PRINCIPLES OF ANIMAL BIOLOGY

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PREFACE

In view of the recent advances in biology during the last ten years we found it essential to add new parts especially those dealing with cell biology and molecular biology. Thus the student is introduced to the fundamental molecular plan and structure that is the basis of all life. In this edition a revision is made to both histology and systematics. Some parts has been omitted, others being added, and new illustrations are incorporated. In addition more emphasis has been given to the interrelationships between organisms, man and environment.

This book is intended to be an introdactory biology book for prospective biologists especially those in their first university year. It will help them to understand the various topics of zoology It coverd most fields, and it is more educational than an arbitrary selection of and concentration on certain topics of the field.

It is a pleasure to acknowledge the debt we owe to our colleagues for their constructive comments. Our thanks are also due to our publisher, DAR-EL-MAARLF, particulary Mr. MOHAMMED ABD EL-RAHMAN for their patience and encouragement.

The authors

PREFACE OF THIRD EDITION

In the third edition of "PRINCIPLES OF ANIMAL BIOLOGY" which appeared previously in two volumes, it is decided to publish it in one volume, but it still retains the previous style. A revision was done in the systematic in view of the latest developments in this field. Some parts have been omitted, others are being added, and new illustrations are incorporated. An introductory part of the recent classification of organisms is given. More emphasis has been given to the medical importance of insects.

In view of the helpful comments and suggestions of our colleagues some alterations were done and we are grateful to them. Any further comments are welcomed and will be taken in consideration in the future revision and publication. Our aim is to fulfil the need of our students especially those studying Zoology in their first year at the University. Thus a brief but uniform coverage of most of fields of zoology was found more educational than an arbitrary selection of and concentration on certain areas of the field.

We wish to acknowledge our colleagues for their constructive suggestions and their interest. Our thanks are also due to DAR-EL-MAAREF for helping in the issue of this book.

The Authors.

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midgut through the grooves of the gizzard. In the gizzard food is crushed and only fine particles are passed into the mid gut. The mid gut and hepatic caeca secrete enzymes that act upon proteins and fats in an acid medium. In the cockroach all classes of enzymes are produced except that represented by pepsin which is characteristic of vertebrates. Digestion in the midgut proceeds in a thin chitinous tube, the peritrophic membrane which is secreted by special cells lining the gizzard. The peritrophic membrane is permeable to enzymes and digested food. It protects the lining of the midgut from hard food particles. Digested food is absorbed in the midgut and hepatic caeca. In the rectum water is absorbed from undigested food, a means of conservation of water in insects. Some of the absorbed food is stored as reserve food in the form of glycogen, fat and albuminous substances in the fat **bodies** lying in the haemocoele.

Respiratory system

The respiratory system of the cockroach consists of :

1. a series of paired respiratory openings, the **spiracles,** on the sides of the body. The spiracles are guarded by valves which can open and close by special muscles to regulate the flow of air.

2. a system of longitudinal tubes which extend throughout the length of the body on each side forming **dorsal** and **ventral trunks.** These trunks are connected with the spiracles and with one another and anastomose to form a network of **tracheae** which send branches to every part of the body (Fig. 210).

3. a series of muscles and skeletal structures by which the insect can pump air in and out of the system of tracheae. By alternate expansion and contraction of the abdominal cavity, alternation of inflow and outflow of air takes place.

A trachea (Fig. 209) is covered with a single layer of thin epithelial cells, and is lined by a thin cuticle called **intima** which in large tracheae forms spiral thickinings to prevent them from collapsing. Each trachea ends into a stellate **end cell,** the tracheal cell from which arises a number of fine **tracheoles** which are lined with a very thin cuticle without spiral thickenings. The tracheoles are less than 1 micron in diameter and they are connected directly to tissue cells where they surround the cells and end blindly within them. Thus, the cells obtain their oxygen from the air directly and not through the blood.

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PART ONE

THE CELL

INTRODUCTION

Though the term "cell" was identified as long as 1665 when the English man, Robert Hooke, first saw the cells of cork, the ground work of the cell theory was not established until the early part of the nineteenth century.

In 1838, the British botanist, Robert Brown, found a small body in the cell and called it the "**nucleus**". In the meantime a German botanist, Schleiden (1938) and a German zoologist, Schwann (1839) were commonly given credit for the formulation of the "**cell theory**" which stated that all plants and animals are formed of similar cellular units.

In 1840, Purkinje was the first author who gave the name "**protoplasm**" to the cell contents. In 1861, another German zoologist, Max Schultz, defined the cell as a mass of protoplasm containing a nucleus.

Since the time of the above mentioned authors, considerable knowledge concerning cells has been accumulated. With Virchow's statement in 1853 that cells arise only from preexisting cells (theory of "**cell lineage**"), the stream of research took a turn that brought it into alliance first with embryology, and then, at the turn of the twentieth century, with cytogenetics.

In more recent years, the development of biochemistry and of new physical and chemical microtechniques has led to an interest in cytochemistry and in the ultra-fine structure of cells, with the result that cytology and cellular physiology become no longer regarded as distinct and separable subjects. In this part of the book, a brief description of the cell and its main components, as seen by the new physical instruments and tested by chemical microtechniques, is given.

CELL STRUCTURE AND FUNCTION

The modern microscope has revealed an astonishing diversity in the form and structure of the cell. Cells may be shaped like rods, spirals rectangles, spheres, snow flakes, runner beans and blobs of jelly. In some cases, the shape of the cell is dictated by its surrounding environment; this is apparently of the rectangular cells found in the stalk of a plant and of the spherical floating eggs of certain marine animals. In other cases, the shape of cell depends on its function; the human blood cells, for instance, are saucer-shaped and fairly flat to permit the ready transfer of the oxygen and carbon dioxide they carry throughout the body, while nerve cells have long, thin extensions to transmit messages.

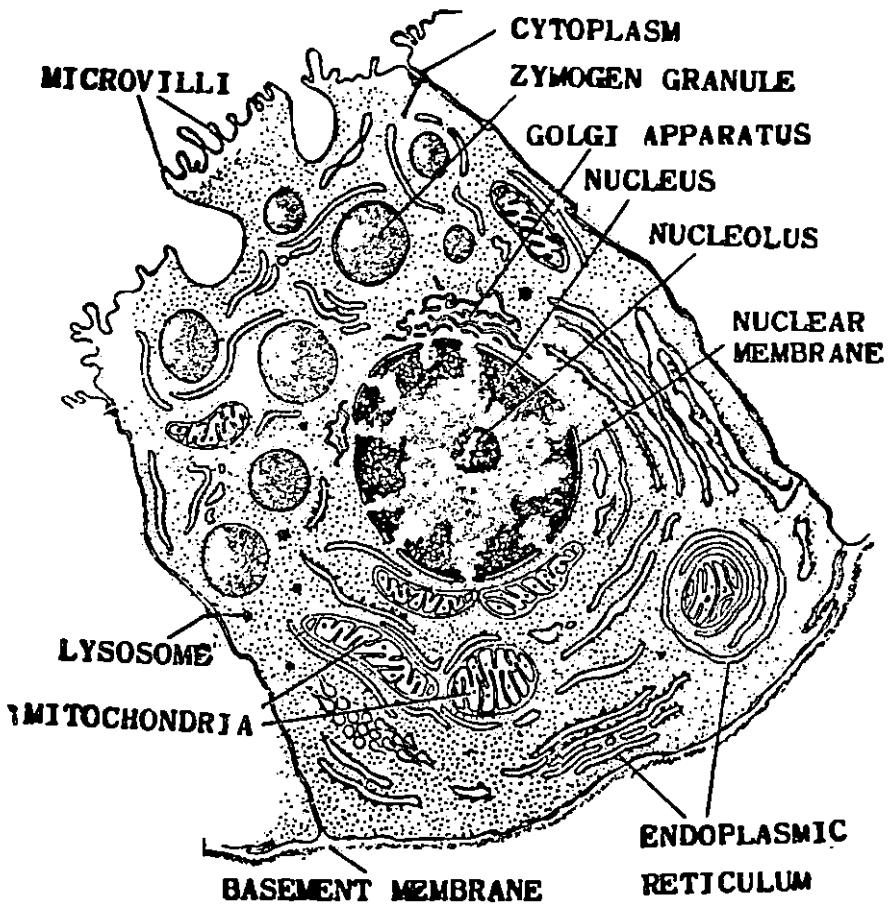


Fig. 1 — An animal cell as seen by the electron microscope.

The size of the cell ranges from that of a microbe which is about 10 microns (the micron = 1/1000 mm.). in diameter to that of an ostrich egg which may reach the size of an orange. Inspite of this diversity all cells are built according to a fundamental design which provides them with certain common features apparently necessary to life.

Older cytology depended very much on visual examination by the ordinary microscope. But, there is nowadays a new look in this connection particularly after the use of modern instruments such as the electron microscope, spectrophotometers and colouremeters and the use of cytochemical tests.

As shown in Figs. 1 the cell consists of two main interdependent parts, the **nucleus** and the surrounding **cytoplasm** which are generally referred to as the **protoplasm**; a term denoting living matter.

THE CYTOPLASM

It is the living substance found inside the plasma membrane and external to the nucleus. It contains the organelles and includes the bulk of cell contents. It is semifluid, semitransparent, viscous, elastic substance. It varies from cells of one species to another, and from one cell to another in the same species. It consists of 75-90% water and the remainder of solid materials including proteins, lipids, carbohydrates, acids and other inorganic and organic compounds. The cytoplasm is a complex highly organized chemical and physical system.

Physically, the cytoplasm is neither a solid nor a liquid, it is a system composed of both solid and liquid. The inorganic constituents and most carbohydrates, are soluble in water and are present in true solutions. The majority of organic compounds, especially proteins and lipids, are present as colloids. In true solutions the particle size of the components is too small and the dispersed particles will not settle. In colloidal solutions the paricles range from 0.001 to 0.1 u and remain suspended on account of the same electric change which causes them to repel each other.

Cytoplasmic colloids undergo reversible sol-gel transformation. In a sol state, the colloidal particles are dispersed in a random fashion. In the gel state the particles interact to form a network. The transformation from sol to gel or the reverse is brought by changes of temperature, concentration of various cytoplasmic components, and salt concentration as well as other factors. Example, gelatine, at high temperature it is in a sol state, when the temperature is lowered it becomes a gel.

The cytoplasm differs from ordinary colloids in :

(*a*) Colloidal components are systematically organized.

(*b*) It contains cell organoids (organelles).

CELL ORGANELLES

(i.e. little organs)

These are highly organized and specialized portions of the cytoplasm which play an important role in cellular maintenance, growth, repair and continuity.

Centrioles (Fig. 2 a)

In the cells of many animals and protistans, one pair of small cylindrical-shaped organelles are found in the nuclear region. These are called centrioles. Each centriole consists of a hollow cylinder 300-500 mu long and 150 mu in diameter. Its wall is composed of nine evenly spaced, triplet

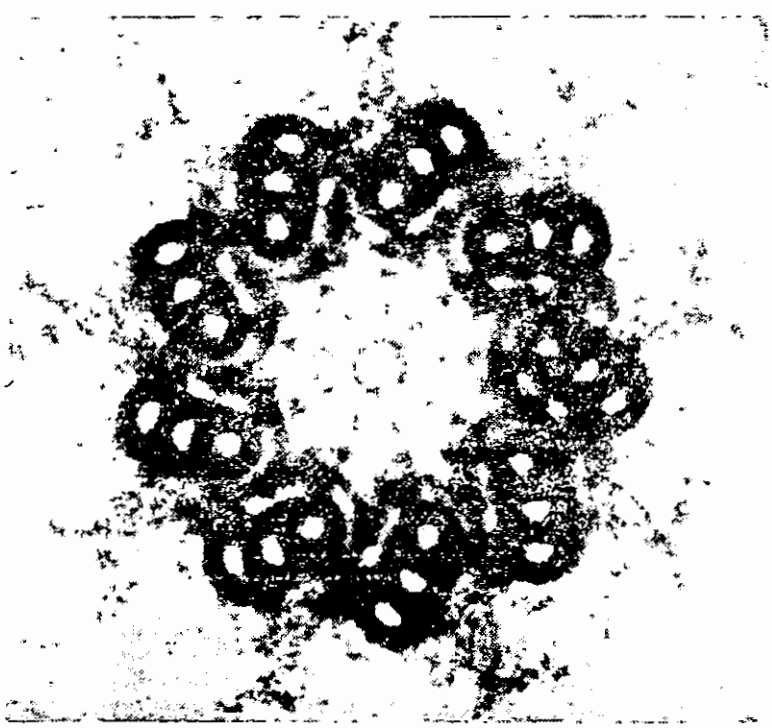


Fig. 2 a — Electron micrograph of a centriole.

hollow tubules embedded in rather dense amorphous matrix, one end of the centriole appears opened while the other is closed. One of the centrioles lies so that its long axis is perpendicular to the other. Before cell division each centriole is duplicated so that each daughter cell receives one pair.

Function

1. They assume a role in cell division.
2. They may serve as basal body from which cilia and flagella emerge.

Golgi Apparatus (Golgi Complex) or Dictyosomes (Fig. 2 b)

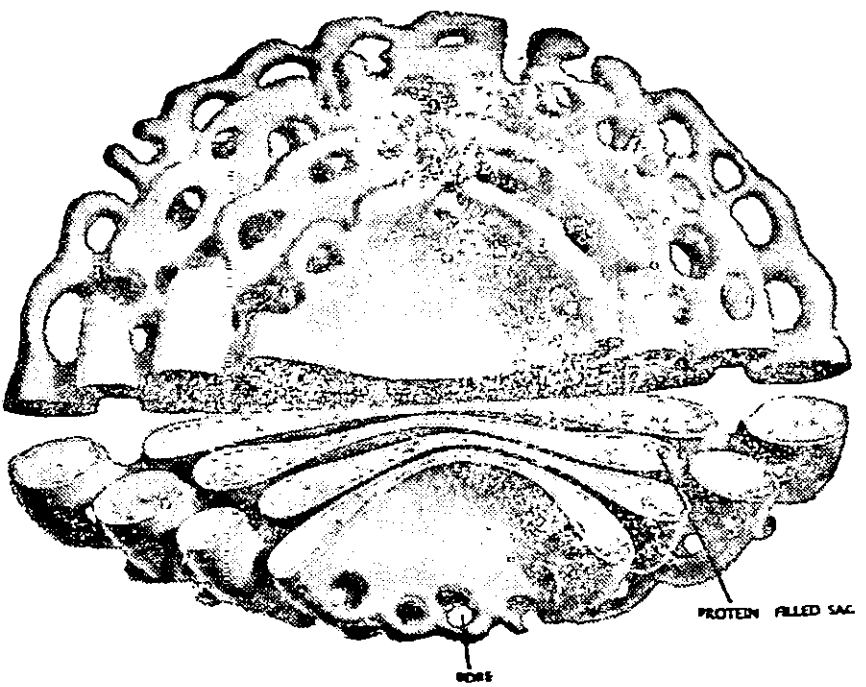


Fig. 2b — Diagramatic scheme of the "Golgi apparatus" as seen in section and top view by electron microscope. (after Pfeiffer)

It was first described in 1898, by an Italian physician Camillo Golgi. It is present in animal and plant cells. It is usually found in the area of smooth endoplasmic reticulum. Structurally dictyosomes appear as a series of flat cavities lined by smooth ER. It is characterized by a system of several parallel stacked saucer-shaped elements called cisternae. These are in the form of four to eight flat or curved layers. Golgi vesicles are

clustered at their ends. There is evidence that the smooth unit membranes of Golgi complex are continuous with those of the ER. Golgi complex is prominent in protein secreting cells.

Functions

(*a*) Storage of secreted products. In pancreatic cells the enzyme zymogen, which may be synthesised in the ribosomes appears to move into the channels of the ER and from there into the Golgi complex, where the enzyme is stored and released by the cell through the ER. Thus the Golgi complex is not involved in synthesis of secretory products.

(*b*) It may be used for transport of substances from one area to another within the cell, i.e. storage and distribution of materials within the cell.

(*c*) It may play a role in keeping a proper concentration of water in the protoplasm.

(*d*) It may be a site of plasma membrane synthesis and formation.

Mitochondria

These are small spherical, rod or filamentous-shaped bodies varying in size from 2-10 u long to 1-2 u wide (Fig. 1). They are present in both animal and plant cells and are the principal sites of energy production. The size, shape, and distribution of mitochondria is fairly constant in each type of cells. In the flight muscles of certain insect these may be lower, 5000 mitochondria ;per cell.

Electron microscope showed that the mitochondrion consists of a double unit membrane similar in structure to the plasma membrane (i.e. lipid and protein in nature). The outer membrane is smooth while the inner membrane is thrown into a series of folds or cristae into the matrix (Figs. 1 and 3 a) These cristae take various forms in different cells. They contain subunits (100 A° in diameter) called elementary particles which may be related to the functional respiratory units in the cristae. The aqueous matrix enclosed by the inner membrane contains a vast array of chemicals in various stages of synthesis and breakdown. The cristae contain a highly ordered-sequence of enzymes that regulate the cell respiration (i.e. enzymes concerened with energy releasing), and hence the generation of energy.

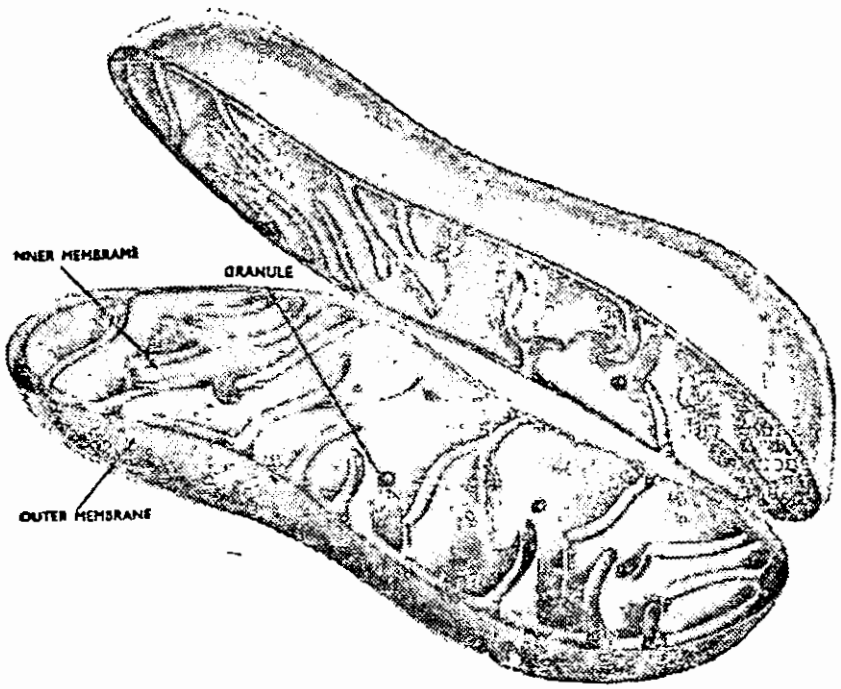


Fig. 3 a — Diagramatic scheme of a "mitochondrion" cut into two halves as seen by the electron microscope. (after Pfeiffer)

Function

The mitochondria illustrate - like other cell organelles - a high degree of correlation between structure and function. These are considered as the "power house of the cells". The cristae are arranged in a specific pattern in the form of uneven incomplete folds. This pattern affords an enormous surface area for chemical reactions, a great deal of reaction space, and the possibility of molecules orienting themselves in a linear arrangement.

By means of enzymes, organic acids derived from the breakdown of more complex molecules (carbohydrates, amino acids and proteins) are further broken down into carbon dioxide and water as a part of a stepwise series of reactions termed respiration. Each reaction is catalyzed by a specific enzyme. Some of the energy released is not dissipated as heat but is passed on to other molecules that contain phosphates where it is stored in high energy phosphate bonds, i.e. ATP (adenosine triphosphate). This molecule is then secreted by the mitochondrium, and utilized in the cell whenever energy is needed.

Mitochondria are capable of self replication, and they contain their own genetic or hereditary information in the form of circular DNA mole-

cules. Mitochondria also contain RNA and ribosomes along with other factors in protein synthesis.

Lysosomes

These appear in the form of spherical membrane-enclosed structures somewhat smaller than mitochondria. They are surrounded by a single external membrane and lack internal structures. They function as storage vesicles for digestive enzymes; hence their name (lyso = degrading, digesting). The outer membrare is impermeable to the outward movement of the enzymes and is resistant to their action. It is believed that lysosomes store enzymes formed on ribosomes in the ER. The latter passes these enzymes to the Golgi complex where they are enclosed in membranes. When lysosomes fuse with food vacuoles or old organelle they become activated and digestion takes place. Lysosomes are prominent in phagocytic protozoans and cells. The lytic enzymes break down large proteins, lipids and carbohydrates, to simple compounds which are used in the synthesis of new organelles or utilized as energy sources by the mitochondria.

Endoplasmic reticulum (or ER Fig, 3 b)

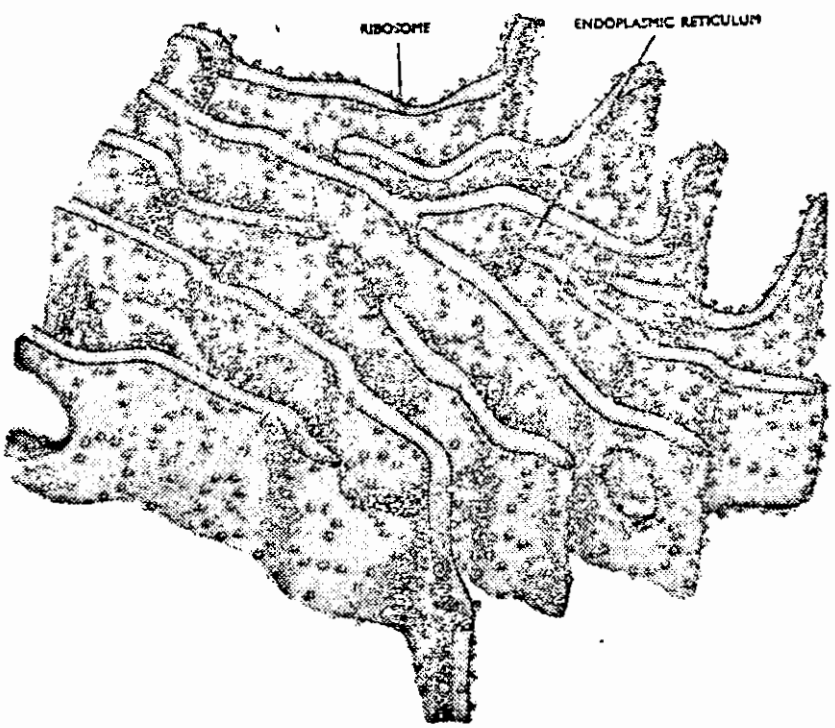


Fig. 3 b. — Diagramatic scheme of a portion of "enodoplasmic reticulum," as seen by the electron microscope. (after Pfeiffer)

It is found in all nucleated cells. It is a system of parallel membranes (similar to the cell membrane) enclosing narrow cavities of various shapes. In some cells it appears as fine tubules (50-100 mu in diameter), in others the membrane bound-cavities form flattened sac-like structures called cisternae. On the surface of the tubules and cisternae are areas where biochemical reactions occur. The ER system may be more or less continuous between the plasma membrane and the nuclear envelope and is assumed to be part of the cells' complex membrane. Cells in which synthesis is intense (e.g. hepatocytes) have a highly developed ER.

Functions

(*a*) ER acts as a cytoskeleton that provides a great amount of surface for chemical reactions.

(*b*) It acts as a pathway for transportation of cellular molecules.

(*c*) It is used for storage for synthesized molecules.

(*d*) It acts as a passage of substances back and forth between the cytoplasmic and nuclear membranes.

(*e*) It provides the site for attachment for the ribosomes.

Ribosomes (Figs. 3 b and 4)

These are small particles, each composed of two subunits of unequal size, both of which contain a protein and ribonucleic acid. Together these subunits are the site of protein synthesis in the cell. When no ribosomes are present on the endoplasmic reticulum it looks smooth. However, the ER with attached ribosomes appear rough or granulated, hence called rough ER. When ribosomes are organized in groups or clusters they are called polyribosomes. Ribosomes are also found in mitochondria and plastids.

Function : Ribosomes are the sites of protein synthesis.

Microtubules and microfilaments

These are thin tube-like structures (200-300 A° diameter), which are mainly common in the center of the cell where they are often closely related to the centrioles. These structures form the spindle apparatus during cell division. They were found in the tail of many sperm cells, in axons and in the cytoplasm of other cells. Microtubules have no regular distribution in animal cells.

Fig. 4 — Electron micrograph of a pancreatic acinar cell showing The endophasmic reticulum, Free ribosomes, and several mitochondria (x 36,000).

Functions

(*a*) Microtubules may act as cytoskeletal elements that play a role in maintaining cell shape by causing stiffness in certain areas of the cell.

(*b*) They may be involved in internal movement of the cytoplasm and alternations in cell shape.

On the other hand, there are thinner structures (i.e. 50 A°) which are called microfilaments.

PLASMA MEMBRANE

It consists of equal parts of proteins and lipids. The original formulation of the plasma membrane was of a biomolecular lipid layer sandwitched between two nondescript layers of molecules called unit membrane (Fig. 5 a). In this case the phospholipid molecules are placed in such a way that their hydrophobic fatty acid chains are adjacent.

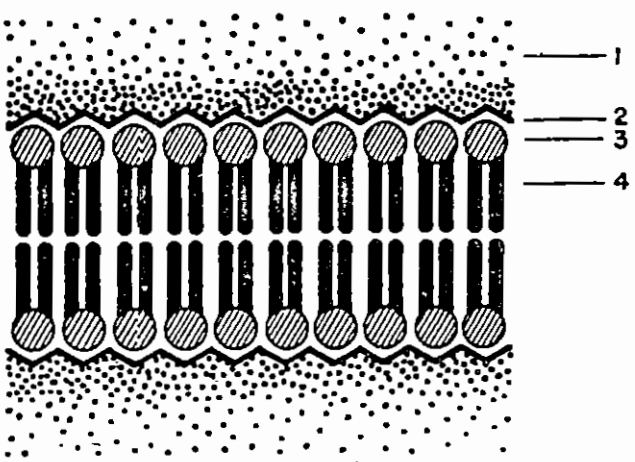


Fig. 5 a — The classical model of plasma membrane structure : 1, globular protein, 2, protein in extended form; 3, hydrophilic ends of lipid molecules; 4, hydrocarbon chains of Lipid molecules.

Recently it is found that protein molecules vary from cell to cell. (Fig. 5 b). The surface proteins of any single cell do not appear to be uniformly distributed. It is of a lipid layer in which various proteins reside. Some proteins are extremely large and protrude through the lipid layer thus ex-

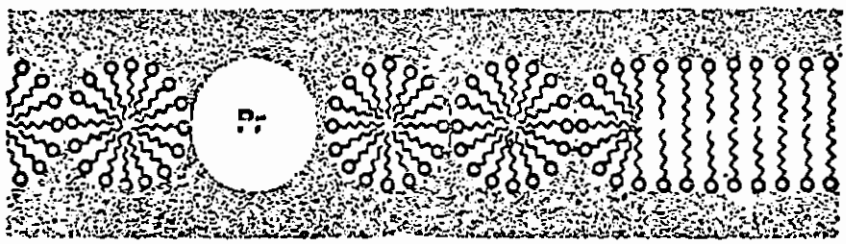


Fig. 5 b—A cross-sectional view of a membrane in which globular micelles of lipid are in dynamic equilibrium with a bimolecular leaflet of lipid. A layer of protein or glycoprotein or both is known on each side of the lipid layer. The structure of each lipid molecule is illustrated in a diagrammatic fashion: only a polar group (O) and a non-polar moiety (wavy line) are shown, and the lipid may be phospholipid or non-phospholipid. One globular micelle of lipid has been replaced by a globular protein molecule (Pr) which may be a functional enzyme.

tending from the cycloplasmic side of the membrane to the extracellular surface. Other proteins may be found only on the inner or outer surface but not both.

Function

The cell membrane is responsible for maintaining the structural integrity of the cell. It also regulates the flow of material in and out of the cell.

Physically the membrane behaves as if it possesses various size pores which permit the entery of molecules. These pores never exist. The mechanisms which control the entry of molecules in the cell are :

1. **Diffusion** which involves the membrane either by : lipid soluble molecules entering by simple diffusion where molecules pass from a region of higher concentration to a region of lower concentration as a result of their intrinsic energy, e.g. acetyl alcohol. (i.e. **passive transport**).

2. By a **carrier-mediated transport** such as highly charged ATP or polar molecules as glucose Glucose is bound to a protein that carries it through the lipid bilayer and deposits it in the cytoplasm. Sometimes the carrier-mediated transport requires cellular energy and may even work against a diffusion gradient. Such a process is called **active transport,** e.g. the cell maintains the K^+ concentration higher on the inside of the nerve

cell than on the outside. If this system failed, i.e. K^+ are equal on either sides the nerves could no longer conduct electrical conductivity.

In some cells the cell membrane is modified to microvilli (when exposed to a lumen) giving the surface a brush appearance. These increase the absorptive surface of the cells. Sometimes two adjacent cells are held by desomosomes where the two cells are held together by discontinuous alternations of their lateral borders, tonofilaments are attached to desomosomes.

3. **Phagocytosis** is an active process of absorbing materials by inward folding of a portion of the plasma membrane. A vacuole is formed which floats freely in the cytoplasm. This occurs in some Protozoa, and in the white blood cells of many animals. Phagocytosis also permits molecules to which the membrane is normally impermeable to enter cells along with ingested particles.

Pinocytosis is another process which involves the engulfing of a liquid containing small particles by adsorption on the cell surface. This occurs either by the infolding of the cell membrane where the vacuoles are formed at its end or are detached directly from the membrane surface.

The plasma membrane may be modified to form :

(*a*) Microvilli which enormously increases the absorptive surface (200 million of microvilli/mm^2 of the intestine).

(*b*) Desmosomes which are local thickenings of the opposing surfaces from which fine filaments radiate into the cytoplasm, e.g. in epithelial cells.

(*c*) Rods and cones of the eye serving as photoreceptors. The upper portion of each rod consists of disc-shaped double layered membranes (sacs) which contain the pigment involved in vision.

(*d*) The myelin sheath of an axon is formed of concentric layers of the plasma membrane. This sheath serves for : 1) protection of the nerve; 2) assists in transmission of impulses, and 3) plays a role in nutrition.

The cell membrane may be surrounded by another structures such as:

(*a*) The cell walls of plant cells which are nonliving structures which has protective and supportive functions, and in addition, determine shape and texture of the cells. The cell wall consists of : an intercellular substance called middle lamella, a primary cell wall and a secondary cell wall.

(*b*) The intercellular substances which include a large number of materials that form the matrix in which the cell lives. They are non-living, produced by the cells and fill the spaces between the cells. Their functions are :

(i) They provide strength and support to the tissues.

(ii) Act as medium for the diffusion of nutrients and waste products.

Intercellular substances may be :

(*a*) Amorphous such as hyaluronic acid and chondroitin. **Hyaluronic** acid is a viscous fluid-like mucopolysaccharide capable of binding readily. It binds the cells together and acts as a lubricant in the fluids of joints and in the humors of eye. It may act to retain water and maintain the shape of the eye. **Chondroitin** is jelly-like and is found in cartilage, bone, in the aorta, heart valves, in the cornea of the eye and in the umbilical cord. It provides support and adhesiveness while affording a degree of flexibility.

(*b*) Fibroses intercellular substances provide strength and support for the tissues. These include collagen (collagenous fibers), elastin (elastic fibers) and reticulin (reticular fibers) all are made of complex proteins.

CELL INCLUSIONS

These are materials which are produced as a result of the cell activity. They are mostly organic in nature and are not constant in the cell, i.e. they appear and disappear at different times in the life of a cell. Some are stored as reserve materials, others are products of biochemical activities, while others have characteristic forms in the cell. In animal cells these inclusions include stored secretory granules, droplets or crystals which appear as zymogen granules (pancreas), mucus (intestinal epithelium), melanin (pigment of skin, hair and eyes of mammals), glycogen (stored polysaccharide) in the liver, lipids (in fat cells) and haemoglobin crystals (red blood cells). In plant cells the cell inclusions are conspicuous and include the vacuoles which are fluid-filled spaces, or specialized vacuoles such as food and contractile vacuoles of some Protozoa. In addition starch grains, and crystals of inorganic origin (e.g. calcium oxalate, calcium carbonate, calcium sulphate etc.) are seen in plant cells. Protein, lipid and starch inclusions are formed when excess foods are produced by the plant cell and they may be digested and utilized during periods of minimum food synthesis.

THE NUCLEUS

It is an essential component of nearly all the cells. It is the controlling center of the cell containing the chromosomes. Without the nucleus the cell may continue to live for a limited period, but it can neither grow nor undergo progressive differentiation. Thus the mammalian red blood cells and the cells comprising the center of the lens of the eye are somewhat restricted in their metabolic activities and are not capable of growth or division. The nucleus is the source of information that controls cell morphology. This was proved by Rammerling in his experiments with **Acetabularia mediterranea** and **A. crenulata.**

The nucleus not only excercises control over structure it also influences cell function. If **Amœba** is cut into two parts, the nucleated half functions, while the enucleate portion cannot form pseudopodia, cannot ingest food, and cannot metabolise, grow or reproduce. If a nucleus or the nucleated portion is transplanted into this enucleate portion it lives normally.

The nucleus may assume various shapes being spherical, oval, elongated etc. with more viscous contents than those of the cytoplasm. Most cells contain one nucleus, some may contain more than a nucleus, i.e. multinucleated. The nucleus is surrounded by the nuclear membrane.

Nuclear membrane (nuclear envelope) (Fig. 6)

It is a double unit membrane with a cavity, the **perinuclear cisterna,** between them. This structure resembles other cellular membranes both in appearance and chemistry. The nuclear membrane is provided by minute pores which communicates with the endoplasmic reticulum. These pores may facilitate an exchange of material between the nucleus and cytoplasm. The nuclear membrane regulates the flow of material in and out of the nucleus.

The nuclear membrane surrounds a gel-like cytoplasm called nuclear sap or nuclear matrix, one or more nucleolei and a thread-like network called chromatin.

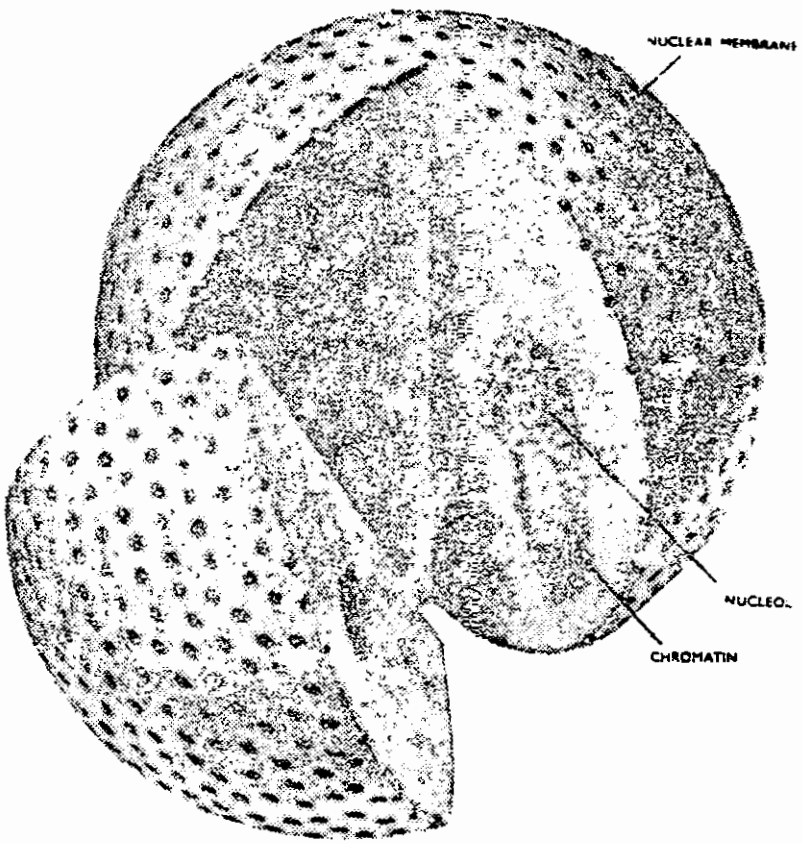


Fig. 6 - - A model of the nucleus and its main parts. (after Pfeiffer

Chromatin

At the beginning of cell division, this chromatin changes into long, thin granular threads called **chromatin strands** which then shorten and thicken to form a definite number of **chromosomes** of specific sizes and shapes.

During the early prophase stage of mitosis, there appears a pair of fiber-like **chromonemata**, or **gene strings**, which are often coiled and run lengthwise within the chromatin material (Fig. 7a). Each chromonema has a special region called a **centromere** or **kinetochore** for attaching it to the spindle when migrating toward the opposite poles during mitosis.

Later, the chromonemata thicken and acquire an accumulation of **matrix** which surrounds them. The two chromonemata and their matrix

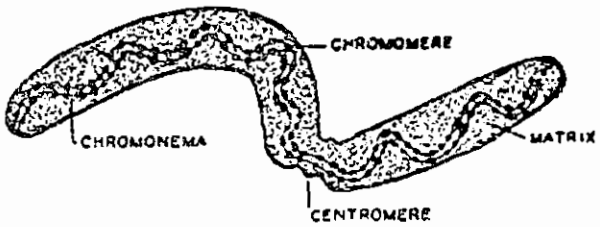


Fig. 7 a — Chromosome in diagramatic detail.

constitute what is known as the **chromatids.** When cells divide and the chromosomes lie at the equatorial plane, the two chromatids of each chromosome move away from each other toward opposite poles.

Attached to each chromonema in a linear series, are numerous bead-like **chromemeres** of various sizes, shapes and arrangements which seem to be specific and unique for each noumal chromosome. As a matter of fact, the size, shape and number of chromosmes for each living organism are constant.

Chromosomes are of two main types : **autosomes** and **sex-chromosomes.** For example, the fruit fly, **Drosophila melanogaster** has three pairs of autosomes and one pair of sex-chromosomes, (Fig. 7b.). In the female, the sex-chromosomes are alike and each is called the **x-chromosome** while in the male there are an **x-chromosome** and a different **Y-chromosome.**

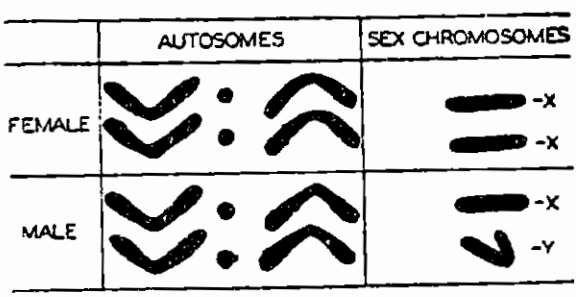


Fig. 7 b — Chromosome in male and female *"Drosophila melanogaster"*

Nucleolus

In almost all resting nuclei, are embedded one or more amorphous, spherical or occasionally rod-shaped bodies of higher density and refractiveness than the surrounding ground substance (Figs. 1 and 2). With

appropriate fixation, the nucleoli stain deeply with basic dyes. As a rule, they break up and gradually disappear as the nucleus begins to divide and are reconstructed at the beginning of the next resting stage.

The nucleolus is composed of ribonucleic acid (RNA) and a high concentration of protein. Sometimes, several nucleoli may be present in a cell. Man may have as many as four. A nucleolus is formed by a specific region of a particular chromosome which is called the "**nuclear organizer**"

Nucleoli are believed to be concerned with metabolism especially in protein manufacture. They may also pass genetic materials and "**information**" from the nucleus to the cytoplasm since they disappear during cell division.

THE PROTOPLASM

Under the microscope, the protoplasm presents the appearance of an optically clear, continuous substance in which certain visible particles are embedded. Most of these substances are products of cell activity and in no sense constituents of the living substance, although some bodies such as the mitochrondia and Golgi bodies may be regarded as organs of the cell.

The protoplasm is a liquid system of variable viscosity. It may exist in a sol state that flows easily or in a more solid gel state in which particles may form a continuous network thus rendering the substance jelly-like (semisolid). Under certain conditions, it may change from the sol to the gel state or back again from the latter to the sol state.

Because protoplasm varies so much when changing from the sol state to the gel state and back again, older investigators have proposed serveral theories (Fig. 8) as to its nature, including the following : (1) **Granular,**

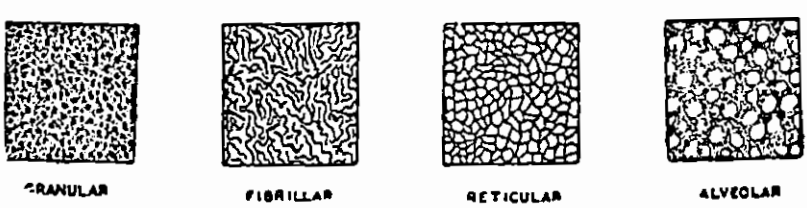


Fig. 8 — Early theories of physical structure of protoplasm.

in which minute granules are suspended in a liquid; (2) **Fibrillar**, in which the spaces between the interwining thread-like fibres are filled with liquid; (3) **Reticular**, in which the spongioplasm forms a net-like reticulum with the space filled with liquid; (4) **Alveolar**, in which the sponge-like part contains minute spaces called alveoli which are filled with liquid, giving a foam-like appearance.

Protoplasm is not soluble in water. It is usually alkaline or somewhat neutral, but never acidic. When heated to about 55° C., it coagulates, i.e. it passes over into a somewhat harder state which has lost plasticity and transparency. Actual freezing kills protoplasm without, however, noticeable alteration of its plasticity and transparency.

THE MOLECULES OF LIFE

Chemical Constituents of Biological Systems

A compound is a result of a chemical combination of atoms of two or more elements. While the fundamental unit of an element is atom, that of a compound is a molecule. The compounds found in organisms are :

1. **Inorganic compounds,** these typically lack carbon, dissolve readily in water, generally resist decomposition, undergo rapid chemical reactions and are usually more ionic than organic compounds in character (NaCl).

2. **Organic compounds** always contain carbon and typically contain hydrogen as their essential constituents.

The principal inorganic substances that comprise living systems are water, gases, certain acids, bases and salts. Of the organic compounds are carbohydrates, lipids, proteins and nucleic acids.

Water.

Water is one of inorganic essential compounds for growth, repair, maintenance and reproduction. It is by far (except enamel of teeth and bone) the most abundant component and is present in 5 to 95% or more, e.g. in man 60% of r.b.c., 75% of muscle tissue and 92% of blood plasma consist of water.

Water possesses unique characters which make it one of the vital constituents of living systems.

(*a*) Water is a solvent which facilitates chemical reactions.

(*b*) It is also a medium in which nutrients are carried into cells and in which waste products pass out of the cells. This property is due to the polarity of a water molecule. Due to the distribution of electrons in the covalent bond $H_2 = O$ the negative and positive charges are not equally distributed within the molecule. The oxygen region is more electronegative and the hydrogen region is more electropositive.

The importance of polarity lies in :

1. Polar moles tend to be arranged in specific configuration with respect of other moles, because of the attraction of unlike charges.

2. Polarity accounts for some of the physical and chemical characteristics of molecules.

Physical properties

Water is an excellent suspending medium and solvent. Many substances will dissolve in water because the positive part of water molecule is attracted to the negative part of the solvent (substance), while the negative part of the water mole is attracted to the positive part of the solute. This will separate the solute molecules which will become surrounded by water.

Water is a solvent which facilitates chemical reactions. It is also the medium in which nutrients are carried into cells and in which waste products pass out of cells.

Chemical properties

Water is a reactant in the digestive process of organisms, a process in which larger molecules are broken down into smaller ones for utilization by cells.

Water is involved in synthetic reactions. Water is the main source of hydrogen and one of the sources of oxygen that enters into a number of organic compounds in living systems as a component of protoplasm, organelles and membranes.

Water is characterized by its latent heat of fusion and high specific heat. Thus water requires a much greater amount of heat to increase its temperature than any other substance. Heat absorption by water is used first to break hydrogen bonds rather than increasing molecular reaction.

Therefore more heat must be applied to raise its temperature than to a nohydrogen-bond liquid. Thus water helps to maintain the temperature of organisms even though there are many changes in the environmental temperature.

GASES

Gases include nitrogen, oxygen and carbon dioxide. Atmospheric nitrogen includes about 78% of the gaseous envelope around the earth. Gaseous carbon dioxide constitutes about 0.03% and is the main source of carbon. The latter is a major component of living matter. Molecular oxygen which comprises about 20% of atmospheric gases is essential for the metabolism of most cells.

ACIDS, BASES AND SALTS

Compounds which lack carbon - to - hydrogen bonds are called inorganic compounds and these may be acids, bases or salts. Such compounds are important to living organisms because they provide the ions to many essential biochemical reactions. These substances are usually found in aqueous solutions in living organisms. Hence an acid is defined as hydrogen ion H^+ donor, a base a hydroxyl ion OH^- donor, a salt is made up of positive ions (except H^+) and negative ions (except OH^-).

In water certain molecules dissolve whether they are less covalent or ionic (i.e. covalently bonded). Water molecules reduce the attraction of atoms within an ionic molecule thus ionization takes place. In solution the electrons forming the original bond will remain with one of the parts and will be free in solution as ion (charged atom or group of atoms). If an ion has more protons than electrons, it is postively charged, and, if an ion had more electrons than protons it is negatively charged. Substances forming ions in water are called electrolytes and these are capable of conducting an electric current.

Examples : (*a*) An acid $HCl \rightarrow H^+ + Cl^-$
one or more H ions and one or more negative ions.

(*b*) A base $NaOH \rightarrow Na^+ + OH^-$
one or more positive ions and one or more OH^-

(*c*) $NaCl \rightarrow Na^+ + Cl^-$
one or more positive ions and one or more negative ions (neither H nor OH ions).

The inorganic acids and bases are important in maintaining the proper pH, or electrolytic environment in which biochemical reactions take place.

For example, reactions of proteins are greatly affected by the number of hydrogen ions present. Small changes in pH (i.e. the amount or concentration of H_2 ions) can alter the structure of protein molecules as well as can change the direction in which a given biochemical reaction will take place. The degree of ionization of electrolytes is different when in solution, some of them are completely ionized in solution, e.g. strong acids (HCl, H_2SO_4); others are not completely ionized, e.g. carbonic acid which is a weak acid.

Examples : (*a*) $HCl \xrightarrow{H_2O} H_3O^+ + Cl$

100 moles of HCl ——— 100 moles of hydronium ions + 100 moles of chloride ions

A hydrogen ion is not free in water as it attaches to a water molecule forming hydronium ion.

$$H^+ + H_2O \longrightarrow H_3O^+$$

(*b*) $H_2CO_3 \longrightarrow H^+ - HCO_3^-$

98 moles ——→ 2H ions + 2 HCO_3 bicarbonate.

Most carbonic acid is in molecular form.

Thus stronger acids are more acidic than weaker acids. The ionization of weak acids or weak bases can be represented by an ionization equation, e.g. ionization of carbonic acid.

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

The arrows mean the concentrations of moles and ions are constant although not necessarily equal.

Inorganic weak and strong bases do not have great application within living organisms. In addition both strong acids and bases are not usually found throughout living organisms. Thus hydrochloric acid is found in the stomach.

Hydrogen ion concentration (pH)

Biochemical reactions are extremely sensitive to small changes in the electrolytic environment. The concept pH has been devised to express the hydrogen ion concentration. The pH of a given solution is equal to the negative logarithm of the hydrogen ion concentration.

$$pH = -\log (H^+)$$

In the ionic equilibrium equation of normal blood plasma, the concentration of hydrogen ions is 0.0000000395 M or 3.95×10^{-8} M. When converted into pH it can be understood by biologists.

$$\begin{aligned} -\text{pH} &= -\log (H^+) \\ &= -\log (3.95 \times 10^{-8}) \\ &= -\log (3.95 \times 10^{-8}) \\ &= -(0.5966 - 8) \\ &= -(-7.4034) = 7.4 \end{aligned}$$

Water ionizes to an extremely small extent thus it produces equal number of hydrogen and hydroxyl ions. Thus it is neutral. It has been found that the concentration of hydrogen ions in water is 1×10^{-7} M.

$$\begin{aligned} \text{Thus pH} &= -\log (H^+) \\ &= -\log (1 \times 10^{-7}) \\ &= -(\log 1 + \log 10^7) \\ &= -(0 - 7) = 7 \end{aligned}$$

Buffers

Inorganic substances play an important role in maintaining an electrolytic balance within the organism. Although there is a variation in pH in the different parts of the organsim, the limits of such variation are specific. Thus the pH of normal blood plasma is 7.4, which if changed within a range of 0.3 above or below will cause acidosis or alkalosis with disasterous effect. Buffer systems are responsible for maintaining a relatively constant pH. In the blood the carbonic-acid-bicarbonate system is the most important buffer system in the blood which operates in the following way :

(*a*) Carbonic acid being a weak one ionizes, and at a given concentration there is an equilibrium between the molecular form of the acid and its ions, i.e.

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

(*b*) If we add a solution of sodium bicarbonate it ionizes completely, thus leading to a great increase of the bicarbonate ion in solution.

$$NaHCO_3 \longrightarrow Na^+ + HCO_3^-$$

(*c*) The presence of the bicarbonate ions causes the formation of carbonic acid molecules thus leading to a new equilibirium concentration :

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$
$$NaHCO_3 \rightarrow Na^+ + HCO_3^-$$

Sodium ions serve to balance electrical changes. At equilibrium there are many carbonic acid molecules and bicarbonate ions than hydrogen ions.

If we add hydrogen ions to this buffer system, they will combine with the bicarbonate ions forming more carbonic acid molecules. Thus the total hydrogen ion concentration is not increased.

If hydroxyl ions are added to the buffer system they will combine with hydrogen ions to form water. The removal of hydrogen ions will cause more carbonic acid molecules to ionize, thus forming more hydrogen ions to replace those removed and to restore the original pH. Thus carbonic acid acts as a reservoir for additional hydrogen ions when removed by alkali or base; and the bicarbonate ions act as a reservoir to combine with hydrogen ions when increased by the addition of an acid. Hence a buffer system helps to maintain a relatively constant pH within limits of acid and base concentration added to the system. If large quantities of acid or base are added a sharp change of pH takes place because of the insufficiency of acid or negative ions.

Buffer systems are of many types and they are organic or inorganic ones. The mechanism of inorganic buffers are essentially the same, i.e. one component ionizes slightly and the other completely.

Physiological function of inorganic components

Inorganic components play an important role in life processes where they react as ions or inorganic molecules. These substances are closely interrelated with the organic components in the living organism. Their major function is : (1) to help to maintain electrolytic balance (buffer system) : (2) play an important part in the formation of bones and teeth; (3) provide the ions for nerve and other cells to respond to stimuli and (4) furnish specific activators for enzymatic reactions.

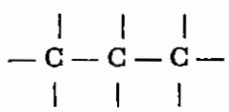
Examples :

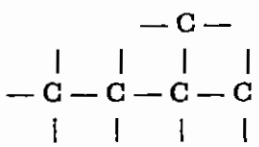
Oxygen : constituent of water and organic molecules used in cellular respiration.
Carbon : component of all organic compounds.
Hydrogen : constituent of H_2O and all organic molecules.
Nitrogen : constituent of organic molecules.
Calcium : component of bone and teeth, required for blood clotting, hormone synthesis, membrane stability, muscle contraction.

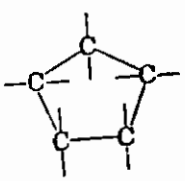
Phosphorus: in proteins, ATP, nucleic acids, component of nerve tissue and bone.
Magnesium: component of many enzymes.

ORGANIC COMPOUNDS

Inorganic molecules serve as raw material for the synthesis of organic compounds and both are interrelated through various chemical processes. Organic compounds are more complex than inorganic molecules. The carbon atom is the principal component by weight of organic compounds which include carbohydrates, fats, and proteins. Carbon is unique in forming four covalent bonds which may be formed between other carbon atoms forming chain, branched or ring structure, i.e.





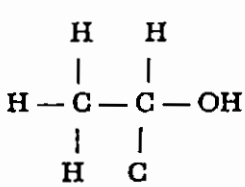


Carbon atoms can bind with double or triple bonds.

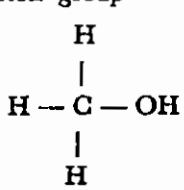
$$-C=C- \qquad -C\equiv C-$$

In addition to carbon, hydrogen (one bond); oxygen (two bonds) and nitrogen (three bonds) are the most common elements in organic compounds. The basic chain of carbon atoms (i.e. chain or ring) forms the carbon skeleton while additional elements with carbon and hydrogen are called functional groups. The latter are responsible for the chemical characteristics and physical properties of a given organic compound. There are many functional groups on the basis of which organic compounds are classified into :

(1) **Alcohols** organic compounds containing (—OH) the hydroxyl group, i.e. R-OH where R is the skeleton group



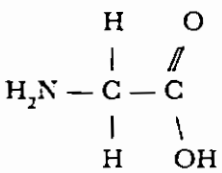
Ethanol



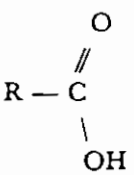
Methanol

2. **Amines** : containing amino group NH_2 (RH_2).

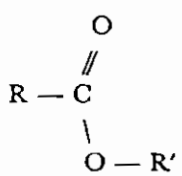
3. **Amino acids** : moles containing amino and carboxyl group.



4. **Organic acid** :



5. **Ester** :



1. CARBOHYDRATES

Carbohydrates contain carbon, hydrogen and oxygen with a general formula $C_n(H_2O)_n$ where n = 3 or more such units. Carbohydrates play an important role in living systems being :

1. They play a pivotal role in energy relations. Thus during photosynthesis green plants synthesize carbohydrates where large amounts of energy are stored. Animals and plants break these carbohydrates to obtain energy needed for their activities.

2. Carbohydrates enter in the formation of important structures of the organism such as chitin which is a part of the exoskeleton of insects and crustaceans; cellulose of plant cells, and nucleic acids.

3. Carbohydrates act as storage of reserve energy as starch in plants and glycogen in animals. The latter is stored in the liver and muscles of higher animals.

4. Carbohydrates may be used for the synthesis of fats and proteins through a series of chemical reactions.

There are three classes of carbohydrates :

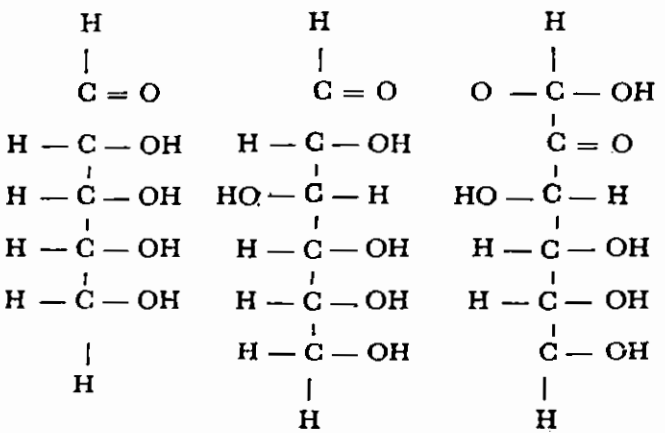
i.e. monosaccharides, disaccharides and polysaccharides.

1. MONOSACCHARIDES

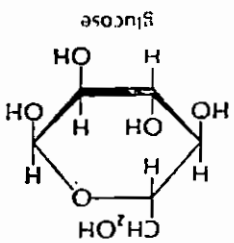
These consist of compounds containing 3 — 7 carbon atoms with names ending in — ose. = sugar and a prefex designating the number of carbon atoms, i.e.

Triose	$C_3H_6O_3$	
Tetrose	$C_4H_8O_4$	
Pentose	$C_5H_{10}C_5$	Ribose
Hexose	$C_6H_{12}C_6$	Glucose and Fructose
Heptose	$C_7H_{14}O_7$	

The most common monosaccharides are glucose and fructose -both are hexoses with identical chemical formula but different molecular configuration. Thus they are called isomers and the phenomenon is isomerism.



Ribose Glucose Fructose



Glucose and fructose assume a ring form when present in solutions in the cell. In such case the first and fifth carbon atoms are bridged together by the oxygen atom.

Glucose is one of the major products of photosynthesis and is the main energy-supplying molecule of all living systems.

Furthermore it is a constituent of cellulose.

Ribose and deoxyribose are pentose sugars which form part of the structure of ribonucleic acid (RNA) and deoxyribonucleic acids. Both acids are important in directing protein synthesis.

The triose glyceraldehyde is fundamental in the process of glycolysis and lipid formation.

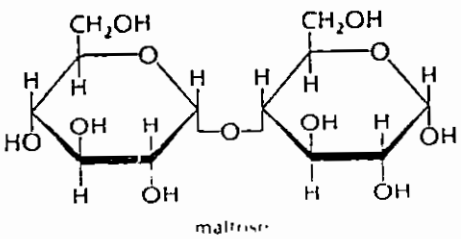
DISACCHARIDES

When two molecules of monosaccharides are coupled together they form a disaccharide. During this process a molecule of water is lost and the reaction is termed dehydration synthesis and the two molecules are joined by a glycosidic bond. Biologically important disaccharides are : maltose, sucrose and lactose.

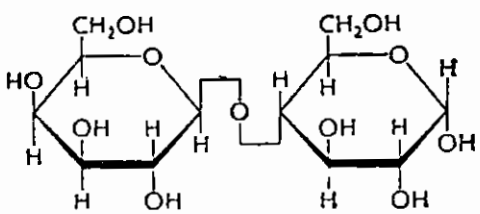
$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{glucose}}{C_6H_{12}O_6} \longrightarrow \underset{\text{maltose}}{C_{12}H_{22}O_{11}} + H_2O$$

Maltose is a degradation product of a larger starch molecule. It is made up of two glucose molecules.

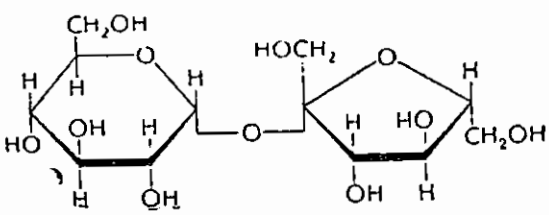
Sucrose the common table sugar and is composed by the linkage of a glucose and a fructose molecule. Lactose the sugar in the milk of mammals is composed of glucose and galactose.



maltose



lactose



sucrose

During the process of digestion the disahaccride molecules are broken down into smaller molecules by addition of water, a process called hydrolysis (i.e. digestion).

POLYSACCHARIDES.

The dehydration synthesis of eight or more monosaccharides with a large number of glycosidic bonds results in the formation of polysaccharides (e.g. starch, glycogen, cellulose). Their molecular formula is $(C_6H_{10}O_5)_n$ Unlike mono- and disaccharides, polysaccharides are usually not soluble in water and not sweet.

Starches are found in most green plants where they are stored in the seeds, stems, leaves, roots etc. Cellulose is an important component of higher plants. It is usually formed in combination with other compounds such as lignin. Cotton fibers are made up of pure cellulose. It is made up of 1000 or more molecules of glucose.

Chitin is another polysaccharide found in crustaceans and insects. Glycogen is found in animals and serves as a storage of glucose. It is more soluble in water than starch and when hydrolysed it gives glucose molecules.

2. LIPIDS

Fats or lipids are compounds which can be extracted by ether, alcohol, chloroform or other nonpolar organic solvents. They are composed of hydrogen, carbon and oxygen (H_2 and oxygen not in the ratio 2 : 1). Most fats are insoluble in water. Lipids contain a heterogenous group of compounds that have many functions in living organisms :

1. Structural components of the cells, e.g. cell membrane.

2. Provide fuels for energy, being the most highly concentrated source of biological usable energy.

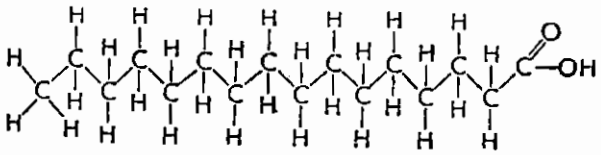
3. Storage material in plants and in animals forming adipose tissue.

The most predominant lipid in a living organism is the fatty acid which is made up of a long hydrocarbon chain with a carboxylic group at one end — COOH :

$$\begin{array}{c} O \\ \| \\ -C-OH \end{array}$$

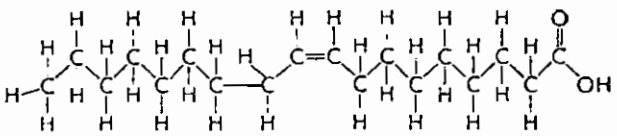
Fatty acids differ in length of the hydrocarbon chain. Most common

fatty acids possess an even number of carbon atoms thus : Palmitic acid contains 16 carbon atoms; 15 are attached to hydrogen.



palmitic acid

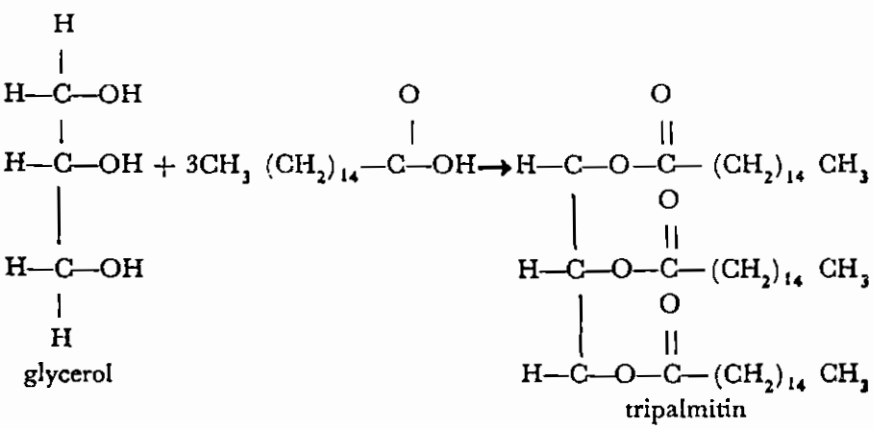
Fatty acids with one or more double bonds occurring between carbon atoms in the chains are known as unsaturated fatty acids such as oleic acid with 18 carbon atoms and a double bond between carbons 9 and 10 :



oleic acid
(unsaturated)

Having a carboxyl group makes fatty acids reactive and most of them combine with other molecules such as glycerol to form fats by a dehydration synthesis.

An ester bond results from elimination of water. Thus three molecules of a fatty acid unite with one molecule of glycerol to form a triglyceride commonly called Fat :



glycerol

tripalmitin

The three fatty acids involved in fat formation may be similar or different. However one or two molecules of fatty acids may combine with one molecule of glycerol to form mono- or diglycerides.

There are many types of lipids which are important for living organisms which include phospholipids, e.g. lecithin, cephalin (formed in brain, nerves etc), waxes, e.g. cutin covering fruits, stems, etc., caratenoids, e.g. carotenes, steroids such as cholesterol, vitamin D, cortisone, bile salts, porphyreins e.g. chlorophyll.

Phospholipids which are important in the formation of biological membranes where glycerol joins two fatty acids molecules, the third carbon is attached to a phosphorus containing substituent, e.g. the class glycerol phospholipids.

Cholesterol is a steroid, a kind of lipids, which is found in all animal cells, blood and especially the nervous system.

PROTEINS

Proteins always contain carbon, oxygen, hydrogen, and nitrogen and usually, but not always, sulfur and phosphorous. Proteins may vary in shape and size from small spheres of 5000 molecular weight to long rods of over 100,000. Proteins play an important role in living matter, thus:

1. Proteins comprise the major component of cells.

2. Some proteins are used as structural support such as collagen and dentine (elastin), while haemoglobin serve a transport function, keratin in the skin and fingernails, etc.

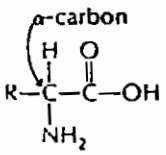
3. Enzymes are functional proteins that catalyse most biochemical reactions (i.e. biocatalyst, i.e. change the rate of a specific chemical reaction without changing its direction.

4. Special proteins perform certain functions e.g. myosin functions in musular contraction; hormones regulate metabolic processes; antibodies which defend the body against foreign substances such as viruses, bacteria, etc.

5. Proteins like carbohydrates and fats may be broken down to provide energy for cellular use.

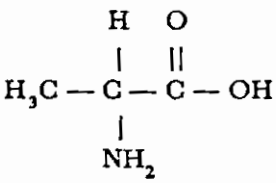
Structure

The structural units of proteins are amino acids. Amino acids contain at least one amino group (—NH_2) and one carboxylic acid group (— COOH) linked to the same carbon, the alpha-carbon.

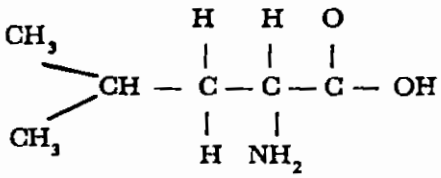


alpha-carbon

R is a side group which differs in the different amino acids. Thus in alanin the R group is CH_3 ;

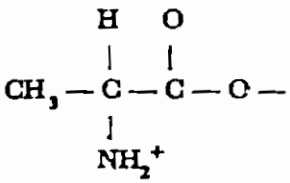


In leucine the R group is $(CH_3)_2 — CH — GH_2$



The side group may be a straight, branched chain, or a ring structure. The structure of amino acids results in two characters, i.e.

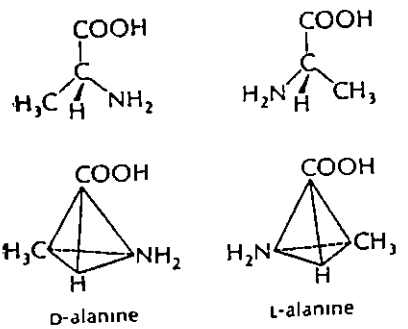
1. Either the amino group or the carboxylic group or both can become charged. In aqueous solution most amino acids have a positive amino group and a negative carboxyl group. Thus, it exists as a dipolar ion or **Zwitterion.** In this case the number of negative charges on the molecule equals the number of positive charges, and the molecule is called **isoelectric.**



alanine

However, if the pH of the aqueous solution is changed, the amino acid molecule either becomes positively or negatively charged when the pH is lowered or elevated.

2. Amino acids are isomeric in nature. The alpha-carbon of an amino acid has four different chemical groups attached to it. This makes the tetrahedral carbon atom asymmetric and offers two ways in which these four different substitutes can be attached.
e.g. **alanine**



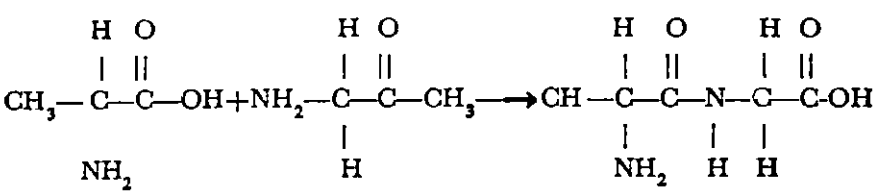
D-alanine (Dextro=right)

L-alanine (Levo=left)

In living systems only the L-amino acids are found. These are the only ones recognized by the enzymes.

There are about twenty known amino acids (i.e. glycine, alanine, valine, leucine and isoleucine; serine, theronine, cysteine, cyctine, methionine, glutamic acid, lysine, arginine, asparagine, glutamine, phenylalanine, tyrosine, histidine, tryptophan and proline).

Different proteins are made up by combination between amino acids. The carboxyl group of one amino acid combines with the alpha amino group of another amino acid with the removal of water and they are joined together by a peptide bond.



alanine + glycine glycl-alanine

Proteins are made up of a large number of amino acids and they assume many forms, i.e.l. straight chain of polypeptide, coiled or twisted (secondary level), the most common of which with a spiral-shaped structure called a helix. 2. Globular proteins or unregular coiling (tertiary structure). 3. Aggregation or polymerisation of individual polypeptide unit.

FUNCTIONAL PROTEINS

1. Enzymes

These are globular proteins with a molecular weight ranging from 10,000 to millions. Each enzyme has a three-dimensional characteristic shape with a specific surface configuration.

1. Enzymes are true biocatalysts, returning unchanged to their original condition after having participated in the reaction they facilitate. Under optimum conditions they catalyse reactions at rates 10^8 to 10^{10} times more rapid than those of comparable reactions without the enzyme. The turnover number (i.e. number of substrate molecules metabolised per one enzyme molecule per minute) is generally 1000 and in some instances as high as one million.

2. Enzymes are specific in the reaction they catalyse as well as in the substrate utilized. This may be related with the active sites.

3. Reactions of enzymes take place in aqueous solutions and at relatively low temperatures.

4. Enzymes are subjected to various cellular controls. The rate of their synthesis and concentration is under genetic control and is influenced by various other molecules present within the cell. They exist in active and inactive forms, and this is determined by the cellular environment.

5. The biosynthesis of enzymes is enzyme controlled.

Action of enzymes

This takes place as follows :

1. The surface of the substrate molecule comes in contact with the enzyme molecule.

2. A temporary intermediate compound called an enzyme-substrate complex is formed.

3. The substrate molecule is transformed, i.e. either broken down or combined.

4. The transformed substrate molecule moves away from the enzyme molecule.

5. The enzyme molecule is freed to react with other substrate molecule.

Active sites : It is a small fraction of the enzyme surface which comes in contact with the substrate molecule. It seems that some of the amino acids of the protein are in direct contact with the substrate forming an active site; while others play an indirect role and still others play no role. Thus it was found that removal of one portion of the enzyme molecule may not affect its ability to catalyse a reaction, while removal of another portion will

Enzymes specificity is related to their active sites. Previously it was believed that enzyme and substrate molecules fit together like pieces of jigsaw puzzle. Recently it was found that the active site of an enzyme consists of contact amino acids whose fit with the amino acid determine specificity. These contact amino acids are positioned fairly close in the enzyme molecule as a result of the typical protein three-dimensional foldings. Such fit with the substrate molecule is called **induced fit** which provides a flexibility needed for catalytic groups.

Composition of enzymes

Some enzymes consist solely of proteins. Others consist of two distinct parts, i.e. (*a*) **apoenzyme** which is the protein portion made up of amino acids, (*b*) **prosthetic group** which assist the enzyme in catalysis. The apoenzyme and its related protein prosthetic group are called **holoenzyme**. Both parts when separated become inactive.

There are two types of prosthetic groups :

1. **Activators** which are usually metals like potassium, iron, copper, zinc, magnesium, manganese, cobalt. It is believed that activators form a bridge between the enzyme and substrates by binding them together. Generally most trace elements act as activators for cellular enzymes.

2. **Coenzymes** (cofactors) which are complex organic moles which assist the enzyme in transforming the substrate by acting as an **acceptor** of atoms being removed from the substrates, or as a **donor** of atoms by contributing atoms in a synthetic reaction.

Many coenzymes are vitamins, e.g. nicotinamide, adenine dinucleotide (NAD^+) and nictinoamide adenine dinucleotide phosphate ($NADP^+$) which are derivatives of vitamin B (nicotininc acid). These function with their respective enzymes in the removal and transfer of hydrogen and electrons from substrate molecules, i.e. **dehydrogenases**.

Enzymes like proteins can be denatured and hence become inactive. This is brought by changes in the arrangement of amino acids at the active site. Denaturing of enzymes may be brought by heat and high concentrations of heavy metal ions (as copper, zinc, silver, arsenic, mercury), alcohols, ultraviolet radiations and concentrated acidic and basic solutions.

NUCLEIC ACIDS

These are found in all living forms. They direct either directly or indirectly the synthesis of proteins. They contain carbon, hydrogen, oxygen and phosphorous. On the bases of the chemical composition there are two classes of nucleic acids :

1. **DNA or deoxyribonucleic acid** which acts as the primary carrier of genetic information, i.e. it is the hereditary material. It is composed of a sugar deoxyribose in equal proportion with phosphate group. In addition it contains purines and pyrimidine bases which are adenine, guanine, cytosine and thyamine.

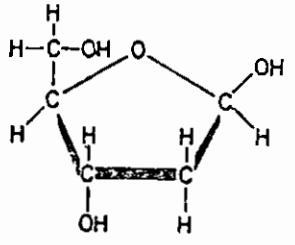
2. **RNA or ribonucleic acid** which is present in both the nucleus and cytoplasm. It is made up of a sugar ribose which has a hydroxyl group (OH^-) at the 2 position where deoxyribose has a hydrogen. In addition it contains purines and pyrimidine bases but it utilizes the pyrimidine base **uracil** instead of thymine. The function of RNA is to build proteins as specified by DNA.

Composition

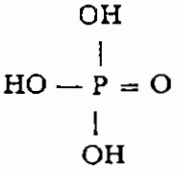
Nucleic acids are long chain-like molecules composed of simple units joined together by removal of water at points of linkage. The basic structural units of nucleic acids are called **nucleotides.** Each nucleotide is composed of three components :

(*a*) a pentose sugar, either ribose or deoxyribose.

(*b*) a nitrogenous base which is a ring-shaped structure made up of carbon, hydrogen, oxygen and nitrogen atoms. There are two types of bases, i.e. purines which include adenine and guanine; and pyrimidines called thymine, cytosine and uracil in RNA only.



Deoxyribose



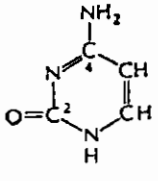
Phosphate group

(*c*) phosphoric acid or phosphate group.

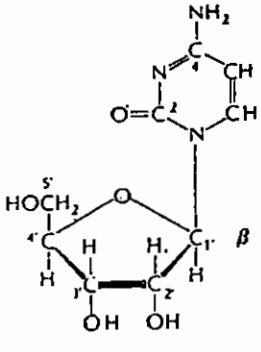
There are four nucleotides found in DNA, i.e. adenine, thymine, cytosine and guanine nucleotides (guanylic acid, adenylic acid, cytidylic acid and uridylic acid).

Example :

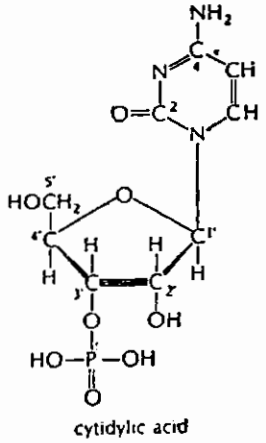
Cystosine



cytosine



cytidine



cytidylic acid

Watson and Crick in 1953 presented a model for nucleic acids based on the data of various investigators. Thus the following is the structure of DNA :

(*a*) Each DNA molecule consists of two strands, with cross members, twisted about each other in a form of a double helix (i.e. like a twisted ladder. (Fig. 8a & b).

(*b*) The uprights of the ladder are made of alternating phosphate and deoxyribose proteins of a nucleotide.

(*c*) The cross members consist of paired purines, and pyrimidines linked together by weak hydrogen bonds.

(*d*) In the pairing of purines and pyrimidines adenine always pairs with thymine and cytosine with guanine (Fig. 8a)

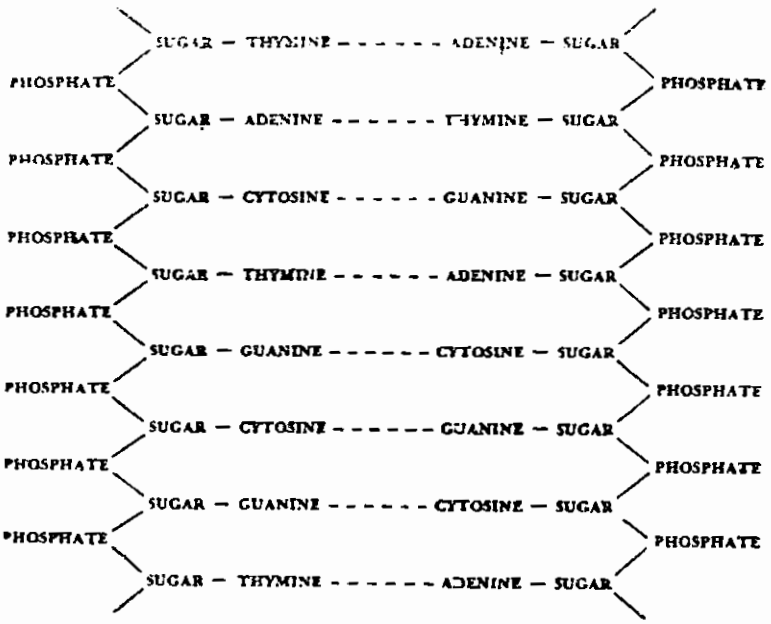


Fig. 8 a. — A model of the way in which two phosphate-sugar chains (represented by ribbons) may be arranged in double helix form held together by bases to form unit structure of DNA. (After Watson and Crick).

(*e*) A complete turn of the coil occurs at every 34 °A.

On the other hand, RNA may consist of only a single strand of nucleotides; in others it is doubly stranded like DNA, and in still others it appears as a combination of both. In addition RNA contains ribose sugar and uracil base instead of thymine. Generally DNA is found in the nucleus while RNA is found in both nuclei and cytoplasm, being more

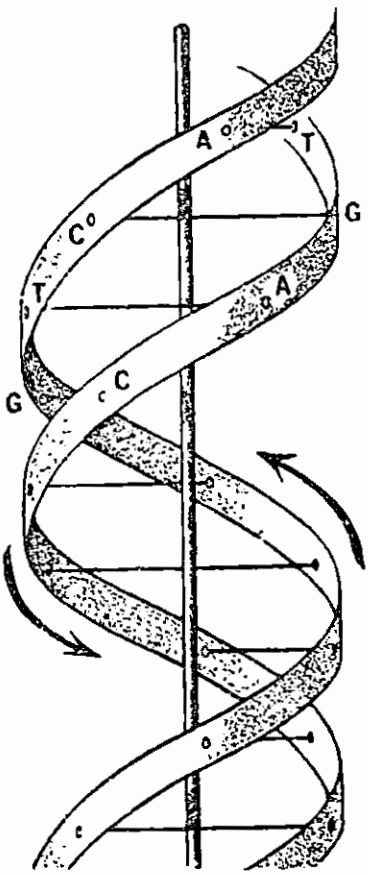


Fig. 8 (b) — Diagramatic structure of DNA (desoxyribose nucleic acid) showing complementary structure of two chains, spirally arranged in what is called a double helix; A, adenine; C, cytosine; C, guanine; T. thymine. (after Watson and Crick).

abundant in the cytoplasm. Furthermore DNA and RNA are found in cellular organelles (mitochondria, and chloroplasts contain).

There are three subgroups of RNA according to certain structural and functional aspects :

(*a*) ribosomal RNA (r RNA), synthesised from the nuclear DNA template.

(*b*) messenger (m RNA) whose size varies depending on the size of protein to be synthesised.

(*c*) transfer (t RNA), which brings amino acids to the ribosome so they can be joined together to form a protein.

It is also synthesised from a nuclear DNA template in the form of a larger procursor molecule. The t RNA are the smallest of the RNA species in the cell.

The three types of RNA are not only synthesised from different regions of the DNA template but it has recently been discovered that the m RNA synthesis is different from that which catalyses the formation of r RNA. As the size of these RNAs is different, hence they can be separated by methods involving high speed centrifugation.

CELL DIVISION

Cell division apparently occurs in a given type of cell when it reaches the limit of the size peculiar to it. It is well noticed in growing tissues. In the adult, while some cells are dying, others are dividing to provide replacements. However, the latter situation is not universal, for in nervous and skeletal muscle tissues, cell division fails to occur in the adult. In other tissues, cell division may be limited to a restricted group of cells.

There are three typs of cell-division :

A) **Amitosis** or direct division.

B) **Mitosis** or indirect division.

C) **Meiosis** or reduction division.

AMITOSIS

It is a rare type of cell division which occurs in abnormal cells, degenerating tissue, transitory cells, pathological tissues and some very specialized cells.

It involves the constriction of the cytoplasm and nucleus into two cells with nearly the same nuclear and cytoplasmic materials. During this process the nuclear membrane remains intact and the chromatin materials are not divided into two equal portions. A centrosome is generally neither active nor even seen during this process. The spindle fibers and chromosomes are not seen. The resulting daughter cells have lost the power to continue as normal cells.

MITOSIS

This is the most common form of cell division which applies to the division of somatic cells. The two principal aspects of such cell division are : 1. precise duplication of the chromosomal material (**karyokinesis**),

and 2. a pinching in half of the protoplasm (**cytokinesis**) so that both the nuclear and the cytoplasmic constituents are divided equally. The most prominent parts, in this process, are played by the centrioles and the nucleus.

Mitosis consists of the follcwing stages : interphase, prophase, metaphase, anaphase and telephose (Fig. 9).

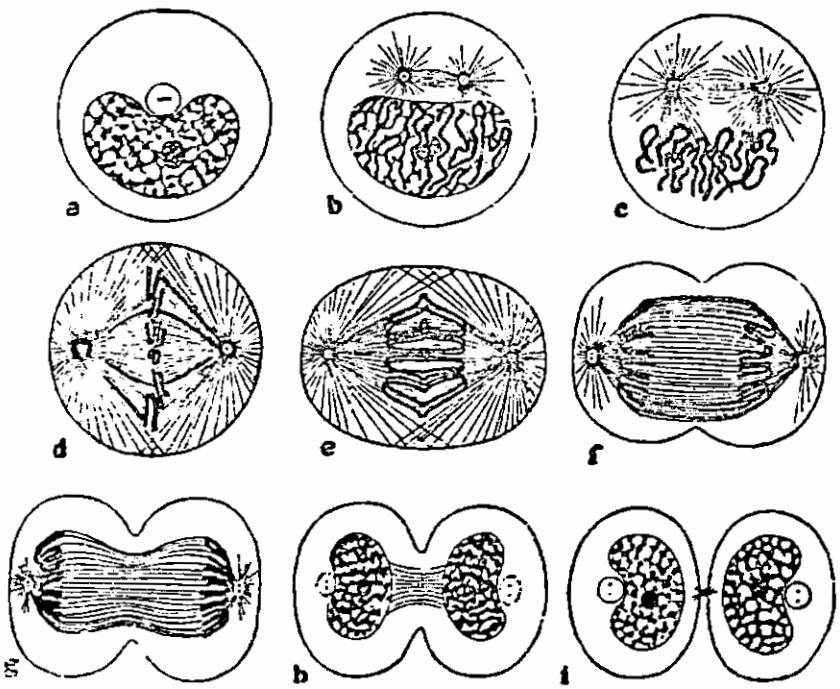


Fig. 9— Diagramatic representation showing the various stages of "mitosis": (*a*) Resting cell; (*b*) prophase; (*c*) transition from prophase to metaphase; (*d*) metaphase; e,f,g, anaphase; (*e*) beginning separation of the split chromosomes; (*f*) diaster; (*g*) chromosomes approaching the centrioles; (*h*) telophase; (*i*) daughter cells connected only by the intermediate body of Flemming which will disappear.

1. Interphase

This is the period between two successive mitosis. It may be referred to as the "interphase".

2. Prophase

At this stage (Figs. 9, b and c), the cell becomes spherical, and the centrioles separate and migrate towards the opposite poles of the cell. As they separate, the cytoplasm becomes arranged in a radiating manner

around each centriole forming a star-shaped figure known as the "**aster**". At the end of prophase, the nuclear membrane breaks down, a mitotic spindle forms between the centrioles and the nucleoli disappear. Also the chromosomes start to appear as delicate spiral filaments which are doubled in the nucleus. Each chromosome possesses two spiral filaments called the "chromatics" which are associaed throughout their entire length without fusion. Then the chromatids become shorter and increase in volume due to accumulation of nucleic acids coming from cytoplasm.

At the end of prophase, each chromosome appears to be composed of two cylindrical longitudinal elements parallel and adjacent to each other. Finally, the chromosomes migrate toward the equator or the middle of the mitotic spindle.

3. Metaphase

During this stage (Fig. 9 d). the chromosomes are seen arranged on the equator of the spindle forming what is known as the "**equatorial plate**". These chromosomes become connected to the fibres of the spindle, the two halves now separate. This longitudinal splitting of chromosomes assures that each future daugther cell will have the same number of chromosomes found in the parent cell.

4. Anaphase

In this stage (Fig. 9, e and f), the two equal halves of each chromosome migrate apart from each other towards the two centerioles along the spindle. After separation of the daughter chromosomes, a zone of filbrillar structure appears between the two separated groups of daughter chromosomes. This zone is called the "**interzonal structure**".

5. Telophase

In this stage (Fig. 9, h), the chromosomes are at the two opposite poles of the spindle. They lie very close to one another, become entangled and finally break into an irregular network of chromatin granules characteristic of the parent nucleus.

During this time, nuclear membranes are formed around each group of daughter chromosomes, thus forming two daughter nuclei at opposite poles. The nucleoli reappear. Then cytokinesis begins by constriction of cytoplasm in the equatorial region. This constriction becomes deeper and deeper until the cell is divided into two daughter cells (Fig. 9, i).

During cytokinesis, the mitochondria undergo division and become

distributed almost equally. Golgi apparatus also divides into two portions, one for each new daughter cell. The centrosomes cease their activity and the asters become less obvious.

SIGNIFICANCE OF MITOSIS

As a result of mitosis each daughter cell has the same number of chromosomes of the same size, shape and structure. Since the chromosomes are the carriers of hereditary qualities, the process of mitosis aims to divide the cell into two daughter cells, which have precisely identical chromosomes with identical chromatin material. This is of great significance since the genes or determiners of hereditary characters are believed to be carried by the chromosomes and to split with the latter.

MEIOSIS.

Meiosis occurs in the testis and ovaries giving rise to sperms and eggs respectively. As a result of it, the mature germ cells contain a haploid (n) number of chromosomes. It consists of two cell divisions which follow each other while the chromosomes divide only once. As a result of this process, four cells are formed each containing a **haploid number** of chromosomes. In this case, when the male and female gametes unite in fertilization the normal **diploid number** of chromosomes (2 n) is restored.

The two cell divisions are known as the **first** and **second meiotic** divisions. Each division includes different stages which are **prophase, metaphase, anaphase** and **telophase**, but there are important differences between meiosis and mitosis especially in the first prophase.

First Meiotic Division

This division is charatterized by a long prophase during which the chromosomes appear as long, thin threads as in mitosis (Fig. 10, (a) Then, they become shorter and thicker and the homologous chromosomes pair longitudinally. They lie side by side along their entire length as shown in Fig. 10, b. Each chromosome becomes double and so it consists of two chromatids (Fig. 10, c). By the end of the first meiotic prophase, the chromosomes have doubled and undergone synapsis to form bundles of four homologous chromosomes or chromatids called **"tetrads"**. The number of tetrads is half the diploid number of chromosomes. During synapsis, exchanges of genetic material may occur between the chrom-

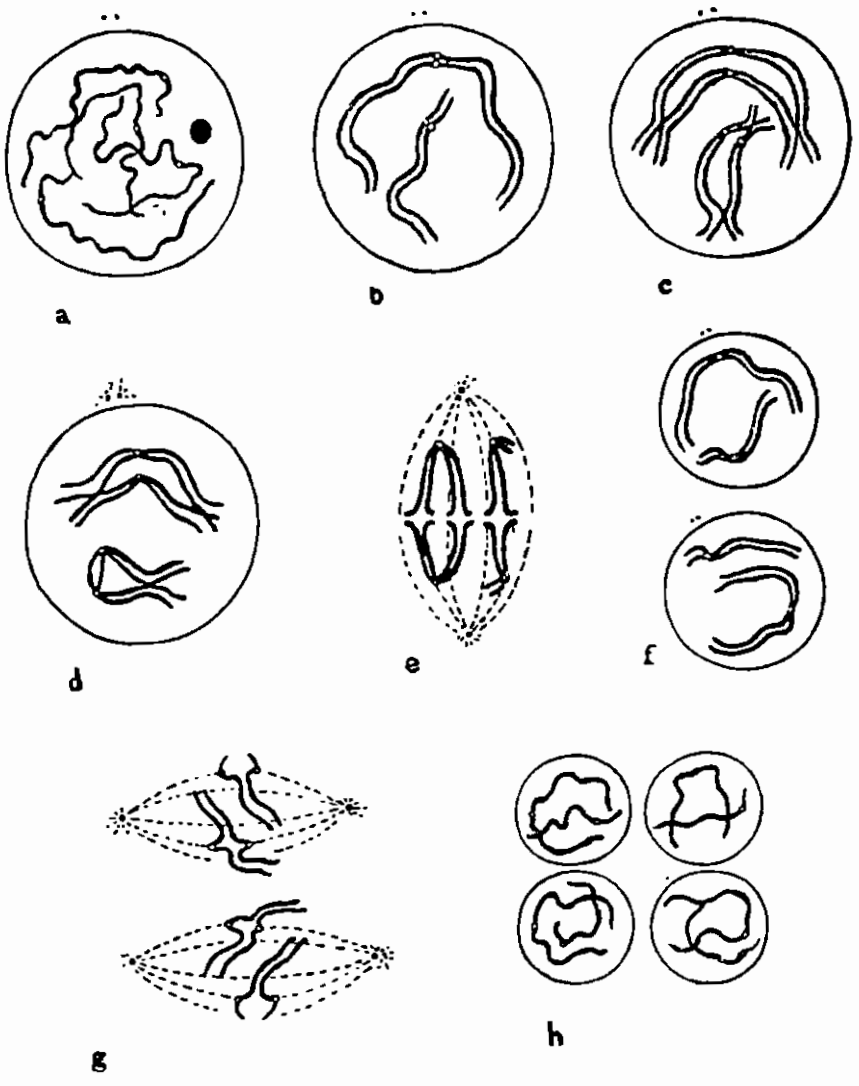


Fig. 10 — Diagramatic representation of "meiosis" illustrated by two pairs of chromosomes; (*a*) interphase; (*b*) pachylene; (*c*) diplotene; (*d*) diakinesis; (*e*) anaphase of first meiotic division; (*f*) interphase; (*g*) anaphase of second meiotic division; (*g*) the four haploid products of meiosis.

atids of the two homologous chromosomes. This phenomenon is called **"crossing over"** as will be mentioned later (see p. 232).

While the above processes are taking place, the centrioles migrato to the opposite poles, the spindle is formed and the nucleoli and nuclear membrane disappear (Fig. 10, d and e). During the metaphase, the tetrads

become arranged at the equator of the spindle. At the anaphase, the homologous chromosomes separate from one another and move toward the pole (Fig. 10e). Each chromosome is made up of two chromatids and is called a "**dyad**". In the telophase, each pole of the cell receives two dyads, and cytoplasmic division takes place giving rise to two cells (Fig. 10, f), each with two dyads.

Second Meiotic Division

This division follows immediately the first meiotic one. As shown in fig. 10,g, the centrosome divides and a new spindle is formed in each cell. The haploid number of double chromosomes (dyads) lie on the equator of the spindle in the **second metaphase.** In the **anaphase**, separation of the members of the dyads takes place, so that one chromatid goes to the opposite pole. From this moment, each chromatid is considered as a chromosome. Thus, there is no further doubling of chromosomes. During the telophase, the cytoplasm divides, the nuclear membrane forms and the chromosomes elongate and become chromatin threads (Fig. 10, h.).

As a result of meiosis four cells are formed, each has a haploid number of chromosomes (n).

The purpose of meiosis is not only the numerical reduction of chromosomes but also the attraction, pairing, interchange and separation of the homologous paternal and maternal chromosomes. Thus, meiosis is concerned with nuclear reorganisation and gene reassortment.

PART TWO

HISTOLOGY

INTRODUCTION

Histology is a branch of science which deals with the minute structures of the different tissues of the body of animals.

The cells of which animals are composed, differ so widely in their size, structure and function. A group of cells, which are similar in structure and specialized in the same way to perform a particular function, form what is called a **tissue**.

An **organ** is an association of a number of tissues which share in one or more functions. A **system** is a group of organs that collectively perform certain related functions Example : the stomach is an organ which secretes the gastric juice and it is made up of epithelial, connective, muscular and nervous tissues. The stomach together with other organs (oesophagus, intestine, liver, etc...) form the digestive system.

The tissues of the body of vertebrate animals are divided into four groups : **epithelial, connective, muscular** and **nervous tissues.**

EPITHELIAL TISSUES

These tissues originate from the three germ layers : ectoderm, (e.g epidermis of skin), endoderm, (e.g. epithelial lining of intestine) and mesoderm, (e.g. liver).

An epithelium is a sheet formed of one or more than one layer of cells. Its cells are closely connected together with a very small amount of **intercellular substance** secreted by the same cells. The epithelial sheet has one of its surfaces free while the other rests on the underlying **basement membrane** which lies on a connective tissue. In a few cases, the basement membrane is absent and the epithelium rests directly on the connective tissue.

The epithelium covers the outer surface of the body of the animal (skin) and lines the walls of the hollow organs and other internal body cavities (intestine, blood vessels, peritoneum, pericardium, pleura etc.). It forms all the different glands in the body (liver, sweat glands, thyroid gland etc.). It also forms the important parts of the sense organs (taste buds, retina of the eye, olfactory cells). The epithelial tissue is richly

supplied with nerve endings but blood and lymph vessels do not penetrate into it.

Usually the component cells of an epithelium or a tissue are distinct, but there are some examples in which the cell boundaries or membranes have disappeard and form what is known as a **"synctium"**.

The epithelial tissues are classified according to their functions into three main groups : **covering, glandular** and **neuro-epithelia.**

COVERING EPITHELIUM

This epithelium covers the outer surface and lines the inner cavities of the body of animals. According to the arrangement of the cells, it is divided into two main types : simple and stratified.

1. Simple Epithelium

This type consists of one layer of cells and according to the shape of the cells, it is subdivided into six types : —

(*a*) Simple squamous epithelium

The cells of this type are flattened, plate like and polygonal in outline. Their edges are either straight or serrated. In vertical section the epithelium appears as a thin line with some bulging areas corresponding to the nuclei which lie in the middle of the cells (Fig. 11, A and B). Such epithelium is found lining the inner surface of the heart, blood and lymph vessels (endothelium). It is also found lining the body cavities and thus found in the peritoneum, pericardium and pleura(mesothelium).

(*b*) Simple cuboidal epithelium

In this type the cells are nearly square in outline (Fig. 11, C). The nucleus of the cell is usually spherical and lies in the centre of the cell. This type of epithelium is found in many glands as the liver, thyroid, salivary and sweat glands. It lines the ureter of **Bufo** and the collecting tubules of its kidney.

(*c*) Simple columnar epithelium

The cells of this type are tall and stand side by side as columns or pillars (Fig. 11, D). The nuclei of the cells lie near the basement membrane. This type lines the stomach and intestine.

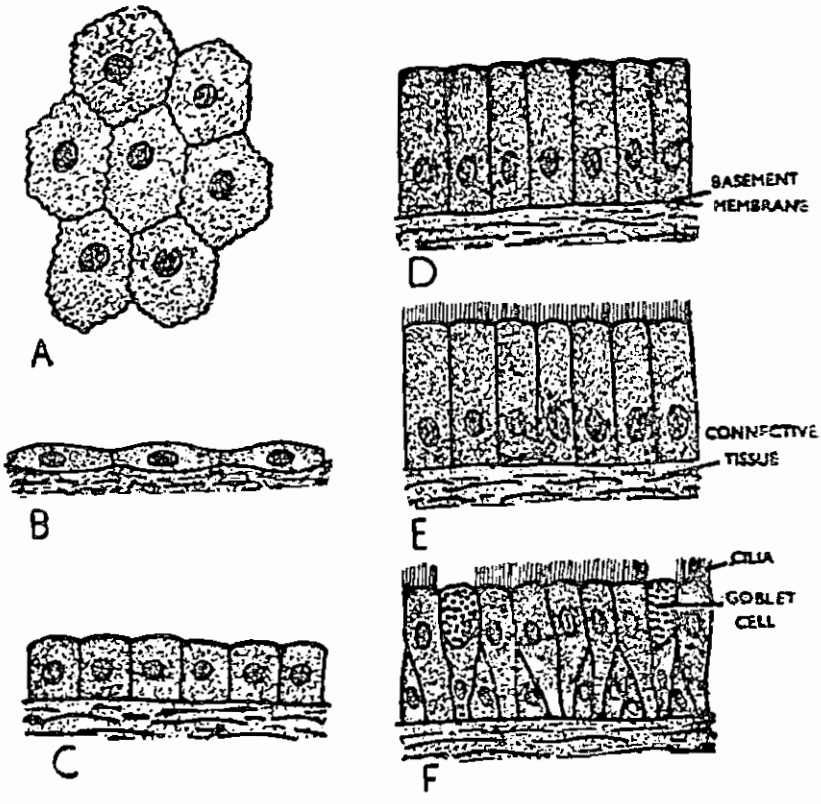


Fig. 11 — Simple epithelium: (*A*) Squamous epithelium, surface veiw; (*B*) Squamous epithelium, v.s.; (*C*) Cuboidal epithelium, v.s.; (*D*) Columnar epithelium, v.s.; (*E*) Columnar ciliated epithelium, v.s.; (*F*) Pseudostratified epithelium, v.s.

