ampullaris which has hair cells. The saccule and utricle contain a projecting ridge called macula. The crista and macula are the specific receptors of the vestibular apparatus responsible for maintenance of balance of the body and posture.

Chemical Coordination and Integration

ENDOCRINE GLANDS AND HORMONES

Endocrine glands lack ducts and are hence, called ductless glands. Their secretions are called hormones.
Hormones: Hormones are non-nutrient chemicals which act as intercellular messengers and are produced in trace amounts.

HUMAN ENDOCRINE SYSTEM

The Hypothalamus

Hypothalamus is the basal part of diencephalon, forebrain and it regulates a wide spectrum of body functions. It contains several groups of neurosecretory cells called nuclei which produce hormones. These hormones regulate the synthesis and secretion of pituitary hormones. However, the hormones produced by hypothalamus are of two types, the releasing hormones (which stimulate secretion of pituitary hormones) and the inhibiting hormones (which inhibit secretions of pituitary hormones).

(ref: http://en.wikipedia.org/wiki/Endocrine_glands accessed on 16th Oct, 2009)
These hormones reach the pituitary gland through a portal circulatory system and regulate the functions of the anterior pituitary. The posterior pituitary is under the direct neural regulation of the hypothalamus.

The Pituitary Gland

The pituitary gland is located in a bony cavity called sella tursica and is attached to hypothalamus by a stalk. It is divided anatomically into an adenohypophysis and a neurohypophysis. Adenohypophysis consists of two portions, pars distalis and pars intermedia.
The pars distalis region of pituitary, commonly called anterior pituitary, produces following hormones:

- **growth hormone (GH):** Over-secretion of GH stimulates abnormal growth of the body leading to gigantism and low secretion of GH results in stunted growth resulting in pituitary dwarfism.
- **prolactin (PRL):** Prolactin regulates the growth of the mammary glands and formation of milk in them.
- **thyroid stimulating hormone (TSH):** TSH stimulates the synthesis and secretion of thyroid hormones from the thyroid gland.
- **adrenocorticotrophic hormone (ACTH):** ACTH stimulates the synthesis and secretion of steroid hormones called glucocorticoids from the adrenal cortex.
- **luteinizing hormone (LH):** LH and FSH stimulate gonadal activity and hence are called gonadotrophins. In males, LH stimulates the synthesis and secretion of hormones called androgens from testis. In females, LH induces ovulation of fully mature follicles (graafian follicles) and maintains the corpus luteum, formed from the remnants of the graafian follicles after ovulation.

• **follicle stimulating hormone (FSH):** In males, FSH and androgens regulate spermatogenesis. FSH stimulates growth and development of the ovarian follicles in females. MSH acts on the melanocytes (melanin containing cells) and regulates pigmentation of the skin.
Pars intermedia secretes only one hormone called melanocyte stimulating hormone (MSH). However, in humans, the pars intermedia is almost merged with pars distalis.
• Neurohypophysis (pars nervosa) also known as posterior pituitary, stores and releases two hormones called oxytocin and vasopressin, which are actually synthesised by the hypothalamus and are transported axonally to neurohypophysis. Oxytocin acts on the smooth muscles of our body and stimulates their contraction. In females, it stimulates a vigorous contraction of uterus at the time of child birth, and milk ejection from the mammary gland. Vasopressin acts mainly at the kidney and stimulates resorption of water and electrolytes by the distal tubules and thereby reduces loss of water through urine (diuresis). Hence, it is also called as anti-diuretic hormone (ADH).

The Pineal Gland

The pineal gland is located on the dorsal side of forebrain. Pineal secretes a hormone called melatonin. Melatonin plays a very important role in the regulation of a 24-hour (diurnal) rhythm of our body. For example, it helps in maintaining the normal rhythms of sleep-wake cycle, body temperature. In addition, melatonin also influences metabolism, pigmentation, the menstrual cycle as well as our defense capability.

Thyroid Gland

The thyroid gland is composed of two lobes which are located on either side of the trachea. Both the lobes are interconnected with a thin flap of connective tissue called isthmus. The thyroid gland is composed of follicles and stromal tissues. Each thyroid follicle is composed of follicular cells, enclosing a cavity.
These follicular cells synthesise two hormones, tetraiodothyronine or thyroxine (T4) and triiodothyronine (T3). Iodine is essential for the normal rate of hormone synthesis in the thyroid. Deficiency of iodine in our diet results in hypothyroidism and enlargement of the thyroid gland, commonly called goitre. Hypothyroidism during pregnancy causes defective development and maturation of the growing baby leading to stunted growth (cretinism), mental retardation, low intelligence quotient, abnormal skin, deaf-mutism, etc. In adult women, hypothyroidism may cause menstrual cycle to become irregular. Due to cancer of the thyroid gland or due to development of nodules of the thyroid glands, the rate of synthesis and secretion of the thyroid hormones is increased to abnormal high levels leading to a condition called hyperthyroidism which adversely affects the body physiology.
Thyroid hormones play an important role in the regulation of the basal metabolic rate. These hormones also support the process of red blood cell formation. Thyroid hormones control the metabolism of carbohydrates, proteins and fats. Maintenance of water and electrolyte balance is also influenced by thyroid hormones. Thyroid gland also secretes a protein hormone called thyrocalcitonin (TCT) which regulates the blood calcium levels.