(*d*) Simple columnar ciliated epithelium

This type resembles the previous one but the cells have at their free surfaces fine protoplasmic outgrowths called cilia (Fig. 11, E). These cilia move together in harmony to form a continuous stream in the mucus covering the epithelium. This type occurs in the oviduct and the respiratory passages.

(*e*) Pseudostratified columnar epithelium

This type consists of one layer of crowded columnar cells which press on each other (Fig. 11, F). They all remain attached to the basement membrane but many cells do not reach the free surface. In section, the nuclei are seen at more than one level. Thus they give the impression that

the epithelium is stratified. This type of epithelium is found in the large excretory ducts of some glands as the parotid gland and in the male urethra.

(*f*) **Pseudostratified columnar epithelium** (ciliated)

This type is similar in structure to the previous one but the cells of the epithelium are provided with cilia. This type is found in the trachea.

2. **Stratified Epithellum**

The sheet of this epithelium consists of several layers of cells. These are developed from a basal layer called the **germinative** or **Malpighian layer** which rests on a basement membrane. This type shows 4 varieties :-

(*a*) **Stratified squamous epithelium**

In this type the deepest layer or the Malpighian layer consists of columnar or square cells while the uppermost layers are of squamous cells. The intermediate layers are composed of irregular polyhedral and more or less flattened cells (Fig. 12, A).

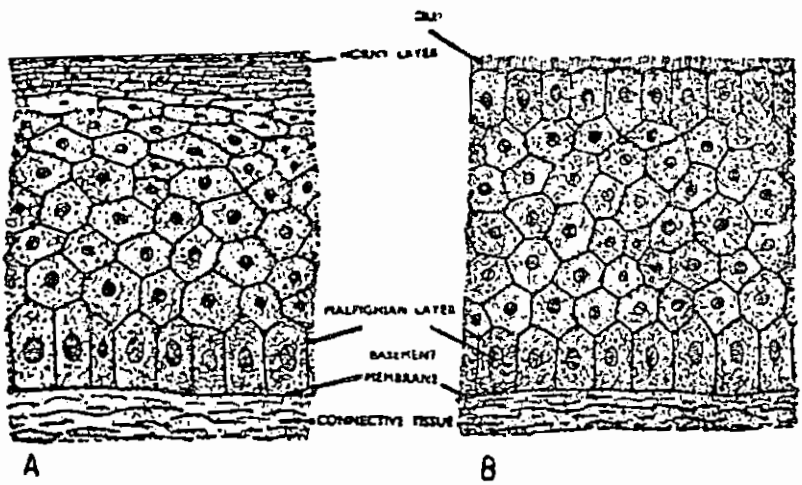


Fig. 12 — Stratified epithelium : (*A*) Stratified squamous epithelium, v.s.; (*B*) Stratified columnar ciliated epithelium, v.s.

The squamous cells are cornified in some places and form **a horny layer.** This is usually shed away at intervals and thus replaced by other cells and so on, e.g. the epidermis of the skin. The non-cornified epithelium is found in the mouth cavity and the oesophagus.

(*b*) Stratified columnar epithelium

In this type, the cells of the superficial layer are columnar while those of the Malpighian layer may be either columnar or irregular in shape. The middle layers are of small irregular polyhedral cells. This epithelium is rare and covers small surfaces. It is found in the conjunctiva, pharynx, epiglottis and large excretory ducts of some glands.

(*c*) Stratified columnar ciliated epithlium

Here the free surface of the columnar cells of the previous stratified columnar epithelium is provided with cilia. This is found on the upper surface of the soft palate and in the larynx. (Fig. 12.B).

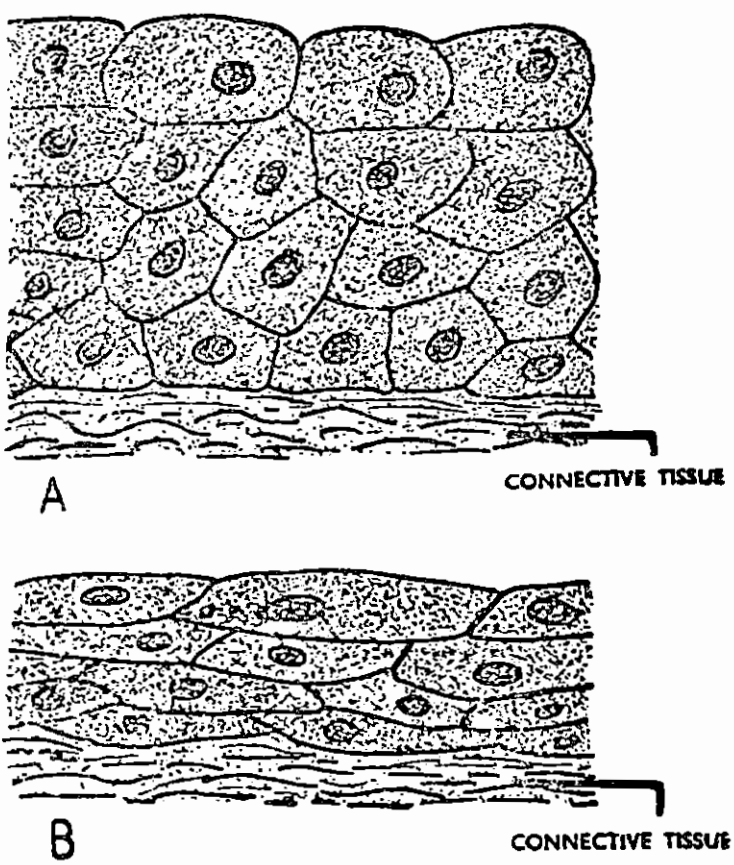


Fig. 13—Transitional epithelium v.s.; *A*) Contracted condition; *B*) Distended condition.

(*d*) Transitional opithelium

This type represents a transition between the stratified squamous and the columnar epithelia. It is found on the walls of hollow organs which are subject to great changes by contraction and stretching.

This epithelium consists of few layers of cells (3 — 6) resting directly on the underlying connective tissue (Fig 13). The basement membrane is absent. The cells of the superficial layer are large flattened and with convex free surface while the organ is distended this tissue appears to be thinner and the cells become more flattened. This epithelium is found in the ureter and urinary bladder.

GLANDULAR EPITHELIUM

This is formed of the simple epithelium which is specialised in a particular manner for the production of useful complex, chemical substances within the body known as **secretions,** (e.g. mucus, enzymes, bile and hormones) and for the ejection of waste products known as **excretions,** (e.g. urine.)

The glands may be either unicellular or multicellular glands.

1. Unicellular glands

The unicellular gland is formed of a single epithelial cell. As an example of a unicellular gland is the **goblet cell.** The goblet cells are scattered among the epithelial lining of both the alimentary canal and the respiratory tract. They secrete **mucin** (**mucigen**) which forms with water a solution called **mucus.** Such epithelial lining is referred to as the **mucous membrane.** The goblet cell consists of a cup-shaped swollen upper part full of mucin and a slender basal part which rests on the basement membrane and contains the nucleus (Fig. 11, F).

2. Multicellular glands

These are of two types : endocrine or ductless glands and exocrine glands.

(*a*) Endocrine glands

These glands have got no ducts, their secretions which are known as hormones pass directly into the blood stream. e.g. adrenal, pituitary and thyroid glands.

(*b*) Exocrine glands

These glands possess ducts that carry their secretions to the epithelial surfaces as the skin, e.g. sweat and mammary glands, or to the inner hollow organs as the stomach and intestine, (e.g. gastric glands, liver and pancreas).

The exocrine glands may be simple or compound. The simple gland has got only one excretory duct while the compound gland has got more than one duct which join and open into a common excretory duct. However, in some compound glands, the excretory ducts do not all join into one common duct, but into few excretory ducts. These compound glands thus open by a number of openings on a restricted area of a free epithelial surface, e.g. prostate, lacrimal and mammary glands.

The exocrine glands may be classified into tubular and alveolar type according to the shape of the glandular epithelum of the gland.

The following types may be considered :

(i) Simple tubular glands

The gland has one duct and the terminal secretory epithelium is simple tube and shaped like a test tube, e.g. crypts of Lieberkühn of the small intestine of man and rabbit (Fig. 14, A).

(ii) Simple coiled tubular glands

Here the secretory tubular part may be elongated and coiled, e.g. the sweat glands in the skin of man. (Fig. 14, B).

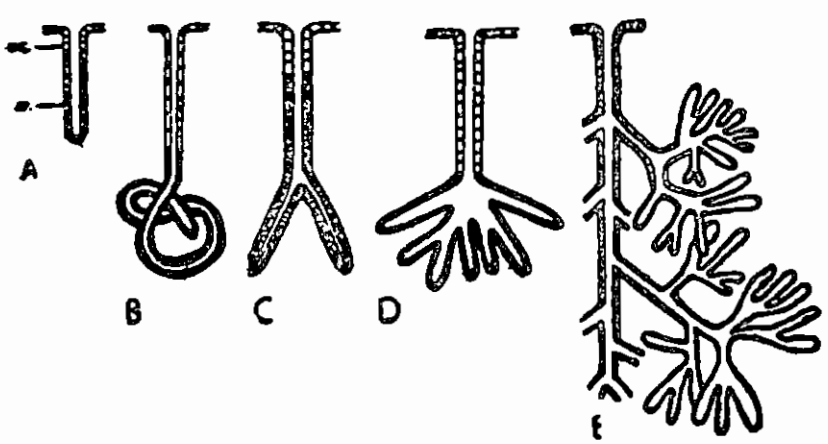


Fig. 14— Exocrine glands : (*A*) Simple tubular; (*B*) Simple coiled tubular; (*C*) *D*) Simple branched tubular; (*E*) Compound tubular (D.C., duct of gland; SP., secretory part).

(iii) **Simple branched tubular glands**

The secretory tubular part is branched and these branches open into one single duct e.g. the gastric glands of **Bufo,** rabbit and man, (Fig. 14, C and D).

(iv) **Compound tubular glands**

The gland here is formed of a large number of simple tubular glands whose small excretory ducts join to from larger ducts which in turn open into a common excretory duct, e.g. lacrimal gland and the kidney, (uriniferous and collecting tubules. (Fig. 14 E).

(v) **Simple alveolar (acinous) glands**

In this type the glandular terminal epithelium is in the form of one spherical sac with one excretory duct, e.g. the poisonous and mucous glands of the skin of **Bufo.** (Fig. 15, A).

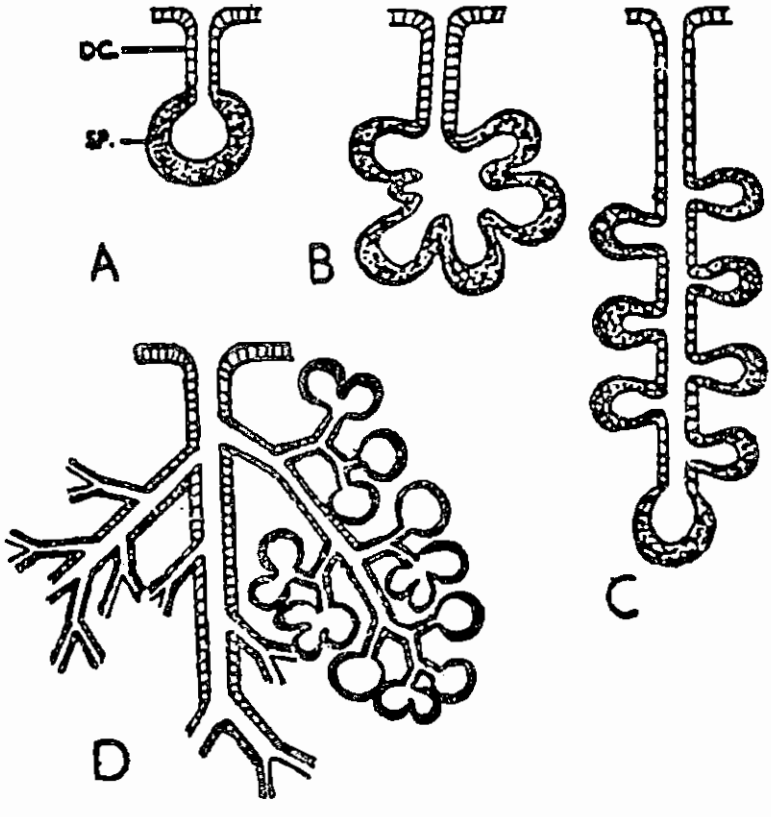


Fig. 15 — Exocrine glands; (*A*) Simple alveolar; (*B*), *C*) Simple branched alveolar; (*D*) Compound alveolar. (D.C. duct of gland; SP., secretory part).

(vi) **Simple branched alveolar glands**

Here either the sac is subdivided into several small sacs or several sacs are arranged along one duct, e.g. sebaceous glands of the skin and the glands of the eye lids in man. (Figs. 15, B and C).

(vii) **Compound alveolar glands**

The gland is formed of numerous branched excretory ducts each of which ends in an alveolar secretory part. The ducts join one another and open into a common excretory duct, e.g. parotid (salivary) gland (Fig. 15, D).

(viii) **Compound tubulo-alveolar glands**

In this type the secretory part of the gland is partly tubular and partly alveolar in shape, e.g. pancreas and mammary glands.

Some authors divide the glands according to the way of their secretion into.

1. **Merocrine type** : In this type the secretion of the gland is generated in the shape of granules, droplets or globules which pass from the cells to the lumen of the gland and then to its duct, e.g. gastric glands, liver, kidney and thyroid gland.

2. **Apocrine type** : Here the secretion of the gland is performed by the disintegration of the apical cytoplasmic free parts of the cells of the gland, e.g. mammary glands.

3. **Holocrine type** : The active cell which is full of secretion is disintegrated and falls into the lumen and passes into the duct of the gland. New cells begin to appear from the interstitial cells, e.g. sebaceous glands.

NEURO - EPITHELIUM

The epithelium, in this type consists of groups of cells which are specialized for receiving certain external stimuli and transmit them to the central nervous system. The cells are columnar or spindle-shaped with one or more stiff processes at their outer ends. Each of these sensory cells is connected with a sensory nerve fibre. Examples of this type are : the sensory epithelium of the retina of the eye, olfactory epithelium of the nose, the lining epithelium of the labyrinth of the ear and the taste buds on the tongue (Fig. 16).

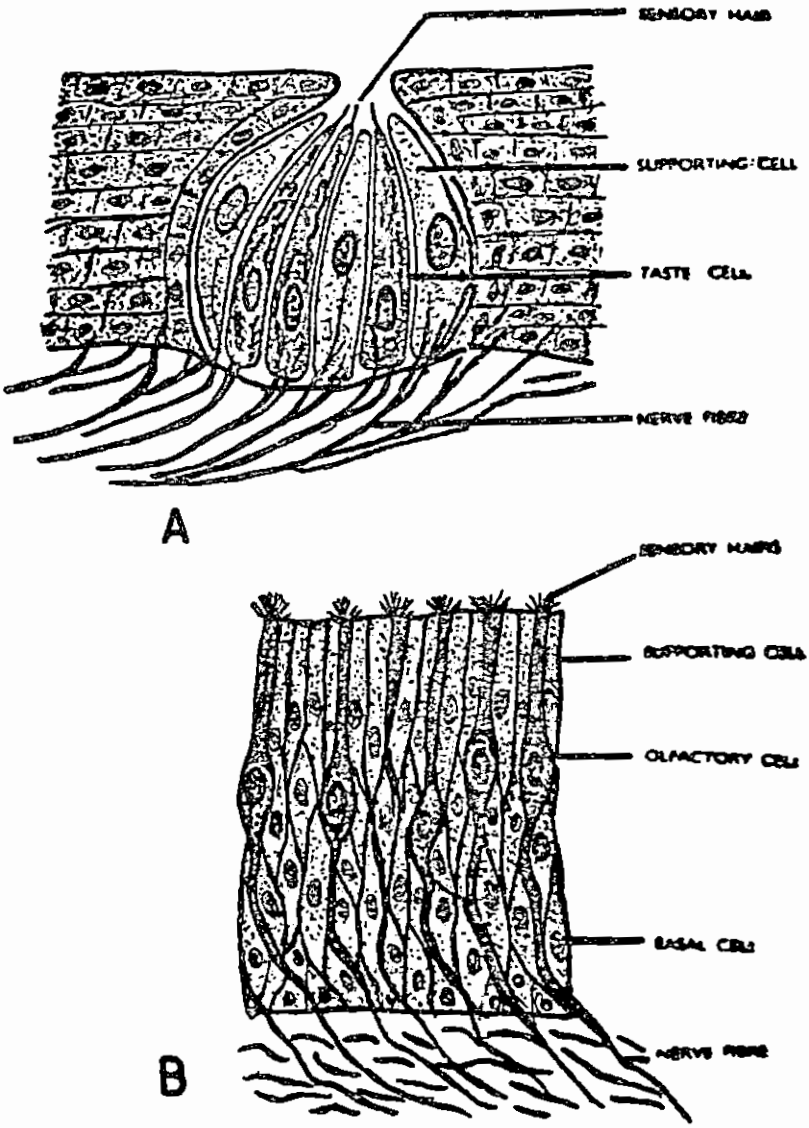


Fig. 16 — Neuro-epithelium : (*A*) v.s. of a taste bud; (*B*) v.s. of an olfactory epithelium.

FUNCTIONS OF EPITHELIA

The main functions of the epithelium are :

1. **Protection** : The horny layer of the epidermis of the skin is resistant to the effect of ferments, acids and alkalies. It is a poor conductor of heat and it is a good defence against infection from outside. A protective cuticle is secreted at the outer surface of most invertebrate animals.

2. **Absorption** : The digested food passes through the epithelial cells of the alimentary canal into the blood and lymph streams.

3. **Respiration** : Exchange of gases is carried out through the epithelium of the lung. Cutaneous respiration is known in some animals.

4. **Secretion and excretion** : The glandular epithelium secretes certain substances as mucus, enzymes, bile and hormones. Moreover, the epithelial cells of the uriniferous tubules of the kidney have the power to eliminate from the blood certain waste products such as urea and excrete these substances in a solution known as urine.

5. **Sensation** : Cells of the neuro-epithelium receive external sensation or stimuli and transmit them to the central nervous system.

6. **Provision of ciliary movement** : This is performed by the ciliated epithelium. The movements produced by the cilia are of various uses to the animals. For example, they may expell foreign bodies from the respiratory tract. In some aquatic animals, ciliary currents carry food particles to the mouth opening.

7. **Reproduction** : The reproductive cells (spermatozoa and ova) are developed from certain epithelial cells in the gonads (testes and ovaries).

II. CONNECTIVE TISSUES

The connective tissues develop from the middle germ layer known as the mesoderm. They are found in all parts of the body except the surface. They connect, support and hold together the various tissues or organs of the body. The cells of the connective tissue are widely separated by a large amount of **matrix** or **intercellular substance** which forms the most important part of the tissue. Fibres are often found in the intercellular substance. The connective tissues are classified into **connective tissue proper, skeletal tissue** and **vascular tissue.**

CONNECTIVE TISSUE PROPER

The tissue includes the following varieties :

1. Areolar or loose connective tissue.
2. White or fibrous connective tissue.
3. Yellow or elastic conne .tive tissue.
5. Reticular connective tissue.
6. Mucous connective tissue.

1. Areolar connective tissue

This is the commonest type of connective tissue. It forms a continuous layer beneath the skin, fills out the spaces between many tissues, acts as packing between muscles, it is found in the peritoneum and mesenteries and surrounds blood vessels and nerves.

The intercellular substance of this tissue is soft and gelatinous in which are embedded numerous **fibres** and **cells**. (Fig. 17).

The **connective tissue fibres** are of two kinds white fibres and yellow fibres.

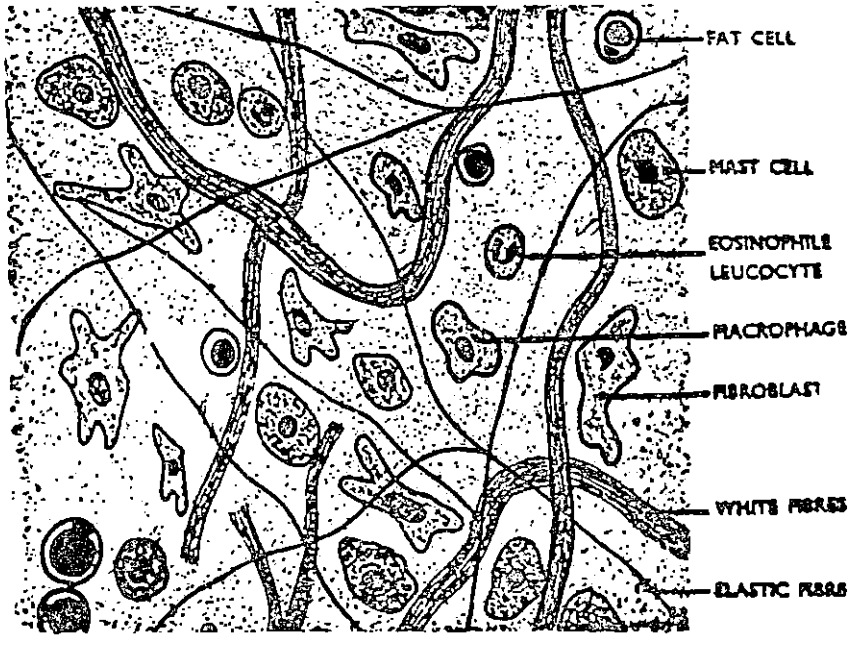


Fig. 17 — Areolar connective tissue.

(*a*) **White or collagenous fibres**

These fibres are colourless and arranged in bundles which have a wavy appearance. Each bundle consists of numerous fine fibrils. The bundles may branch but the individual fibrils do not branch. The white fibres are called collagenous fibres for they are formed of a kind of protein called **collagen**. These fibres are dissolved if boiled in water and forms a solution of glue or gelatin. They are affected by acids and alkalies.

(*b*) **Yellow or elastic fibres**

The yellow fibres are less in number than the white ones. They run singly in a straight course and appear yellowish in colour. The fibres may branch and join one another to form a delicate network. They are highly elastic and made up of a protein called **elastin** which resists boiling water, acids and alkalies.

(c) **The Connective tissue cells**

The connective tissue cells are of various kinds. The most important are the following :

(i) **Fibrocytes** (**old fibroblasts**) These are the most common cells with flattened ovoid nuclei, non granular pale cytoplasm and with fine processes. They are stained lightly with basic stains. These cells take part in the formation of different fibres but never transformed to them. The basic molecules from which collagen fibres are made are secreted by the fibroblasts and then polymerised outside cells into microfibrills.

(ii) **Macrophages** (Histocytes) are phagocytic cells which are able to take up foreign particles. They defend the body against invastion of disease organism such as tubercle bacteria.

(iii) **Plasma cells** are rare but abundant in lymphatic tissue. They are derived from lymphocytes. They are rounded cells with eccentric spherical nuclei with dense staining chromatin flakes in the basiphilic cytoplasm. The plasma cells are responsible for the production of antibodies.

(iv) **Mast cells** are round or oval cells with short protoplasmic processes and granular cytoplasm. They are believed to take part in the secretion of heparin which prevents blood from clotting. Recently it was found that they play an important role in healing of wounds, and they secrete substances which neutralize the toxic action of histamine. Plasma cells contain serotonin.

(v) **Undifferentiated mesenchymal cells** remain with loose connective tissue from embryonic development. These cells when given an unusual type of stimulus develop and form some tissues different from that around them.

(vi) **Fat cells** are spherical in shape and are found either singly or in groups. Each encloses a big fat globule which is surrounded by a very thin layer of cytoplasm in which the nucleus is embedded.

(vii) **Lymphocytes**

Lymphocytes are numerous in the submucosa of the alimentary canal and respiratory tract. They are greatly increased in number in chronic inflammation. These are identical with those of the blood. They are probably concerned with the production of antibodies.

(viii) **Pigment cells or Chromatophores**

Pigment cells are flattened branched connective tissue cells which contain pigment granules in their cytoplasm. The pigment granules may be black (melanin) or yellow (xanthin). The pigment cells are particularly present in or underneath the skin. They are common in lower vertebrates (fishes and amphibians) but rare in mammals.

2. White or fibrous tissue

This tissue is a very dense connective tissue which consists mainly of bundles of collagenous or white fibres running parallel to one another (Fig. 18). Between these bundles, very fine elastic networks have been formed. The cells are merely fibroblasts found between the bundles and

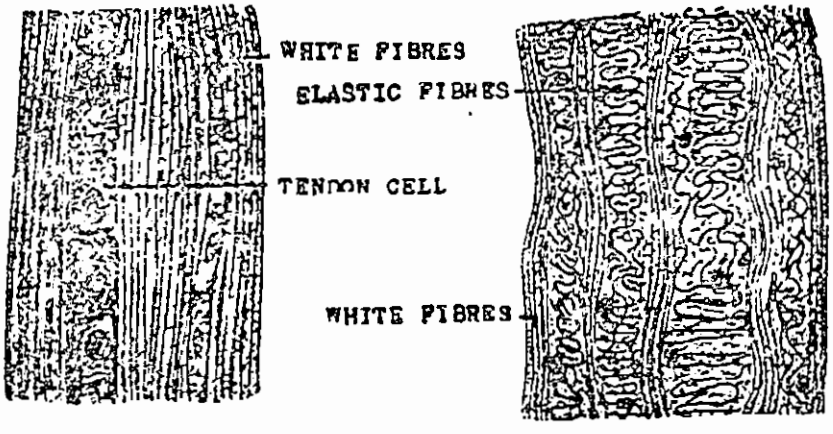


Fig. 18 — Fibrous tissue from a L.S. of a tendon.
Fig. 19 — Elastic tissue, from a L.S. of a ligament.

are arranged in parallel rows. This type of connective tissue is found in the tendons where muscles are connected to bones, e.g. tendo-Achillis.

3. Yellow or elastic tissue

This type is mainly formed of yellow elastic fibres (Fig. 19). The fibres are rather thick and are arranged as a reticulum or in bundles separated from one another by areolar connective tissue. This tissue is found in ligaments which attach bones to one another, e.g. ligamentum nuchae (attaching the skull with the neck vertebrae). It is also found in the walls of the hollow organs which are subjected to a considerable change in pressure, e.g. arteries, trachea and bronchi.

4. Adipose tissue

The adipose connective tissue is composed of lobules or groups of fat cells which are supported by fibrous bands and septa supplied with small blood vessels. The cells are swollen into globules full of fat. The cytoplasm is a thin membrane containing the nucleus.

The fat cells arise from the connective tissue cells by a deposit of fat droplets within its cytoplasm. The fat droplets continue to increase in number and fuse with each other to form globules of increasing size, until the cytoplasm finally becomes a thin wall or a membrane containing the nucleus.

During periods of starvation or malnutrition, fat globules decrease greatly in volume and then many of the fat cells return back to their former state.

This tissue occurs beneath the skin especially in women and fatty persons. It is also found in the mesenteries and round some organs as the kidney.

5. Reticular tissue

This is in the form of a reticulum which is formed of both cells and fibres (Fig. 20). The reticular cells are stellate and their processes are connected with those of the neighbouring cells. The reticular fibres (white) branch and cross one another to form a network.

The cells resemble the undiffentiated mesenchymal cells. These can develop to macrophages, fibroblasts, lymphoblasts and to other cell types. The meshes of the reticulum are full of lymph and lymph cells.

This tissue is present in the spleen, bone marrow and other lymphoid organs.

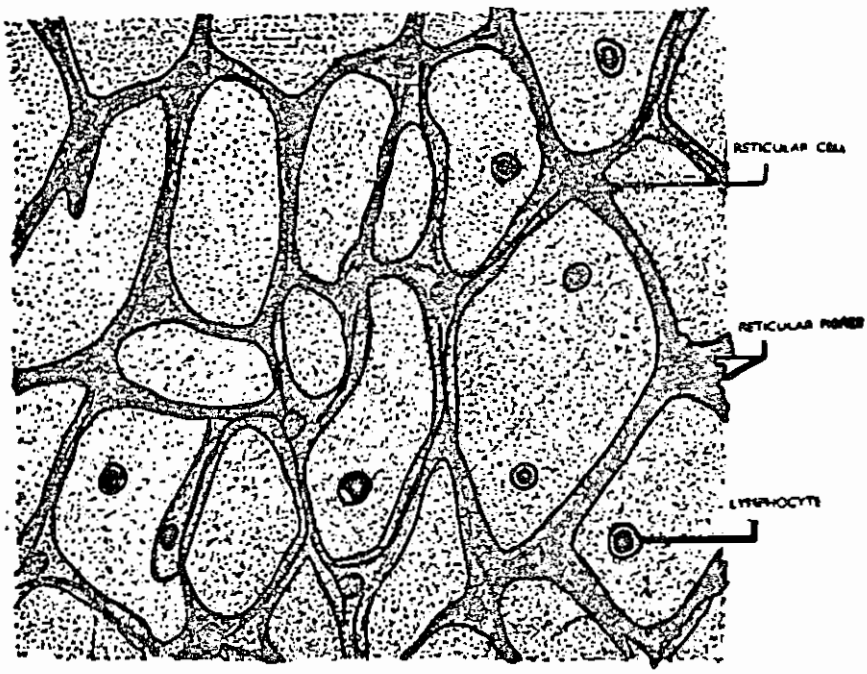


Fig. 20. — Reticular tissue.

6. **Mucous tissue**

The cells of this tissue are stellate, their processes may join those of the neighbouring cells (Fig. 21). The intercellular substance is soft and jelly like. It contains mucus and some white fibres but no elastic ones.

This type rarely occurs in the adult. It is found in the vitreous humour of the eye and in the umbilical cord of the human foetus. It is normally present in many parts of the embryo and this will be changed to other types later.

SKELETAL TISSUE

This is found in the vertebrates and forms their skeletons to which many muscles are attached. It protects some of the soft organs. This tissue is divided into two kinds : **cartilage** and **bone.**

1. **Cartilage**

Cartilage is a rigid and flexible connective tissue (Fig. 22). Its intercellular substance or matrix is formed of a substance called **chondrin.**

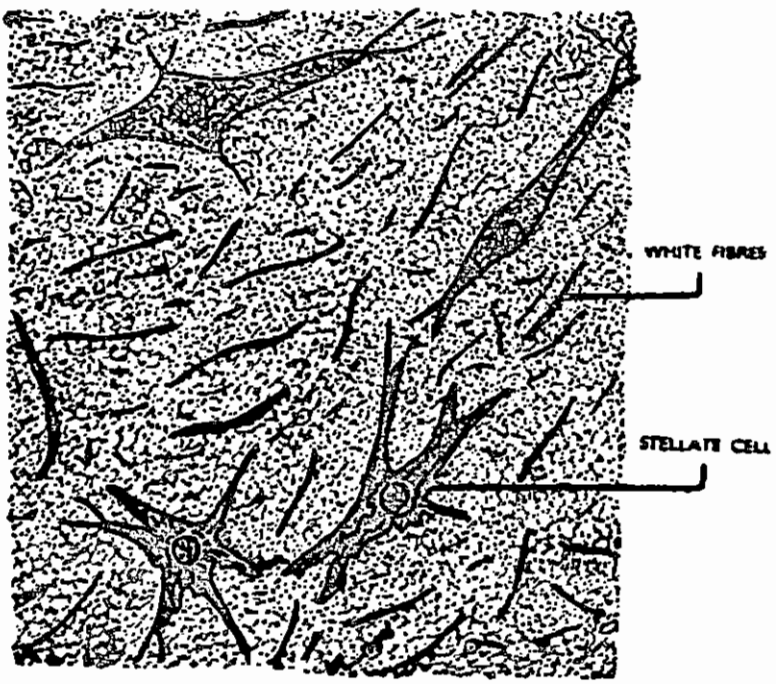


Fig. 21 — Mucous tissue.

This is secreted by the **cartilage cells** or **chonroblasts.** The chondroblasts are large and lie in cavities in the matrix called **lacunae.** The layer of the matrix that surrounds the lacuna and forming its wall is known as the **capsule.** The chondroblasts occur either singly or in groups. No lymph or blood vessels penetrating into the cartilage. Cartilage is always bounded by a dense fibro-elastic membrane called **perichondrin.** This membrane is richly supplied with blood vessels from which nutritive substances diffuse to the cartilage.

There are four varieties of cartilage: hyaline, yellow or elastic, white or fibro - and calcified cartilage.

(*a*) Hyaline cartilage

In this type, the matrix is apparently homogeneous (Fig. 22, A). Few collagenous fibres may be seen in the matrix after special treatment and staining. Hyaline cartilage occurs at the ends of the long bones, the **articular cartilage,** and at the ventral end of the ribs, the **costal cartilage.** It is also found in the trachea, nose and larynx. In the embryo, the entire skeleton except some of the bones of the skull and face are laid down

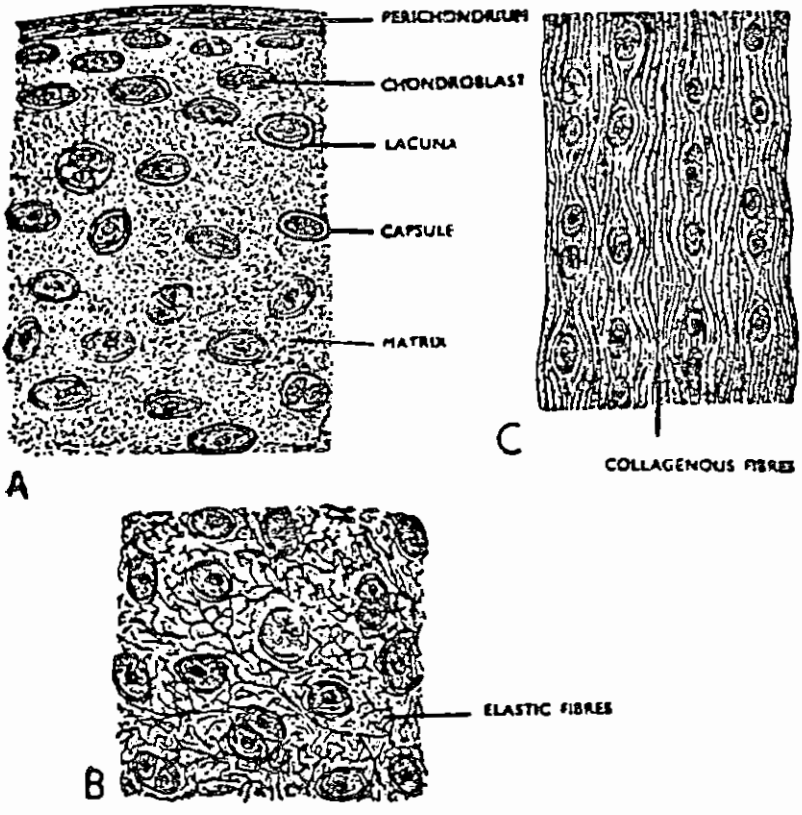


Fig. 22 — (*A*) S. of hyaline cartilage; (*B*) S. of elastic cartilage; (*C*) S. of fibro-cartilage.

as hyaline cartilage, later they are replaced by bone. The xiphoid cartilage of **Bufo** is of this type.

(*b*) Yellow or elastic cartilage

In this type, the matrix is supported by many elastic fibres in the form of a network winding in between the cartilage cells (Fig. 22, B). This type is found in the ear pinna (external ear), Eustachian tubes and epiglottis.

(*c*) White or fibro-cartilage

Here the matrix shows thick bundles of white or collagenous fibres which run parallel to one another (Fig. 22, C). This type is found in the intervertebral discs and the symphyses.

(*d*) Calcified cartilage

In this type, calcium salts are deposited in the amatrix and thus the tissue is rendered white in colour and relatively hard, e.g. suprascapula of **Bufo**.

2. Bone

Bone is a special form of hard connective issue. It acts as a supporting skeleton for the other tissue of the body. It also serves as a calcium reservoir, if for any reason, the blood calcium falls below a certain level.

Its matrix is formed of two main components, the organic portion amounts to about 35% or more of the dry weight of bone and is made chiefly of bundles of fibres similar to collagen ones called the osteocollagenous fibres. The inorganic part attains to about 65% of the dry weight. This consists essentially of calcium phosphate and a considerable amount of calcium carbonate and citrate and also salts of magnesium, sodium, potasium and iron.

Unlike cartilage, bone tissue is richly supplied with blood vessels and nerves. Bone is surrounded from the outside by a membrane called **periosteum**, while the cavity ofthe bone is lined by another delicate membrane called **endosteum.** The periosteum is mainly formed of a dense white fibrous connective tissue and contains large vessels. It provides an attachment for ligaments and tendons. The endosteum is a more delicate membrane formed of a loose connective tissue.

According to the structure of tissue, it is divided into spongy and compact bones.

(*a*) Spongy or cancellous bone

This type of bone is made up of a network of bars and plates of bone of different shapes and thickness. These enclose large inter-communicating spaces filled with a soft tissue called **red bone marrow.** This types is found in the inner parts of the flat bones of the skull, ribs vertebrae and epiphyses of long bones. It is often covered by compact bone.

(*b*) Compact or dense bone

This type of bone is very firm and dense and forms the main part of the shaft of the long bones. It forms an external covering for the spongy bone. The long bones are those found in the limbs as humerus and femur. Each long bone consists of three parts : the **shaft** and two **epiphyses.** The shaft or diaphysis is formed of compact bone and covered by perios-

teum. It shows a central elongated cavity full of **yellow bone marrow** and lined by endosteum. The epiphysis is formed of spongy bone which is covered by hyaline cartilage called articular cartilage. This is not covered by periosteum.

The compact bone is foumed of elongated cylindrical units called **Haversian systems** (Fig. 23). These systems run close to one another and parallel to the long axis of the bone. Each system has a thick wall and a central longitudinal canal called the **Haversian canal.** The Haversian canals contain blood vessels and nerves together with few connective tissue. These blood vessels communicate with one another and with the vessels of the bone marrow and with those of the periosteum through short

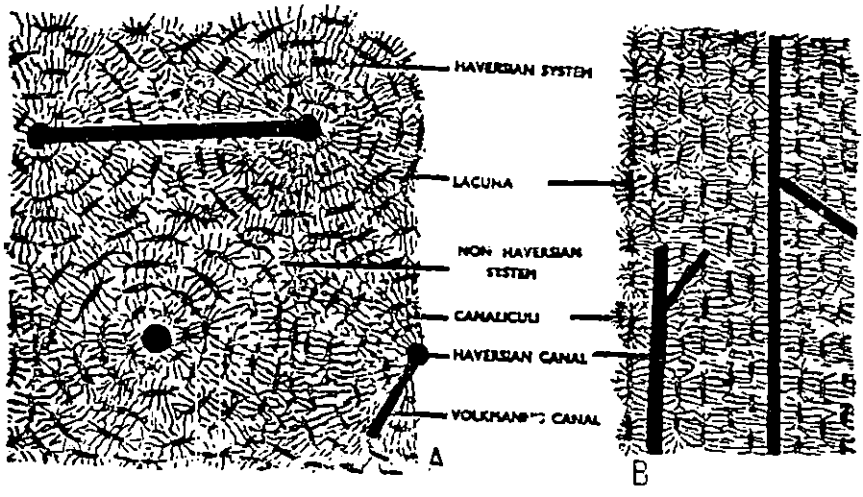


Fig. 23 — (*A*) T.S. of compact bone; (*B*) L.S. of compact bone.

lateral and oblique canals referred to as **Volkmann's canals.** The wall of the Havesrain system that surrounds the Haversian canal is, more or less, thick and is arranged in the form of thin concentric cylindrical layers called **bone lamellae.** These in the transverse section appear as concentric circles enclosing the Haversian canal. There are from 5 — 20 of these circular bone lamellae in each Haversian system. Between these bone lamellae there are minute cavities or cell spaces called **lacunae.** Each lacuna contains a branched bone cell called **osteocyte.** From each lacuna extends a number of very fine canals called **canaliculi** which unite with those of the neighbouring lacunae. The branches of the bone cells are

lodged and join one another in these canaliculi. The canaliculi serve to put the bone cells in communication with one another as well as with the blood vessels in the Harvesian canals. Thus through these canaliculi food and gases are exchanged.

The bony lamellae between the neighbouring Haversian systems are known as the **interstitial lamellae** or **non-Haversian systems.** These have got lacunae with osteocytes but no Haversian canals.

Immediately beneath the periosteum and endosteum of the shaft of a long bone, there are several layers of bone lamellae called the **outer** and **inner circumferential lamellae** respectively.

DEVELOPMENT OF BONE (OSSIFICATION)

Bones may be divided into two types according to the tissue in which they are formed. These types are membrane bones and cartilage bones.

Membrane bones : These first appear in the foetus as a membrane of embryonic connective tissue. In this membrane, bone is being laid down by a process known as the **intramembranous ossification**. By this process are formed most of the bones of the skull and face.

Cartilage bones: These first appear in the foetus as hyaline cartilage for which bone is substituted. The process forming this type is known as **intracartilaginous ossification** or **endochondral ossification.** It is responsible for the development of all limb bone, vertebral column and few bones in the skull.

1. Intramembranous ossification

The membranous embryonic connective tissue. in which the future bone is to be formed, becomes richly supplied with blood. Bundles of osteogenic fibres begin to appear. Then some of the connective tissue cells increase in number and enlarge in size and become aggregated and attached with one another by their fine processes. These cells are called the **osteoblasts** (the bone forming cells). The osteoblats then secrete small interconnected bars of bone which gradually increase in thickness.

Some of the osteoblasts become enclosed in the bone as it is formed around them and called **osteocytes.** Other cells remain free on the surface of the newly secreted bone, but they retain their connection with the osteocytes by means of their processes through the formed canaliculi.

This process is repeated and thus bone grows in thickness by the addition of new layers of bone to its surface. Bone which has been formed in this way remains usually of the spongy variety for a considerable time. In certain parts, the typical Haversian systems may develop later on as a result of a process known as the reconstruction or rearrangement of bone tissue.

2. Intracartilaginous ossification

The intracartilaginous ossification, in one of the long bones as the femur which first starts at certain ossification centres situated centrally in the shaft and the two epiphyses.

At the ossification centre, the cartillage cells multiply rapidly and become arranged in columns roughly parallel to the longitudinal axis of the cartilage. Then begining from the centre and radiating gradually outwards. the cartilage becomes calcified and many of its cells degenerate and die. From this stage onwards, the perichondrium is known as the periosteum. The inner layer of the periosteum sends buds which invade and dissolve the calcified cartilage. The first invading tissue consists of large multinucleate amoeboid cells termed osteoclasts. It is believed that these osteoclasts destroy or dissolve the existing calcified cartilage so making cavities or channels which will soon be filled with blood and osteoblasts. Then the osteoblasts begin to deposit spongy bone which nearly fills these cavities formed by the osteoclasts. The spaces in this newly formed spongy bone are filled with blood vessels and connecive tissue known as the embryonic bone-marrow. This process is continued and radiating outwards until all the shaft is formed of bone. Ossification of this type is called **intracartilaginous or endchondal ossification.**

While this process is being continued, another process of intramembranous ossification takes place in the surrounding periosteum. This process is called **perichondral ossification.** It forms an outer layer of memberane bone around the shaft. By this process, the shaft increases gradually in width.

Between each epiphysis and the shaft lies a narrow plate of hyaline cartilage, the **epiphysial cartilaginous plate.** The increase in thickness of this plate allows the shaft to increase in length. Around the age of 21 in man, this cartilaginous plate ossifies and thus the increase in length ceases.

The above mentioned way of ossification shows that the cartilage is gradually replaced by spongy bone. Then, this newly formed bone undergoes reconstruction or rearrangement before being an adult bone.

3. Reconstruction of bone

In this process, the spongy bone is gradually destroyed or absorbed in a definite way most probably by the osteoclasts and then rebuilt again by the osteoblasts. The middle of the shaft is absorbed and the formed cavity is filled with red bone marrow which will be changed into the yellow type afterwards.

In the mean time, the bony cylinder beneath the periosteum becomes invaded at numerous points by osteoclasts. These cells destroy and dissolve the bone making wide longitudinal channels which communicate with one another and are filled with blood and osteoblasts. Then the osteoblasts lining the cavity of each channel begin to deposit concentric lamellae of bone. The formation of these bone lamellae reduces the dimension of the cavity of the channel and forms a narrow canal which is known as the Haversian canal. Thus in this way the Haversian systems are formed. This process of destruction and construction of bone is repeated many times until the formation of adult dense bone is complete.

From the above description, it is noticed that the long bone, femur, shows at the same time the two kinds of ossification and thus it consists of the resulting two types of bones which are the membrane and cartillage bones.

VASCULAR TISSUE

This tissue is also called **liquid tissue.** It includes **blood, lymph** and their vessels. Vascular tissue differs from other types of connective tissues in the fact that :

(i) The intercellular substance is formed of a liquid called **plasma.** It shows no fibres in the normal condition but fibres could be demonstrated in the coagulated state.

(ii) The cellular part is represented by the **corpuscles** which are not responsible for the formation of the plasma.

(iii) The corpuscles are formed in special organs outside the blood vessels and then enter into the vessels in a fully formed condition.

THE BLOOD

Blood consists of a fluid **blood plasma** in which are suspended **blood corpuscles** of different types and other more minute bodies called **blood platelets.**

1. Blood Plasma

The plasma is a yellow or grey coloured fluid. It is a complex mixture of inorganic salts in solution (mainly of sodium and potassium) and proteins and fats in colloidal sol (fibrinogen, globulins and albumins). Other substances normally present in the plasma include nutritive substances (glucose and amino acids), excretory products (urea), hormones, antibodies and other substances as oxygen and carbon dioxide. It transports various substances to the different cells of the body.

2. Blood Corpuscles

Blood corpuscles fall into two groups : red blood corpuscles or erythrocytes and white blood corpuscles or leucocytes.

(*a*) Erythrocytes

The red blood corpuscles vary in size and number in the different groups of vertebrates (Fig. 24). In the vertebrates other than mammals

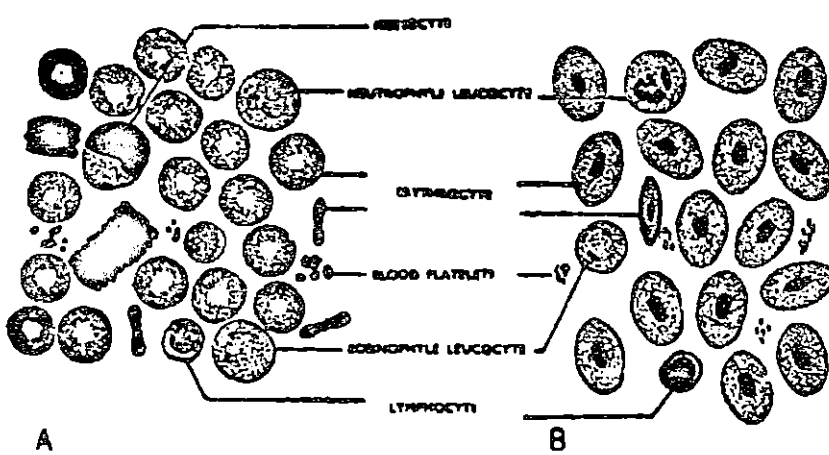


Fig. 24 — (*A*) Blood film of man; (*B*) Blood film of "Bufo"

(birds, reptiles amphibians and fishes) the red blood corpuscles are oval, biconvex and nucleated. In camel and Llama, they are oval, biconevx and non-nucleated. In mammals they are circular, biconcave and non-nucleated dices.

In man the erythrocytes have a diameter of about 8 microns and thickness of about 2 microns. The corpuscle is greenish yellow in colour but when corpuscles are examined in bulk, they are red coloured. The corpuscles are soft and flexible. They are bounded by a thin elastic semi-

permeable membrane formed of lipid and protein. When the corpuscle is squeezed through a narrow capillary, it becomes deformed but soon it regains its disc shape when enters a larger vessel.

Haemoglobin mainly forms the red corpuscle and it is referred to as the **respiratory pigment.** It is the colouring matter of the blood and formed of a complex protein substance containing iron. It forms with oxygen in the lungs a loose combination called **oxyhaemoglobin** which is bright red in colour. This oxyhaemoglobin gives up its oxygen readily to the tissues of the body and becomes reduced again to haemoglobin which is dark red in colour.

The erythrocytes have a marked tendency to adhere to one another by their broad surfaces and to assemble in long columns resembling piles of coins called **reuleaux.**

The average number of the erythrocytes in a normal adult man is about 5 millions and in woman it is about 4.5 millions per cubic millimetre of blood. Variations in number, however, occur within the same individual under different physiological conditions as well as in disease.

The red blood corpuscles are formed, in the human adult, in the red bone marrow which is found in the vertebrae, ribs, sternum, bones of the skull and the epihyses of long bones. In the embryo and the new-born child, the cavities of all bones contain only red bone marrow. With progressing age, the red bone marrow of the shafts of long bones is gradually substituted by the yellow bone marrow which is rich in fat cells.

During its development from the erythroblast, the erythrocyte loses its nucelus. It lives for about 120 days. Thus milions of new erythrocytes must enter the blood stream daily to replace the destroyed old ones. They are mainly destroyed by phagocytes in the lymphatic tissues particularly in the spleen. The haemoglobin of the ingested erythrocyte is broken into haematin and globin. Haematin is further split into bilirubin which is excreted with the bile and into iron which is retained by the spleen and utilized for the formation of new erythrocytes.

Moreover, some of the old erythrocytes are disintegrated into small fragments in the circulation itself. These fragments are ingested most probably by the monocytes.

Haemoglobin in the blood of vertebrates is found in the corpuscles. It is found in solution in the plasma of some worms and some other invertebrates. In case of most Crustacea and Mollusca, it is replaced by another respiratory pigment known as **haemocyanin** which is a compound protein containing copper in place of iron. Haemocyanin never contained

in corpuscles but in solution in the plasma. It is bluish coloured when in contact with oxygen and colourless when deprived of oxygen.

The erythrocytes play an important part in respiration. They are the carriers of oxygen which is carried from the lungs and distributed to the different tissues of the body for their metabolic activities. They can also carry the carbon dixoide produced by the cells of the body after metabolism and get rid of in the lungs.

(*b*) Leucocytes

The leucocytes are nucleated spherical cells containing no haemoglobin or other blood pigment. They are generally larger in size than the erythrocytes and present in different types (Fig. 24). They are capable of amoeboid movement and thus able to penetrate through the walls of the blood capillaries and penetrate into the tissues where they mainly carry on their functions. They are capable of engulfing small foreign particles such as bacteria and can produce antibodies in some cases.

The leucocytes are far less numerous than the red cells. The proportion between them being 1 (white) : 600 (red) for their number in normal man is about 8,000 per cubic millimetre of blood. This number increases or descreases according to the physiological or pathological conditions.

The leucocytes are classified into : -

Non-granular leucocytes or agranulocytes

These have no granules in their cytoplasm and develop from the lymphatic tissues. They include two types : **lymphocytes** and **monocytes.**

Granular leucocytes or granulocytes

These show granules in their cytoplasm and develop from the red bone marrow. The nucleus consists of several lobes (from 2 to 5 lobes) connected together by threads of nuclear substance. They include three types of leucocytes which are : **neutrophile leucocytes, acidophile leucocytes and basophile leucocytes.**

1. Lymphocytes

Lymphocytes range from 6 to 8 microns in diameter with a large nucleus and a small amount of cytoplasm. They form 20-25 per cent of the total number of leucocytes. Their phagocytic power is very slight.

The function of lymphocytes is not clearly defined. It is suggested that

they produce detoxifying substances or antibodies. They can also break down to take part in the formation of nucleoproteins. Some assume that they can change into monocytes.

(ii) **Monocytes**

Monocytes are the largest type of leucocytes, their diameter ranges from 10 - 14 microns or even up to 20 microns when stretched and dry. They constitute about 3 - 7% of the total number of leucocytes. The nucleus is oval or kidney-shaped and eccentric in position.

The monocytes are highly motile and phagocytic especially towards foreign bodies and parasitic organisms.

(iii) **Neutrophile leucocytes (neutrophils)**

These range from 9 - 12 microns in diameter and constitute from 60 - 70% of the total number of leucocytes. The nucleus is large and usually divided into 3 - 5 lobes so these cells are called **polymorphonuclear leucocytes.** The cytoplasm contains a number of fine granules which stain with neutral stains in human blood. In other animals they are called **heterophils** for their staining reactions are different according to the species.

The neutrophils are highly motile and phagocytic. They ingest many types of bacteria and other foreign particles. They can also produce enzymes which act on phagocytosed matter within their own bodies. It is also suggested that these cells secrete a substance to stimulate the fibroblasts to multiply and form fibres to repair the damaged tissues.

(iv) **Acidophile leucocytes (acidophils or eosinophils)**

The diameter of the acidophils ranges from 9 - 12 microns. These leucocytes constitute from 2 - 4% of the total number of leucocytes. The nucleus is usually 2 - 3 lobed. The cytoplasm possesses large spherical granules which stain deeply with acid stains as eosin.

It is suggested that these cells secrete detoxifying substances in the blood when parasitic nematodes infect the body. They may be involved in the state of allergy, for they increase in number in various allergic conditions as bronchial asthma and certain skin diseases.

(v) **Basophile leucocytes (basophils)**

These are nearly of the same size as the acidophils (9 - 12 microns in diameter). They constitute only about 0.5 - 1.0% of the total number of leucocytes. The nucleus is elongated or S-shaped. The cytoplasm contains

granules of variable number and size which stain deeply with basic dyes. The granules dissolve readily in aqueous solutions.

The basophils are feebly motile and are not phagocytic Their function is still not definite. In certain pathological conditions, these cells increase in number together with the increase of the eosinophils.

3. Blood Platelets

In mammals, blood platelets are minute bodies in the form of spindles or rods of 2-4 microns in diameter. Their number is about 250,000 per cubic millimetre of blood. These are not true cells because they possess no nuclei. Each consists of a mass of cytoplasm in the middle of which is a group of granules which when packed together may give the impression of the presence of a nucleus.

It is believed that they live for about eight days after which they are destroyed and phagocytosed in the spleen. Their number, however, is consantly maintained by replacement from either certain cells in the red bone marrow or they are the products of the disintegration of the red blood corpuscles.

Blood platelets are believed to take an important part in the process of blood clotting. It is noticed that when a considerable fall in their number takes place (60,000), a tendency for haemorrhage always appears. They possess the enzymes that play a role in carbohydrate metabolism. Moreover, it is suggested that they furnish a material that helps to maintain the integrity of blood vessels.

Blood platelets are absent from the blood of the lower vertebrates. In these animals instead of the platelets they have spindle true cells called **thrombocytes** which play the same role of the platelets in the blood coagulation.

THE LYMPH

Lymph is a yellowish fluid which resembles the plasma of the blood in composition, in the fact that some white corpuscles are suspended in it and that it has the power to form a clot. It arises by the diffusion of the blood plasma through the walls of the blood capillaries and surrounds the tissues of the body.

Excess of lymph in the tissues is conducted in special blind small cavities or tubes called **lymph capillaries.** These in the wall of the intestine are **lacteals.** Lymph capillaries join one another and form larger lymph

vessels or **lymphatics** through which the lymph passes in one direction till it is returned back to special veins of the blood system. The lymphatics are provided with valves to prevent the backward flow of the lymph and a muscular coat may also be present.

Lymph plays an important part in facilitating the exchange of materials and gases between blood and the cells of the body.

Closely connected with the lymph vessels are collections of lymphatic tissues forming the different lymphatic organs such as lymph nodules, lymph nodes, tonsils and spleen. These organs serve as filters for various particles and bacteria brought with the lymph where they are taken up and destroyed. In their sinuses old erythrocytes are phagocytosed by special cells. Moreover, lymphatic tissues form the agranulocytes and may produce antibodies by some of their cells.

III. MUSCULAR TISSUE

The movements of the various parts of the body of most animals are brought about by means of the contraction of its muscles. The muscles propel body liquids and excretions from place to place. The muscular tissue is built up of units of muscle cells called **muscle fibres. A muscle** is a number of muscle fibres bound together in bundles or fasciculi by connective tissue. Muscles are richly supplied with blood vessels but these do not penetrate into the individual muscle fibre. However, fine nerve fibres end in the muscle fibre. The muscles are developed from the middle germ layer, the mesoderm.

Vertebrates have three types of muscles, these are ; unstriated or smooth muscles, striated or skeletal muscles and cardiac muscles.

A) Unstriated muscles

The unstriated or smooth or visceral muscles are formed of a number of elongated, spindle shaped muscle fibres (Fig. 25). Each fibre has an oval or rod shaped nucleus which is situated in the middle of the muscle fibre. The nucleus is surrounded by an amount of undifferentiated cytoplasm known as **sarcoplasm.** The fibre consists of numerous delicate **myofibrils** running throughout the whole length of the fibre. These run close to one another and separated by fine sarcoplasm. The myofibrils represent the differentiated and contractile part of the cytoplasm of the fibre. The smooth muscle fibres do not show any transverse striations. They are joined together by a delicate system of connective tissue.

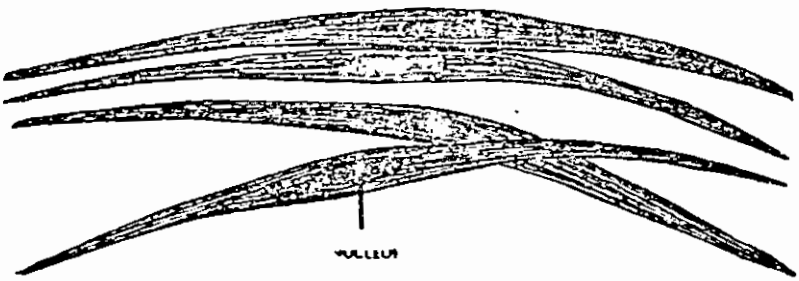


Fig. 25 — Isolated unstriated muscle fibres.

The unstriated muscles respond very slowly but work for a long time without being fatigued. They are involuntary in action and are supplied with autonomic nervous system.

The visceral muscles are generally arranged in layers, but within connective tissue they may be scattered singly or in groups. They are found in the walls of the alimentary canal, blood vessels, glands and their ducts and the urinary bladder.

B) **Striated muscles**

The striated or skeletal muscle fibre is an elongated and cylinidrical structure with more or less tapering ends (Fig. 26). The whole fibre is enclosed in a thin delicate membrane called sarcolemma. The fibre is formed of numerous longitudinal contractile fibrils called **myofibrils** or **sarcostyles.** These run close and parallel to one another and to the long axis of the fibre. They are separeted by fine undifferentiated cytoplasm called sarcoplasm. The striated muscle fibre contains several elongated nuclei, each of which is surrounded by a portion of sarcoplasm. The striated muscle fibre contains several elongated nuclei, each of which is surrounded by a portion of sarcoplasm. Thus each striated muscle fibre is regarded as a group of cells in a syncytial form. In mammals the nuclei are situated peripherally close to the sarcolemma while those of the lower vertebrates are scattered throughout the fibre.

The striated muscle fibre is characterestically striated transversely. This is brought about by the division of each myofibril, along its length, into alternate dark or (A) bands and light or I. bands. Since dark and light bands of one myofibril lie beside those of the adjacent myofibrils and at the same level, thus the combined effect produced gives the fibre a transversely striated appearance. In the middle of each light band runs a dark line called **Krause's membrane** or (Z) membrane. Similarly, the dark band is also divided by a line called Hansen's line or

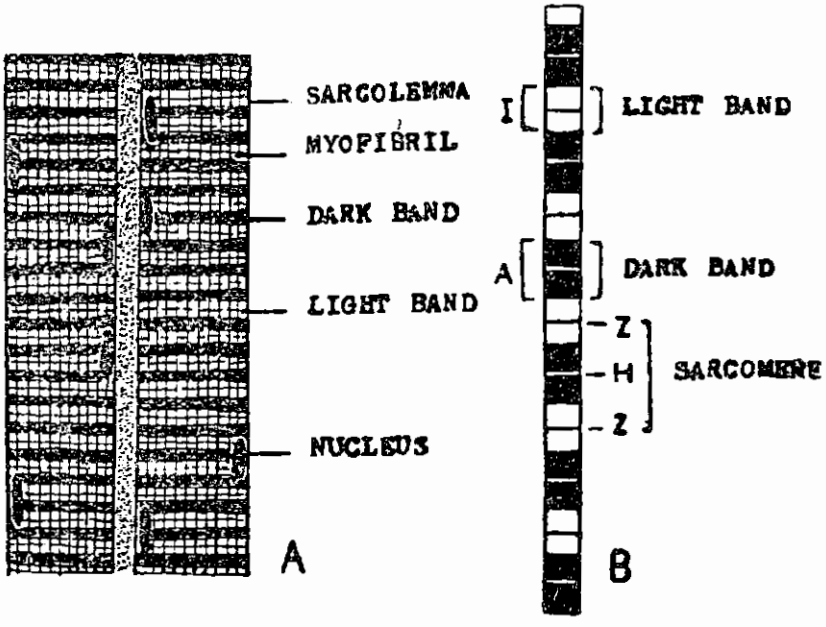


Fig. 26 — (*A*) L.S. of striated muscle; (*B*) An enlarged part of a sarcostylte.

(H) membrane. The part of the myofibril which lies between two successive Z membranes is known as a **sarcomere.**

Concerning the structure of a myofibril, it is believed that there are two types of protein filaments in the sarcomere (Fig. 27).

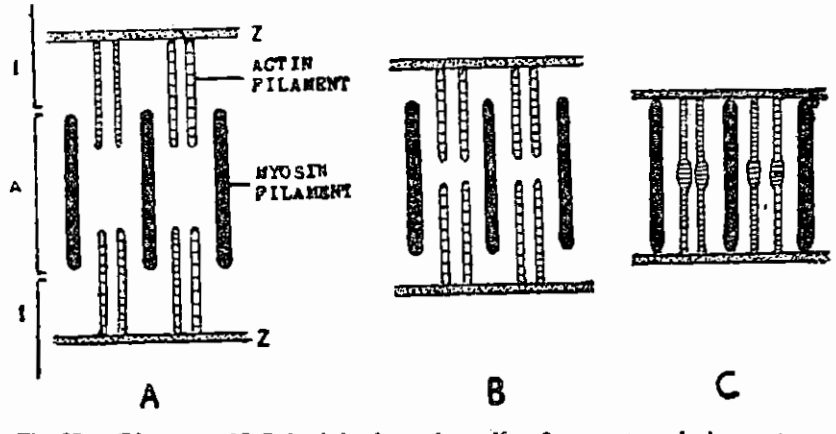


Fig. 27 — Diagrams of L.S. in skeletal muscle to show fine structure during contraction : (*A*) resting muscle; (*B*) partially contracted; (*C*) contracted.

(*a*) Thin actin filaments extending between Z and H membranes. thus extending through I and A bands.

(*b*) Thick myosin filaments which are confined to A bands.

The two sets of filaments are found in the A bands while there is only the thin type in the I bands. These two types of filaments are hexagonally arranged, i.e. each myosin filament is surrounded with six actin ones.

Shortening and stretching of the fibrils involve the slipping of the thin actin filaments relative to the thick myosin filaments. Thus, the decrease or increase in length of the I bands is attained when the thin actin filaments are either drawn into or pulled out of the A bands.

There are two varieties of striated muscles, red and white. The red muscles contain abundant granular sarcoplasm, numerous nuclei which may be centrally located and poorly developed transverse striations. They contract more slowly but are less fatigued than the white ones. Their colour is due to the presence of myoglobin (myohaemoglobin) which is closely related to haemoglobin. Myoglobin takes up oxygen from the blood and passing it on to the myofibrils.

The white or pale muscles contain less sacroplasm, well defined transverse striations and peripheral nuclei. These muscles respond more rapidly to stimulation but fatigue more quickly than the red ones.

The two types of muscles are found, in some animals, as separate muscles. However, in mammals, they are combined in single muscles. In general, the constantly active muscles contain the largest proportion of red fibres, (e.g. diaphragm, ocular and masticatory muscles).

The striated muscle fibres are connected together by connective tissue called **endomysium** to form bundles or fasciculi. Each bundle (fasciculus) is surrounded by a connective tissue called **perimysium** and togther with other bundles form a visible muscle which is surrounded by a sheath of connective tissue called **epimysium.** This epimysium is connected with tendons which attach muscles to bones.

Striated (skeletal) muscles comprise all muscles attached to the skeleton. They are all voluntary with the exception of the muscle fibres of the pharynx and those of the upper part of the oesophagus which although striated are involuntary.

C) Cardiac muscles

Cardiac muscles are only found in the wall of the heart. They are intermediate in structure between the unstriated and striated muscles (Fig. 28). They are involuntary and have the property of contracting rhythmically. They are innervated by the outonomic nervous system.

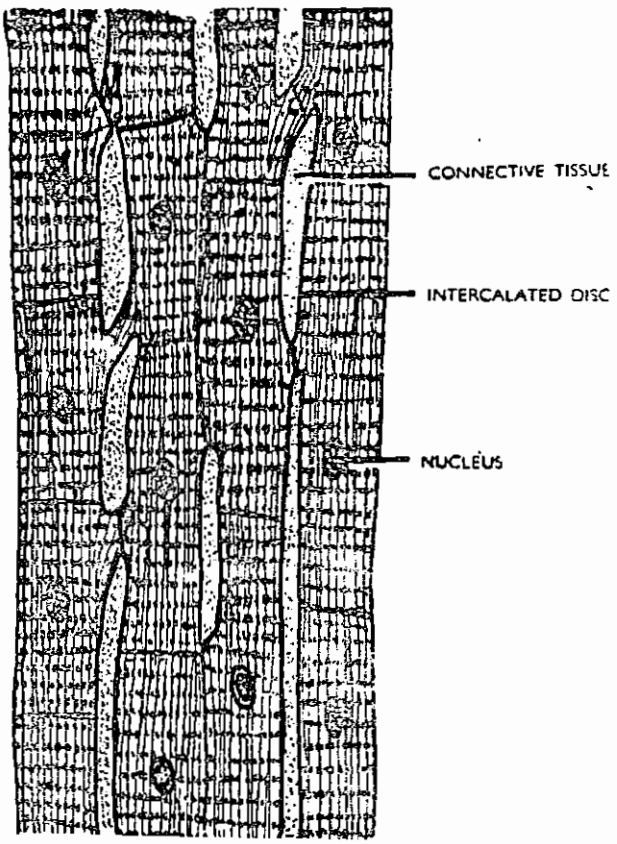


Fig. 28 — L.S. of a cardiac muscle

Cardiac muscle fibres are relatively short, branched and unite to form a network of muscle tissue. The fibres are feebly striated transversely. Granular sarcoplasm is abundant around the nuclei which are oval and lie near the centre of the fibres. There is no distinct sarcolemma. There are transverse markings known as the **intercalated discs** which cross the fibres and at variable distances from one another.

IV) NERVOUS TISSUE

The nervous tissue is the most highly differentiated tissue of the body. In this tissue irritability and conductivity, which are two of the fundamental properties of the living protoplasm, are more highly developed

than else where in the body. Nervous tissue develops entirely from the ectoderm.

Histologically, nervous tissue consists of **nerve cells or neurons** which are the nervous elements proper and of **neuroglia** which serve mainly to support and bind the nerve cells together.

A) NEURON

The neuron is the structural and functional unit of the nervous tissue. It consists of a **cell body** which contains the nucleus and a number of **cell processes** which are the **axon** and **dendrites** (Fig. 29).

Neurons are of 3 types :

Unipolar neurons — where every nerve cell gives off one process which divides into two processes.

Biploar neurons — where every nerve cell gives off two processes one called the axon and the other is the dendrite.

Multipolar neurons — where every nerve cell carries several processes, one is the axon and two or more dendrites.

1. The cell body

The cell body of the neuron contains the **nucleus** and the **cytoplasm** or **neuroplasm** in which are embedded many granules and fine fibrlis called **neurofibrils.**

The nucleus is large spherical and contains a well marked nucleolus. The neurofibrils are numerous and run both in the body of the cell and in the cell processes. They neither branch nor anastomose. In the cell body they cross one another but in the processes of the neuron they run parallel to their long axes. It is believed that these neurofibrils play an important part in the conduction of the nerve impulses. Usually, neuroplasm shows numerous granules called **Nissl bodies** or **granules.** These granules are also found in the dendrites but they are entirely absent from the axon and from the part of the neuroplasm from which the axon emerges. Their physiological significance is not quite clear. It is suggested that Nissl granules represent a reserve food substance which is used during the activity of the neuron.

Bodies of neurons are found in the grey matter of the brain and of the spinal cord. In some parts of the body, they are found in groups forming structures called **ganglia.**

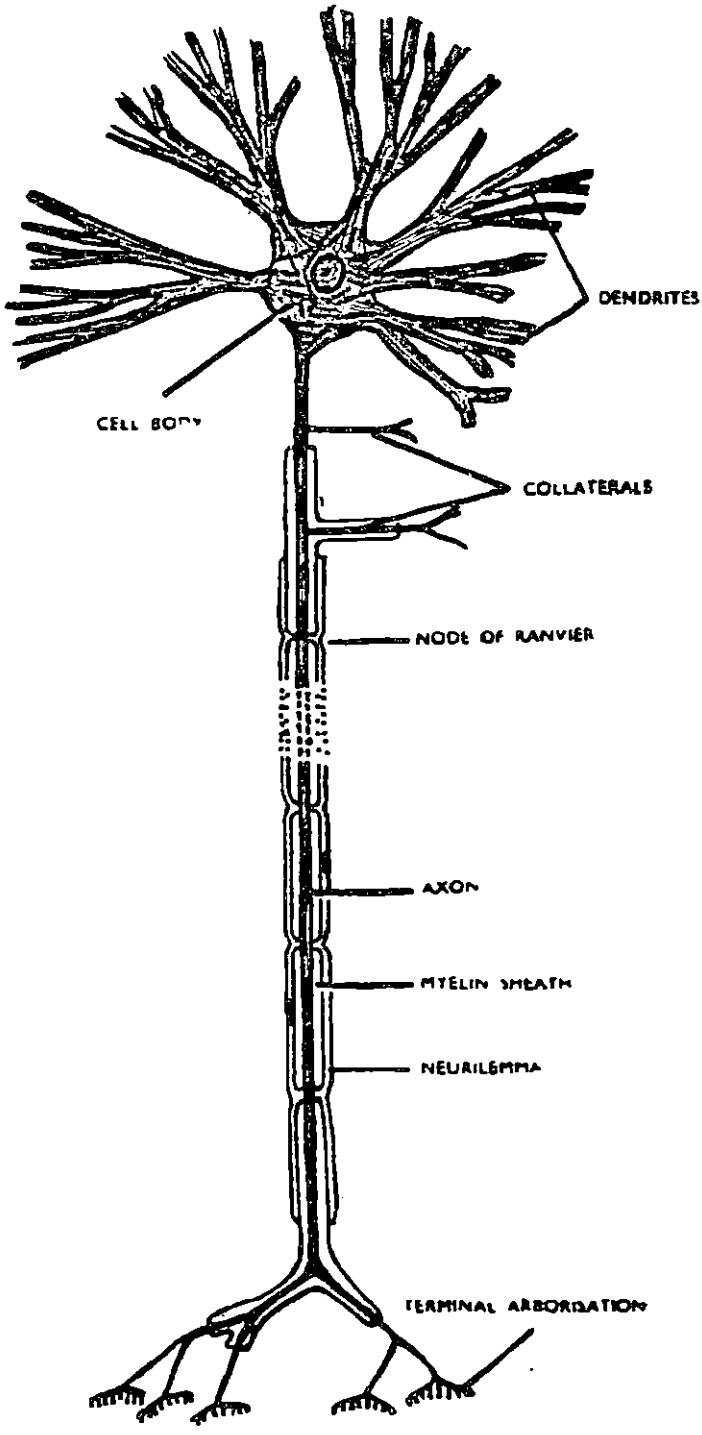


Fig. 29 — A multipolar neuron.

2. The processes of the neuron

The processes of the neuron are of two kinds : the dendrites and the axon.

The dendrites or **dendrons** are thicker and shorter than the axon. The dendrite branches repeatedly and terminates not very far from the cell body. It is formed of numerous parallel neurofibrils embedded in the neuroplasm or interfibrillar substance.

The axon or **axis cylinder** — Every neuron has got only one axon, The axon is thinner and longer than the dendrites of the same neuron. It does not branch like the dendites but it may give off lateral fine branches known as the **collateral** branches. It ends by breaking up into a tuft of fine branches known as the **nerve endings** or **terminal arborisation.** The axon is formed of numerous parallel neurofibrils embedded in neuroplasm which is called **axoplasm.** Nissl granules are absent.

Physiologically, the axon is that process which transmits nerve impulses away from the body of the neuron whereas a dendrite is that process which transmits the nerve impulses towards the body of the neuron.

The terminal arbortstation of many neurons usually occur close to the branches of the dendrites of other neighbouring neurons without being actually connected together and the place between them is known as the **synapse.** Through this synapse, nerve impulses are transmitted, in one direction, from one neuron to another.

NERVE FIBRES

The axon of a neuron is often of great length and is then called a **nerve fibre.** Bundles of numerous nerve fibres connedted together by fibrous connective tissue form what is known as a **nerve.**

The nerve fibres are of two types : -

Medullated or myelinate nerve fibres, and non-medullated or amylinate nerve fibres.

1. Medullated nerve fibre

The axon, which forms the central part of the fibre, is covered by a relatively thick layer of a fatty substance called **medullary** or **myelin**

sheath. This sheath invests the whole fibre except at its proximal and distal ends. Another thin sheath or membrane covers the myelin sheath called **neurilemma or Schwann's sheath.** This neurilemma is a thin layer of cells in the form of long hollow tubes with oval nuclei. The myelin sheath is not continuous throughout the whole length of the nerve fibre, it is interrupted, at more or less regular intervals, at places called **nodes of Ranvier.** At each node of Ranvier the neurilemma comes into direct contact with the axon. The part of the nerve fibre which lies between two successive nodes is called an **internode.**

A medullated nerve fibre is naked from its two sheaths at its proximal and distal ends. It has a myelin sheah but no neurilemma in the white matter of both the brain and spinal cord. It has both sheaths in its other peripheral course.

Functionally, both the myelin sheath and neurilemma probably act as insulators against the loss of the nerve impulses passing along the axon during the activity of the neuron. Moreover, the myelin sheath may have a nutritive function and may probably take a part in the formation of the nerve impulses. The neurilemma is very important in the regeneration of nerve fibres.

Medullated nerve fibres are sometimes called **white fibres.** They are principally found in cranial and spinal nerves. The white matter of the central nervous system consists chiefly of these fibres. In lower animals they are rarely present.

2. Non-medullated nerve fibre

The axon of this type, forms the bulk of the fibre. The axon is directly covered with the neurilemma as the myelin sheath is absent. Non-medullated nerve fibres are sometimes called **grey fibres.** These are found in the autonomic nervous system. They are common among invertebrates.

THE STRUCTURE OF A NERVE

In the peripheral nervous system, groups of nerve fibres are united together by connective tissue to form a **nerve** or a **nerve trunk** (Fig. 30). Each nerve is covered with a thick layer of fibrous connective tissue called **epineurium.** The epineurium carries blood vessels and nerves. It is

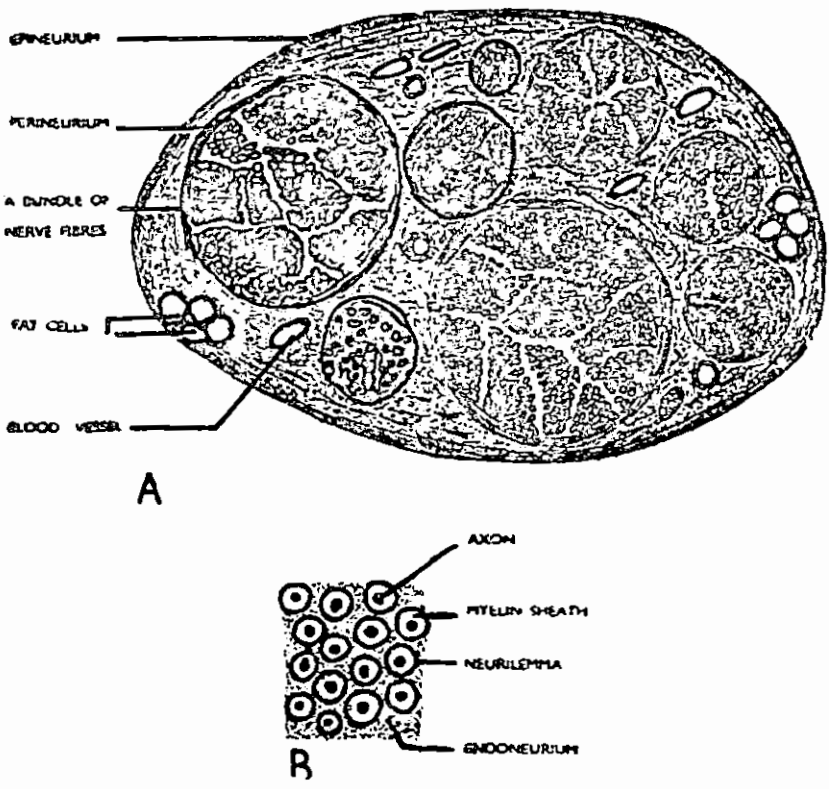


Fig. 30 — (*A*) T.S. of a sciatic nerve of cat; (*B*) An enlarged portion of a nerve bundle.

continuous with the conective tissue dividing the nerve into bundles. Each bundle is then encircled by a dense lamellated connective tissue called **perineurium.** From this perineurium fine strands of connective tissue extend inwards, separating and surrounding the individual nerve fibres. These fine strands are called **endoneurium.**

B) NEUROGLIA

Besides the nerve cells and their processes, there occurs in the brain and spinal cord a peculiar tissue which is called **neuroglia.** This neuroglia is composed of branched cells (glia cells) of different types (Fig. 31). These cells form a kind of spongework to support and bind together the delicate nerve cells and other nervous elements.

Some of the neuroglia cells are found to be radially arranged. They start from the lining layer of the ventricle of the brain and the central canal of the spinal cord. They run in a radial direction and slightly diverging and branching as they proceed towards the surface of the organ.

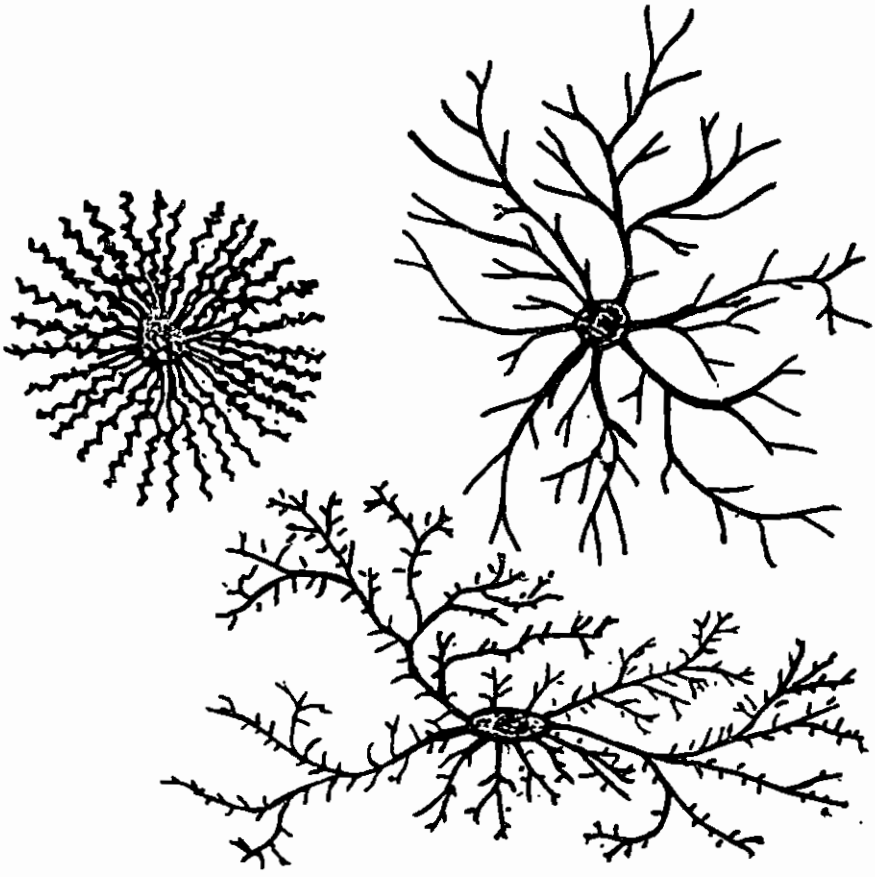


Fig. 31 — Some types of neuroglia cells.

PART THREE

PHYSIOLOGY

INTRODUCTION

Physiology (Gre. Physis = function; logos = study) is a branch of science which deals with the study of the functioning or working of an organism or its parts or in other words, the manner in which the whole body of an organism or its main organs carry out the various processes of life such as digestion, respiration, excretion, reproduction, circulation, etc. In this part of the book, students may revise the detailed structure of the organs, which will be dealt in later chapters.

DIGESTION

It is a process by which food is borken down into simpler form so as to be easily absorbed and assimilated. This process is brought about by certain **ferments** or **enzymes** which are thermolabile proteinous substances responsible for the chemical changes produced in the food, (called here **substrate**) leading to its conversion into simpler forms.

The activity of these enzymes is influenced by tempertaure, pH, time and presence or absence of activators, (e.g. **enterokinase**) and **co-enzymes,** (e.g. Cl.).

Digestive enzymes are classified into : -

(*a*) **Carbohydrases** or amylolytic enzymes acting on carbohydrates.

(*b*) **Proteinases** or proteolytic enzymes, acting on proteins.

(*c*) **Lipases** or lipolytic enzymes, acting on fats.

FOOD

Substances which may serve as food are carbohydrates, proteins, lipids, vitamins, mineral salts and water.

Water is very important as it makes up about two thirds of the human body. It helps in the chemical changes during digestion or any other process. It aids also in peristalsis and renders the process of osmosis possible. Besides, it helps in regulating the body heat. Man can live weeks without food, but only a few days without water. Certain desert animals live

indefinitely without drinking water as they obtain it from the food they eat.

CARBOHYDRATES

These are products of three main elements, carbon, hydrogen and oxygen. Hydrogen and oxygen are found in the same proportion as in water. Carbohydrates differ according to the number of the carbon atoms, contained in them. They may be **dioses** in case the molecule contains two carbon atoms, **trioses**, with three carbon atoms, tetroses, with four, **pentoses** with five and **hexoses** with six carbon atoms.

Examples of trioses are dihydroxy-acetone and glyceraldehyde ($C_3H_6O_3$). Of the pentoses ($C_5H_{10}O_5$) there are xylose, arabinose and ribose. Hexoses are the most common and they are divided into three main groups : -

Monosaccharides	($C_6H_{12}O_6$)
Disaccharides	($C_{12}H_{22}O_{11}$)
Polysaccharides	($C_6H_{12}H_5$)n

1. **Monosaccharides.**

These comprise easily digested sugars and include **glucose** (grape sugar), **fructose** (fruit sugar), **galactose** (milk sugar) and **mannose.**

2. **Disaccharides**

Formed by the condensation of two molecules of monosaccharides with loss of a single molecule of water. Examples are **sucrose, maltose** and **lactose.**

By the process of digestion each molecule of disaccharides splits into two molecules of monosaccharides.

Sucrose ⟶ glucose + fructose.

Lactose ⟶ glucose + galactose.

Maltose ⟶ glucose + glucose.

3. **Polysaccharides**

These are formed by the combination of n molecules of monosaccharides with loss of n molecules of water. These complicated substances are divided into :

(*a*) Nutrient polysaccharides, e.g. **dextrin, starch and glycogen.**

(*b*) Skeletal or structural polysaccharides, e.g. cellulose and chitin.

Carbohydrates supply the body with heat and energy.

PROTEINS

These are highly complicated substances which contain carbon, hydrogen, oxygen, nitrogen and sometimes sulphur or phosphorus or both.

Protein molecules are made of simpler components known as amino-acids joined together via the peptide linkage — CO.NH --, which results from the combination of NH_2 - group of one amino acid with COOH - group of another acid.

1. Simple proteins

Examples of this group are **albumins, globulins, glutelins** and **albuminoids.**

2. Conjugated proteins

Examples of this group are **caseinogen, haemoglobin** and **mucin.**

3. Derived proteins

Proteoses, peptones and **polypeptides** are examples of this group.

In the process of digestion, carried out by hydrolytic enzymes, proteins are broken at first into proteoses, then to peptones, to polypeptides (carboxypolypeptides or aminopolypeptides) to dipeptides then finally to amino acids. Thus amino acids are the simplest form of proteins.

. The principal function of proteins is the building up of protoplasm either for the sake of growth or for rebuilding the tissues which have been destroyed.

LIPIDS

Lipids are divided into simple and compound lipids. The simple lipids comprise fats, waxes and sterols while the compound ones contain phospholipids, aminolipids and glycolipids.

1. **Fats**

These are substances derived from animal and plant sources, composed of carbon, hydrogen and oxygen and possess a greasy or oily consistency. Each molecule of fat is composed of one molecule of glycerol combined with three molecules of fatty acid. Examples of fats are the very simple fats known as **tributyrine** found in butter a combination of glycerol and butyric acid, **tristearine** (glycerol and stearic acid), **tripalmitine** (glycerol and palmitic acid) and **triolein** (glycerol and oleic acid).

Fats are important both as fuels and as structural constituents. Their digestion results in splitting them into **fatty acids** and glycerine.

2. **Waxes.**

These are substances formed as a result of combination of fatty acids with complex monohydric alcohols and found in blood, lymph, medullary sheath of nerve fibres, sebaceous glands and in the cortex of the adrenal gland.

3. **Sterols**

These are very important substances. Examples are **cholesterol** (zoo-sterol) and **ergosterol** (phytosterol). Cholesterol is found in blood, milk, egg yolk, medullary sheath, liver, kidney and adrenal gland and is considered as an important component of the nervous tissue. Irradiation of ergosterol by ultra-violet rays leads to the synthesis of vitamin D_2.

VITAMINS

Vitamins are important substances the deficiency of which leads to a number of diseases. This classical nomenculature. based upon Greek origin (vita = life, and amine = substance with NH_2 radical) was introduced by Funk 1912. Vitamins are generally referred to by letters A,B,C,D,E,G and P.

Some are soluble in fats and occur naturally together in association with them while others are water soluble.

Fat-soluble vitamins are : -

A or **Axerophthol,** the **anti-xerophthalmic** or **anti-infctive vitamin.**

D or **anti-rachitic vitamin.**

E **Tocopherol** or **anti-sterility factor.**

K **Anti-haemorrhage vitamin.**

Water soluble vitamins are :

B Complex (B_1-B_7 and B_{12}) and **pantothenic** acid, **para amino benzoic acid, biotin, follic acid, choline and inosital.**

C **Ascorbic acid** or **anti-scorbutic** factor.

P **Citrin** or **hesperidin.**

Vitamin activity is expressed in units and the most common of which are the international units (I.U.).

The deficiency of vitamins was noticed to cause diseases, also the increase of certain vitamins was found to cause disturbances. For example **hypervitaminosis** of vitamin D was noticed to lead to **arteriosclerosis.**

1. **Vitamin A** (anti-xerophthalmic or anti-infective).

This is a fat soluble vitamin occurring in fish-oil, egg-yolk, green vegetables and carrots. Its difficiency causes :

(*a*) Night blindness.

(*b*) Drying of the cornea of the eye.

(*c*) Low resistance to bacterial infections.

This vitamin is not destroyed by ordinary cooking.

2. **Vitamin B**

This is a water soluble vitamin. It is composed of several substances B_1, B_2, B_3, B_4, B_5, and B_6 and B_7 thus it is referred to as vitamin B-complex.

(*a*) **Vitamin B_1** (anti-neuritic or anti-beri-beri)

This is identified chemically as aneurin or thiamin. It occurs in green vegetables, unpolished rice, yeast and wheat. Its deficiency causes the disease known as Beri-beri. This disease causes inflammation to the nerves thus leading to paralysis. It is common in China and Japan where the polished rice is the main food. Its deficiency also causes destruction to the appetite and retardation of growth as well as disturbance in carbohydrate metabolism and digestion in general. It is not easily destroyed by heat.

(*b*) **Vitamin B_2** or **G.**

This vitamin is chemikally known as **Riboflavin.** It occurs in some vegatables, yeast, milk, egg-yolk and liver. Its deficiency will cause inflammation and cracking of skin at the corners of the mouth, a case known as **cheilosis.**

(*c*) **Vitamins B_3 -- B_6**

Little is known about these vitamins and they are all necessary for growth and occur in yeast, liver, and egg-yolk. B_6 or pyridoxine was found to aid in amino acid reactions.

(*d*) **Vitamin B_7** (anti-pellagra or p-p factor)

Chemically this vitamin has been shown to be either nicotinic acid (niacin) or its amide (nicotinamde). It is abundant in yeast, milk, yolk of eggs, liver, fresh meat, green vegetables and tomatoes. Its deficiency leads to pellagra disease which is most common in Egypt and is characterised by skin lesions, muscular weakness as well as digestive and nervous disturbance.

3. **Vitamihs B_{12}**

This vitamin is very important for the maturation and formation of the red blood corpuscles. Its deficiency lead to anaemia (pernicious anaemia). It occurs in milk, liver, cheese, meat and egg-yolk.

4. Vitamin C (**anti-scorbutic vitamin**)

Chemically this vitamin is known as ascorbic acid. It is a water soluble vitamin found in large quantities in citrus fruits as well as in tomatoes, cabbages and lettuce. Its deficiency causes scurvy characterised by the partial destruction of the blood capillaries, thus leading to bleeding gums, haemorrhage in mucous membranes under skin and in joints as well gastric ulcers and decay of teeth.

This vitamin is easily destroyed by heat and also in alkaline medium.

5. **Vitamin D** (anti-rachitic vitamin)

This is a fat soluble vitamin occuring in fish liver oil, butter, milk, cheese, egg-yolk and liver. Its lack causes rickets especially in children. Sunlight is the cheepest source for this vitamin. It has been suggested that the ergosterol forend lelow the skin transforms to vitamin D on exposure to sunlight (containing ultra violet rays : Accordengly this vitamin is also called sunshine vitamin.

6. **Vitamin E** (anti-sterility vitamin)

It is a fat soluble vitamin. Chemically it was found to be **alpha-tochopherol.** It is abundant in green vegetables, egg-yolk, and oils. It has been tested in rats and its lack leads to sterility in both sexes.

7. **Vitamin K** (anti-haemorrhage vitamin).

This is a fat soluble vitamin. It occurs in green leaves, tomatoes and egg-yolk. It is essential for formation of prothrombin of blood and its deficiency leads to bleeding due to delay in the clotting of blood.

8. **Vitamin P**

This is also known as **citrin** or **hesperidin.** It is water soluble and is associated with vitamin C and believed to supplement its action.

MINERAL SALTS

Some elements of mineral salts are known to be essential for the diet, Examples are sodium (mainly from sodium chloride), calcium, iron, potassium, phosphorus, copper, iodine, magnesium, and zinc. Sodium and chlorine have an important role in maintaining osmotic balance in the body and are also major components of the secretions of digestive tract, (e.g. hydrochloric acid of the somach, pancreatic and intestinal juices). Potassium and magnesium are necessary for muscle contraction. Calcium and phosphorus are chief constitutents of bones and teeth. Phosphorus is extremely important in carbohydrate metabolism and is essential for body tissues in general and brain tissue in particular. Iodine is a constituent of the **thyroxine hormone** and its deficiency leads to goitre cases.

Iron is a constituent of haemoglobin and of the cytochromes. Small amounts of copper are necessary to bring about the proper utilization of iron and for normal growth. Traces of manganese, zinc and coblat are also required for normal growth and as activators of certain enzymes. Traces of fluorine in drinking water was found to be remarkably effective in preventing dental decay.

PROCESS OF DIGESTION

Digestion takes place throughout the alimentary canal and it may be divided into buccal, gastric and intestinal as follows :

BUCCAL DIGESTION

Buccal digestion takes place in the mouth. There are two processes, one **mechanical** or "**mastication**", involving the break down or grinding of food by teeth, and other chemical, involving the action of **saliva**, secreted by the salivary glands. **Saliva** is an alkaline watery fluid contain-

ing an enzyme called **ptyalin.** This ferment acts on **starch** and converts it into **maltose.** The food is then swallowed after it is partly digested, and passed through the oesophagus by peristaltic movement to the stomach.

In the stomach the food mass is liquified and prepared for gastric digestion. The action of ptyalin continues for a while until the food has become permeated by the acidic gastric juice, then the action of ptyalin stops owing to the acidity of the gastric juice as ptyalin acts only in an alkaline medium.

GASTRIC DIGESTION

The gastric juice is a colurless acidic fluid which consists partly of inorganic and partly of organic matter in solution. Among the inorganic matter is HCl which is produced from certain cells of the tubular glands called oxyntic cells. HCl is formed in these glands by interaction between NaCl, CO_2 and water. It acidifies the medium in which the gastric ferments can act. Besides, it acts as an antiseptic and disinfectant against harmful organisms. The organic parts on the other side are mainly formed of three enzymes namely **pepsin, rennin** and **lipase.**

Pepsin is secreted from the peptic cells of the tubular glands in an inactive form of mother substance or precursor called **pepsinogen**, which is converted into active pepsin in the presence of HCl. Pepsin acts on **proteins** converting them into **peptones.**

Rennin is usually known as milk-curdling ferment. It acts on soluble **caseinogen** present in milk and liberates **casein** in the presence of **calcium phosphate.** Casein, then, can be acted upon by pepsin.

Lipase acts on fats to give **glycerine** and **fatty acids.** But since the fat must be emulsified for the proper action of such an enzyme and also for the reason that the medium is acidic and not alkaline, the action of this enzyme is insignificant.

The secretion of the gastric juice is influenced by mechanical and psychical stimuli. The mechanical stimulus is brought about by the presence of food in the stomach in contact with its wall which causes glands to secrete gastric juice. The psychic stimulation depends on impulses reaching the central nervous system through senses as smell, thought or sight of food. The secretion of the gastric juice may be

inhibited by the sympathetic nervous system as may happen in strong motions such as fear or anger. The food remains in the stomach for about two hours, after which it is finally transformed into a viscous opaque yellow acidic liquid called the **chyme.**

INTESTINAL DIGESTION

As soon as the acidic liquid called **chyme** is formed, it begins to pass out of the stomach to the small intestine at intervals. The passage is controlled by the pyloric sphincter muscles which close and open, being regulated by the pH of the passing fluid, until the whole chyme passes to the duodenum and becomes alkaline.

In the small intestine three digestive fluids act on the chyme descending from the stomach by the peristaltic movement. These fluids are secreted, and their secretion is stimulated by a hormone called **secretin,** produced by the duodenal wall. The fluids are, the **pancreatic** juice from the pancreas, **bile** from the liver and **intestinal juice** from the small intestine.

(*a*) Pancreatic juice

This is an alkaline watery fluid containing mineral salts and ferments. Mineral salts are mainly NaCl and Na_2CO_3. The ferments are, proteolytic, amylolytic and lipolytic.

(i) Proteolytic ferments.