Parathyroid Gland

In humans, four parathyroid glands are present on the back side of the thyroid gland, one pair each in the two lobes of the thyroid gland. The parathyroid glands secrete a peptide hormone called parathyroid hormone (PTH). The secretion of PTH is regulated by the circulating levels of calcium ions.
Parathyroid hormone (PTH) increases the Ca2+ levels in the blood. PTH acts on bones and stimulates the process of bone resorption (dissolution/ demineralisation). PTH also stimulates reabsorption of Ca2+ by the renal tubules and increases Ca2+ absorption from the digested food. It is, thus, clear that PTH is a hypercalcemic hormone, i.e., it increases the blood Ca2+ levels. Along with TCT, it plays a significant role in calcium balance in the body.

Thymus

The thymus gland is a lobular structure located on the dorsal side of the heart and the aorta. The thymus plays a major role in the development of the immune system. This gland secretes the peptide hormones called thymosins. Thymosins play a major role in the differentiation of T-lymphocytes, which provide cell-mediated immunity. In addition, thymosins also promote production of antibodies to provide humoral immunity. Thymus is degenerated in old individuals resulting in a decreased production of thymosins. As a result, the immune responses of old persons become weak.

Adrenal Gland

Our body has one pair of adrenal glands, one at the anterior part of each kidney. The gland is composed of two types of tissues. The centrally located tissue is called the adrenal medulla, and outside this lies the adrenal cortex.
The adrenal medulla secretes two hormones called adrenaline or epinephrine and noradrenaline or norepinephrine. These are commonly called as catecholamines. Adrenaline and noradrenaline are rapidly secreted in response to stress of any kind and during emergency situations and are called emergency hormones or hormones of Fight or Flight. These hormones increase alertness, pupilary dilation, piloerection (raising of hairs), sweating etc. Both the hormones increase the heart beat, the strength of heart contraction and the rate of respiration. Catecholamines also stimulate the breakdown of glycogen resulting in an increased concentration of glucose in blood. In addition, they also stimulate the breakdown of lipids and proteins.
The adrenal cortex can be divided into three layers, called zona reticularis (inner layer), zona fasciculata (middle layer) and zona glomerulosa (outer layer). The adrenal cortex secretes many hormones, commonly called as corticoids. The

corticoids, which are involved in carbohydrate metabolism are called glucocorticoids. In our body, cortisol is the main glucocorticoid. Corticoids, which regulate the balance of water and electrolytes in our body are called mineralocorticoids. Aldosterone is the main mineralocorticoid in our body.
Glucocorticoids stimulate, gluconeogenesis, lipolysis and proteolysis; and inhibit cellular uptake and utilisation of amino acids. Cortisol is also involved in maintaining the cardio-vascular system as well as the kidney functions. Glucocorticoids, particularly cortisol, produces antiinflamatory reactions and suppresses the immune response. Cortisol stimulates the RBC production.
Aldosterone acts mainly at the renal tubules and stimulates the reabsorption of Na^+ and water and excretion of K^+ and phosphate ions. Thus, aldosterone helps in the maintenance of electrolytes, body fluid volume, osmotic pressure and blood pressure. Small amounts of androgenic steroids are also secreted by the adrenal cortex which play a role in the growth of axial hair, pubic hair and facial hair during puberty.

Pancreas

Pancreas is a composite gland which acts as both exocrine and endocrine gland. The endocrine pancreas consists of 'Islets of Langerhans'. There are about 1 to 2 million Islets of Langerhans in a normal human pancreas representing only 1 to 2 per cent of the pancreatic tissue. The two main types of cells in the Islet of Langerhans are called α-cells and β-cells. The α -cells secrete a hormone called glucagon, while the β-cells secrete insulin.
Glucagon is a peptide hormone, and plays an important role in maintaining the normal blood glucose levels. Glucagon acts mainly on the liver cells (hepatocytes) and stimulates glycogenolysis resulting in an increased blood sugar (hyperglycemia). In addition, this hormone stimulates the process of gluconeogenesis which also contributes to hyperglycemia. Glucagon reduces the cellular glucose uptake and utilisation. Thus, glucagon is a hyperglycemic hormone.
Insulin is a peptide hormone, which plays a major role in the regulation of glucose homeostasis. Insulin acts mainly on hepatocytes and adipocytes (cells of adipose tissue), and enhances cellular glucose uptake and utilisation. As a result, there is a rapid movement of glucose from blood to hepatocytes and adipocytes resulting in decreased blood glucose levels (hypoglycemia). Insulin also stimulates conversion of glucose to glycogen (glycogenesis) in the target cells. The glucose homeostasis in blood is thus maintained jointly by the two – insulin and glucagons.
Prolonged hyperglycemia leads to a complex disorder called diabetes mellitus which is associated with loss of glucose through urine and formation of harmful compounds known as ketone bodies. Diabetic patients are successfully treated with insulin therapy.