The proteolytic ferments are **trypsin, chymotrypsin, carboxypolypeptidase.** Both trypsin and chymotrypsin are secreted in an inactive form called **trypsinogen** and **chymotrypsinogen** , which by the action of the activator **enterokinase** secreted by the duodenum, become converted to **trypsin** and **chymotrypsin.** These act on the peptones changing them to **polypeptides** either carboxypolypeptides or amino-polypeptides. **Carboxypolypeptidase** acts on carboxypolypeptides converting them into **dipeptides.**

(ii) Amylolytic ferments

The amylolytic ferment is called pancreatic **amylase** or **amylopsin.** It acts on starch in an alkaline medium and changes it into **maltose.**

(iii) Lipolytic ferments

The lipolytic ferment is steaspsin or pancreatic **lipase.** It acts on **fats**

converting them into **glycerine** and **fatty acids.** The action of this enzyme is accelerated by the role played by the **bile.**

(*b*) **The bile**

This is a yellowish alkaline fluid (sometimes greenish) containing about 98% water and the rest being **mucin,** bile salts which are sodium salts of glycocholic and taurocholic acid (**sodium glycocholate and sodium taurocholate**), bile pigments, cholesterol, lecithin, fats and other substances.

Bile pigments (**bilirubin** and **biliverdin**) are formed in the liver from the disintegrated haemoglobin of the dead red blood corpuscles. They are acted upon by the digestive ferments and bacteria and are converted into **stercobilin** which gives faeces its normal colour. Bile does not contain any digestive enzymes but it helps **steapsin** in its action on fats, by lowering the surface tension (by the bile salts) and thus emulsifies fats.

(*c*) **Intestinal Juice**

This juice is called also succus entericus and is secreted by the tubular glands (crypts of Liberkühn). It is an alkaline fluid containing from 1 to 2 per cent solids which are either inorganic containing mainly NaCl and Na_2CO_3 or organic formed of proteolytic and amylolytic ferments as follows :

1. **Proteolytic ferments**

These ferments are **erepsin and enterokinase. Erepsin** is a mixture containing **amino - polypeptidase** which acts on **aminopolypeptides** in an alkaline medium giving **dipeptides,** and **dipeptidase** which converts the **dipeptides** into **amino-acids.**

Enterokinase is an activator which changes **trypsinogen** into active **trypsin** and **chymotrypsinogen** into **chymotrypsin.**

(ii) **Amylolytic ferments**

The amylolytic ferments are **Invertase, lactase** and **maltse. Invertase** (**sucrase**) acts on sucrose or cane sugar converting it into **glucose** and **fructose.** Lactase or milk sugar enzyme splits **lactose** into **glucose** and **galactose. Maltase** hydrolyses **maltose** into **glucose.**

By the action of the various ferments previously mentioned, the different food materials are converted to their final state which becomes ready for absorption and assimilation. Carbohydrates are converted into

monosaccharides (mainly glucose); proteins into amino acids and fats into fatty acids and glycerines.

ABSORPTION

Absorption takes place in the small intestine. The amino acids and monosaccharides together with mineral salts and water are carried by the blood stream to the liver. The fatty acids and glycerine, on the other hand, pass into the lymphatic vessels or lacteals, found in the villi of the small intestine and in this case they will reach blood via the thoracic duct.

METABOLISM OR ASSIMILATION

These terms are applied to the sum total of various essential processes, including assimilative changes that lead to the building up of complex substances (anabolism) and disintegrative changes (catabolism).

1. METABTLISM OF PROTEINS

Amino acids are carried to the liver where they are reconverted again into proteins by the action of enzymes. These proteins are used in the building up of new protoplasm.

The excess of amino acids undergo in the liver a process of **deamination** which leads to the formation of **urea** that will be excreted by the kidneys.

2. METABOLISM OF CARBOHYDRATES

In the liver, the excess of sugar (the amount which is not wanted immdiately by the body) is convereted into **glycogen** by the help of a hormone called **insulin** secreted from the **islets of langerhan's** found in the pancreas. Glycogen is stored in the liver until it is needed. If it happens that the normal sugar content of the blood (about 0.1% in normal fasting individuals) decreases, then some of the glycogen in the liver is converted into glucose by the help of a hormone called **adrenalin** secreted from the medulla of the adrenal gland, to restore the normal content of blood glucose.

The sugar constantly taken from the blood by the tissues for their metabolism is oxidised to CO_2 and water thus yielding energy required for the performance of bodily movement, maintenance of body tempera-

ture and other vital functions. Such oxidation is expressed as follows :

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6\,CO_2 + 6\,H_2O + \text{Energy}$$

Some of the sugars may be also converted into fat in the body.

Persons suffering from diabetes have a high blood sugar concentration, a condition known as **hyperglycaemia.** This is followed by the escape of glucose into urine, a case known as **glycosuria.** This disease is correlated to the lack in the production of the hormone called **insulin.** Without insulin neither combustion nor storage of sugar will take place in the body.

3. METABOLISM OF FATS

Glycerine and fatty acid, after being absorbed into the lacteals or lymph vessels, are immediately transformed into minute fat globules. These fats, for the most part, are stored in the subcutaneous tissues and other parts of the body where they remain until required. Sometimes, a part of the fat is oxidised into CO_2 and water liberating energy as in the case of carbohydrates.

Beside their chief function which is the production of energy, fats may also take part in the building of protoplasm, particularly cell membranes.

FUNCTIONS OF THE LIVER

There are several functions of the liver which are : -

1. Secretion of bile containing bile salts which help steapsin to split fats easily.

2. Formation of urea, where deamination of amino acids takes place.

3. Formation of glycogen from the monosaccharides absorbed by the action of enzymes.

4. Desaturation of fats, because stored fat when required by the tissues cannot be used directly, but must be unsaturated by removal of hydrogen and prepared for its final break down into CO_2 and water.

5. Maintanence of body temperature brought about by the size of the liver and the numerous metabolic activities in it which cause the blood passing to be raised in temperature.

6. The liver acts as a store for vitamins, especially vitamins A and D.

7. Formation of **fibrinogen** and **prothrombin** which are important for blood clotting.

CIRCULATION IN MAN

The transport of blood material and oxygen to all parts of the body as well as the removal of carbon dioxide and other waste products from the cells and their delivery to the proper excretory organs to be eleminated, are carried out by the **circulatory** system which consists of two closely associated systems namely the **blood** and **lymphatic** systems.

BLOOD SYSTEM

This system is essentially composed of the **heart, arteries, veins** and **capillaries.** The **heart** is the central pump of propulsion of blood. The **arteries** are the vessels which come out of the heart and carry the blood from it to the other parts of the body. The **veins** are the vessels coming back to the heart, carrying the blood to it. The **capillaries** are a network of minute tubes that connect the terminations of the small arteries or **arterioles** to the commencements of the small veins or venules.

THE HEART

The human heart (Fig 32a) is a hollow muscular organ of a somewhat conical shap lying between the **lungs** and is enclosed in the **pericardium.**

It is composed of four chambers, two **auricles** (right and left) and two **ventricles** (right and left). Such division is indicated from outside by grooves. The auricles are separated from each other by **inter-auricular** groove and from the ventricles by **auriculo-ventricular** groove. Also the two ventricles are separated from each other by an **inter-ventricular** groove. Internally, the two auricles are separated from each other by an **inter-auricular septum** while the ventricles are separated by an **inter-ventricular** one.

In the right auricle two **vena cavae** open, one superior in the upper part and one **inferior** in the lower one. In the left auricle, four **pulmonary veins** open, two on either side. The opening between the right auricle and the right ventricle (auriculo-ventricular) is guarded by a **tricuspid** valve, while the opening between the left auricle and left ventricle is guarded by a **bicuspid** valve called **mitral** valve. Both valves are connected to muscular ridges in the wall of the ventricle called **columnae carneae** by means of cords called **chordae tendineae.** From the front end of the right ventricle, comes out the **pulmonary artery** which goes to the lungs, while from the left ventricle arises the **aortic arch** which

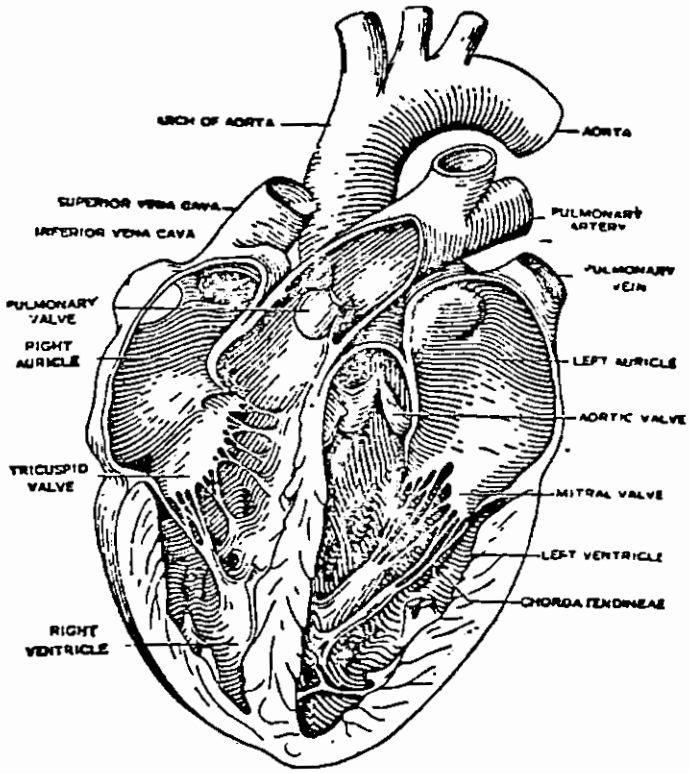


Fig. 32 (*a*) — Human heart shown in longitudinal section.

passes to the different parts of the body. The opening of each of these two vessels is guarded by three semilunar valves.

The pulmonary artery divides to supply the two lungs, and the aortic arch gives rise to arteries which pass to the various parts of the body.

HEART BEATS

The contractions of the muscular wall of the heart is known as the **heart beats.** The state of contraction is called **systole** and the state of relaxation is called **diastole.** In man the two venticles relax during the contraction of the auricles. This process is repeated regularly about 70 times per minute and this successive movement at regular intervals is called the **rhythm** of the heart. Some authors stated that the rythmic power is located in the heart muscle fibres themselves and this statement is referred to as the **myogenic theory.** Other authors suggested that the rythmic activity represents simple responses to stimuli arising in some

parts of the nervous system and transmitted to the heart muscle through the nerve fibres. This statement is referred to as the **neurogenic theory.**

The neurogenic theory is based on the fact that there are nerve ganglia scattered in the body wall of the heart. However the myogenic theory is supported by the following facts : -

1. The ganglia may be removed from the frog's heart without altering the automatic contractions of the heart.

2. The ganglia may be paralysed by nicotine without disturbing the heart bearts.

3. A small portion of cardiac muscles entirely free from ganglia may be seen to contract rythmically.

4. The heart in the developing chicken begins to contract on the second day of incubation before the appearance of nerve cells which take place after the fifth day.

5. Isolated cardiac muscles in tissue culture outside the body show rythmic contraction.

FACTORS AFFECTINC HEART BEATS

In general there are three main factors affecting the heart beats. These factors are the following :

1. Nerves

Both the **vagus** and the **sympathetic** nerves have a great influence. The vagus is inhibiting while the sympathetic is accelerating.

2. Chemical substances

Certain chemical substances have effects similar to those of nerves, e.g. adrenaline accelerates the heart beats as the sympathetic, while **muscarine** causes slowing of the heart beats as the vagus nerve.

3. Temperature

Temperature has also its effect on heart beats. Warming of the heart quickens the rythm and cold slows it.

HEART SOUNDS

Listening to the heart by a **stethoscope,** two sounds can be heard **Lubb** and **Dup.** The first sound (**Lubb**) is caused mainly by the contraction of the ventricular muscles which will force the anterior region of the

heart against the chest wall and also by the closure of the auriculo-ventricular valves.

The second sound (**Dup**) is caused by the closure of the semilunar valves, found at the beginning of the aortic arch and pulmonary artery.

BLOOD VESSELS

There are two main types of blood vessels, arteries and veins (Figs. 32 b and c).

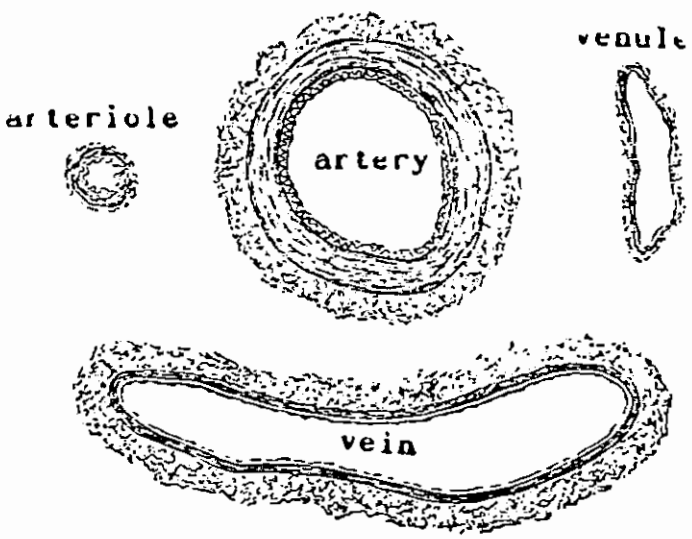


Fig. 32 (*b*) — Transverse sections of different blood vessels.

(*a*) Arteries

These are the vessels which come out of the heart whether they carry, oxygenated or deoxygenated blood. Their wall is thick. Histologically they are composed of the following coats as shown in fig. 32 c.

(i) Outer coat or tunica adventitia

This coat is formed of areolar connective tissue containing **white fibres** as well as **elastic fibres.**

(ii) Middle coat or tunica media.

This coat contains unstriated muscles and elastic fibres.

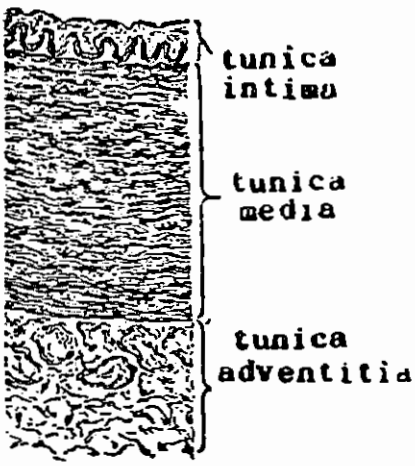


Fig. 32 (*c*) — Portion of a transverse section of an artery.

(iii) **Inner coat or tunica intima**

This is formed of three layers : the **endothelial lining** which makes the lining of the artery smooth and thus the blood may flow with the smallest friction; the **sub-endothelial** connective tissue and an **elastic layer** separating the tunica intima from the media. This layer as generally known as the **fenestrated membrane of Henle.**

In general the elastic fibres are responsible for the flexibility of the arteries and allow for greater expansion to face the high blood pressure to which the large arteries are subjected. White fibres guard arteries against rupture while unstriated muscles are responsible for contraction of the wall of the artery to regulate the quantity of blood passing to different parts of the body.

(*b*) **Veins**

These are the vessels carrying blood back to the heart whether oxygenated or deoxygenated. Their wall (Fig. 32 b) consists of the same three layers as in the artery but the adventitia is much thicker in comparison to other layers, if compard to that of the artery. Here, the layers are less elastic than those of the arteries. Their lumen is also wider. In the limbs, veins have valves arranged in such a manner to allow the blood to flow toward the heart only and not in the opposite direction.

(*c*) **Capillaries**

These are minute blood vessels in which the arteries and veins begin and which form a delicate network around the tissues of the body. They

are very thin consisting of one layer which is the inner **endothelial** layer (Fig. 32 b). Such a case permits transudation or oozing of lymph and the interchange of gases.

THE PULSE

The sudden expansion of the arteries, during systole gives rise to an impulse, felt over the artery, called the **pulse.**

This can be detected most easily over the radial artery at the wrist where this vessel is superficial. The rate of pulse is an indication to the rate of heart beats and the tension of the pulse, that is to say the pressure necessary to stop the pulse is an indicator of the blood pressure. The average pulse rate is 72 per minute. This may differ considerably in different individuals and under different conditions. For instance, it is increased during muscular exercises or anger and fear.

FUNCTIONS OF BLOOD

The main functions of blood can be summarized as follows :

1. It conveys the nutritive food substances to the different parts of the body.

2. It carries away the waste products from the different tissues to the excretory organs to be eliminated.

3. It carries O_2 from lungs to tissue cells and CO_2 from tissues to lungs again.

4. It distributes hormones to the different places to bring about co-ordination of the various parts of the organism, thus serving as a control of the various metablolic processes.

5. It equalises the body temperature.

6. It protects the body from bacterial infection and from different toxins.

7. When the blood vessels are injured it protects the body from loosing blood through haemorrhage by forming the blood clot.

8. It keeps the tissues under balnaced physiological conditions by furnishing them with the necessary salts.

CIRCULATION OF THE BLOOD

The circulatory system is closed in all vertebrates that is it does not open into tissue spaces or coelomic cavity. During the beating of the heart,

the auricles contract simultaneously and the ventricles contract immediately afterwards. During the contraction of the auricles, the deoxygenated blood passes from the right auricle to the right ventricle, and the oxygenated blood goes from the left auricle to the left ventricle. On contraction of the ventricles the deoxygenated blood in the right ventricle is pushed towards the lungs via the pulmonary artery while the oxygenated blood goes to the different parts of the body through the aortic arch and its branches.

From the different regions, the deoxygenated blood recollects and is poured in the right auricle through the superior and inferior vena cavae..

The blood is kept circulating in one particular direction by means of the valves present between the auricles and ventricles and also at the beginning of the pulmonary and aortic arches.

BLOOD TRANSFUSION

When more than 40% of human blood is lost over a short period of time, intravenous injection of blood or some artificial solution is necessary for the maintenance of life. This process is generally known as **transfusion** which when the injected material is blood. If the injected material is fluid the process is called **infusion.**

It must be noticed that not any one's blood could be used in transfusion. Great care must be taken for the choice of the **donor** (the person who will give blood) and the **recipient** (the receiver) otherwise death may occur.

The donor must be healthy, free from infection and of a suitable blood group otherwise agglutination or aggregation of blood corpuscles into clumps may occur.

Agglutination is due to the interaction between substances called antigens or agglutinogens found in the corpuscles and substances found in the plasma or serum called **agglutinins** or antibodies. Two agglutinogens called A and B may exist in the human red cells and these can react with two agglutinins called α and β found in the plasma or serum. The cells of an individual may contain one or both agglutinogens or none at all and similarly for agglutinins of the plasma or serum.

Individuals, thus fall into groups A, B, AB or O. The blood with A cells contains the β-plasma that with B. contains α plasma while that with the O group contains α and β-agglutinins in the plasma.

Thus when the sera of one group are mixed with the corpuscles of the other groups the results are as in the following table :

(+ = agglutination, — = no agglutination).

Donor			Recipient			
			Serum group			
	Corpuscles group	Serum group	O	α	β	$\alpha\beta$
			Corpuscles group			
			AB	B	A	O
	A	β	—	+	—	+
	B	α	—	—	+	+
	AB	O	—	+	+	+
	O	$\alpha\beta$	—	—	—	—

From this table it clear that corpuscles of group O are not agglutinated by the plasma of any group and thus group O are called "**universal recipients**".

BLOOD PRESSURE

This is the pressure under which the blood is flowing. The easy the blood can be foreced in the arteries, when it receives the least resistance from the periphery of artery, the lower will be the blood pressure.

Variation in the strength of the muscles in the wall of the arteries is one of the main factors raising or lowering the blood pressure. If the arterioles are constricted the pressure rises but if they are dilated the pressure falls.

Since the flow in the arteries and arterioles is continuous, it follows that at each heart beat the pressure in the whole of arterial system must rise as more blood entered it during systole. During diastole the blood pressure is less than that during systole but the difference in blood pressure during systole from that during diastole is not so great since the extra blood flowing into the arterioles is accomodated partly but not entirely by the distension of the arteries. The actual values of blood pressure in man are as follows : -

Systolic pressure is about 120 mm. Hg.

Diastolic „ „ „ 80 „ „

The difference between the two pressures is called the **pulse pressure.**

Thus the arterial blood pressure depends on :

1. The output of the heart.
2. Elasticity of the arteries.
3. Peripheral resistance.
4. Viscosity of blood.

The blood pressure rises during exercise owing to increase of the cardiac output and constriction of the arterioles.

As age advances, the walls of the blood vessels lose their elasticity. This loss of elasticity causes a rise in the systolic pressure. The diseased vessels are not capable of resisting the increased pressure and so they may break when occurring in the small arteries of the brain. This causes the condition of "**cerebral haemorrhage**".

BLOOD CLOTTING (COAGULATION)

A great variety of theories have been proposed and all are in agreement with the following facts : —

1. Plasma contains all the substances necessary for clotting.
2. Blood does not clot in normal blood vessels.
3. The essential factors in clotting are **fibrinogen** and **thrombin** and the secondary factors which govern the formation of thrombin are **prothrombin** and **thromboplastin** (thrombokinase) and **calcium** ions.

The most efficient theory which can be explained here for blood clotting is perhaps that of Howell.

Briefly, **fibrinogen,** which is a soluble form of protein found in the plasma, is converted into **fibrin** through the action of an enzyme-like substance called **thrombin.** Fibrin is precipitated as a network, thus enclosing the corpuscles and blocking the injured place. That blood does not clot in the vessels is correlated to the fact that thrombin is found in an inactive form called **prothrombin. Heparin** was found to be the cause that stops the change since it is united to prothrombin. In case there is a wound, **thrombokinase** or **thromboplastin** is liberated as a result of the blood platelets and combines with heparin thus liberating **prothrombin.** Prothrombin changes to **thrombin** in the presence of **calcium ions** that precipitate- **fibrinogen** as fibrin. This process can be summarised as follows :

Prothrombin — heparin complex
↓ thromboplastin
Prothrombin + heparin — thromboplastin complex
↓ Cā
Thrombin + fibrinogen — fibrin

LYMPH SYSTEM

This system comprises independent group of vessels that carry the colourless or slightly yellowish clear fluid called **lymph.** Lymph like tissue-fluid is derived from blood by exudation or oozing or filtration through the thin walls of the capillaries, and resembles blood closely with the exception that it contains much less proteins and has no red blood corpuscles. Lymph system differs from blood system in the point that its vessels serve only to return fluid towards the heart. There are no arteries, only capillaries and veins. The lymphtic capillaries resemble blood capillaries but they are closed at one end. In other words they start blindly (Fig. 33). Lymph diffuses into capillaries (**lymph capillaries**) from the surrounding tissue fluid and these capillaries connect to form **lymph veins** which empty into larger veins, the biggest of which drains into the left shoulder veins of the blood system. So one can say that fluids reach the tissue cells by one way or route only of the arteries, arterioles and capillaries of blood circulatory system.

But there are two possible return ways, one via the blood capillaries and veins and the second via the lymph capillaries and veins. At the point where the lymph vessels join, one gets what is known as **lymph nodes.** These are aggregations of cells which manufacture lymphocytes and act as a filter to filter out dust particles and bacteria which may be of danger to the body.

SECRETION

This is a process by which various kinds of secretions, usually of use to the body, are produced by glands. These glands are of two main types : **exocrine** or **duct glands** which secrete directly to outside or into a cavity and **endocrine or ductless glands** which have no ducts and their secretions pass directly into the blood stream.

EXOCRINE GLANDS

These glands vary greatly in character of their products. For instance, they may be of digestive value such as the tubular glands of the stomach, pancreas, liver, intestinal and salivary glands which secrete digestive fluids or they may be of protective value such as as the mucous glands which secrete mucus. Also they may be nutritive in function such as the mammary glands which secrete milk.

Sometimes, they may be poisonous and used for defensive or offensive purposes such as the poisonous glands of the frog or the scorpion.

ENDOCRINE GANDS

These are ductless glands whose secretion either passes directly into the blood stream or into the cerebro-spinal fluids.

In higher vertebrates and man, endocrine glands include : —

1. Glands found in the alimentary canal, in parts of either the gastric or intestinal mucosa. 2. Pancreas. 3. Thyroid. 4. Parathyroids. 5. Suprarenal or adrenal (epinephric). 6. Gonads including testes and ovaries. 7. Pituitary. 8. Placenta and 9. Thymus.

The **pineal** was previously thought as an endocrine gland but there is no clear evidence to support this view.

The secretions of the endocrine glands are generally referred to as **hormones**. These **hormones** are chemical messengers carried by the blood to the different parts of the body where they cause stimulation in some organs or inhibition in others or may modify the action of some particular organs.

PROPERTIES OF HORMONES

1. They are not rendered inactive by boiling. In this respect, they differ from enzymes.

2. They are dializable, i.e., they pass easily through membranes.

3. Many of these substances are instantanous (for a short time) in their action. In this respect they act in a way similar to many of the drugs.

4. None of these substances cause the formation of antibodies within the body when introduced from a foreign source.

GASTRIC AND INTESTINAL HORMONES

These hormones include : (*a*) gastrin, (*b*) enterocrinin, (*c*) secretin, (*d*) pancreozymin, (*e*) cholecystokinin and (*f*) enterogastrone.

(*a*) Gastrin

This hormone is secreted from pyloric mucosa, and its secretion is stimulated by the presence of food, particularly meat and soup, in the stomach. The target organ here is the mucosa of the fundus part of the stomach which is stimnlated to secrete the gastric enzymes.

(*b*) **Enterocrinin**

This hormone is secreted by the stomach mucosa to stimulate the secretion of the intestinal juice from the duodenum.

(*c*) **Secretin**

This hormone is secreted by the duodenal mucosa. It is found in the cells of the duodenal mucosa in an inactive form called **prosecretin.** By the presence of acid food in the duodenum, it is stimulated to be secreted as active **secretin.** The target organ is the pancreas which is initiated to secrete its pancreatic juice.

(*e*) **Pancreozymin.**

This hormone is secreted by the intestinal mucosa to stimulate the secretion of the pancreatic juice.

(*a*) **Cholecystokinin**

This hormone is secreted by the duodenal mucosa. Its target organ is the gall bladder. It initiates the contraction of the muscular wall of the gall bladder and relaxation of the muscles of the valve controlling the bile duct, thus leading to the passage of the bile into the intestine.

(*f*) **Enterogastrone**

This hormone is secreted by the duodenal mucosa. Neutral fat is the stimulus for secretion and the stomach is the target organ. This hormone leads to the decreased motility of the stomach and secretion of hydrochloric acid.

PANCREAS (Fig. 33)

Histologically the pancreas consists of two kinds of tissues. The first tissue consists of pancreatic **acini** and each acinus is made of pancreatic cells. These elements form an **exocrine type** of glands responsible for secreting the **pancreatic juice** that contains several **digestive enzymes.** The second tissue is collectively knwon **"islets or Langerhans"**. It forms an **endocrine type** of glands. In the islets of Langerhans two types of cells were differentiated, α-cells responsible for the secretion of a hormone known as **glucagon** and β-cells for the secretion of **insulin.**

Both **insulin** and **glucagon** take part in the regulation of carbohydrate metabolism along with certain hormones secreted by the pituitary, adrenal, medulla and adrenal cortex.

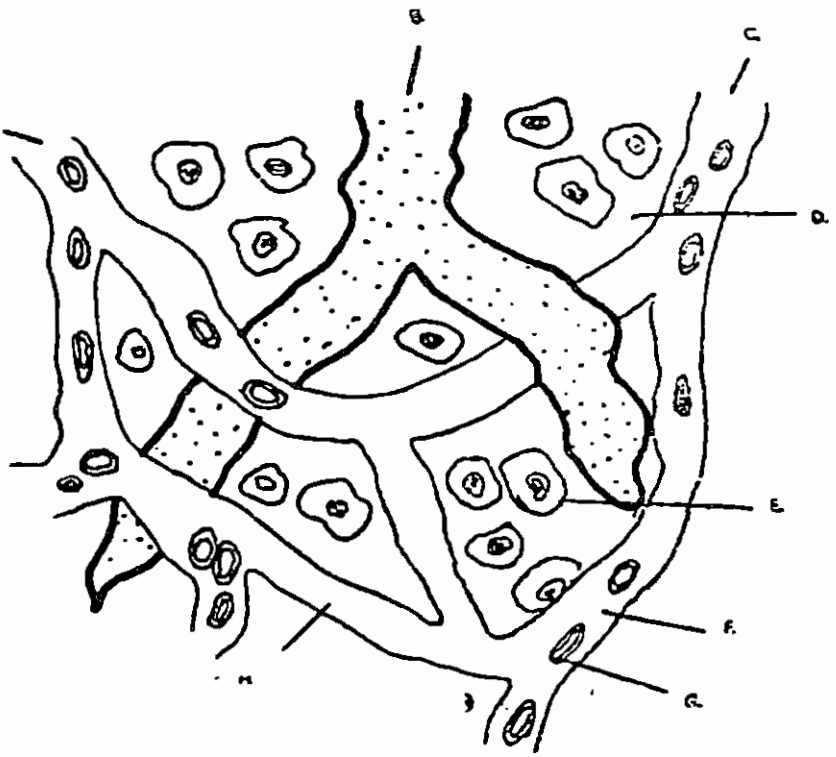


Fig. 33 — Diagram to show the relation of blood and lymph capillaries to tissue cells; *A*) arteriole; *B*) lymph; *C*) venule; *D*) tissue fluid; *E*) tissue cell; *F*) plasma; *G*) erythrocyte; *H*) blood capillary.

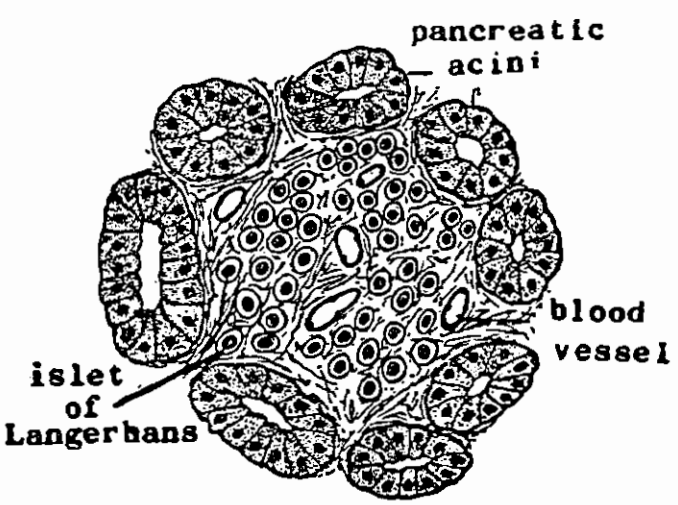


Fig. 33 — Portion of a section in a pancreas

Glucagon activates the enzyme **phosphorylase** which is involved in the conversion of liver glycogen to blood glucose and thus raises the concentration of blood glucose to **intra-cellular glucose** —6— **phosphate** and thereby decreasing the blood glucose level, increasing the storage of glycogen in liver and muscle and increasing the metabolism of glucose to carbon dioxide and water. Any disturbance in the **islets of Langerhans** leads to **diabetes mellitus** which results in high concentration of glucose in blood (hyperglycemia) and the excretion of large amounts of glucose in the urine (**glycosuria**).

THYROID (Fig. 34)

This gland is composed of 2 lobes, one on either side of the upper part of the trachea. These lobes are connected by a transverse band called the **isthmus.** The gland is usually larger in children and women than in men. In pregnant women, it becomes still larger. Histologically (Fig. 34), the

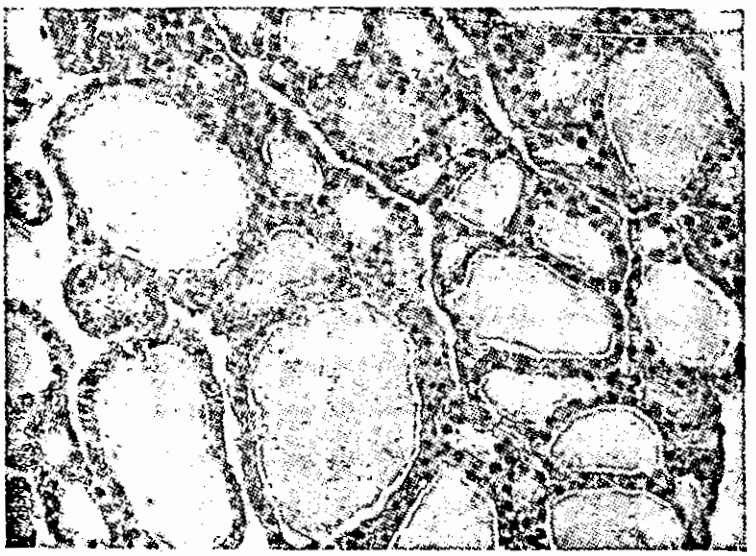


Fig. 34 — Section of thyroid of cat.

gland is surrounded by a capsule of connective tissue from which passes inwards **trabeculae** dividing the substance of the gland into lobules. These trabeculae are rich in blood vessels. Each lobule, in its trun, is made of **vesicles** lined with cubical epithelium. Inside these vesicles, there is a nucleo-proteinous colloidal substance combined with iodine. From this substance an active hormone called thyroxin ($C_{15}H_{12}O_4NI_4$), is derived.

The thyroid gland performs two main functions, the first dealing with

the regulation of the metabolic rate and the second concerns promotion of growth and development. These functions have been concluded from the following observations : —

In the first observation, it was found that in young children **hypothyroidism** (hyposecretion of thyroxin), causes a disease known as **cretinism** and the case itself is known as a **cretin** (Fig. 35). Symptoms of this disease are stopping of mental and physical development of the hild. In adults hypothyroidism leads to a disease known as **myxoedema** characterised by reduction of metabolic rate which causes a storage of fats in the body and dullness of mental capacity (Fig. 36). The suggestion that the above-mentioned manifestations are due to deficiency of thyroid secretion is supported by the fact that when **thyroxin** is orally administered, the symptoms are relieved.

Fig. 35 — A cretin.

Fig. 36 — Myxoedema.

Another type of **hypothyroidism** results when the diet contains insufficient iodine for the formation of thyroxin. In such case the gland itself tends to compensate for the insufficiency by increasing in size. The resulting enlargement known as simple **goiter** may be small swelling or a large mass. The symptoms accompanying this goiter resemble those of **myxoedema** but are much milder. Symptoms of this disease can be relieved by oral administration of iodine.

In the second observation, **hyperthyroidism** (the hyperactivity of the gland) causes acceleration of the metabolic rate whereby the body loses

weight through the reduction of its fat and in addition symptoms of nervous exitability and exhaustion are manifested. Hyperthyroidism brings about the **exophthalmic goiter** (Fig. 37) in which, the increased activity of the gland is associated with the protrusion of eye balls, acceleration of pulse rate, excessive sweating and loss of weight. The validity of the above mentioned symptoms is supported by the fact that when the gland is partially removed the disease is relieved.

Fig. 37 — Exophthalmic goitre.

PARATHYROIDS (Fig. 38).

These glands are situated near the upper portion of the thyroid. They are four in number, two on each side. Each gland (Fig. 38), consists of a connective tissue capsule surrounding some epithelial cells of two types : principal and oxyphil cells. It secretes a hormone called **parathormone** or **parathyrin.**

The main function of the **parathyroids** is to regulate the calcium and phosphorus contents by activity of its hormone. The normal calcium content in blood is about 10% mgs. when the parathyroid is overactive, the calcium in blood rises to about 15% mgs. or more. This condition is called **hypercalcaemia** and this excess of calcium is brought about from the bones which accordingly soften and ultimately lead to a rickety condition. In **hypercalcaemia,** there is laso an increased viscosity of blood together with vomiting and finally coma sets and terminates in death.

On the other hand removal of parathyroid or decrease of its activity causes a condition of **hypocalcaemia** which leads to a disease known as

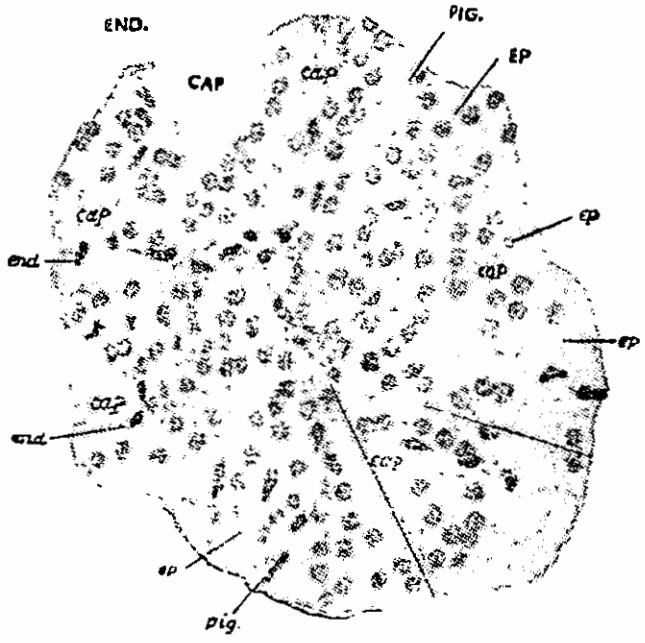


Fig. 38 — Section of parathyroid; ep., secreting epithelial cell; CAP., sinusoids; END, endothelium of sinusoids; PIG. endothelial cells containing pigments.

tetany characterised by tonic spasms of the limbs (successive steady contraction of muscles).

Hypocalcaemia is also associated in grownups, by defective maintenance of bone and teeth while hypercalcaemia and the conditions associated with it can be treated by giving calcium along with an extract of parathyroid.

SUPPRA-RENAL GLANDS (Fig. 39).

In mammals, including man, these small paired glands are located at the anterior end of each kideny. Each gland (Fig. 39), is enclosed by a connective tissue capsule and consists of two parts; an outer pale, yellowish-pink **cortex** and a dark reddish-brown inner medulla. The cortex is composed of three layers or zones, namely, (*a*) outer **zona glomerulosa,** (*b*) middle **zona fasciculata** and (*c*) inner **zona reticularis.** The medulla is composed of cells arranged in irregular cords and masses around the blood vessels. There is a third zone of large mass of cells, interposed between the cortex and the medulla called the **foetal zone.** This is only found in the embryo and causes the enlargement of the gland and after

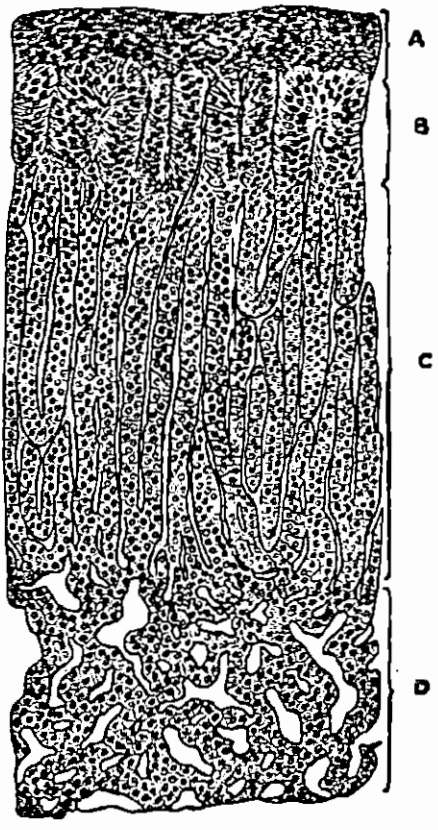


Fig. 39 — Section of cortex of suprarenal glomerulosa of dog;

A) capsule;

B) zona fasciculata

C) zona fasciculata;

D) zona reticularis.

birth it regresses and disappears. From the adrenal cortex some thirty different hormones have been extracted and most of them have been grouped into three categories : —

1. **Glucocorticoids** which stimulate the conversion of proteins to carbohydrates. The most potent is **cortisol** (compound (F) = (17-hydroxy-corticosterone). Besides, there is **cortisone** (compound E) = (11-dehydro-17-hydroxycorticosterone) which releives pains and is used for the treatment of rheumatism.

2. **Mineralocorticoids** which regulate sodium and potassium metabolism. The most potent is **aldosterone.** Also **deoxy-corticosterone** which is an effective regulator of salt and water metabolism and is the most effective in the treatment of **Addison's disease** which is characterised by muscular weakness, vomiting and bronzy pigmentation.

3. **Androgenic steroids** which have male sex hormone activity The

complete removal of the **adrenal cortex** or its hypofunction in Addison's disease results in disturbance of sodium, chloride and water. Enlargement of the cortex and hypersecretion of the hormones is known as **cushing's syndrome.** Females with this disease may develop a pattern of body hair like males.

The **medulla,** on the other hand, produces another hormone called **adrenaline** or **epinephrine** whose effects are : —

1. It raises blood pressure as it constricts the blood arterioles and increases the heart rate.

2. It accelerates the conversion of liver glycogen into sugar and so raises the sugar content of blood and urine. In this respect, it is antagonistic to insulin.

3. It dilates the bronchi of the lung and so it is used in the treatment of broncheal diseases.

4. It causes the hairs to stand on one end in cases of emotion and fear.

GONADS

(*a*) Testis (Male gonad)

The male gonad is composed of three distinct elements each of which is specialized to perform a particular function as follows :

1. The **seminiferous** or **spermatic tubules** which produce spermatozoa and are controlled by the follicle-stimulating hormone of the pituitary.

2. The **Sertoli cells** which exert a nurturing effect toward the spermatozoa.

3. The **interstitial cells** of "Leydig" which secrete the **androgens** or male sex hormones, the most famous of which is **testosterone.**

The male sex hormones or androgens are responsible for the following : - 1. They stimulate the development and maintenance of the secondary male sexual characters comprising growth of the beard, moustache and body hair and deepening of the voice and enlargement of the external genitals. 2. They help in protein building. 3. They stimulate growth at the epiphyses.

A castrated man (Eunuch) has a high pitched voice, beardless face and small genitals. The injection of testosterone into a castrated animal restores all of the sex characters to norma The failure of the testis to descend normally from the body cavity to the scrotal sac, called

cryptorchidism produces sterility but has little or no effect on production of testosterone.

(*b*) **Ovary** (**Female gonad** – Fig. 40).

The ovaries are endocrine organs as well as the source of eggs. They produce female sex hormones or **oestrogens** including :

(i) **Follicular hormones** of which **oestrin** and **estradiol** are the most important. These hormones are secreted by the Graafian follicle. They control he **menestrual cycle.** They also stimulate the changes which occur at sexual maturity as the growth of the uterus and vagina, the development of the breasts, the voice quality, growth of pubic hair and broadening of the pelvis.

(ii) **Corpus luteum hormone** known as **progesterone** or **progestin.** This hormone together with estradiol is required for the growth of the uterine lining, for the maintenance of the developing embryo in the uterus and also for development of the breasts during pregnancy.

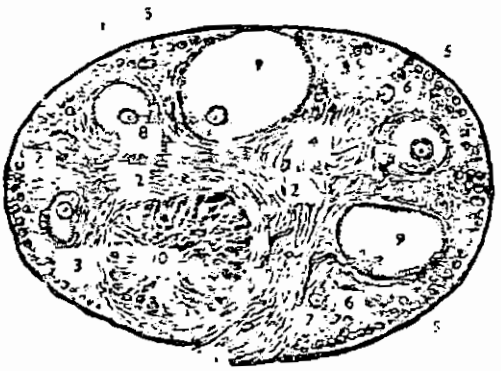


Fig. 40 – T.S. in ovary of cat. 1, tunica albuginea; 1. hilum. 2. stroma; 3. peripheral stroma; 4 blood vessel; 5. young Graafian follicles; 6. 7. 8. more advanced follicles; 9. follicle from which ovum has fallen out n preparing the section; 10. corpus luteum.

PLACENTA HORMONE (CHORIONIC HORMONE)

This hormone is known as **chorionic gonadotrophin** and it is secreted by the placenta during pregnancy. It was noticed to inhibit the secretion of **prolactin** hormone, which is one of the hormones of the anterior lobe of the pituitary, during pregnancy. After delivery this inhibition is stopped.

PITUITARY GLAND (Fig. 41)

This is an ovoid unpaired endocrine gland which is also **called "hypophysis cerebi"** as well as **"master gland"** (Fig. 41). It lies on the ventral surface of the brain, just below the **hypothalamus** to which it is attached by a narrow stalk. Anatomically, it is differentiated into 2 components :

(*a*) **Adenohypophysis** comprising three subdivisions, namely **pars tuberalis, pars distalis** and **pars intemedia,** and these three represent collectively the lobus **glandularis.**

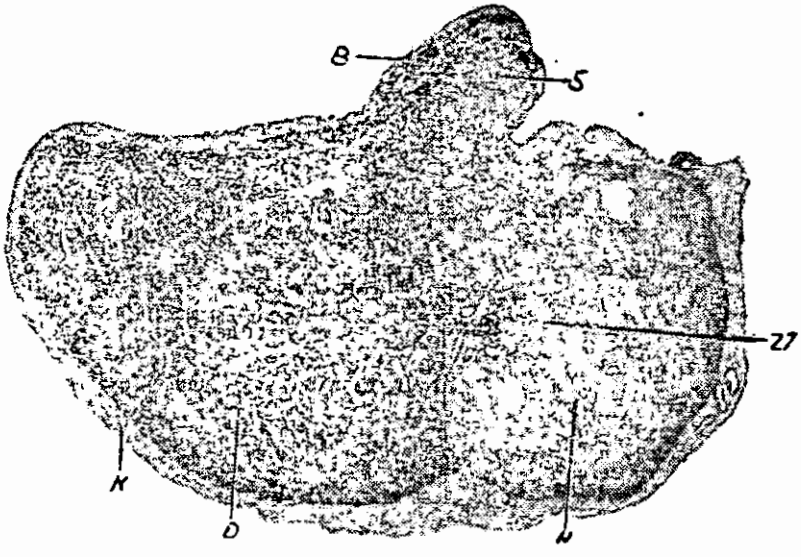


Fig. 41 — Sagittal section through the base of brain and pituitary of cat. (B) pars tuberalis. (D) pars distalis, (K) capsule; (S), stalk; (ZI) pars intermedia, (N) pars nervosa.

(*b*) **Neurohypophysis** comprising two main subdivisions namely **lobus nervosus** which is also known as **pars nervosa,** and infundibulum or neural stalk.

Histologically the **pars distalis** is formed of groups and columns of epithelial cells. About half of these cells are chromophils. The others are **chromophobes.** Among chromophil cells, α-cells and β-cells are distinguished. The α-cells take the acid stain while β-cells take the basic one and the β-cells are also comparatively larger than α-cells. Most of the chromophobe cells have relatively small amounts of cytoplasm. Some authors believe that these cells are chromophils which have lost their

granules and do not like any stain.

The **pars tuberalis** resembles in structure the pars distalis but contains more chromophobe cells. The **pars nervosa** is composed mainly of nerve cells and nerve fibres. The **pars intemedia** is quite small in man and consists of a few rows of basophil granular cells which are usually slightly smaller than those of pars distalis. In addition non-granular cells are arranged in follicles whose lumen is filled with a material which is much like the colloidal substance of the thyroid gland but lacking iodine.

Functions of the pituitary gland

The pituitary gland secretes a great variety of hormones which have the property of exerting a stimulating action on some other endocrines.

Hormones of Pars Distalis (anterior lobe)

1. Growth hormone (phyone),
2. Sex hormone (gonadotropic hormone),
3. Lactogenic hormone (prolactin),
4. Thyrotropic hormone,
5. Adrenotropic hormone,
6. Pancreatotropic hormone.

1. **Growth hormone**

Hyperactivity of the growth hormone in children causes **gigantism** brought about by the great increase in length of the long bones. An individual may reach from 7—9 feet in length. Such development is accompanied by weakness and retarded development of sexual and mental activity. Hyperactivity in adults causes thickening of the jaws, hands, feet, fingers and toes. The result of this uncontrolled growth leads to a horrible deformity. This state is known as **acromegaly** (Fig. 42).

Fig. 42 — Acromegaly

On the other hand hypoactivity of this hormone results in **dwarfism** where bones do not grow to be normal size but remain small as the bones of a child.

2. **Sex hormone**

It was found that subcutaneous transplanation of fresh anterior pituitary glands into young animals leads to early sexual development. As a result the gonads not only mature early but produce sexual hormones affecting development of secondary sexual characters.

The existence of this hormone has been proved by the atrophy of testis or ovary when pituitary is removed. In the female, it stimulates the ripening of the **Craafian follicle** and the development of the **corpora leutea.** In the male it promotes growth of the **interstitial** cells and thereby production of male sex hormones.

In women this gonadotropic hormone is found in urine a few days after fertilization and so its presence or absence indicates pregnancy.

3. Lactogenic hormone

This hormone stimulates lactation of mammary glands. When the flow of milk is unsatisfactory, extracts of **pars distalis** are usually given.

4. Thyrotropic hormone

The hormone controls growth and activity of thyroid gland.

5. Adrenotropic hormone.

This hormone stimulates the medulla of suprarenal gland to secrete its hormone and so raises the adrenal concentration of blood, the blood pressure becomes high and hyperglycaemia occurs. Also the **adrenocorticotropic** stimulates the cortex to secrete its hormones.

6. Pancreatotropic hormone

It is antagonistic in effect to the adrenotropic hormone. It accelerates growth of islets of langerhans and so more **insulin** is put into circulation whereby the blood sugar falls.

Hormones of pars nervosa

The pars nervosa lobe contains a hormone called **pituitrin.** The principal effects which follow injection of this hormone into a normal man or animal are capillary constrictions and a decrease in the excretion of water by the kidney. Also the injection of this hormone into blood stream of a pregnant woman is followed by a contraction of the uterus which just expels the foetus (embryo) and later the placenta. From pituitrin have been isolated two active substances **vasopressin** or **pressor hormone** and **oxytocin** or **oxytocic hormone.** The **vasopressin** causes a general increase in blood pressure when injected intravenouly. This is due to a direct action of hormone that results in constricting muscles of arteries. **Oxytocin** produces contraction of smooth muscles of uterus, bladder, intestine and mammary glands.

Hormones of the intermediate lobe

This lobe secretes the hormone **intermedin** which controls the colour change in lower vertebrates as fishes, amphibians and reptiles.

RESPIRATION

The term respiration is used to refer to those processes by which animal cells utilize oxygen, produce carbon dioxide and convert energy into biologically useful forms. In other words, it comprises the exchange of gases between the cell and its environment.

Respiration may be either direct as in case of **Amoeba** or **Hydra** for example, where the cells of the organisms exchange oxygen and carbon dioxide directly with the surrounding environment, or may be indirect as in higher complex forms where it becomes impossible of each cell of the body to exchange gases directly with the external environment. Accordingly specialized structures of the body are formed and characterised by thin walled semipermeable membranes, so that diffusion could easily occur.

For indirect respiration, fishes, crabs and many other animals develop gills, scorpions have lung books, and higher vertebrates (reptiles birds and mammals) develop lungs.

In indirect respiration, both an external and internal phases can be distinguished : **external respiration** comprises the exchange of gases by diffusion between the blood stream and air by means of lungs for example. The **internal respiration** comprises the exchange of gases between the blood stream and the cells of the body.

STRUCTURE OF THE HUMAN RESPIRATORY SYSTEM

The respiratory system in air-breathing vertebrates and man includes the lungs and the tubes by which air reaches them. It starts by the external **nares** or **notsrils** which open into the **nasal chamber,** and this leads to the pharynx through the internal nares, then to the **larynx** or the **voice** box, which is demarked from the outside as **Adam's apple** and which contains the vocal cords. After this follows the **trachea** characterised by the rings of cartilage. At the level of the first rib, the trachea branches into two cartilaginous **bronchi,** one going to each lung. Inside the lung each **bronchus** branches into **bronchioles,** which in turn branch repeatedly into smaller and smaller tubes leading to the **air sacs** (Fig. 43). In the wall of these air sacs are minute cup-shaped cavities known as **alveoli** just outside of which are thick networks of blood capillaries.

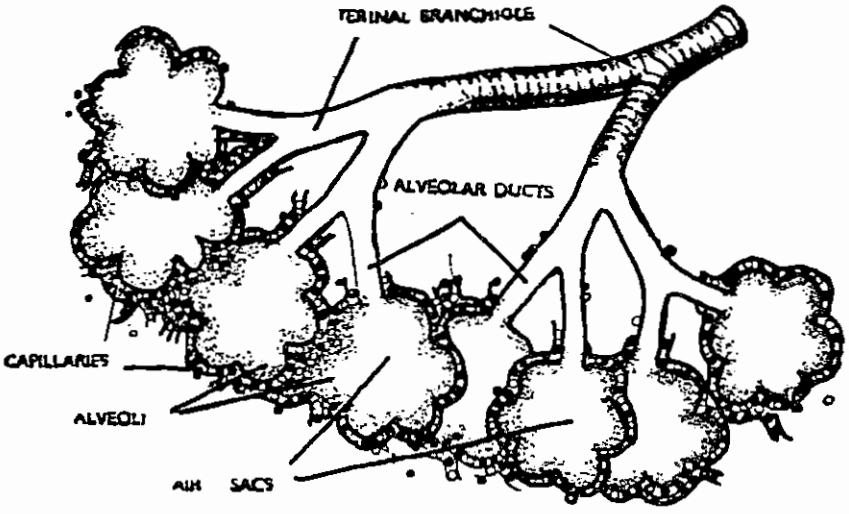


Fig. 43 — Diagram of a small portion of the lung showing the air sacs at the end of the alveolar ducts

MECHANISM OF BREATHING

One must not mix between **respiration** which is the exchange of gases between body cells and the environment and breathing which is simply the mechanical process of taking air into the lungs, **inspiration,** and sending or letting it out again, i.e. **expiration.** In man the breathing cycle is repeated about 15 - 18 times per minute.

During inspiration, the rib muscles contract, drawing the front ends of the ribs upward and outward and the floor of the chest cavity and the diaphragm contracts decreasing its convexity and consequently enlarging the cavity. This increase in volume results in a lowering of the pressure in the lungs and accordingly air from outsides rushes into the lungs when the pressure inside falls below atmospharic pressure. In expiration, the rib muscles relax, the ribs return to the original position and the diaphragm also relaxes to its original convex shape. This decreases the chest volume and allows the distended elastic lungs to contract and expel the air which was inhaled.

TRANSPORT OF OXYGEN BY BLOOD

At rest the cells of man's body need about 50 millilitres of oxygen per minute. After oxygen enters the capillaries in the lungs, it diffuses into the

red blood corpuscles and unites with the respiratory pigment called **haemoglobin** to form oxyhaemoglobin.

$$\underset{\text{purple}}{Hb} + O_2 \rightleftharpoons \underset{\text{scarlet bright}}{Hb\,O_2}$$

The arrows indicate that the reaction is of the **reversible type.** In other words, it can go in either direction. In the lungs the reaction goes to the right to form oxyhaemoglobin and in the tissues, to the left releasing oxygen. The combination of oxygen with haemoglobin and the break down of oxyhaemoglobin are controlled by two factors, primarily the amount of oxygen present and to a lower extent the amount of carbon dioxide. In the lungs the concentration of oxygen is relatively high and thus oxyhaemoglobin is formed. In the tissues, the oxygen is little and accordingly oxyhaemoglobin breaks down releasing oxygen to diffuse to the tissue cells. As regards the carbon dioxide factor, it is known that carbon dioxide reacts with water forming carbonic acid and so an increase in CO_2 increases the acidity of the blood and accordingly decreases the oxygen carrying capacity of haemoglobin. So in the capillaries of the tissues the CO_2 concentration is high and O_2 is released from haemoglobin by the combined effect of low oxygen tension and high carbon dioxide tension.

TRANSPORT OF CARBON DIOXIDE BY BLOOD

Some carbon dioxide is carried in a loose chemical union with haemoglobin as **carbaminohaemoglobin** and a small amount is present as carbonic acid, H_2CO_3, but most of the latter is converted into bicarbonates of sodium or potassium. Carbon dioxide passes from tissues to blood and from blood to lungs by diffusion from a region of high tension to one of lower tension.

The process of converting carbon dioxide into carbonic acid in the capillaries of tissues and of converting carbonic acid into carbon dioxide in lung capillaries is catalysed (speeded up) by an enzyme called **carbonic anhydrase.**

ASPHYXIA

Asphyxia results whenever there is an interruption in the delivery of oxygen to tissues or failure in the utilization of oxygen by tissues. So the cause may lie in (*a*) the lungs, e.g. in drowning when the lungs become filled with water, or in pneumonia when the lungs become filled with body

fluids. Also in (*b*) blood, e.g. in carbon monoxide (CO) poisoning, when haemoglobin unites with CO instead of O_2. Also in (*c*) tissues, e.g. in case of cyanide poisoning where asphyxia is caused by the inactivation of respiratory enzymes (cytochrome oxidase).

EXCRETION

It is a process of eliminating all kinds of waste products which are useless or harmful to the body. The main excretory organs are lungs, liver, large intestine, skin and kidney.

LUNGS

These are considered as excretory organs in addition to their respiratory function. The body gets rid of CO_2 and water by them. Also the disagreable smell from the mouth of some people is due to the fact that gaseous products of intestinal fermentation are absorbed in the blood and circulate with the blood stream to the lungs where they are eliminated.

LIVER

This organ is considered as an excretory organ because it secretes bile which is poisonous and composed of by-products of some food material. It is known that bile salts as **sodium taurocholate** and **sodium glycocholate** are disintegration products of proteins. Also the bile pigments **bilirubin and biliverdin** are disintegration products of haemoglobin found in red blood corpuscles. These waste products or bile pigments will pass into the intestine and are converted by bacteria into **stercobilin** which is excreted for the most part with faeces. Moreover the liver splits up and denitrifies excess of amino acids and converts them into ammonia which is set free into urine. This is passed from liver to blood from which it is removed by kidney. Cholesterols are also excreted.

LARGE INTESTINE

In the large intestine the remains of food are accumulated and fermented. Fermentation takes place because of the growth of anaerobic bacteria. As a result of this fermentation, toxic substances and toxic gases are formed and the rectum (large intestine) gets rid of these toxic substances by driving them with the faeces. If the rectum is inactive constipation takes place and toxins formed circulate with blood and may lead to illness of animal.

SKIN

It is well known that skin is one of the respiratory organs in frogs. This means that it is also an excretory organ since it can get rid of CO_2. Furthermore, in most higher vertebrates including man excretion by the skin is confined to the sweat glands. These glands take from the blood a large amount of water together with traces of proteins, fatty acids and salts, mainly NaCl, which all pass to the surface of the skin.

KIDNEY

In man, there are two kidneys, located in the posterior part of the abdominal cavity one on either side of the vertebral column. Each

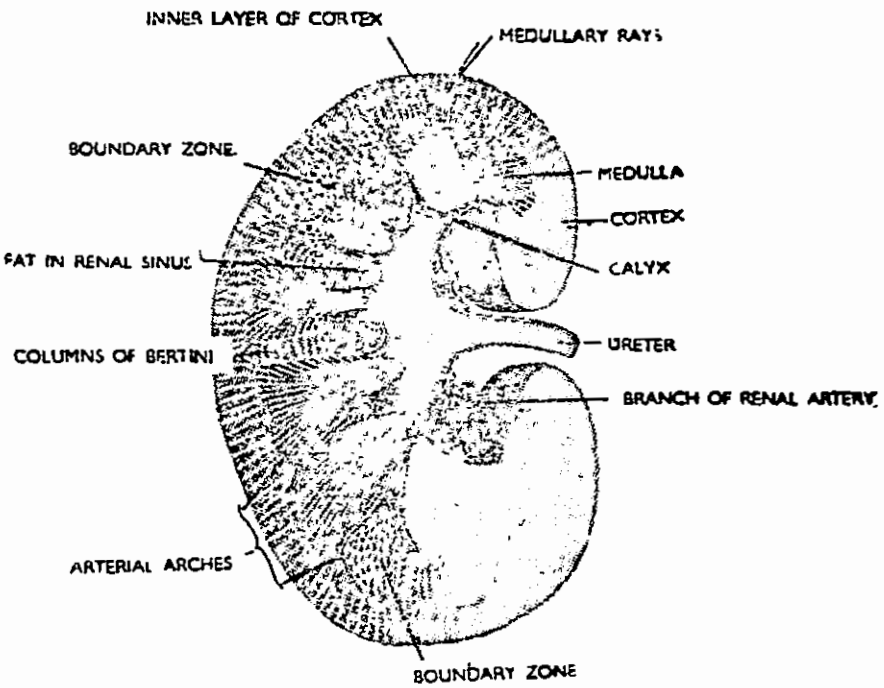


Fig. 44 — Longitudinal section of the human kidney

kidney is in the shape of a bean with an outer, more or less, convex surface and an inner concave one (Fig. 44). From the inner concave surface the ureter emerges leading to the urinary bladder. Also the kidney receives from this edge renal arteries as well as renal veins.

The ureter, at its point of emergence, is dilated and forms the **pelvis.** This pelvis gives rise to two or more branches called the **major calyces.**

These again are provided with a varying number of smaller branches called minor **calyces.** The glandular substance consists of an outer **cortex** and inner **medulla.**

The medulla and cortex, so dissimilar in appearance, are very similar in structure being made up of separate units or nephrons, which are intricate tubules embedded in scanty connective tissue and richly supplied with blood vessels. In the medulla, Malpighian pyramids are found. They are roughly conical bodies placed with their apeces or **papillae** opening in the minor calyces.

In the cortex the nephron (Fig. 45) starts by the **Melpighian bodies** which are composed of a double thin walled sacs called **Bowman's capsules,** enclosing bunches of capillary blood vessels or **glomeruli.** From the Bowman's capsule the uriniferous tubules commence. The first part is a constricted portion or the neck, which leads to a wide convoluted tube, the **proximal convoluted tube.** This will become spiral and enters the medullary structure as a narrow straight tube or the **descending limb of Henle's loop.** This will curve forming the loop of Henle and becomes dilated and ascends forming the ascending limb of Henle. Its course is spiral and again it enters the cortex and becomes irregular and angular in outline and called **zigzag tubule.** This then becomes convoluted form-

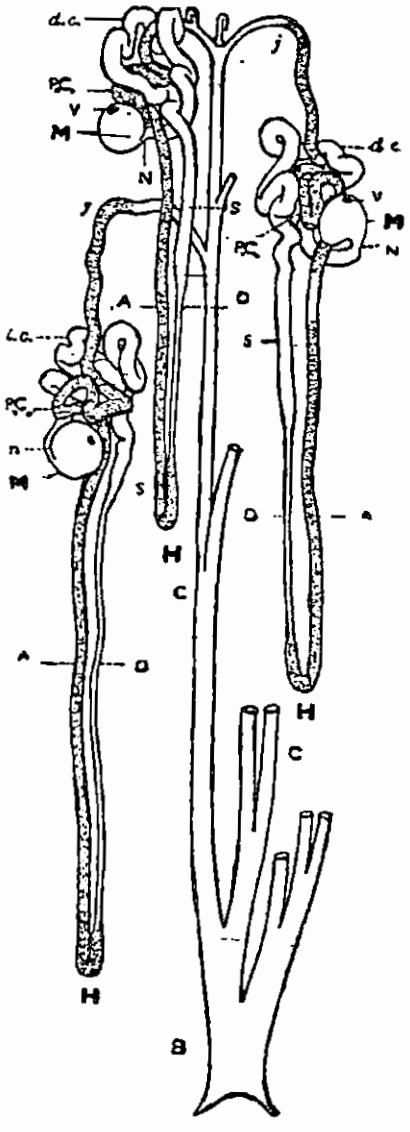


Fig. 45 — Plan of the arrangement of the urinferous tubules; M. Malpighian corpuscles; v, point of entrance of vessels of glomerulus; n, neck; d.c., distal convoluted tubule; (*s*) spiral tubule; (*d*) narrow descending limb of loop of Henle : (*h*) loop of Henle; .1) wider ascending limb of Henle; p.c., proximal convoluted tubule; (*j*) junction tubule; (*c*) collecting tubule; *B*) duct of Bellini.

ing the distal **convoluted tubule** which afterwards diminishes in size and forms the **junctional tubule.** This finally joins a straight tube, the **collecting tubule.** These join others and form the **duct of Bellini** that opens at last at the apex of the pyramid (the papilla).

REGULATORY FUNCTIONS AND URINE FORMATION

The kidney plays a very important role in regulating the composition of the blood and other body fluids. Any excess or acid or base released during metabolic activities, is excreted by the kidney and accordingly a proper pH of the blood is maintained. The kidney regulates the osmotic pressure of the body fluids bathing the cells by regulating the concentration of salts in the blood. Also the kidney regulates the total volume of blood. In case the total amount of blood is decreased, e.g. after haemorrhage, the blood pressure is also lessened and accordingly the fltration pressure is decreased and a smaller volume of urine is produced and thus body fluids are conserved. On the contrary when the blood volume is increased due to uptake of a great deal of liquid, the blood pressure and accordingly the filtration pressure are both raised, a large volume of urine is formed and thus the blood volume is brought back to normal.

As regards the urine formation, opinions differed but the most acceptable view considers the urine formation as a combination of three processes of **flitration, reabsorption** and **augmentation.** Filtration occurs at the junction between the glomerular capillaries and the wall of the Bowman's capsule, where blood is filtered so that water, salts, sugar, urea and all the substances in the blood, except the blood cells and the large molecules as the plasma proteins; pass into the cavity of the Bowman's capsule to become the glomerular filtrate. The mechanism is purely physical and depends upon the fact that the small artery entering the glomerulus is larger than the vessels leaving it. Accordingly the blood pressure in the glomerular capillaries is relatively high and thus help in filtration. As the filtrate passes through the long coiled tubules to the collecting tubules, the cells lining these tubules reabsorb much of the water and also all the glucose, amino acids and other substances needed and secrete them back into the blood. Not only this but also these cells excrete waste materials from the blood stream into the filtrate, a process called **augmentation.**

On reaching the end of the distal convoluted tubule, after reabsorption of some substances and addition of others, the glomerular filtrate becomes urine.

Urine

Urine is an acidic liquid excreted by kidneys. Under normal conditions, it is composed of about 96% water, and 4.0% organic and inorganic components. The organic part comprises, urea, uric acid, ureates, creatine, creatinine and urochrome. Urea represents half of the solids that are about 60 grms. in 1200 to 1500 millilitre of urine excreted daily and it comes from the deamination of proteins. Uric acid is a break down product of nucleic acids, and creatinine comes from muscle metabolism. Urochrome is a pigment that gives urine its yellow colour and comes from break down of haemoglobin.

The inorganic salts are chiefly sodium chloride with small amounts of other salts as, for example, calcium phosphate and sodium sulphate. The amounts and kinds of salts excreted in the urine are controlled by **aldosterone** which is the hormone secreted from the adrenal cortex.

CO-ORDINATION

Co-ordination or control and integration of the organism or body's many activities is brought about by the two systems : (*a*) **Nervous** and (*b*) **Hormone** or **endocrine** systems. Hormones, previously discussed (see p. 123), are principally for internal co-ordination and integration of functions between the various organs while the nervous co-ordination comprises the regulation of responses to stimuli that reach the body via the sensory organs. Nervous co-ordination was noticed to be more rapid and exact than that brought about by hormones.

NERVOUS CO-ORDINATION

Because of the fact that all living protoplasm is irritable or exitable, every organism is sensitive to changes (stimuli) from its environments. To these it responds or answers in ways that varies from the simple action of **Amoeba** to the most complex bodily function or mental process in man. Most animals have a nervous system to perceive stimuli, to transmit these to various parts and to effect responses and co-ordinate the functions of cells, tissues and other parts so that they act harmoniously as a unit. In most protozoan animals (with the exception of some ciliates, e.g. **Paramecium**), there are no specialized structures for co-ordination except the living protoplasm.

In case of **Paramecium** one finds a definite system of fibrils that connect the basal granules of cilia and these granules and fibrils comprise a fibrillar neuromotor or neuromotor system that co-ordinates the ciliary action.

In metazoan animals one finds a nervous system the simplest type of which is the nerve net known in coelenterates and this is quite apart from the centralised or synaptic type found in other higher forms. The nerve net is composed of nerve cells called **protoneurones** with dendrites and they are unlike typical neurones of higher forms in being joined to one another via their protoplasmic processes or dendrites (only physiological contact) also in the finding that conduction is of the diffused or non-polarised type, where impulses are transmitted in any direction. In animals higher than the coelenterates, the principal nervous system is of the centralised type, being composed of neurones. Neurones (see histology of the nervous tissue, p. 92) are of varied forms and the neuron usually has a large cell body, conspicuous nucleus and protoplasmic processes. The neuron may have one dendrite and one axon, thus considered as **bipolar. Multipolar neurones** possess many dendrites and a single axon. The dendrites are often short and commonly much branched forming a tree like arborization or branching. The axon is often long ending with the terminal **arborizations.** Neurones are joined to the dendrites of other cells. This is only a physiological contact known as the **synapse.** In the synapse one can find a **synpatic membrane** that may be doubled in certain cases. The neurones differ from the protoneurones in the fact that the nerve impulses travel in one direction, in other words, the conduction is of the polarised type. Impulses pass from the cell to the axon to the terminal arborization to the branching of the following cell.

Neurones are of several types as follows :

1. **Sensory** or **afferent** neurones, which carry impulses from the sense organs through the nerves to the brain or spinal cord.

2. **Motor** or **efferent** neurones which carry impulses from the brain or spinal cord through the nerves to the muscles and other effectors of the body.

3. **Connectory** or **intermedial** (correlation, association or adjustor) neurones, which lie entirely within the C.N.S. and are interposed between the other two.

REFLEXES

These are responses that may be either simple, compound or of the chain type.

The **simple** is a two neuron reflex and is very rare. It is called the **simple reflex action.** The neuronal pathway along which the impulse travels is called a **reflex arc** and involves : 1. a **receptor** to receive stimuli, 2. a **sensory neuron** or **afferent** for the transmission of impulse from the receptor to the grey matter of the spinal cord, 3. a **motor neuron** or **efferent,** that carries the **impulse** to the effector, 4. an **effector** that may be a muscle or a gland, (Fig. 46).

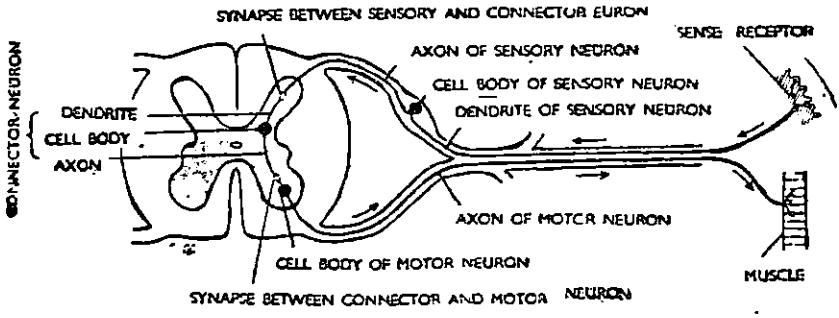


Fig. 46 — Diagram of a reflex arc showing the pathway of an impulse.

Examples of this simple two-neuron reflex are : -

(*a*) The familiar knee jerk, when the human leg is bend and suspended freely, the leg jerks forward.

(*b*) Winkling of the eye lids when an object is thrust before the eyes.

(*c*) The sudden secretion of tears by the tear glands when a bit of dust lodges on the cornea.

The majority are **compound** reflexes wherein an impulse entering on one sensory neuron influences several motor neurons through intermediate or adjustor neurones, or impulse of several sensory neurones are compounded to act on one motor neuron.

According to Pavlof, reflexes were divided into : -

(*a*) **Inborn** or **unconditioned reflexes,** and

(*b*) **Acquired** or **conditioned reflexes.**

The first type is invariable and fixed by inheritance, e.g. defaecation,

lactation, scratching etc. The second or acquired type is brought about by training and is specific to the trained aniaml only and this reflex is conditioned to follow upon some environmental stimulus other than the original inborn one that evoked it.

REPRODUCTION

It is an important characteristic of living organisms that involves the production of new individual and by this means races or organisms are preserved. The process of reproduction varies from one kind of animal to another, but two basic types, the **asexual** and the **sexual** can be distinguished.

ASEXUAL REPRODUCTION

This process involves only a **single parent** which splits, buds or fragments to give rise to two or more individuals. The splitting of the body of a parent termed as **fission** may be **simple binary fission** in case the body of the parent simply splits into two, more or less, equal daughter parts. Many protozoan animals multiply by this process that may be sometimes of the longitudinal type as in case of **Trypanosoma.** (Fig. 98).

Sometimes the splitting is of a **multiple fission.** or **sporulation.** This mothod accurs in sporozoan animals as **Plasmodium,** where the nucleus of the parent body divides repeatedly and then the cytoplasm subdivides so that a part of it surrounds each of the many daughter nuclei. (Fig. 113).

Budding is another form of asexual reproduction in which a new individual arises as an outgrowth or bud on the parent's body, either taking up an independent existence or becoming a more or less independent member of the colony. This process occurs in **colelenterate** animals as **Hydra.** (Fig. 137).

A third form of asexual reproduction is **fragmentation** that occurs in some flat worms as Turbellaria and comprises the break of an individual into two or more parts — as many as several hundreds — each of which develops into a new individual.

SEXUAL REPRODUCTION

By this process, most animals increase. It is a process in which **two sex cells** (also known as **germ cells** or **gametes**), join to produce a new individual.

The male sex cell, in multicellular animals, is called a **sperm or a spermatozoon,** while the female is known as **ovum.** The gametes of various animals differ in form and size.

The ovum is spherical or oval and nonmotile. Spermatozoa are small, motile and able to swim in fluid, usually thread-like although some are amoeboid or of certain peculiar shape. Those of man are 52 to 62 μ long. The sex cells are produced in sex organs known as **gonads,** the male gonad that produces the sperms is called **testis** while the female gonad that produces the ova is called **ovary.**

Both ovaries and testes are considered as primary sex organs and they form in association with each other accessory genital structures or reproductive system which are either male or female.

When both male and female reproductive systems are in one individual, as in so many lower animals (**coelenterates,** flat **worms,** etc.), the animal is termed **monoecions** or **hermaphrodite** and **sometimes bisexual.**

In other invertebrates and practically all vertebrates, animals are unisexual and each individual is either male or female; in other words, sexes are separate and such animals are **dioecious.**

FERTILIZATION

This is a process comprising the union of a mature spermatozoon and an ovum to form a **zygote** or fertilised egg. The process involves the physical entery of the sperm and also physiological processes in both egg and sperm. A sperm cannot cause the fertilization of an immature egg.

Fertilization is usually species-specific and only in exceptional cases will a foreign sperm fertilizes an egg.

Some recent experimental work suggests that the outer portion of the egg secretes a substance called, **fertilizin,** to which the sperm reacts in effecting fertilization.

Types of fertilization

There are two main types of fertilization, i.e. **external** and **internal.** They are performed in so many ways. In external fertilization, there is no definite copulation and the meeting and union of gametes takes place outside in the open water where eggs and sperms are shed freely (in case of

many invertebrates and most of the aquatic animals as marine fishes), or during the simultaneous extrusion of eggs and sperms by the clasped pairs as in the case of toads.

In internal fertilization, definite **copulation** takes place, where sperms are transferred by accessory sex organs of the male to the female so that fertilization occurs within the latter as in the case of nematodes, some mollusces, most of arthropods, some fishes, all reptiles, birds and mammals.

Most animals perform, **cross** fertilization that comprises the combining of gametes from two different individuals. As an exception to this general rule, a few hermaphroditic animals may be **self-fertilizing.**

REPRODUCTION IN MAN

This process is accomplished sexually, in common with that of most animals, with exception to the production of monozygotic identical twins from the splitting of a single fertilized egg which is cosidnered as a kind of **asexual reproduction.**

Fertilization is of the internal cross type. In copulation the penis, inserted in the vagina, ejaculates about 200,000,000 sperms. These sperms travel up the vagina and into the uterus, most of them become lost on the journey, but a few find their way to the openings of the oviducts and swim up them. Sperms can swim against a current and the same current which draws the egg from the abdominal cavity (after it is discharged from the ovary) into the oviduct probably assists them in finding their way. If ovulation has occurred shortly after or before copulation, the egg which passes into the oviduct probably will be fertilized by one of the sperms. Fertilization usually takes place in the upper third of the oviduct. Each human egg is surrounded by a layer of cells, derived from the follicle, called the **corona radiata,** which must be pierced before a sperm can unite with the egg.

The cells of the corona radiata are held together by an organic complex substance known as **hyaluronic acid** which is acted upon by **hyaluronidase.** Since each sperm contains only a small amount of hyaluronidase, it requires the combined supply of several hundred thousand sperms to break down the hyaluronic acid and separate some corona radiata cells in order that one sperm may enter and fertilize the egg. As soon as the egg has united with a sperm, it develops a **fertilization membrane** that prevents the entrance of others. The unused sperms

and the unfertilized eggs die in the oviducts and uterus and are removed by white corpuscles. It was recently found that the sperms can remain alive and retain their ability to fertilize for twenty-four to forty-eight hours at most after having been deposited in the female tract, while the egg loses its ability to be fertilized having about twenty-four hourts after ovulation.

After fertilization, the zygote while passing down the oviducts to the uterus, begins to divide and it takes from eight to ten days after fertilization, until it is implanted in the uterine wall. (Fig. 46 a).

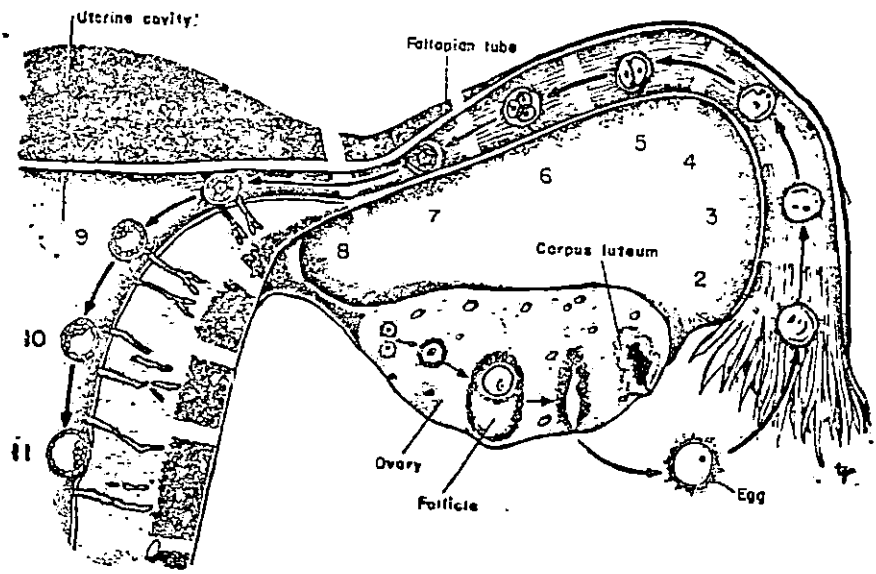


Fig 46 (*a*) — The maturation of an egg in a follicle in the ovary.
1. Its release (ovulation), 2. fertilization in the upper part of the oviduct, (3 : 7). cleavage of the egg as it descends the oviduct, (8 : 10). stages in the development of the embryo in the uterus before implantation, and (11). implantation of the embryo in the wall of the uterus

PART FOUR

EMBRYOLOGY

INTRODUCTION

Embryology is a branch of science which is concerned with the division, growth and differentiation of a fertilized egg into a remarkable complex and interdependent system of organs which is the adult animal.

There are, of course, an enormous variety of different types of embryonic development in the animal world corresponding to the great range of types of adult that are finally produced. However, one can get a good idea of the general problems we have to deal with by considering two or three cases.

HISTORY AND THEORIES OF DEVELOPMENT

The correct interpretation of developmental phenomena rests on the cell theory put forword by **Schleiden and Schwann** (1838-1839). Most of the observations recorded before that time were erroneous and even grotesque. That was due to the lack of microtechnique and the inadequacy of instruments and optic equipments.

At that time two distinct theories took form in the mind of man :

1. **Theory of preformation.**
2. **Theory of epigenesis.**

THEORY OF PREFORMATION

This theory stated that the ovum contains in its substance a more or less perfect miniature of the adult animal and that development consists of the growth of this miniature creature to the adult form. For instance, in the case of human being, the miniature organism as called **"homunculus"** and every ovum of the female was assumed to contain such a "homunculus which by proper stimulation by the seminal fluid would develop into the adult.

2. THEORY OF EPIGENESIS

This theory supposes that many features of the adult are not represented at all in the fertilized egg, but the latter contains only a number of

elements, which react together to produce the much larger number of adult features.

A discussion of the merits of these two opposing views was carried on vigorously for many centuries. Nowadays, the issue ought to be finally settled and understood, since we know that a fertilized egg contains some preformed elements namely the **genes** and a certain number of different regions of cytoplasm and we know that, during development, these interact to produce final adult characters and features that are not individually represented in the egg. In this case, both preformation and epigenesis may be involved in embryonic development. (cf. Waddington, in his book of principles of development and differentiation, 1966).

GAMETOGENESIS

The process of production of gametes is called **gametogenesis.** When this process is concerned with the formation of sperms it is called **spermatogenesis,** but when it is for the production of ova, it is called **oogenesis.**

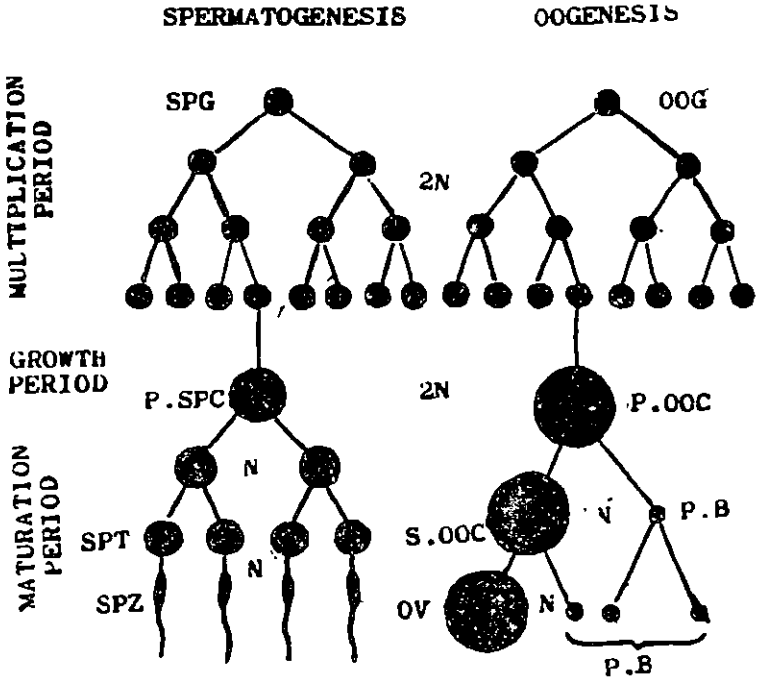


Fig. 47 a. — Gametogenesis : SPG, spermatogonia : OOG, oogonia : P.SPC, primary spermatocyte : P.OOC, primary oocyte : SPT. spermatids : SPZ, spermatozoa : S.OOC, secondary oocyte : OV, ovum : P.B. polar bodies.

In this process, the diploid number of chromosomes (2 N) becomes reduced to a haploid number (N) by two meiotic divisions, and so when fertiization takes place, the diploid number is restored, (Fig. 47 a).

SPERMATOGENESIS

The sperms are formed in the testis from some cells known as the **primordial germ cells.** These cells possess a **diploid number** of chromosomes which can be denoted by the symbol 2N. They give rise to the sperms after passing through three successive periods of development. These periods are, the **multiplication, growth** and **maturation periods** (Fig. 47 a). In the multiplication period, the **primordial germ cells** divide repeatedly by **mitotic divisions** into numerous cells known as **"spermatogonia"**. These cells then enter upon the **period** of **growth** by which the cells increase in size and give rise to the **primary spermatocytes** with the same diploid number of chromosomes.

The growth period is then followed by the maturation one in which the primary spermatocytes undergo two successive divisions referred to as the maturation divisions. The first division is known as the **first meiotic division.** At this division, each primary spermatocyte with the diploid number of chromosomes (2 N) divides into **two secondary spermatocytes,** each containing half the original number (N), i.e. it becomes haploid. Then, at the second maturation division, each secondary spermatocyte divides by the **second meiotic division** into **spermatids** each of which contains a haploid number of chromosomes (N). Thus from each primary spermatocyte, four spermatids are produced, each with a haploid number of chromosomes.

Finally each spermatid gives rise to a **spermatozoon** or **sperm,** the head of which is derived from the nucleus while the tail or flagellum develops from the cytoplasm.

OOGENESIS

Oogenesis is the process by which the ova are formed. The ova are formed in the ovary from **primordial germ cells** which possess a dipolid number of chromosomes (2 N). The primordial cells give rise to the ova after passing through the **multiplication, growth** and **maturation periods** as in the case of spermatogenesis.

At the **multiplication period,** the primordial germ cells divide seperately by mitotic divisions into a large number of cells known as **oogonia,**

each of which possess a **diploid number of chromosomes** (2 N). In the growth period, each oogonium increases in size and modifies into a **primary oocyte.**

Then the primary oocytes undergo two successive maturation divisions following the same plan of the spermatocytes. When the first maturation division is completed, each primary oocyte gives rise by **first meiotic division** to a large cell known as the **secondary oocyte** and a small one on its surface known as the **first polar body.** Each of the secondary oocytes and the first polar body possesses a **haploid number of chromosomes** (N.) In the second maturation division, each secondary oocyte divides again by **second meiotic division** into a large cell which is the mature **ovum** and a small cell known as the **second polar body.** At this division, the first polar body may also divide into **two daughter polar bodies.**

Thus each primary oocyte gives rise to a single mature ovum which is the actual female gamete, and three polar bodies which will soon degenerate.

TYPES OF EGGS.

The cytoplasm of the egg is provided with a certain amount of food material known as **yolk.** According to the amount of yolk the eggs can be divided into two main types : -

1. **Isolecithal eggs** : e.g. of **Amphioxus.** In these eggs, the amount of yolk is very small and is equally distributed throughout the cytoplasm.

2. **Telolecithal eggs** : e.g. eggs of Amphibia, reptiles and birds. These eggs are heavliy charged with yolk which is concentrated near the lower side of the egg. i.e. near the **vegetative pole.** The cytoplasm which is found at the upper pole (or **animal pole**) contains the nucleus of the egg.

The frog's egg is about 50 per cent yolk, whereas the hen's egg is more than 95 per cent yolk, and its cytoplasm is restricted to a small disc at the animal pole. The hen's egg is generally defined as **exagerated telolecithal.**

THE SPERMATOZOA

The spermatozoa of most species are organized according to a definite pattern. One may easily differentiate two main parts, the head and the flagellum (fig. 47 b). The latter is usually composd of several minor divisi-

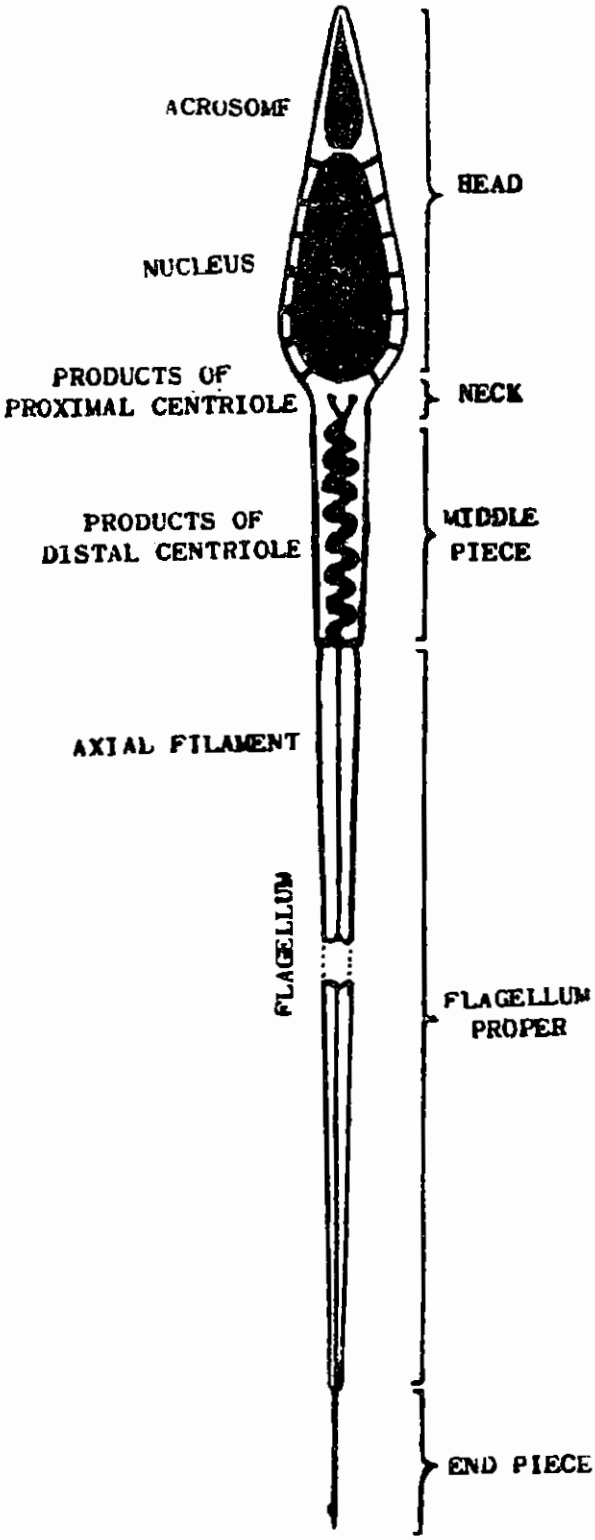


Fig. 47 (b) — A spermatozoon in the mammalian condition.

ons, namely the **middle piece,** the **flagellum proper** and the naked **end piece.** In many spermatozoa, the anterior portion of the middle piece is differentiated into a narrow part containing one of more **centrioles.** This region is called the **neck.**

The head is highly variable in appearance in different species and groups. The chief cellular elements in the head are the **"nucleus"** and **"acrosome".** The acrosome is anterior and some authors referred to it as the **"perforatorium"**, a term which is indicative of its supposed function, namely, the piercing of the ovum.

From one of the centrioles in the neck, arises a slender thread called the **"axial filament"** which forms the central elastic rod of the remainder of the flagellum. It may extend beyond the flagellum to form the **end piece.** The main bulk of the middle piece is composed of one or more **mitochondrial sheaths** which may be granular, ribbon or spiral-shaped.

FERTILIZATION

When the spermatozoa reach the ova, only one spermatozoon penetrates one ovum. The rest of spermatozoa which are very numerous perish. **Fertilization** is the fusion of the nucleus of a spermatozoon with that of an ovum with the result of the formation of a zygote. As each one of these two nuclei contains a haploid number of chromosomes, the nucleus of the zygote contains a diploid number characteristic of the species.

CLEAVAGE OR SEGMENTATION

When the zygote is formed, it passes through a process of successive mitotic divisions. This process is referred to as **cleavage** or **segmentation** and the resulting cells are called **blastomeres.**

Cleavage either affects the entire substances or only a part of the zygote. In the first case, cleavages is known as **"holoblastic"** or **"complete cleavage"** as in **Amphioxus,** while in the second case it is called **"meroblastic" or "incomplete cleavage"** as in **reptiles** and **birds.** In the complete cleavage the ovum contains comparatively little or no yolk, being formed mainly of protoplasmic matter. In the incomplete cleavage, eggs are usually very rich in yolk.

EMBRYOLOGY OF AMPHIOXUS

CLEAVAGE (Fig. 48).

The development of Amphioxus starts with a process of cleavage or segmentation which begins by the division of the fertilized egg by a vertical septum extending from the animal pole to the vegetative one, and divides it completely into two equal cells called **blastomeres.** These two blastomeres divide again by another vertical septum which extends at right angles to the first septum, and thus four equal blastomeres are formed. The thrid division is horizontal and leads to the formation of eight blastomeres, the four lying near the animal pole are small and called **micromeres,** and the other four near the vegetative pole are larger and called **macromeres.** After that, the division goes on regularly, and the eight blastomeres give rise to sixteen then to thirty two, and these give sixty four and so on. These resulting cells arrange themselves in a hollow spherical mass known as the **blastula.** The wall of the blastula is formed of a single layer of cells and known as the **blastoderm,** and its cavity is called **blastocoel.**

GASTRULATION

The blastula represents the last stage of cleavage, and after its formation the developing embryo passes through another developmental process known as **gastrulation.** In **Amphioxus** the first phase of gastrulation is the flattening of the vegetative pole of the blastula. This is followed by the appearance in this flattened region of a small depression which gradually increases in size until the cells of the vegetative pole come in contact with those of animal pole. As a result of this process the blastocoel disappears, and the single-layered blastula is transformed into a double-layered structure known as the **gastrula.** The outer layer of the gastrula consists of **micromeres** and is called **ectoderm,** while the inner layer consists of **macromeres** and is known as **endoderm.** At the inside of the gastrula is found a cavity called **archenteron** or **primitive gut cavity.** It communicates with the exterior by an opening called mouth of the gastrula or **blastopore.** It possesses a dorsal lip and a ventral lip. During gastrulation, cell division also takes place, and as a result of this division the hemispherical gastrula becomes gradually elongated, and the dorsal lip of the blastopore approaches the ventral lip. Thus the wide blastopore becomes transformed into a narrow opening. During gastrulation the cells

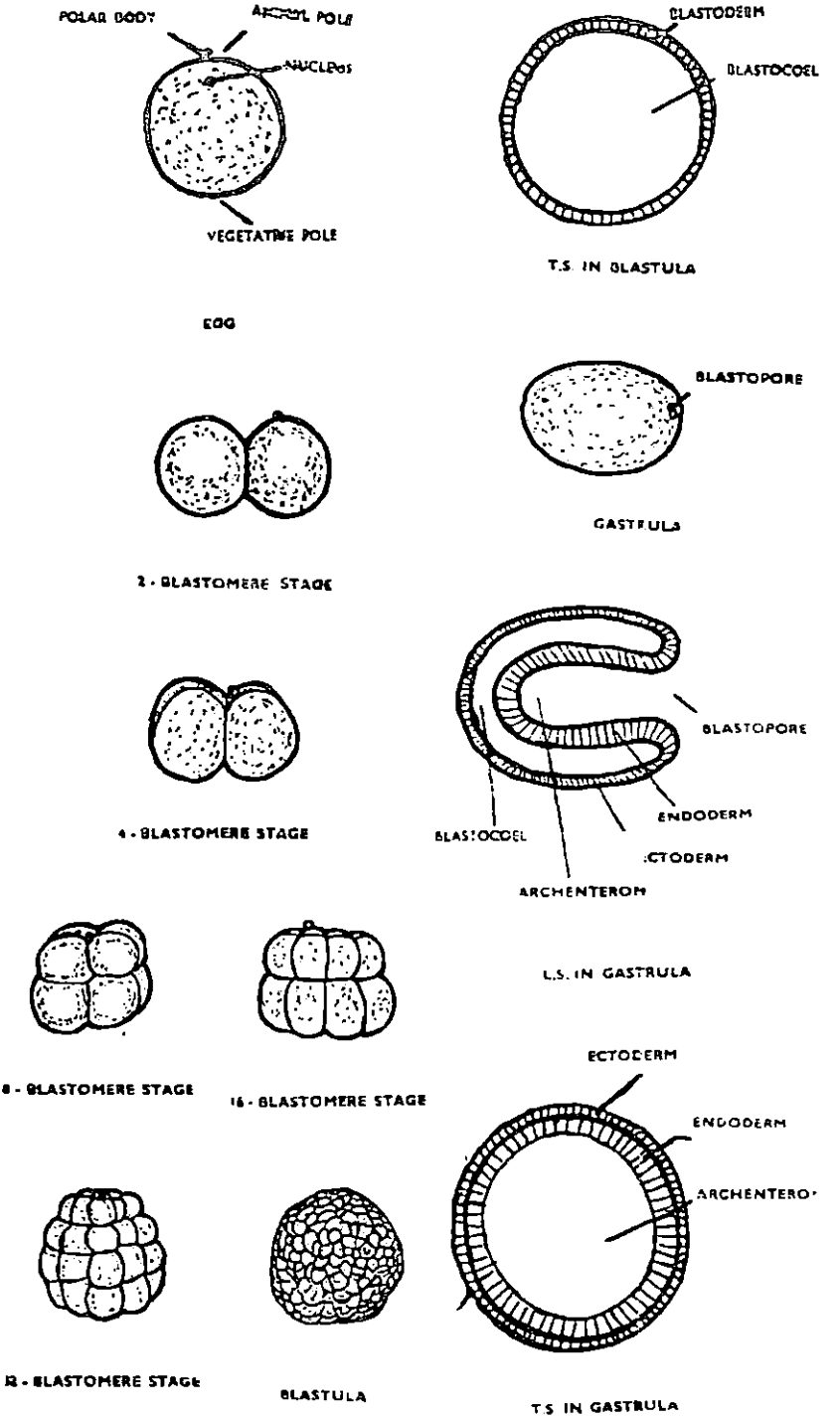


Fig. 48 — Cleavage and gastrulation in Amphioxus

of the ectoderm develop cilia by means of which the developing embryo can move in the sea as a free-living larva.

DEVELOPMENT OF MAIN ORGANS

After the processes of cleavage and gastrulation the main organs of the embryo begin to develop by the differentiation of the primary germ layers which are the ectoderm and endoderm. The central nervous system, develops from a strip of ectrodermal cells extending along the dorsal flattened surface of the gastrula (Fig. 49, A). This strip of cells which is known as the neural plate sinks below the level of ectoderm. At the same time the ectodermal cells on both sides of this plate become slightly elevated forming the neural folds (Fig. 49, C). Then, these folds approach each other until they fuse together in the mid-dorsal line,thus covering the neural plate externally. The neural plate which is originally flat becomes gradually converted into a **neural tube** by the rolling up of its margins until they fuse together in the mid dorsal line (Fig. 49, E). Then, the anterior end of the neural tube becomes slightly enlarged and gives rise to the **brain vesicle,** and the rest of the neural tube forms the **spinal cord.** From these two structures, the peripheral nerves will grow out. The anterior end of the neural tube remains for sometime in communication with the exterior through a minute opening known as the **neuropore.**

The **notochord** develops from a band of endodermal cells forming the roof of the archenteron and lying directly below the neural plate (Fig. 49 B). These endodermal cells are known as the **notochordal plate.** Then this plate becomes curved and is soon transformed into a solid mass of cells. After sometime, the notochord becomes completely separated from the endoderm, whose two margins fuse together in the middle line ventral to the developed notochord (Fig. 49 E and F). This fusion leads to the formation of a tube which is the **gut.** It encloses part of the archenteron known as the gut cavity or **enteron.**

The third layer of the body which will later on form its great mass is known as the **mesoderm.** It is represented in the gastrula by two longitutdinal bands of cells which form the dorso-lateral walls of the archenteron. (Figs. 49 B and C). These bands are known as the **mesdermal bands.** After some time, they become folded and form the **mesodermal folds** which soon become sharply differentiated from both the notochord and endoderm. They surround parts of the archenteron which later on become completely separated from it. Then, the mesoderm folds which are originally continuous structures become divided into a series of paired **mesodermal** somites by means of transverse septa. The first pair of these somites appear at the anterior end of the developing embryo. Then division

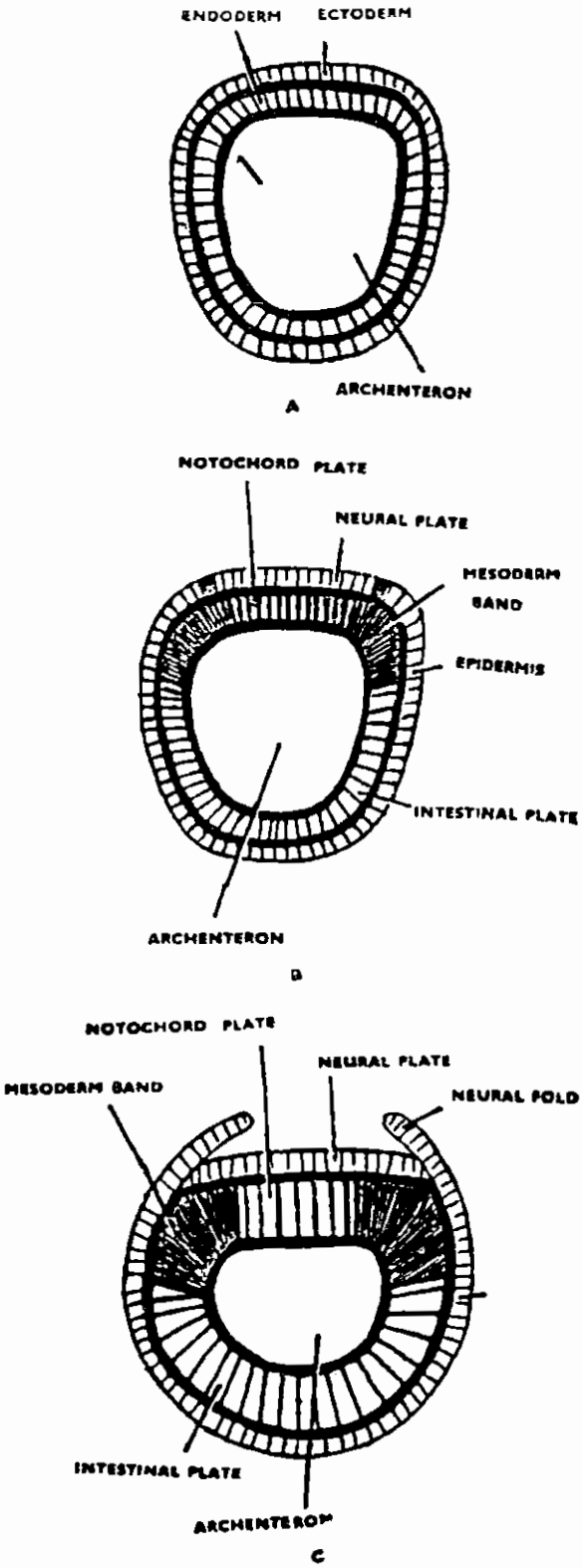


Fig. 49 (*a*)— Development of main organs in Amphioxus, stages A, B and C.

goes on regularly toward the posterior end. Each somite contanis part of the archenteron known as the enterocoel. The appearance of these paired mesodermal somites is the first indication of **metameric segmentation** in adult Amphioxus. As development proceeds, these somites become greatly enlarged and they extend ventrally between the wall of the gut and ectoderm until they meet those of the opposite side in the midventral line (Fig. 49, F.). During this enlargement, the somite becomes differentiated into an upper part known as **epimere** and a lower part known as **hypomere** (Fig. 49, G). The inner layer of the epimere, which is in contact with the neural tube and notochord, becomes thick and forms the **myotome.** Its outer wall which lies below the ectoderm forms the **dermal plate.** The part of the enterocoel lying between these two layers is called myocoel. The hypomere is also differentiated into an inner layer known as **splanchnopleure,** and an outer layer known as **somatopleure,** with a cavity in between which is known as **splanchnocoel.** During development, the septa separating the various splanchnocoels disappear so that they give rise to one continuous cavity which is the **coelem or** body cavity.

The ventral part of the endoderm which remains after the separation of the notochord and splitting of the mesodermal somites becomes closed dorsally forming the **gut.** It is at the beginning a closed tube, then it communicates with the exterior by the mouth which is formed near, its anterior end and the anus which is formed at its posterior end. The gut elongates rapidly and becomes differentiated into a wide anterior part reperserting the **pharyngeal** region, and a narrow posterior part representing the **stomach-intestine** region. Then perforations take place in the wall of the pharyngeal region, leading to the formation of the **gill slits** which put the pharynx in communication with the exterior. During development the pharyngeal region becomes surrounded by the atrial wall which arises from two lateral folds growing toward each other and ultimately fusing together. From the anterior end of the stomach-intestine region a small pouch grows anteriorly to form the **liver diverticulum** which represents the liver of higher animals in a primitive condition.

EMBRYOLOGY OF THE FROG

SEGMENTATION (Fig. 50).

The egg of the frog is considered as a **telolecithal** type as it is provided with a large quantity of yolk which is concentrated at the vegetative pole. It is covered externally by a thin coat of dark pigment which is accumulated at the animal pole. The fertilized egg is subjected first to the process

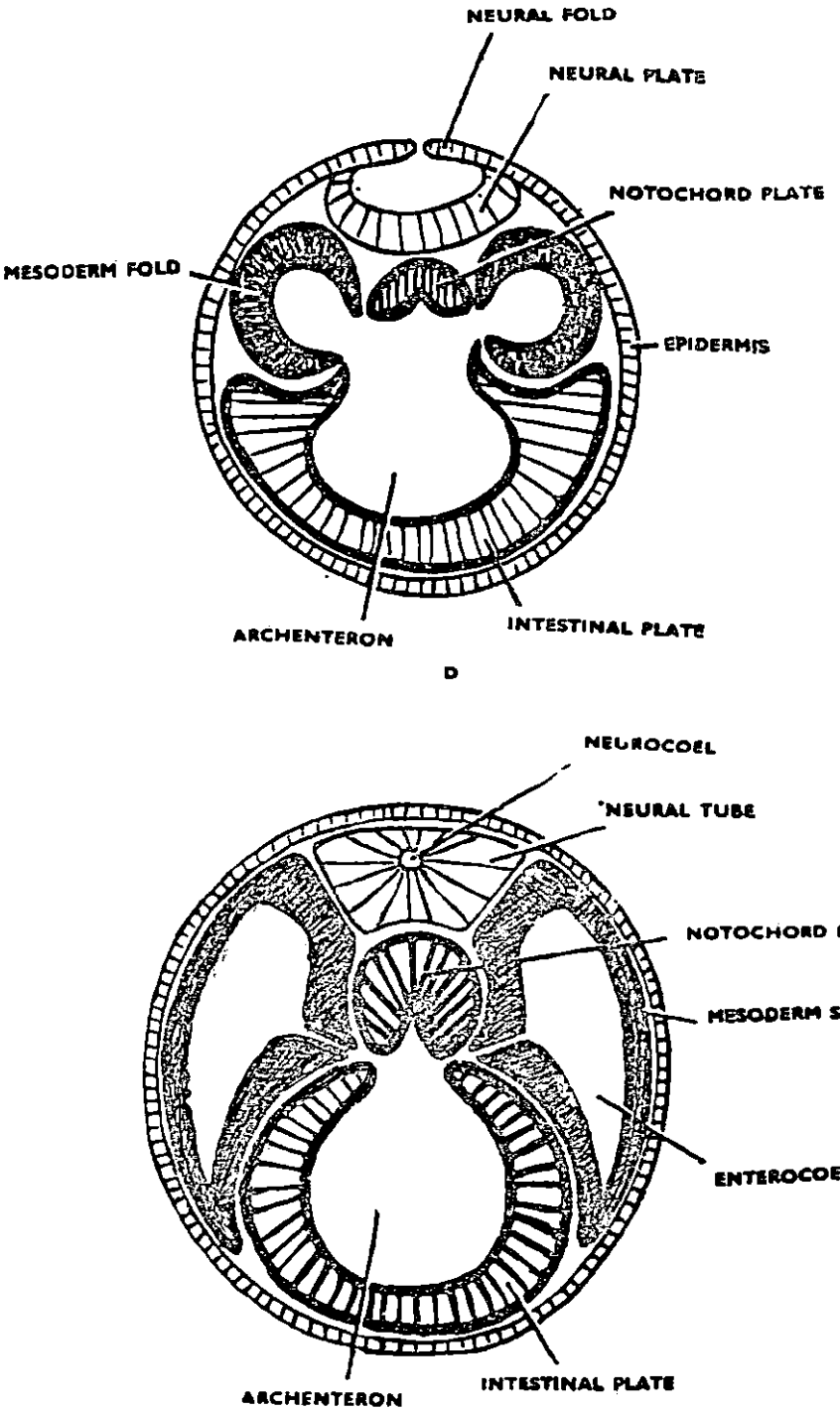
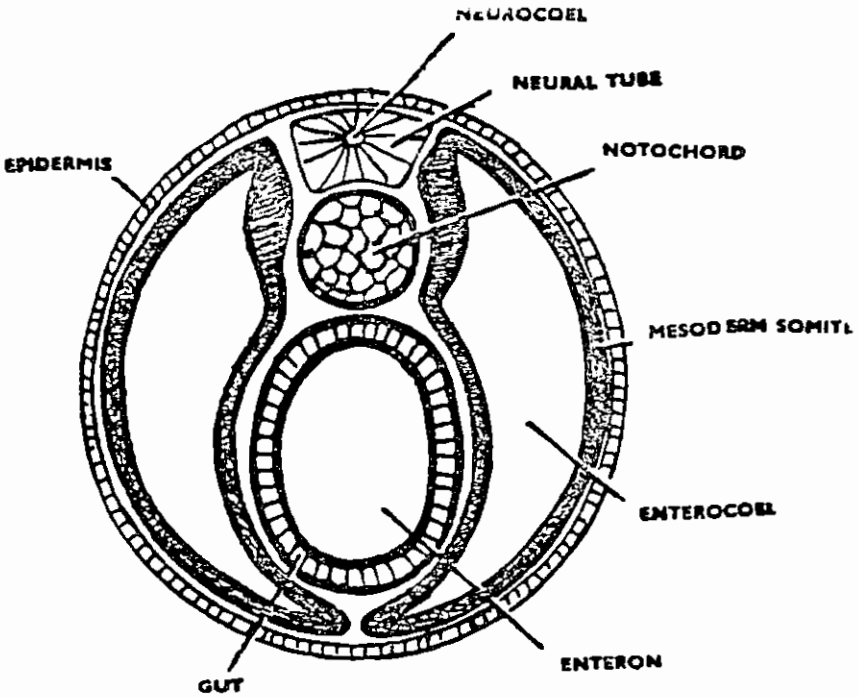
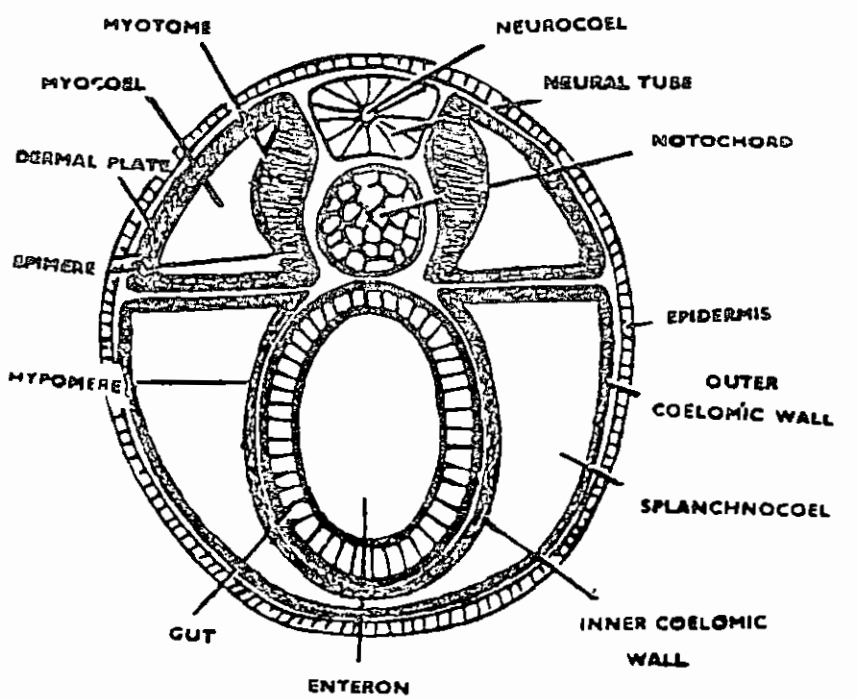


Fig. 49 (*b*) — Development of main organs in Amphioxus, stages D and E.





G

Fig. 49 (*c*) — Development of main organs in Amphioxus, stages F and G.

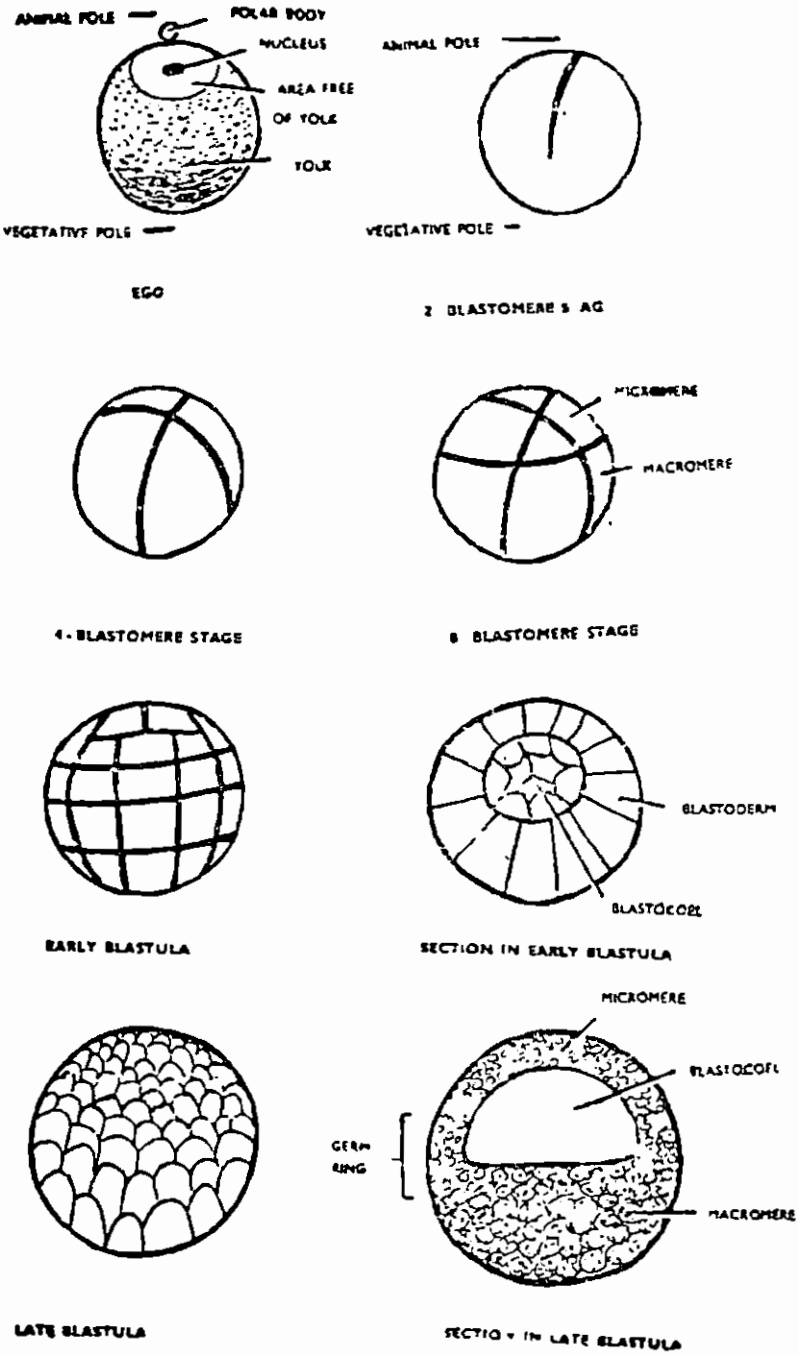


Fig. 50 — Cleavage in the frog.

of cleavage which starts by the appearance of a vertical septum extending from the animal pole to the vegetative one and thus divides the egg into two equal blastomeres. It is to be noted here that such division is relatviely slower in the vegetative pole owing to the accumulation of yolk. The second division takes place by another vertical septum extending at right angles to the first and so four equal blastomeres are formed. The third division is horizontal, and divides the egg into eight blastomeres, but the plane of division is nearer to the animal poes, and thus the eight blastomeres are differentiated into four **micromeres** above and four **macromeres** below. As division proceeds, more cells are produced, and they become arranged in the form of a hollow sphere known as the **blastula.** In the blastula of frog, the segmentation cavity or blastocoel is much nearer to the animal pole than to the vegetative pole, and the early blastula is composed of a single layer of cells, but as division proceeds it becomes composed of several layers of cells and such stage represents the **late blastula.**

GASTRULATION (Fig. 51).

In the frog, the process of gastrulation is greatly modified according to the presence of a large quantity of yolk in the cells of the vegetative pole. The small pigmented cells found near the animal pole representing the micromeres are more rapidly dividing than the larger yolk cells of the vegetative pole or macromeres. This process of overgrowth is known as **epipoly.** While such process is taking place the macromeres are themselves undergoing a process of **invagination** (Figs. 51, A, B and C). Both epipoly and invagination continue to take place until the macromeres are covered by the micromeres, except a small part referred to as the **yolk plug** which protrudes through the **blastopore** (Fig. 51, E). Thus the single layered blastula is transformed into a double-layered **gastrula.** The outer layer is the **ectoderm,** and the inner layer represents both the **endoderm** and **mesoderm.** Inside the gastrula is a cavity which is the **archenteron.**

DEVELOPMENT OF MAIN ORGANS

As in **Amphioxus,** the **central nervous system,** of the frog develops from the neural plate which is the ectoderm extending along the dorsal side of the gastrula (Fig. 52, A). The margins of this plate become thick, and then they become elevated above the general surface of the ectodem to form the two **neural folds.** These neural folds extend upwards and inwards until they fuse together in the mid-dorsal line, and thus trans-

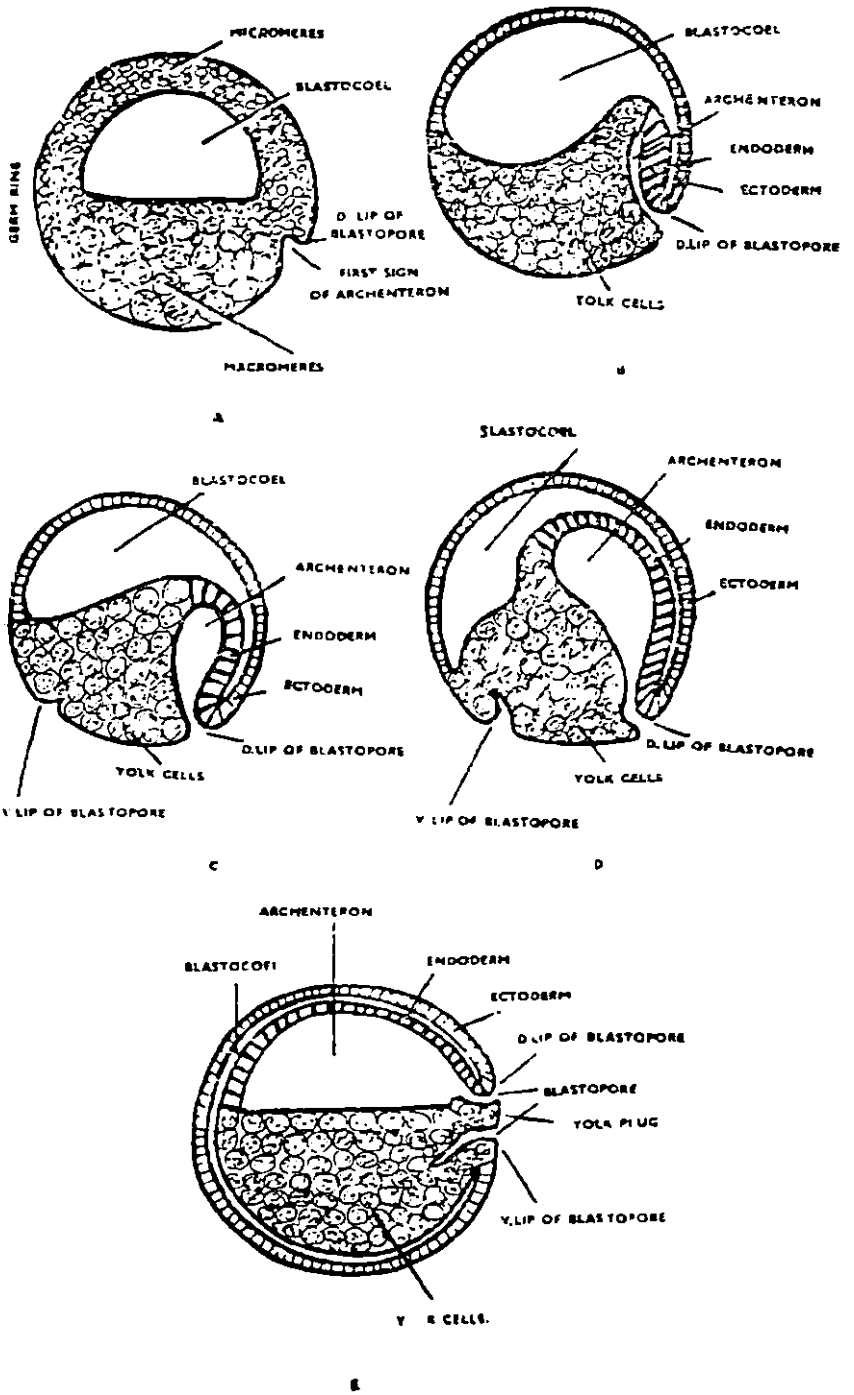
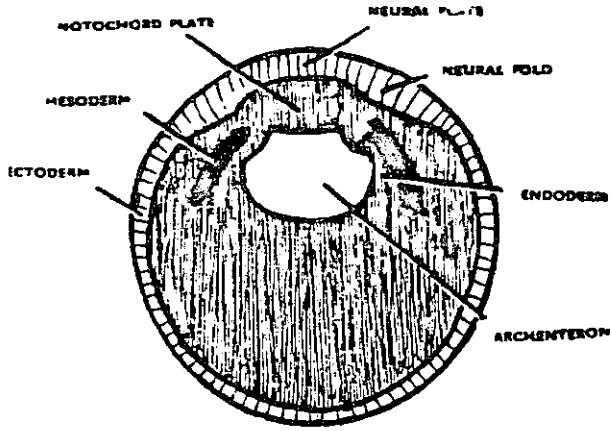
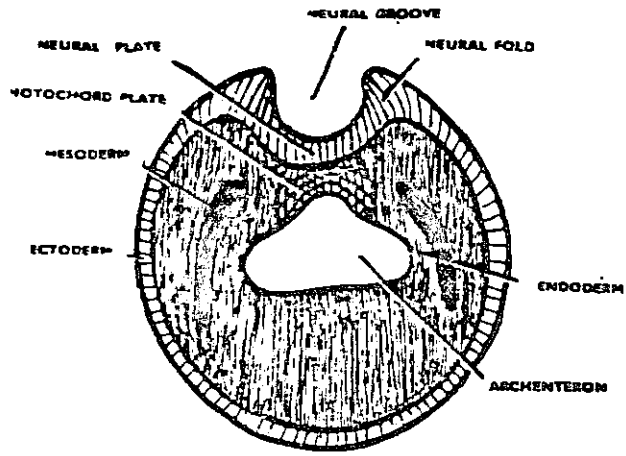
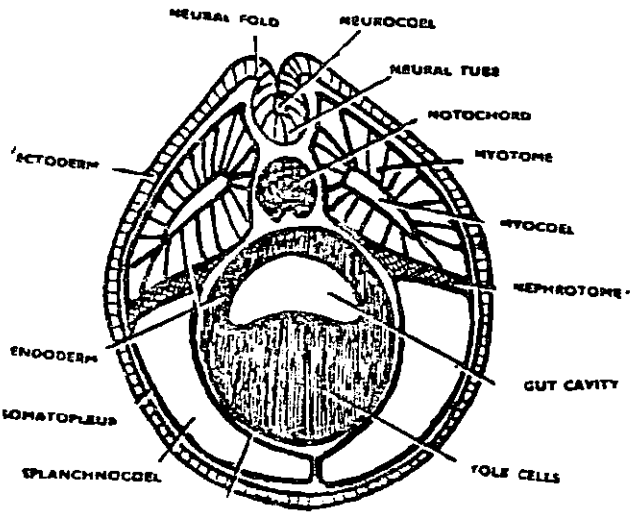


Fig. 51 — Gastrulation in frog.


NOTOCHORD PLATE
NEURAL PLATE
NEURAL FOLD
MESODERM
ECTODERM
ENDODERM
ARCHENTERON


NEURAL GROOVE
NEURAL PLATE
NEURAL FOLD
NOTOCHORD PLATE
MESODERM
ECTODERM
ENDODERM
ARCHENTERON


NEURAL FOLD
NEUROCOEL
NEURAL TUBE
NOTOCHORD
ECTODERM
MYOTOME
MYOCOEL
NEPHROTOME
ENDODERM
GUT CAVITY
SOMATOPLEUR
SPLANCHNOCOEL
YOLK CELLS

forming the neural plate into a neural tube (Fig. 52, C). The place of fusion is marked by a deep groove which remains distinct for sometime. As shown in Fig. 53 the neural tube becomes differentiated into **fore-brain, mid-brain** and **hind-brain,** and the rest of the neural tube gives rise to the **spinal** cord.

The **notochord** arises from a band of endodemral cells extending along the roof of the archenteron. These cells become transformed into a wedge-shaped elevation which later on splits off as a solid rod from the roof of the archenteron (Fig. 52, C).

The **mesoderm** arises by the splitting of a layer of cells from the wall of the archenteron (Fig. 52, A and B.) The remaining part of this wall forms the gut. Soon after the separation of the mesoderm, it becomes differentiated into the typical mesoderm structures. The parts which lie next to the neural tube become aggregated into paired masses of cells forming the mesodermal somites. They are at first continuous with the lateral region of the mesoderm, but later on they become completely separated from it. The lateral region of the mesoderm is known as the **lateral plate.** It is at the beginning a solid mass of cells, but later on a cavity known as the **splanchnocoel** arises inside it. When such cavity appears the lateral plate is differentiated into two layers an outer **somatopleure** and an inner **splanchnopleure** (Fig. 52, C). The splanchnocoel will give rise to the coelom. The parts of the mesoderm originally connecting the mesodermal somites with the lateral plate remain as small masses of cells knows as the **nephrotome,** and will later on form the **urinogenital system.** After the separation of both the notochord and mesoderm, what remains of the wall of the archenteron forms the **gut.**

The cavity of the gut becomes greatly enlarged at the anterior end directly in front of the yolk sac containing the mass of yolk cells (Fig. 53). This enlarged part of the gut will give rise to the **fore-gut** which will later differentiate into the **pharynx, oesophagus** and **stomach.** The posterior part of the gut also becomes enlarged forming the **hind-gut** which will give rise to the rectum. Connecting these anterior and posterior enlargements of the gut, there is the narrow mid-gut containing the yolk cells, and which will form the small intestine.

In the pharyngeal region the **gill pouches** appear as paired lateral evaginations of the wall of the gut, and then become perforated and communicated with the exterior. The gill pouches are separated from each other by the **gill arches,** some of which carry branching outgrowths projecting out from the surface of the body and known as the **external gills.**

The developing embryo in such later stages of development is known as the **tadpole larva** (Fig. 54). It is more or less fish-like in its appearance and it possesses a laterally compressed tail which is used for locomotion. It attaches itself to aquatic plants by means of a special embryonic organ known as the **adhesive organ.**

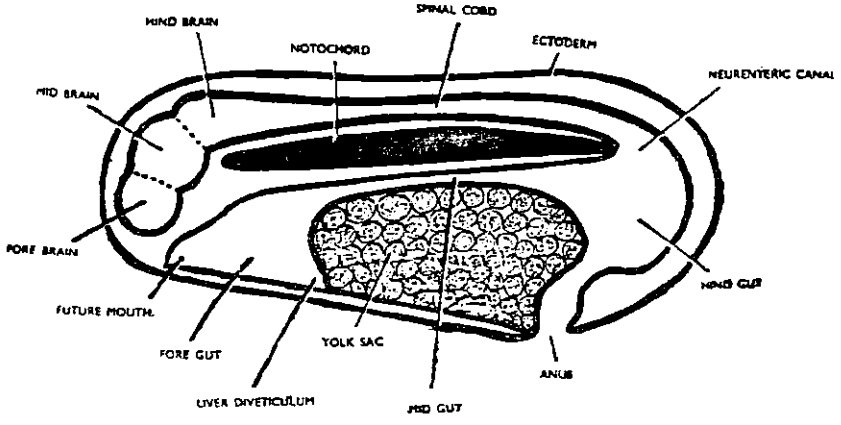


Fig. 53 — Lateral view of a young embryo of frog.

EMBRYOLOGY OF THE CHICK

Structure of the hen's egg (Fig. 55).

In general the term "ovum" in birds is applied to the yolk sphere while the term „egg" is used in its more familiar sense, including the yolk, the albumen and the shell.

In the hen, the ovum proper is only the central spherical yellow portion which is generally referred to as the "yolk". In spite of the large size of this ovum, it is merely a single cell. The ovum has a well-defined animal and vegetative poles and in regard to its yolk disribution must be classified as telolecithal.

The protoplasm of the ovum is a very small amount and it is in the form of a small disc which is called the **germinal** disc. This disc is situated above the surface of the large yolk mass at the animal pole. It is about 3 mms. in diameter.

During the passage of the ovum through the oviduct toward the cloaca, it becomes surrounded by the **white of the egg** or **albumen** which is secreted by the glandular wall. The albumen secreted from the upper glandular portion of the oviduct is thicker than that which is added furth

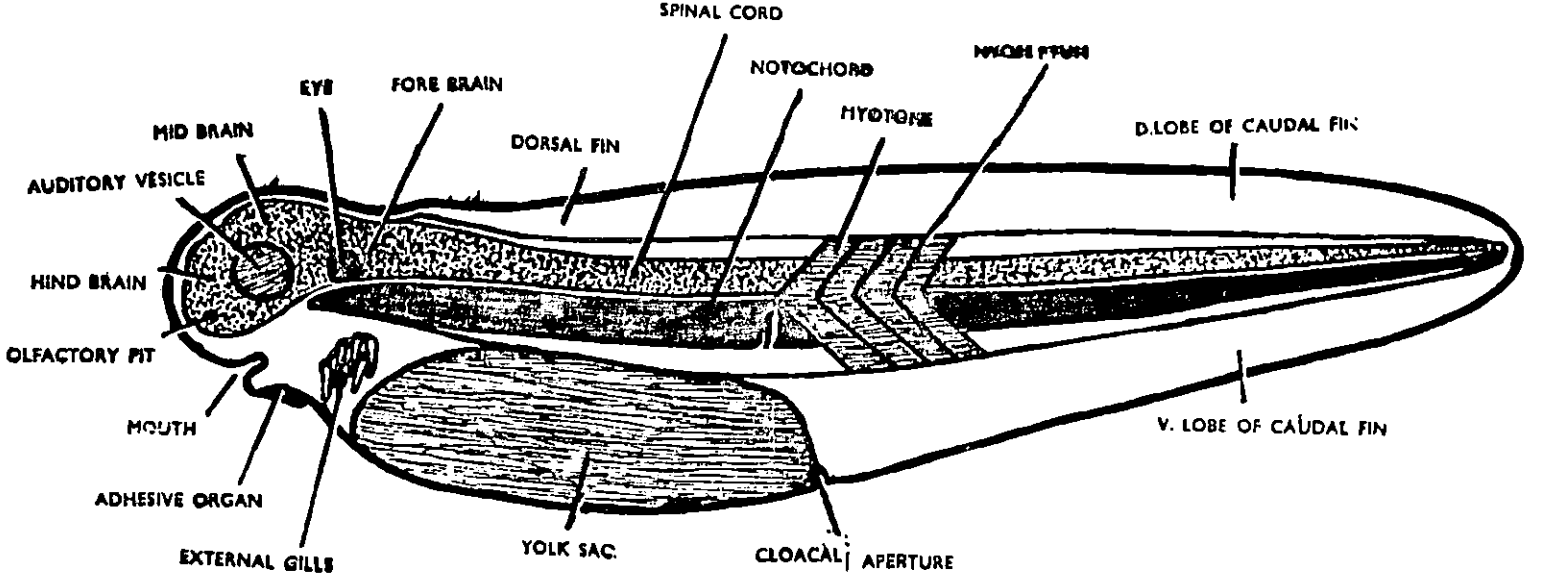


Fig. 54 — Tadpole larva of "Frog".

back. The two ends of the albumen are twisted to form two cords which are called the **chalazae.** They are twisted because the ovum while passing through the oviduct becomes rotated by the spirally arranged grooves and ridges of the oviduct.

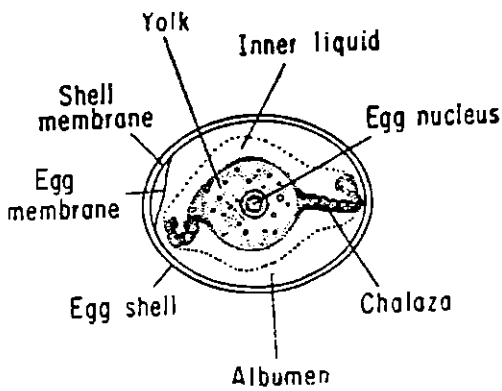


Fig. 55 — Sagittal section through a chick egg.

Around the thin albumen, is found a very thin double membrane which is called the **shell membrane.** Near the broad end of the egg, these two membranes are separate from each other forming an **air space.** Following the shell membrane is found an outer calcium impregnated egg **shell** or **calcareous shell** which is so porous that it can allow the passage of gases and water vapour during the development of the embryo.

Fertilization

Fertilization in the chick occurs in the upper region of the oviduct. The passage of the fertilized egg is slow, lasting approximately 22 to 24 hours. This means that most of the early development, i.e. cleavage and formation of the blastoderm takes place in the body of the hen before the egg is laid.

Cleavage or segmentation (or blastula formation)

As a result of the heavily telolecithal yolk distribution cleavage is limited to the germinal disc. This type of cleavage is **meroblastic** or **discoidal** or **partial.**

As mentioned before, segmentation and blastula formation take place inside the body while the egg is passing through the oviduct. So when the egg is laid, the embryo will be in the blastula stage. Then development stops and the eggs have to be incubated by the female or artificially in an

incubator to make develompent continues. The temperature necessary for incubation is about 38°C.

The first cleavage is initiated by the formation of a **small** vertical furrow near the middle region of the germinal disc. The two first blastomeres formed in this manner do not have complete walls. Their cytoplasm merges with the adjoining and uderlying yolk except where they touch each other.

The second cleavage becomes apparent as a second furrow at right angles to the first.

The third cleavage is initiated by the appearance of two furrows across the second cleavage and at right angles to the first. They are followed by similar furrows across the first cleavage plane so that eight blastomeres are formed.

In the fourth cleavage (Fig. 55 a), each one of the resulting blastomeres divides into a small central cell and a larger marginal one. Then, this process is continued, the small central cells increasing in number by their own division as well as by the division of the marginal cells which add to the central cells. This process is continued until a multicellular **blastodisc** or **blastoderm** having a large number of small central cells and large marginal ones connected together at their edges, is formed. Then, the blastodisc becomes several cells in thickness by cleavage planes which are parallel to the surface. This multicellular blastodisc which is several cells in thickness will be lying just above the surface of the yolk. such a stage may be described as the "**morula stage**".

In later cleavage, the central blastomeres detach themselves from the underlying yolk to form a central shallow cavity which represents the **blastocoele** while the peripheral cells extends into the yolk. When these processes take place the embryo will be in the **blastula stage.** The blastodisc may now be referred to as the blastoderm. (Fig. 55 b)

The central area of the blastoderm which cosnists of the small central cells is called **area pellucida** as this area appears transparent after its detachment from the underlying yolk. On the other hand the marginal area is called **area opaca** because some of the yolk granules are attached to it.

Gastrulation

A second layer is eventually formed over the top of the yolk. This layer, which may be referred to as the **hypoblast,** originates from cells that have left the original blastodisc.

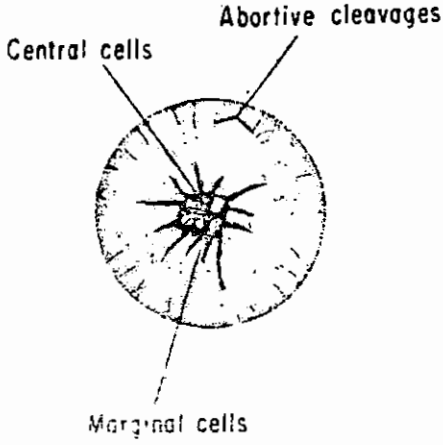


Fig. 55 *(a)* — Early cleavage in a hen's egg.

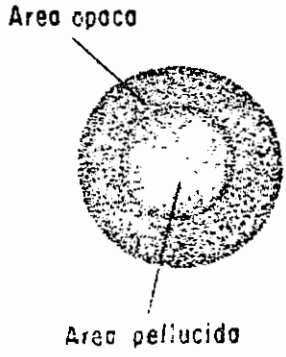


Fig. 55 *(b)* — Dorsal view of the blastodisc after cleavage

As a matter of fact, three primary hypothesis have been advanced to explain the origin of the endoderm :

1. Some investigators believe that cells simply leave the blastodsisc to drift down to the yolk. This is known as the method of infiltration.

2. Others think that the cells of the blastodisc are delaminated, that is, horizontal cleavages occur which separate the original single layer of cells into two layers.

3. A third school favours an involution hypothesis indicating that cells in the peripheral area of the blastodisc turn under and grow over the surface of the yolk as mentioned before.

Formation of the Primitive Streak (Fig. 55 C)

This first indication of a true embryo is the formation of a **primitive streak** (Fig. 55 C). This streak appears directly after the area pellucida

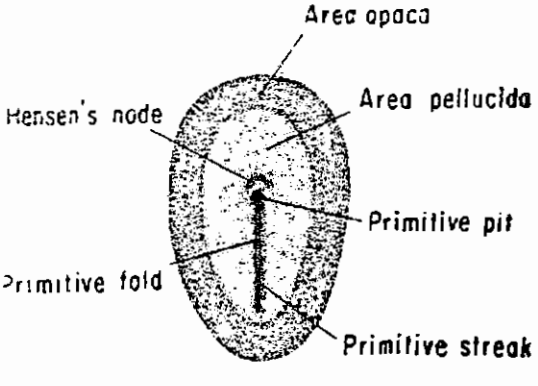


Fig. 55 *(c)* — Whole mount of a 20 hour chick embryo.

becomes two-layered through the extension of the endoderm. At the beginning, it appears as an elongated, slightly thickened band which occupies the posterior half of the area pellucida.

As development proceeds, the primitive streak grows towards the posterior direction whereas its anterior end remains nearly in a fixed position so that the whole blastoderm becomes oval instead of being round. At the same time a groove appears in the middle of its structure. This groove is generally referred to as the **primitive groove.** It is bounded laterally by two elevated folds which are called the **primitive folds.** Anteriorly it has a depressed portion which is called the **primitive pit.**

Just anterior to the primitive streak is an elevation of the ectoderm which is called primitive knot or **Hensen's node.**

24-hour Chick Embryo (Fig 55 d)

In the head region of this stage, the neural folds become quite distinct and closely adjacent to each other posteriorly, The two folds diverge from each other and become less distinct. The notochord becomes clearly seen through the overlying ectoderm.

The mesoderm has already started dividing. It has given three to four mesodermal somites. As development proceeds it becomes

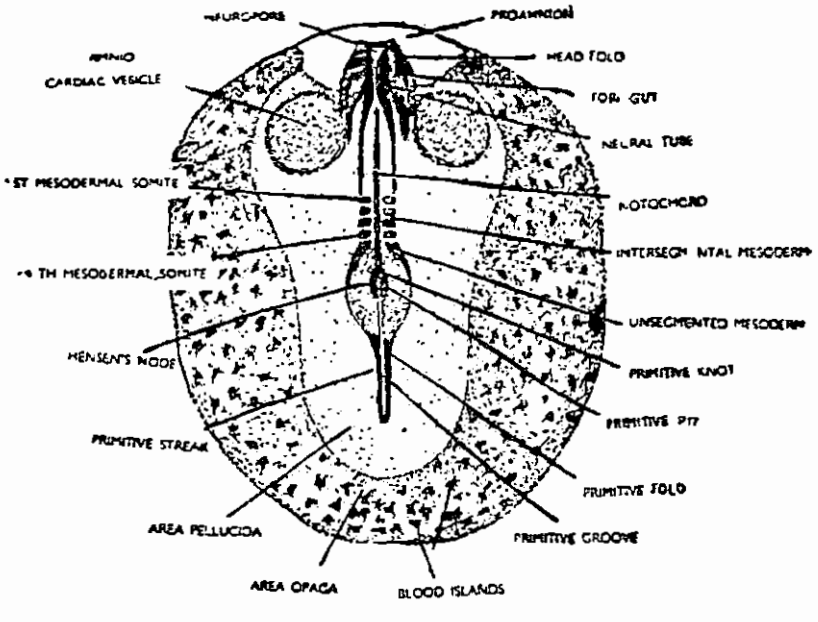


Fig. 55 d. — 24-hour chick embryo.

differentiated into three main parts namely, the axial, intermediate and lateral mesoderms. Then, the lateral mesoderm splits into two layers, the **somatic mesoderm** toward the ectoderm and the splanchnic mesoderm toward the endoderm (Fig. 55e). Between the somatic and splanchnic mesoderms is formed a space which is the **coelom.** The somatic mesodarm and ectoderm form together the **somatopleure** while the splanchnic mesoderm and endoderm form the **splanchnopleure.** Also the axial mesoderm gives rise to the myotomes, and the intermediate mesoderm to the nephrotome.

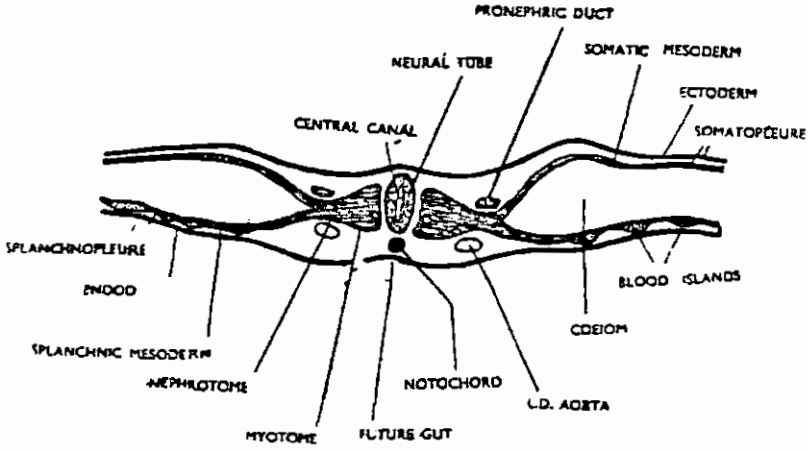


Fig. 55 (*e*) — T.S. of the trunk region of 48-hour chick embryo.

In the area opaca, the mesoderm forms irregular masses of cells known as the blood islands. These islands will, later on, join together to form a network of blood capillaries.

The cavity which lies between the yolk and the endoderm forms the primitive gut.

48-hour Chick Embryo (Fig. 56)

At this stage, the head region becomes disitnct and bent. The neural folds have fused with each other in the mid-dorsal line, thus transforming the neural plate into a neural tube. Anteriorly, this neural tube becomes enlarged to form the brain which is differentiated into three parts referred to as the fore, mid-and hind-brains. The remaining portion of the neural tube forms the spinal cord.

From the lateral walls of the fore-brain, two optic vesicles are produced, one on each side.

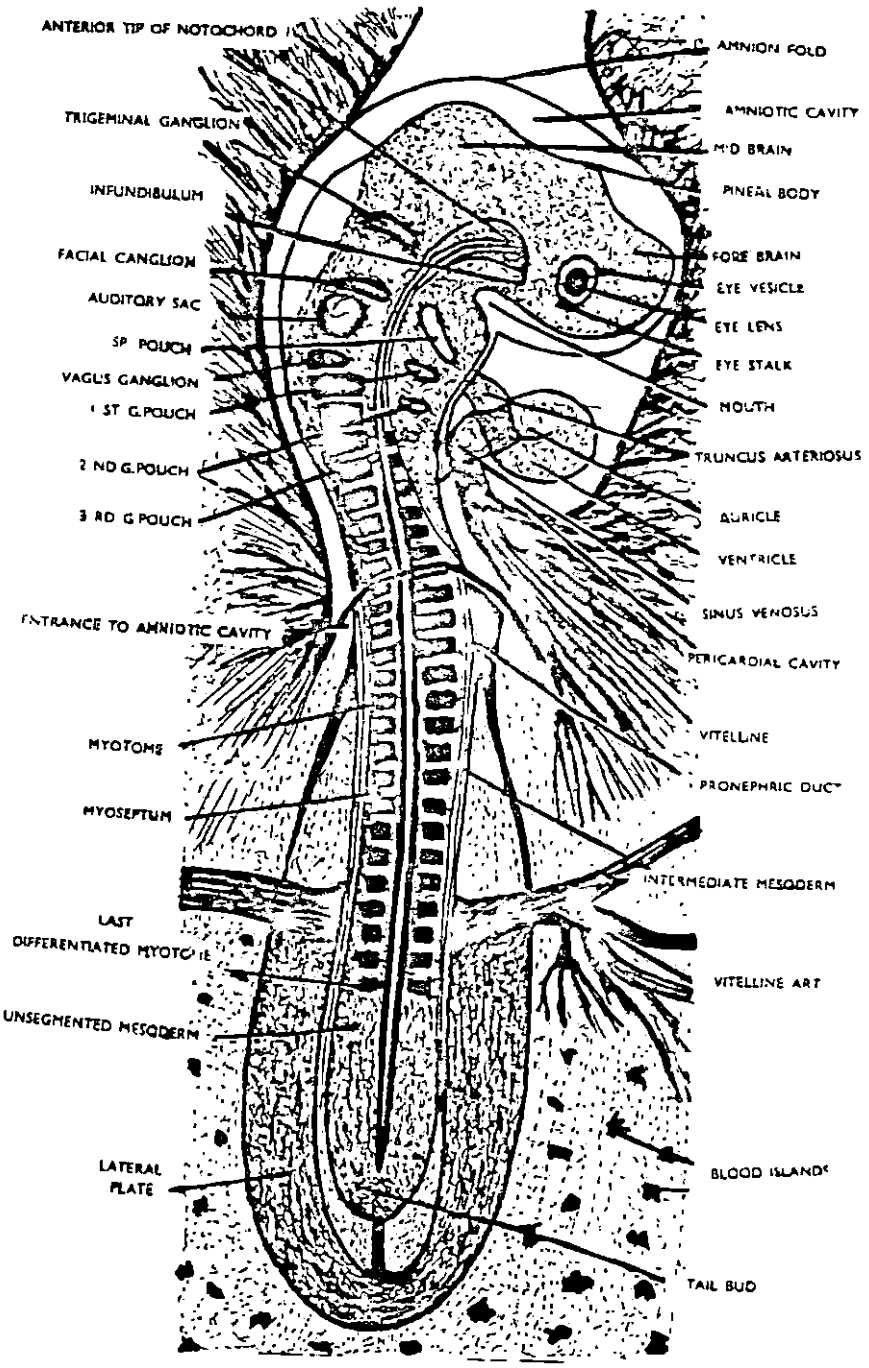


Fig. 56 — 48-hour chick embryo.

Opposite the posterior part of the hind brain arises the auditory sac (future ear) as a circular patch of thickened ectoderm.

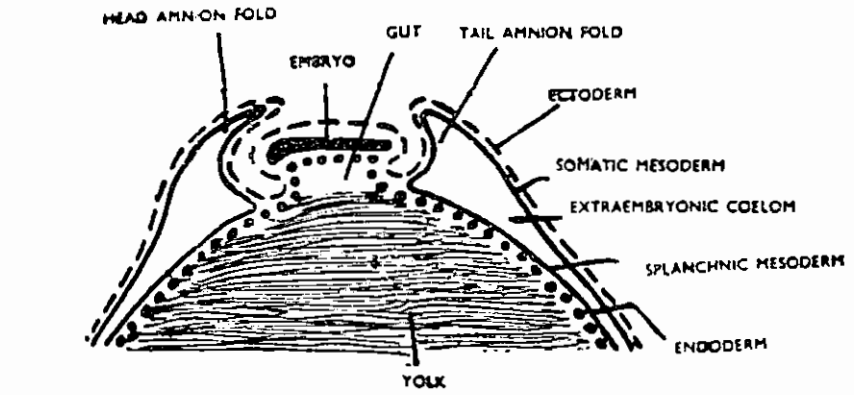
At this stage, the mesoderal somites attain twenty seven somites. Also the heart becomes distinct.

EMBRYONIC MEMBRANES

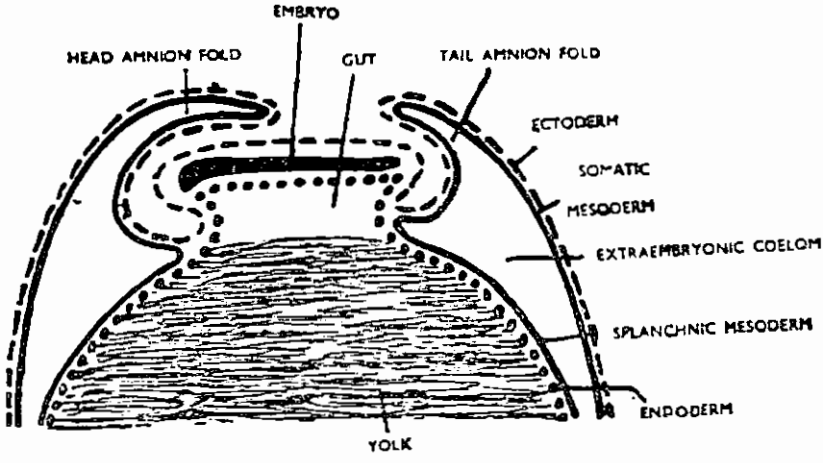
While the development of the embryo is taking place a number of structures known as the **embryonic membrane** are being formed (Figs. 57 a and b). These are the **amnion, chorion, allantois** and **yolk sac.** Although they are formed from the egg, they do not form an actual part of the embryo. They perform a number of functions during the developmental stages and then they are thrown away at the time of hatching The amnion and chorion arise in common with each other from the **extraembryonic blastoderm.** In front of the head of the embryo, arises a folde of the blastoderm which is known as the **head amnion fold,** and it becomes directed backwards covering the head (Fig. 57 a, A & B). Then. its sides become elongated backwards giving rise to two **lateral amnion folds** which become elevated upwards to cover the lateral sides of the embryo. The right and left lateral folds become fused together, and their fusion starts in the region of the head fold and gradually proceeds backwards. Thus, the embryo becomes gradually covered by the fused folds. While this is taking place, a new fold arises behind the **tail-bud** covering it in the same way as the head fold covers the head. This fold is called **tail amnion fold,** and it extends forwards and soon meets the fused lateral folds with which it also fuses. When this fusion takes place the embryo will be completely covered with two membranous layers, the inner one is called the **amnion** and encloses a space known as the **amniotic cavity** which surrounds the embryo. This cavity is filled with amniotic fluid which protects the embryo. The outer membrane is known as the **chorion** and it also prtotects the embryo.

The **allantois** arisés as an outgrowth from the ventral wall of the hind gut (Figs. 56 D and E). This growth is directed backwards, and gradually increases in size and extends between the amnion and chorion. It acts as a urinary bladder, and later in development its wall becomes highly supplied with blood vessels and it acts as a respiratory organ for the developing chick while it is in the egg. Interchange of gases takes place in the capillaries of the allantois through the thin chorion and porous outer shell.

The **yolk sac** which is the fourth embryonic mambrane is represented



A.



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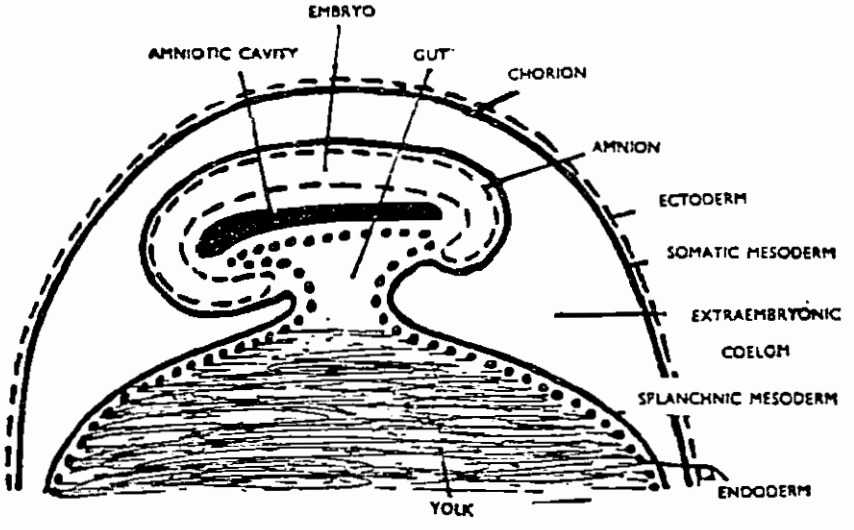


C.

Fig. 57 *(a)* — Formation of embryonic membranes, stages A, B and C.

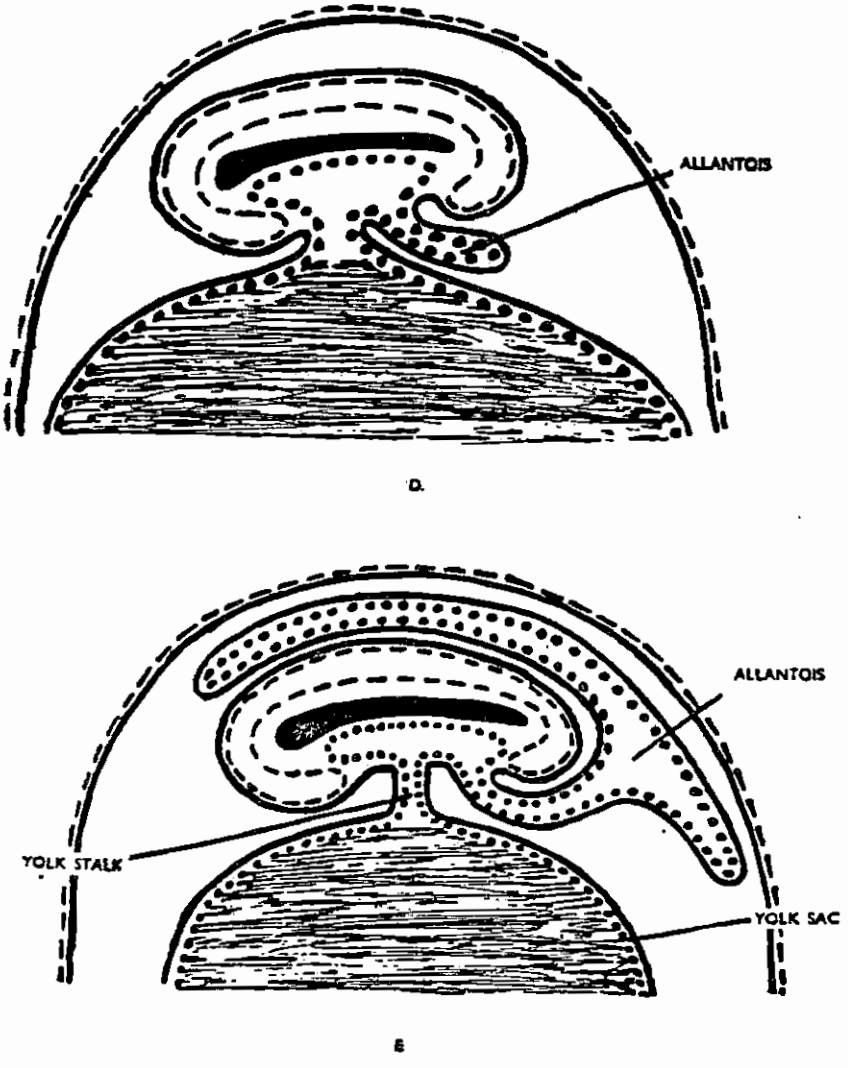


Fig. 57 (*b*) — Formation of embryonic membranes, (Stages D and E).

by the inner lining of the extraembryonic coelom (splanchnopleure) that completely surrounds the yolk. This sac remains connected with the intestine by the **yolk stalk.**

PLACENTA

The embryonic membranes are an important character of an important group of the vertebrates known as **Amniota** which comprises **reptiles,**

birds and **mammals.** The description of the embryonic membranes already mentioned can be met with in the case of reptiles and birds, but in mammals both the chorion and allantois are modified to take part in the formation of a structure known as the **placenta.** In both reptiles and birds the egg is very large and contains a large quantity of yolk which is utilised in the formation of the embryo, but in most mammals the egg is very small and nearly contains no yolk, and the embryo lives parasitically inside the body of the mother from which it receives all the necessary food. This food is transferred from the body of the mother to that of the developing embryo through the placenta which is formed in the following manner.

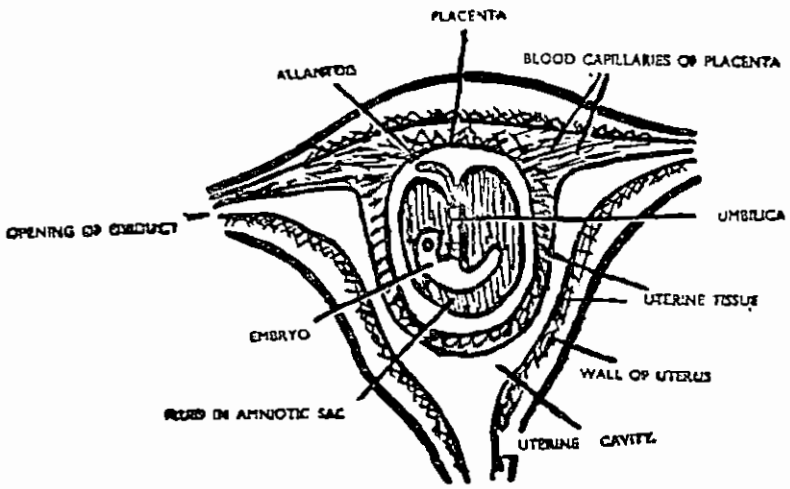


Fig. 58 — Relation of placenta to uterus in mammals.

The **allantois** and **chorion** become closely united together. The chorion also forms an intimate relation with the **mucous membrane** lining the uterus (Fig. 58). This relation is brought about through the development of certain structures known as the **chorionic villi.** These are processes which arise from the chorion and project towards the wall of uterus with which they become closely united. Thus a close contact is made between the maternal and foetal tissues. These tissues form the **placenta** which is composed of two parts, the **maternal placenta** and the **foetal placenta.** Both of them become richly supplied with blood vessels, but the blood circulation inside the maternal placenta remains quite distinct from that inside the foetal placenta. So the blood of the mother is never intermingled with that of the developing embryo.

All what takes place inside the placenta is the interchange of materials between the blood of the mother and that of the embryo. Food materials and dissolved oxygen pass from the blood capillaries of the uterus to those of the embryo. Carbon dioxide and urea pass from the blood capillaries of the embryo to those of the mother.

PART FIVE

GENETICS

INTRODUCTION

Genetics may be defined as the science which tries to discover the laws which determine why certain individuals related by descent resemble one another, or why they differ from one another. In other words, genetics is the science of heredity and variation.

However, geneticists are, nowadays, interested not only in heredity and variation, but also in knowing how genes came into exisence in the first place, what their chemical constitution is, how they influence development, and a number of things which concern the study of hereditary material.

In man and other animals, the hereditary material consists for the most part of genes. The same can be said of plants. However, green plants contain bodies, known as **plastids** located in the cytoplasm. These plastids are self-duplicating bodies and are inherited usually only through the egg and therefore constitute part of the plant's hereditary material.

Some biologists are of the opinion that the cytoplasm contains other bodies which resemble genes, in addition to plastids. However, the problem of **cytoplasmic genes** is still under investigation, but the evidence, as it stands at present, strongly supports the theory that in both plants and animals the hereditary material consists for the most part of **nuclear genes** which are bodies arranged in linear order in the chromosomes.

PHYSICAL BASIS OF HEREDITY

Genes and Chromosomes

Chromosomes contain minute bodies known as genes. These are the ultimate units of heredity. They are arranged in linear order in a chromosome like beads on a string. It has been estimated that a chromosome contains thousands of genes and so they are very small and invisible even under the highest power of the electron microscope. Evidence of their existence is, for the most part indirect and is based on breeding experiments.

The genes are composed of DNA (deoxyribonucleic acid). Each gene has a specific location on the chromosome. This location is called locus

(plural = loci). Since body cells have paired chromosomes, there must be paired genes, one from each parent. Such genes may be alike or unlike. The alternative members of a pair of genes are called "**alleles**" or "**allelomorphs**" and they occupy the same loci on the homologous pair of chromosomes.

Gene Action

Genes determine the fundamental characters of the organism and strucure of the cell. They control the nature and production of proteins which are the essential part of all living protoplasm. By controlling the nature of proteins, genes control the nature of cell enzymes. As metabolic activites of cells require enzyme action, it would be concluded that genes determine and control the cellular metabolic processes.

Genes also play a role in the determination of sex of an organism, and influence the development of sexual traits which distinguish the two sexes. They may change or **mutate.** When such a **mutation** takes place, the mutated copy may be as stable as the original and may be transmitted to future cells and the organism may exhibit altered traits. So this phenomenon may play an important role in the evolution of the organism.

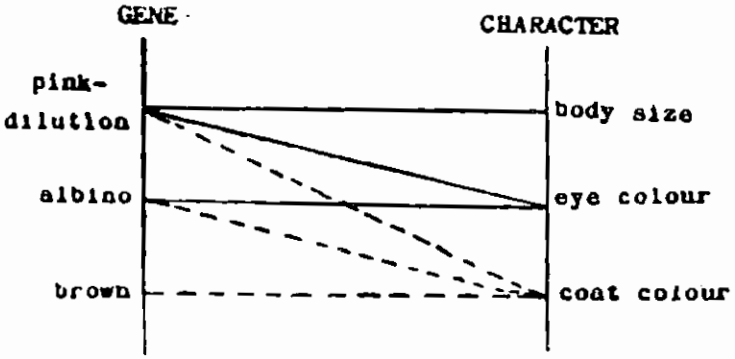
Genes and Characters (or **traits**)

In the study of heredity, we must clearly distinguish between genes and traits. The gene, interacting with the environment, determins the trait. For practical purposes, it is often possible to correlate one gene with **one character.** Such a character is then called a **unit character.**

It has been found, however, that one character is the result of the interaction of several or many genes and that one gene may influence many traits. A gene which has an effect on several traits is generally described as **"plelotropic".**

This relation between genes and characters can be expressed, graphically in the following diagram in which a number of genes of the **house mouse** are indicated in one column and a number of characters in the other.

In this diagram, the connecting lines indicate the action of a gene on a character. Thus pink-dilution gene has **pleiotropic** effects on coat colour, eye colour and body size, whereas coat colour depends on the interaction of pink-dilution, albino and brown genes. This diagram is over-simplified, even for the few genes and characters listed.



Genotype and Phenotype

Difference in hereditary constitution are due to differences in genes. The total gene content of an individual is called its **"genotype".** The sum of the characteristics of an individual comprising its physical and mental traits, is called its **"phenotype".** The phenotype is produced by the interaction of genes with one another and with the environment.

Mutation and Allelomorphs

Genes do not undergo any permanent change from one cell division to the next or from one generation to the next. They are relatively stable, but on very rare occasions, a gene does **change.** As a result a new type of animal or plant might arise such as a white-eyed instead of red-eyed fruit fly (**Drosophila melanogaster**). A permanent change in a gene is known as **mutation** and the new type of animal or plant as a **mutant.** Once a gene has mutated, it is as stable in its new form as it was in its original one. The original gene and its mutated form are called **allelomorphs or alleles.** Allelomorphs are thus genes which occupy the same position (= locus) on the same chromosome, and influence the same developmental process or processes, but in different ways.

Homozygosity and Heterozygosity

Chromosomes are arranged in pairs. The two members of each pair are called **homologous chromosomes.** With the exception of the sex-chromosomes which will be discussed later (see page 225), homologous chromosomes are alike in shape, behaviour at cell division, gene content and arrangement of genes. They may, however, carry different allelomorphs of the same gene. Thus, like the chromosomes, the genes are arranged in pairs; the members of a pair being either identical or allelomorphic.

An individual is called **homozygous,** or a **homozygote,** for a given

gene when it carries the same allelomorph of this gene on both members of the homologous pair. It is called **heteroxygous** or a heterozygote when it carries two different allelomorphs. Example : Let **B** denote the gene for brown eyes, and **b** its allelomorph for blue eyes, then a person can be homozygous for brown eyes (**BB**) or homozygous for the blue eyes (**bb**) or heterozygous (**Bb**). according to the type of genes on the same locus of a pair of homologous chromosomes.

Dominant and Recessive Genes

The phenotype of a heterozygote depends on the relative powers of the two allelomorphs or alleles on the homologous chromosomes. Very often one gene dominates the other so that it expresses itself while other hides. So when the two members of a given pair contrasting genes are brought together, they differ markedly in their ability to express themselves. The gene which produces its effect on the character concerned is called a **"dominant gene".** The other gene which hides and does not produce its effects is called a **"recessive gene".**

Geneticists are accustomed to denote a recessive gene by a small letter, (e.g. r= gene for red hair) and its dominant allelomorph by the corresponding capital letter (R=allelomorph for non-red hair). When a mutation has caused an abnormality in the phenotype of the wild type of the species, the original or wild type gene is often denoted by the sign"+". Thus the gene for albinism, being recessive. is shown as a small "c" meaning colourless. Its normal allelomorph may be denoted either by "C" or by $-^{c}$ or simply by $-$.

Dominance may be complete or incomplete. In the latter case, the heterozygote has a special phenotype caused by a blending between the effects of both alleles.

MENDEL'S EXPERIMENTS AND LAWS

Who is Gregor Mendel ?

Gregor Mendel (Fig. 59) was a monk in a monastery at Brünn, Austria (now Brno, Czechoslovakia). He had come as a poor boy to the monastery and was ordained priest in 1847. In 1851, he was sent to study natural science at the University of Vienna. In 1853. he returned to Brünn and became a teacher of science. In 1857, he started to collect numerous varieties of garden peas differing in height, flower colour, seed colour, seed size and other ways.

Fig. 59 — Gregor Mendel (1822 - 1884), the founder of genetics.

After seven years of observations and experimentations in the monastery gardens, he reported the results of his experiments together with the generalizations which we know as Mendel's laws in 1865. Although his laws do not explain all types of inheritance, they are just as valid today as when they were formulated.

Mendel died before his generalizations were truely accepted. However, in 1900, his laws were rediscovered by three botanists working independently. They are De Vries in Holland, Correns in Germany, and Von Tschermark in Austria. The laws which Mendel formulated may be summarized as follows : -

1. **Law of Unit Characters**

   * Genes occur in pairs, and control the inheritance of each pair of traits as a unit.

2. **Law of Dominance**

One gene of a pair may mask or inhibit the expression of the other or opposite member of that pair. In an individual pea plant having one gene for tallness (T) and one for shortness (t), the tall one will dominante the

(*) Mendel used the word "**factor**". The term "**gene**" was not used until several years later.

the other and expresses itself. The one which expresses itself is called **dominant gene** and the other the **recessive gene.** The trait so developed is **dominant trait.** When there are two recessive genes (tt), they will express themselves and develop the recessive trait.

3. **Law of segregation**

The genes which make up the different pairs are segregated (separated) from each other when gametes are formed in animals or spores in plants. Only one of each pair of genes goes into a gamete or into a spore of a plant.

4. **Law of independent assortment**

The genes representing two or more contrasting pairs of traits are distributed independently of one another at the time of gamete formation in animals and at the time of spore formation in plants. The individual genes are assorted to the gametes independently of one another, and then the gametes unite at random.

Sometimes, these laws are combined into only three laws.

MENDEL'S LAW OF SEGREGATION

Mendel simplified his breeding experiments of garden peas by concentrating his attention upon a single trait at a time, counting and classifying the following generations according to the different forms he observed. As a result of his experiments, Mendel discovered the law of segregation which states, as it now stands, that "the genes which occur in pairs in the individual do not blend or contaminate each other, but segregate (or separate) during meiosis, each going into a mature germ cell or gamete. When such gametes unite, the genes are brought back to their paired condition".

The following experiments are illustrations of Mendel's principle of segregations in cases of complete and incomplete dominance.

Complete Dominance

One of the first facts brought about by Mendel's experiments was that the two members of a given pair of contrasting characters, when brought together in a cross, differ markedly in their ability to express themselves in the resulting hybrid offspring. For example, when he crossed a pure breeding red-flowered plant with a pure breeding white-flowered one, the

progeny were found to resemble the red-flowered parents. No white-flowered plants and no intermediates appeared. But in the hybrid itself whiteness appeared in the subsequent generation.

As these characters were produced by genes, so the gene which produces its effect on the character concerned, is called a **"dominant gene"**. The other gene which hides and does not produce its effect is called a **"recessive gene"**. Two such genes forming a contrasting pair and occupying a **locus** or position on a homologous pair of chromosomes are called **"alleles"** or **"allelomorphs"**.

Similar symbols are used to designate the two members of a pair of alleles. Usually the first letter of the character caused by the dominant gene is always in capital, while that for the recessive is the corresponding small letter.

Mendel crossed various races of edible peas. For instance he crossed a red-flowered race with a white - flowered one. He found that the offspring in the first generation F_1, was all red - flowered plants. Then he self fertilized the offspring and found that they produced an offspring in the second generation "F_2" in the ratio of 3 reds : 1 white. This experiment of Mendel can be easily explained in terms of **chromosomes** and **genes** as shown in figs. 60 and 61.

In the cross of red- and white-floweerd plants, let "C" stand for the gene for red flowers and "c" for its allele for white flowers. The true breeding red-flowered parents may, therefore, be repressented as "CC" and its gametes as "C". In the same manner, the true breeding white-flowered parents as "cc" and its gametes as "c" as shown in the diagrams.

When the two plants are crossed, an egg "C" is fertilized by a male gamete "c" and its gametic formula will be "Cc". When the two members of a given pair of alleles carried on the locus of a pair of homologous chromosomes in an individual, are alike, the individual is said to a "homozygote" or a "homozygous" individual. So the true breeding red "CC" and white "cc" plants are "homozygotes".

On the other hand, when the two members of an allelic pair are unlike, the individual is a "heterozygote" and can be described as being "heterozygous". So the red-flowered plants obtained by Mendel in the "F_1" generation are "heterozygotes". They are red because the gene "C" is dominant over "c".

According to the principle of segregation, the two genes borne in the heterozygous "Cc" plants, do not fuse or contaminate each other as this hybrid shows only the red flower.

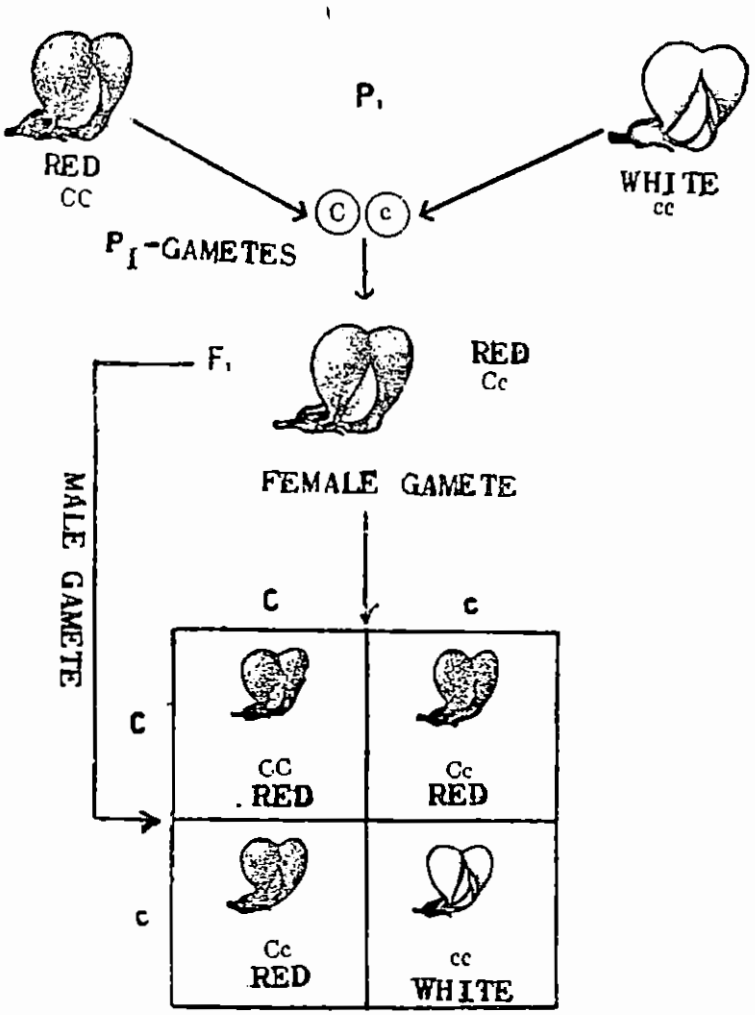


Fig 60 — A chart showing the behaviour of genes during a cross between a red-flowered race of peas and a white-flowered one.

Let us assume that these allelic genes segregate or separate when the hybrid forms its gametes so that half of the gametes will carry "C" and the other half "c". Let us assume further that in fertilization, the gametes combine at random. Finally, let it be supposed that the plants of all genotypes are equally viable.

As shown in Fig. 61 male gametes with "C" may fertilize "C" eggs forming "CC"-plants; C-male gametes may fertilize c-eggs forming Cc-plants, c-male gametes with C-eggs give also Cc-plants, and finally c-male

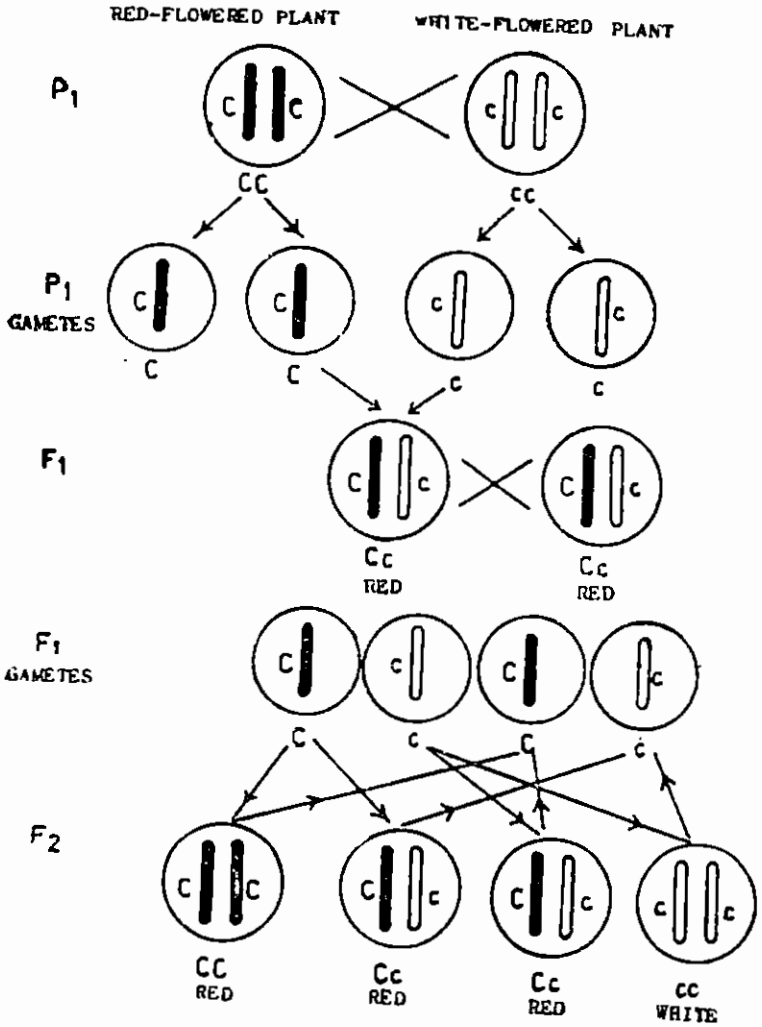


Fig. 61 — Chart showing the behaviour of genes and chromosomes during a cross between a red-flowered plant of peas and a white-flowered one.

gametes and c-eggs produce cc-plants.

CC-plants have only the genes for the red-flowered colour, and so will have the red flowers.

Cc-plants have a gene for red and a gene for white colour but since C is dominant over c, these plants will have red flowers.

cc-plants have two genes for white and so will produce only white flowers.

Hence, if the assumptions stated above are valid, the phenotypic ratio (or appearance) between the red-flowered plants and the white-flowered ones = 3 : 1.

The red-flowered plants however, although looking alike, they do not behave in the same manner. About one third of them or the homozygous for the gene "C" should breed true, and give only red-flowered plants with the genotype "CC". But two thirds of the reds, the so called heterozygotes "Cc" should breed like the F_1 hybrid plants. That is, they should produce red- and white-flowered plants in the ratio of 3 reds : 1 white.

In conclusion, the phenotypic and genotypic ratic of the above mentioned cross will be as follows :

phenotypic ratio = 3 reds : 1 white

genotypic ratio = 1 CC : 2 Cc : 1 cc

In order to facilitate the different possibilities of combination of the F_2-gametes, they are inserted in a checkerboard as follows :

male gametes

female gametes	C	c
C	CC red	Cc red
c	Cc red	cc white

The same results can be obtained when crosses where made between different strains of the fruit fly, **Drosophila melanogaster.** For instance, when pure grey flies are crossed with black ones and this can be experimentally done in special vials containing special food culture (mainly molasses, agar and yeast in definite proportions), all the hybrids which are called the first filial generation or F_1 are grey. When these F_1—flies are mated together, their offspring which are called second filial generation or F_2 contains both grey and black individuals in the phenotypic ratio

of 3 grey : 1 black and the genotypic ratio 1 BB : 2 Bb : 1 bb where the grey colour of the body is caused by B-gene and the black one by b-gene.

Mendel's principle of segregation is also applied to other contrasting traits like those mentioned in Table 6 where **dominant and recessive** characters are represented in some animals.

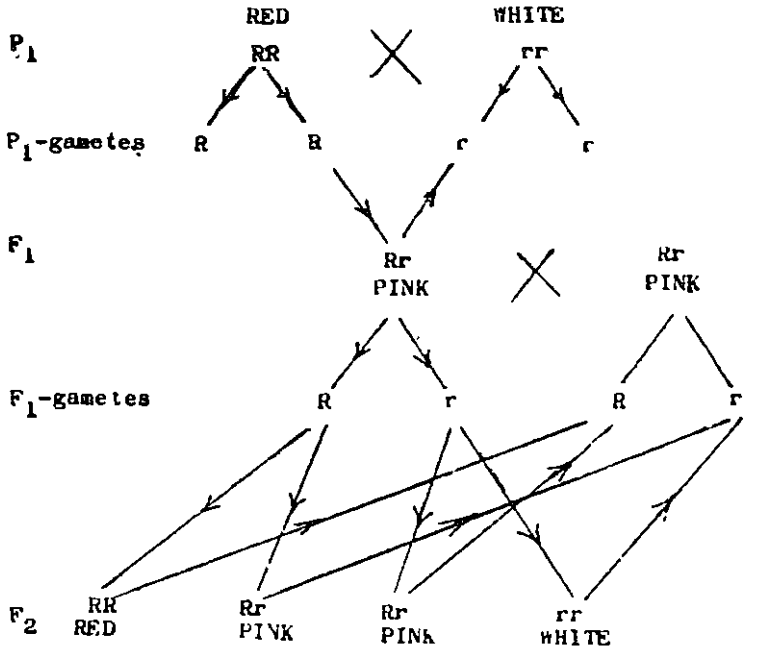
Table 6. Cenetic Characteristics of some animals

Animal	Dominant	Recessive
Fruit fly		
Eye colour	Red	White
Body colour	Grey	Black
Wing length	Long	Vestigial
Poultry		
Comb	Rose (as in **wyandottes**)	Single (as in **Leghorns**)
Shank	Feathered	Bare
Number of toes	Extra toes	Normal number
Cattle.		
Leg length	Short	Long
Horns	Hornless	Horns present
Horses		
Hair colour	Grey	Other colours
Running form	Trotting	Racing

Incomplete dominance.

It is not always necessary that one member of a pair of alleles be dominant over the other. The heterozygote, in this case, has a special phenotype caused by a blending between the effects of both alleles. Incomplete dominance can be demonstrated in many plants such as the **four o'clock** and **snapdragon** plants, and animals like the **andalusian chicken** and the short-horn cattle.

In the four o'clock plant (Fig. 62 a and b) in which a homozygous white (rr) is crossed with a homozygous red (RR), the F_1 is neither red



Genotypic ratio : 1 RR : 2 Rr : 1 rr

Phenotypic ratio: 1 red: 2pink: 1 white

Fig. 62 (*a*) — Incomplete dominance showing the behaviour of genes diagramatically during a cross between red and white four o'clock plant (Miriabilis).

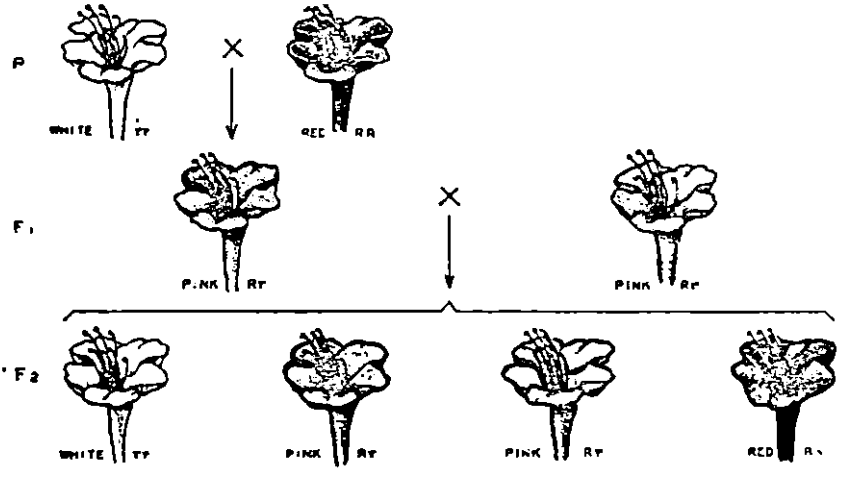


Fig. 62 (*b*) — Incomplete dominence when homozygous white- flowered four O'clock (Miriabilis) is crossed with homozygous red-flowered four-Oclock.

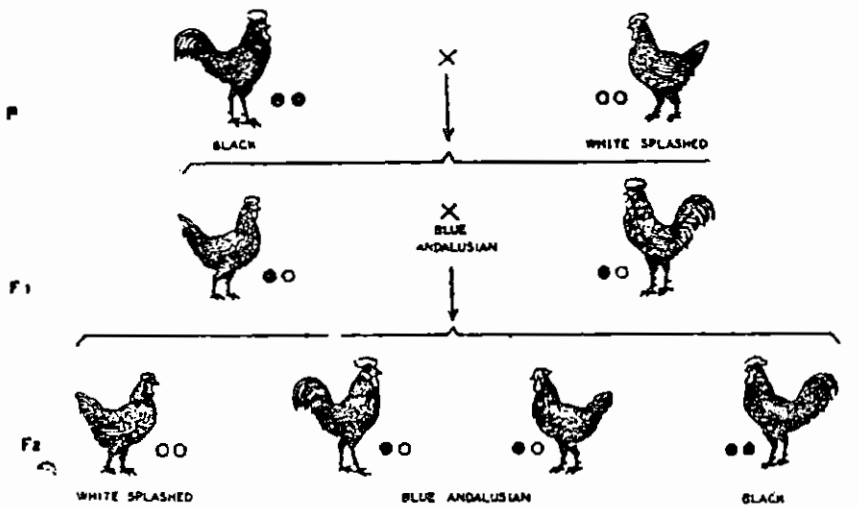


Fig. 63 — Incomplete dominace in blue Andalusian fowls. Genes are represented by dark and white circles.

nor white, but pink (Rr). The F_2 are red, pink and white in the ratio of 1 red: 2 pink : 1 white. If R is the gene for red and its allele r for white, neither of them being dominant over the other, they act in such away that RR individuals are red, Rr pink and rr white. The genotypic ratio in the F_2 is 1 RR ; 2 Rr ; 1 rr.

This phenomenon is also illustrated by the blue Andalusian fowl (Fig. 63). When a black and a white-splashed individuals are crossed, the F_1 shows an intermediate shade of blue Andalusian which is heterozygous. When two blue Andalusian fowls are crossed, individuals of the offspring will be black, blue and white splashed in the ratio of 1 : 2 : 1.

FAMILY PEDIGREES

The study of human genetics faces many difficulties not found in animals and plants because experimental crosses in human beings are impossible and the number of offspring from each marriage is usually small. Moreover, the interval between generations is too long for studying human inheritance.

However, much of our information regarding human inheritance has been obtanied by accurate collection of data and their proper evaluation and interpretation. One of the methods of recording such data is in the

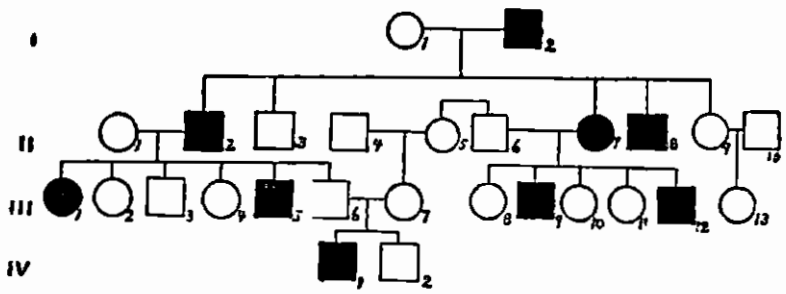


Fig. 64 — Family pedigree of insanity.

form of a **pedigree** (or family tree), two of which are shown in Figs. 64 and 65.

In pedigrees, females are usually symbolized by circles and males by squares. The symbols of parent are joined by a marriage line and the symbols of their children are placed usually below those of the parents under a horizontal line joined to the marriage line by a short vertical line. The number of generations are numbered with Arabic one. The individuals who exhibit the character in question are colourd black. Symbols may also be used in human crossed wherever possihle.

As shown in the diagram Fig. 64 which is a pedigree for **a dominant insanity,** it is noticed that the trait in question is present in every generation, i.e. it never jumps a generation. Also both men and women should have nearly equal chance of being affected and of being parents to affected children whereas in recessive inheritance, as illnstrated by the inheritance of albinism (Fig. 65), the trait jumps certain generations and both men and women have no equal chance of being affected, i.e. there is **sexual preference.**

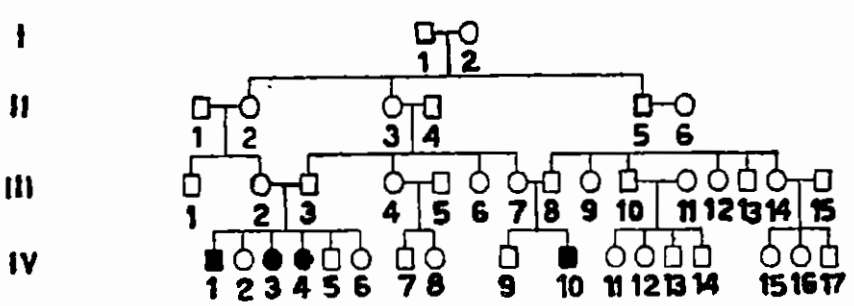


Fig. 65 — Family pedigree of albinism.

Table 7. — **Some dominant and recessive characters in Man.**

	Dominant	Recessive
Hair	Dark	Light
	Nonred	Red
	Curly	Straight
	Abundant on body	Little on body
	Baldness (sex-influenced)	Normal
	White forelock	Normal
Skin and teeth	Piebald (spotted pigmentation of skin and hair)	Normal
	Pigmented skin, hair and eyes	Albinism
	Black skin (multiple genes)	White skin
	Freckles	Normal
	Brown	Gray or blue
Eyes	Hazel or green	Gray or blue
	Pigmented eye colour	Albino (nonpigmented)
	Farsightedness (hyperopia)	Normal
	Normal	Nearsightedness (myopia)
	Long eyelashes	Short eyelashes
Nose and ears	Broad nostrils	Narrow nostrils
	High narrow bridge of nose	Low, broad bridge
	Curved nose ("Roman")	Straight nose
	Free ear lobe	Attached lobe

Table 7. — **Continued.**

	Dominant	**Recessive**
General	Short stature	Tall stature
	Extra digits on hand and toes (polydactyly)	Normal
	Short digits (brachydactyly) (web)	Normal
	Split hand or foot ("lobster claw")	Normal
	Normal	Haemophilia (sex-linked)
	Blood groups A,B (multiple genes)	Blood group O
	Blood group-Rh-positive blood type (multiple genes)	Rh-negative blood
	Harelip and cleft palate	Normal
	Normal (incomplete dominance)	Allergy
Nervous system	Normal	Schizophrenia (multiple genes)
	Normal	Amaurotic (juvenile) (idiocy nervous system degeneration)
	Manic-depressive psychoses	Normal
	Sick headache (migraine)	Normal

SOME HUMAN INHERITED TRAITS

In table 7, some dominant, recessive and incompletely dominant inherited traits are shown, as given by E.W. Sinnot and L.C. Dunn in their text-book of principles of genetics (1958).

SEX-INFLUENCED DOMINANCE

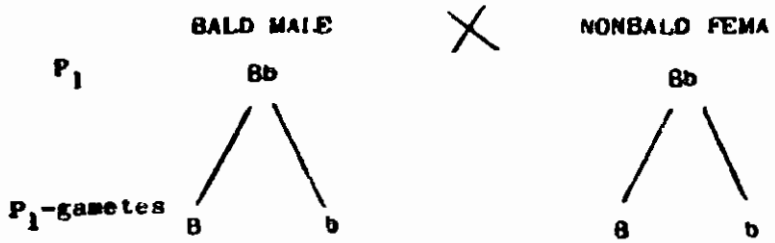
Some genes were discovered in which dominance and recessiveness depend on the sex of individual. These genes are usually carried on the autosomes and not on the sex-chromosomes. The degree of expression of the traits is influenced by the endocrine glands which produce sex-hormones.

An example is the type of inheritable baldness called **"pattern baldness"**, in which the hair recedes around the temples and then becomes thinned on the top of the head, finally leaving a fringe of hair low on the head. Scientific analysis of pedigree show that the genotype BB results in baldness in both sexes whereas the genotype Bb results in baldness in men but normal hair in women. The genotype bb results in normal hair in both sexes. Thus the different genotypes have the following phenotypes.

GENOTYPES	PHENOTYPES	
	MEN	WOMEN
BB	bald	bald
Bb	bald	nonbald
bb	nonbald	nonbald

This indicates that the gene B is dominant in males but recessive in females, and its allele b for normal is recessive in males but dominant in females.

Thus in families where both parents are heterozygous the ratio of the bald and nonbald offspring is worked out twice, once for males and once for females as follows : —



IN MALES : 3 bald : 1 nonbald

female gamete \ male gamete	B	b
B	BB bald	Bb bald
b	Bb bald	bb nonbald

IN FEMALES : 3 nonbald : 1 bald

female gamete \ male gamete	B	b
B	BB bald	Bb nonbald
b	Bb nonbald	bb nonbald

THE SIX MONOHYBRID CROSSES

.The following scheme summarises all the possible matings between individuals carrying one pair of alleles and belonging to three different genotypic classes which are : homozygous dominant (AA), homozygous recessive (aa) and heterozygous (Aa), where A and a are a pair of alleles, "A" being either completely dominant or incompletely dominant over a.

Table 8. — **Genotypes and phenotypes of the six monohybrid crosses.**

Cross No.	Parent's genotype	Progeny's genotype	Progeny's phenotype	
			Complete dominance	Incomplete dominance
1	AA × AA	AA	all A	all A*
2	aa × aa	aa	all a	all a
3	AA × aa	Aa	all A	intermediate
4	Aa × AA	1AA : 1Aa	all A	1 inter. : 1A
5	Aa × aa	1AA : 1aa	1A : 1a	1 inter. : 1a
6	Aa × Aa	1AA : 2Aa : 1aa	3A : 1a	1A : 2 inter : 1a

* Note : The letters in the column for the phenotypes do not stand for the genes but for the unit characters determined by those genes.

Interpretation

1. Crosses (1) and (2) are matings between homozygous races of true breeding races. They cannot give any thing new except an offspring like themselves.

2. Cross (3) is a mating between homozygous dominant and homozygous recessive parents. It produces heterozygous offspring. The phenotype of the offspring differs in accordance with complete and incomplete dominance as shown in the scheme.

3. Cross (4) is a back-cross of a heterozygote with a parental homozygous dominant. It produces the genotypic ratio 1 : 1. The phenotypic ratio is only 1 : 1 in the case of incomplete dominance.

4. Cross (5) another back-cross of a heterozygote to a parental homozygous recessive. Its genotypic and phenotypic ratio is 1 : 1 whether with complete or incomplete dominance.