Testis

A pair of testis is present in the scrotal sac (outside abdomen) of male individuals. Testis performs dual functions as a primary sex organ as well as an endocrine gland. Testis is composed of seminiferous tubules and stromal or interstitial tissue. The Leydig cells or interstitial cells, which are present in the intertubular spaces produce a group of hormones called androgens mainly testosterone. Androgens regulate the development, maturation and functions of the male accessory sex organs like epididymis, vas deferens, seminal vesicles, prostate gland, urethra etc. These hormones stimulate muscular growth, growth of facial and axillary hair, aggressiveness, low pitch of voice etc. Androgens play a major stimulatory role in the process of spermatogenesis (formation of spermatozoa). Androgens act on the central neural system and influence the male sexual behaviour (libido). These hormones produce anabolic (synthetic) effects on protein and carbohydrate metabolism.

Ovary

Females have a pair of ovaries located in the abdomen. Ovary is the primary female sex organ which produces one ovum during each menstrual cycle. In addition, ovary also produces two groups of steroid hormones called estrogen and progesterone. Ovary is composed of ovarian follicles and stromal tissues. The estrogen is synthesised and secreted mainly by the growing ovarian follicles. After ovulation, the ruptured follicle is converted to a structure called corpus luteum, which secretes mainly progesterone.
Estrogens produce wide ranging actions such as stimulation of growth and activities of female secondary sex organs, development of growing ovarian follicles, appearance of female secondary sex characters (e.g., high pitch of voice, etc.), mammary gland development. Estrogens also regulate female sexual behaviour.
Progesterone supports pregnancy. Progesterone also acts on the mammary glands and stimulates the formation of alveoli (sac-like structures which store milk) and milk secretion.

HORMONES OF HEART, KIDNEY AND GASTROINTESTINAL TRACT

• Hormones are also secreted by some tissues which are not endocrine glands. For example, the atrial wall of our heart secretes a very important peptide hormone called atrial natriuretic factor (ANF), which decreases blood pressure. When blood pressure is increased, ANF is secreted which causes dilation of the blood vessels. This reduces the blood pressure.
• The juxtaglomerular cells of kidney produce a peptide hormone called erythropoietin which stimulates erythropoiesis (formation of RBC).

• Endocrine cells present in different parts of the gastro-intestinal tract secrete four major peptide hormones, namely gastrin, secretin, cholecystokinin (CCK) and gastric inhibitory peptide (GIP).
• Gastrin acts on the gastric glands and stimulates the secretion of hydrochloric acid and pepsinogen.
• Secretin acts on the exocrine pancreas and stimulates secretion of water and bicarbonate ions.
• Cholecystokinin or CCK acts on both pancreas and gall bladder and stimulates the secretion of pancreatic enzymes and bile juice, respectively.
• Gastric Inhibitory Peptide or GIP inhibits gastric secretion and motility.
• Several other non-endocrine tissues secrete hormones called growth factors. These factors are essential for the normal growth of tissues and their repairing/regeneration.

MECHANISM OF HORMONE ACTION

Hormones produce their effects on target tissues by binding to specific proteins called hormone receptors located in the target tissues only. Hormone receptors present on the cell membrane of the target cells are called membrane-bound receptors and the receptors present inside the target cell are called intracellular receptors, mostly nuclear receptors (present in the nucleus). Binding of a hormone to its receptor leads to the formation of a hormone-receptor complex. Each receptor is specific to one hormone only and hence receptors are specific. Hormone-Receptor complex formation leads to certain biochemical changes in the target tissue. Target tissue metabolism and hence physiological functions are regulated by hormones. On the basis of their chemical nature, hormones can be divided into groups:

(i) peptide, polypeptide, protein hormones (e.g., insulin, glucagon, pituitary hormones, hypothalamic hormones, etc.)

(ii) steroids (e.g., cortisol, testosterone, estradiol and progesterone)

(iii) iodothyronines (thyroid hormones)

(iv) amino-acid derivatives (e.g., epinephrine).

Hormones which interact with membrane-bound receptors normally do not enter the target cell, but generate second messengers (e.g., cyclic AMP, IP3, Ca^{++} etc) which in turn regulate cellular metabolism. Hormones which interact with intracellular receptors (e.g., steroid hormones, iodothyronines, etc.) mostly regulate gene expression or chromosome function by the interaction of hormone-receptor complex with the genome. Cumulative biochemical actions result in physiological and developmental effects.