5. Cross (6) is a mating between two heterozygotes. It produces the genotypic ratio 1 : 2 : 1, the phenotypic ratio depends on complete and incomplete dominance of alleles. With complete dominance it is 3 : 1, and wtih incomplete dominance it is the same as the genotypic ratio, i.e. 1 : 2 : 1.

MENDEL'S PRINCIPLE OF INDEPENDENT ASSORTMENT

When Mendel crossed varieties of peas which differed in characters at one time, he observed that the characters of the parents did not stick together, but assorted freely in the F_2 zygotes. From this observation Mendel drew out his law of independent assortment or random assortment, which was mentioned before (p. 190). This law, as it now stands, provides that "the different pairs of genes located on different chromosomes in the individual behave independently of each other in the way they recombine to form new individuals".

The independent assortment of genes is due to the independent assortment of the chromosomes which carry them. This fact has been explained cytogenetically in dihybrid and trihybrid crosses as follows.

Dihybrid crosses

The following are two examples of dihybrid crosses, i.e. in which two pairs of genes are involved to illustrate random assortment.

Plant Example

Mendel studied seven pairs of characters in peas, involving sead colour,

seed surface, flower colour, height, colour of unripe pods, pod shape and position of flowers.

One of Mendel's experiments was a cross between a pea plant having round and yellow seeds with one having green and wrinkled ones. In this cross, he found that all the F_1 hybrids had round and yellow seeds since the yellow colour is dominant over the green and the round shape is dominant over the wrinkled.

When the F_1 hybrids were crossed to each other, or allowed to self-fertilize, F_2 generation was obtained consisting not only of the two original combinations of characters round with yellow and wrinkled with green, but also two new combinations : round with green and wrinkled with yellow. These four kinds of plants were not equal in number but appeared

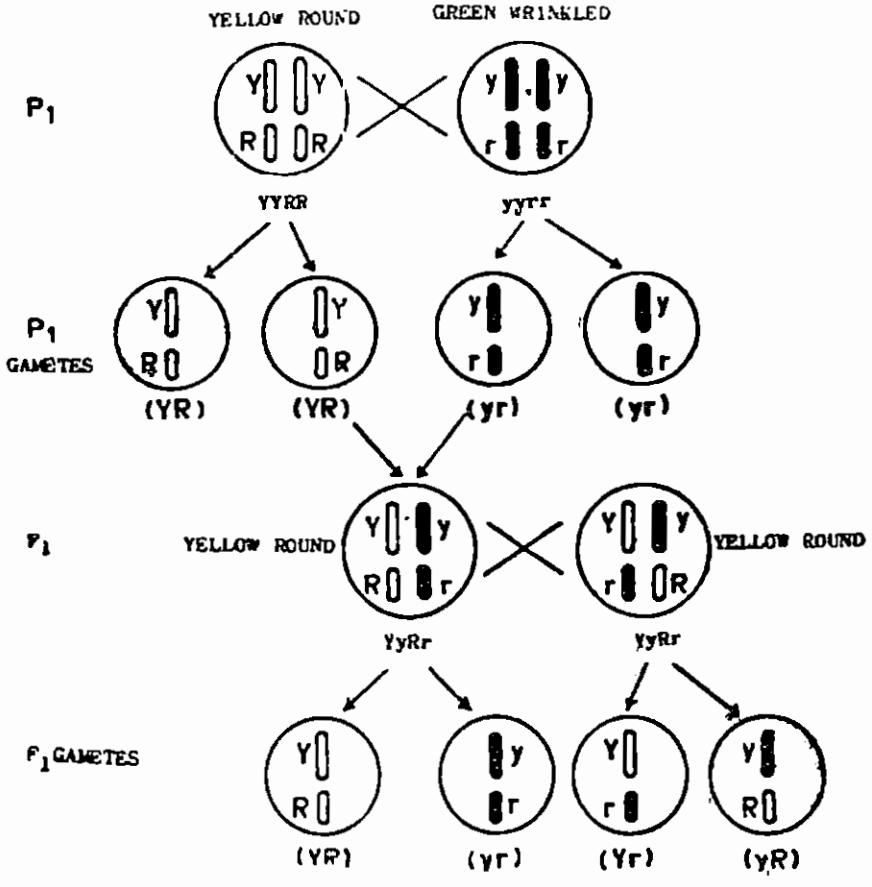


Fig. 66 — A chart for explaining the cross of a yellow round pea by green wrinkled pea.

in a definite ratio which is **9 yellow round : 3 yellow wrinkled : 3 green round : 1 green wrinkled.** This observation led to the second law of Mendel which is stated before.

This fact can be easily explained in terms of genes and chromosomes as in the diagram (Fig. 66). Let the gene for yellow seed be represented by Y and its allele for green by y, and the gene for round seeds by R and for wrinkled seeds by r. In this case, the original yellow round parent plant would be represented by the genotype YYRR, and the wrinkled green plant by yyrr. The F_1 offspring will be yellow rounded and represented by YyRr.

Before the dihybrid F_1 reproduces, it must form its gametes and before it forms the gametes, the chromosomes arrange themselves in pairs and reduction division takes place at the metaphase. There are two possible ways for the arrangement of chromosomes as shown in the diagram. The two chromosomes carrying the genes of dominant characters may be on one side or on the opposite side. In this manner four possible types of gametes can be produced in equal proportion which is 1 : 1 : 1 : 1. These four types of gametes are YR : Yr : yR : yr as shown in Fig. 66.

male gametes

female gametes	YR	Yr	yR	yr
YR	YYRR yellow round	YYRr yellow round	YyRr yellow round	YyRR yellow round
Yr	YYRr yellow round	YYrr yellow wrinkled	YyRr yellow round	Yyrr yellow wrinkled
yR	YyRR yellow round	YyRr yellow round	yyRR green round	yyRr green round
yr	YyRr yellow round	Yyrr yellow wrinkled	yyRr green round	yyrr green wrinkled

When the F_1 plants are crossed with each other, each of the four types of gametes produced by the male has an equal chance of fertilizing each of the four types of gametes produced by the female. Thus sixteen possible types of fertilized ova can be produced as shown in the following checkerboard in the proportion 9 yellow round : 3 yellow wrinkled : 3 green round : 1 green wrinkled. This result is really what was obtained by Mendel in his garden peas.

Animal example

The same result can be obtained in a hybrid mating between a pure long winged fruit fly (**Drosophila**) with black body and a vestigial-winged fly with grey body. The F_1 hybrids will be long winged and grey bodied When these flies are inbred. they produce an F_2 generation consisting of 9 long grey : 3 long black : 3 vestigial grey : 1 vestigial black.

Genetically, these results can be interpreted on the basis of genes and chromosomes as in the case of the yellow round and green wrinkled seeds. As grey is dominant over black and long dominant over vestigial, then the genotype of the long-winged grey bodied flies is VVBB and that of the vestigial winged black-bodies flies is vvbb where grey is denoted by B, black by b, long winged by V and vestigial by v.

	Long grey		**Vestigial black**
P_1	VVBB	X	vvbb
gametes	VB	X	vb
F_1	VvBb	X	VvBb
	long-winged grey bodied flies.		
F_1 gametes	VB Vb vB vb	X	VB Vb vB vb

In this cross, each of the male gametes has the chance of fertilizing a female one and this can be well represented in the following checkerboard :

male gametes

female gametes	VB	Vb	vB	vb
VB	VVBB long grey	VVBb long grey	VvBB long grey	VvBb long grey
Vb	VVBb long grey	VVbb long black	VvBb long grey	Vvbb long black
vB	VvBB long grey	VvBb long grey	vvBB vestigial grey	vvBb vestigial grey
vb	VvBb long grey	Vvbb long black	vvBb vestigial grey	vvbb vestigial black

The result of this dihybrid is 9 long grey : 3 long black : 3 vesitgial grey, 1 vestigial black. This result is what was obtained practically in the laboratory and it confirms the validity of Mendel's principle of independent assortment.

Trihybrid crosses

Crosses between individuals carrying three pairs of contrasting genes are called trihybrid crosses. Using Mendel's peas, a cross may be made between plants with yellow, round seeds and with red flowers, and plants with green wrinkled seeds and with white flowers. Using the same letters for the gene symbols as those used before, then the genotypes of the parents may be denoted by RRYYCC and rryycc respectively. Their gametes are RYC and ryc and the F_1 trihybrid RrYyCc or plants with round-yellow seeds and with red flowers.

According to Mendel's principle of independent assortment, this trihybrid will produce eight kinds of gametes as follows :

RYC	rYC
RYc	rYc
RyC	ryC
Ryc	ryc

As every male gamete has the chance of fertilizing a female one, so there will be 64 possible combinations as can be seen by constructing a checkerboard representing the trihybrid cross. The result will be as follows:

27 round-yellow-red : 9 round-yellow-white : 9 round-green-red : 9 wrinkled-yellow-red : 3 round-green-white : 3 wrinkled-yellow-white : 3 wrinkled-green-red : 1 wrinkled-green-white.

EXPRESSION AND INTERACTION OF GENES

Sometimes, more than one pair of genes may affect the same character. The genes controlling such character interact together and produce their expression. In general, all the genes constituting the genotype of an individual interact with each other and also with the environment to produce the phenotype of that individual. In this case, the classical Mendelian ratio, such as 3 : 1 and 9 : 3 : 3 : 1 etc..., do not by any means occur in all crosses. The following example will show this behaviour of gene expression and interaction.

Combs in fowls.

Each variety of poultry possesses a characteristic type of comb. The **Wyandotte** breed has a comb known as the "rose" comb; **Brahams** and some other varieties have a comb known as the **"pea,,** comb : **Leghorns** and breeds of similar origin have **"single"** combs. Each of these types can be bred true.

In crosses between pea-combed and single-combed birds, pea was dominant over single. A new and interesting result was obtained when rose was crossed with pea, for the F_1 birds showed a new comb known as **Walnut.** Also when the F_1 walnut-combed birds were bred together, there appeared in the F_2 generation not only **walnut, rose-** and **pea-combed** fowls but **single-combed.**

From these facts, it was found that walnut comb depends on the presence of dominant genes, R and P. The first gene (R) produces the rose-comb and the other (P) produces the pea comb. The combination of the recessive alleles of these genes produces the single type of comb rrpp.

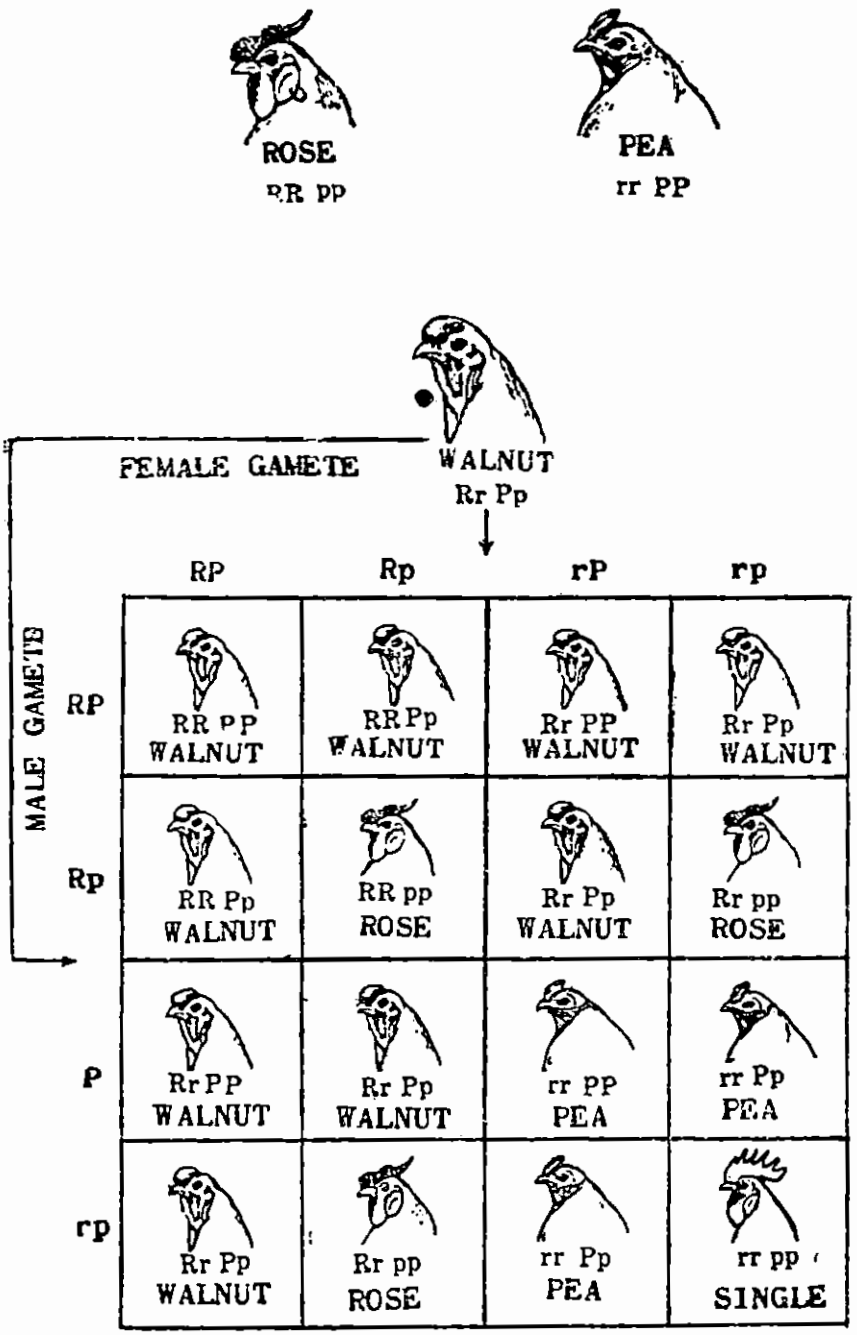


Fig. 67 — A chart representating the interaction of two independent pairs of alleles affecting comb form in fowls.

These assumptions are illustrated in the diagram (Fig. 67), where 9 walnut : 3 rose : 3 pea : 1 single combs are produced.

MULTIPLE FACTOR INHERITANCE

Mendel succeeded in his experiments on peas because he used varieties of peas that differ in clear-cut visible traits. However, not all difference between individual and between varieties or race are of this kind. Variations such as those in body size, stature, weight, strength, intelligence in man, economically important traits in domestic animals and cultivated plants, such as yield of fruits, seeds or eggs, and amount of milk or meat produced do not fall into clear cut classes. These characters are described as quantitative. Mendel's methods of analysis are difficult to apply to such continuously varying traits because they seem to mix or blend instead of segregation in the offspring of hybrids.

This apparently blending inheritance is accounted for by supposing that continuosuly varying traits are due to joint action of several genes or polygenes, each of which has individually a small effect on the trait in question.

The number of polygenes controlling such quantitative character may range from two pairs up to hundred and even more pairs. When two parents which differ in such type of characters are crossed, the F_1 are

Fig. 68 — Skin colour extremes in a mulatto family. Compare the child on the mother's lap and the next child to the right. (From Davenport Carnegie Institution of Washington, Publication No. 199)

more or less intermediate between the parents and the F_2 show many gradations from one extreme like one of the original parents to the other extreme of the other parents. The inheritance of skin colour in mutations, who are hybrids between **negroes** and **whites,** is a very good example (Fig. 68).

It is assumed that negroes have four colour genes SSTT and whites no colour genes, sstt. These genes have cummulative effect, so that, for example SS produces more colour than one S. The different genetotypes are as follows :

SSTT	black
SSTt, SsTT	dark brown
ScTt, SStt, ssTT	medium brown (mulatto)
Sstt, ssTt	light brown
sstt	white

A marriage between black and white parents produces medium brown (mulatto) offspring as follows :

	SSTT	X	sstt
	black		white
gametes	ST		st

↘ ↙

SsTt

medium brown (mulatto)

Marriages between medium brown parents may produce children of all different colours as shown in the following checkerboard :

	SsTt				SsTt					
	medium brown				medium brown					
gametes	ST,	St,	sT,	st	X	ST,	St,	T,	s	st

male gamete

female gamete	ST	St	sT	st
ST	SSTT black	SSTt dark brown	SsTT dark brown	SsTt medium brown
St	SSTt dark brown	SStt medium brown	SsTt medium brown	Sstt light brown
sT	SsTT dark brown	SsTt medium brown	ssTT medium brown	ssTt light brown
st	SsTt medium brown	Sstt light brown	ssTt light brown	sstt white

1 black : 4 dark brown : 6 medium brown : 4 light brown : 1 white.

It may be observed that one sixteenth of the children produced by mulatto parents are as extremes as negroes or whites in skin colour.

MULTIPLE ALLELES

The examples given before have involved the segregation and relative expression of only two alleles of each gene. However, it has been found that many and possibly all genes are able to change in variety of ways and to give rise to several alternative variants of **multiple alleles.** Thus a gene "A" may change or mutate not only to "a" but to other stable alleles such as a^1, a^2... a^n. These are called multiple alleles. Only two of any set, however may be present in an individual.

MULTIPLE ALLELES IN RABBITS

A set of four alleles is known in rabbits (Fig. 69), (actually they are six, but reduced here for simplicity). These are : C is a gene for full colour

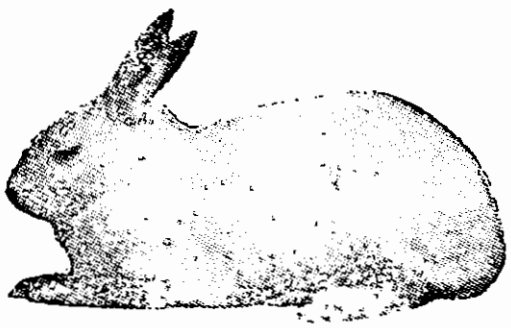
and is dominenet over C^{ch}. C^{ch} is a gene for chinchilla colour (silver) and is dominent over C^{h}. C^{h} is a gene for himalayan colour (white body with coloured ears, nose, feet and tail).

c is a gene for albinism (absence of pigmentation).

The dominance relationship between them is such that :

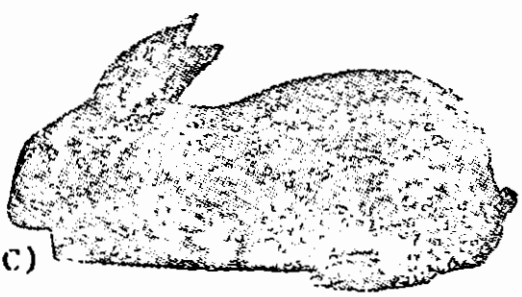
C is dominant over C^{ch}, c^{h} and c.

C^{ch} is dominant over c^{h} and c



ALBINISM (cc)

HIMALAYAN ($c^{h}c^{h}$)



FULLY COLOURED (CC)

Fig. 69 — Three alleles of a gene for coat colour in rabbits.

C^h is dominant over c

c is recessive to the other three.

As there is only one pair of loci on a homologous pair of chromosomes in each rabbit, only two of this set of alleles may exist in one animal. The different possible genotypes and phenotypes are :

CC		c^{ch} c^{ch}	c^h c^h	himalayan
Cc^{ch}	full	c^{ch} c^{ch}	chinchilla c^h c	
C^{ch}	colour	c^{ch} c		
Cc				

cc albino.

The mating between any two individuals belonging to different genotypes follows the same rules of segregations and dominance described before.

MULTIPLE ALLELES IN MAN

(The A-B-O Blood Groups)

The blood of different individuals was found to belong to one of four different types according to the reactions observed in mixtures of their blood (Fig. 70). These reactions, which occur between the red blood cells of one individual and the blood serum or plasma of another individual, consists in the clumping or agglutination of the red blood cells, as described before (see page 120).

It has been found that the A-B-O blood groups are inherited through a set of alleles which are :

IA : a gene for group A, dominant over i

IB : a gene for group B, dominant over i

i : a gene for group O, recessive to both IA and IB

However, neither IA nor IB are dominant to one another. When both are present together, they produce their effects simultaneously. The four possible blood groups are produced by the following genotypes:

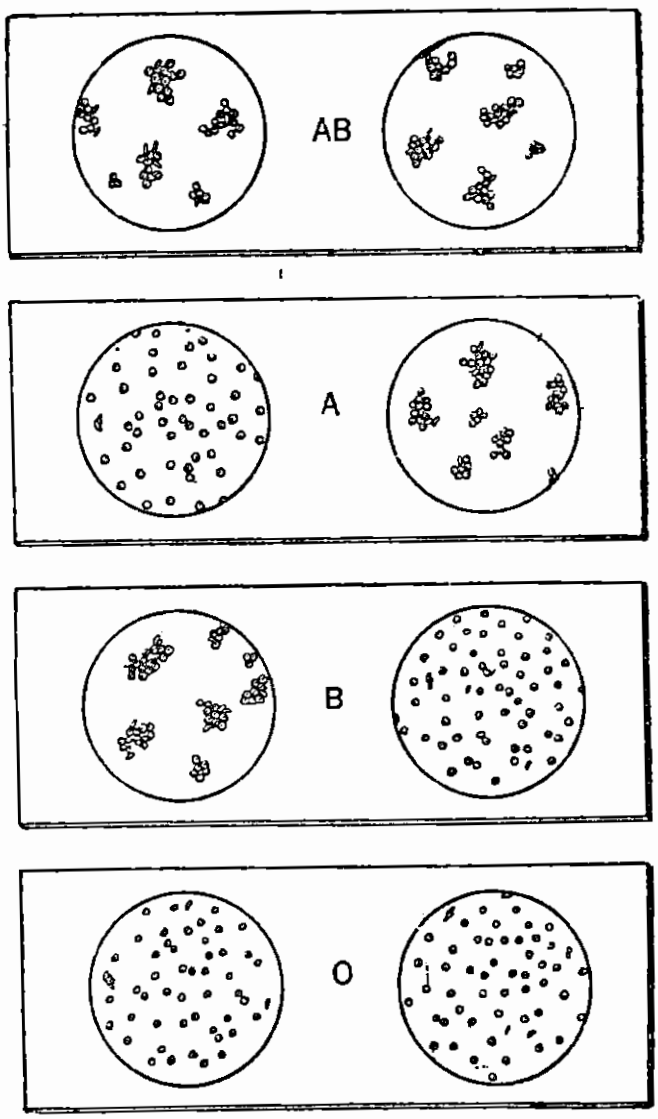


Fig. 70 — Appearance of red blood cells of the four classical blood groups when tested by anti-B serum (left) and anti-A (right).

When the blood groups of the parents are known it is easy to predict the blood groups possible in the children. This has a legal application in cases of uncertain parentage. Thus the possibility or impossibility of a child being the result of a specific marriage may be proved by knowing

GROUP	POSSIBLE GENOTYPE
A	I^AI^A or I^Ai
B	I^BI^B or I^Bi
AB	I^AI^B
O	ii

the blood group of the child and the alleged or suspected parents. The possible types of marriages and the resulting children as well as those groups, which are impossible to occur in the children are shown in table 8.

Table 8. **Possible types of marriage and blood groups of their children.**

No.	Blood groups o. Parents.	Blood groups possible in Children	Blood groups which do not occur in Children
1	O X O	O	A, B, AB
2	O X A	O, A	B, AB
3	A X A	O, A	B, AB
4	O X B	O, B	A, AB
5	B X B	O, B	A, AB
6	A X B	O,B, AB	
7	O X AB	A, B	O, AB
8	A X A B	A, B, AB	O
9	B X AB	A, B, AB	O
10	AB X AB	A, B, AB	O

As an example, case 2 in the table can be analysed as follows :

O x A :

the genotype of O is ii
the genotype of A is IAIA or IA i
if the genotype of A is IAIA
then ii x IAIA
gametes ——— i IA
∴ child will be IA i
or of **group** A
if the genotype of A is IA i
then ii x IAi
gametes ——— i IA i
∴ child will be IAi ii
or **group** (A) **and** (O)

Thus the blood groups which are possible from this marriage are O and A. The other groups (B and AB) should not occur in the children of this marriage.

Many instances of multiple alleles are known among plants. In the snapdragon, there is a series of nine alleles all affecting the flower colour and leading from deep red through various paler shades to ivory colour with or without red stripes. Each allele appears to be more or less dominant over those lighter than itself.

THE RHESUS ALLELES IN MAN

When a rabbit was injected with blood from the Rhesus monkey, the latter produced antibodies which would agglutinate the red blood corpuscles of about 85% of the human American white population. The agent which causes the production of an antibody is called an antigen. As it was found that man and Rhesus monkey share this antigen, investigators named it Rh.

Persons whose blood contain the Rh-antigen are called Rh-positive whereas those whose red corpuscles lack it are called Rh-negative. Also, Rh-negative persons do not have anti-Rh antibodies in their blood serum, unless they have been previously immunized by Rh-antigen. Such immunization may occur in women (Rh-negative) by being pregnant with Rh-positive foetus (Fig. 71) or by previous transfusion of Rh-positive blood.

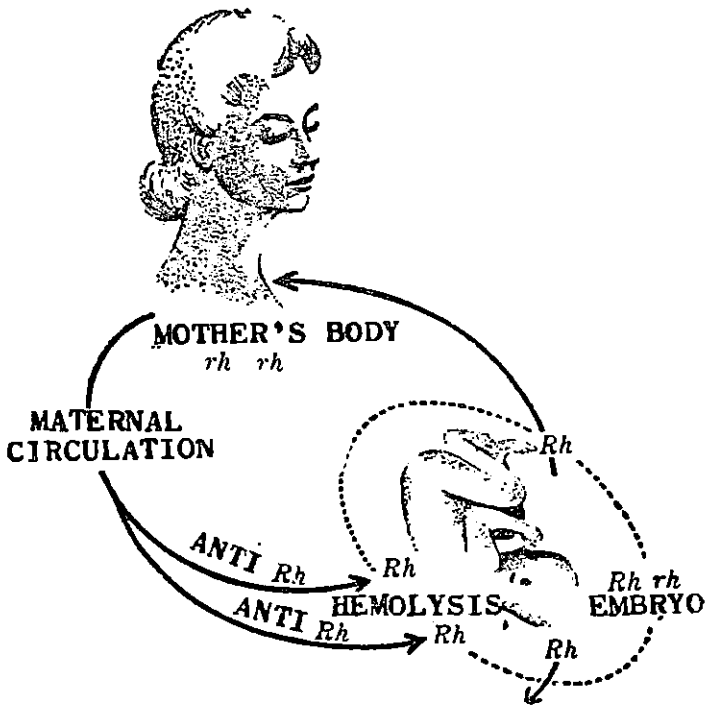


Fig. 71 — Induction of anti-Rh anti-bodies in the mother's blood by Rh-antigen in the embryo.

The previous authors showed that mothers of affected babies were Rh-negative and the father's and the surviving babies were Rh-positive. It was pointed out that the Rh-antigens from the positive baby, must pass through the connecting placenta into the mother's blood where anti-Rh antibodies are produced. When the latter returns to the foetus, its red cells become agglutinated.

On the basis of the above reaction to the anti-Rhesus serum, the population can be divided into two blood groups : Rh-positive and Rh-negative. Early it was suspected that these two blood groups depend on just a single pair of alleles : R or Rh for determining Rhesus-positive, and r or rh for determining Rh-negative. Population consists of three main genotypes : RR, Rr, and rr or RhRh, Rhrh and rhrh.

The haemolytic disease or **erythroblastosis fetalis** has once occurred during pregnancy of an Rh-negative woman. Often, its severity increases in each successive prengancy in which the baby genotype is the undesirable Rhrh. This is true if the father is a homozygous RhRh. But, if he

is heterozygous Rhrh. there is a 50 - 50% chance of a normal, rhrh child, or another afflicted child Rhrh being born.

LETHAL GENES

Lethal genes are those which cause the death sooner or later of their possessors, usually before reaching their reproductive ages. They are of three main types, **complete lethals, semilethals** (or **subvitals**) and **latent lethals.** The complete lethals kill all or nearly all, homozygous individuals before they reach sexual maturity. The semilethals on the other hand, kill some of the afflicted persons but permit others to survive long enough to have families. Latent lethals produce their effect late in life.

Complete lethals

There are two main types of complete lethals, dominant and recessive. The dominant lethal genes have been suspected but their possessors die as soon as they are produced. The yellow mouse case is a good illustration for such type of genes and so will be discussed here.

Some mice are yellow, but when they are mated together, they produce yellow and grey offsprings in the ratio of 2 yellow : 1 grey (Fig. 72). When the grey offspring are again mated together, they give only grey. This means that grey is recessive and yellow is dominant and yellow mice are heterozygous.

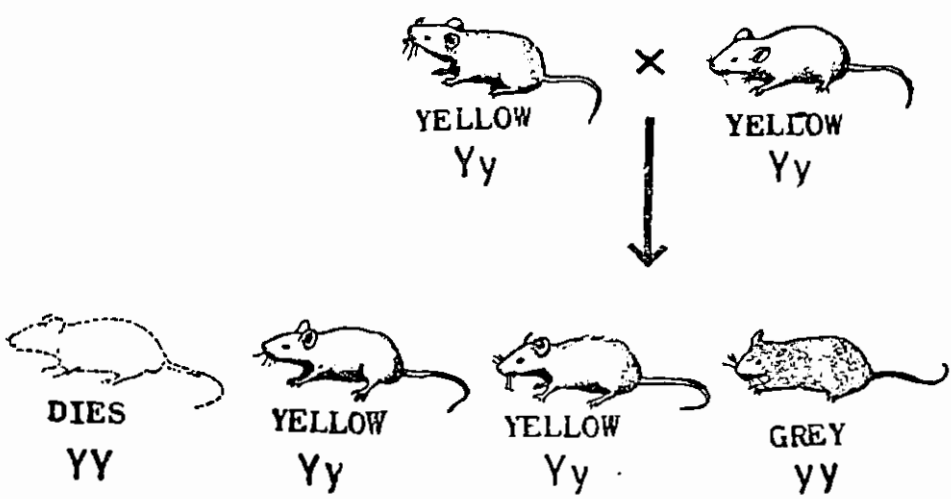


Fig. 72 — A chart representing the inheritance of a lethal gene in mice.

Since in a monohybrid cross the typical phenotypic F_2 — ratio is 3 : 1, but, in this case the homozygous yellow mice died in the uterus of their mothers, modifying the 3 : 1 ratio to 2 : 1 as shown in Fig. 72, then there must be a lethal gene which kills the mice in the homozygous condition.

A recessive lethal gene can continue its existance in the heterozygote and in this case only the individuals carrying the lethal gene in the homozygous state would die.

The following human diseases may serve as examples for the effect of the recessive lethal genes.

1. **Juvenile amaurotic idiocy**

In this disease the affected child becomes blind, paralysed, mentally deficient and dies within a short time.

2. **Infantile amaurotic idiocy** (or the so-called **Tay-Sachs** disease) :

This disease results in early death of the homozygotes. The genes for juvenile and infantile forms of amaurotic idiocy have no known effects in heterozygotes.

3. **Sickle-cell anaemia**

This disease is caused by a gene with a lethal affect when homozygous. The name of this disease refers to the sickles-haped red blood cells of the carriers (Fig. 73). The homozygotes usually die of a fatal anaemia before

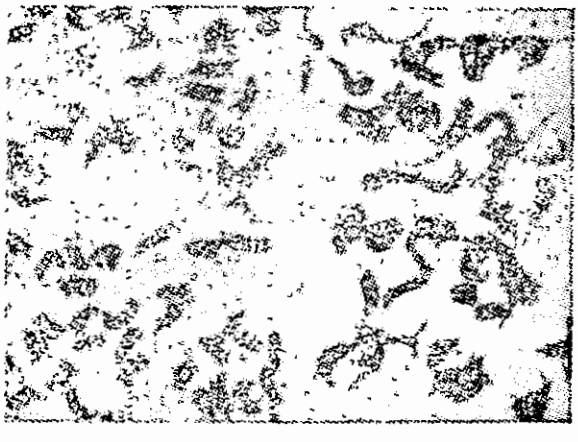


Fig. 73 — Sickle cells is man, Left, red blood cells from a patient with sickle-cell anaemia; right, cells from a person with sickle cell trait. (after Neel)

the advent of sexual maturity. The heterozygotes are healthy people occasionally showing signs of a mild anaemia. Since the heterozygotes are indentifiable by means of a microscopic examination of their blood, the birth of children with the fatal anaemia could be prevented by avoidance of marriages among the carriers.

4. **Thalassemia (or microcytemia)**

In this disease, the gene in the homozygous condition causes a fatal anaemia. It was thought to occur chiefly among people native to countries near the Mediterranean Sea (Italians, Greeks and Syrians) but is found also in Persia, India and Thailand.

5. **Phenyl Ketonuric Imbecility**

In this disease, the urine develops a temporary deep bluish green colour upon addition of a few drops of a 5% solution of ferric chloride. This reaction revealed the presence of phenylpyruvic acid which is excreted by the patients but metabolized in normal persons. All persons who continuosusly excrete this substance have some degree of mental deficiency, their muscular reflex reactions are accentuated, and they have a characteristic poisture and a dilution of skin and hair pigments. They have a reduced life and seldom have children.

Semilethal (or subvitals)

The term lethal is usually applied to the killing in early life whereas semilethal or sublethal (or subvital)is reversed for those conditions which cause death in childhood or at least before the reproductive age. The following human diseases may serve as examples.

1. **Epiloia**

This is a rare disease. Its victims are heterozygous carriers of a gene that causes a combination of morbid traits, including severe mental deficiency, abnormal growths on the skin and tumours in internal organs. Most persons with epiloia die during childhood, but some of them manage to survive, marry and beget children.

2. **Retinoblastoma**

This disease is due to a semilethal gene. It causes malignant tumours in the eyes and almost always leads to death in early childhood.

Latent lethals

These are lethal genes which may produce effects late in life. It is a known fact that there are certain families in which most individuals are short lived. This may be due to latent lethal genes. Also the genes for hereditary, susceptibility to certain diseases like tuberculosis and diabetes mellitis may be considered as latent lethals.

SEX-LINKED INHERITANCE

Chromosomes normally occur in pairs in diploid organisms. A difference, however, was observed between the male and the female sets of chromosomes in animals belonging to certain species. This difference was discovered in only one pair of chromosomes, called the **"Sex-chromosomes"**. the rest being alike in males and females, and are called **"autosomes"**. In many animals including man, the pair that differs in the two sexes, (i.e. the sex-chromosomes) is composed in the female of two members which look exacly alike and which are called **X-chromosomes.** However, in the male only one **X-chromosome** is present, together with an odd shaped chromosome that has a hook on one end is called the Y- chromosome (Fig. 74). In this case the male is an XY type and the female an XX type. During reduction division, the male produces two kinds of spermatozoa in equal proportion one kind containing a Y-chro-

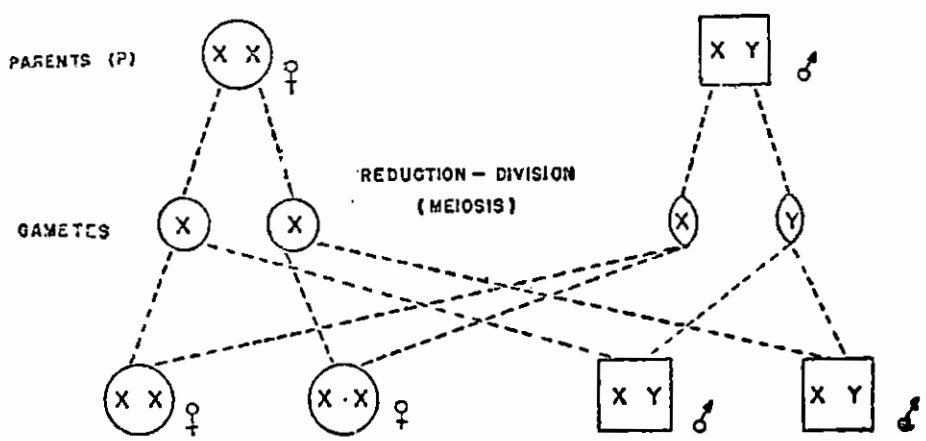


Fig. 74 — Inheritance of sex in either plant or animal of the XY-type.

mosome and other an X-chromosome. Accordingly the male is called, in this case, the heterogametic sex. In the female, only one kind of ova are produced, each containing one X-chromosome. Hence this type of female is the homogametic sex. When a Y-sperm fertilizes an egg, an XY male zygote is produced. An X-sperm produces on fertilization an XX female zygote.

The conditions of XY in the male and XX in the female is the most common in animals. In certain animals including some arthropods, nematodes and mammals, the male has no Y-chromosome, but simply one X-chromosome, while the female has the normal two X-chromosomes. This condition is called the XC type.

In certain other animal forms, the female was found to be the heterogametic sex. In order to distinguish this type, the name Z-chromosome replaces the X-chromosome. In birds, some mammals and a few arthropods, the female contains one Z-chromosome and an odd shaped W-chromosome. Thus, the males would be ZZ. the females ZW. In some species there is no W-chromosomes, the females being ZO.

Whenever a gene is located on the X-chromosome it is called a **sex-linked gene.** The homogametic sex can have two such genes, while the heterogametic sex can only have one.

SEX-LINKAGE IN DROSOPHILA

Sex-linkage was first discovered in the fruit fly **Drosophila melanogaster.** In the somatic cells of this fly, there are three pair of autosomes and one pair of sex-chromosomes (Fig. 7 b). In the female two rod-like sex-chromosomes are similar (XX). In the male, there is one rod-like X-chromosome and a Y-chromosome with a hook in one end.

The wild type of **Drosophila** has red eyes. A mutant type with white eyes was discovered and was found to be caused by sex-linked gene which is recessive to its allele causing red eyes in the wild type. If W is used as a symbol for red eyes and w for white eyes then the male can only have one of them. Thus the genotype of the male is either WY (= red eyes) or wY (= white eyes). The Y is the symbol for the Y-chromosome which does not carry the sex-linked gene. The female, which contains two X-chromosomes, has two of the genes concerned and the genotype may be WW (= red eyes), ww (= white eyes).

When a cross is made between homozygous red-eyed-females and white-eyed males all the F_1 are red-eyed, while the F_2 are in the ratio of 3 red-eyed males and females : 1 white-eyed male (Fig. 75). This result can be predicted by the use of two methods as follows ;

(*a*) **First Method** by segregation of chromosomes as follows.

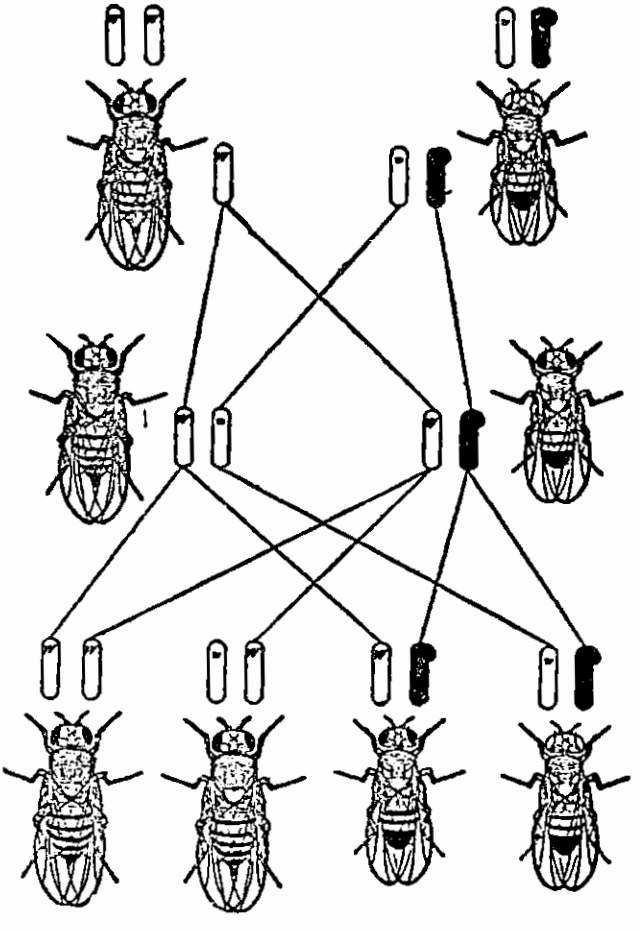
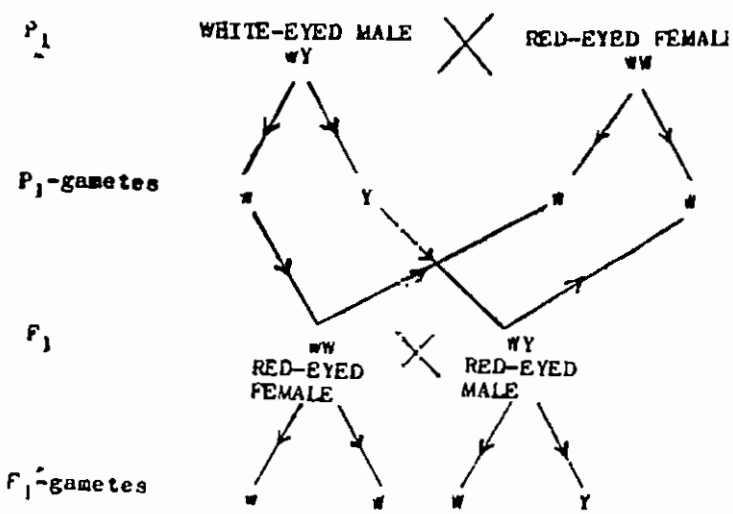


Fig. 75 — Sex-linked inheritance in fruit fly (Drosophila). A cross between white-eyed male and red - eyed female. (after Morgan).

(*b*) **Second Method** by ckeckerboard and gene segregation as follows :



female gamete	male gamete: W	male gamete: Y
W	WW red-eyed female	WY red-eyed male
w	Ww red-eyed female	wY white-eyed male

F_2-GENOTYPE :
1WW : 1Ww : 1WY : 1 wY

F_2-PHENOTYPE :
1) Two red-eyed females
2) One white-eyed male
3) One red-eyed male

The reciprocal cross between white-eyed females and red-eyed males gives a different result shown in Fig. 76 and the accompanying diagrams

and checkerboards. In this cross, half the females and males in the F_2 offspring prossess red-eyes and the other half white eyes as shown in the following two methods :

(*a*) **First Method** by segregation of chromosomes as follows :

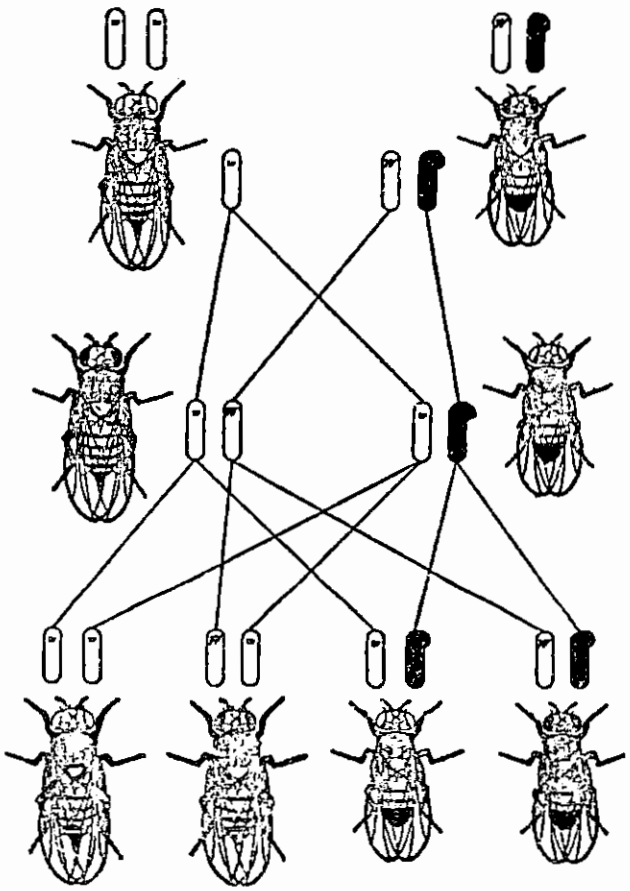
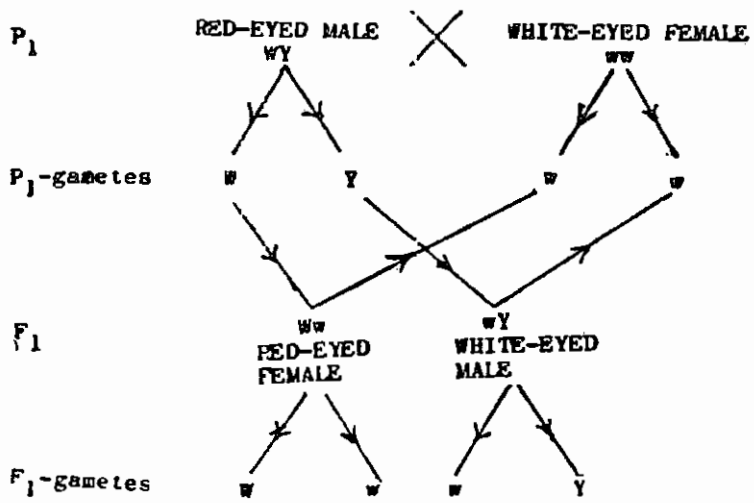


Fig. 76 — Sex-linked inheritance in fruit fly (Drosophila). A reciprocal cross between red - eyed male and white - eyed female, (after Morgan).

(*b*) Second method checkerboard and gene segregation as follows :



male gamete

female gamete	w	Y
w	Ww red-eyed female	wY red-eyed male
w	ww white-eyed female	wY white-eyed male

F_2-GENOTYPE :
1 Ww : 1 ww : 1 wY : wY

F_2-PHENOTYPE :
1) One red-eyed female
2) One white-eyed female
3) One red-eyed male
4) One white-eyed male

SEX-LINKAGE IN MAN

Many sex-linked traits were discovered in man. These include certain types of night blindness, optic atrophy, colour blindness, absence of sweat glands, toothlessness and hairlessness, a blood-condition known as haemophilia, in which the blood does not coagulate properly, leading to haemorrhage, and others. These are caused by recessive sex-linked genes.

Red-green colour blindness is an affection causing the inability to distinguish red from green. It is caused by a sex-linked recessive gene c while the normal condition is caused by its alleles C. When a colour-blind man marries a normal homozygous woman (Fig. 77), only the daughters will have the colour-blindness gene in the heterozygous form as follows:

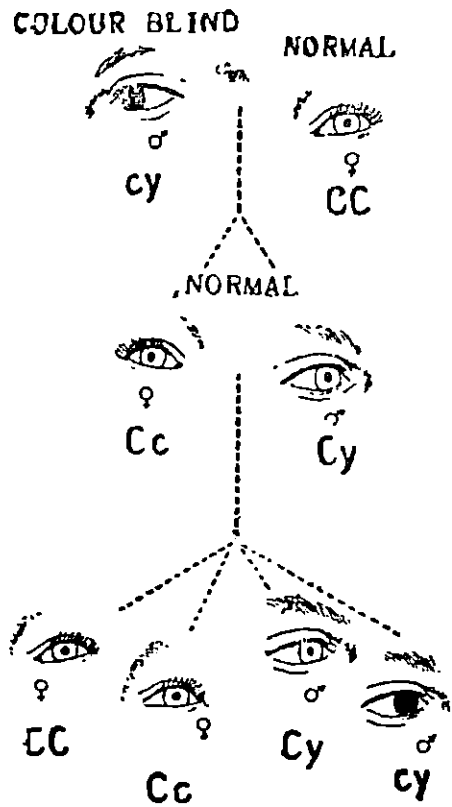


Fig. 77 — A chart showing the inheritance of red - green colour blindness in a marriage of a colour blind man and a normal homozygous woman.

CC X cY

normal woman colour-blind man

gametes C X c Y

1 Cc 1 CY

1 normal (heterozygous) daughter 1 normal son

When a heterozygous woman marries a normal man, about half their sons will be colour-blind as shown in Fig. 78.

A colour blind woman cc must receive c from her father, who would be cY (colour-blind), and c from her mother, who must be either Cc or cc (Fig. 78). A colour-blind man inherits this condition from his mother and never from his father.

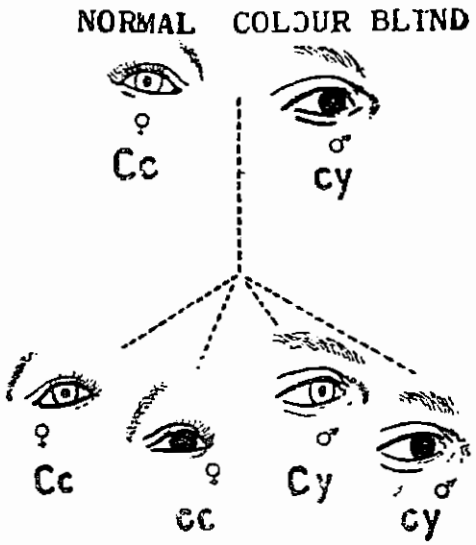


Fig. 78 — Another chart showing the inheritance of red - green colour blindness in a marriage between normal heterozygous woman and colour blind man.

LINKAGE AND CROSSING OVER

Many genes may be located on the same chromosome and would thus be linked together like beeds on a string in a single row and in definite order. These are the **linked genes.** Free or independent assortment is impossible between **linked genes,** which are not free to assort in different combinations, but tend to stick together and are transmitted as such from one generation to the next. Linked genes, however, do not stick together all the time. During synapsing in reduction division, a certain percentage of the chromosomes exchange homologous parts, thus breaking the linkage. This phenomenon is called **crossing** over, and its results differ from those of independent assortment.

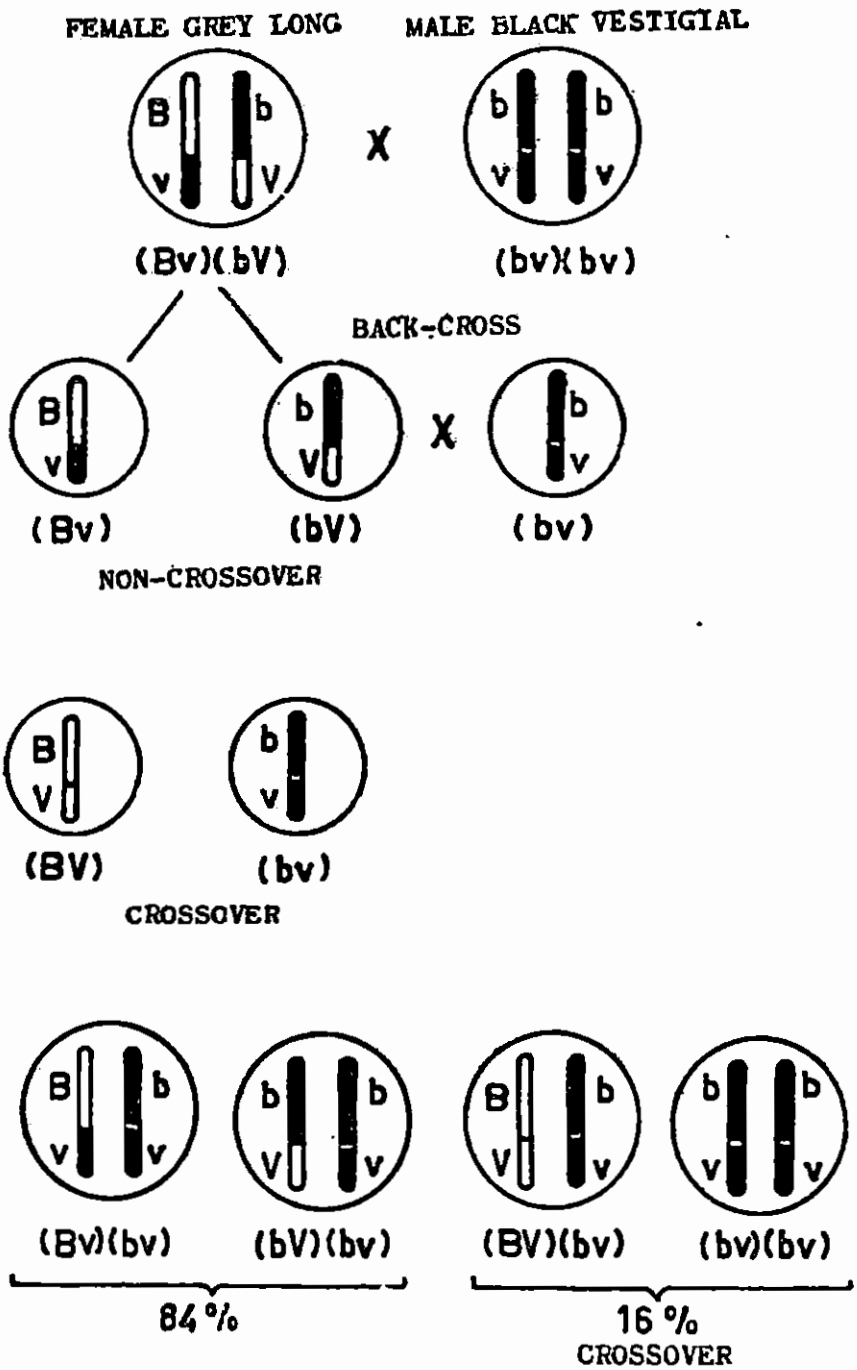


Fig. 79 — A chart showing a case of linkage in "Drosophila" (grey long X black vestigial).

LINKAGE AND CROSSING OVER IN DROSOPHILA

When homozygous **black long-winged** flies are crossed with homozygous **grey vestigial winged** flies, the F_1 are all **grey bodies long-winged.** If the male F_1 are backcrossed with homozygous recessive females (black vestigial) only two kinds of offspring are poduced in the ratio of 1 **black long-winged** : 1 **grey vestigial,** which are the same types as the original parents. This denotes that two kinds of sperms are produced in the F_1 and thus independent assortment could not have occurred.

The b and V genes stayed together in the F_1, and were transmitted together in the F_1 gametes to their offspring, because these genes are located in the same chromosome. Wherever b goes V would also go. The same thing happened with B and v. This may be presented diagramatically as follows :

P_1 (bV) (bV) X (Bv) (Bv)
black long grey vestigial

P_1 gametes (bV) (Bv)

(Bv) (bV)
grey long

Back-cross (Bv) (bV) X (bv) (bv)
male grey long female black vestigial

gametes (Bv) (bV) (bv)

	(bv)	
(Bv)	(Bv)	(bv) grey vestigial 1
(bV)	(bV)	(bv) black long 1

Male F_1 flies were used in the above back-cross to illustrate complete linkage, because no crossing over occurs in male **Drosophila.** If in the above back-cross, heterozygous F_1 females were crossed with homozygous recessive males (Fig. 79), four kinds of offspring instead of two, are produced, but not in equal proportion. The proportion of each of the two parental types is about 42% while each of the two new types constitute about 8% of the total number of offspring. This indicates that there is exchange of parts during synapsis or in other words crossing over occurs. Crossing over may also be explained diagramatically as follows:

Back-cross	(Bv) (bV) female grey long	X	(bv) (bv) male black vestigial
gametes	(Bv), (bV) **non-crossover**		(bv)
	(BV), (bv) **crossover**	X	(bv)

				(bv)
(Bv)	(Bv)	(bv)	grey vestigial	42
(bV)	(bV)	(bv)	black long	42
(BV)	(BV)	(bv)	grey long	8
(bv)	(bv)	(bv)	black vestigial	8

In the accompanying diagram, the chromosome carrying (bV) exchanges homologous parts with the other member carrying (Bv) in the F_1 females, and in this way (BV) and (bv) new gametes could be produced due to crossing over. The percentage of the types resulting from **crossover gametes** i.e. the 16% is called the **crossover percentage.**. (BV) and (bv) are called the crossover gametes and (bV) and (Bv) are the **non-crossover gametes.**

LINKAGE AND CROSSING OVER IN MAIZE

In this case, the genes C and c (C for **coloured** seeds dominant over c for **colourless** seeds) and the genes S and s (S for full seeds dominant over s for **shrunken** seeds) are linked on the same pair of chromosomes. When homozygous **coloured** full seeds are crossed with homozygous **colourless shrunken** seeds, the F_1 are all **coloured fulled** seeds (Fig. 81).

If the male F_1 are back-crossed with homozygous recessive females (**colourless shrunken**), only two kinds offspring are produced in the ratio of 1 coloured full : 1 colourless shrunken which are the types as the original parents. This denotes that two kinds of male gametes are produced in the F_1 and thus independent assortment could not have occurred. The C and S genes stayed together in the F_1 and were transmitted together in the F_1 gametes, to their offspring because these genes are located in the same chromosome. Wherever C goes, S would also go. The same thing happened with c and s. This may be presented diagramatically as follows :

P_1 (CS) (CS) coloured full X (cs) cs) colourless shrunken

(CS) (cs)

F_1 coloured full

Back cross (CS) (cs) male coloured full X (cs) (cs) female colourless shrunken

Gametes (CS) (cs) (cs)

	(cs)	
(CS)	(CS)	((cs) coloured full
(cs)	(cs)	((cs) colourless shrunken

However, when the cross was experimentally done, this expectation was not realized but the following result was obtained :

coloured full	48.2%	parental
colourless shrunken	48.2%	
coloured shrunken	1.8%	new
coloured full	1.8%	recombinations

In this case, the coloured full and colourless shrunken are more frequent while coloured shrunken and colourless full seeds are less frequent than expected. Now, the parents had coloured full and colourless shrunken seeds and these are the parental combinations of characters while in the recombinations, the associations of characters have changed. This is because the linked genes have separated and change of homologous parts occurs.

Thus, the gene for seed colour, C and for full S, remains associated in parental combinations in about 3.6% (see above). Morgan, ascribed the combination of linked genes to interchange of parts between homologous chromosomes, which he called crossing over.

From the above diagram, it could be seen that the chromosome carrying (CS) exchanges homologous parts with the other member carrying (cs) in the F_1 and in this way (Cs) and (cS) genes could be produced. (CS) and (cs) are known as the **non-crossover** while (Cs) and (cS) are the **crossover** gametes.

Evidence of linkage and crossing over between two pairs of alleles are represented in ears of maize (Fig. 81) where most of the kernels show

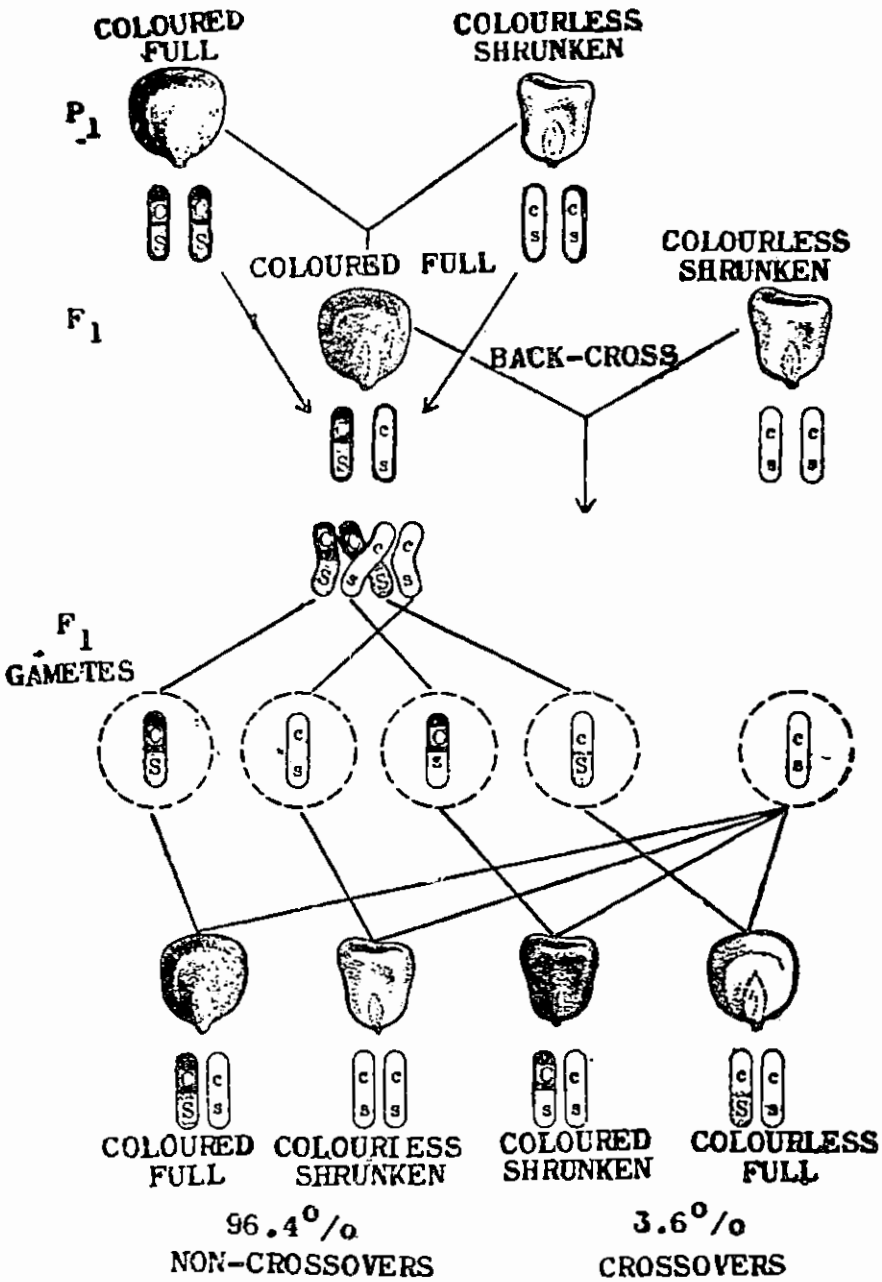


Fig. 80 — A chart showing another case of linkage in maize, (coloured full X colourless shrunken).

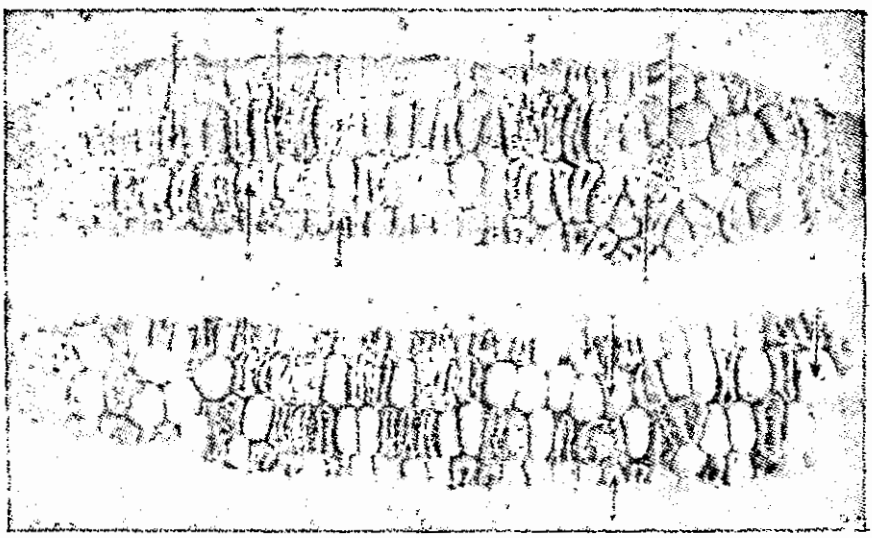


Fig. 81 — Evidence of linkage between two pairs of alleles in maize. Above: an ear resulting from a cros of a heterozygous plant with a double recessive colourless shrunken. Most of the kernels show the "parental combinations" of characters but a few denoted by X have the new combinations coloured shrunken and colourless full. Below, an ear from another heterozygote crossed with the double recessive. In this case, the recombinations (X) are coloured full and colourless shrunken, (after Hutschison).

parental combinations characters (coloured full and colourless shrunken) but a few designated by X have the recombinations (coloured shrunken and colourless full).

CHROMOSOME MAPS

A chromosome may be defined as a line on which genes are represented by points separated by distances proportional to the amount of crossing over, and so it may be referred to as a **crossover map.**

It is based on two assumptions : 1. that the genes are arranged in a line and 2. the percentage of crossing over between two genes is an index of their distance apart.

Thus, by studying the crossover percentage, genes may be located in their relative positions along the chromosomes. The most adequate chromosome maps are those for **Drosophila melanogaster** (Figs. 82 and 83).

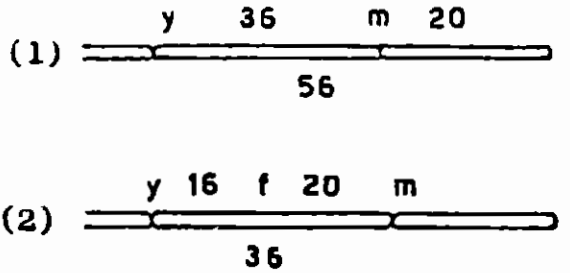


Fig. 82 — A chromosome map, showing the possible arrangements of three genes only two of the distances are known.

Suppose we have three linked genes y, m, f (**yellow, miniature** and **forked**) and the total amount of crossing over between y and m is 36%. This makes the distance between y and m = 36.

The distance between m and f may be known in a similar manner.

If the total amount of crossover between m and f is 20%. This makes the distance bewteen m and f 20. Then the crossover percentage between y and f will be either the sum (Fig. 82,1) or the difference (Fig. 82,2) of two percentages.

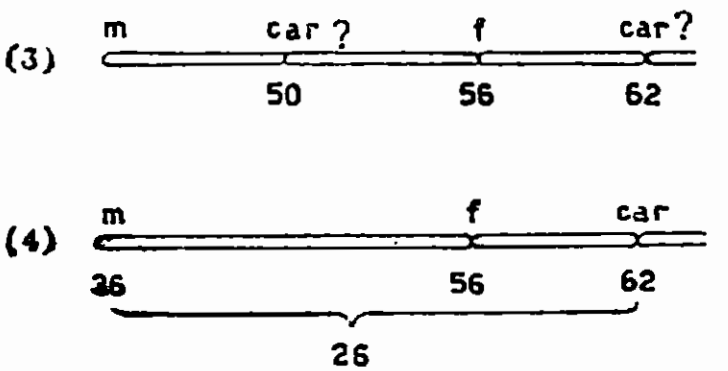


Fig. 83 — A chromosome map showing the method of adding a new gene.

Suppose, now we had mapped y, m and f and we want to add a new gene, say carnation (car); an eye colour gene in the X. We have to get a female hybrid for forked and carnation and then make a test-cross. It has been found that there are about 6% crossing over between f and car.

Since f is at 56, this would put car at either 62 or 50 depending on

whether car was to the right or left of f as shown in diagram (Fig. 83,3.) To decide between these two possibilities we should find the distance of car from some other gene, say m (miniature wings at locus 36).

If car is at 62 then its distance from m would be 62 — 36 or 26; if at 50, then its distance from m would be 50 — 33 or 14. We should actually find that car is about 26 units from m and therefore at 62 (Fig. 83,4).

Thus in order to add a new gene to the map, we might do so by finding its distance from at least two other genes on the map.

SEX-DETERMINATION

Many attempts have been made to cause an unborn child to be a male or female at will. Feeding experiments have been tried on the mother before the birth of the child. But all such attempts have failed, because they were started too late in development. Usually, the sex of the embryo is determined just after fertilization.

HEREDITY AND SEX

Sex determination by means of the sex-chromosomes was discussed under sex-linkage. It may be added here that the Y-chromosome does not determine sex. In some animals having the XY method of sex-determination, such as Drosophila, the Y-chrosomosome may be lacking and the sex of the individual will still be male.

The theory of **genic balance** assumes that the autosomes contain certain female-determining genes, and the balance between the autosomes and the X-chromosomes determines sex. The female determining genes in a haploid set of autosomes. The relative strength of the two appears to be about 1.5 to 1.

The sex of the individual, then, is determined by which of the two is stronger in the zygote. This theory was proved by testing the effects of the presence of normal and abnormal numbers of X-chromosomes and of autosome sets on sex determination in **Drosophila melanogester** (Fig. 84). The following table shows the different results obtained.

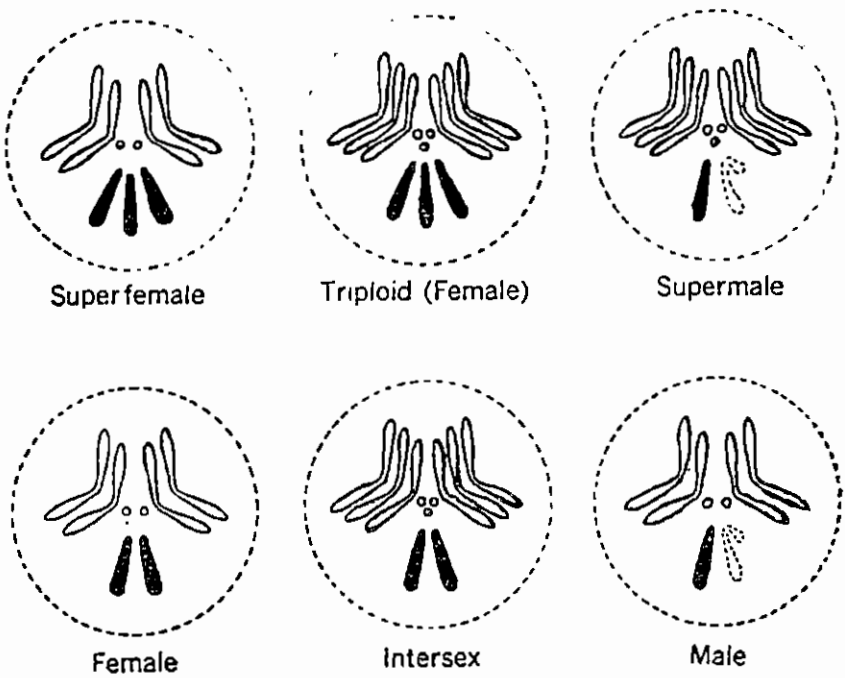


Fig. 84 — Effect on sex of the balance between X-chromosome and autosomes in "Drosophila melanogester".

Table 9. **Sexual types in Drosophila melanogaster**

Number of X chromosomes	Number of Autosome sets	Ratio of female to male tendency	Sex Type
3	2	4.5 : : 2	Superfemale
4	4	6 : 4=3 : 2	Female (4n)
3	3	4.5 : 3=3 : 2	Female (3n)
2	2	3 : 2	Female (2n) normal case
1	1	1.5 : 1=3 : 2	Female (n)
2	3	3 : 3	Intersex
1	2	1.5 : : 2	Male normal case
1	1	1.5 : 3	Supermale

N.B. : To obtain the ratio in the table, multiply the number of X-chromosomes by 1.5 to obtain the female tendency, and multiply the number of autosomes sets by 1 to obtain the male tendency.

Supermales and superfemales are flies in which the sex characters are more accentuated. Intersex combines characters of both sexes.

ENVIRONMENT AND SEX

Certain external as well as internal environmental factors were found to influence sex in some animals.

1. **Temperature** : In certain frogs, where there are chromosomes of the XY types young tadpoles kept at a temperature of 20°C. develop, in a normal manner, into approximately equal numbers of males and females. But, if the young tadpoles are raised at a high temperature (32°C), they all develop into males regardless of their chromosomal constitution.

2. **Chemical Stimuli**

In the marine worm **Bonellia viridis** the female is large with a slender proboscis, while the male is small and lives as a parasite in the uterus of the female. The fertilized eggs develop as free-swimming larvae, which later settle down and continue their development. Those larvae which settle on the sea bottom grow into females, while those which happen to settle on the long proboscis of the females become males. It has been suggested that a chemical substance (probably hormonal) is secreted in the proboscis of the female and determines the maleness of the larvae settling on the proboscis. The male passes into the body of the female and settles finally in the uterus, where it lives its life parasitically, fertilizing the eggs as they are laid.

3. **Metabolic Rate**

In general, metabolic rate differs in the two sexes of any animal species. It has been possible to increase metabolic rate in **rotifers** by a change of food and by an increase in oxygen consumption. This led to the production of males rather than females.

4. **Hormones**

In vertebrates, the primary gonads in addition to being producers of gametes, they also secrete sex hormones. These influence sex-determination during embryonic development leading to the full development of both primary and secondary sexual characters. Any significant alteration in

the production of sex horomones may lead to a corresponding change in sexual characters. **Intersexuality** or even complete **sex reversal** may result from hormonal imbalance.

INTERSEXUALITY

Intersexes are individuals which exhibit characteristics intermediate hetween the two sexes. There seems to be a gradual transition from the normal female through the different forms of intersexuality to the normal male. Genic imbalance may cause intersexuality (Table 9). Abnormal changes in hormone production, due to disease or other causes at certain stages, may lead to intersexuality. There are several types of intersexuality of which the following may be mentioned.

1. Hermaphrodism

This is one form of intersexuality in which male and female primary gonads are present together in the same individual. True **hermaphrodism** is rare in bisexual animals (including man).

2. Pseudohermaphrodism

This is the common type of intersexuality in which only one kind of primary gonads (male or female) is present, but secondary sexual characters or both sexes occur in the same individual.

3. Gynandromorphism

This is a condition in which the affected individual contains female tissue in one part of the body and male tissue in another due to chromosomal abnormalities that occur during embryological development. The relative amounts of male and female tissues may vary. One type of gynandromorph is **bilateral,** having one side of the body male and the other side female. Such an individual could be produced from an XX zygote in which during early development one of the X-chromosomes from a cell was lost by an accident of mitosis. The cells deriving from this cell would have but one X-chromosome and would be male, whereas the cells retaining two X-chromosomes would be female. The proportion of male tissue would depend to some extent upon the stage of development at which the aberration occurred. If it were enough the result would be a **bilateral sex mosaic,** or **gynandromorph.** Cases of human gynandromorph of the bilateral type have been reported.

MUTATION

The permanent change in a gene is known as **mutation** and the new type of plant or animal, as a **mutant.** Mutation has no noticeable effect at the time it occurs, because it is at first confined to one cell. But if the mutation takes place in a sperm or an egg or in a cell that is ancestral to a sperm or an egg, the mutated gene might be passed on to an offspring and from this a new race might be derived which shows the mutant trait such as white eyes instead of red in the fruit fly, **Drosophila melanogaster** which is very favourable for the study of mutation.

As a matter of fact, millions of **Drosophila** have been studied

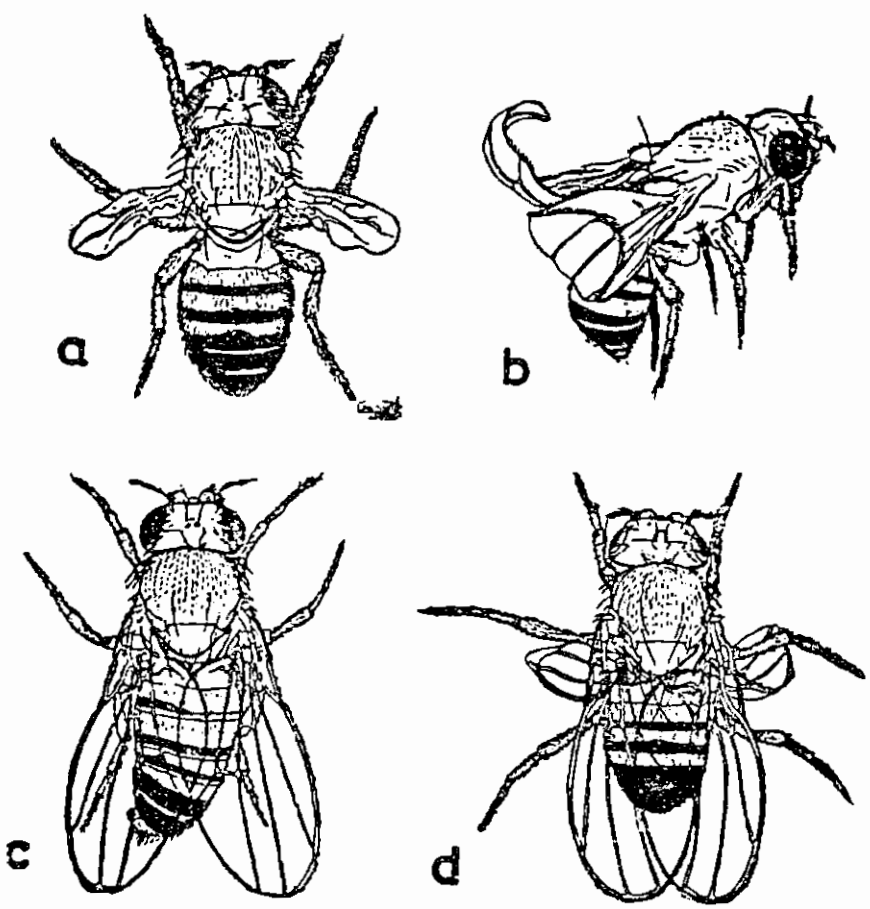


Fig. 85 — Four mutants of "Drosophila melangoaster" : (*a*) vestigial wings, (*b*) curly wings, (*c*) rotated abdomen and (*d*) bithorax.

by research workers in the laboratory and it has been observed that occasionally new mutants arise. For instance, the normal wings may be changed to vestigial or curly, and the abdomen from straight to rotated and the eyes from normal round to bar as shown in Fig. 85.

Also in the latter part of the eighteenth century, there appeared a male **lamb** with short, lowed legs in the flock of an English farmer who reared it and breed from it the **"ancon"** breed of sheep with **short** legs. These sheep could not jump over an ordinary stone fence (Fig. 86).

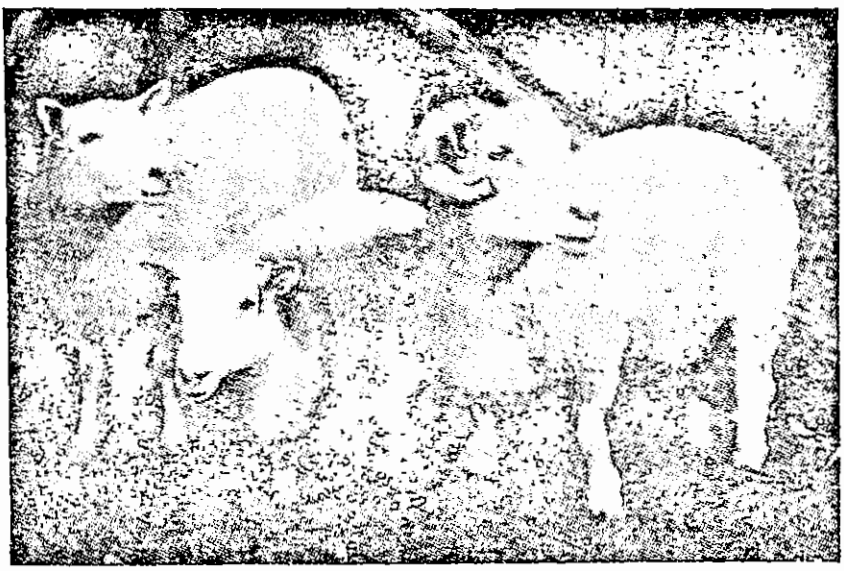


Fig. 86 — Ancon (short-legged) mutation in sheep (ewe in center, ram at right) compared with a normal ewe at left.

In the same way, **hornless** individuals appeared in breeds of horned cattle. Racing horses, double-toed cats, albino-rats have appeared after mutations. A mutaion in man is shown in Fig. 87. It is a recessive mutiation called **"albinism"** in a pair of identical twins.

In some events, mutations can have the most drastic effects such a deformed skeleton in a chicken, an unstable nervous system in "waltzing" mice and so on. Yet mutation are not always drastic as such, as in other cases many have very slight effects. For instance, in the fruit fly, it has been found that mutation might cause the eye colour to become slightly ligther than normal, the wings slightly shorter, the bristles slightly thinner

and so on. Moreover, mutation are not always deletorius. The increased speed of the thoroughbred horse in modern times is almost certainly due to mutation and this is of great use to animal breeders.

Fig. 87 — A recessive mutation. Albinsism, in a pair of identical twins, (From Rife, Schonfeld and Hunstead in Journal of Heredity)

FORMS OF MUTATION

Mutation may be due to a change in a gene (**genic mutation**) or in the chromosomes (**chromosome mutation**). Chromosome mutations are called also chromosome aberrations.

GENE MUTATION

Most genes are exceedingly stable. However, genic mutations occur at certain low rates. They consist in minor chemical changes in the genes concerned. Genic mutations have the following features :

1. Different genes have different rates of mutation.

2. Mutation may occur at any stage in the life history of an organism.

3. A genic mutation is a change in a gene, not the loss of a gene, and may be dominant or recessive, or neither.

4. More than one change may occur in a given gene producing multiple alleles, which while usually affecting the same character in different degrees, they may affect different characters.

5. The changes in genes appear to be chemical processes.

6. Genic mutations are usually harmful to the organism.

7. Genic mutations are usually recessive to the wild type.

8. Mutations do not ordinarily occur in more than one gene at a time.

9. Two identical genes at corresponding loci in a pair of chromosomes mutate independently, just as different genes do.

10. Mutations with slight effects, (e.g. polygenes) are much more common than those with marked effects.

11. Radiations like X-rays, radium rays, ultraviolet light, etc., may greatly increase the natural mutation rate, (i.e. they act as mutagens).

12. Certain chemicals also serve as mutagens, (e.g. mustard gas). Both radiations and chemical mutagens are used in artificial production of mutation.

CHROMOSOME MUTATION OR ABERRATION

Chromosome mutation may be structural or numerical.

(*a*) Structural Chromosome Aberration

The delicacy of chromonemata in certain stages of interphase and prophase facilitates the production of various aberrations since in many instances the filaments come in contact. This makes possible the breaking and joining of the chromosome, giving rise to a different organization of the parts as follows :

(i) Deficiency or Deletion

This consists in the loss of a part of a chromosome which contains one or more genes. (Fig. 88a). The missing piece is lost during gametogenesis. A deletion in a chromosome with genes A B C D may become A C D. Deficiency may occur in the heterozygous form in an individual. An individual with homozygous deficiency, (i.e. with similar parts missing from both chromosomes of a homologous pair) can rarely survive. Genetically, a deletion of one gene behaves like a recessive gene in the presence of the dominant allele. In deficiency heterozygotes, the pair of chromosomes (of which one member shows deficiency) forms a buckle at the point of deficiency during pachytene of meiosis as in Fig. 88 a.

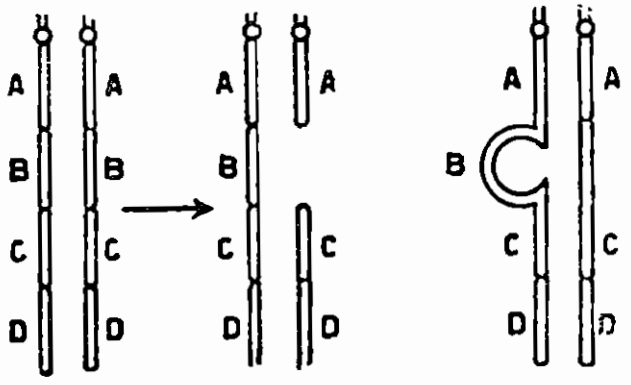


Fig. 88 (*a*) — Chromosome aberration : deficiency

(ii) **Duplication**

This is the reverse of deficiency. An extra segment is added to the chromosome during gametogenesis (Fig. 88 b). This segment may contain one or more genes from a homologous or non-homologous chromosome. Thus a chromosome with the genes A B C D becomes A B G H C D. Cytologically, a similar configuration to that of deficiency is produced during pachytene in the duplication heterozygote.

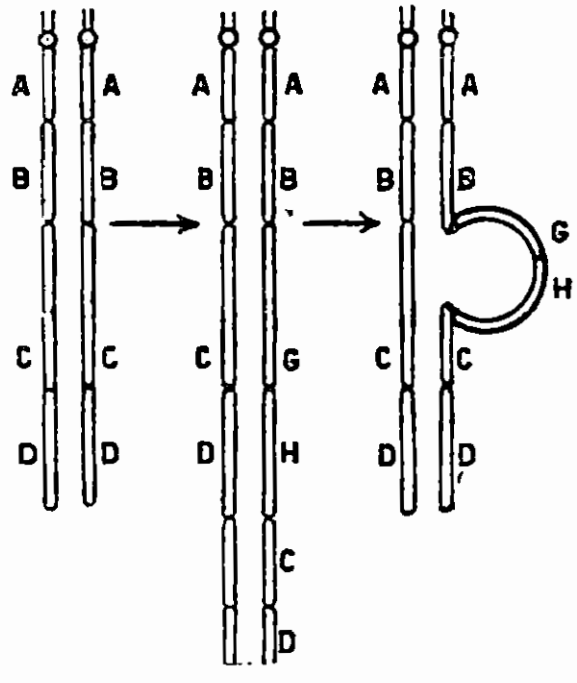


Fig. 88 (*b*) — Chromosome aberration : duplication.

(iii) **Inversion**

Within a chromosome, a block of genes may rotate by 180 degrees. For example, a chromosome with genes in the order A B C D may change to A C B D (Fig. 88 c). Inversion can be, detected genetically by the abnormal linkage relationships, and sometimes by the absence of crossing over.

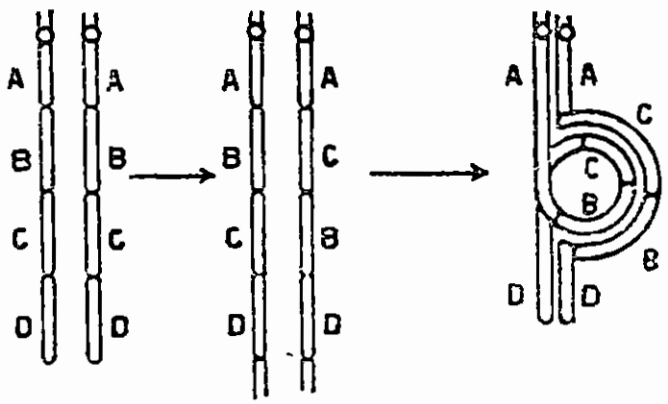


Fig. 88 (*c*) — Chromosome aberration : duplication.

(iv) **Translocation : (also called segmented interchange)**

This is an exchange of parts between non-homologous chromosomes to form two new chromosomes. For example, if the original chromosomes were A B C D and E F G H, the new ones may become A B G H and E F C D (Fig. 88 d). Translocation can be detected genetically by the

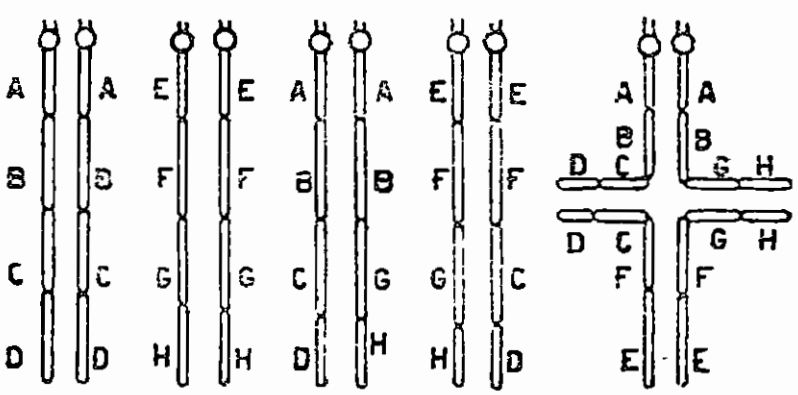


Fig. 88 (*d*) — Chromosome aberration : translocation.

abnormal linkage relationships. Cytologically, chromosomes with translocation may produce cross-shaped configuration as shown in the diagram.

(*b*) Numerical chromosome aberrations

I) Heteroploidy

Changes involving the number of chromosomes in a set. One chromosome may be lost from a diploid set, making the chromosomes 2n-1 or added to the diploid set, making them 2n + 1,2, etc.

II) Polyploidy

This involves addition of one or more whole chromosome complements to the diploid set (2n), changing the organism to a triploid (3n), tetraploid (4n), pentaploid (5n), etc. Polyploidy is rather rare in animals, but is supposed to play an important role in the evolution of plants.

PRODUCTION OF ARTIFICIAL MUTATION

Mutation can be produced artificially by the following agents :

1. X-rays

X-rays were able to produce practically all the different kinds of visible mutations in **Drosophila.**

2. Ultraviolet Light

This type of light is very effective in producing mutations in **Drosophila.**

3. Mustard Gas

This gas is a very powerful mutagenic agent. When mustard gas is administered in the proper dose to adult **Drosophila,** it produces mutations as high as 10% or even more. It yields all categories of mutations, e.g. lethals, visibles and chromosomal arrangements.

4. Chemical Mutagens

A large number of chemicals have been found to be **mutagens,** i.e. capable of producing mutation. The most important of these are peroxides, formaldehyde, permanganate, urethane, and caffeine.

Most chemical mutagens other than mustard gas and peroxides produce only a very small percentage of mutation and many of them are effective in certain animals and not in the others. Or, they are effective only at certain stages of mitosis or at certain stage of development or even

in one sex but not the other (formaldehyde is effective in the male **Drosophila** but not in the female).

DETECTION OF LETHAL MUTATION

The CIB method

This method is a standard technique for detecting new lethals only in the X-chromosome of **Drosophila** (Fig. 89). It involves the use of females in which one X contains a **crossover suppressor** (C), a **recessive lethal** (1) and the dominant gene **Bar eyes** (B). The other X is normal. Such flies are known as **CIB females.**

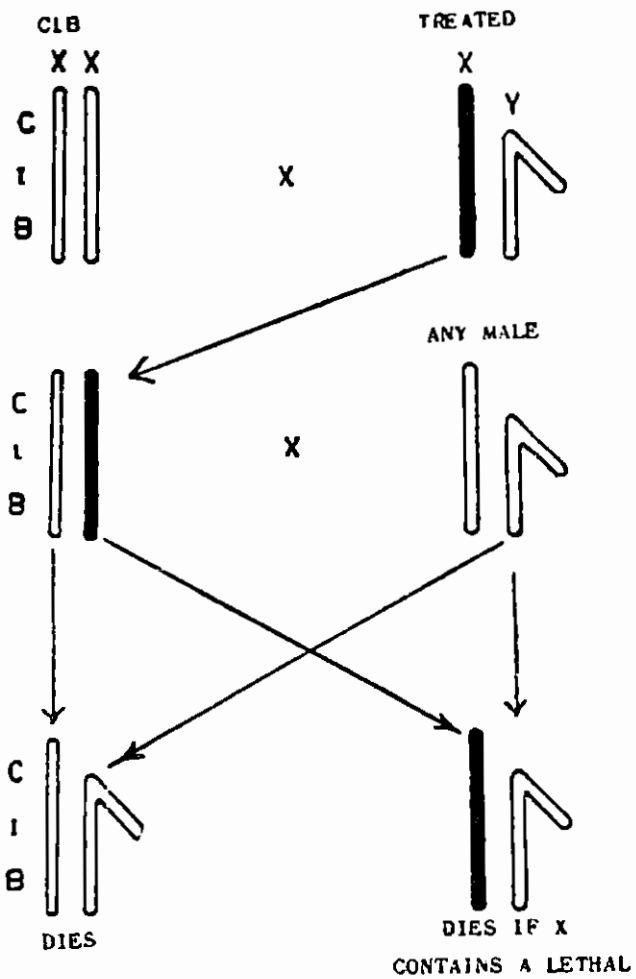


Fig. 89 — The CIB method of detecting lethals.

Males are treated with X-rays and mated to CIB females. In F_1 the Bar daughters contain the CIB chromosome (derived from their mother) and the treated X (derived from their father).

When the Bar daughters are crossed to any male, half their sons (F_2) receive the CIB chromosome and die and the other half receive the treated X and they also die if the treated X contains a lehal. But all the F_2 daughters survive since they receive a normal X from their father, any male.

Hence, if an F_1 CIB female produces daughters but no sons we should conclude that the treatment has produced lethal father.

This experiment must be accompanied by a control in which males are not treated. So if the number of lethals in the treated series is more significant than that in the control, then we should conclude that the treatment has produced lethal mutation.

If the treated X had contained a visible mutation (such as white eyes) then the mutation would show in the F_1 sons that received the treated X. Hence the CIB method can be used for detecting visible mutation as well as lethals.

GENETICS AND ANIMAL BREEDING

The main purpose of animal breeding is the raising of improved type of domestic animals which can yield larger amount and better quality of eggs, milk, wool, meat, etc., than the existing types. As all these characters are inheritable, a good knowledge of genetics is essential for the breeder of animals.

SELECTION

One of the most powerful tools in the hands of animal breeders is **artificial selection.** This consists in the choice of better animals, and mating them together in order to produce desirable offspring. This kind of selection is called, **positive selection. Negative selection** signifies the elimination of undesirable individuals.

Selection against a dominant undesirable character is easier than against a recessive one. This reason is that both homozygotes and heterozygotes exhibit the dominant character and can be easily eliminated. In

case of a recessive character, getting rid of those individuals exhibiitng it does not eliminate the character. This is because the heterozygotes are indistinguishable and survive to the next generation.

Selection does not create anything new. It merely sorts out, isolates, recombines and differentially preserves the genes responsible for the characters selected. Two types of selection are known : **phenotypic** and **genotypic selection.**

1. Phenotypic Selection

This type depends on the appearance of the trait in the individual disregarding its actual genetic consititution or genotype. Phenotypic selection is not effective enough to attain improvement, because the transmitting ability of the animal does not depend on its own merits, but on the genes that it carries.

2. Genotypic Selection

This is a type of selection based on the genotype of the individual. It is of greater value to the animal breeder than phenotypic selection. The economic characters in animals such as milk and egg production are controlled by a large number of **polygenes.** This makes it impossible to know the exact genotype of the animal. However, if the merits of the progeny (offspring) of a certain animal are known, its actual transmitting ability becomes also known. This is called **progeny testing,** and is considered the best method of selection. It gives an idea about the quality of the genes transmitted by the tested animal.

B) INBREEDING

By inbreeding we mean the mating of closely related individuals. There may be various grades of inbreeding depending on the closeness of the relationship, variation of self-fertilization in few lower animals, through brother-sister mating to the mating of distant cousins. Inbreeding increases rapidly the homozygosity of the population as it isolates pure lines of families. However, it brings to light the homozygous conditions of any recessive genes which may have been carried in the heterozygous state in the stock. The simplest illustration of this fact is given below :

Aa X Aa.

F_1 1 AA : 2 Aa : 1 aa

or 1/2 AA, 1/2 Aa, 1/2 aa.

One half of the progeny produced by the above mating are homozygous and one half heterozygous. Thus homozygosity was increased by inbreeding the F_1 individuals. The undesirable characters which might appear as a result of recessive gene for example, may then be eliminated by selection.

VARIATION

Veriation is the tendency of related organisms to differ from each other. It may be either clear and significant as **tallness and dwarfness** in peas or it may not be clear as **irregularities in the arrangement of teeth.** It may be also **quantitative** as difference in weight, length and height or **qualitative** as difference in colour and shape.

CAUSES OF VARIATIONS

There are two types of variations : **environmental variation** and **hereditary variation.** The former is caused by the external influences on the individual and this is not inherited. The latter is caused by something within the nucleus and is inherited.

Environmental variations

These variations may be **external or internal**

(*a*) External environmental variations

The chief external environmental factors are food, temperature, light, humidity, etc.

1. **Food**

Differences in the amount of food usually leads to differences in size. Absence of certain elements in food causes certain diseases, e.g. deficiency of vitamin D and C from food in man are the main causes of **rickets.**

2. **Moisture)**

In case of **Drosophila,** the colour of the body is either grey or black. It becomes striped when the insect is brought in humid atmosphere.

3. **Light**

When some aphids are kept in continuous light, they become wingless but when they are exposed to atlernative light and dark they become winged.

4. Temperature

When **Primula** plants are kept at 20°C. they produce red flowers but if they are kept at 35°C., the plants produce white flowers.

(*b*) Internal environmental variations

These are mainly due to the endocrine glands which are only found in animals. Such glands secrete hormones which regulte or control the activity of certain organs or systems of the body. The pancreas secretes insulin which controls the amount of blood sugar. The absence of such hormone causes diabetes. Also the testes and ovaries secrete sexual hormones by means of which the male and female sexual characters appear. Deficiency or disturbance in such hormones may lead to the changes or even disappearance of such secondary sexual characters.

Hereditary variations

Such variations are caused by some things in the nucleus itself. They are of two types :

1. Genetic variations

These variations are inherited through the gametes.

2. Somatic variations

These variations are inherited through the somatic cells. They may be due to somatic mutation. The desirable somatic variations are always propagated vegetatively.

Hereditary variation may be due to :

(*a*) **Gene mutation** : which may be due to sudden and permanent, change in the physiology or chemical nature of one or more genes.

(*b*) **Chromosome mutation** : which may be due to change in number or shape of the chromosome.

e.g. Some individuals may have a number of chromosomes more than the diploid and are known as polyploids. They show an increased size. Such mutation can be induced by certain chemicals.

(*c*) **Recombination** in which there is nothing new but except new arrangements or interactions of factors which have been previously described.

HUMAN GENETICS OR EUGENICS

This branch of science deals with the improvements of human race. Its aid is to decrease the inherited defects of man and to increase the useful qualities. The former is called **negative eugenics** while the latter is referred to as **positive eugenics.**

A) Negative Eugenics

This can be carried out by :

1. Sterilization

Persons with undesirable inherited characters are treated surgically to prevent their possible parenthood.

2. Marriage Regulation

Certain states of America have laws for forbidding the marriage of certain diseased persons, e.g. **epileptics, idiots,** and **insane.**

3. Control of Immigration

There are some immigration laws in certain countries wich do not accept those who have some inherited undesirable defects. But the weak point of such immigration laws is that they depend mostly on phenotypic characters rather than on genotypic ones.

B) Positive Eugenics

These can be carried out by :

1. Intelligent mate selection

In choosing the mates, intelligence is only the guide.

2. Removal of Social Hinderance

There are many conditions which act non-eugenically. These are :

(*a*) **Late marriage** : this may be due to the high cost of living. In this case, much of the best germplasm is often withheld from circulating until it becomes too little to produce succeeding generation.

(*b*) **Enforced celibacy** in various religions.

(*c*) **Lack of opportunity** to develop causes waste of much good human characters.

(*d*) **Premature death** either due to war or accidents or disease acts non-eugenically. e.g. during war the brave and wellfit persons go to fight while the unqualified stay at home and reproduce the succeeding generation. It is the task of the society to safeguard the population from war, diseases, accidents and atomic radiation.

QUESTIONS

1. Define genetics in your own words.
2. Describe the different kinds of chromosomal aberrations.
3. Describe the structure, composition, and functions of genes.
4. Define and give examples of : alleles, loci of genes, chromosome map.
5. Define with examples : dominant, recessive, homozygous, heterozygous, synapsis, phenotype ratio, genotype ratio.
6. State and give examples of Mendel's laws.
7. Explain and give examples of monohybrid crosses, dihybrid crosses, trihybrid crosses in animals.
8. What is the value of the checkerboard (Punnett square) in studying genetics ?
9. Explain with examples : complete dominance, incomplete dominance.
10. Discuss multiple genes and interaction of genes, describing each type with examples of each.
11. Discuss lethal genes and the results of their presence, including examples.
12. What are the chief causes of mutations ? What are their chief characteristics and what benefits may be derived from them ?
13. Explain the phenomena of linkage and crossing over, with the results which follow in each case.
14. Explain how a chromosome map might be constructed from properly collected data.
15. Explain how sex is determined genetically in plants and animals.

What has this to do with heredity ? Explain with examples: sex-linked traits, sex-influenced traits.

16. In what ways can hybridization be of practical importance ? List several examples to prove your point.

17. Define with examples : gynander, hermaphrodite, intersex.

18. Define with examples : hybird, pure line.

19. Discuss variations, including causes, effects, inheritance, and various classifications of them, including examples of each.

20. List several human traits, including the dominance or recessiveness of each.

21. Explain how sex is inherited in man.

22. Explain some of the difficulties which might be encountered in studying human heredity.

23. Explain the importance of family trees (pedigrees) in studying human heredity.

24. Explain multiple genes and interaction of genes in human beings, with examples.

25. Explain lethal genes in human beings, with examples,

PROBLEMS

26. NOTE : In poultry the genes for rose comb, R, and pea comb, P; if present together, produce walnut comb. The recessive alleles of both, when present together in homozygous condition, produce single comb.

What will be comb character of the offspring of the following crosses, in which the genotypes of the parents are given :

Rr Pp	×	Rr Pp		Rr Pp	× Rr pp
RR Pp	×	rr Pp		Rr pp	× rr Pp
rr PP	×	Rr Pp		Rr pp	× Rr pp

27. Work the following prablem in peas the following : T, tall plant; t, dwarf plant, Y, yellow seed; y, green seed.

Work out the entire monohybrid cross using the proper symbols and carry through to the F_2 generation in each case (1) homozygous tall X dwarf (homozygous); (2) heterozygous tall X heterozygous tall.

28. In mice, what will be the coat colour of the offspring of the following crosses, in which the genotypes of the parents are given : (C, fundamental colour gene, A, agouti; B, black).

    Cc Aa Bb × CC aa Bb

29. NOTE : Assume that in the following families, the allele for brown eyes in dominant to that for blue.

    (*a*) A Brown-eyed man marries a blue-eyed woman, and they have eight children, all brown-eyed. What are the genotypes of all the individuals in the family ?

    (*b*) A blue-eyed man both of whose parents were browneyed marries a brown-eyed woman. They have one child, who is blue-eyed. What are the genotypes of all the individuals mentioned ?

30. What will be the phenotype, as to blood groups, of offspring of parents of the following genotypes for blood groups : $I^Ai \times I^Bi$ and $I^AI^B \times I^Bi$.

31. If a person of blood group AB marries one belonging to group O, what will be the blood groups of their children ?

32. In the two following cases of disputed paternity, determine the probable father of the child.

    (*a*) The mother belongs to group B, the child to O, one possible father to A, and the other to AB.

    (*b*) The mother belongs to group B, the child to AB, one possible father to A, and the other to B.

33. In the choice of donors for blood transfusion, a patient's brother or sister is often selected. Would these be more likely to be successful donors if both parents belonged to blood group AB or if both belonged to group O ? Explain.

34. In **Drosophila,** vestigial wings, v, are recessive to the normal long wings, V, and the gene for this trait is not in the sex chromosome. If a homozygous white, long female is crossed with a homozygous red, vestigial male, what will be the appearance of the F_1; of the F_2; of the offspring of a cross of the F_1 with each parent type ?

35. A girl of normal vision whose father was colour-blind marries a man of normal vision whose father was also colour-blind. What type of vision can be expected in their offspring ?

36. A colour-blind man marries a woman of normal vision. They have sons and daughters, all of normal vision and all of whom marry persons of normal vision. Where among the grand children may colour blindness be expected to appear ? If there are cousin marriages among these grandchildren, where among their offspring may colour blindness be expected to appear ? (All persons of normal vision mentioned are homozygous).

37. **Note** : In **Drosophila** the mutant known as "black", b has a black body in contrast to the wild type, which has a grey body; and the mutant "arc", a, has wings that are somewhat curved and bent downward, in contrast to the straight wings of the wild type.

From the data below, calculate the crossover value between black and arc.

I — Black straight × grey arc.

F_1 × black arc gives :

Grey straight	281
Grey arc	335
Black straight	335
Black straight	335
Black arc	239

II — Black arc × wild type

Grey straight	1,641
Grey arc	1,251
Black straight	1,180
Black arc	1,532

PART SIX

SYSTEMATIC ZOOLOGY
INVERTEBRATA

INTRODUCTION

There are more than one and half million species of living organisms inhabiting the earth. These organisms are classified into groups according to certain criteria which may be anatomical embryological, biochemical and recently molecular approaches are being used, as well as the use of computor methods for ascertaining calculation of similarity.

Classification of animals was tried by Aristotle (384-322 B.C.) who attempted to classify animals on the basis of structural similarities between them. **Linnaeus** (1707-1778) introduced a general method of classification and published his work in "Systema Naturae." He divided living organisms into Plant and Animal Kingdoms, and classified each Kingdom into phyla; the phyla into classes; the classes into orders and the latter into families; the familties into genera and the genera into species. On the basis of morphologic distinctions and genetic implications a speices is now defined as "a group of organisms of interbreeding natural populations that are reproductively isolated from other groups and that share in common gene pools".

Each of the above mentioned divisions (phyla, classes, orders etc.) may be subdivided into other subdivision such as subphylum, subclass, grade, order etc.

Linnaeus has also used a special system of nomenclature to each individual organism. He used two names for each organism, a **generic** name beginning by a capital letter and a **specific** one beginning by a small letter. Such naming of organisms is termed **"binomial nomenclature".** However a species may be divided into **subspecies** in which three names are used **i.e. trinomial nomenclature".** In some subspecies there are more than a **variety** and the name is written in four names i.e. **quadrinomial nomenclature.** It should be noted that names of organisms are usually written in Latin.

According to the above mentioned system, the taxonomic (or systematic) positions of man, cat, and toad are as follows :

Examples of classification of animals (Kingdom **Animalia**)

	Man	Cat	Egyptian toad
Phylum	**Chordata**	**Chordata**	**Chordata**
Subphylum	**Vertebrata**	**Vertebrata**	**Vertebrata**
Class	**Mammalia**	**Mammalia**	**Amphibia**
Subclass	**Eutheria**	**Entheria**	**Salientia**
Order	**Primates**	**Carnivora**	**Anura**
Suborder	**Anthropoidea**	**Fissipedia**	——
Family	**Hominidae**	**Felidae**	**Bufonidae**
Genus	*Homo*	*Felis*	*Bufo*
Species	*sapiens*	*domestica*	*regularis*

The name of the author who first described the species may be placed after the scientific name. For instance the name of the common Egyptian toad is written : *Bufo regularis Reuss*, where Reuss is the name of the first author. If the species has been moved to a different genus, the name of the author is written in parentheses.

BASIS OF ANIMAL CLASSIFICATION

Animal classification is based on some basic factors which include the following :

1. Presence or absence of cellular differentiation

Animals formed of a mass of protoplasm not differentiated into cells and in which cellular level of organization is found are called **Protozoa.** Animals whose body is made up of a large number of cells and which show higher levels of organization are called **Metazoa.**

2. Types of symmetry

Animals may be spherical, radial, biradial, bilateral and asymmetrical.

3. Number of germ layers.

One the basis of this number, Metazoa were divided into the following groups :

(*a*) **Diploblastica** whose bodies are made up of two germ layers. ectoderm and endoderm as in **Coelenterata.**

(*b*) **Triploblastica** with three germ layers. **ectoderm. endoderm** and **mesoderm.**

4. Type of body cavity

Triploblastic metazoa are generally divided into the following three subgrades according to the nature of the body cavity.

(*a*) **Acoelomata** — without a body cavity. The mesoderm forms a solid mass between ectoderm and endrom as in **flatworms.**

(*b*) **Pseudocoelomata** — with a body cavity, which is not coelomic, found between the ectoderm and endoderm and is not lined by any membranes as in **nematodes.**

(*c*) **Coelomata** — with a well developed body cavity called the **coelom** which is lined by the mesoderm as in **annelids.**

5. Presence or absence of segmentation

In many coelomates the body is composed of number of segments. each of which have the same fundamental plan with or without variation.

Segmentation is pronounced in annelids, (e.g. earthworms); arthropods (e.g. insects) and vertebrates. In higher coelomates, segmentation is obscured and in man, for example, it is only represented by the vertebrae and spinal nerves.

6. **Unique features**

These are characteristic to one phylum of the animal world as the presence of **nematocysts** in **coelentrates.**

On the above mentioned basis and others which are mainly evolutionary and embryonic, the **Animal Kingdom** is classified according to some authors into :

Subkingdom 1. **Protozoa** — acellular organisms.
2. **Metazoa** — cellular organisms.

Metazoa is divided into two branches :

Branch 1. **Parazoa** with a high level of organization but without organs or organ systems.

It includes Phylum **Porifera (Sponges).**

Branch 2. **Eumetazoa** characterized by the presence of tissues, organs and systems. It is divided into :

Grade 1. **Radiata** with radial symmetry. It includes Phylum **Coelenterata** and **Ctenophora.**

Grade **II. Bilateria** including animals with bilateral symmetry, with elongated bodies and a head. It includes the following subgrades :

1. **Acoelomata** which includes phylum **Platyhelminthes** (flatworms).
2. **Pseudocoelomata.** including phylum **Aschelminthes.**
3. **Eucoelomata,** including all the other phyla, i.e. **Annelida, Arthropoda, Mollusca, Echinodermata and Chordata.**

As a matter of fact, it is not our intension that this part of the book should compete with any text-book of taxonomy. It is meant to be an introductory course of systematic invertebrate zoology which would be of great benefit to prepharmacy and preveterinary and perhaps, science students of the first and second years.

In view of the recent advances in biology it was found that the designation of all organisms as either plants or animals is inappropriate. One of the recent classification systems groups organisms into five principal Kingdoms on the basis of levels of structural organisation and patterns of

nutrition to conform to current biochemical and evoluntionary evidences. These five Kingdoms are :

Kingdom MONERA

1. lacks plastids. mitochondria and complex flagella.
2. without well defined chromosomes and nuclear membrane.
3. nutrition by absorption or autotrophic (photosynthetic or chemosynthetic) : saprophytic or parasitic.
4. reproduction entirely asexual by binary fission i.e. no gametes are formed.
5. locomotion absent or by simple flagella.

Monera includes **bacteria** and **blue-green algae.**

Kingdom PROTISTA

This term was introduced by E. Haeckel to include all acellular (unicellular) organisms neither plants nor animals. Protistans are characterised by :

1. well defined chromosomes, nucleolei and nuclear membrane.
2. it may contain plastids.
3. nutrition autorotrophic (i.e. photosynthetic); heterotrophic as saprophytic, holotrophic or parasitic.
4. reproduction either asexual or sexual by formation of single-celled gamete.
5. solitary or colonial acellular organisms.

Protistans include **protozoans,** and **diatoms.**

Kingdom FUNGI

1. multinuclealed cells with true nuclei.
2. no plastids or photosynthetic pigment.
3. nutrition by absorption, some members (slime molds) engulf or ingest their nutrients.
4. reproductive cycle include both sexual and asexual processes.

This Kingdom includes **slime moldo** and **true fungi.**

Kngdsm PLANTAE

It includes multicellular organisms which contain photosynthetic

pigments in specialized organelles called plastids. This Kingdom characterised by :

1. most if its members has a photosynthetic mode of nutrition ; few are parasitic or partly absorptive.
2. reproduction is mainly sexual; and gametes are multicelleular with alternation of haploid and diploid generations.
3. mostly non motile.

Plantae include red, brown and green algae and all higher plants.

Kingdom ANIMALIA (METAZOA)

1. multicellular animals with true nuclei but lack plastids and photosynthetic pigment.
2. holophytic (i.e. heterotrophic) mode of nutrition.
3. reproduction is typically sexual by the formation of gametes in multicellular structures.
4. all animals have developed a sensory-neuromotor system and motility based on a cor tractile mechanism.

This Kingdom includes all multicellular animals and is divided into three Subkingdoms :

Subkingdom I. Agnotozoa including phylum Mesozoa which are worm-like parasites.

Subkingdom II. Parazoa which include phylum Porifera consisting of sponges.

Subkingdom III Eumetazoa — with advanced multicellular organization and tissue differentiation. Eumetazoa include all other higher animals.

Subkingdom PROTOZOA

Phylum PROTOZOA

Protozoa is a group of heterogenous microscopic animals characterised only by their acellular structure. They exhibit all types of symmetry, a great range of strutural complexity and adaptations for all types of environment. Also, they should not be thought as the equivalent of a single cell of a multicellular animal. A protozoon is a complete organism which carries out all the functions of life. Hyman (1940) termed them acellular and

not unicellular. Although there are no organs or tissues. parts of the protoplasm are specialized to form organelles which perform various functions.

Protozoa occur wherever moisture is available. In other words, they may be found in soil, fresh or sea water. They are either free living or parasitic, commensal or symbiotic where they exchange mutual benefit with other organisms.

Most Protozoans are solitary individuals yet there are numerous colonial forms such as *Volvox* which attains a degree of interdependence that they approach true multicellular level of structure. Both solitary and colonial species may be either free-moving or sessile.

Most protozoans are microscopic, although few are big enough to be seen by the naked eye (large amoebas, 1 mm. long; *Spirostomum* 3.0 mm. long).

The protozoan body is usually surrounded by a thin flexible or rigid **cellular membrane.** This membrane may be surrounded by non-living external covering or shell which may be simple gelatinous or cellulose covering or composed of inorganic and organic materials. The part of the cytoplasm underneath the cell membrane is clear gelatinous cytoplasm called **ectoplasm** in contrast to the more fluid internal **endoplasm.** Both ectoplasm and endoplasm are merely different colloidal states of cytoplasm and are reversible. The nucleus may be large containing considerable amount of nucleoplasm or may be compact with dense chromatin material.

The **locomotory organelles** of Protozoa are varied and are used as a basis for its classifidation into the following subphyla :

I) Subphylum **Mastigophora** — flagellate Protozoa. using flagella.

II) Subphylum **Sarcodina** — amoeboid Protozoa, using pseudopodia.

III) Subphylum **Ciliophora** — ciliate Protozoa, using cilia.

IV) Subphylum **Sporozoa** — without special locomotory organelles.

Most Protozoa are characterised by water balancing structures called **contractile vacuoles** which act as pumps to remove excess water from cytoplasm. One or more vacuoles may be present within the animal. Contractile vacuoles may take part in excretion. Their position and structure vary within the different classes. They are most common in fresh-

water, protozoa. However, these vacuoles may be present in some marine groupes.

Modes of nutrition

1. **Autotrophic** (self-nourishing) in which organisms synthesise their food by the use of water, carbon dixoide, inorganic salts and a source of energy. There are two main types of autotrophs : (*a*) **photosynthetic** as in green plants, (*b*) chemosynthetic, as in few bacteria which make use of energy obtained by oxidizing certain inorganic substances.

2. **Heterotrophic** organisms live at the expense of autotrophs or upon decaying organic matter. There are several types of heterotrophic nutrition, i.e.

(*a*) **holozoic** which ingest complex organic food stuffs.

(*b*) **saprophytic** nutrition involves direct absorption of dissolved organic matter through the cell membrane.

(*c*) **parasitic** when the parasite lives at the expense of its host and absorbs its nourishment from it.

Digestion takes places intracellularly inside food vacuoles which at the beginning of digestion are small and acidic. then enzymes are secreted in an alkaline medium and the food vacuoles increase in size. Digested food is absorbed and undigested remnants are egested to outside.

Respiration takes place by diffusion of oxygen through the cell membrane. Many protozoans such as those living as parasites in the digestive tract of other animals or those who live in active decomposing matter can exist with little or without oxygen. Some protozoans are facultative anaerobes, using oxygen when present but capable of anaerobic respiration. Others die when exposed to oxygen.

Excretion takes place by diffusion of metabolic wastes through the cell membrane. Ammonia is the main nitrogenous waste product.

Reproduction is of two main types as follows :

1. **Asexual** reproduction which occurs in all protozoans. It may take place by :

(*a*) **binary fission** when the animal is divided into two equal daughter cells.

(*b*) **multiple fission** or **schizogony** where the individual divides into a number of daughter individuals.

(*c*) **budding,** when one or more much smaller daughter individuals are produced.

2. **Sexual reprodction** which involves fusion of gametes which may be indentical, **isogametes**; or different in size and structures **anisogametes.** Meiosis occurs during the formation of gametes. In **ciliates** gametes are not formed and exchange of nuclei takes place between two individuals in a process called **conjugation.**

Encystment is also characteristic of the life cycle of almost all protozoans. During this process the protozoan animal secretes a protective cyst which is resistant to desiccation, change of temperature and other unfavourable conditions. Cyts help the animal to overcome severe environmental conditions. In addition, cysts are used as a means of dispersion of some species. In some protozoan reproductive cycles, such as budding, fission, and syngamy may occur in the cyst.

Encystment may be an important stage during the life cycle of some protozoans and may occur even under favourable conditions.

Subphylum — MASTIGOPHORA

This subphylum includes flagellated Protozoa with one or more flagella present throughout life or at any stage of their life cycle. They are uninucleate. Mastigophores are considered as the most primitive of all protozoan subphyla.

Mastigophora is divided into two main classes :

1. **Class PHYTOMASTIGOPHOREA**: These possess chromoplasts called **chromatophores** which are pigmented bodies necessary in photosynthesis. They are holophytic. The most common examples are *Euglena, Chlamydomonas, Certium,* and *Volvox.*

2. **Class ZOOMASTIGOPHOREA** : These lack **chromatophores** and are either holozoic or saprozoic. Some of them are free living but the majority are either commensal. symbiotic or parasitic on other animals, such as arthropods and vertebrates. Examples are *Trypanosoma, Trichonympha* and *Leishmania.*

EUGLENA VIRIDIS

Habitat

Euglena viridis lives in freshwater ponds and streams especially in waters which are rich in organic nitrcgenous substances and vegetation. They are sometimes so numerous that they give a distinct greenish colour to the water.

Morphology

Euglena viridis is a spindle-shaped animal about 60 u long with a rather pointed posterior end (Fig. 90). It is covered by a firm but flexible

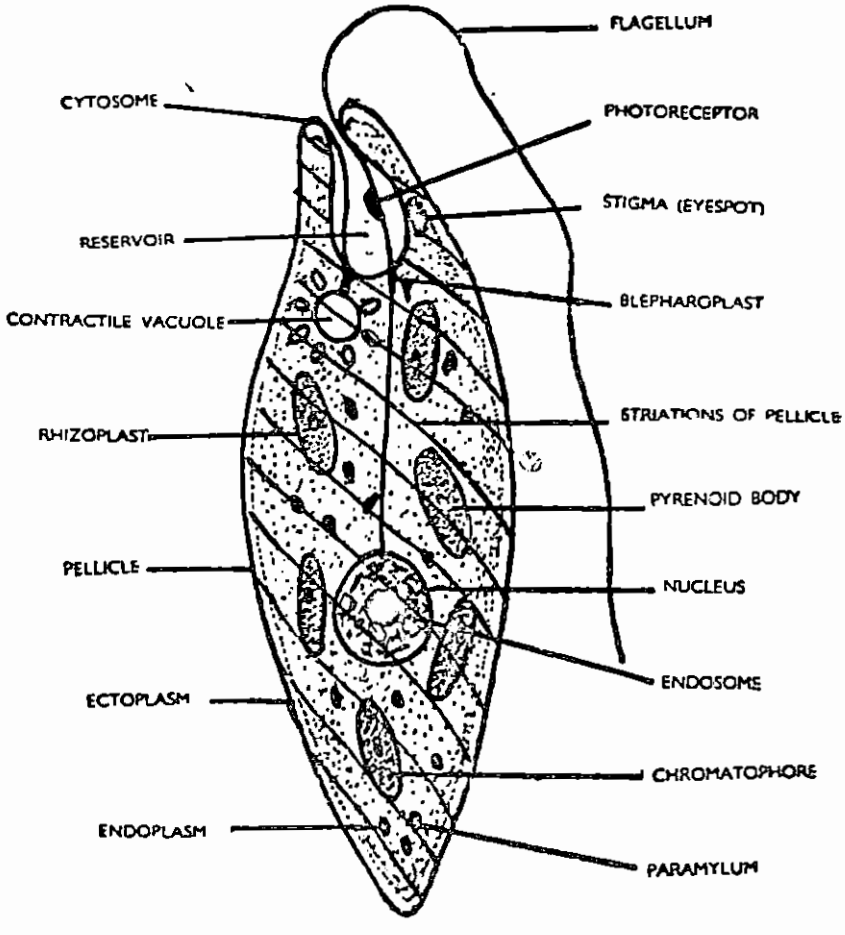


Fig. 90 — Euglena viridis

pellicle which permits movement and gives it a constant shape. The pellicle is formed of two separate membranes. It is protein in nature and not cellulose. It has oblique but parallel thickenings that run diagonally over the body. The pellicle is followed by clear ectoplasm and inner granular endoplasm. At the anterior end there is a flask-shaped reservoir called the cytopharynx from which emerges the flagella. It was formerly believed there is a single flagellum which arises by two roots. Recently it is clamied that there are two flagella; a long and a short vestigial one which does not extend beyond the neck of the reservoir and often fuses with the long flagellum. Each flagellum arises from a **basal granule** or **blepharoplast** located at the base of the reservoir. From the **blepharoplast** extends the **rhizoplast** which connects it with the nucleus. The blepharoplast may function as a centriole during mitotic division.

The flagellum, like the cilia or flagellum of a sperm. is a protoplasmic extension with two central axial filaments and nine peripheral paired fibrils surrounded by a thin sheath of cytoplasm (Fig. 91).

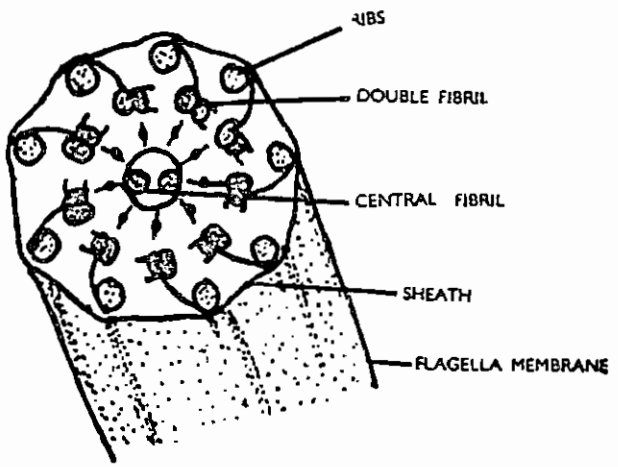


Fig. 91 — Structure of a typical flagellum or cilium.

Near the reservoir there is a red **eye spot** or **stigma.** It is a cup of a carotinoid pigment of haematochrome, which allows the passage of light in one direction to strike a light-sensitive receptor, the **photoreceptor** located as a swelling near the base of the long flagellum (Fig. 92). The stigma contains in its concavity oil droplets which act as a lens. The stigma and photoreceptor act as a photoreceptive apparatus directing *Euglena* towards light.

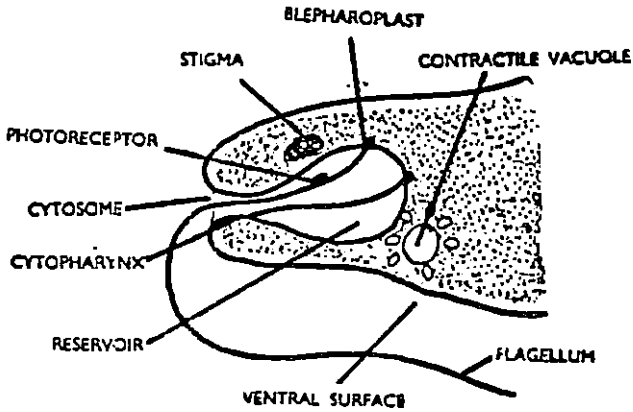


Fig. 92 — **Euglena viridis.** Anterior end showing different organelles

The **nucleus** is an oval body found near the centre with a clear nuclear membrane, chromatin granules and endosome which functions as a divsion centre in mitosis. There is a large **contractile vacuole** which is found near the reservoir, within the cytoplasm, there are many round discs containing chlorophyll and called **chloroplasts.** In the centre of each chloroplast and in the cytoplasm itself there is a protein called **pyrenoid.** This is a round transparent body acting as a centre for the manufacture of **paramylum,** which is a carbohydrate allied to starch which gives no colour with iodine. The paramylum bodies are of various shapes and found scattered in the endoplasm (Fig. 93).

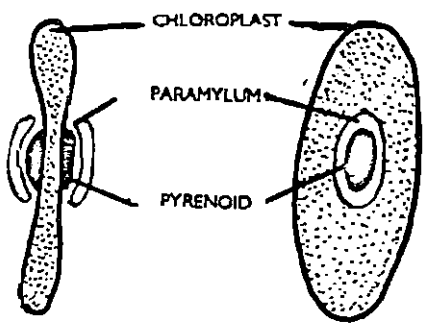


Fig. 93 — A chromatophore of **Euglena viridis.**

Metabolism

Euglena derives its food through holophytic nutrition, in the same way as plant, by using **photosynthesis.** However *Euglena gracilis* makes use

of saprophytic nutrition by the absorption of dissolved nutrient material. If it is put in darkness. and in water rich in organic matter, it loses the chloroplasts and the pyrenoid centres, and becomes saprophytic. This indicates the presence of digestive enzymes which is not a plant character. When returned to light, such *Euglena* develops chloroplasts and pyrenoid bodies and lives like plants. While *Euglena viridis* can not live well under such conditions, *E. gracilis* can live in darkness for a long time provided that the medium in which it lives is rich in nutrient material. Although *Euglena* has a cytopharynx but it is very doubtful whether it ingests solid food particles. However. some other flagellates as *Peranema* can ingest other organisms.

Water balance

Very little is known about water balance and excretion in flagellates. In *Euglena* there is a **contractile vacuole** surrounded by small secondary vacuoles (Fig. 92). It is located near the reservoir where it discharges its contents. It is believed that the secondary vacuoles collect excess water from the surrounding cytoplasm and empty it in the central large vacuole which contracts when filled discharging its contents into the reservoir.

Respiration and excretion

The exchange of respiratory gases and elimination of waste products of metabolism, takes place by diffusion through the surface of the body.

Sensory organelles

The **photoreceptive apparatus** (eye spot and photoreceptor) permits the light to strike the phtoreceptor body in one direction only. As *Euglena* is positively phototactic, it is able to orient and move in the direction of light source. This reaction is important to the animal as it needs light to carry out photosynthesis. *Euglena* prefers moderate light and avoids direct sunlight. Such reaction is an adaptive one as *Euglena* moves away from harmful stimuli (strong direct sunlight) and towards beneficial ones.

The flagella may be used as accessory sense organelles receiving mechanical or even chemical stimuli.

Movement

This takes place by :

1. **Flagellar movement** caused by beating of the flagellum (12 beats

per second) in a circle from the base to the tip. This leads to swimming in a spiral path while *Euglena* is rotating on its long axis. The rotation causes the tip of the organism to rotate while. at the same time, pushing it to one side.

2. **Euglenoid movement** is a slow and limited one brought about by a peristaltic wave of contraction and expansion of protoplasm. This wave passes over the body from the anterior to the posterior ends (Fig. 94).

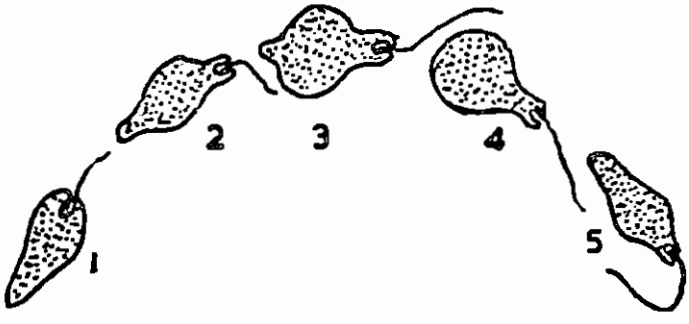


Fig. 94 — Diagram showing euglenoid movement

Reproduction

1. **Asexual reprodction** takes place by longitudinal **binary fission** (Fig. 95). The nucleus divides by paramitosis, the anterior structures such as the eye spot, reservoir and flagella are duplicated. Then, the animal splits longitudinally into two, beginning from the anterior end downwards. The contractile vacuole disappears, and appears in the daughter individuals. Such division is **symmetrogenic** (mirror image division).

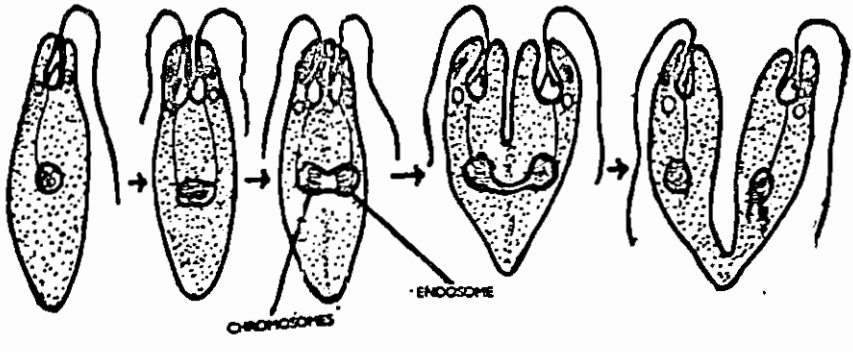


Fig. 95 — Reproduction of Euglena by longitudinal binary fission

In **paramitosis** the chromosomes remain elongated and no typical equatorial plate is formed. The chromosomes appear around the endosome; no spindle is formed, the endosome acts as a centriolar apparatus. The chromosomes are drawn out and each is broken into two. Thus two sets of chromosomes are formed, one set at each pole.

2. **Encystment** takes place under unfavourable conditions. *Euglena* which is in the active or trophic phase loses its flagella, rounds up and secretes a gelatinous thick covering forming a resistant cyst, thus becoming in the encysted phase (Fig. 96). Within the cyst it may undergo repeated **binary fission** forming 2,4 or more individuals. When the favourable conditions return, the encysted organisms are liberated from the cyst, develop flagella and become active.

Sexual reproduction is unknown in *Euglena*.

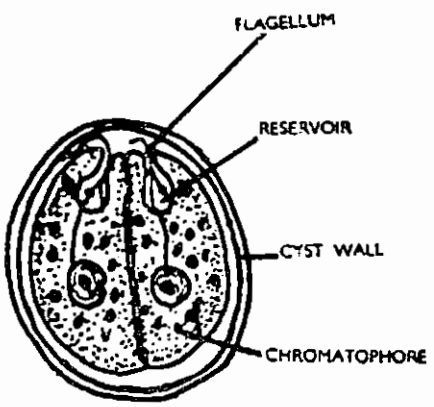


Fig. 96 — **Euglena virdis** Asexual reproduction by encystment

Position of Phytomastigophorea

These are treated by Botanists as plants, while Zoologists consider them as animals. For the following reasons Phytomastigophorea are grouped within the Plant Kingdom :

1. They possess chromoplasts.
2. They are holophytic, feeding in the same way as plants.
3. The pigments of some of them like *Chlamydomonas* and *Volvox* are identical to those of higher plants.
4. The power for moving by flagella cannot be considered as an animal character as many filamentous algae produce unicellular zoospores similar to phytomastigophores.

However, the following characters justify classifying Phytomastigophorea within the Animal Kingdom :

1. Many of them have lost their chromoplasts and live a saprophytic life like animals.
2. Saprophytic life necessitates the secretion of certain types of enzymes wich are not found in plants.
3. Some genera as *Euglena* include coloured and colourless forms.
4. *Euglena* can change its shape.

Nevertheless the gradation of Phytomastigophorea into the algae on one hand and Protozoa on the other is an indication of their prmitive position. On account of the difficulties to distinguish between acellular organisms all non multicellular organisms are included under a separate Kingdom, **Protista,** which are neither plant nor animal in nature.

PARASITIC FLAGELLATES

1 — TRYPANOSOMES

Trypanosomes live as endoparasites in the blood and tissues of vertebrates such as fishes. amphibians, reptiles, birds and mammals including man. The transmission of *Trypanosoma* from one host to another takes place by an invertebrate **intermediate host** which may be a blood sucking insect (fly or bug) or leeches which feed on the blood of animals that live or dwell aquatic habitats.

Some trypanosomes are nonpathogenic, i.e. do not cause diseases in their natural reservoirs, but those which infect mammals (man and his domestic animals as sheep, cattle, horses etc.), produce serious diseases. In man it causes the **African sleeping sickness** which is widespread in Central, West and East Africa, and **Chagas' disease** in Central and South America.

Types of human Trypanosomes

1. *T. gambiense* causes the African sleeping sickness. It is common in Central and West Africa where it is transmitted by the tsetse fly *Glassina palpalis* and *G. tachinoides*. It was first discovered in Gambia. The parasite also lives inside the antelopes, sheep, goat and pigs from where it can be

transmitted to man by the fly. However, human infection usually takes place from one person to another.

2. *T. rhodesiense* is common in East Africa and more dangerous than T. gambiense. It causes the Rhodesian sleeping sickness which leads to death in a short time. The chief intermediate hosts are tsetse flies. *Glossina morsitans* and *G. swynnertoni.*

The natural reservoirs of this species are the antelopes and other wild animals, which are not apparently harmed by the parasites, but the parasite can be transmitted from them to human beings. Hence, they act as reservoir hosts from which infection is spread to vectors.

The disease is characterised by stages of fever, enlarged lymph glands and anaemia. In late stage of the disease the parasite (*T. rhodesiense*) invades the fluid around the brain and spinal cord and spaces inside the brain causing drowsiness, coma, emaciation and finally death.

3. *T. cruzi* is common in Central and South America and causes Chagas' disease where the parasite invades the skeletal and cardiac muscles. It causes fever accompanied by heart failure and subsequent death. It is transmitted by the kissing bug, *Triatoma* sp. which lays its faeces contraminated with the infective stage of the parasite, on the mucous membranes of the eye lids or mouth or even on the skin. When man rubs or scratches the irritating wound caused by the bite of the bug, the infective stage enters into the blood through the wound. Reservoir hosts may be armadillos and opossums.

General morphology of Trypanosoma

The same species of *Trypanosoma* may exist in several forms which are different in size, shape and position of nucleus from the typical type, thus it is said to be polymorphic. Typically *Trypanosoma* is a slender leaf-like elongated curved parasite with tapering ends (Fig. 97). It is covered with a firm but elastic pellicle which gives it a definite shape. The nucleus is large, oval and central in position. The flagellum arises from a **basal granule** or **belpharoplast** situated at the posterior end. It extends anteriorly and becomes curved around the body where it is joined to it by a thin extension of a double pellicle thus forming the **undulating membrane.** The flagellum forms the axoneme of that membrane and extends beyond the anterior end as a free flagellum. A **parabasal granule** or **kinetoplast** which lies near the blepharoplast may control the locomotor organelles. Under the electron microscope, the kinetoplast is rich in DNA and it is a small part of a large mitochondrion which may extend

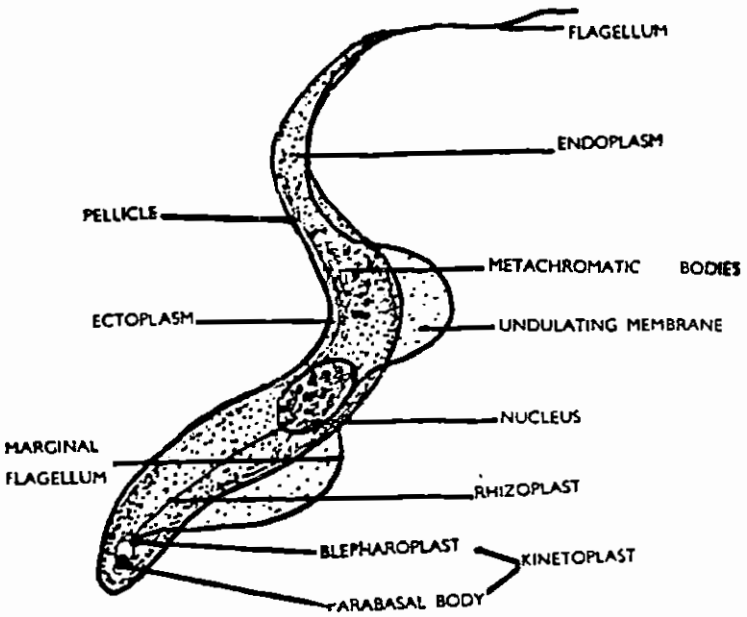


Fig. 97 — **Trypanosoma gambiense**

for nearly the length of the flagellum. The cytoplasm contains reserve food in the form of metachromatic granules. There is also a pit near the basal body which may serve as a, cytosome.

The presence of the flagellum and undulating membrane is an adaptation to movement in a fluid (blood) which offers great resistance to the movement of the parasite.

General physiology

Trypanosomes swim freely in the blood plasma by the flagella and undulating membranes as well as by the wavy motions of the body.

Nutrition is osmotrophic occurring by diffusion of nutritive material through the pellicle. **Respiration** and **excretion** take place also by diffusion. The kinetoplast may take part in the metabolism of glucose absorbed from the blood. Recent studies, however, showed that trypanosomes engulf small droplets of blood plasma by a process called **pinocytosis** (page, 23).

Reproduction

It takes place by simple binary longitudinal fission. The kinetoplast divides and then the nucleus. The flagellum and undulating membrane

remain with one half, while new ones develop from the other. Then, the animal splits logntitudinally starting from the anterior end (Fig. 98).

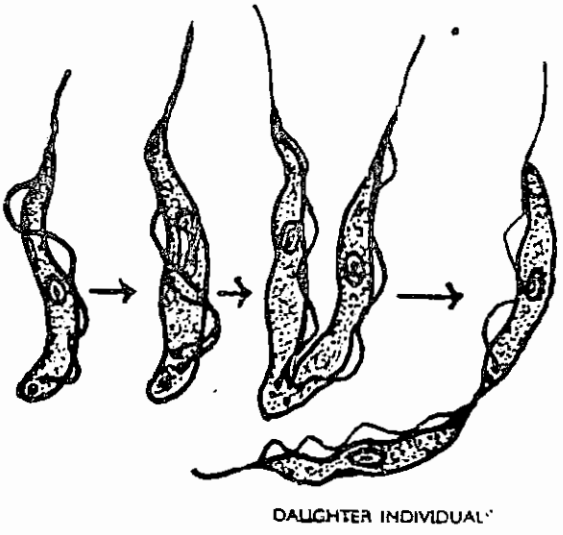


Fig. 98 — Reproduction of Tryanosoma by longitudinal fission

Life cycle

The life cylce of *Trypanosoma* is a complicated process which differs from one species to another. The following is a description of the **life cycle** of *T. gambiense* (Fig. 99).

1. In the blood of **man** the parasite exists in different forms which vary in size and shape. Two main forms can be distinguished — short thick stumpy forms with a very short free flagellum or none at all; and long. slender forms with a long free flagellum. Between the two forms, intermediate forms are usually found in the blood.

The parasite multiplies in the blood of human being and liberates its poisonous by-products of metabolism which cause fever when the parasite becomes numerous in the blood stream. If not destroyed by suitable drugs the parasite invades the cerebrospinal fluid and the central nervous system and finally leads to death.

2. When a **testse fly** bites an infected person or a reservoir host, some of the parasites are sucked with the blood into the fly's midgut. In the intestine all the forms are digested except the stumpy forms which resist digestion. These stumpy forms mutiply intensively by longitudinal binary fission giving rise to the slender long forms. After about 15 days

these slender forms invade the proventriculus of the fly from where they migrate forwards to the anterior part of the gut (buccal cavity), then pass to the hypopharynx and reach the salivary glands through the opening of the salivary duct.

In the salivary glands the long slender forms multiply by binary fission giving rise to **crithidal forms.** The latter froms have the kinetoplast and basal granule in front of the nucleus, thus the flagellum is connected to the front half of the body (Fig. 99). The crithidial forms undergo morphological and physiological changes and give rise to the infective **metacyclic forms.** These forms are short, stumpy and characterised by having the kinetoplast and basal granule at the posterior end. Thus the fly becomes infective.

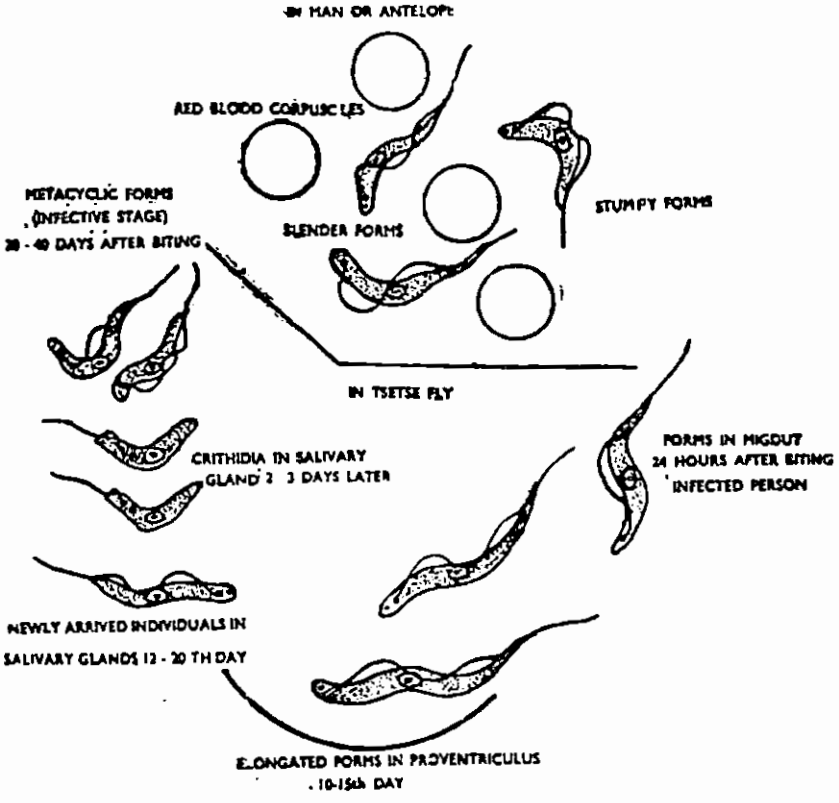


Fig. 99 — Diagram showing life cycle of Trypanosoma gambiense

The cycle inside the fly takes place about 20 to 40 days depending on the external temperature. Thus the fly will be infective after this period, or immediately after sucking the blood of an infected person. In the latter case the infective stage is carried mechanically from one human being to

another as after a blood meal the proboscis of the insect is contaminated with the parasite.

The control of sleeping sickness is a complicated task because many wild animals act as reservoir host. The best control may be the ultimate destruction of the intermediate host (tsetse fly) which is also a difficult process on account of the vast areas in which this fly is common. The prevalence of sleeping sickness has hindered the development of natural sources in many areas of Africa which are considered as the richest tropical resources.

2 — LEISHMANIA

It includes species which infect man and other mammals. There are three species which cause diseases in man and which are widely spread in Africa, Mediterranean area, Asia, United States etc. *Leishmania donovani* causes visceral Leishmaniasis or Kala-Azar infecting the spleen and liver causing their enlargment and leading to anaemia and leukopenia. *Leishmania tropica* causes cutaneous leishmaniasis or **oriental sore** which appears in the form of local nodules and ulcerations of the skin.

Leishmania is transmitted by the blood-suckting sandflies of the genus *Phlebotomus*. Various vertebrates (e.g. dogs and rodents) act as reservoir hosts for the causative organism.

Leishmania is dimorphic. In man it is oval in shape with a central nucleus, anterior basal and parabasal bodies and a short flagellum which does not extend beyond the body. When the sandfly (intermediate host) sucks the blood of an infected man the parasite multiplies asexually in the midgut giving rise to the leptomonas forms. The latter is spindle-shaped, with a central nucleus and a single long slender flagellum which arises from the basal granule. The leptomonas form is the infective stage which is injeted into the blood of man when the insect bites him.

OTHER MASTIGOPHORA

1. **Trichonympha** (Fig. 100).

It lives symbiotically inside the intestine of wood-eating termites. The termite is incapable of digesting wood it eats, but these flagellates are able to ingest the wood particles and change them into soluble carbohydrates used by both the termite and the protozoan. Both animals are dependent

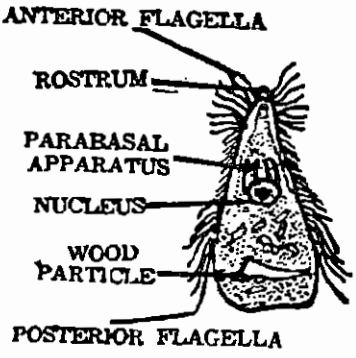


Fig. 100 — Examples of flagellates : Trichonympha

on each other. Such a symbiotic association is called mutualism where both partners are benefited.

Recent studies showed that *Trichonympha* does not contain mitochondria essential for oxidative processes. The flagellate lives as an obligate anaerobe inside the intestine of the termite. This is a physiological adaptation to live in an environment where oxygen is so little and thus the flagellate is unable to use oxygen. The presence of a large number of flagella on the body of *Trichonympha* is an adaptation to move in the fluid contents of the intestine.

2. **Choanoflagellates** (Fig. 101).

These include a number of colonial forms which are mainly sessile. Each individual has a cylindrical collar round the flagelleum. The electron

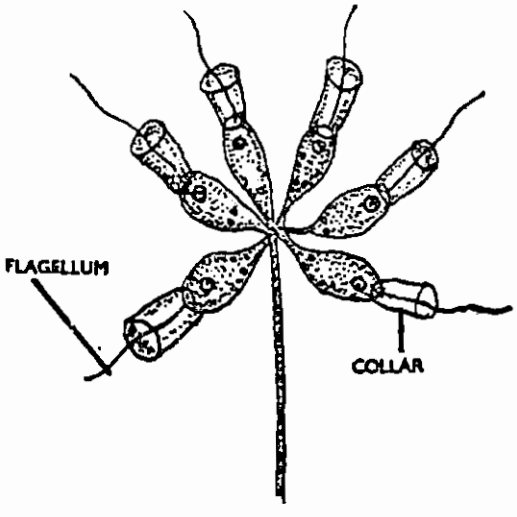


Fig. 101 — A colony of choanaflagellates

microscope shows that the collar consists of a circlet of finger like cytopla--mic extensions. The flagellum creates a current which sweeps food toward the cell, where it is trapped in the collar and then engulfed.

Subphylum SARCODINA

This includes Protozoa in which the adult moves by flowing extensions of the protoplasm called pseudopodia. These may be tube - like and are called lobopodia; thread-like, filopodia; needle-like, axopodia; or branched and interconnected to form rhizopodia. The pseudopodia are used as locomotor organelles or for capturing the prey. This subphylum includes amoebas which are either marine or freshwater or terrestrial.

Sarcodinans are either uni- or multinucleate forms and reproduce asexually by binary and multiple fission; or sexually by syngamy. The majority possess skeletal structures. Sarcodinans are close relatives to mastigophores. *Mastigamoeba* looks like typical *Amoeba* but it has a long flagellum. Moreover, many sarcodinans have flagellated gametes, a fact that suggests the **Mastigophora** as the ancestral group.

Subphylum **Sarcodina** is divided into two classes : -

I — Class **Actinopodea** — These with pseudopodia in the form of axopodia.

Order Heliozodia, e.g. *Actinosphaerium.*

Order Radiolarida, e.g. *Acanthometra.*

II — Class **Rhizopodea** — These with pseduopodia not in the form of axopodia.

Order Amoebida, e.g. *Amoeba*

Order Testacida, e.g. *Arcella*

Order Foraminiferida, e.g. *Globigerina.*

AMOEBA

The genus Amoeba includes a number of species which live in fresh, brackish and, salt waters and in moist soil. *Amoeba preteus* is common in freshwater ponds and streams. It is found in the slimy bottom of ponds and on the lower surface of leaves of aquatic plants.

General morphology (Fig. 102).

Amoebae protaus is irregular in shape and is hardly seen by the naked eye (Fig. 102). It is about 500 microns (0.5 mm.) in diameter. Although Amoeba has no definite shape, it has a distinct outline as it is covered by a cell membrane or plasmolemma. The plasmolemma is made up of filamentous molecules probably mucopotein which aids in the adhesion of the animal to the substratum. This is followed by an outer thin layer of ectoplasm and inner granular endoplasm. The ectoplasm is homogenous, non

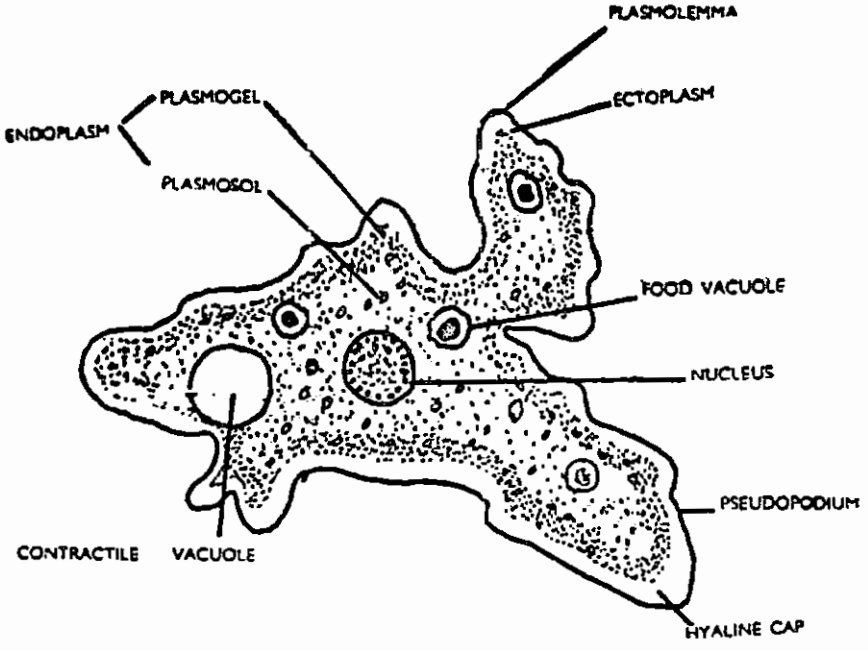


Fig. 102 — Amoeba proteus

granular, elastic translucent layer. The endoplasm is a granular heterogeneous fluid. There is no fixed line to separate the ectoplasm from the endoplasm. The endoplasm is distinguished by an outer relatively stiff plasmogel which is more solid, and an inner more fluid highly granular, plasmosol.

Inside the endoplasm there is a disc-shaped nucleus which is not easily seen in living *Amoeba*. In young amoebas the nucleus is in the form of a biconcave lens. It has no fixed position and varies with the movement of the plasmosol. The nucleus is surrounded by a firm nuclear membrane

and contains chromatin which may form granules or a network embedded in a small quantity of nuclear sap. Animals where the nucleus is removed remain alive for a short time and soon die. The nucleus controls the vital activities of the animal.

The endoplasm contains food vacuoles, a contractile vacuole, crystals, granules of various forms, fat droplets and other inclusions such as bits of debris and mitochondria.

Locomotion

Locomotion of *Amoeba* which is known as amoeboid movement takes place by finger-like processes called the "pseudopodia". The pseudopodium may arise at any point on the surface but it is always formed in one direction. If two are formed at one time one remains and the other is withdrawn gradually. There are many theories to explain the formation of the pseudopodium, the most important of these are :

1. According to **HYMAN** and **MAST** the formation of the pseudopodium is affected by a reversible change in the colloidal form of the protoplasm from the fluid sol state into a gel condition, at the point where it is formed (Fig. 103).

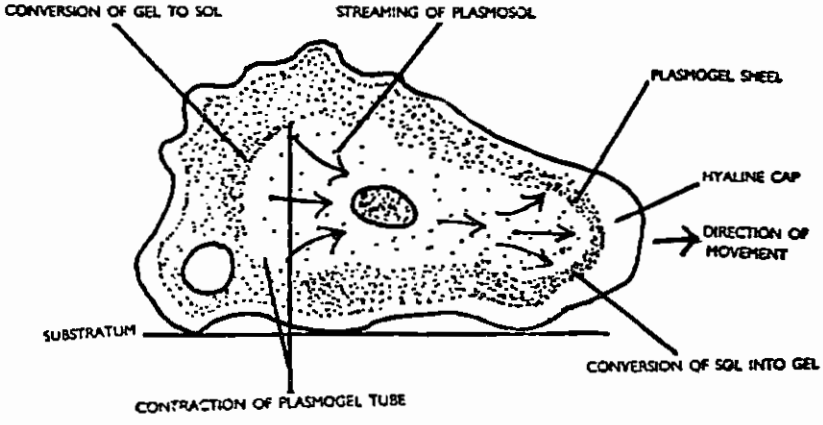


Fig. 103 — Diagram to illustrate locomotion of Amoeba (According to Mast's theory)

A pseudopodium is formed by the appearance of a blunt projection or hyaline cap which then gradually grows in size through the flowing of granular cytoplasm into it. In a moving *Amoeba* the plasmosol moves in the direction of the movement and as it reaches the anterior tip it changes to plasmogel at the sides thus forming a tube inside which more plasmosol moves towards the tip (Fig. 103). As the movement continues a constant

flow of plasmosol is maintained because the plasmogel which liquifies at the posterior end flows forward as plasmogel. The flow of plasmosol inside the plasmogel is probably due to the contraction of the plasmogel which causes a squeezing action on the sol pushing it along into the pseudopodium. This causes pressure in the liquid inside which is forced forward where the plasmogel is thinnest and weakest.

Amoeboid movement can be summarised as follows :

(*a*) Attachment of *Amoeba* to substratum;

(*b*) gelation of the plasmosol at the anterior tip of the advancing pseudopodium;

(*c*) change of plasmogel at the posterior end of the receding pseudopodium;

(*d*) contraction of the plasmogel tube at the posterior end to derive the plasmosol forwards.

2. The second theory was put forward by **ALLEN** (1962) who explained the amoeboid movement as being a result of changes of the molecular structure of the protoplasm and the amœboid movement is actually a type of slow contraction similar to muscle contraction. The endoplasm contains long unfolded protein chains. At the anterior end these protein chains become folded, i.e. contract and the endoplasm is converted to ectoplasm. i.e. from plasmosol to plasmogel. At the posterior end the protein chains unfold and the ectoplasm liquifies during its conversion to endoplasm. Thus the body of *Amoeba* is pulled forward by the contraction at the anterior end.

Nutrition and food vacuoles

Amoeba feeds on small organisms such as bacteria, aquatic plants, protozoans and organic matter. However, it shows preference to certain food such as diatoms.

When *Amoeba* comes in contact with its food, a cup-shaped pseudopodium is formed and soon bends arounds the food until it forms a vacuole containing some water (Fig. 104). The amount of water surrounding a fast-moving animal is usually larger than that taken with a nonmotile algal cell. When the food is immotile the protoplasm becomes in direct contact with the food. The vacuole circulates in the endplasm.

In this food vacuole enzymes from the surrounding endoplasm are secreted. Digestion takes place by a process similar to that of higher animals. At first the food vacuoles become small and lightly acidic. This is due to the absorption of fluids. The enzymes convert proteins to amino

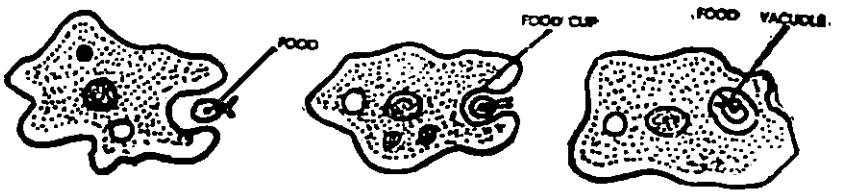


Fig. 104 — Stages in taking food in Amoeba

acids, fats into fatty acids and glycerine. *Amoeba* is unable to digest starch. The digested material now in solution is absorbed in the surrounding endoplasm where it is used as a source of energy and for the synthesis of complex compounds needed to build the protoplasm and used for vital processes. By the end of digestion the food vacuole becomes small due to the absorption of the digested food.

Undigested food particles. are ejected at any point, thus there is no definite opening to the exterior for egestion. These particles being heavier than the protoplasm are gradually shifted towards the temporary posterior end where they are left behind as the animal moves forward.

Amoeba. not only eats but also drinks by a process known as **pinocytosis** or cell drinking. When placed in a suitable solution, minute pockets or tubes, pinocytic canals, appear on the surface These tubes gulp in droplets of the solution which form vacuoles at the base of the tube and enter the protoplasm. *Amoeba* drinks about 30% of its own volume in 3 hours.

Respiration and excretion

By respiration is meant taking in oxygen and eliminating carbon dioxide. Exeretion is to get rid of waste nitrogenous products. *Amoeba* like other organisms needs energy to carry on its vital activities. By a process of oxidation the potential energy stored in highly complex compounds of the cytoplasm is released giving off carbon dioxide, water and nitrogenous compounds such as ammonia and less often urea.

Respiration and excretion in *Amoeba* take place by simple diffusion through the plasmolemma. Thus while the oxygen concentration inside the protoplasm is less than that of the surrounding water the nitrogenous waste products and carbon dioxide are in a higher concentration. Thus gaseous exchange and excretion will take place. The method of respiration and excretion is efficient because the surface area of *Amoeba* is large relative to its bulk. Carbon dioxide and waste nitrogenous products may diffuse through the wall of the contractile vacuole.

Osmo-regulation (water balance)

Since the plasmolemma is a semipermeable membrane, so in freshwater *Amoeba* there is a continuous influx of water by osmosis inside the protoplasm. In addition water is produced as a result of osidative processes. Also water enters the body with the ingested food. The accumulation of water inside the protoplasm will lead to the rupture of the animal and its subsequent death. The excess of water is periodicaly expelled through the "contractile vacuoles" which are formed regularly at the posterior end. A contractile vacuole is formed by the accumulation of minute water droplets which form small vacuoles. The latter fuse together to form a large contractile vacuole which grows gradually. The contractile vacuole appears near the hind end of the animal and moves towards the nucleus and finally towards the temporary posterior end where it is discharged by contraction of its wall. A contractile vacuole is surrounded by mitochondria which provide the energy for actual formation and function of the vacuole.

After the disappearance of the contractile vacuole a new vacuole is formed which moves towards the nucleus where it grows and repeats the process again.

Marine and parasitic *Amoeba* living in a medium having nearly the same osmotic pressure as that of the protoplasm do not possess contractile vacuoles. When placed in freshwater, marine *Amoebae* will form contractile vacuoles.. On the other hand freshwater *Amoebae* will form contractile vacuoles when placed in salt water.. Thus the main function of the contractile vacuole is osmoregulation.

Reproduction

As *Amoeba* grows it reaches to a certain size where reproduction takes place by simple binary fission. Typical mitosis occurs with all its phases (prophase, metaphase, anaphase and telophase). The process of binary fission takes place as follows :

(*a*) the body of *Amoeba* becomes spherical and crossed with small radially arranged pseudopodia. The contractile vacuoles cease to function. A hyaline layer appears in the centre,

(*b*) the nucleus divides promitotically and the nuclear membrane disappears during the metaphase.

(*c*) during the anaphase the pseudopodia become thick and coarse and the hyaline layer is no longer visible;

(*d*) at the telophase the nucleus divides into two nuclei, the animal elongates and divides into two small daughter *Amoeba* (Fig. 105).

This process of binary fission takes about 30 minutes at 24°C. The resulting *Amoeba* feed and grow until they reach a maximum size in about three days under ordinary conditions.

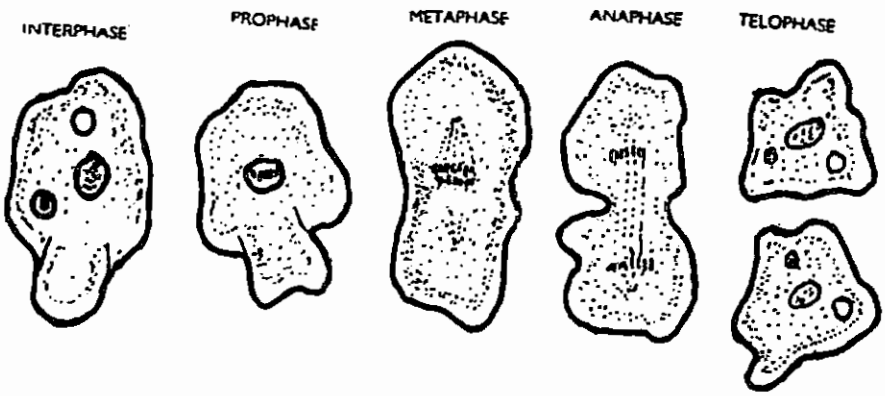


Fig. 105 — Binary fission in Amoeba. (Notice mitosis in the nucleus)

This process of asexual reproduction leads to *Amoeba* which are immortal. There is no natural death for old age.

Dying of old age was recorded only in one Protozoan *Tokophyra infusionum* (Fig. 106). The death at old age is one of the most interesting and important problems which is studied extensively to know its cause especially in human being, RUDZINSKA (1968) found that aging in *Tokophyra* proceeds in step with accumulation of minute granules in the cytoplasm of the protozoan. These granules are very similar to the lipafuscins found in the cells of human body as he gets older. It is believed

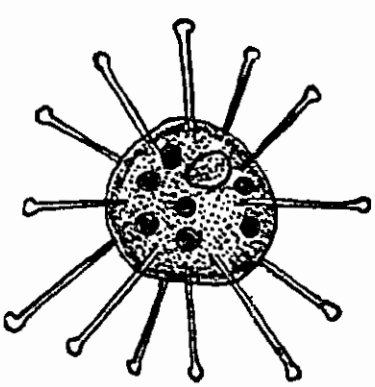


Fig. 106 — Tokophyra infusionum

that these granules are indications of the inability of the organism to get rid of metabolic waste whose accumulation causes self-intoxication which leads to the death of the cell.

Encystment

Under unfavourable conditions such as scarcity of food, severe temperatures and dryness of the pond, certain species of *Amoeba* canot carry out its vital activities. In order to tolerate these conditions *Amoeba* forms a resting stage where it is encysted. It becomes spherical, the pseudopodia are withdrawn, streaming of protoplasm ceases, cytoplasm becomes minutely granular and the protoplasm secretes an outer hard three layered cyst (Fig. 107). Inside this cyst the metabolic activities fall to minimum, and the animal is protected from the unfavourable environmental conditions. When the conditions become favourable the cyst bursts and *Amoeba* comes out to resume its normal life.

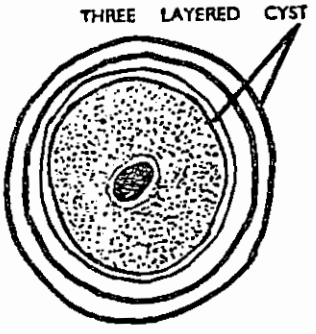


Fig. 107 — Eucysted Amoeba

Encystment is not only a means of survival but also it aids in the distribution of the animal. Thus the dried mud containing encysted *Amoeba* is blown away to different areas thus helping in the distribution of the animal. Recent studies showed, however, that in *Amoeba proteus* encystment does not take place.

Irritability and behaviour

Amoeba responds to various kinds of stimuli including contact, chemicals, heat, light, electric current, etc. Its reactions is similar to, but simpler than those of higher animals. The response to stimuli is indicated by the movement of the animal towards the stimulus, a positive reaction; or away from the stimulus. a negative reaction. The reaction

depends on the intensity of the stimulus and state of the animal. Thus *Amoeba* may react differently to chemicals having two different concentrations.

If touched by a needle *Amoeba* moves away but when floating it reacts positively to a floating object. Amoeba reacts negatively to mechanical shocks. intense light, high temperature strong acids, alkalies and many other chemicals. It shows a positive reaction to a weak light. Strong light causes gelation of the plasmosol adjoining the plasmogel, making it thicker and increasing the elastic strength, this will cause a negative reaction. *Amoeba* responds to electric current by moving toward the cathode.

Amoeba shows a selective power in choosing its food and this may be due to chemical stimuli. If the food subject is a moving organism the forward food-cup becomes wide and does not touch the prey. This may be due to mechanical stimuli.

Although *Amoeba* has no sense organs as those of higher animals but its response to stimuli is due to the irritability of the protoplasm. The reactions of *Amoeba* to stimuli keep the animal in the most favourable environmental conditions.

PARASITIC AMŒBAE

Amoeba which live in the interior of another animal are called parasitic *Amoeba* since they depend in their life on the animal (host) in which they live. The most important parasitic forms are those living in the intestine of man causing various diseases. There are six species which infect man mainly belonging to genus *Entamoeba*.

1. **Entamoeba histolytica** (Fig. 108).

Although it infects 10% of the general population. but most of the infected persons are carriers, that is the *Amoeba* live and multiply in their large intestine and produce cysts without injuring their host. In other persons *Entamoeba histolytica* attacks the mucous membrane of the large intestine, bores into the tissues till it reaches the connective and muscular layers causing bleeding ulcers. Enterance into the tissue is facilitated by secreting enzymes that dissolve away the tissues. Hence its name. *E. histolytica* (histo = tissues; lysis = dissolution). This parasite causes amoebic dysentery characterised by pains of the colon and severe diarrhaea accompanied by blood and mucus. *Entamoeba* may reach the liver and less often the lungs and brain, or even the skin where it causes serious abscesses.

In structure *E. histolytica* is similar to *Amoeba* but without contractile vacuoles. It has a characteristic nucleus which is ring-shaped with a central nucleolus and a layer of fine chromatin granules lining the nuclear membranes (Fig. 108). The animal moves by a single pseudopodium which consists mainly of hyaline ectoplasm.

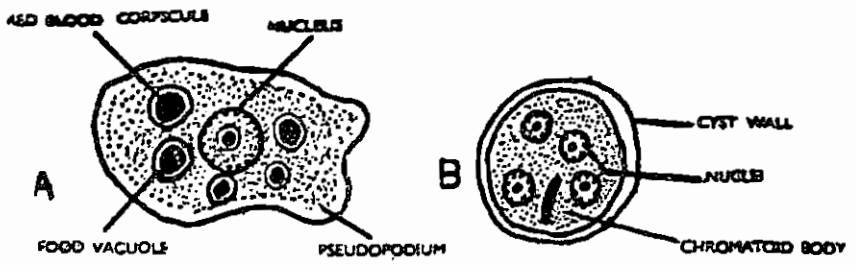


Fig. 108 — Entamoeba histolytica : A) trophozoite; B) cyst with four nuclei

Entamoeba feeds by forming food vacuoles, ingesting bacteria, starch granules, tissue cells and liberated red blood corpuscles. It exists in three forms :

1. **Tissue form** (vegetative stage, (Fig. 108 A) which is active feeding from about 20 — 40 μ in diameter. It feeds on the tissues and red blood corpuscles which can be seen in its cytoplasm. This is a dangerous form as it can penetrate through the tissues and is responsible for liver, lung and brain abscesses. It is found in acute infection.

2. **Minute form** which is about 15 — 20 μ in diameter, which is also active and moves by its blunt pseudopodia and feeds on bacteria and erythrocytes. It is usually found in the upper portion of the large intestine in chronic infection. It is the only form capable of forming cysts.

3. **Cyst form** which is found in lower portions of the large intestine and is the infective stage. Under relatively unfavourable conditions the minute forms give rise to the cysts by elimination of water and formation of a protective cyst. During the passage of the cyst through the intestine. the nucleus divides twice thus forming a four nucleated cyst which is spherical and about 8 — 15 μ in diameter. It contains glycogen and chromatoid bodies which appear refractile when alive but dark on staining. (Fig. 108 B). The chromatoid body represents stored protein nutrient.

The cyst is transmitted from one human being to another with contaminated food. The common house fly may act as a vector carrying the cysts either passively or in its faeces after contact with faecal material of infected

persons. Cysts are also carried in drinking water as a result of faulty disposal of human faeces and general uncleanliness.

When swallowed by man the cysts hatch in the small intestine and the four nucleated *Entamoebae* are liberated each divides to form eight uninucleate organisms. Encystment of *Entamoeba* is associated with reproduction as awell as distribution. Furthermore encysted Entamœba reproduces by multiple fission since the cytoplasm contains four nuclei before its division.

Cysts are killed by hot water or 1% solution of potassium permangnate, a method used to wash fruits and uncooked vegetables before eating them especially in areas where amoebic dysentery is spread.

2. **Entamoeba coli** (Fig. 109, A)

It is a harmless nonpathogenic parasite living in the large intestine of man usually associated with *E. histolytica*. It feeds on bacteria and other food particles in the intestinal contents. It may cause some intestinal disturbances. The cytoplasm contains glycogen granules, and numerous vacuoles most of which contain bacteria. The vegetalive form is about 20 — 30 μ with a distinct nucleus and two pseudopodia.

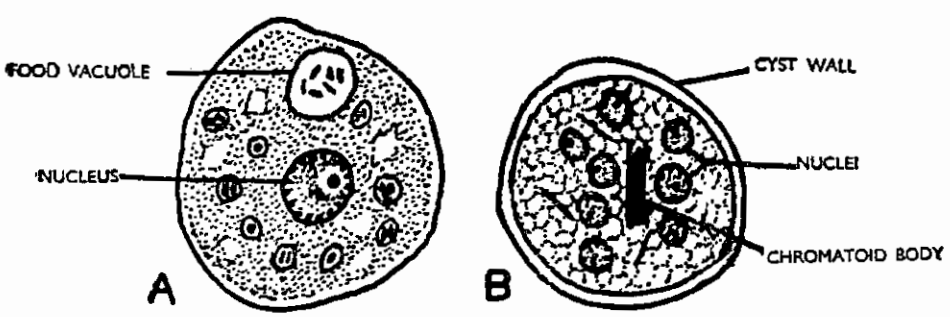


Fig. 109 — Entamoeba coli : A) trophozoite; B) cyst with eight nuclei.

The cysts which are larger than those of *E. histolytica* (18 — 25 μ in diameter). usually contain 2 to 8 nuclei (Fig. 109 B).

3. **Entamoeba gingivalis** (Fig. 110)

It lives in the mouth around the bases of the teeth where it feeds on bacteria and leucocytes. It may cause pyorrhea by dissolving the cement that holds the teeth to bone. It infects about 50% of the population. It does not from cysts and is spread from mouth to mouth during kissing or from a contaminated drinking vessel.

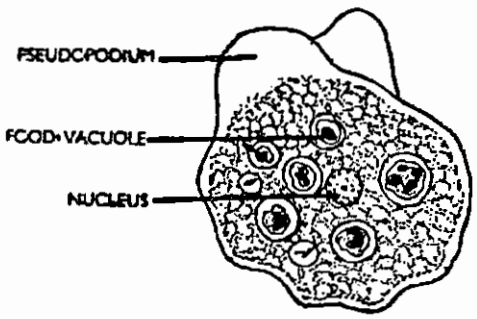


Fig. 110 — Entamoeba gingivalis

THE FORAMINIFERA

These are large protozoans characterised by the presence of a shell with many chambers (Fig. 111). The shell is made up of calcium carbonate with small amount of silica and magnesium sulphate. All its members live in the seas or oceans, being marine. The pseudopodia which are thread-like, branched and interconnected to form rhizopodia extend from tiny pores in the shell, hence the name of the group "hole bearers". The pseudopodia are used to catch, and digest the prey. The digested food is carried into the interior by the flowing protoplasm.

In forms with many chambered shells, the individuals begins its life in a single chamber which is followed by the formation of additional chambers as the animal grows in size. Different forms have different shells (Fig. 111). *Globigerina* which is a common species has spherical chambers arranged in a spiral fashion. The life cycle is rather complicated. They reproduce by multiple fission and alternation of sexual and asexual cycles occurs.

The majority of foraminiferans live on the bottom of the ocean where *Globigerina* ooze forms about 35% of the ocean floor. *Globigerina* results in the production of limestone in the form of chalk.

THE RADIOLARIA

They are entirely marine protozoans chiefly pelagic living in open water, either surface or deep water. Radiolarians are large and some species may measure few millimeters in diameter. The body consists of an inner **central capsule** which may be spherical, ovoid or branched,

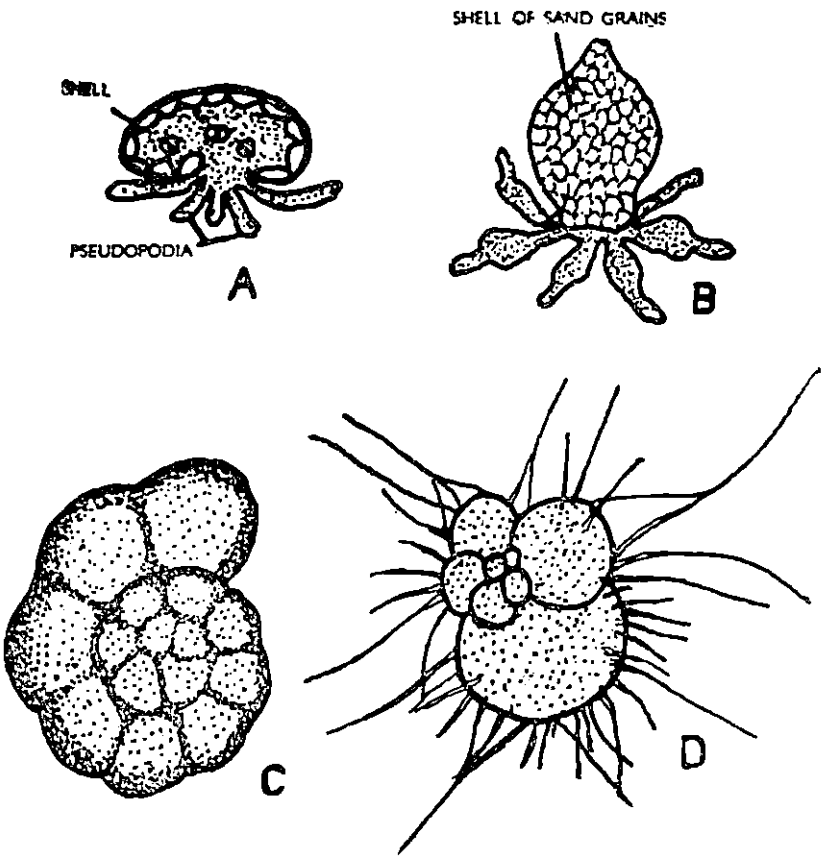


Fig. 111 — Examples of Sarcodina : A) Arcella with a secreted shell, B) Diffulgia with a shell of sand grains; C) Discorbis, foraminiferan with many chambers; and D) a living Globigerina, a foraminiferan with several compartmets of differet sizes

and an outer **cortex** of vascuolated cytoplasm (Fig. 112). The central capsule is surrounded by a thin membrane. provided by tiny pores and made up of pseudochitin. These pores allow the continuity of the outer and inner protoplasm.

From the central capsule project stiff pseudopodia, the axopods or filopods which radiate from the surface giving a characteristic appearance. The skeleton is made of silica or strontium sulphate. Radiolarians may possess one or more nuclei. Reproduction takes place by binary fission, budding or sporulation.

Radiolarian ooze, is usually found at greater depths of 4500 — 6000 meters. It may become sedimentary rocks and may be burried under other types of rocks forming flint and chert. Radiolarians as well as foraminiferans

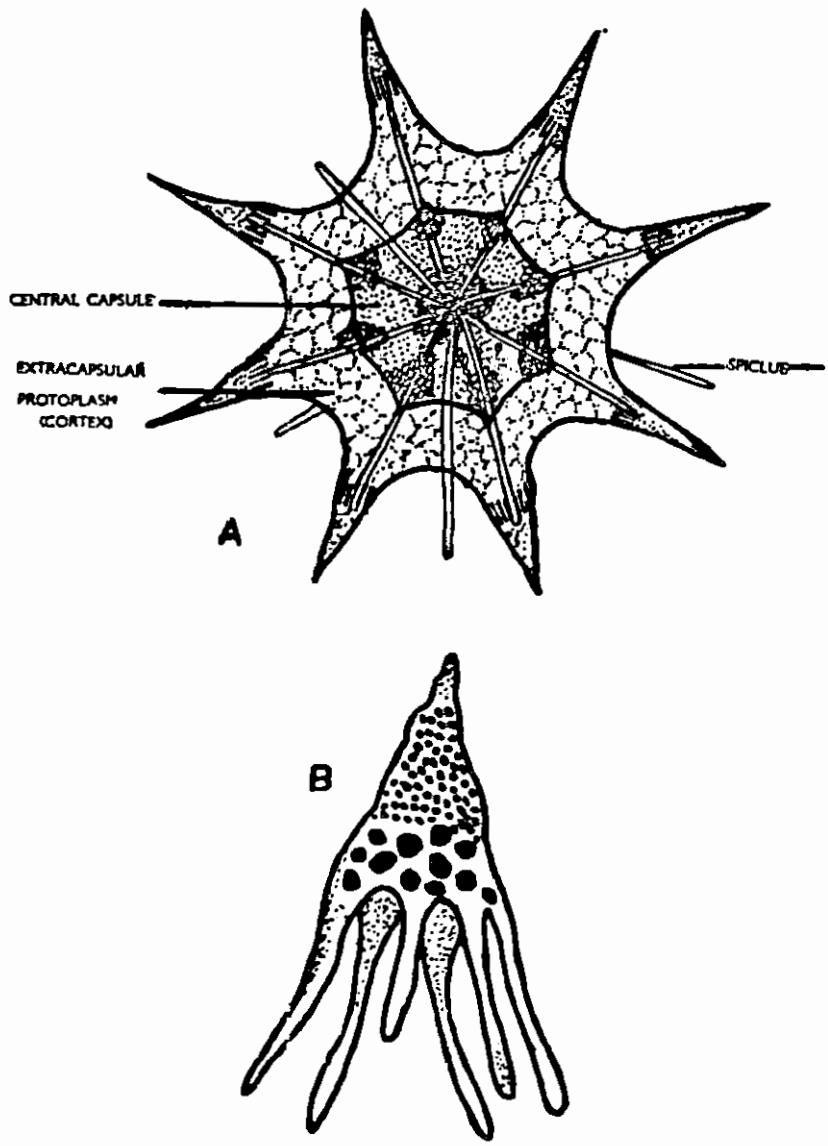


Fig. 112 — Examples of radiolarians : A) Acanthometra, a radiolarian with skeleton of radiating pieces; B) Polocystis, a radiolaraian with a non-spherical skeleton

are of great importance from the geologidal point of view especially to oil geolgogists when analyzing the results of drilling operations. Foraminiferans and radiolarians are the only protozoans which are recorded as fossils. Deposits of certains fossil foraminiferan as **Numunulitidae**

which reach 25 mm. in diameter, are frequently associated with petroleum deposits. They are important for geologists examining oil strata for signs of oil.

Subphylum SPOROZOA

All the members of this subphylum are parasitic. The immature stages of many species are usually surrounded by resistant coverings and are called **spores,** hence the name of this subphylum **Sporozoa.**

The body shape is variable but usually oval or round. There are no locomotor organelles in the adult stage, however immature stages possess pseudopodia or flagella. Nutrition is entirely saprozoic by the direct absorption of food material through the general body surface. They may infect any part of their host or body spaces as gut, bladder or coelom but they are usually intracellular parasites living inside muscle tissue, blood cells, epithelial cells etc.

Sporozoans reproduce by multiple fission or sexually by syngamy. The most common example in man is *Plasmodium* which causes malaria.

1. PLASMODIUM

(Malarian Parasites)

All the members of *Plasmodium* are parasites and are responsible for the occurrence of malarian fever. It was discovered in the blood of a patient in 1880 by **Loveran.** It has two hosts, man is the primary host where asexual reproduction takes place, and the mosquito of the genus *Anopheles* which is the secondary host where sexual reproduction occurs. The mosquito acts as a vector because it transmits the parasite from one human being to another. There are two common genera of mosquitos, i.e. *Culex* and *Anopheles*. One can distinguish between both genera by their position at rest. While Culex holds its abdomen parallel to the surface on which it rests, the abdomen of *Anopheles* is held at an angle. Monkeys carry malaria which can be transferred by mosquitos to human beings. Hence monkeys are considered as reservoir hosts.

Life cycle (Fig. 113)

It involves three phases as follows :

1. An asexual phase of growth and muliplication (**schizogony**) which.

takes place in the liver cells and red blood cells of man.

2. Sexual cycle which begins in the human being and is continued in the mosquito.

3. An asexual cycle (sporogony) occurring in the mosquito.

Asexual cycle in man (pre-and exo-erthrocytic schizogony)

When the infected female mosquito bites a human being to suck his blood it injects the sporozoites (zoites) with its saliva into the blood. The mouth parts of the mosquito are adapted for piercing and sucking as they feed on the blood of their victims. The saliva contains a weak poison which is supposed to prevent blood from clotting.

The **sporozoites** are minute sickle-shaped cells with oval nuclei. When they enter the blood stream they are carried to the liver where they penterate the endothelial cells of the liver. After half an hour of entering the blood stream all the sprozoites disappear. In the liver cells the sporozoites grow to form large round **schizonts.** Each schizont divides by multiple fission (a process called schizogony) to produce about 1,000 small spindle-shaped **merozoites.** The schizont ruptures and the merozoites are liberated in the liver sinusoides and the residual protoplasm of the schizont is destroyed by the action of phagocytes. This phase of asexual reproduction is called **pre-erythrocytic schizogony,** and the merozoites produced are known as **cryptozoites.** This process takes about ten days, a period called incubation period. During this stage the parasite is resistant to the action of drugs or to the immunity of the host. (Fig. 113).

The cryptozoites either pass into the general blood stream or reinfect new liver cells where another process of multiplication takes place. This process is called **exo-erythrocytic schizogony** where the cryptozoites give rise to schizonts in the liver cells. These divide to form the merozoites called **metacryptozoites** Thus the liver acts as a reservoir of parasites which prolong the disease and even after the relapse the symptons may appear.

Erythrocytic schizogony

In the blood stream each **merozoite** penetrates a red blood corpuscle— usually old corpuscles are attacked — where it becomes disc-like which feeds and grows at the expense of the protoplasm of a red corpuscle. A vacuole appears in the merozoite, the nucleus is pushed aside, and the **merozoite** is now called **trophozoite.** The trophozoite grows and becomes a rounded amoeboid, schizont which fills the enlarged blood corpuscle and

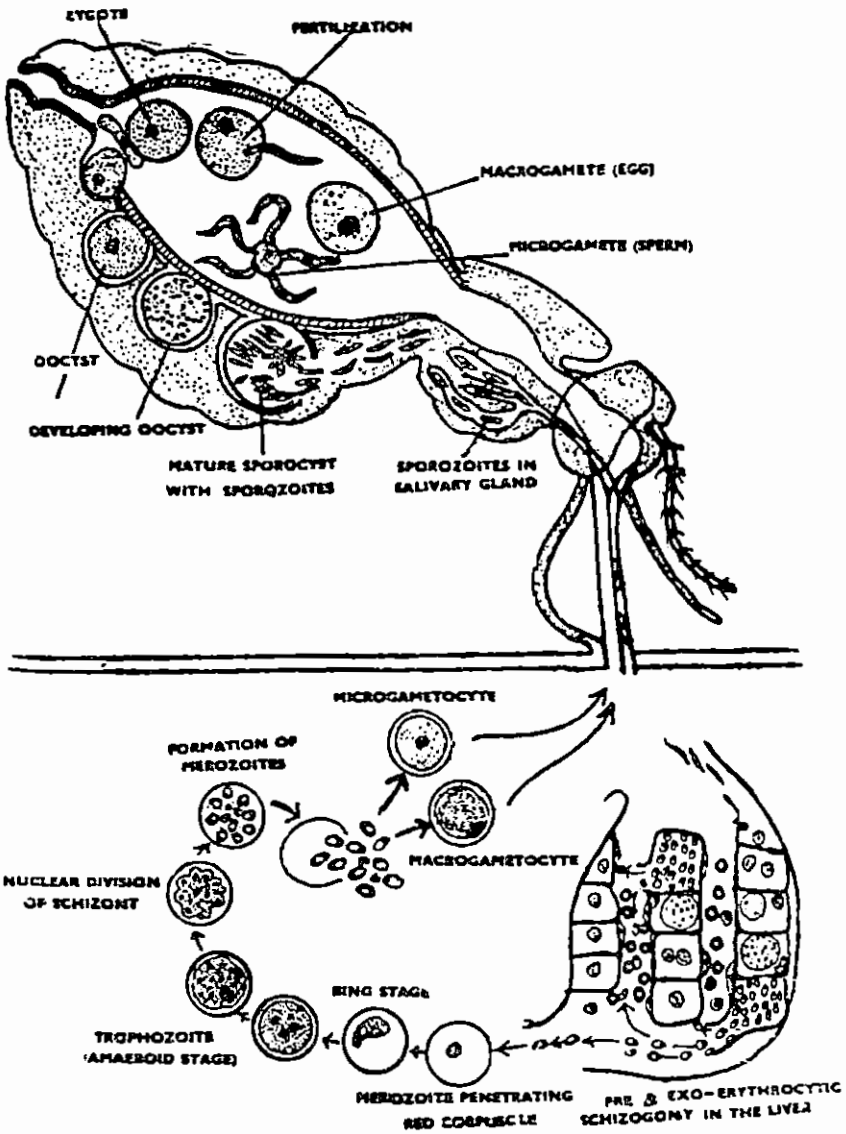


Fig. 113 — Life cycle of Plasmodium malariae

contains light-brown haemazoin granules. The latter are derived from the haemoglobin of the erythrocyes. The schizont undergoes multiple fission to form about 24 merozoites. The red blood corpuscle bursts after 72 hours and the liberated merozoites attack new blood corpuscles and repeat the cycle again.

When the blood corpuscle bursts, the residual protoplasm, pigment

and toxins (formed during the metabolism of the parasite) are liberated in the blood causing malaria fever in which the patient suffers from chills shivering and high temperature. The toxins are deposited in the liver, spleen and under the skin so that the host gets a yellow colour.

Some of the merozoites instead of attacking new blood corpuscles, continue their multiplication in the liver in the same way as the exo-erythrocytic stage. This is called **posterythrocytic schizogeny**. Thus the liver acts as a reservoir of parasites which can prolong the disease in a latent form. The patient may be cured but when his resistance is lowered, a relapse occurs.

The sexual cycle

While the process of asexual reproduction is taking place, the host develops a better resisting power, or if the infection is severe the host dies. In order to keep the race, the parasite undergoes the sexual cycle giving rise to gamonts or gametocytes. Some of the merozoites become rounded compact bodies without vacuoles and grow more slowly inside the red corpuscle to give rise to two types of gametocytes : **macrogametocytes** and **microgametocytes.** The gametocytes appear in the peripheral blood at various intervals after the onset of the fever. They remain inactive in the human blood.

The **macrogametocyte** is the female, with round body and a small excentric nucleus. Its cytoplasm is laden with food. The microgametocyte is the male, with a clear cytoplasm and a large central nucleus. When a female *Anopheles* feeds on the blood of an infected person it sucks all stages including the gametocytes. In the stomach of the mosquito the following takes place :

(*a*) all stages are digested except the gametocytes which can withstand the action of digestive fluids.

(*b*) the **microgametocytes** undergo repeated divisions each giving rise to 4 — 8 small slender **microgametes** by a process of exflagellation.

(*c*) the macrogametocytes undergo little change, the nucleus of each loses a part of its contents. it projects outwards with some cytoplasm, thus forming one **macrogamete.**

(*d*) the microgametes which are active penetrate the macrogametes, fertilization takes place and round zygotes are formed.

Sporogony

It is the process by which the sporozoites are formed and takes place in the following steps :

(*a*) The round zygote which is believed to metamorphose into an active crawling **"ookinete"** passes between the epithelial cells of the stomach to lie in the haemocoele. Some authors, however, claim that the zygote is mechanically pushed into the stomach wall and suggest that the ookinete is a dying stage which is passed out with the faeces.

(*b*) The zygote which is lying below the outer epithelium of the stomach becomes surrounded by a cyst and is called oocyst.

(*c*) The oocyst grows by absorption of nourishment and bulges out of the wall of the stomach. The nucleus of oocyst undergoes a series of repeated divisions giving rise to spindleshaped cells, the sporozoites (zoites).

(*d*) The oocyst bursts and the sporozoites are set free into haemocoel which forms the body cavity of the mosquito. Then, they migrate to the salivary glands and enter the duct of the hypopharynx. The mosquito is now infective when it bites a healthy human being. This process of sprogony takes from 10 days to 3 weeks depending on the temperature.

Adaptation of Plasmodium to parasitic life

1. The sturcture of the parasite being simple that it can live easily inside the tissue cells and red blood corpuscles.

2. The life cycle involves sexual and asexual reproduction leading to the formation of large number of parasites either in the primary or secondary hosts.

3. The presence of an intermediate host or vector which is a blood sucking insect or mosquito. This insect is active and transmits the parasite from one human being to another. The mosquito also ensures the spreading of the parasite, if the original host died or developed biological resistance.

Control of malaria

There are at least three steps which are effective in the control of malaria :

1. Treatment of infected human beings by the use of suitable antimalarian drugs such as primaquine, plasmochin. atebrin etc.

Table. **Characters of different species of "Plasmodia"**

	P. vivax	**P. malariae**	**P. falciparum**
Incubation period	10 days	27 - 37 days	10 days
Trophozoite	Ring shaped, fills 1/2 - 1/3 red corpuscle	Ring-shaped, fills 1/3 - 1/2 red corpuscle	Ring - shaped, fills 1/6 - 1/5 red corpuscle
Schizont	Fills enlarged blood corpuscle, with yellowish brown haemozoin 12 - 24 merozites	Fills normal red corpuscle, dark brown golden yellow pigment 6 - 12 merozoites	2/3 - 3/4 red corpuscle which is not enlarged 8 - 36 merozoites
Erythrocytic gametocytes	Fills enlarged erythrocyte	Fills normal erythrocyte	sickle - shaped occupying one side
Fever	Every 48 hours tertian malaria vivax malaria	every 72 hours quartian malaria	24 - 48 hours tropical malaria (malignant tertian)

2. Protection of uninfected persons by :

(*a*) using mosquito curtains, screens, nets etc.

(*b*) application on the skin of repellents which repels the mosquito from biting the human being.

(*c*) using prophylactic drugs such as quinine.

3. Systematic extermination of the mosquitos :

(*a*) in their habitats : by using very effective insecticides which are available nowadays.

(*b*) in their breeding grounds : by draining swampy places, filling up ditches and ponds where mosquitos breed, by spraying the surface of ponds with kerosine oil or with insecticides which kill the early stages of the mosquitos, or by introduction of natural enemies such as fish, *Gambusia* which feed on the larvae and pupae of mosquitos.

Subphylum CILIOPHORA

Class CILIATA

The subphylum **Ciliophora** includes the ciliates which are characterised by the presence of cilia or ciliary structures used as a locomotor, sensory or food acquiring organelles at some time in their life. Cilia and flagella have the same fundamental structure, but cilia differ from flagella in being much shorter, more numerous and their mode of beating and type of movement. Cilia are considered to have evolved from flagella.

A cilium (Fig. 91) consists of a matrix surrounded by a membrane continuous with the plasma membrane. The matrix contains eleven straight fibrils which run throughout the whole length of the cilium; two fibrils are central while nine paired peripheral fibrils surround the central ones.

Ciliates are characterised by the presence of an intraciliary system composed of basal granules or kinetosomes below the cell surface, and interconnected by longitudinal fibrils known as interciliary fibrils (neurofibrils). Most ciliates posses a cell mouth or cystosome, and two types of nuclei a large dense vegetative macronucleus and a small reproductive micronucleus. Reproduction takes place asexually by transverse binary fission. Sexual reproduction never involves the formation of gametes. Sexual reproduction takes place by conjugation.

Ciliates are widely distributed in both fresh and marine waters. Most

of them are free living, few are true parasitic forms such as *Balantidium coli*. (Fig. 124) which is a large ciliate living as a parasite in the large intestine of man causing severe ulcers and dysentery. Some ciliates live as ecto- or endocommensals. *Balantidium coli* lives as an entocommensal inside the intestine of pigs causing no disease.

PARAMŒCIUM

It is abundant in fresh-water containing bacteria, decaying organic matter and in sewage water. It is about 15 — 300 microns in length. It is slipper - shaped hence called slipper animacule with a blunt anterior end and somewhat pointed posterior end (Fig. 114). The body is covered with a complex living stiff but flexible pellicle which gives it a definite shape. The animal has asymmetrical appearance due to the presence of an oral groove which runs obliquely backwards. The oral groove leads into a conical - shaped vestibule (Fig. 114) which is followed by the buccal cavity (peristome or pre-oral chamber). At the base of the buccal cavity there is the cytosome (cell mouth) which opens into a funnel-shaped canal, the cytopharynx that extends down the cytoplasm. At the end of the cytopharynx food vacuoles are formed. While the buccal cavity contains compound ciliary organelles which serve in feeding, the cytopharynx is devoid of cilia. The buccal cavity is lined with the undulating membrane which is composed of a row of fused cilia adhering together to form a delicate sheet whose action helps to propel food into the cytopharynx. In addition there are membranelles which are formed by the fusion of several rows of short cilia. Some of these membranelles extend in the cytopharynx.

The cytoplasm is differentiated into an outer clear ectoplasm and an inner more granular endoplasm. The ectoplasm consists of :

1. The pellicle is a double membrane being firm and elastic enough to allow the animal to bend and squeeze through various passages. The pellicle is composed of hexagonal areas which are slightly concave (Fig. 115). From the centre of each one projects one or more cilium. These cilia are regularly arranged to form rows. All the cilia are of uniform size except in some species of *Paramoecium* where the posterior cilia are longer hence called *P. caudatum* The cilia are organelles of locomotion. food collection and sensory receptors which detect stimuli of the external environment.

2. **Alveolar layer** containing the basal granules or *kinetosomes* which

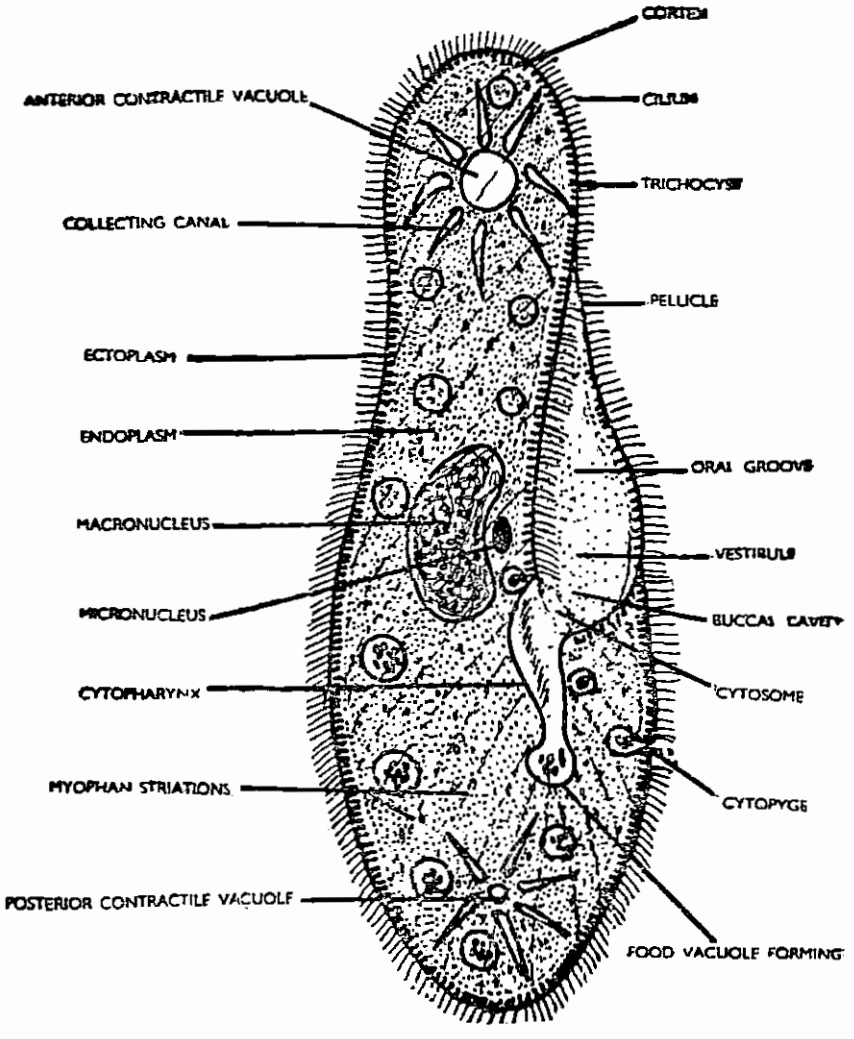


Fig. 114 — Structure of Paramoecium

are connected by means of fine fibrils called kinetodesmata. The cilia, basal granules and the kinetodesmata which make up a row are called kinety. The base of each cilium is surrounded by a ciliary corpuscle. Alternating with the ciliary corpuscles are bottle-shaped organelles, the trichocysts (Fig. 115). Each trichocyst opens through a pore found on ridges of the pellicle. When excited by pressure or by irritant liquids the trichocyst is discharged into a long striated thread-like shaft with a terminal short spine. The discharged trichocysts may be used in anchoring the animal on solid objects when feeding. They may be used for defence and

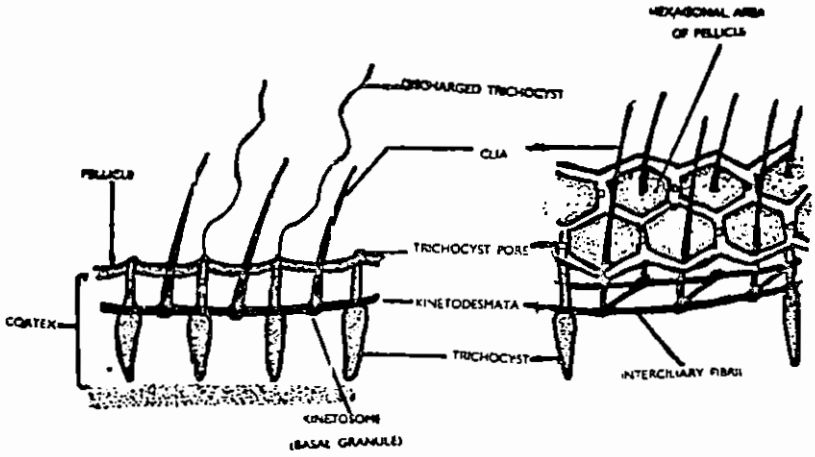


Fig. 115 — Diagram showing part of the neuromotor system, trichocysts and cilia of Paramoecium

in some ciliates (*Dileptus*) for capturing the prey or even organs of offense. In some ciliates the trichocytsts are filled with a fluid which has a paralysing effect on other protozoans. The trichocysts are discharged as a reaction to local contact, injury, action of weak acid solution or even when attacked by an enemy.

The cilia with their basal granules and longitudinal fibrils form a neuromotor system concerned with the coordination of the ciliary action. Another type of fine fibrils extend in the ectoplasm and are connected to the basal granules. These longitudinal fibrils converge and join a larger granule called motorium. The motorium and associated fibres form a conducting and coordinating mechanism compared to some extent to the nervous system of metazoa.

The endopasm contains food vacuoles with food in various stages of digestion. Toward each end of the animal and near the surface are two contractile vacuoles. Each vacuole is made up of a central space surrounded by a system of radiating collecting canals which extend throughout the protoplasm. The contractile vacuoles are fixed in position and associated with the innermost layer of ectoplasm and empty through a distinct canal that penetrates the pellicle. There are two nuclei : a large bean or kidney-shaped macronucleus called the vegetative nucleus. and a small micronucleus which lies in a depression within the macronucleus. The micronucleus contains typical chromosomes, but the macronucleus do not.

The macronucleus is essential for normal metabolism as it controls trophic and vegetative functions and is responsible for the genic control

of the phenotype. The micronucleus is a reproductive and hereditary nucelus which gives rise to macronuclei. An animal can survive with the macronucleus alone. If the macronucleus is lost or removed the animal dies even if the mioronucleus is present.

Locomotion

The beating of the cilia is directed obliquely and posteriorly. This causes the animal to rotate on its longitudinal axis as it moves. As the cilia on the cral groove are longer and their beat is stronger than the other cilia covering the body, so that the anterior end turns aborally, *Paramoecium* swims in a spiral path (Fig. 116) when it moves forward. When moving backwards the beat and path of rotation are reversed.

When coming, across an obstacle or an irritating chemical substance, *Paramoecium* reverses its ciliary movements, then swims back for a short

Fig. 116 — Locomotion of Paramoecium (notice spiral path while swimming).

distance, pivots its posterior end, then it turns its anterior end aborally. Then, it swims forward. Such reaction is called "avoiding reaction" which is the basis of **"trial and error"** behaviour.

Metabolism

Paramoecium is a holozoic animal feeding upon other protozoans, bacteria, algae and other small organisms. The aniamal selects its food. *Paramoecium* feeds only when it is swimming slowly or when it is at rest. it never feeds when swimming quickly.

Food is brought to the body and into the buccal cavity by the action of the ciliary organelles (cilia in the oral groove, undulating membrane and membranelles). From the buccal cavity the food particles are driven by the undulating membrane through the cytosome and into the cytopharynx. At the end of the cytopharynx the food particle which becomes surrounded with some water, is constricted off and dropped into the cytoplasm thus forming a food vacuole. Constriction of the food vacuoles is aided by certain long fibres that extend beyond the cytosome (Fig. 117). The food vacuoles circulate along a more or less definite path by the slow movement of the endoplasm termed *cyclosis*. The food vacuole moves

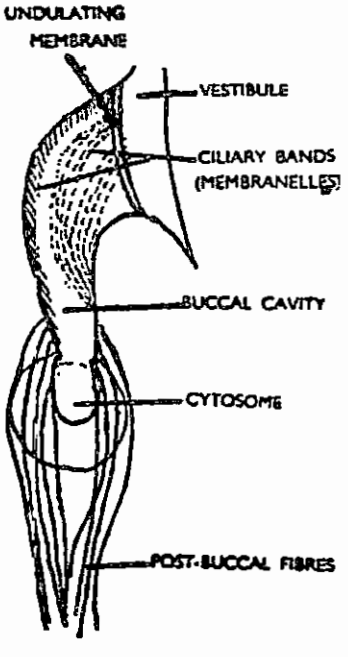


Fig. 117 — Feeding apparatus of Paramoecium

posteriorly then forward near the aboral surface (the surface opposite the one which contains the cytosome) to the anterior end, then posteriorly and downwards to the cytopyge (anal pore) (Fig. 118). During this course the food is digested by enzymes secreted from the endoplasm. At the beginning the food vacuole becomes small due to the absorption of water. Then it becomes acidic probably due to an acid secretion. Then it increases in size and gets larger due to the secretion of enzymes which function in an alkaline medium. It has been shown that the digestive enzymes are found in small vesicles surrounding the food vacuole, which later fuses with it.

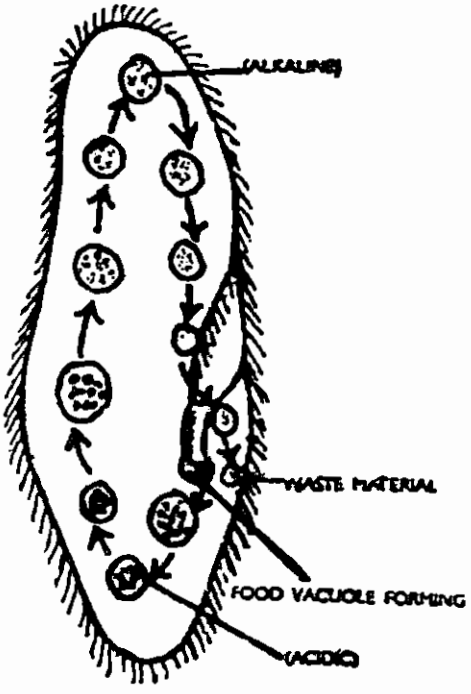


Fig. 118 — Cyclosis in Paramoecium

These vesicles are called lysosomes. After digestion, the digested food is absorbed through the wall of the food vacuole, while the undigestible part of the food is rejected through a definite but temporary anal pore or cytopyge (cytoproct) which is situated on the oral surface near the end of the cytophlarynx. The absorbed food is stored in the form of glycogen and fat droplets scattered throughout the endoplasm. *Paramoecium* is able to digest proteins, fats and small amounts of starch are broken down.

Although *Paramoecium* is a holozoic organism it has been possible to

culture it in a medium containing salt solution. sugar, vitamins, amino acids and nucleic acids. In this case absorption of food material takes place through the plasma membrane and through the fluid food vacuoles that it continues to form.

Respiration and excretion

Respiration takes place by exchange of respiratory gases by diffusion through the pellicle and plasma membrane. Nitrogenous waste products mainly ammonia compounds and some urates and water are excreted. While water is given off by the contractile vacuoles, ammonia and other waste products diffuse through the pellicle. Carbon dioxide and some waste products may diffuse through the wall of the contractile vacuole.

Osmoregulation (water balance)

Excess water is collected from the cytoplasm by the collecting canals. By the fusion of small droplets drived from the canals a large vacuole is formed which when reaching certain size contracts to discharge its contents through a narrow canal in the pellicle. The radiating canals do not disappear entirely since they are permanent structures. The two vacuoles pulsate at different rates. The posterior vacuole pulsates faster than the anterior vacuole because of the large amount of water being delivered into the posterior region by the cytopharynx with the food.

Although contractile vacuoles are present in marine species, their rate of pulsation is considerably slower than that in fresh water species; they probably remove water entering which equals the volume of the animal in half an hour.

Behaviour

Being an active animal *Paramoecium* is characterised by the coordination in the movements of its cilia which lead to different responses toward the various stimuli. *Paramoecium* behaves in such a way that it moves into a favourable environment. It usually discovers the medium by the avoiding reaction which is the basis of "trial-and-error" behaviour. In this method the animal tries many directions until it finds one that is favourable and then make its escape from the injurious environment (Fig. 119).

The response of *Paramoecium* depends on its physiological state. Thus a hungry animal reacts in a different way from one that is well fed. The responses of Paramœcia and other protozoans are called taxes. A taxis is

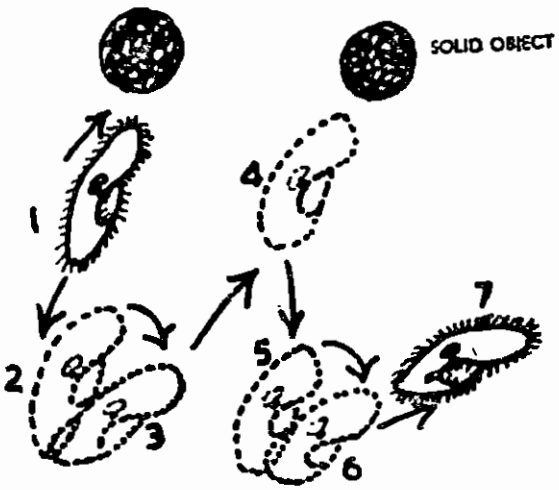


Fig. 119 — Avoiding reaction of Paramoecium

an orientation of the body either toward — a **positive response,** or away—a **negative** response — from the stimulus. *Paramoecium* shows negative response to mechanical objects, excessive heat or cold, irritating chemicals, predaceous enemies total darkness or bright light. It is negatively geotrophic. *Paramoecium* responds positively to mild acid solution (Fig. 120). This response is probably associated with feeding, because bacteria are found near decaying objects that makes the surrounding water more acid.

Taxes are classified as follows in respect to the different stimuli :

1. **Thermotaxis** — response to heat. *Paramoecium* prefers a temperature between 24°C and 28°C (Fig. 120 C).

2. **Rheotaxis** — response to current — *Paramoecium* shows a positive response toward a current of water if not too swift.

3. **Galvanotaxis** — response to constant electric current — it responds positively toward the negative pole (cathode) due to the effect of electrodes upon the action of cilia. (Fig. 120 D).

4. **Geotaxis** — response to gravity — *Paramoecium* responds negatively to the force of gravity.

5. **Phototaxis** — response to light — *Paramoecium* reacts positively to direct sunlight, it avoids bright light.

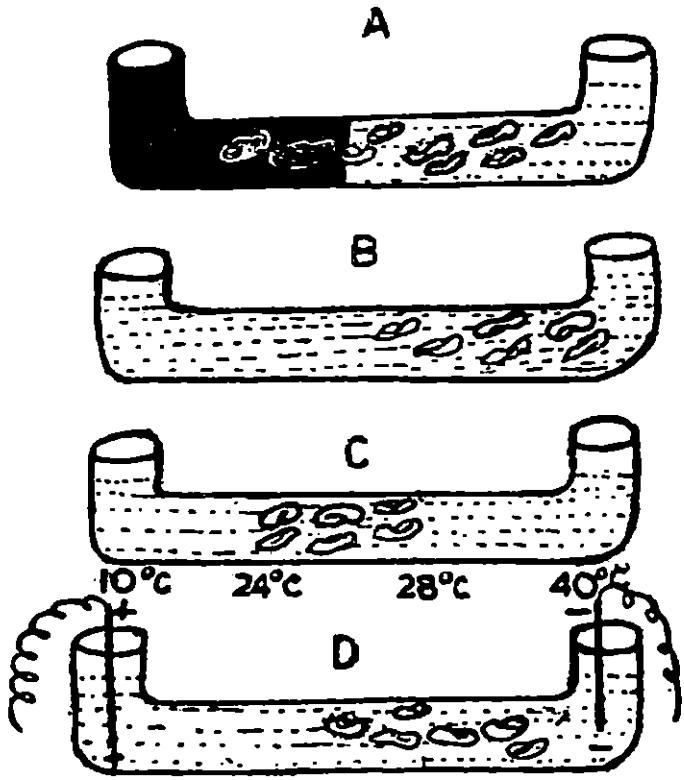


Fig. 120 — Taxes in Paramoecium : A) light : B) acid; C) temperature D) electric current

6. **Thigmotaxis** — response to contact — It avoids objects if touched by the anterior end.

7. **Chemotaxis** — response to chemicals — *Paramoecium* reacts negatively to most chemicals, but a positive reaction to mild acids (Fig. 120 B).

Reproduction

1. Asexual reproduction takes place by transverse binary fission (Fig. 121). While the micronucleus divides mitotically, the macronucleus divides by direct division (elongation and dividing amitotically). During the mitotic division of the micronucleus the nuclear membrane remains throughout the process of divsion and the spindle extends into the polar caps that may contain centrioles (Fig. 121). The two daughter micro- and macronuclei move to the opposite ends of the cell. Another cytopharynx is budded off and two new contractile vacuoles appear, one near the anterior end

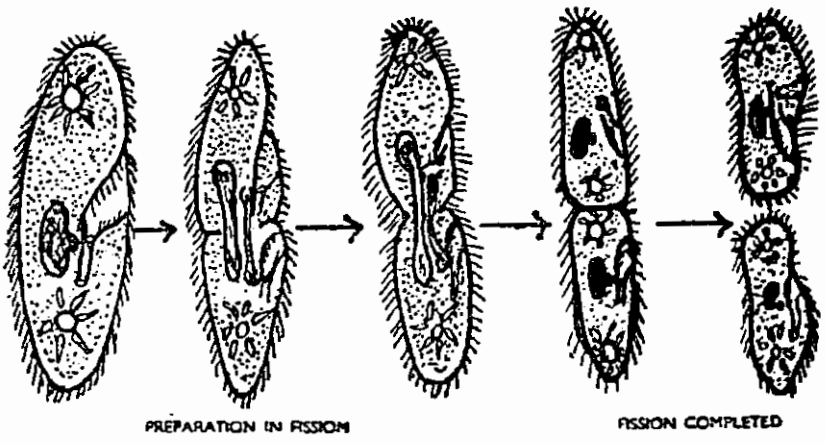


Fig. 121 — Binary fission in Paramoecium

and the other posteriorly. A constriction furrow appears near the middle of the body and deepens until the cytoplasm is completely divided. The term **"clone"** is used to refer to all the individuals that have been produced from one individual by repeated binary fission. All individuals of a clone are hereditarily alike.

2. **Conjugation.** It is a type of sexual reproduction which involves the union of two individuals which mutually exchange micronucleus material. Two individuals each from a different **mating type** come together and attach by their oral surfaces. Adhesion results from the secretion of a sticky substance by the cilia. then a protoplasmic bridge is formed between the **conjugants.** During this process of conjugation the following series of nuclear divisions take place (Fig. 122).

1. The macronucleus breaks up and disappears gradually being absorbed in the cytoplasm.

2. The micronucleus enlarges, forms a spindle and divides by meiosis giving four micronuclei. After the second meiotic division three of the micronuclei degenerate and one remains.

3. The remaining micronucleus of each conjugant divides mitotically giving rise to a large stationary micronucleus (male pronucleus) which migrates through the protoplasmic bridge into the other animal.

4. The two nuceli fuse forming the synkaryon or zygote in which the diploid number of chromosomes is restored. Then the two conjugants separate and are now called exconjugants.

5. The synkaryon divides three times giving eight nuclei. Four

becoming micronuclei and four large macronuclei. Three of the micronuclei are then resorbed. The remaining micronucleus divides mitotically to give four micronuclei. During this process Paramœcium divides twice giving rise to four individuals each with a macronucleus and a micronucleus.

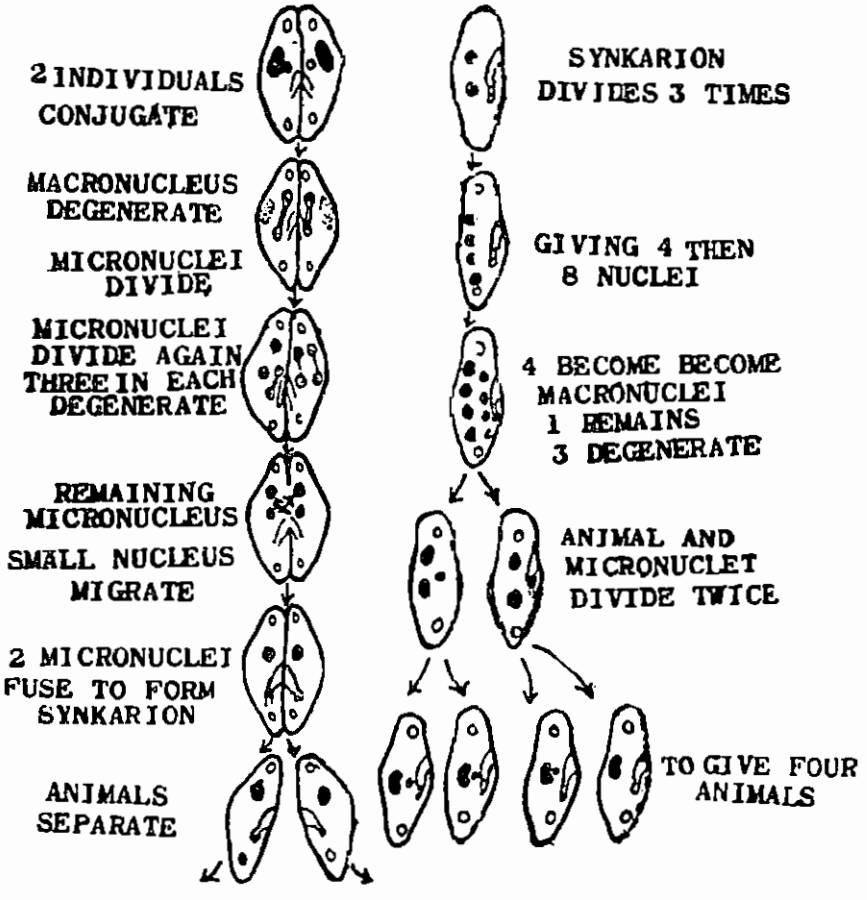


Fig. 122 — Diagram showing conjugation of Paramoecium

Recent studies showed that conjugation takes place only between different mating types. Thus not every Paramœcium would conjugate with any other individual of the same species. Conjugation is restricted to a number of opposite mating types and does not occur between members of the same type. SONNEBORN described seven varieties of *P. aurelia*. In each of the first six varieties there are two mating types designated I and II, while in the seventh variety there is only one mating type. SON-

NEBORN found that there are physiological differences between the mating types, a fact which suggest that mating types may be considered as sexes.

Significance of conjugation

1. Exchange of hereditary material so that each conjugant profits from a new hereditary constitutionn
2. The macronucleus in each individual is recreated out of the micronuclear material. As a result of continual binary fission the chromatin metrial in the macronucleus may undergo structural abnormalities as the chromosomes are distributed at random during amitosis.
3. Nuclear reorganization has a rejuvinating effect and is necessary for continued asexual reproduction and restoring the vital activities.

In some species of *Paramoecium* it was found that after 350 continuous generations, the asexual line (clone) will die out if nuclear regeneration does not occur. However, many species can reproduce asexually indefinitely and conjugation is not necessary. These are termed "deathless clones".

However, recent studies showed that although conjugation does not occur in deathless clones of *P. aurelia*, another type of nuclear organisation called **autogamy** (self fertilization) takes places. **Autogamy** involves the same nuclear behaviour as does conjugation but there is niether conjugation nor exchange of micronuclear material between two individuals.

Autogamy in P. aurelia (Fig. 123).

P. aurelia possesses two micronuclei and one macronucleus. Autogamy takes place as follows :

1. Macronucleus degenerates and is resorbed in the cytoplasm.
2. The micronuclei undergo a series of divisions, one of which is meiotic division, thus forming eight or more nuclei.
3. Two of the micronuceli (each with the haploid number of chromosomes) fuse together to form a synkaryon or zygote. The rest of the micronuclei degenerate.
4. The synkaryon divides mitotically twice to four micronuclei in the same way as during conjugation.

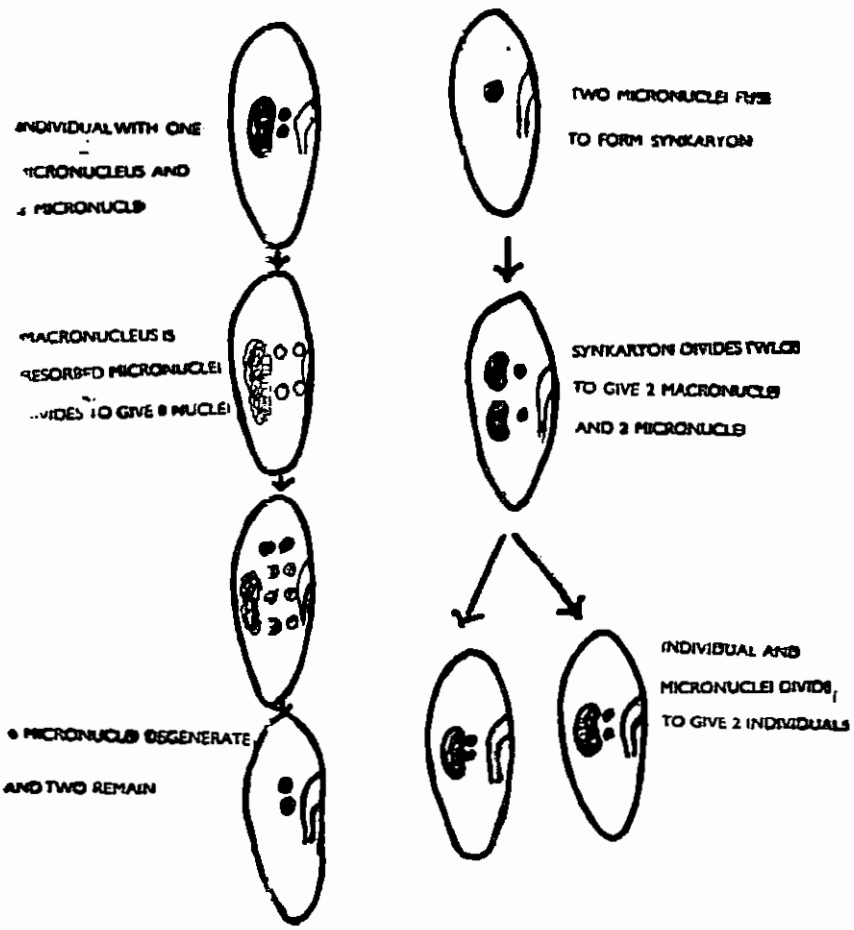


Fig. 123 — Paramoecium aurelia. Autogamy

5. Two micronuclei become macronuclei. Then, the animal and micronuclei divide to form two daughter individuals each with one macronucleus and two miconuclei.

Cytoplasmic inheritance and cell transformation

The studies on *Paramoecium aurelia* during recent years throw light on the explanation of the phenomenon of cell transformation, this is the change of one type of cell into another type, and cytoplasmic inheritance. SONNEBORN found two hereditary strains of paramacia which he termed **killer** and **sensitive** traits. The killer strain produces and secretes in the medium in which it lives, particles of ribonucleoprotein the

paramœcin which kills other sensitive individuals present in that medium. There are two factors responsible for the secretion of paramoecin : **Kappa particles** (**cytoplasmic genes**) found in the protoplasm and a dominant K gene in a chromosome. Both should be present in order that paramœcin is secreted and *Paramoecium* is a killer, without one or the other Paramœcium is not a killer. Kappa particles are transmitted by cytoplasmic genes (plasmogenes) from the cytoplasm of the parent animal to the daughter animal. These plasmogenes are similar to the genes in the nucleus. They multiply in the cytoplasm independent of the cell division. Under certain cultural conditions the indivdual may divide at a faster rate than the kappa particles and the result is the production of some individuals which are devoid of kappa particles, sensitive individuals.

If successful mating took place between a sensitive and a killer trait before the sensitive one is killed by paramœcin, it may acquire some kappa particles during mating. Thus the sensitive individual is converted into a killer which produces paramœcin. Thus one type of individuals can be transformed to another.

PARASITIC CILIATES

Parasitic ciliates are widely distributed among invertebrates and vertebrates where they live inside the digestive tract of fishes, toads, mammals including man.

1. **Balantidium coli** (Fig. 124).

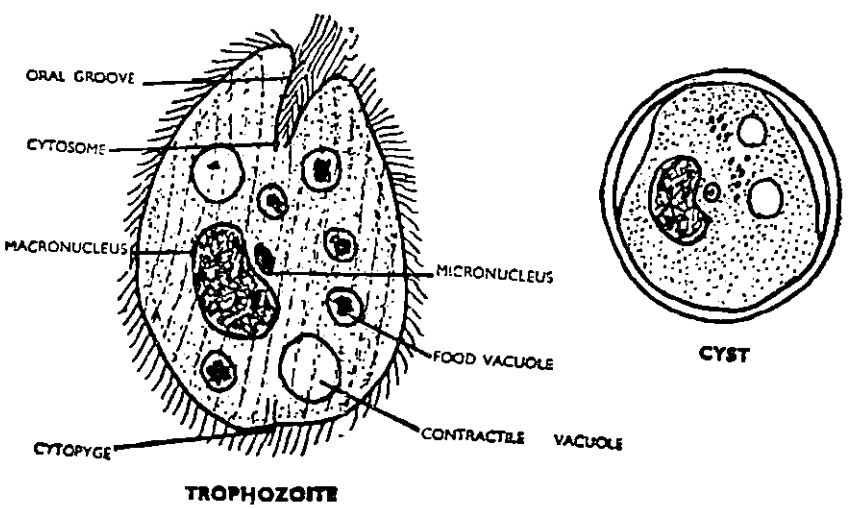


Fig. 124 — Balantidium coli

It is an entocommensal in the intestine of pigs and is passed in the form of cysts in their faeces. Pigs are considered as a source of infection to man. When the cysts are swallowed by man, they dissolve in the intestine and the parasite is liberated. It lives inside the colon where it invades the submucosa and causes ulcers, haemorrhage and even fatal dysentery. It is transmitted by the cysts.

2. **Nyctotherus** (Fig. 125).

It lives inside the colon of toads and frogs. The paraite is carried from one animal to another by the encysted stage which is carried with the faeces. Tadpoles are infected when they eat the faeces of toads containing the cysts.

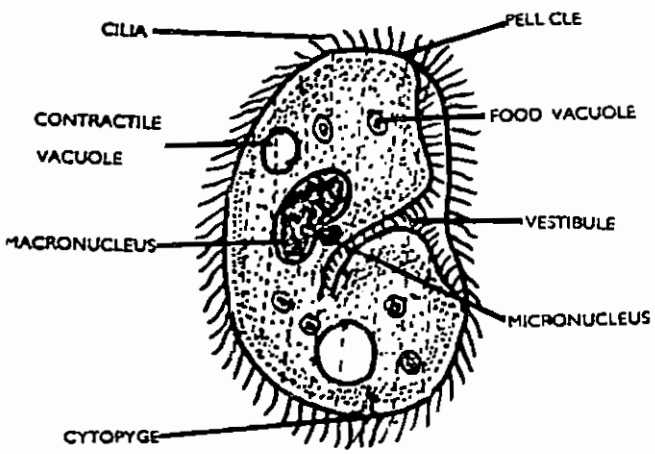


Fig. 125 — Nyctotherus

Importance of Protozoa in biological studies and economy

The study of **Protozoa** in recent years was given great importance especially the generalization which apply to these Protozoa also apply to higher animals. This study gives contributions to understand the basic problems of life processes, problems of population crowding. nutritional needs, serology and immunity. Protozoans reproduce rapidly thus giving a large number of generations in a short time which makes them ideal for biological research. Many of the basic facts concerning the physicochemical properties of protoplasm, osmosis, permeability, behaviour of organisms were discovered by the study of protozoans.

The study of protozoans gave explanations to cytoplasmic inheritance

and cell transformation (page 318). The discovery of mating types in Paramœcium (page 316) may give an indication of sex. There is a definite physiological difference between individuals of *Paramoecium* which may be compared to what is found between sexual forms.

From the practical point of view protozoans took a great part in building up soil and forming earth; formation of plankton, responsible for contamination of water; play an important role in food chains and many of them live in association with other animals being parasites causing serious diseases to man and his animals.

The deposits of foraminifera and radiolaria during past geological periods lead to the formation of a great part of the earth's crust (page 297). Radiolarians skeleton may be converted into siliceous rock such as flint. Deposits of certain species of foraminifera such as **Nummulitidae** are frequently associated with petroleum deposits.

Protozoans constitute a major part of the **plankton** in marine and freshwater habitats. This planktor may form the important food for many economic fish and even the largest animals, the whales which feed exclusively on plankton.

During recent years mass mortalities of fish in several parts of the world were associated with the **"red tide"** which gives the water a brownish-red

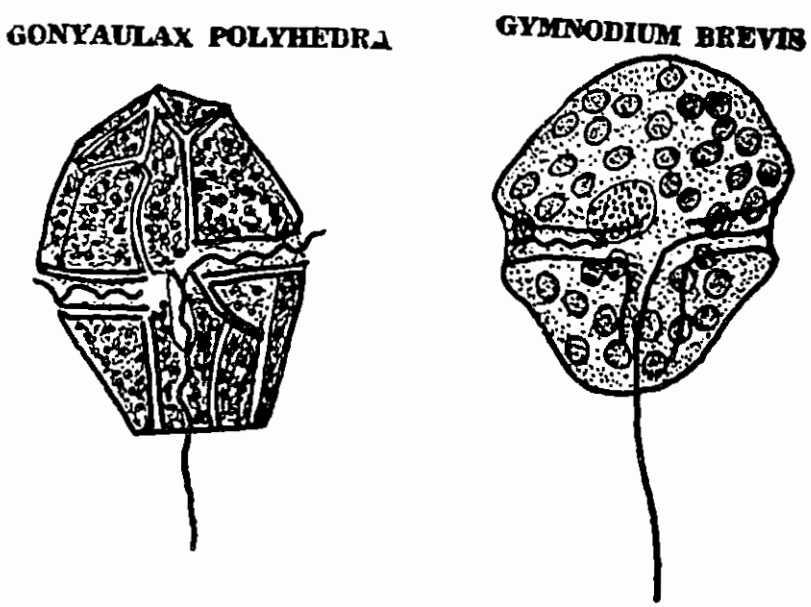


Fig. 126 — Dianoflagellates responsible for red tide

tinge. The water becomes viscid yellow and poisonous to fish. Analysis of such water revealed the presence of a heavy concentration of a marine dinoflagellate protozoan, *Gymnodinium brevis* or *Gonyaulax* (Fig. 126) which secrete a toxic alkaloid which kills the fish. Death of the fish may be brought by reduction of oxygen in surface water. The red colour of the water is due to the pigmented bodies within the cells.

The contamination of water which may be used as a source of drinking) with certain protozoans makes it undesirable as a water supply. The presence of certain protozoans may cause a change in the taste or odour of the water which may become bitter spicy taste, fishy odour or other odours. Such changes are caused by *Uroglenopsis*. *Eudorina*, *Pandorina*. *Volvox*, *Dinobryon*, *Synura etc.*

The presence of protozoans in the soil affects its fertility. Such protozoans reduce the number of nitrogen fixing bacteria and thus limits the production of nitrates essential for soil fertility.

A large number of protozoans live as parasites on man and his animals and even in every known animals even protozoans themselves. Some of these protozoans cause serious diseases to man such as *Entamoeba histolytica*, *E. gingivalis*, *Trypanosoma* sp., *Balantidium coli*, *Plasmodium* sp. etc. In vertebrates *Opalina* lives inside the intestine of toads, *Trypanosoma bruceci* causes nagana disease of African animals. Texas fever of cattle is caused by *Babesia*, *Coccidia* leads to coccidiosis of rabbits, poultry and other animals.

Many protozoans live as mutuals with other animals where both (the protozoan and the host are benefited as in case of *Trichonympha* (**mutualism**), others live as **commensals** where one animal is benefied while the other is not harmed as *Balantidium coli* which is an entocommensal in the intestine of pigs. The same protozoan lives as an **endoparasite** inside the intestine of man where the latter is harmed.

In addition the study of certain protozoans such as *Tokophyra* may throw light on problems of senility of cells.

KINGDOM METAZOA
Subkingdom PARAZOA
Phylum PORIFERA

This phylum includes sponges or bore bearers on account of the large nomber of tiny pores that are basic structures in their fundamental activity, Sponges are considered as a separate Subkingdom **Parazoa,** because they vary so much from other true Metazoa (Eumetazoa). Their organisation does not go beyond the **cellular level,** neither true tissues or organs are psesent. Although their cells are often collected into groups, their relationship is so loose that they do not form definite tissues. Thus sponges have cellular levels of organization as compared to the protoplasmic level in *Protozoa.* Here it is more advanced as there is a division of labour between the somatic cells instead of being carried by one cell.

Sponges have unique characters which justify placing them in a separate Subkingdom **Parazoa** in addition to their isolated phylogenetic position :

1. Lack of definite germ layers which are characteristic of metazoans;
2. No mouth and no digestive cavity;
3. Complicated system of water canals and flagellated chambers;
4. Absence of an integrating nervous system;
5. Presence of a gelatinous mesenchyma which contains various free cells and skeletal elements in the form of spicules or spongin fibres.
6. They lack either differentiated muscular tissue or a hydrostatic skeleton.

Habitat and shape

Sponges are sessile, fixed, mostly marine primitive animals which are attached to rocks, shells, corals or any suitable substratum. They are usually found in relatively shallow water, but some groups such as the glass sponge live at great depths (Fig. 136). Few species live in freshwater.

Sponges vary in size from very small organisms to large forms reaching 1 — 2 meters in diameter. They may be cylindrical, branching, vase-like, irregular or globular. The appearance of one species varies with the different environmental conditions such as type of substrarum, velocity of water current and wave action. Thus, one species may have different

growth patterns. Primitive sponges are radially symmetrical, but most members have lost this characters and are irregular. The study of sponges is always understood by studying the radial species which show the simple morphology and basic structure and histology.

Sponges have various colours; red, orange, purple, green; yellow or dull colour. Bath sponge look much like a piece of fresh liver and may be black, yellow, grayish or brown colour

Sponges have a commercial importance. They are used as bath sponges, in surgical operations to pick up excess of blood, for sound absorption and as packing material. Sponges are collected by hooks, diving, dredging or trawling. After the living sponge has been taken out of water it is left in shallow water to rot the soft tissues leaving the skeleton. Then, they are beaten, washed and bleached in the sun.

LEUCOSOLENIA

This is the simplest type of sponge (ascon type) which lives attached to the seashore. It is a colonial form consisting of a number of horizontal branches from which vase-like vertical branches extend up into the water. The branches anastomose thus forming a network (Fig. 127).

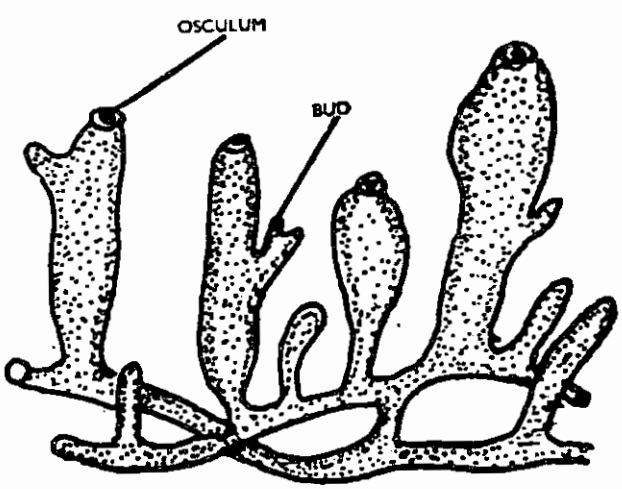


Fig. 127 – Leucosolenia colony

Structure

The body of each branch is thin-walled provided with a large opening at its free end called **osculum.** The central cavity is known as **spongo-**

coel or **paragastric cavity.** The surface is perforated by small openings the **ostia** or **incurrent** (inhalent) pores which lead to the spongocoel (Fig. 128). A continuous current of water passes through the incurrent pores into the spongocoel and out the osculum.

Body wall

It consists of two layers of cells, the dermal and gastral layers. A skeletogenous layer or mesoglea is present between them.

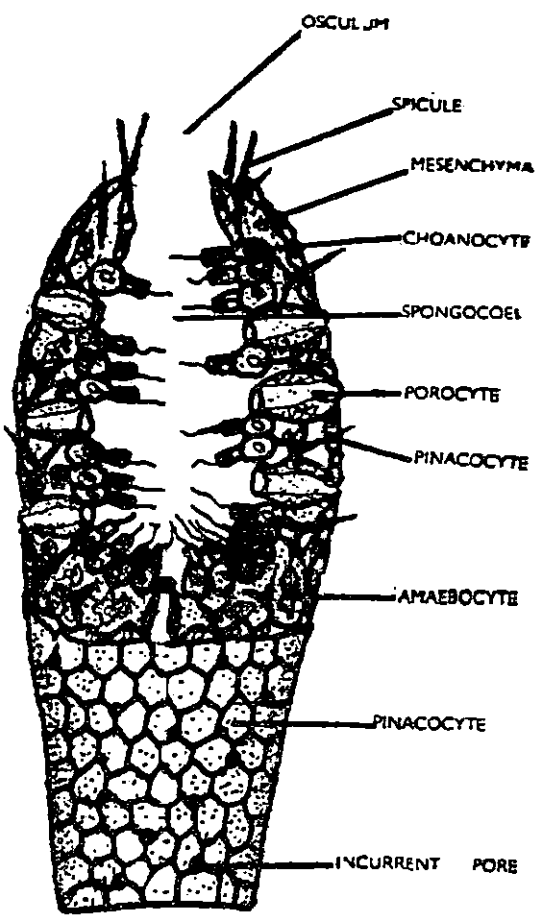


Fig. 128 — Diagram of Ascon type with its upper part cut to show internal structure

1. Outer **dermal layer** or **epidermis** is formed of flattened polygonal highly contractile cells called **pinacocytes** (Fig 129). The outer margins of these cells can be contracted or withdrawn thus the animal can increase

or decrease slightly in size. The movement of pinacocytes is rather amœboid in character than muscular. The outer ostia are guarded by **porocytes** which are modified pinacocytes. Each porocyte has large tubular lumen which extends from the outer surface to the spongocoel. The outer opening of the porocyte can be closed or opened by contraction.

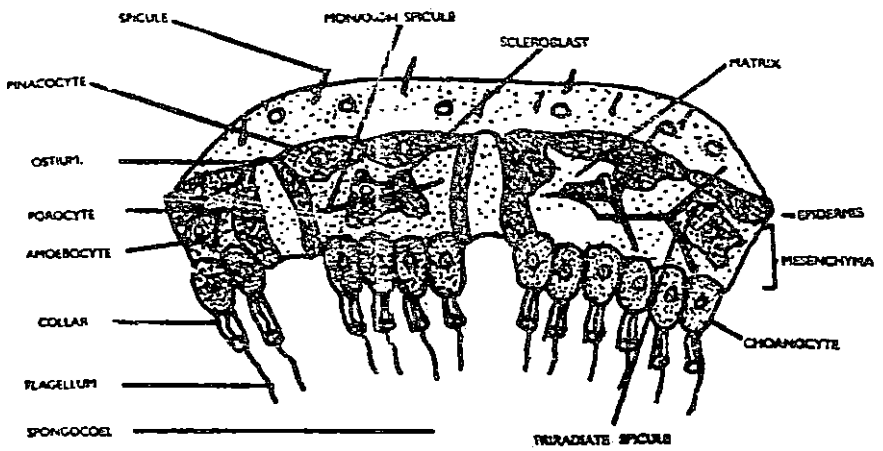


Fig. 129 — T.S. of a simple sponge, Leucosolenia

2. The inner gastral layer is composed of flagellated collar cells, the **choanocytes,** which are loosely connected and resemble in their structure the choanoflagellate protozoans (Fig. 101). A choanocyte is an ovoid cell with one end adjacent to the middle mesenchyma, and the free end bearing a flagellum surrounded by a basal contractile collar. The flagella of the collar cells move continuously and create a constant current of water bringing food and oxygen and removing waste products.

3. The skeletogenous layer or **mesoglea** is a layer of mesenchyma located between the outer and inner layers (Fig. 129). It consists of a gelatinous protein matrix containing skeletal material and many wandering amoebocytes.

The skeleton in sponges provides a complex framework for the living cells of the animal. It is made up of calcareous spicules which may be monoaxons (like needles or rods); triradiate or quadriradiate spicules. The spicules frequently project through the epidermis. In other types of sponges siliceous spicules (made up of silica) or protein spongin fibres or combinations of both are found (Fig. 130).

The mesoglea contains different types of amoebocytes which perform

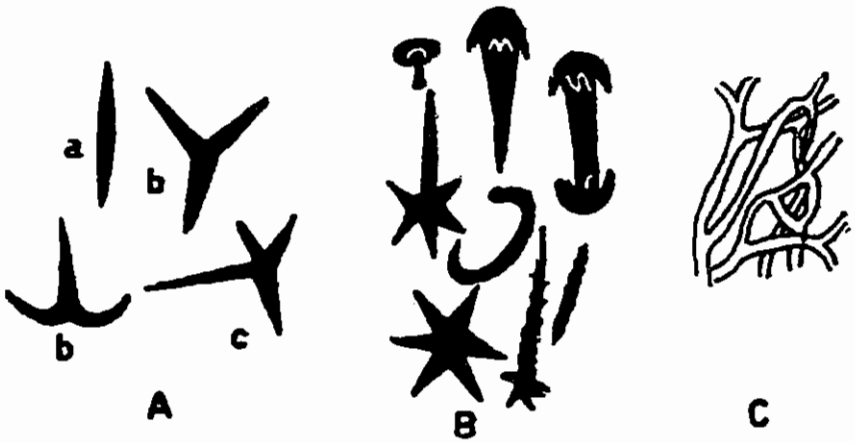


Fig. 130 — Types of spicules of sponges: A) calcareous spicules: (*a*) monaxon; (*b*) triradiate; (*c*) tetraxon; B) siliceous spicules; C) spongin fibres of bath sponge

different functions which in higher animals are carried by certain tissues. The most important of the amoebocytes are :

(*a*) **The archaeocytes** (Fig. 131) which are large cells with blunt pseudopodia and large nuclei. They are primordial germ cells which give rise to sperms or eggs and are capable of forming any other type of cells.

(*b*) **Scleroblasts** which secrete the skeletal structures, spicules or spongin fibres. After the formation of the spicules the scleroblasts migrate away or degenerate.

(*c*) **Mycocytes** (Fig. 131) which show some similarity to involuntary muscle cells in shape and contractility. They are spindle-shaped cells found around the osculum and other openings where they are arranged like a band of circular muscles which control the size of these openings. However, they may often be supporting or secretory in function.

(*d*) **Gland cells** are attached to the surface by long strands. These secrete slime which helps in the attachement of the animal to the substratum.

(*e*) **Collencytes** are stellate contractile cells with numerous branches or pseudopodia which anastomose to form a syncytial network, thus acting as connective tissue cells in the mesoglea. They extend across the spaces through which the water passes and serve to reduce the size of these spaces when needed. In addition food storing cells, pigment cells and jelly-secreting cells are found.

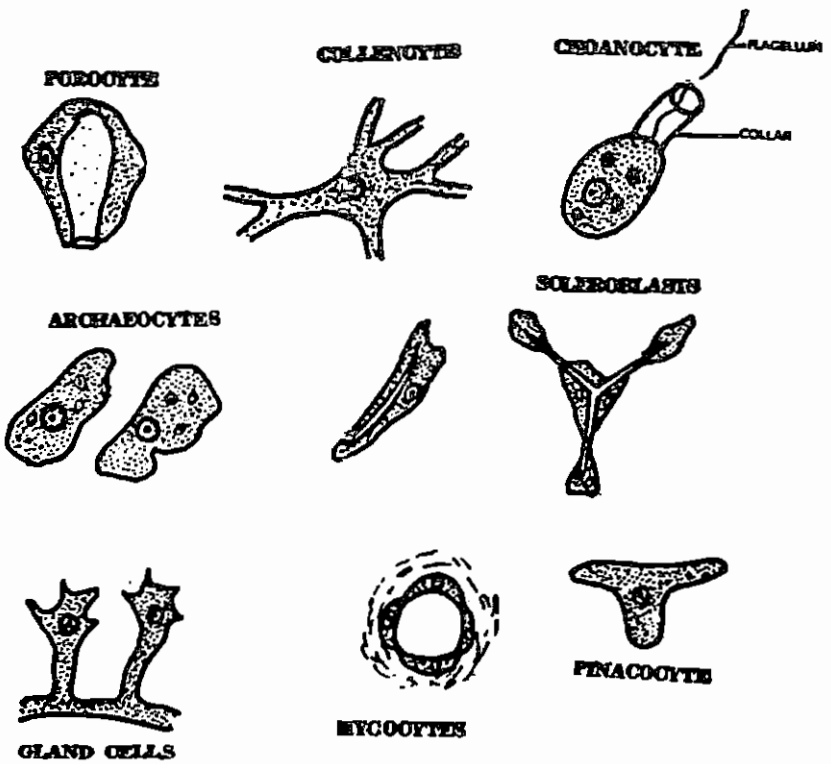


Fig. 131 — Types of sponge cells

The outer and inner layers of sponges are not comparable to the ectoderm and endoderm of metazoans.

The structure of the sponge imposes limitations on sponges such immobility. Due to the absence of nervous and muscular tissues comparable to those of metazoans, the sponges depend for protection upon their spicules in the body wall, or the tough spongin fibres, upon the force of exhalent jet of water, and their capacity to contract the inhalent openings and thus keep away the intruders. Adult sponges depend on obtaining their food on organized hydrolic system of its canals and flagellated chambers.

Metabolism

Sponges depend mainly on the water current flowing through the body from the ostia, through the porocytes and the spongocoel then the osculum. This water current is produced by beating of the choanocyte flagella. Food,

oxygen and waste removal even eggs and sperms are carried by this water current.

Nutrition

Sponges feed on detritus particles, small organisms such as protozoans, diatoms and bacteria brought by the water current. By the action of the flagella of the collar cells food particles are carried to the collars. These food particles adhering to the collars of the choanocytes are carried downwards by the protoplasmic flow to the base of the collar where they are engulfed by the cell bodies. These are either digested by these cells, or they are passed to the amoebocytes after partial digestion. In addition amoebocytes engulf directly food particles. In either cases digestion is intracellular where food vacuoles are formed and digestion proceeds in the same way as in Protozoa. Digested food is distributed to various cells by diffusion aided by the amoeboid wandering cells. Amoebocytes also act as storage centres for reserve food. Undigested food is ejected by the amoebocytes and choanocytes into the outgoing current.

Respiration and excretion.

Gaseous exhange takes place by simple diffusion between the flowing water and the various cells along the course of water flow.

Excretion of waste nitrogenous products mainly ammonia is taken by each individual cell by simple diffusion. The excretory products of the sponge are repulsive to many animals, thus protecting the sponge from being eaten by its enemies.

There is probably no nervous system and the reactions are local and independent, depending on the conductivity and contractility of the protoplasm of the cells. Although many investigators claimed the discovery of bipolar nerve cells in the mesenchyma (PAVANS DE CECCATTY, 1955) yet their claim has not been proved on physiological basis.

Reproduction

Sponges reproduce asexually and sexually.

Asexual reproduction is characteristic of freshwater sponges and in some marine species. It takes place by :

(*a*) **Budding** : Buds arise mainly near the base, and when reaching a full size they either break off or remain to form a colony (Fig. 127).
(*b*) By the formation of aggregates of essential cells, such aggregates are

called **reduction body.** In freshwater sponges and some marine forms these aggregates are known as **gemmules** (Fig. 132). A gemmule is formed of a mass of archaeocytes filled with reserve food material. These cells become surrounded by other amoebocytes which secrete a hard double shell in which spicules may be deposited between the two layers. At the approach of unfavourable conditions — usually during autumn — a large number of gemmules are formed inside the sponge. With the onset of these conditions the parent sponge dies and disintegrates. The gemmules resist these severe environmental conditions as freezing and drying, thus survive during winter or droughts. When the conditions become favourable, the cells in the gemmule escape from the shell through a fine pore called **micropyle** (Fig. 132). These cells develop and grow into a new sponge.

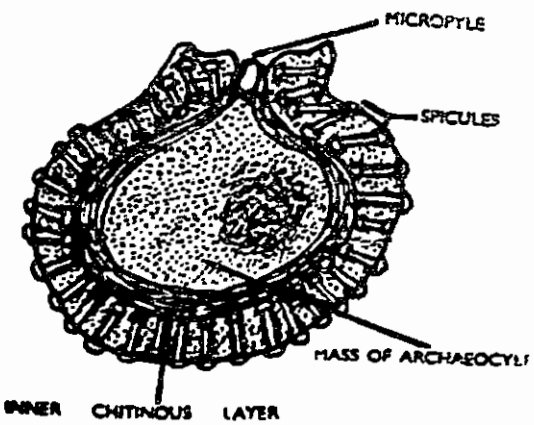


Fig. 132 — A gemmule of a freshwater sponge

Sexual reprodction

Sponges may be hermaphrodite or diocious. Ova and sperms develop from choanocytes or archaeocytes or even from amoebocytes. Some of these germinal cells develop either by engulfing other amoebocytes or becoming surrounded by amoebocytes that act as nurse cells. Eggs are large cells with reserve food material, while sperms are smaller, active each with a head and an elongated tail (Fig. 133).

Sperms leave the parent sponge with the outgoing current and enter another sponge in the same way. In the spongocoel the sperms are either trapped by a choanocyte or an amoebocyte. In either case it is carried to the eggs found in the mesoglea. The choanocyte (or amoebocyte) carrying the sperm fuses with the egg setting free the sperm which fertilizes the egg to form the zygote.

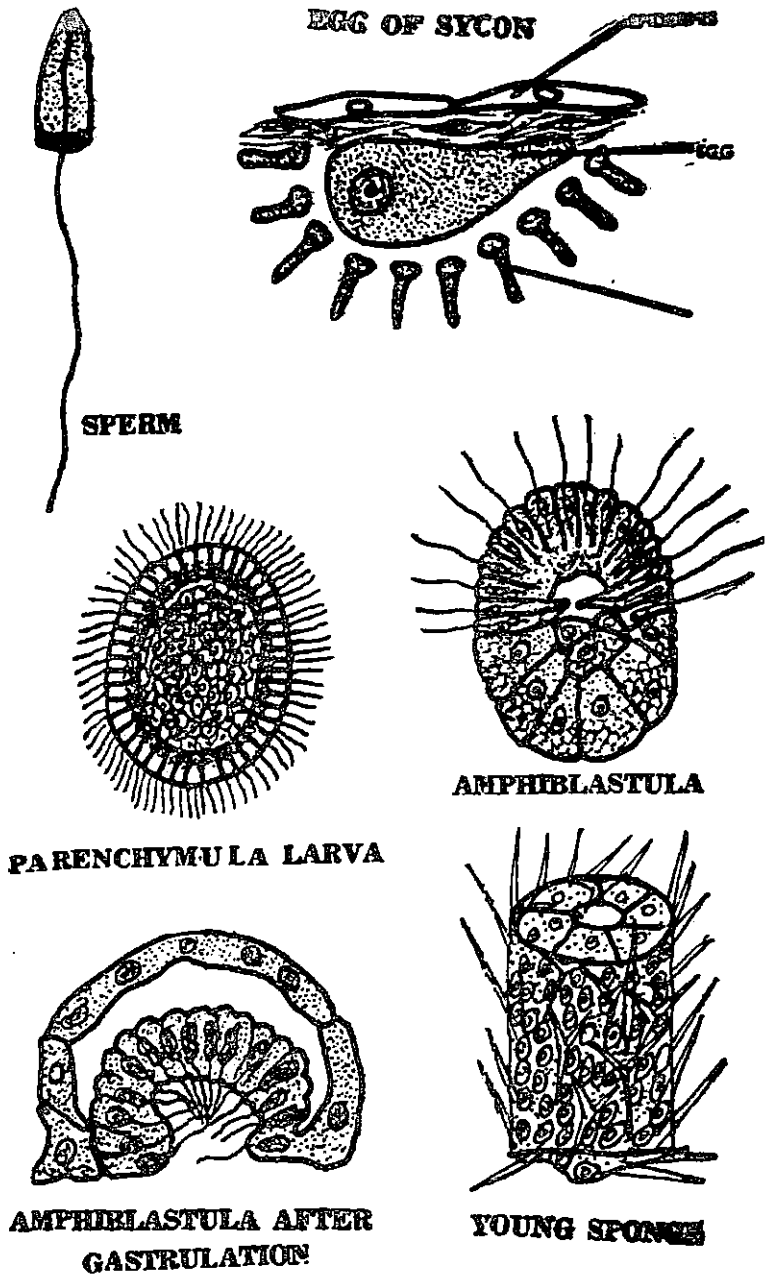


Fig. 133 — Development of a sponge

The zygote begins development within the mesenchyma of the parent sponge. The cleavage is complete and unequal giving rise to a solid blastula, with small micromeres and large macromeres. It is covered externally by flagellated cells and internally it is full with archaeocytes and amoebocytes. This larva is called **parenchymula larva** which is a **stereoblastula** (Fig. 133). This flagellated larva escapes from the parent by the water current, swims for several days then it settles to the bottom where it becomes attached to a substratum to develop into a young sponge. The cells of the exterior layer lose their flagella and migrate to the interior, where they form the choanocytes. The interior amoeboid cells migrate to the exterior where they are arranged around the flagellate cells and develop into pinacocytes and mesenchyma and form the dermal layer. A spongocoel develops later and soon becomes lined by the flagellated cells which develop to choanocytes and form the gastral layer. Thus an asconid structure is reached.

In the calcareous sponges as sycon a hollow **amphiblastula larva** develops (Fig. 133). This larva is characterisd by having its anterior half formed of clear columnar flagellate cells while its posterior half is formed of rounded granular cells. The amphiblastula larva swims for sometime and settles to give rise to a sponge. The flagellated hemisphere invaginates into the nonflagellated hemisphere. The non flagellated cells on the outside give rise to pinacocytes, porocytes and skeleton-forming amoebocytes. The inner cells develop into choanocytes and mesenchyma cells.

Regeneration

Sponges have a remarkable power of regeneration on account of the relative independence of their cells. Regeneration which is a common means of reprodction may result in new individuals. Regeneration may take place as follows : (*a*) some sponges constrict near the ends of the branches to fall off and regenerate into new individuals; (*b*) a cut part of a sponge tissue will regenerate into a new complete sponge; (*c*) if a living sponge is squeezed through a fine cheese cloth, the separated cells reorganize after a time and form a new sponge.

The regenerating power of sponges is used for cultivation of bath sponges. Pieces of sponges called "cuttings" are attached to cement blocks; and placed into the desired place. After several years sponges of commercial size are produced.

Types of sponges

There are three kinds of sponges based on the type of canal system.

1. **Ascon type** (Fig. 134) with a thin body wall the ostia lead directly into the spongocoel which is lined with choanocytes. It is radially symmetrical. Eamples, *Leucosolenia, Ascetta.*

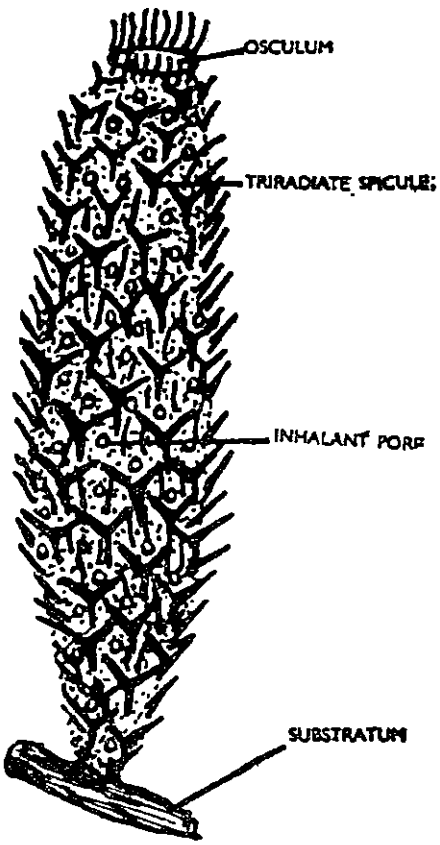


Fig. 134 — A young sponge of Ascon type

2. **Sycon type** with a thick body wall which is folded to form two types of canals connected together by tiny pores : (*a*) the incurrent (or inhalant) canals lined by pinacocytes and open to the outside by ostia. These canals end blindly near the central sponogocol; and (*b*) the flagellted chambers which are lined by choanocytes and open into the spongocoel (Fig. 135). The spongocoel is lined by pinacocytes. Examples, *Sycon, Grantia.*

3. **Leucon type** (Fig. 135). The body wall is very thick and highly folded with multibranched inhalant and exhalant canals. The choanocytes are found in special cavities opening into the exhalant canals and called

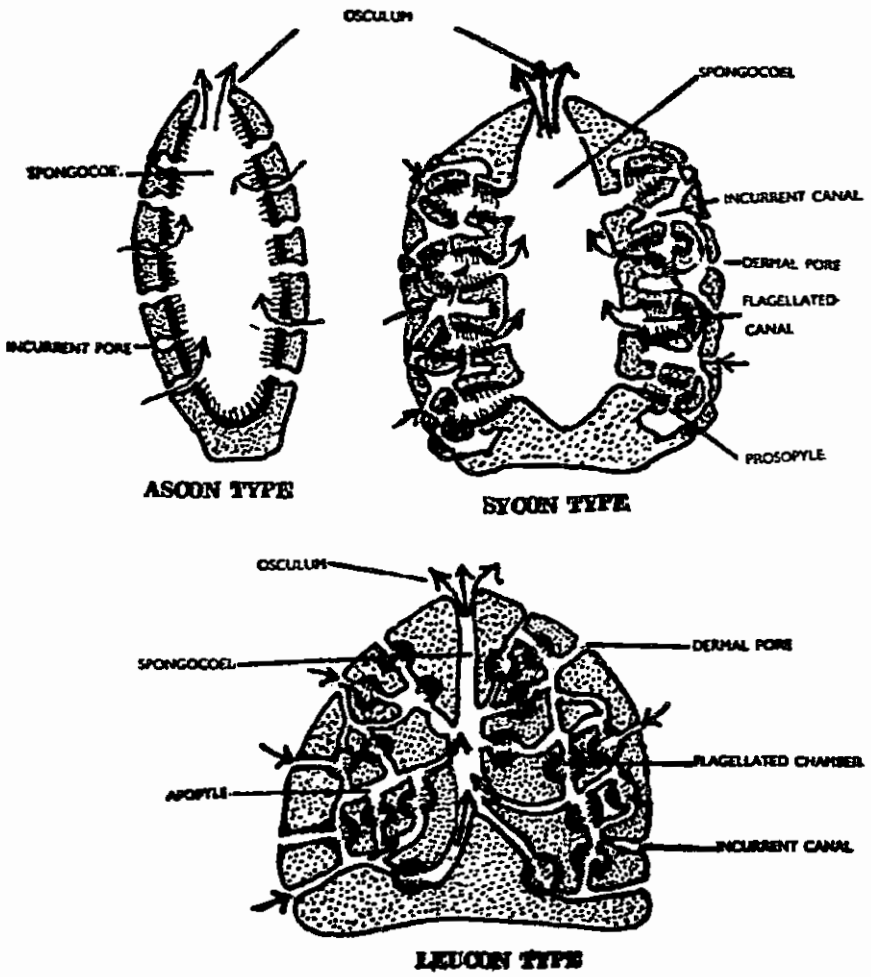


Fig. 135 — Diagram of the canal system of different types of sponges, (arrows indicate the direction of the water current)

flagellated chambers. The canals and spongocoel are lined with pinacocytes. Examples, the bath sponge, *Euspongia*.

Example of sponges

1. *Euplectella* (Venus flower basket Fig. 136). It lives in deep water of the sea and its skeleton is siliceous.
2. *Spongilla* a freshwater sponge, yellow brown in colour due to symbiotic zoochlorellae in the amoebocytes, the skeleton is siliceous.

3. *Euspongia* (bath sponge, Fig. 136). It is characterised by its round large body with a skeleton made up of spongin fibres.
E. officinalis is common in the Mediterranean especially near Saloum.

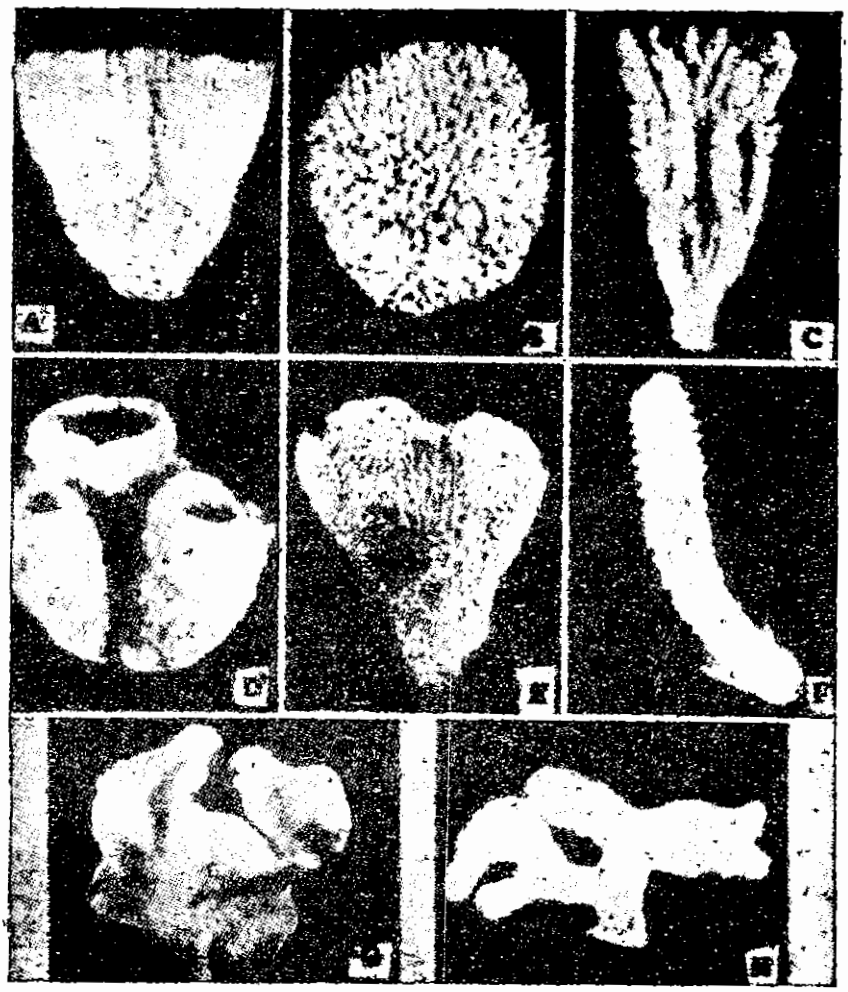


Fig. 136 — Examples of sponges. A) grass sponge; B) bath sponge; C) finger sponge; D) tube sponge, E) sheep wool sponge; F) Venus flower basket (glass sponge); G) paper sponge and H) bread sponge.

Subkingdom EUMETAZOA

The only acellular organisms are protozoans, all the other animals are built on a multicellular plan of structure and constitute the Kingdom **Metazoa.** While Protozoa are characterised by their small size, Metazoa are not only of large size but also show considerable degree of morphological differentiation. Metazoa are divided into **Agnotozoa, Parazoa** and **Eumetazoa.** Acellular organisms are complete organisms which often show complicated organization and division of labour, such as skeletal elements, locomotor devices, fibrils, beginnings of sense organs and many others. On the other hand, Eumetazoa are multicellular animals having cells differentiated into tissues and organs which are specialized for different functions. The metazoan cell is not equivalent to a protozoan; it is only a specialized part of the whole organism and usually cannot exist by itself.

In Eumetazoa in addition to morphological differentiation there is a physiological division of labour where a given part of the orgnism performs a definite function. Thus Eumetazoa is characterised by the presence of **tissues, organs** and **systems.** The animal being large, needs complicated device in order to perform its vital activities; thus a digestive system is specialized in dealing with the food; circulatory system to carry the digested food and gases to various cells, a nervous system to coordinate the different functions, etc.

Eumetazoa are divided into a number of phyla.

Phylum COELENTERATA

This phylum includes the hydras, jellyfish, sea anemones and corals. The brilliant colouring of many species combined with a radial symmetry, often creates a beauty that is surpassed by a few other animals. Coelenterates are entirely aquatic, some live in fresh water, (e.g. **Hydra**) but others are mostly marine. They are characterized by :

1. The body is formed of two layers, an outer layer of **epidermis,** an inner layer of gastrodermis, in between these is a form of connective tissue, the **mesoglea.** The mesoglea ranges from noncellular membrane to thick fibrous jelly-like mucopolysaccharide with or without wandering amoebocytes. The cells of the epidermis and gastrodermis are not grouped together to form tissues. Furthermore, most of the cells perform the functional and structural specialization of higher metazoans.

2. They are tentaculate and radially symmetrical.

3. Two types of individuals are encontered : attached **polyps** (polyp = many feet) with a cylindrical stalk, with an oral end provided with the mouth and tentacles; free **medusae** with a body resembling an umbrella, with the convex side upward, and the mouth in the centre of the concave underface (Fig. 148). The medusoid mesoglea is extremely thick and constitutes the bulk of the animal. Cœlentrates having this form are called jellyfish due to jellylike matrial forming the mesoglea.

4. Exoskeleton is made of chitin or lime.

5. There is a single cavity known as gastrovascular cavity (or coelenteron) provided with a single opening which serves as both mouth and anus (Fig. 138).

6. The nerve net with synaptic and non-synaptic patterns; with some sensory organs.

7. Presence of special stinging cell organoids called nematoblasts in either or both epidermis and gastrodermis.

8. No excretory or respiratory systems.

9. Muscular system (myoepithelial type) is composed of an outer layer of longitudinal fibers at the base of epidermal cells and an inner one of circular fibers at the base of gastrodermal cells.

HYDRA

It is a solitary polyp which is common is freshwater. It is found attached on the underside of aquatic leaves and lily pads in cool clean fresh water of pools and streams. Hydras are cylindrical animals that range from a few milimetres to a centimetre or more in length when fully extended. However, the diameter seldom exceeds a millimetre. The aboral end of the cylindrical body stalk forms the basal (or pedal) disc for attachment (Fig. 137). This basal disc is provided with gland cells to enable the hydra to adhere to the substratum, and also to secrete a gas bubble for floating. The oral end contains the mouth located on a conical cone called the hypostome. Around the base of the hypostome there is a circle of 6 - 10 hollow tentacles. The number of tentacles increases with the age of the individual. Hydras may have different colours depending on the species of algae which lives symbiotically within their bodies. The green hydra (*Chlorohydra viridis*) is green containing green algae.

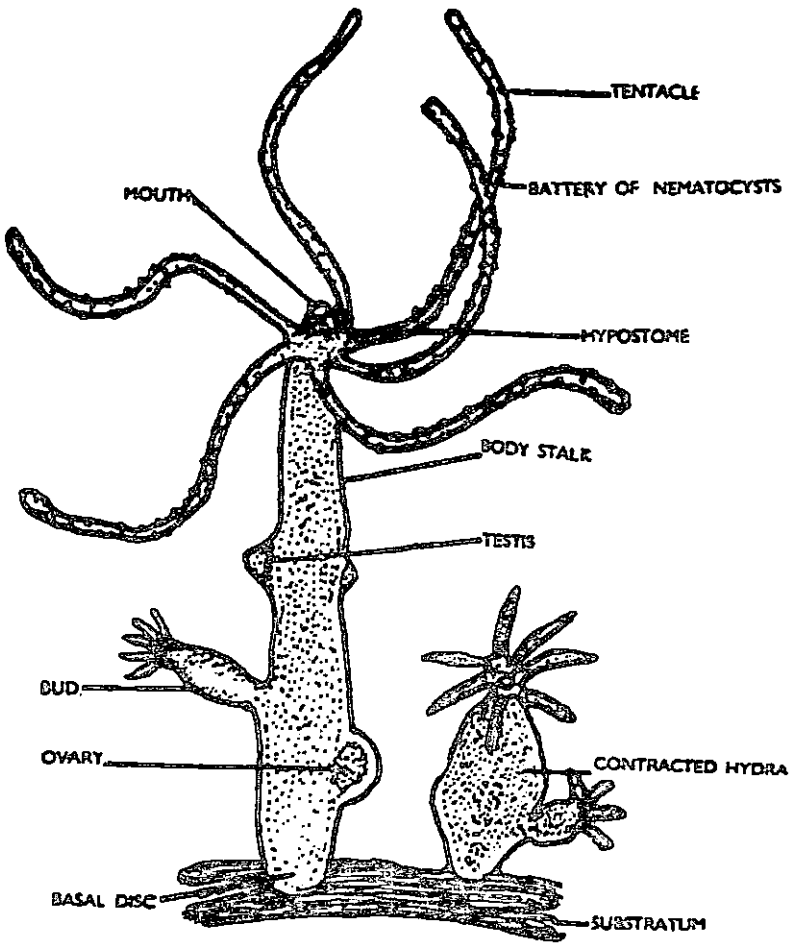


Fig. 137 — Adult Hydra with male and female reproductive organs and a bud

Structure of the body

The body of Hydra is composed of an outer epidermis, an inner gastrodermis and a noncellular mesoglea which lies in between the two layers. It is gelatinous jelly-like and has no fibers or cellular elements. It is a continuous layer which extneds over the body and tentacles. It is thickest in the stalk portion and thinnest in the tentacles (Fig. 138). This arrangement allows the pedal region to withstand great mechanical strain and gives the tentacles more flexibility. The mesoglea supports and gives rigidity to the body, thus acting as a sort of elastic skeleton.

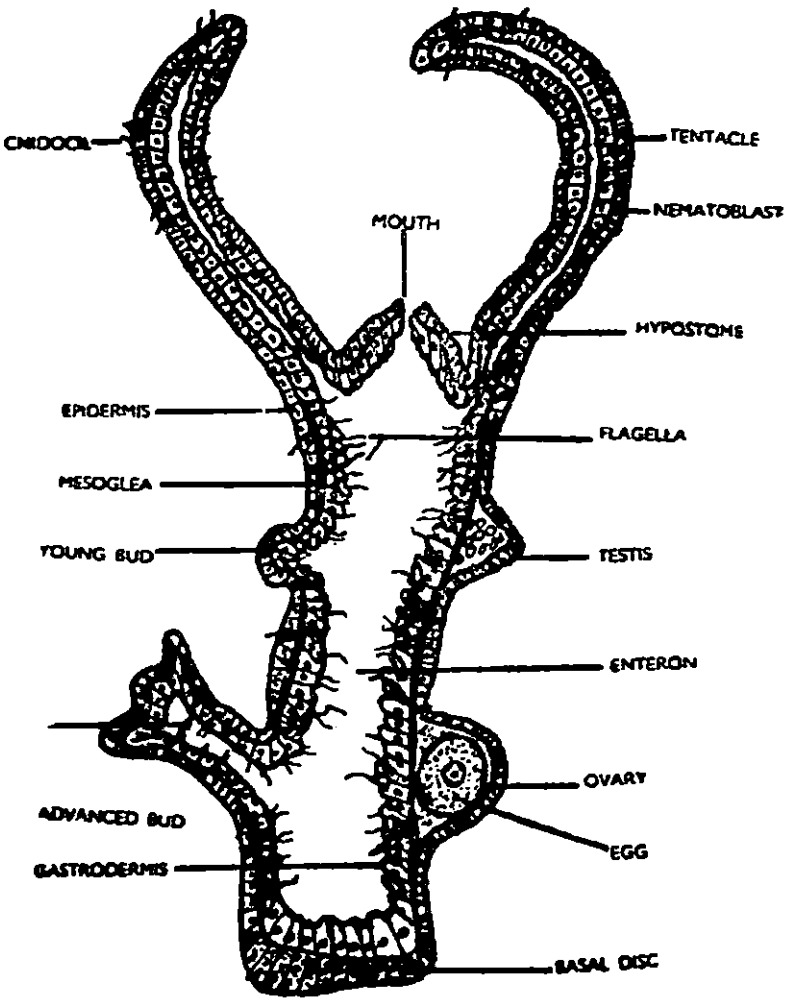


Fig. 138 — Diagramatic longitudinal section of Hydra bearing testis, ovary and two buds

The body wall

A) **The epidermis** is composed of five main types of cells (Fig. 139).

1. **Epithelio-muscular cells** which make up most of the epidermis and serve both for epithelial covering and for muscular contraction. Each cell consists of an outer portion extending to the body surface, and two, three or more basal extensions each containing a longitudinal contractile fibre or myoneme attached to the surface folds of the mesoglea (Fig. 142). Contraction of the fibers shortens the body. Although this layer of contra-

ctile fibers corresponds to a layer of longitudinal muscles, it is not composed of true muscle cells.

2. **Interstitial cells** are small rounded cells with relatively large nuclei. They are located beneath the epidermal surface or between the eipithelio-muscular cells (Fig. 139). These cells retain the properties of embryonic cells and are capable of transforming into any of the other types of cells such as cnidoblast, sex cells or buds. BRIEN (1951) estimates that over a period of 45 days all the cells of Hydra are replaced from the interstitial cells.

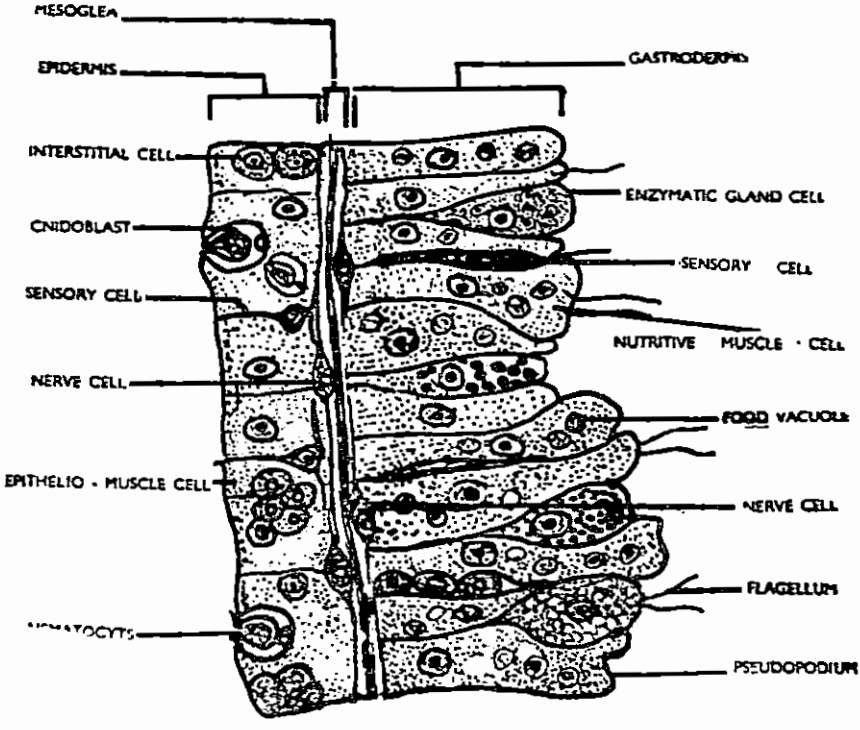


Fig. 139 — L.S. of the body wall of Hydra

3. **Cnidoblasts** (nematoblasts) are specialized cells containing stinging structures or nematocysts characteristic of all coelentrates. They are found throughout the epidermis and especially on the tentacles. Cnidoblasts are scattered all over the epidermis, and in the tentacles. They are found in groups called batteries with a large nematoblast in the centre surrounded by smaller ones. A cnidoblast is a rounded or ovoid cell with a basal nucleus, an outer fine projection, the **cnidocil** and a process which connects it with nerve cells or the contractile fibrils of the epithelio-muscular cells (Fig. 140). Each cnidoblast contains a nematocyst which is a capsule

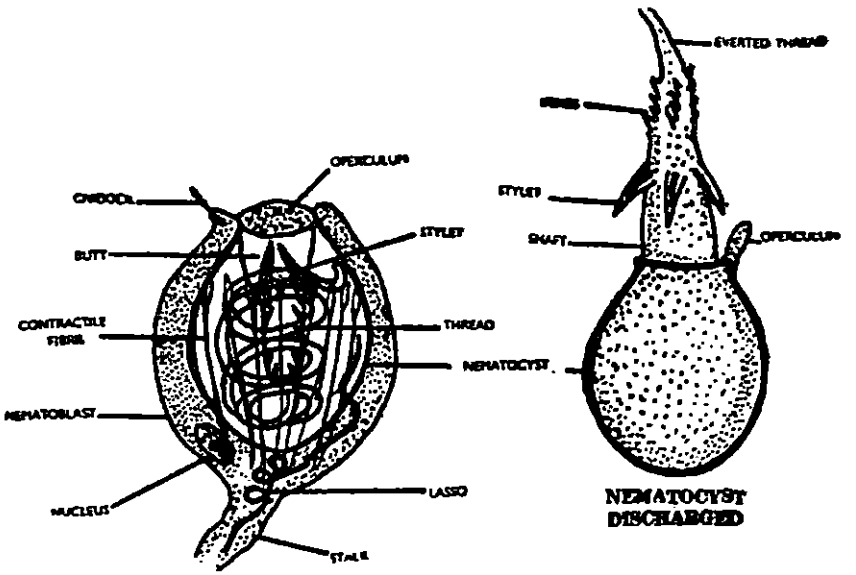


Fig. 140 — Penetrant cnidoblast (nematoblast of Hydra)

filled with fluid and contains a long spirally coiled thread. The outer end of the capsule is covered by a lid or cap, called operculum.

Nematocysts are used for anchorage, for defense or for the capture of prey. They are not under direct control of the nervous system. There are three types of nematocysts (Fig. 141) :

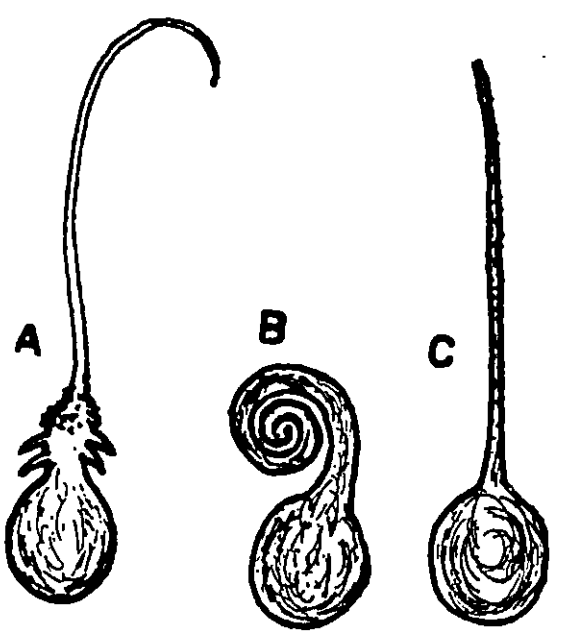


Fig. 141—Types of nematocysts of Hydra : (*a*) Penetrant; (*b*) Volvent; (*c*) Glutinant

(*a*) **volvent** with a tube closed at the end and coiled. It turns around and entangles the prey.

(*b*) **penetrant** with an open tube and usually armed with spines and barbs. It is discharged with such a force that the thread penetrates the body of the prey and injects a protein toxin that has a paralysing action. The toxic effect of nematocysts of *Hydra* and other cœlenterates is not perceptible by man. Larger marine forms, e.g. Portugese man-of-war, causes very severe burning sensation and irritation (Fig. 149).

(*c*) **glutinant** in which the tube is open and sticky. It responds to mechanical stimuli and is used in anchoring the animal (locomotion and attachment) when it walks on its tentacles.

The discharge of nematocysts is brought about by mechanical stimuli preceded by chemical stimuli. Thus neither touch alone nor the presence of animal fluids (food) alone causes discharge, but touch combined with presence of food does. Under the combined effect of chemical and mechanical stimuli, which are received and conducted by cnidocil, the permeability of the capsule increases. This results in entering of the water and increasing of the pressure inside the nematocysts which aided by the contraction of the cnidoblast causes the lid to be forced open. Then the tube turns inside out and the entire nematocyst explodes to the outside. When a nematocyst is discharged the cnidoblast is digested and replaced from intersititial cells. Cnidoblasts are formed in a zone of growth near the base of the tentacles. When mature, they are carried out along the tentacles by normal growth of the whole epidermis.

4. **Mucous-seereting cells** : These are tall cells found mainly on the basal disc and around the mouth region. They are provided with contractile extensions and produce a secretion by which the animal can attach itself. Sometimes they secrete a gas bubble by which the animal can rise and fasten on the surface of water and float (Fig. 144).

5. **Sensory cells** are long slender cells oriented at right angles to the epidermal surface (Fig. 145). They are abundant around the mouth, on the tentacles and on the pedal disc. Each sensory cell terminates near the surface in a sensory bristle while the base gives rise to a number of neuron-like processes or fibrils. These fibrils are attached to a nerve plexus found in the epidermis next to the mesoglea. Sensory cells both receive and transmit stimuli. They serve as receptors for touch, temperature and other stimuli.

6. **Nerve cells** are located at the base of the epidermis next to the mesoglea (not in the mesoglea). They are similar to the bipolar and multipolar cells of higher animals, but are more primitive. The processes are not differentiated into axons and dendrites (Fig. 142). The processes of the nerve cells connect with sensory cells, with the longitudinal fibres and epithelio-muscular cells and with other nerve cells.

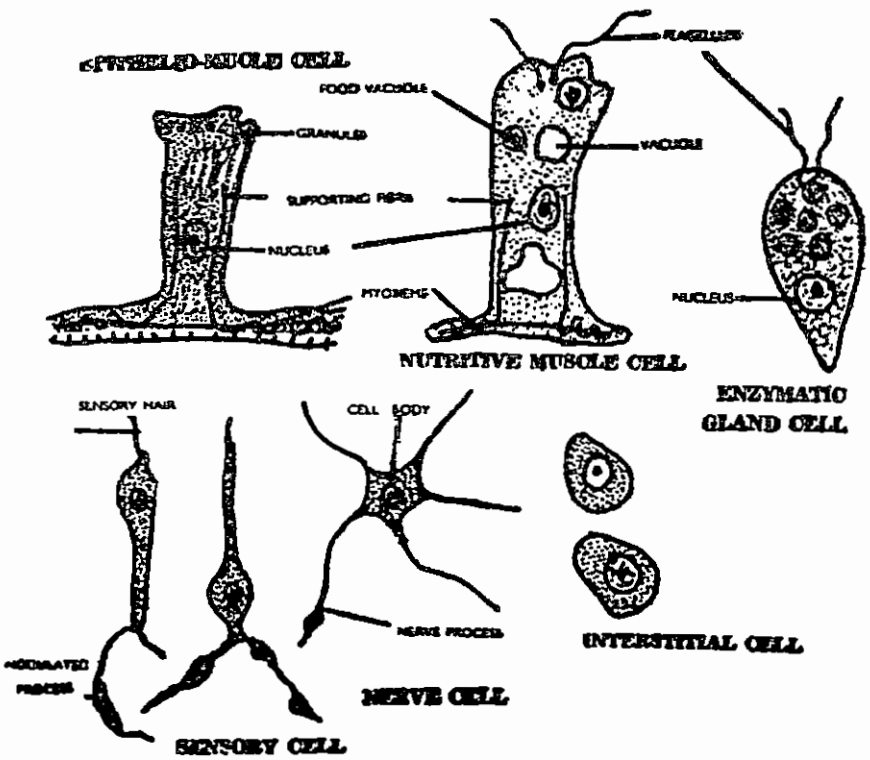


Fig. 142 — Principal cell types of Hydra

B) Gastrodermis

This includes the cells lining the coelenteron and is made up mainly of large columnar cells with irregular bases. It includes :

1. **The nutritive-muscular cells** are similar to the epithelio-muscular cells, but their contractile extensions run circularly around the body or tentacles (Figs. 142). They are more developed in the hypostome round the mouth where they form a sphincter and at the base of the tentacles. When the myonemes contract they lengthen the body by decreasing its

diameter. There are various types of nutritive-muscular cells; some secrete enzymes into the gastrovascular cavity: others are provided with pseudopodia to ingest food particles. while others are flagellated, the movements of the flagellae keep the material in the gastrovascular cavity in circulation.

In the green *Hydra*, the gastrodermal cells bear green algae (*Zoochlorella*), which is an example of symbiotic mutualism. The algae utilize carbon dioxide and waste to form organic compounds useful to *Hydra* and receive shelter and other advantages in return.

2. **The gland cells** are spread among nutritive cells. They are flagellated club-shaped cells with their tapered ends directed toward the mesoglea (Fig. 139). They secrete digestive enzymes. They are devoid of muscular extensions.

3. **Mucus-secreting cells** are abundant around the mouth and secrete mucus which aids ingestion, and passage of food into the coelenteron.

4. **Sensory and nerve cells** are scattered among the cells of the gastrodermis but are fewer than those in the epidermis.

5. **Interstitial cells** : These are few and scattered among the bases of nutritive cells. They may transform into other types of cells.

The nervous system

It is of a primitive type formed of nonpolarised nerve cells arranged to form an irregular nerve net or plexus, one located on each side of the mesoglea (Fig. 143). The two nets are joined by interconnecting fibers. The epidermal plexus is much more strongly developed, and the system is mainly concentrated in the mouth and tentacle regions. Since the neurons are not polarised the impulses can travel in any direction. The most recent studies in *Hydra* show that this system is not synaptic but a continuous net, that is the endings of the neurons are in direct contact.

The nerve cells of the net are connected to the slender sensory cells which receive external stimuli and to epitheliomuscular cells which react by contracting. Sensory cells may be directly connected to a contractile fibre, or to a motor nerve cell innervating a contractile fibre. All degrees of complexity of the association of neurons are represented. The nerve net is mainly found around the hypostome and pedal disc where nerve and sensory cells are more numerous. The sensory-nerve cell net and epitheliomuscular cells form a combination which is called **neuro-muscular**

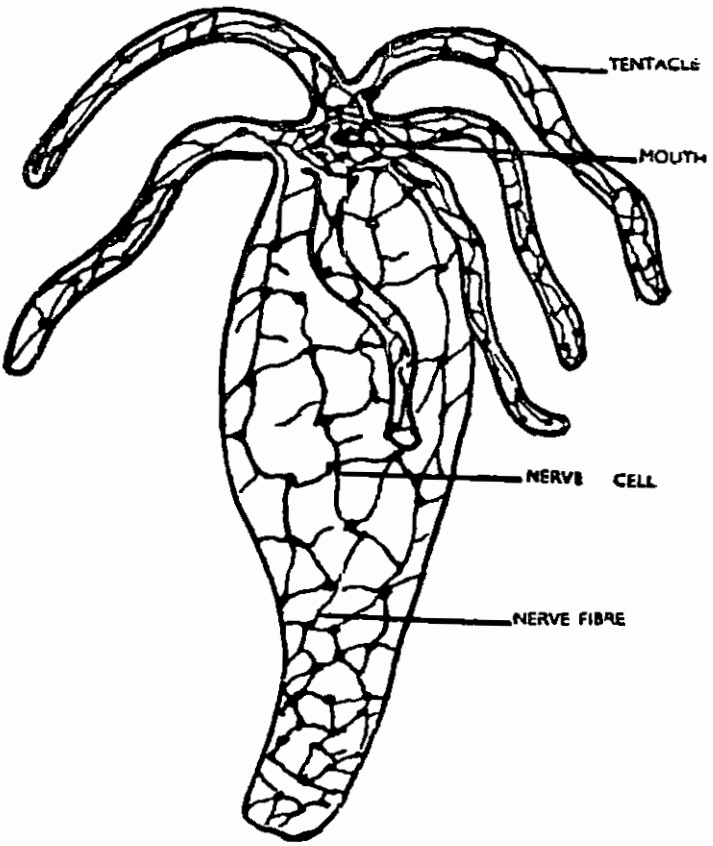


Fig. 143 — Diagram showing the nerve net of Hydra

system which represents the early step in the evolution of the nervous system.

Behaviour and coordination

Hydra responds to various stimuli both internal (hunger) or external, (i.e. temperature, light, etc.). If a tentacle is touched with a needle all of the tentacles and the body will contract. Response to various stimuli depends upon the physiological state of the animal. When well fed, the movements of *Hyda* are slow, but it steps up whenever it becomes hungry. In addition, the response to stimuli depends upon the kind and intensity of stimulus. The animal responds negatively toward strong stimuli, (e.g. strong light, strong and injurious chemicals etc.). It responds positively to light of moderate intesity. When subjected to a weak constant electric

current, hydras become oriented so that the oral end is toward the anode and the basal end toward the cathode. Hydras, by using the trial and error method, seek the situations which suit them.

Nutrition

Hydras are carnivorous, feeding upon small crustaceans such as water fleas, *Cyclops*, *Parmaecium*, insect larvae etc. Contact with the tentacles brings about a discharge of nematocysts which paralyse and entangle the prey. The tentacles then pull the captured prey toward the mouth, which widely opens to receive it. Mucous secretions aid in the passage of the prey into the gastrovascular cavity. The prey is not pushed in or swallowed by muscular action. The stimulus which causes the mouth to open is a chemical substance known as glutathione which is released from the prey through the wounds made by the nematocysts.

Inside the gastrovascular cavity, digestion takes place. It starts with **extracellular digestion** followed by the **intracellular phase.** In extracellular digestion, the gland cells of the gastrodermis secrete trypsin-like enzymes that begin the digestion of proteins which are hydrolysed to form polypeptides. The beating of flagella of the gastrodermal cells aids in mixing food with the enzymes.

The food which is in the form of fine particles is taken by the pseudopodia of the musculo-nutritive cells, where intracellular digestion takes place in the same way as in Protozoa. Digestion of proteins and fats is continued within the food vacuoles of the nutritive cells. The products of digestion are circulated by cellular diffusion. Fats and glycogen are the chief storage products of excess food. Undigested materials are ejected from the mouth on contraction of the body.

Locomotion

Hydra moves by several ways, this is attributed mainly to the outer longitudinal muscle fibres of the epidermal cells. Thus, the body stalk and tentacles can extend, contract and bend to one side or another. Movement may be either by gliding, somersaulting, floating or swimming (Fig. 144 .

In **gliding** locomotion, the animal uses its basal disc which slides slowly over the substratum wetted by mucus secreted from the mucous glands. In **"measuring worm"** movement hydra bends over and attaches its tentacles on the substratum, then slides its basal disc up close to them,

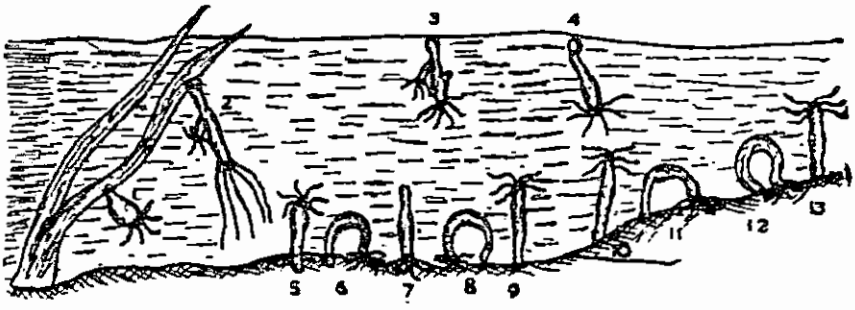


Fig. 144 — Methods of locomotion of Hydra: 1. contracted; 2. extended; 3. floating on the surface; 4. rising to surface by gas bubble; 5-9. moving by "somersaulting"; 10-13. locomotion that of a measuring worm (looping)

and then releases the tentacles and takes an upright position. *Hydra* moves by **"somersaults'** where it extends its body as much as possible, then it is bend to one side and the tentacles are fixed to the substratum by the aid of glutinants. Then the basal disc detaches and the animal stands on its tentacles. The body contracts and extends then bends to place the basal disc on the substratum. The tentacles are released from the substratum and the animal takes an upright position. This movement is repeated several times, thus carrying the animal from one place to another.

Sometimes *Hydra* uses its tentacles as legs for walking. It takes an inverted position, the tentacles are fixed to the substratum and are used for walking. In **floating** the basal disc detaches and secretes a gas bubble which carries the animal to the surface where it can float in an upside down position. In such position it can be carried by the water currents.

Respiration and excretion

There are no special respiratory or excretory organs. Every cell is actually exposed to water either on the outside of the body or within the gastrovascular cavity. Exchange of oxygen and carbon dioxide takes place through the general body surface. Excretions of waste nitrogenous matter, mostly ammonia, takes place also by diffusion through the body surface into the surrounding water. It is believed that the gastrodermis of the basal disc accumulates waste substances which are discharged through a temporary pore on the basal disc.

Reprodction

Hydra reproduces either **asexually** or **sexually.**

Asexual reproduction takes place by **budding** where one bud (or several buds) develops as a simple evagination of the body wall which

gradually grows and elongates. At its distal end a mouth and tentacles are formed and the cavity of the bud is continuous with that of the parent Hydra (Figs. 137 & 138). When mature, the bud separates from its parent and becomes an independent Hydra. Budding occurs when the conditions are favourable especially during the warmer season. Buds are usually formed at the budding zone found at the junction of the gastric region and stalk.

Asexual reproduction may take place by fission which may be longitudinal or transverse. Every portion will grow to give rise to a complete animal. TREMBLEY (1744) showed that if Hydra is cut, even into eight pieces, every piece (containing the two layers) will grow to form a complete individual.

Sexual reproduction involves the formation of gonads which are common in the autumn. The eggs which are formed are used as a means by which the species can survive the low temperature of winter. Most hydras are dioecious, but some species are monoecious or hermaphrodite. The formation of the gonads may be promoted by reduction of water temperature. Recent studies, by LOOMIS, however, showed that the high pressures of free carbon dioxide and reduced aeration in stagnant water may be responsible for the appearance of gonads.

Carbon dioxide was thus termed the 'sex gas' which when present in certain concentration induces the formation of gonads.

Gonads are temporary structures which originate mainly from the interstitial cells. Generally in monoecious species the testis are located in the epidermis of the upper half of the stalk, and the ovaries in the lower half. In each ovary a single egg is formed, while the other interstitial cells serve as food for the egg. Then, the egg undergoes two maturation divisions, thus producing two polar bodies and the egg with half the number of chromosomes. When the egg matures the epidermis lying over it reptures and thus it is exposed.

The testis is a conical swelling where the sperms are formed all with the haploid number of chromosomes (Fig. 145). When mature the sperms escape from a nipple at the tip of the testis, The sperms penetrate the exposed surface of the egg and fertilization takes place, The formed zygote undergoes holoblastic cleavage and forms a hollow blastula (Fig. 145). The outer layer of the blastula becomes the ectoderm which later forms the epidermis. The endoderm is formed by the inner part of the blastula, which at the beginning is in the form of a solid mass. Later a

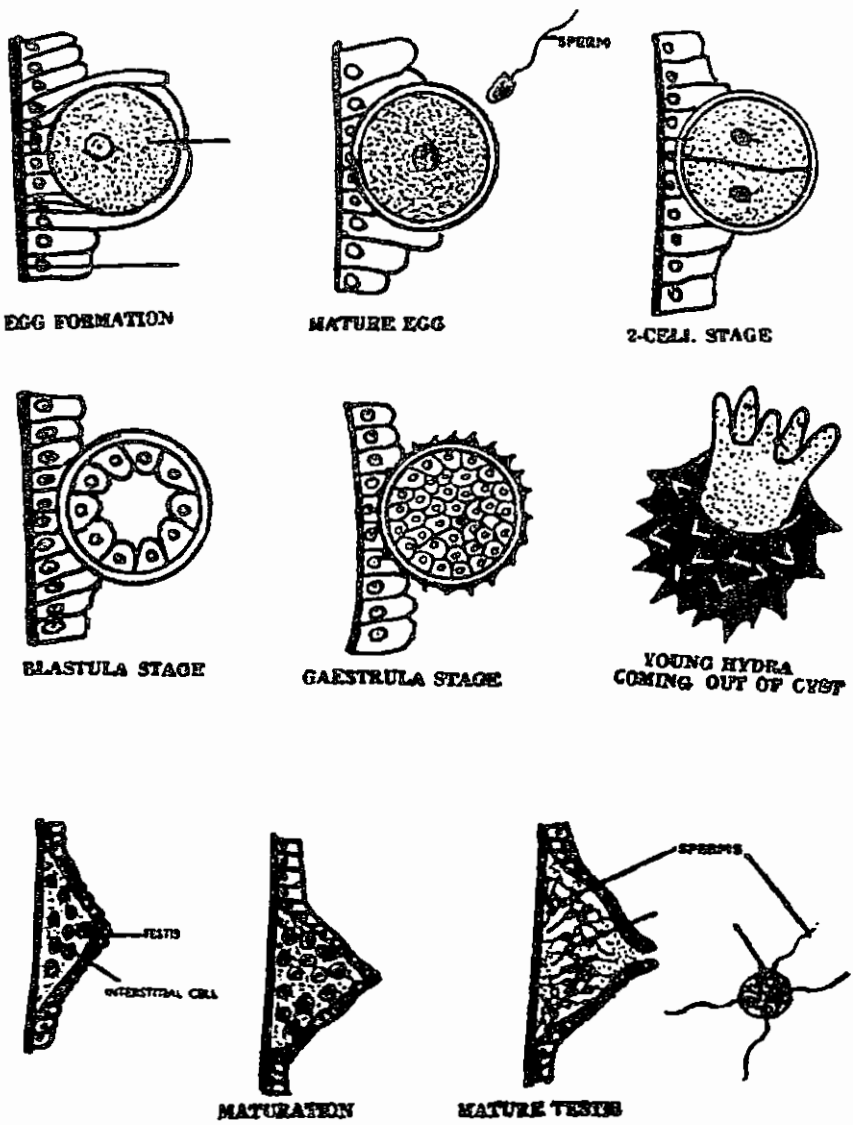


Fig. 145 — Sexual reproduction of Hydra

cavity, the coelenteron, appears in the endoderm which forms the gastrodermis of the adult. About this time, the embryo is covered by a chitinous shell, then it drops off the parent and remains in this protective cyst through the winter. When the conditions become favourable development is completed, then the shell ruptures and a young Hydra hatches out which soon grows into the adult condition.

Regeneration

Regeneration is the process of replacing lost or injured parts of an organism or even of forming a whole organism by a small part. *Hydra* has great abilities to restore lost parts through regeneration. This power of regeneration of *Hydra* was discovered by TREMBLEY (1745) who found that if Hydra is cut into eight pieces, each piece will give rise to a new individual. Even parts of individuals of the same species or different species may be grafted together even though these fragments are too small to grow independently. The ectodermal cells with their amoeboid processes are responsible for this fusion. If a *Hydra* is splitted through the mouth, a two headed individual is formed (Fig. 146). If the hypostome and tentacles are cut off, they will give rise to new individuals.

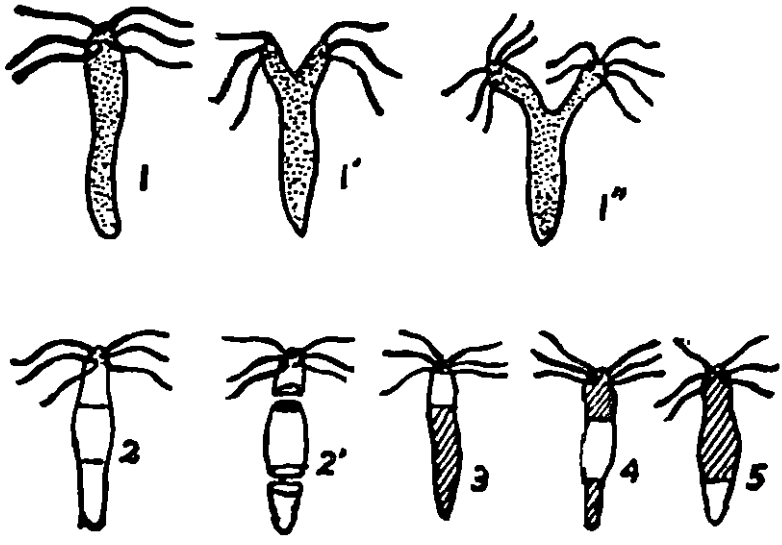


Fig. 146 — Regeneration of Hydra : 1. splitting Hydra through mouth 1' and hypostome. will give rise to two headed Hydra; (1''); 2. when Hydra is cut into parts (2') each part will give rise to a whole individual 3, 4, 5.

Investigations by BRIEN and BERRILL on the growth pattern of *Hydra* indicate that it may be considered immortal. They showed that there is a growth zone just below the tentacles (Fig. 147). The cells that arise from this growth zone make their way upward to the tip of tentacles, and downwards to the base. The renewal of the cells of all the individual takes place in about 45 days and appears to continue indefinitely. It is

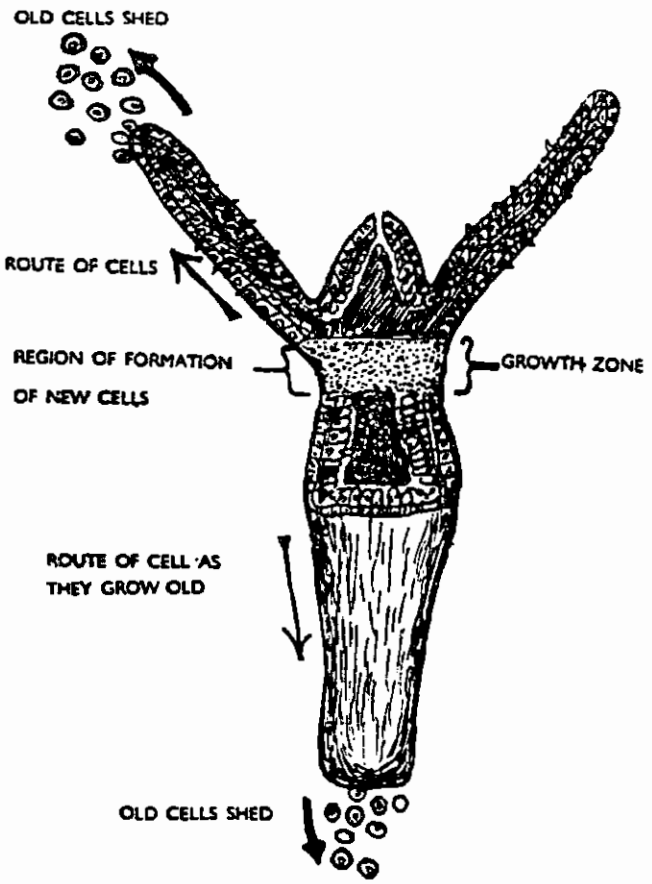


Fig. 147 — Hydra, Diagram showing renewal of all cells from a growth zone below tentacles

found that if the interstitial cells are destroyed by X-rays the *Hydra* will live only for few days.

When a *Hydra* is turned out, either by natural or artificial means, either it turns itself right side out or migration of the inside cells to the outside and the outside cells to the inside thus restoring the original arrangement of the cells. Recently MARTIN MACKLIN (1968) showed that cell migration across the mesoglea takes place only in damaged areas. Regeneration of everted *Hydra* occurs as a result of re-turning by two methods : (*a*) slow returning resembling the turning of a sock when it is being removed; and (*b*) fast returning caused by a rapid contraction by the everted animal followed by relaxation to the normal body layer orientation.

Classes of COELENTERATA

Class I HYDROZOA

This is charcterised by : (*a*) the mesoglea is never cellular: (*b*) the gastrodermis lacks nematocysts and (*c*) the gonads are epidermal and if gastrodermal the eggs and sperms are shed directly to the outside and not into the gastrovascular cavity Hydrozoa includes solitary or colonial forms. They may be either in the polyp form as in case of *Hydra* or medusa form as *Physalia*, the portuguese man-of-war (Fig. 149). Some species pass through both forms during their life cycle as *Obelia* (Fig. 148 .

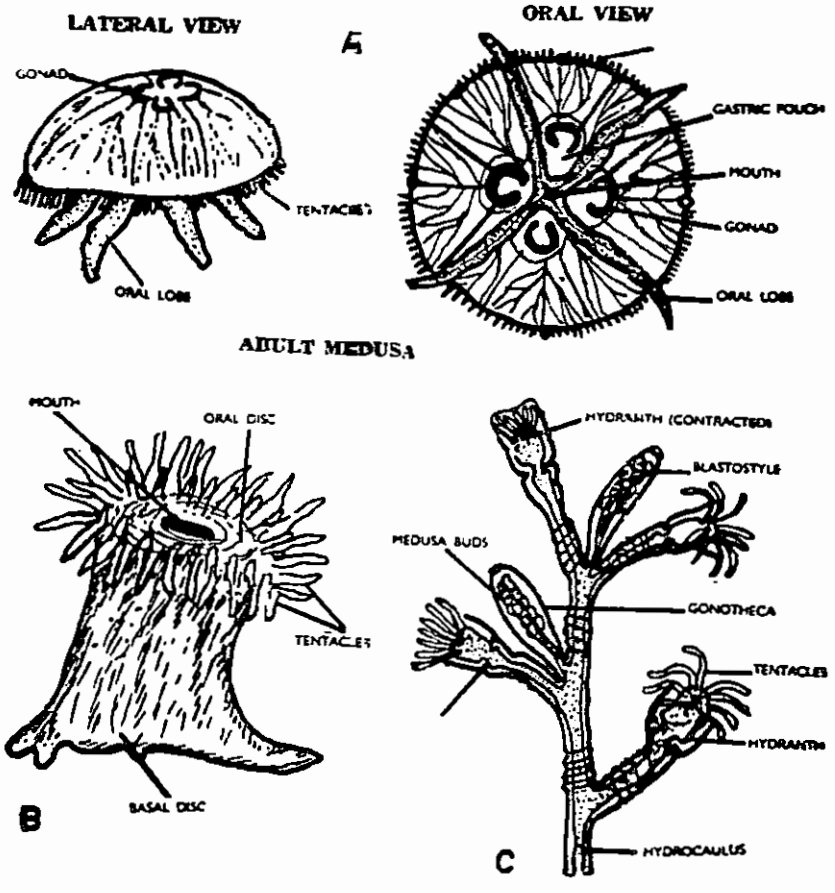


Fig. 148 — Representatives of coelentrates . A jelly fish Aurelia; B) sea anemone; C) Obelia (part of a colony)

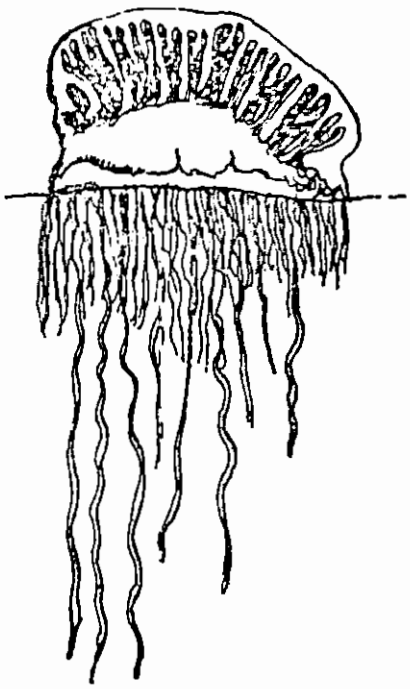


Fig. 149 — Portuguese man-of-war, Physalia physalia with stinging organelles which secrete a powerful neurotoxin

Class 2 **SCYPHOZOA**

These are usually called jellyfish. The medusa is the dominant and conspicuous individual in the life cycle, the polyps being a small larval stage. Members of this class are characterised by : (*a*) the mesoglea is thick, gelatinous and fibrous. It contains amoeboid cells and is a true cellular layer; (*b*) the gastrovascular cavity is divided into pouches by septa which are provided with threads and nematocysts; (*c*) the gonads are located in the gastrodermis. The largest jellyfish, *Cyanea* may be 3.6 meters in diameter and have tentacles 30 meters long. They live in the North Atlantic Ocean.

Examples : *Aurelia* (Fig. 148). and *Physalia* (Fig. 149).

Class 3 **ANTHOZOA** (**Actinozoa**)

This includes solitary or colonial polypoid coelentrates in which the medusa is completely absent. It includes sea anemones; corals; sea fans, etc. All are marine forms which are most characterised by a calcareous exo- or endoskeleton. It is characterised by : (*a*) absence of the oral cone,

the mouth leads into a tubular pharynx that opens into the gastrovascular cavity; (*b*) the gastrovascular cavity is divided by longitudinal septa (mesenteries) into many compartments, the edges of the septa are provided with nematocysts; and (*c*) the gonads are gastrodermal and the mesoglea is cellular.

Examples : sea anemones (Fig. 148); corals Fig. 150) as organ

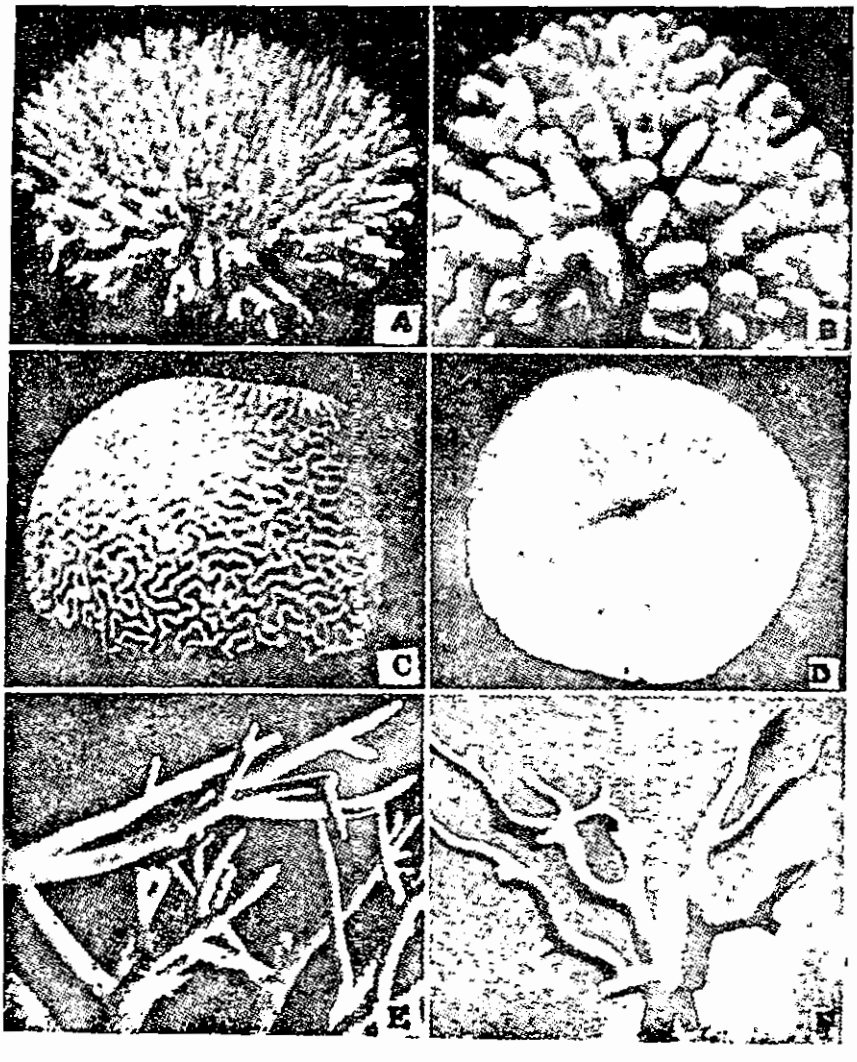


Fig. 150 — Varieties of corals. A star coral. Pocillipora grandis, B finger-like madrepora, Madrepora digitata; C brain coral Meandrina sinuosa, D mushroom coral, Fungia dentata; E staghorn coral. Madrepora cervicornis and F red coral. Corallium rubrum

pipe coral (*Tubipora*); the brain coral (*Meandrina*); fungus coral (*Fungia*) etc.

Corals live in shallow warm seas. The polyps are alive only on the surface of coral massses, and are rarely found below 60 meters depth. The Great Barrier Reef of the Australian coast is more than 1000 miles long. The Red Sea is rich in coral reefs which render navigation difficult in certain regions.

PHYLUM PLATYHELMINTHES

General consideration

The flat worms are acoelomate animals which are more highly organised than coelenterates. The development of an extensive mesoderm (which is a mass of cells separating the ectoderm from endoderm) has resulted in the formation of a number of organ systems such as the digestive, excretory and reproductive systems. Thus there is more specialization and more division of labour resulting in more definite tissue layers to form organs. In flat worms there is tissue-organ level of differentiation which is more advanced than the tissue level of organization of coelenterates.

The body of flat worms is differentiated into an anterior and posterior ends and dorsal and ventral surfaces, thus showing a bilateral symmetry which is contrasted to the radial symmetry of coelenterates. The flat worms are considered as the most primitive of all the bilateral phyla which include the rest of the animal kingdom. In flat worms well developed muscular layers occur. The development of muscular contraction and muscle fibres freely and at any point in the mesenchyma is found in flat worms instead of being restricted to the outer epidermis or inner gastrodermis of coelenterates. Digestion is mainly extracellular, a character associated with the increase of size of animals. The nervous tissue is more developed than that of coelenterates with a tendency towards centralization of the nervous system by the formation of nerve cords provided with ganglia.

Parasitism is common among flatworms. Associated with parasitism there is a tendency to lose or have reduced some of the structures found in free-living forms. In addition the reproductive capacity is greatly developed, and many parasites are adapted to live in more than one host.

General characters

1. Animals with their body formed of an outer ectoderm, an inner endoderm and a middle cellular mesoderm. There is no definite body cavity
2. Bilaterally symmetrical with definite polarity of an anterior and posterior ends.
3. Body flattened dorsoventrally, and hence their name Platyhelminthes (platys, flat; helmin, worm), with an oral and genital openings.
4. The digestive system is primitive with a single opening, the mouth (anus is absent). In some species it is absent.
5. The muscular system is in the form of a sheath which originates from the mesoderm and forms circular, longitudinal and oblique muscle layers beneath the epidermis, in addition to a mesenchymal system of fibres. The arrangement of muscle layers allow the flat worms to deform reversably their bodies by twisting and flattening to an extent that cannot be reached by coelenterates.
6. The nervous system consists of anterior ganglia with longitudinal nerve cords connected by transverse nerves (ladder type) and located in the mesenchyma in most forms.
7. The excretory system is composed of two lateral canals with branches ending in flame bulbs (cells).
8. Simple sense organs and eye spots are found in some species.
9. The respiratory, circulatory and skeletal systems are lacking.
10. Most forms are monoecious. The reproductive system is well developed.

Classification

Phylum Platyhelminthes is classified into three classes :

Class **Turbellaria** (L. terbella, a stirring). Mostly free-living worms. The body is soft; epidermis ciliated at least on the ventral surface; mouth located on the ventral surface; epidermis with rodlike bodies, the rhabdites.

Example : *Dugesia* (Fig. 153).

Class **Trematoda** (Gr. trematodes, with holes . Ecto-or endoparasites, with a thick tegument, no cilia, most species possess suckers: alimentary canal with two branches, mostly monoecious.

Examples *Fasciola* (Fig. 159), *Schistosoma* (Fig. 163), *Heterophyes* (Fig. 166).

Class **Cestoda** (Gr. kestos, girdle : cidos, form). All are parasitic usually with alternate hosts. Ribbon-like in shape with a thick tegument. The body is divided into a series of segments (proglottids); alimentary canal and sense organs are lacking, an anterior scolex provided with suckers or hooks or both for attachment.

Example : *Taenia* (Fig. 168), *Diphyllobothrium*, *Echinococcus* (Fig. 172) and *Hymenolepis*.

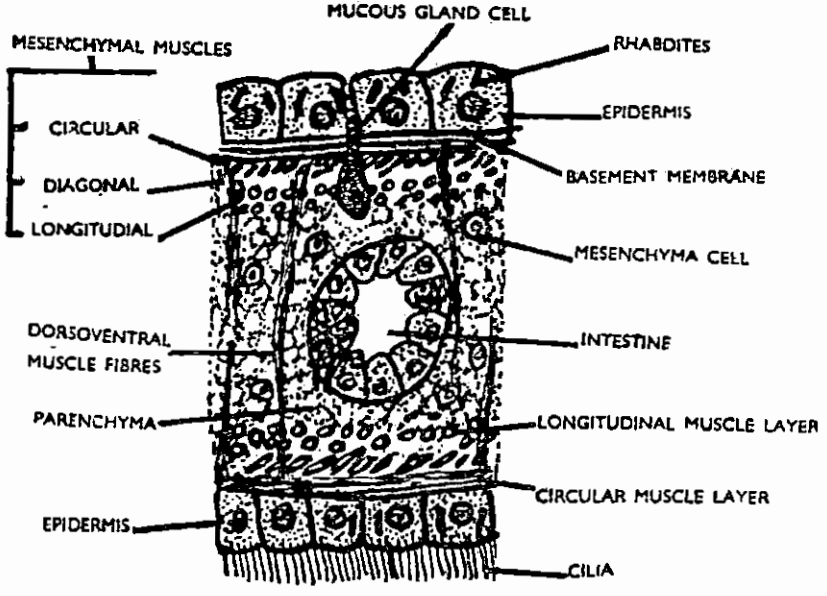


Fig. 151 — T.S. through the body of a freshwater planarian

GENERAL ORGANIZATION OF FLAT WORMS

Structure of the body wall

The body wall in flat worms differs in both free living and parasitic worms. In the free living **planarians** the epidermis consists of a single layer of cuboidal cells resting on a basement membrane. The epidermal cells on the ventral and lateral surfaces are ciliated (Fig. 151). They contain rod-shaped bodies called **rhabdoides** (rhabdites), which when discharged into water swell and form a protective gelatinous sheath around

the body. In addition there are single mucous glands which are located within the epidermis or underneath it but they open on the surface.

The epidermis is followed by the muscle fibres which form the circular, diagonal and longitudinal muscle layers. A network of parenchyma (mesenchyma) cells fill the spaces between the muscles and visceral organs.

In parasitic flat worms (*Fasciola* and *Taenia*) the body wall is characterised by the lack of cilia and the presence of an outer thick tegument or epidermis — the so-called cuticle. The electron microscope revealed that the tegument is composed of syncytial living protoplasm — rather than lifless secretions — that represents extensions of deeper laying nucleated cells i.e. tegument-secreting cells (Fig. 152). In trematodes the outer surface is smooth and is provided with small sharp spinules which are used to fix the fluke inside the tissues of the host. In cestodes (*Taenia*) the outermost surface contains microvilli which may serve to increase the absorptive surface. The tegument contains pinocytic vesicles, cytoplasmic reticulum and in its deeper layers mitochondria. The tegument lies on a basement membrane followed by circular and longitudinal muscles layers. A diagonal muscle layer may be present. The dorsoventral muscles connect the dorsal and ventral surfaces of the body to ensure the maintenance of the flattened body form. The mesenchyma (parenchyma) lies underneath the muscle layer and is formed of large branching cells with a syncytial network of fibres with spaces filled with fluid. The mesenchyma fills the spaces between the various organs and body wall (Fig. 152). The parenchymatous tissue acts as a hydrostatic skeleton which is less easily deformed as compared to the fluid enclosed in a cavity.

Digestive system

The mouth leads to a pharynx which may be muscular and serves as a suctorial fore gut (Figs. 153 and 154). The pharynx leads to a short oesophagus which joins the intestine which has two or three blind branches or caeca. Each caecum is provided with a large number of diverticula which increase the digestive and absorptive surfaces. The wall of the intestine (gastrovascular cavity) is lined by large columnar epithelial cells and small gland cells. The free living turbellarians capture their prey by entangling them in the mucous secretion. Then they ingest the prey by swallowing or by a sucking or pumping action of the pharynx. At the beginning, digestion is extracellular where the gland cells of the intestine secrete proteolytic enzymes that disintegrate the ingested food. The food fragments are then engulfed by the phagocytic cells, in which digestion is completed intracellulary. The digested food is absorbed through the

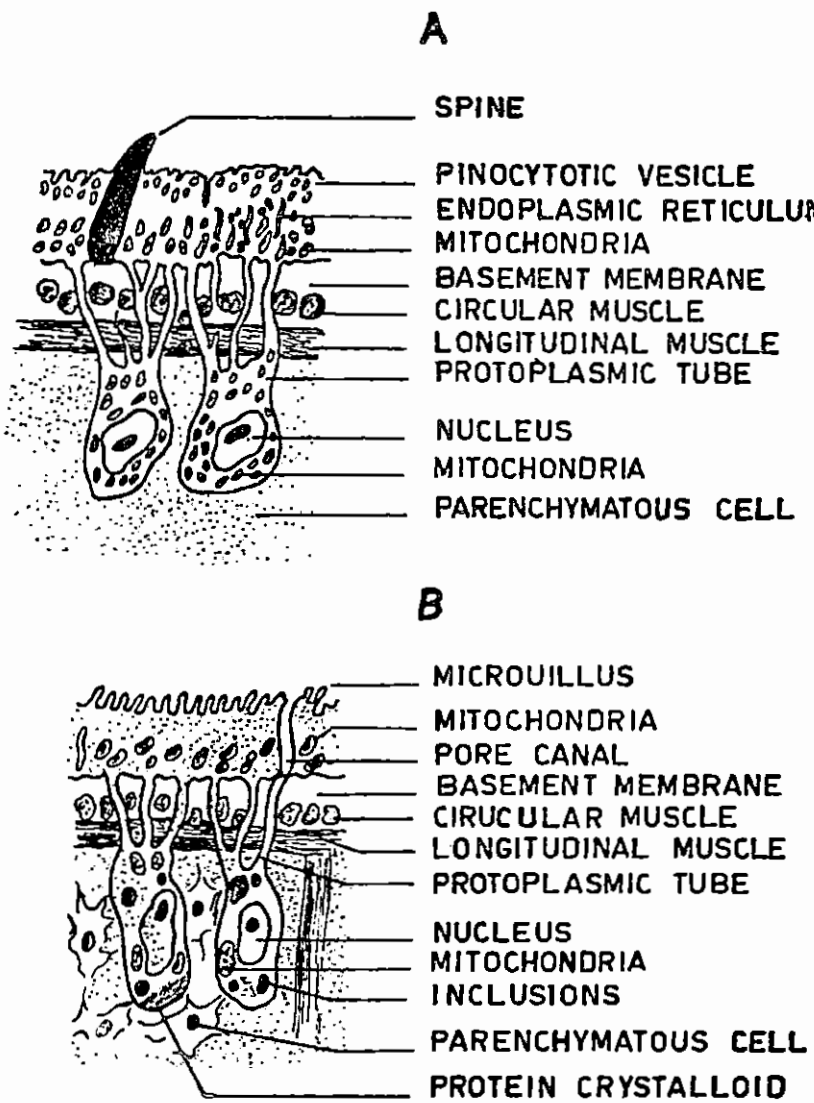


Fig. 152 — L.S. of the body wall of flat worms : A) Fasciola (a trematode) : B) Taenia (a cestode)

wall of the intestine and its diverticula where it is distributed to the various parts of the body (Fig. 154).

Planarians can live for a long time without food. They draw their food by digesting their own tissues, the reproductive organs, then the mesenchyma, muscles, etc. The body volume may be reduced to as little as 1 : 300 of the original. When they feed again they regenerate the missing parts.

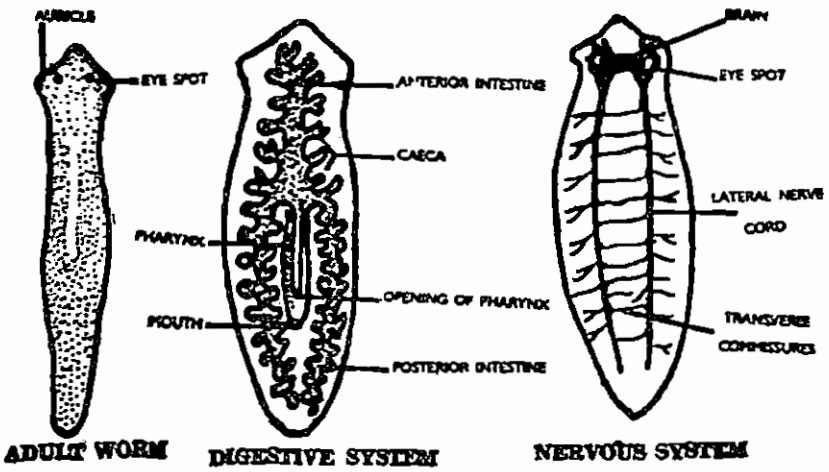


Fig. 153 — A planarian (Dugesia)

In **trematodes** such as the *Fasciola* (liver fluke) (Figs. 154A) and *Schistosoma* (blood fluke) (Fig. 163) the worms feed on the blood, lymph, and tissues of their host. In addition amino acids and sugars may be utilised from the blood of the host by pinocytosis through the tegument. The food passes from the mouth into the pharynx by its muscular action,

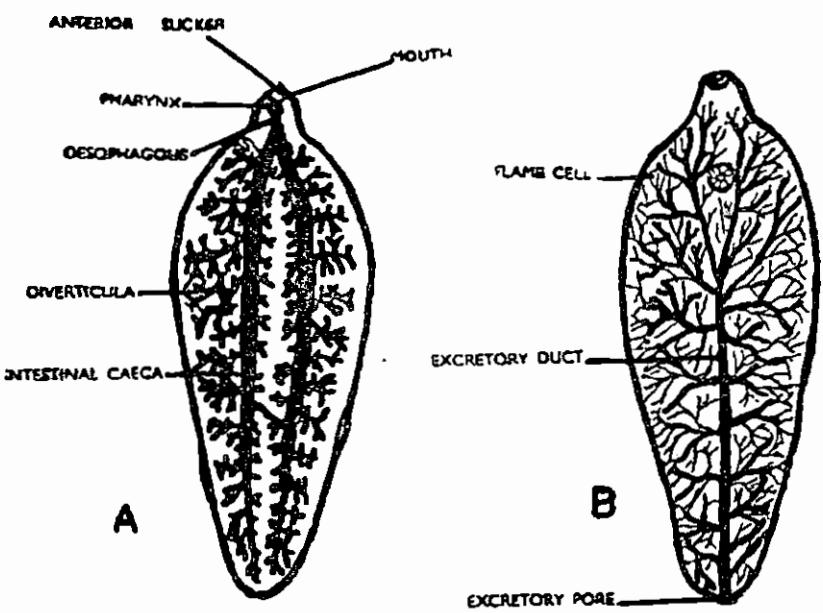


Fig. 154 — Fasciola hepatica : A) digestive system; B) excretory system

then to the intestine where digestion and absorption takes place. The caeca, diverticulae, and parenchyma ensure the distribution of digested food to various cells. The undigested food is rejected through the mouth aided by the muscular contraction of the worm.

In cestodes (e.g. *Taenia*) there is no alimentary canal and ready-digested food passes through the pinocytes in the tegument by some kind of active process called pinocytosis and not by simple diffusion.

Nervous system

It is more advanced over the nerve net of **Hydra.** It is composed of two cerebral ganglia (brain) in the head region containing nerve cells, and

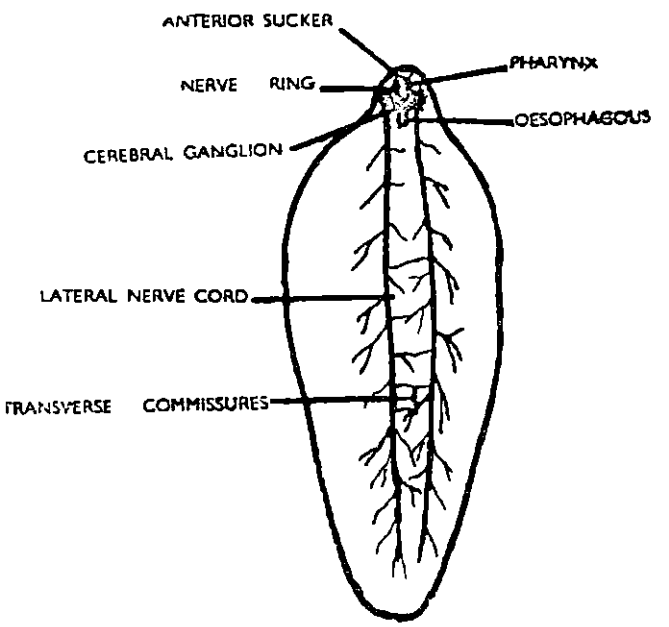


Fig. 155 — Fasciola hepatica. Nervous system

connected together by a circumpharyngeal nerve ring (Figs. 153 and 155). From the latter two main longitudinal lateral nerve cords extend posteriorly. The ventral nerve cords are connected with each other by transverse nerves giving the appearance of a ladder. From the lateral nerves extend peripheral nerves, while short nerves from the brain innervate, the anterior end and sensory organs (eye spots in planarians).

This well developed nervous system is found in both free living and parasitic flat worms. Its presence in parasitic worms, which live in a constant environment, is difficult to explain.

The **sensory organs** are well developed in free living flat worms. These inclue the eye spots and sense organs concerned with taste, smell, touch and reception of water currents. The eye spots are cup-like structures lined with black pigmented cells and filled with retinal cells with photosensitive ends (Fig. 156). The ends of the retinal cells continue as nerves that are connected to the brain. The eye spots are located in a nonpigmented area and are sensitive to light intensities and can distinguish the direction of light source. The pigment cups serve as shields which allow light to reach the light-sensitive ends of the cells through the openings of the cups only, thus permitting the animal to respond to the exact direction of the light source. Planarians are mainly negatively phototactic and are most active at night.

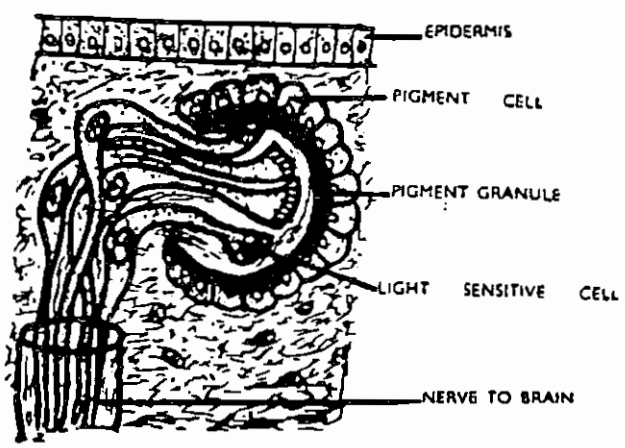


Fig. 155 — Section through the eye of a planarian

In addition to the eye spots there are the **chemoreceptors** which are scattered allover the body, but more concentrated in the head region.

In parasitic flatworms the sense organs are degenerate or completely absent and this is associated with the constant environment in which they live. Their free living stages may be provided with sensory organs.

Excretory system

This is in the form of tubules scattered in the mesenchyma throughout the body, and is not connected in the form of compact organs as in higher animals.

It consists of a single median excretory tubule or two lateral tubules extending throughout the body and open to the exterior by excretory pore or pores (Fig. 154). The main tubules are connected to a network of ciliated tubules which branch to all parts of the body and end in flame bulbs or flame cells (Fig. 157). Each flame cell is hollow and contains a tuft of cilia arising from basal granules. A flame cell has an outer thin elastic wall provided with a nucleus. The cilia of the flame cells which are joined at their distal regions, beat continuously like the flickering of a candle flame and hence their name. Beating of the cilia carries excess water and some waste metabolic products into the tubules by the hydrostatic pressure of the flame cells. Water and waste products diffuse into the cells and then into its cavity, where it is pumped into the excretory tubules by the action of cilia.

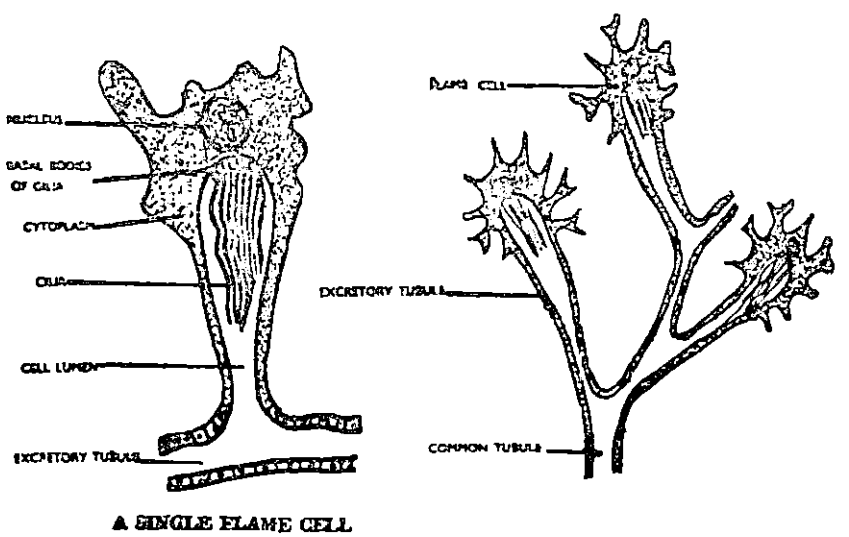


Fig. 157 — Excretory organs of flatworms

In free living flatworms the main function of the excretory system is water regulation, thus it acts as a water balancing organ removing excess water. Excretion of nitrogenous wastes takes place by certain cells in the fine tubules and also through the epidermis and gastrodermis.

Respiration.

There are no special respiratory organs. Respiration takes place by diffusion of the respiratory gases through the body surface into the surrounding water where the worms live, or into the fluids of host in parasitic worms. This is aided by the thinness and flattening of the body.

In the parasitic worms as *Fasciola* oxygen is obtained from the bile and adjacent tissues. *Fasciola* lives under relatively anaerobic conditions as in the liver oxygen is not abundantly present. Under such conditions anaerobic respiration takes place where glycogen undergoes anaerobic glycolysis to pyrivic acid. The pyrivic acid is decarboxylated to form carbon dioxide and an acetyle group. The latter combines with coenzyme A to form acetyl-coenzyme A, which is then condensed and reduced to form fatty acids. Thus the products of respiration are carbon dioxide and fatty acids. The carbon dioxide leaves the body by diffusion through the body surface. Fatty acids-being relatively insoluble and less reactive than lactic acid-which is produced in most animals — are thus excreted by the way of excretory system.

In blood flukes (*Schistosoma*) oxygen is obtaind from the blood in which they live.

Regeneration

Planarians have great power to regenerate lost parts. If a planarian is cut into two portions, each part will regenerate into a whole worm. Also if it is cut into three pieces, three whole worms are regenerated (Fig. 158). The capacity of regeneration is related to certain cells of the mesenchyma, (i.e. neoblasts) which retain their embryonic nature and can proliferate and differentiate into the different tissues of the worm. Recent work reveals that when a planarian is cut across, the neoblast cells migrate to the cut surface and aggregate there to form a blastema, which develops into the new part. If a worm is exposed to X-radiation the neoblasts are destroyed and no regeneration will occur. Neoblasts may be attracted to the cut region by chemical substances which cease when the blastema formed (Fig. 158).

Regeneration in planaria was used by C.M. Child as evidence of the axial gradient theory. According to this theory, there is an anterior-posteterior gradient of a physiological nature. Thus the metabolic rate is greatest at the anterior end and decreased gradually to the posterior end. In any piece a head will regenerate on the cut end with the higher metabolic rate, while a tail will develop on the cut surface with lower metabolic rate. If a narrow piece is cut from a planarian just back of head, two heads will regenerate on either surfaces, being of nearly the same high metabolic rate.

In addition to regenerating lost parts, planarians may be grafted in such a way as to produce strange designs such as two heads or two tails.

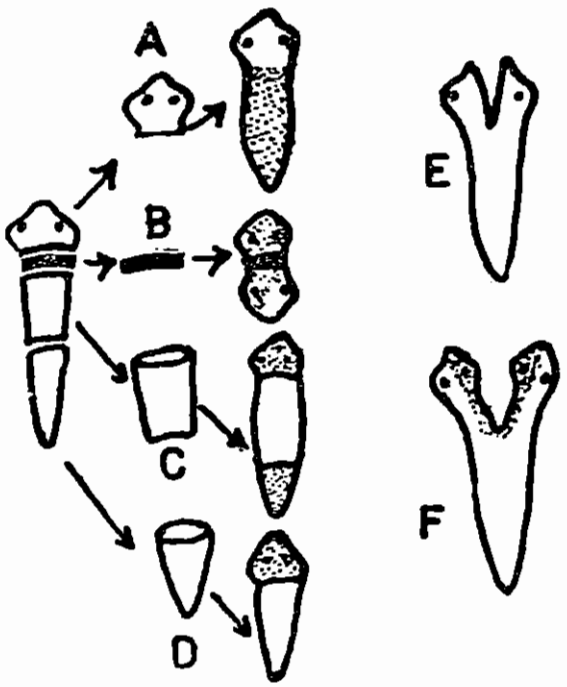


Fig. 158 — Regeneration in a planarian, a worm is cut into four pieces: A) regenerates a tail; B) regenerates two heads; C) regenerates a head and a tail; D) regenerates a head; E) & F) if head is split a double headed worm results

Also if a worm is cut through the head region till the middle, a two-headed worm is produced, just the same as two headed pig or dog.

CLASS TREMATODA

1 — Liver Flukes

FASCIOLA HEPATICA

(Sheep Liver-fluke)

It is an endoparasite living in the liver and bile ducts of sheep, cow, cattle and pigs where it causes serious damage, in addition to high mortality among infected animals. This fluke may infect man but this occurs rarely. In Egypt the most common species is *Fasciola gigantica* which is slightly different in its morphology and life cycle than *F. hepatica.*

External features (Fig. 159).

The fluke is leaf-like reaching 25 - 30 mm long with an anterior conical lobe in the middle of which there is an anterior oral sucker surrounding the mouth. The ventral sucker which is larger, lies on the ventral surface behind the head lobe. Both suckers are used for attachement to the host. The genital pore lies on the ventral side anterior to the ventral sucker. The median excretory pore lies at the posterior end.

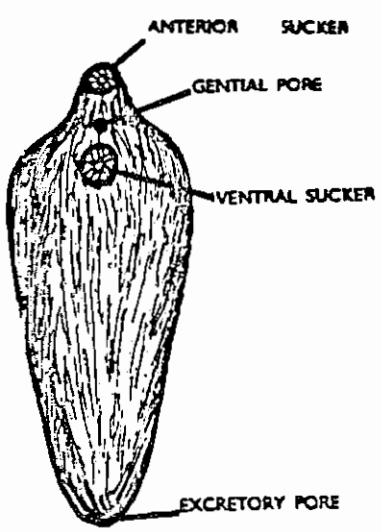


Fig. 159 — Fasciola hepatica. Ventral view of adult

Reproductive system

The liver fluke possesses a complicated hermaphrodite system where a complete set of male and female organs are found in each animal.

Male reproductive organs (Fig. 160).

The two branched testes lie one behind the other, at the posterior half. The two vasa defferentia one leading from each testis, unite near

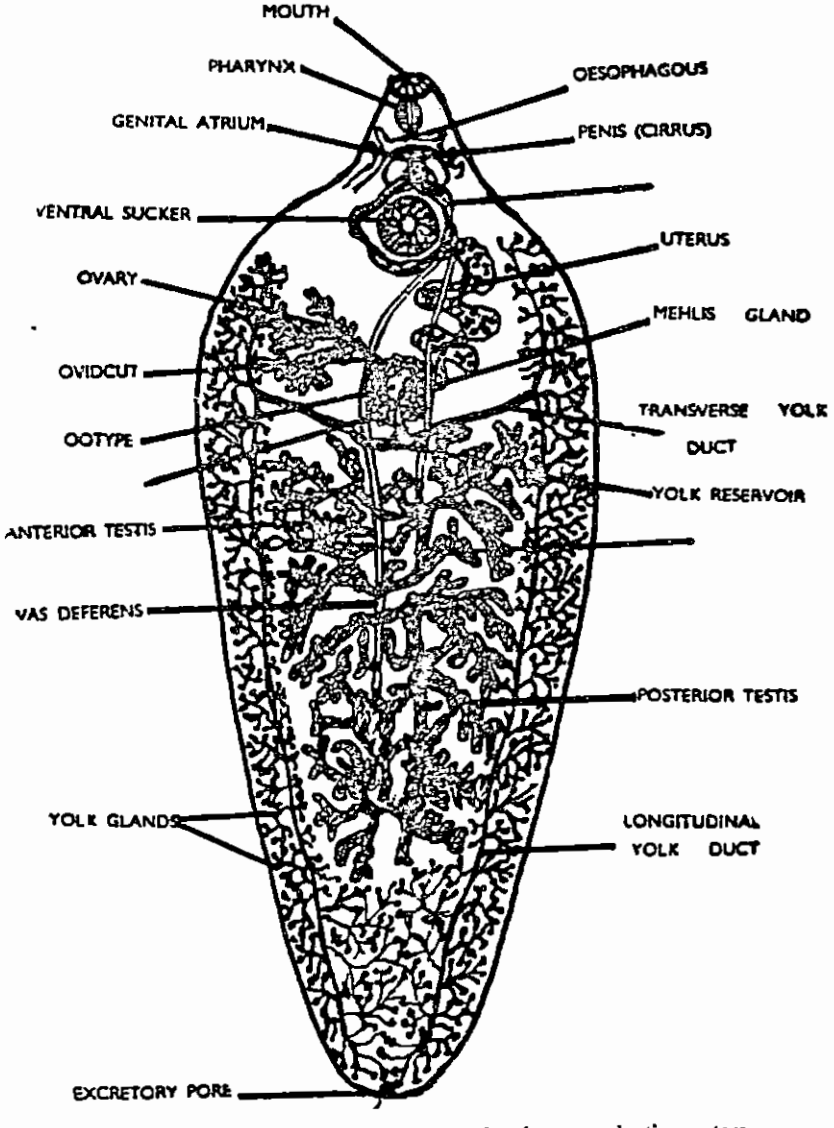


Fig. 160 — Fasciola hepatica. Diagram showing reproductive system

the ventral sucker, to form the seminal vesicle. From the seminal vesicle narrow ejaculatory duct extends to open into the duct of a muscular copulatory organ, the cirrus (penis) which protrudes during copulation. Several small prostat glands open into the ejaculatory duct (Fig. 161) The cirrus, ejaculatory duct and prostate glands are surrounded by the cirrus sac. The latter opens into the genital atrium by the male genital opening.

The female reproductive organs (Figs. 160 and 161).

The female system consists of a single branched ovary which lies in front of the testes to the right of the mid line. A short oviduct carries the ova to a centrally placed ootype which is surrounded by Mehlis' gland (ootype gland). The ootype receives a short common vitelline duct which carries vitelline cells necessary for the development of the embryo. The two yolk glands occupy the lateral and posterior regions of the body. The yolk (vitelline) cells are carried by two lateral longitudinal yolk ducts from each of which arises a short transverse yolk duct (Fig. 161). The right and left transverse ducts open into a median triangular vitelline reservoir from which the

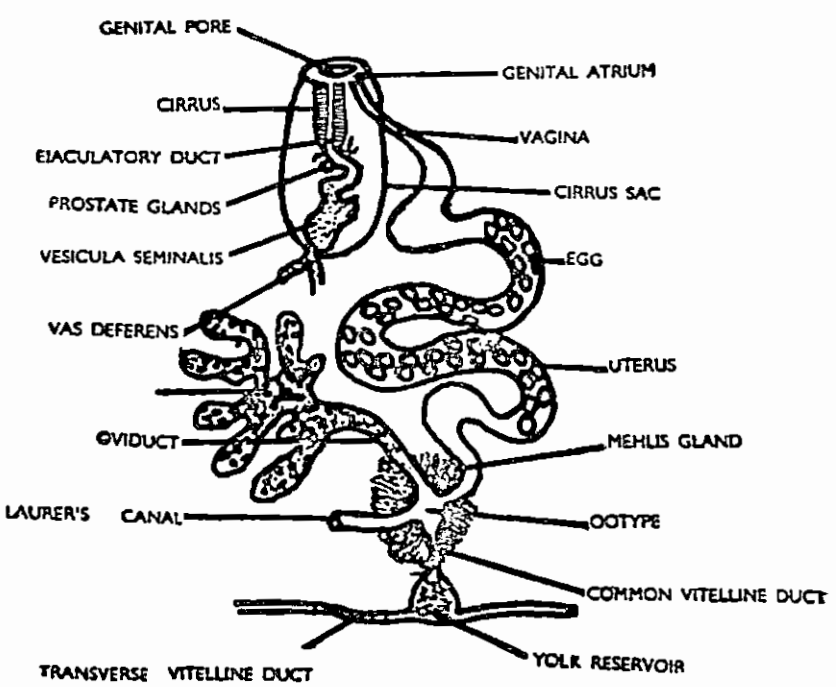


Fig. 161 — Diagram to show the genital ducts of Fasciola hepatica

short common median vitelline duct extends. From the point of junction of the vitelline duct and ootype, originates a short Laurer's canal whichl opens on the dorsal surface of the fluke. This canal is considered as vestigia vagina and may be used for copulation, for the discharge of excess spermatozoa or yolk cells or for the passage of eggs. The Mehlis' glands are unicellular glands which give a secretion to lubricate the passage of eggs into the uterus and increase the rigidity of the egg shell. The Mehlis' gland secretion may activate the spermatozoa but it does not secrete the egg shell as the latter is secreted by the yolk glands (Fig. 161).

From the ootype arises a wide convoluted uterus which opens by the female genital pore into the genital atrium. The ootype is considered as the place where the various parts of the egg are assembled.

Life cycle (Fig. 162).

Fertilization takes place between two different flukes i.e. cross fertilization, where the sperms are passed from one animal to the other by the penis being inserted in Laurer's canal or the uterus. Self fertilization may occur where the sperms of the same fluke are introduced into the female genital opening and pass down the uterus. Eggs are fertilized in the oviduct where they become surrounded by the yolk and shell formed by granules in the yolk cells. When completed the eggs pass into the uterus where development begins, then they are discharged into the bile ducts of the host from where they reach the intestine and are passed out with the faeces.

1. **Egg** (Fig. 162).

The fertilized egg is comparatively large (about 140μ) and is provided with a small lid or operculum which is used for the exit of the larva. After fertilization the egg divides to give rise to two types of cells; somatic cells which develop to form the larva (miracidium), and germ or propagative cells which will give rise in later stages to other larvae.

2. **Miracidium**

When eggs are shed with faeces into water they continue development under favourable conditions of suitable temperature (22 — 25°C), sufficient oxygen, and pH 6.5. After 2 — 5 weeks the eggs hatch and small ciliated larvae, the miracidia, force their way through the operculum. This process is facilitated by proteolytic enzymes which erode the lower surface of the operculum. The conical-shaped miracidium is a free living stage covered by cilia, with an anterior protrusible apical papilla on which opens the apical gland. On the sides of the apical gland there are small penetration

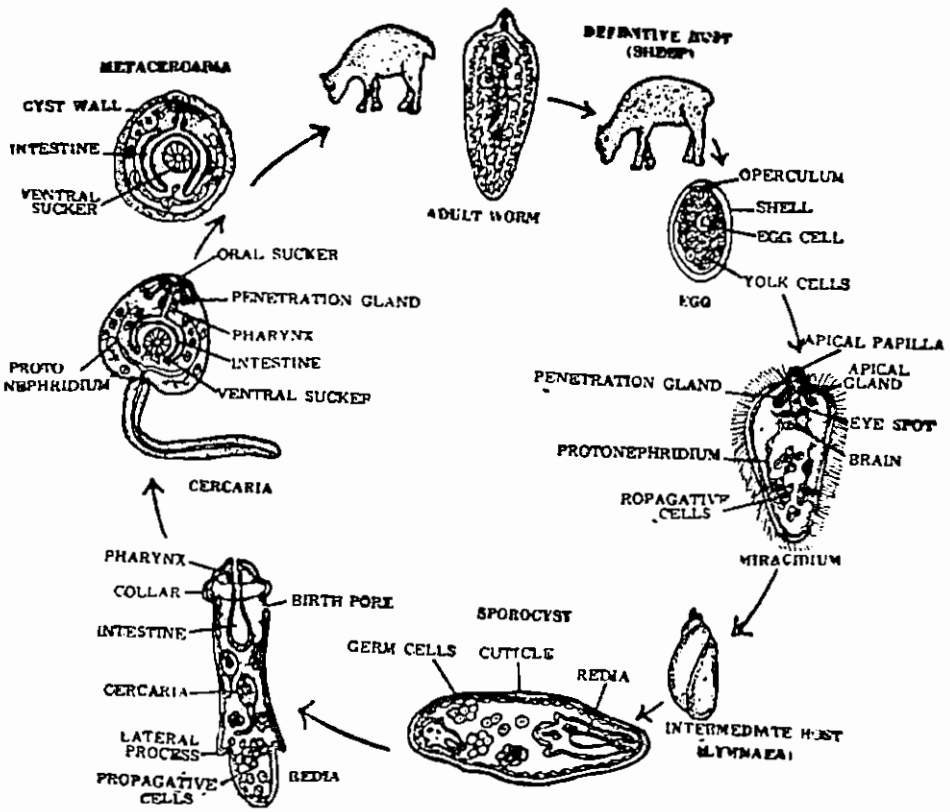


Fig. 162 — Life cycle of Fasciola hepatica

glands. At the anterior end there is the larval brain and a pair of pigmented eye-spots. On either side of the body there is a protonephridium with two flame cells. Near the posterior end there are germ cells. (germ balls, Fig. 162).

The miracidium, which is not a feeding stage, swims in the water or the surface film, but dies after 8 — 24 hours if it fails to find its intermediate host. The intermediate host is the snail *Lymnaea truncatula* (*L. caillaudi* in *F. gigantica*,) which is common in freshwater and pastures.

Larva in snail

When the miracidium reaches its intermediate host it penetrates its tissues by the aid of secretions of the penetration glands. In the large blood spaces at the roof of the pulmonary cavity of the snail, the miracidium sheds its ciliated epidermis, and passes to where it is transformed into an elongated sac covered with a thin cuticle and containing mesenchyma and

propagative cells. This stage is called sporocyst where the propagative cells develop into other larvae called rediae (Fig. 162). The rediae pass out of the sporocyst and develop in the digestive gland of the snail. A redia is an elongated larva with an anterior mouth, a muscular pharynx and a simple intestine. It is provided with an anterior muscular collar, a birth pore and a pair of posterior muscular processes.

Each redia contains propagative cells (germ balls) which in summer give a second generation of rediae, and in winter produces cercariae. The cercariae formed in the first or second generation of rediae escape from the birth pore.

The cercaria (Fig. 162).

The cercaria has an oval body and a long unforked tail. It contains the rudiment of most adult organs. It has a small anterior sucker surrounding the mouth, a large ventral sucker, a sucking pharynx leading to a short oesophagus and intestine with two branches. In addition there is a pair of excretory tubules with a number of flame cells. Rudimentary reproductive organs are also found. The epidermis is shed and is replaced by the tegument. Underneath the tegument there are muscles and epidermal cystogenous glands.

After the exit of the cercaria from the birth pore of the redia it migrates through the tissues of the snail into the pulmonary chamber then to the exterior. The time taken from the enterance of the miracidium till the cercariae are set free is about 5 to 6 weeks depending on the temperature.

The cercariae swim in water for few days by the aid of their tails. After which they become encysted by losing their tails and the secretion of chitinous shells by the cystogenous glands. Encystment takes place mainly in water or on vegetation on which the primary host feeds. The encysted cercariae are called **metacercariae.** These can live for a year provided that they are not exposed to direct sunlight or complete dryness. On vegetation the metacercariae live for a few weeks.

If the metacercariae, which are the infective stages, are swallowed by the primary host either while drinking or feeding, the cyst walls are digested in the intestine. The young flukes bore their way through the wall of the intestine and migrate into the body cavity. After wandering in the body cavity for 3 — 5 days they enter the liver by boring through its capsule causing serious damage to the liver and bleeding in the body cavity. The young flukes may enter the bile ducts from the intestine. After

feeding on the blood and tissues of the liver, the flukes enter into the bile ducts and bile passages where they become fixed by their suckers. They become sexually mature (adults) within 3 to 4 months.

Man may get infected if he swallows the metacercaria but this occurs rarely. If the adult flukes are eaten by man — and this occurs when eating raw liver; a habit in Sudan, Lebanon and other countries — the flukes stick to the mucous membrane lining the pharynx, larynx, glottis or even nasal cavities where they cause serious inflamations and difficulty in respiration or swallowing. If the flukes are passed into the intestine they are digested.

Control and Pathology of Liver Rot

The liver fluke causes a disease called "Liver rot" in sheep, goats, cattle and numerous other vegetarian animals. This disease is caused by the irritation of the tegumentary spinules of the flukes. The animals become weak, lose weight, functions of the liver are upset, decrease in the amount of milk and reproductive capacity. This is due to the toxins secreted by the flukes. When there is a large number of flukes in the liver, the host dies.

The disease can be controlled by the following measures :

1. Infected animals must be treated by the use of suitable drugs as hexachlorothane which kills most of the flukes.

2. Killing the secondary host, *Lymnaea* by draining pastures where the snails live, or by introducing ducks which feed on the snails.

2 — Blood Flukes

SCHISTOSOMA (*BILHARZIA*)

The adult worms (*S. mansoni*) live chiefly in the mesenteric blood vessels of the intesine and in the veins of the liver, or in the blood vessels of the bladder (*S. haematobium*). The two species are parasitic on human being, some other species are parasitic on birds and mammals. Infection by these flukes is known as schistosomiasis or bilharziasis which is common in many countries : Morocco, Algeria, Tunis, Egypt, the Nile Valley, South Africa, Uganda, Congo, Arabia, Palestine, Persia, Iraq, Cyprus, China, South and Central America and Southern Europe.

Bilharziasis of human being is caused mainly by three-different species :

1. *Schistosoma haematobium* (BILHARZ 1852) causing vesical bilharziasis.
2. *S. mansoni* (SAMBON, 1907) causing intestinal bilharziasis.
3. *S. japonicum* (KATSURADA, 1904) causing asciatic bilharziasis.

SCHISTOSOMA HAEMATOBIUM

General morphology

The blood flukes are dioecious, but usually males and females are found together in pairs during most of their sexual life. The worm can live in human being for 26 or even 40 years (Fig. 163).

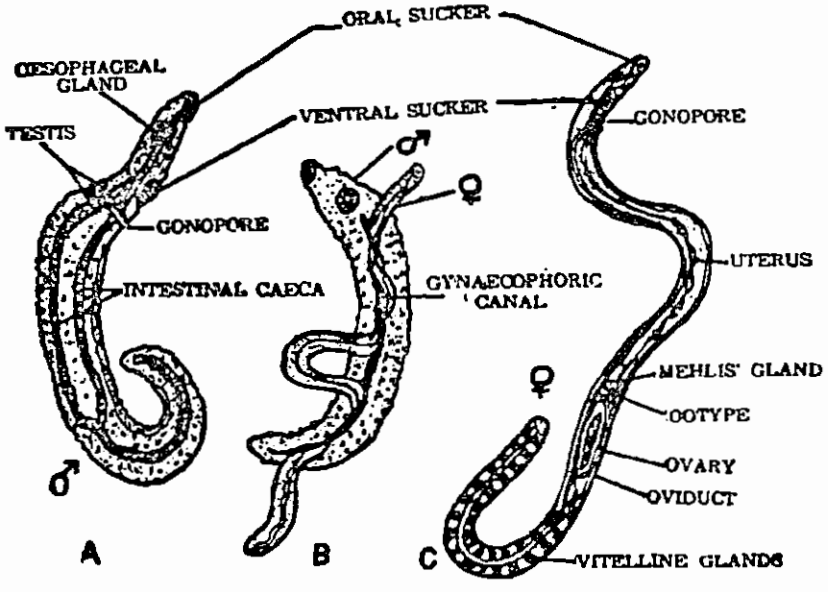


Fig. 163 — Schistosoma mansoni : A) adult male; B) adult male carrying female, and C) adult female

The males are elongated leaf-like and broad (about 10 — 15 mm. long) usually enclosing the female in a ventral tube-like groove extending from the ventral sucker till the posterior end (Fig. 163). This groove is the **gynaecophoric groove** which is formed by the folding of the ventral margins of the body. The body of the male is covered with a thin tuberculated tegument provided by fine papillae which aid the male in fixing to the wall of the small veins when passing against the blood stream. The

small anterior sucker lies somewhat ventral. The ventral sucker is larger and stronger in the male. The body of the female is smooth with papillae at the posterior end and on the suckers. The association of males and females is an adaptation to ensure successful fertlization in such unisexual parasitic worms. After fertilization the female leaves the male to lay eggs.

Internal anatomy

In general the internal anatomy of blood flukes is built on the same plan as that of liver flukes.

Digestive system

It is similar in both sexes being formed of a mouth leading into a short oesophagus surrounded by a digestive oesophageal gland and provided by two dilatations. The sucking pharynx found in liver flukes is absent on account of the abundant easily digested blood used as food for the fluke. The oesophagus leads into a biforked intestine which reunites at the beginning of the posterior third of the body to form a median blind caecum ending near the posterior end.

The intestinal wall is composed of simple columnar epithelium surrounded by a delicate layer of circular and longitudinal muscles.

Reproductive system

Unlike that of liver flukes, the testes and ovaries are not branched. The male has four or five testes found at the anterior end just posterior to the ventral sucker (Fig. 163 A). The short vas deferens formed by the union of tubules arising from each testis, leads to a seminal vesicle. This opens on the ventral surface by the male genital opening which lies behind the ventral sucker. There is no penis.

The elongate ovary is found above the point where the two intestinal branches reunite. The short oviduct arises posteriorly and bends forward to open into the ootype (Fig. 163 C). The vitelline duct is formed by the union of two lateral vitelline ducts which arise from the vitalline glands at the posterior end. This duct opens into the oviduct which joins an ootype which is surrounded by Mehlis' gland. The straight uterus arises from the ootype to open by the female genital opening found on the ventral surface posterior to the ventral sucker. The anterior portion of the uterus contains 20 — 30 eggs.

Life cycle (Fig. 164).

During copulation the ventral surfaces of the male and female are opposed against each other. The female genital opening enlarges to ensure the transfer of the sperms into its genital tract. Fertilization takes place into the oviduct and completion of the egg occurs in the ootype. After fertilization the female leaves the male to lay eggs one at a time in the smaller blood vessels. The female moves against the blood stream aided by its slender smooth body, a morphological adaptation to ensure deposition of eggs near the urinary bladder which carries them to the outside to continue their development. When a venule is full with eggs the worm migrates to another one.

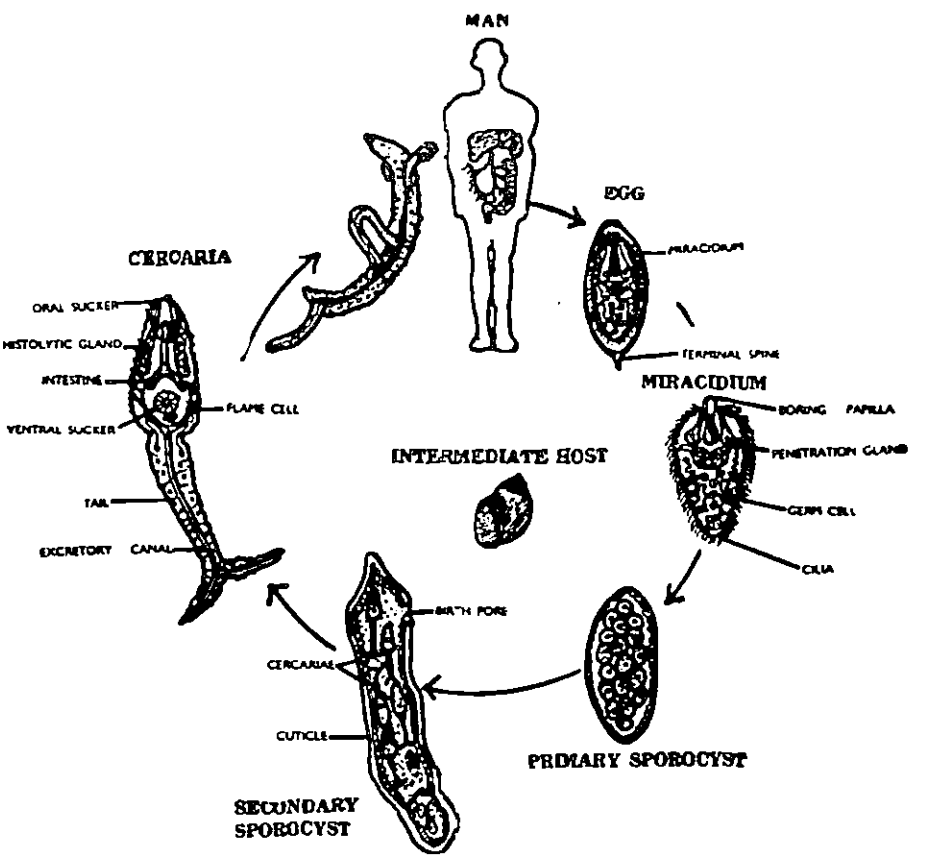


Fig. 164 — Life cycle of Schistosoma haeobium

The egg is oval, large (135μ) provided with a terminal spine (a lateral spine in *S. mansoni*; 150 μ). The miracidium develops inside the egg while

it is still in the host. In order to pass out of the body the eggs have to bore the tissues of the urinary bladder. This is aided by

(*a*) The terminal spine causes irritation of the tissues which leads to muscular contraction. This helps in the slow expelling of the egg through the wall of the urinary bladder.

(*b*) The glands of the **miracidium** secrete proteolytic enzymes which dissolve the tissues of the host, thus facilitating its penetration through these tissues.

The spine is not directly responsible for boring through the tissues.

During the passage of the eggs through the wall of the urinary bladder, some bleeding and pain occurs due to the lacerations of its wall. Thus the urine becomes mixed with blood a phenomenon called **haematuria.** The passage of eggs through the tissues may cause inflammation which may lead to malignant tumours, cancer of the urinary bladder. Ova may act as nuclei for kidney stones. In additions eggs may be passed to the liver where they cause serious damage.

The eggs of *S. haematobium* are usually found in the urine of persons and occasionally in the faeces. When laid, the eggs contain fully formed miracidia. The eggs hatch a short time (36 hours) after reaching freshwater (0.04% total solids) by absorbing water due to osmosis which will cause their rupture and the release of the miracidia. The eggs do not hatch in undiluted urine or salt water. Temperature is important for hatching. The eggs can remain alive in sterile urine or faeces for 2 weeks.

The ciliated **miracidium** is more or less similar to that of *Fasciola*, but it does not possess eye spots. It has a rudimentary alimentary canal and two pairs of flame cells (Fig. 164). The miracidium lives for a short time (24 — 48 hours) afterwhich it dies unless it finds the suitable intermediate host which is the snail *Bulinus truncatus* common in freshwater. When coming in contact with the snail the miracidium bores through the soft tissues helped by secretions from its cephalic (salivary) glands. In the tissues of the snail the cilia are shed within 1 — 2 days, and the miracidium develops into the **mother sporocyst.** The latter makes its way to the digestive gland of the snail. Inside the tube-shaped sporocyst there are masses of propagative (germ) cells which develop into a large number of **daughter sporocysts.** These daughter sprocysts grow in size and the propagative cells inside them give rise to a large number of cercariae (no redia stage). The **cercaria** which is the infective stage leaves the sporocyst through a certain pore, then penetrates the tissues of the snail and passes out through

its respiratory apreture and thus reach the water. The discharge of the cercariae occurs during day. In the water the cercariae swim searching for a human being otherwise they die after few hours. The time taken for the formation of carcariae since the miracidium enters the snails is about 4 — 8 weeks. About 250,000 cercariae are produced by one miracidium.

The cercaria (Fig. 164) has an elongated oval body with an oral sucker (which develops later into anterior sucker), a posterior sucker, a mouth leading to a pharynx, oesophagus and a short biforked intesine. It contains four pairs of flame cells, three excretory pores and 4 — 5 cephalic glands. It is covered by posteriorly directed spines and has a long forked tail (furocercous tail). The nervous and excretory systems and propagative cells are present.

In order to develop, the cercaria must penetrate through the skin of the final host (man) either when drinking, washing, walking or bathing in water containing the infective stage. The cercariae are attracted to the human being by the radiant heat as they are positively thermotactic. They actively penetrate the skin or mucous membrane of the mouth or throat by the aid of the proteolytic enzymes secreted by special penetration glands. The tails are shed and the cercariae are carried passively by the veins to reach the right ventricle of the heart. Clothes do not prevent penetration of the skin by the cercariae. This is associated with severe irritation and subcutaneous bleeding.

The cercariae pass from the right ventricle of the heart to the alveolei of the lungs from which they are carried to the left ventricle by the pulmonary veins. Then they are carried from the heart by the arteries to the body then they reach the hepatic portal vessels via the lungs; worms carried to other blood vessels die. In the hepatic portal vessels the worms grow up and the females do not become sexually mature until after pairing. Then they migrate out of the hepatic portal system to the mesenteric vessels especially those attached to the urinary bladder where they lay their eggs. The worms become sexually mature after about forty days from their entrance into the body of the human being The worms may mature in the liver and produce the terminal-spined eggs.

SCHISTOSOMA MANSONI

This species is similar to *S. haematobium* in most of its characters and internal organisation and life cycle. It differs in the following :

1. Adult worms being smaller.

2. The tegumentary papillae of the male are coarser.
3. The branches of the intestine reunite at the end of the anterior third of the body.
4. The male possesses 8 — 9 testes.
5. The ovary lies in the anterior half of the body.
6. The uterus is short and contains few eggs (may be one). In *S. haematobium* 20 — 30 eggs may be found in the uterus.
7. The eggs are larger, being 150 μ.
8. The female prefers the venules of the rectum to lay its eggs.
9. The egg is provided with a lateral spine and it is passed with the faeces, very rarely with the urine.
10. The secondary host is the snail *Biomphalaria* (*Planorbis alexandrina*) (Fig. 165).

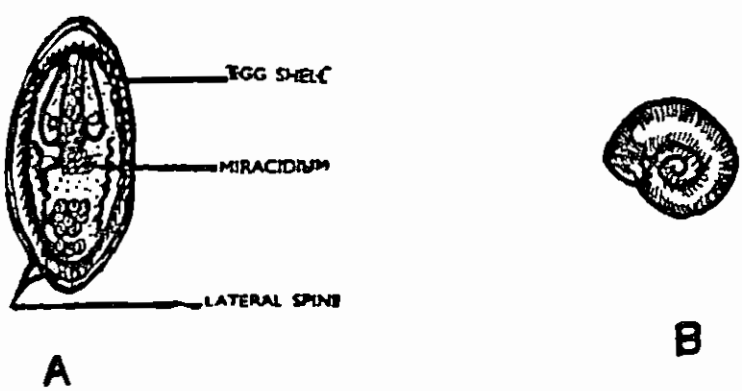


Fig. 165 — Schistosoma mansoni : A) Egg; B) Intermediate host, shell of Biomphalaria alexandrina

11. The symptoms may be diarrhoeal stools containing blood and mucus. In severe infections enlargement of the spleen and liver cirrhosis may develop.

CONTROL OF BILHARZIA

1. Factors associated with human beings.

(*a*) Extensive treatment of infected persons.

(*b*) Education of native population who must know the life cycle and epidemological relationships.

(*c*) Protection against infection by :

1. Avoidance of infected water. or the use of suitable protective clothing during contact with such water.

2. Water taken from ponds or streams should be either heated to 50°C or left for 48 hours before drinking or even adding fresh lemon juice which was found to kill the cercariae within an hour.

3. In villages sanitary measures must be taken not to use natural water and people should be encouraged to use latrines in order to prevent the contamination of water with urine or faeces of infected people or animals.

2. Factors associated with the intermediate host

(*a*) Periodical dryness of streams in order to kill the snails.

(*b*) Destruction of snail by the use of molluscides such as copper sulphate, pentachlorophenol. etc.

(*c*) Periodical removal of aquatic vegetation to eradicate the snails which are attached to them.

(*d*) Deepening of streams in order to increase their current velocity.

(*e*) Introduction of natural enemies that feed on snails such as ducks, certain fishes like *Gambosia* or even certain snails as *Marisa cornuarietis*.

(*f*) Growing aquatic plants that secrete metabolitis that kill the snail.

3 — Intestinal Flukes

HETEROPHYES HETEROPHYES

This is the smallest trematode infecting man, being about 3 mm. long (Fig. 166). It lives in the intestine and is very common in Northern Egypt, Palastine, Japan etc. In Egypt the infection in the areas of Lake Manzaleh and Port Said may reach about 88% among the children. It also infects domestic animals such as dogs and cats which may be a source of infection to man. It was first discovered by BILHARZ (1851) but the life cycle was revealed by KHALIL ABDEL KHALIK in 1933. Severe infections cause diarrhea accompanied by mucus and blood, general weakness and loss of weight. Some eggs may pass through the lymphatic circulation to the heart where it leads to heart failure, or to the brain causing cerebral haemorrhage.

General morphology and internal organisation

The body is pear-shaped with three suckers, an oral, a large ventral sucker and a genital sucker lying behind and lateral to the ventral sucker (Fig. 166). The genital sucker surrounds the genital pore. There is a pair of testes at the posterior end. A single median ovary leads to a short convoluted uterus. The vitelline glands are found on the latero-posterior sides.

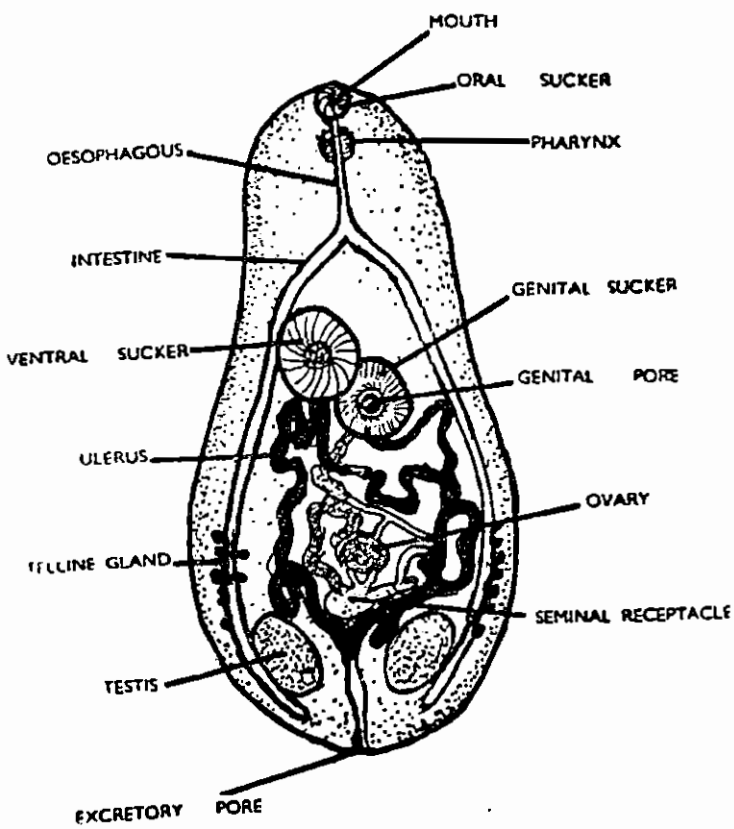


Fig. 166 Adult Heterophyes heterophyes

Life cycle

The eggs are small, yellowish brown in colour, flask-shaped operculated with a double layered shell provided with a knob. The egg which contains a completely formed miracidium is eliminated with the faeces of the host. The asymmetrical **miracidium** does not hatch from the egg as in other

flukes but remains inside the egg until swallowed by the first secondary host the snail *Pirenella conica* which is very common in the Delta lakes of Egypt (Fig. 167). This snail is elongated with a dextral opening. In the body of the snail, the miracidium is liberated and develops into a **sporocyst,** rediae and cercariae. The cercaria is characterised by the presence of a single sucker (oral sucker), two eye-spots and a membraneous (lophocercous) tail. The cercaria is not infective to man. It swims in water searching for the second intermediate host which is a fish. It lives in water for 60 hours and dies if it does not find the suitable host. When coming in contact with the fish which is usually *Mugil cephalus* (Bouri) or occasionally *Tilapia* (Bolti), the cercaria penetrates the skin of the fish where it is encysted for 20 days, in the tissues especially the muscles. The encysted cercaria is the infective stage. If a human being eats infected fish either raw or poorly cooked as when preparing salted fish, the cysts dissolve in the intestine and the young flukes are released where they grow to the adult stage.

Fig. 167 — Shell of Pirenella conica

Control

1 Fish should be completely cooked.

2. Salted fish should not be eaten unless ten days have passed from their preparation.

3. Avoiding eating raw or poorly cooked fish.

CLASS CESTODA

This class includes the tapeworms which are long ribbon-like flat worms whose body is made up of a large number of segments (proglottids). Very few members are unsegmented, leaf-like resembling flukes. All cestodes are parasites of the alimentary canal of vertebrates including man. Cestodes have many characters which differ from other Platyhelminthes and in which adaptation to parasitic life is advanced. These characters are :

1. Absence of cilia in the adult stage and the thick tegument is provided with microvilli (Fig. 152 B). The tegument is followed by the basement membrane and muscular layers. The latter which consist of unstriated muscles are composed of an outer circular and inner longitudinal layers (Fig. 152 B). The parenchyma (mesenchyma) cells fill the spaces between the various organs. In addition to their skeletal function, the parenchyma cells act as important transport medium since flatworms lack a blood vascular system. The tegument, which is secreted by the tegument-secreting cells, contains pore canals. It is believed that the intracellular secretions act as anti-enzymes which neutralize the effect of the digestive enzymes found in the intestine of the host.

In the mesenchyma there is an inner mesenchymal (meaullary) muscle layer composed of outer longitudinal, inner circular layers and transverse fibres. This layer may be weakly developed or completely absent from the lateral sides. Dorsoventral muscles connect the dorsal and ventral body walls.

2. Complete absence of the digestive system. Digested food materials pass through the tegument by an active process of pinocytosis. The flattening of the body accompanied by its great length is an adaptation for this process. Such characters necessitate the life of the adult inside the intestine of the host. It does not only depend on the host for food but also for the digestion of this food.

3. The excretory and nervous systems are poorly developed and are similar to those of trematodes. The adult worm lives in a constant environment protected by the host. They have no special sense organs but have free sensory nerve endings.

4. The body is usually formed of a small anterior scolex provided by suckers or suckers and hooks used to fix it to the mucous membrane of the intestine of its host. In some species the scolex is provided by shallow bothria. The scolex is followed by a narrow neck, a region of proliferation which continually grows to give new segments to the body. The body is made up of a large number of segments or proglottids. Each proglottis is comparable to a complete flatworm as it is a sexually complete unit being hermaphrodite and contains parts of the nervous and excretory systems. The number of proglottids varies from 3 or 4 to 3,000. The worm may reach 30 meters in length.

The adult worm may be considered as :

1. a series of separate individuals held together and forming a colony, or :

2. a single animal with many segments.

The latter view is more acceptable and the animal is considered a segmented worm, but the segments are not comparable to the segments of true segmented animals like the annelids.

More than a thousand species of tapeworms are known which infect almost all vertebrates. Usually the primary host feeds upon the intermediate host.

1 — *TAENIA SAGINATA*

(Beef tape-worm)

This is a common intestinal parasite in Egypt. The adult worm reaches about 4 — 10 meters long. It lives in the small intestine of human being causing injury to the mucous membane, it may also block the intestine. The adult worm may live inside the intestine for many years up to 20 years. Its presence leads to abdominal pains, weakness, loss of weight and appetite although hunger, digestive disorders, nervous complaints and pruritus ani are often observed. It also causes vitamin deficiency.

Morphology

The worm adheres to the wall of the intestine by a muscular cubical scolex (about 2 mm. in diameter) provided by four hollow suckers, but no hooks (Fig. 168). The scolex is not considered a head as it is not specialized for handling food. It is connected to the body by a narrow neck which grows continuously and proliferates proglottids by transverse fission or asexual budding. The body is made up of a large number of proglottids which may reach 2,000, the youngest is next to the neck, the oldest being at the posterior end. The proglottids are not considered metameres corresponding to those of annelids as each proglottis is a complete individual which is budded off from the anterior neck. In annelids and chordates the oldest segment (metamere) is found at the anterior end.

The young proglottis is broader than long and contains rudiments of sex organs. As the proglottis grows it increases in size, becomes square-like in the middle of the worm, and towards the end they are longer than broader (Fig. 168). The reproductive organs develop gradually, the male organs appear first followed by the female organs. The most posterior segments are gravid containing mainly the uterus full with eggs.

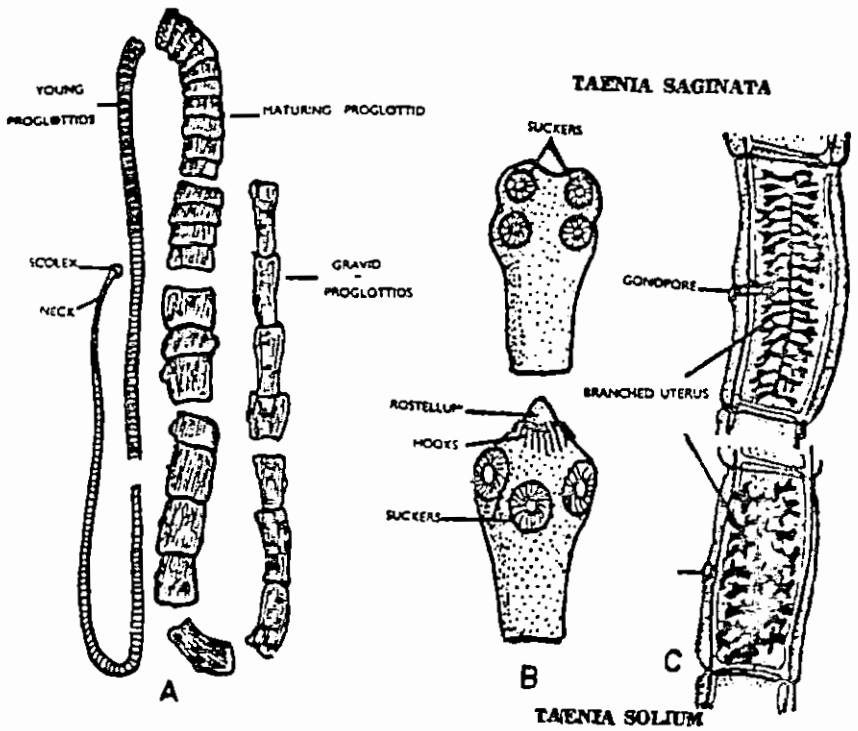


Fig. 168 — Tape-worm : A) adult Taenia saginata; B) scolices of T. saginata and T. solium; C) gravid proglottids

There is neither a mouth nor an alimentary canal. Food passes through the thick tegument. Nitrogenous nutrients are absorbed during contact of the worm with the mucous membrane of the intestine. Carbohydrates, vitamins and liquids are absorbed from the lumen of the intestine. The worms even depends on the sex hormones of its host. Reserve food material is stored in the form of glycogen and lipids.

Excretory system

It is similar to that of other flat-worms being formed of flame cells and excretory tubules. There are two main lateral excretory canals, each extends throughout the whole (proglottids) length of the worm inner to the lateral nerve cord. They open to the exterior by a single median excretory pore at the posterior end of the worm. When the last proglottis becomes gravid and is detached, each excretory canal opens by a separate excretory pore. The two excretory canals are connected at the scolex by a ring vessel and are joined by a transverse excretory canal found at the posterior margin of each proglottis (Fig. 169). The canals are not ciliated and are lined by

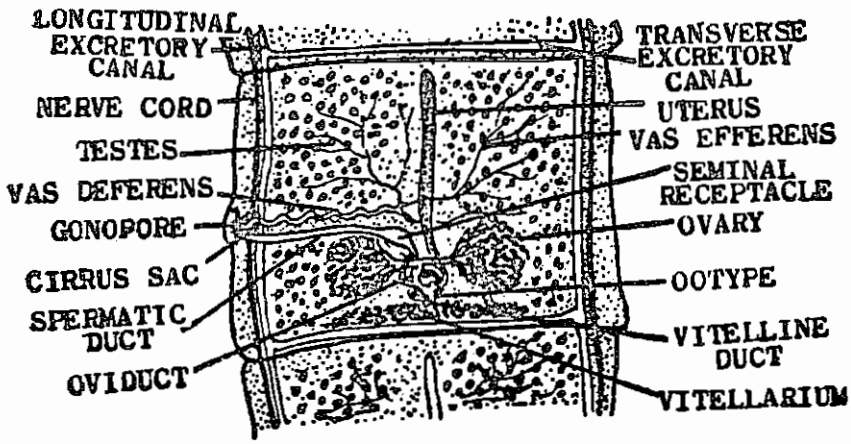


Fig. 169 — Mature proglottis of Taenia

cuticle. By the action of the cilia of flame cells waste products and excess fluids are driven along the excretory tubes. It is believed that the excretory system regulates the osmotic pressure of fluids inside the body i.e. acting as osmoregulators.

Reproductive System

A mature proglottis is hermaphrodite :

The **male reproductive organs** (Fig. 169) consist of :

(*a*) Numerous spherical testes (300 — 400) which are scattered throughout the proglottis inside the parenchyma.

(*b*) Fine vasa efferentia which collect the sperms from the testes and unite to form a coiled vas deferens.

(*c*) The vas deferens terminates into a muscular protrusible cirrus (penis) surrounded by a cirrus sac. The cirrus is used for the transfer of sperms.

(*d*) The cirrus opens by the male genital opening into a cup-shaped genital atrium at the edge of each proglottis on a swollen genital papilla. The genital atrium opens to the exterior by the genital pore.

The **female reproductive organs** (Figs. 169 and 170) are composed of :

1. A bilobed ovary with two lobes joined by a bridge. The ovary is formed of branching tubules and lies at the posterior border of the proglottis.

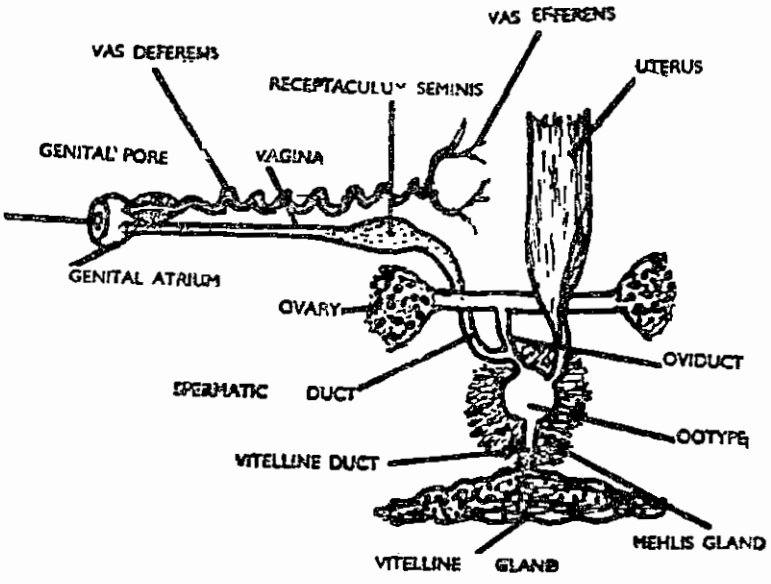


Fig. 170 — Diagram showing the reproductive ducts of Taenia

2. From the bridge of the ovary a short median oviduct joins the vitelline (yolk) duct at the ootype which is surrounded by Mehlis' gland (Fig. 170). The vitelline gland lies at the posterior region of the proglottis.

3. The ootype leads to a cylindrical blind uterus which extends in the middle of the proglottis.

4. From the oviduct a narrow spermatic duct arises which runs outwards and dilates to form a seminal receptacle which leads to a narrow tubular vagina. The latter opens into the genital atrium by the female genital pore.

Life cycle

Self-fertilization occurs in the same proglottis or usually between different proglottides of the same worm or cross fertilization between two different worms present in the same host. In any case the cirrus is inserted into the vagina and the sperms are transferred into the seminal receptacle. Fertilization takes place in the oviduct. The fertilized egg becomes surrounded by yolk cells from the vitelline gland. Then it is surrounded in the ootype by an inner thin shell formed by the yolk cells. The eggs pass into the uterus. During its development the embryo secretes a hard chitinous shell, the embryophore which is made up of chitin and has a striated appearance. The embryophore becomes surrounded by a thin capsule

shell. Then the embryo develops six chitinous hooks at its posterior region. This embryo is called hexacanth embryo. The embryo with its capsule, embryophore and membranes is called onchosphere (Fig. 171).

The last proglottis or proglottides become gravid, the uterus enlarges and later develops numerous branches to fill most of the proglottis and becomes full of onchospheres. The rest of the reproductive organs of such proglottides degenerate gradually. These gravid proglottides break off singly and pass out of the anus of the host either with or without the faeces. They are active and can force their way out of the anus. They can crawl on the skin discharging a milky fluid containing fertilized ova. Outside the host the proglottides disintegrate and the spherical onchospheres are liberated. These can remain alive for sometime as long as they are in moist places. Each gravid proglottis may contain about 79,000 eggs.

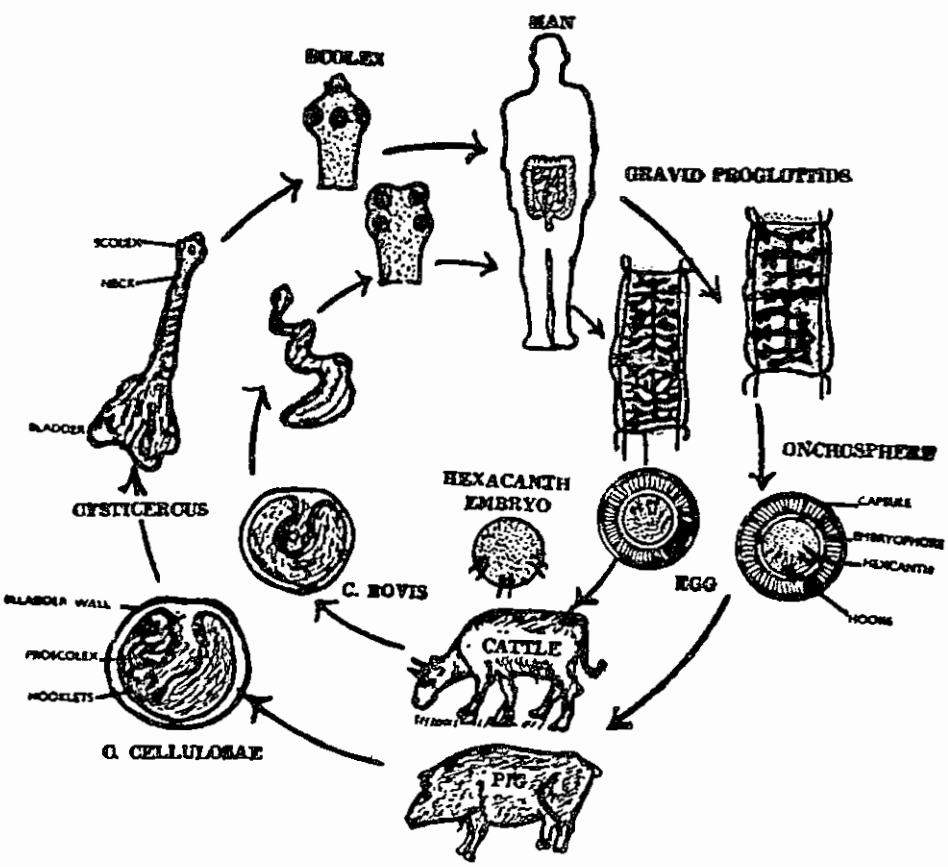


Fig. 171 — Life cycles of Taenia saginata (inner cycle), and Taenia solium (outer cycle)

The onchosphere may be taken by a cow or a camel with its food (vegetation on which human faeces are deposited), the embryophore is digested in the stomach and the hexacanth embryo is relased. Usually the outer egg shell is generally lost and the embryophore may be mistaken for the egg shell. By means of special penetration glands the hexacanth embryo bores its way through the wall of the gut. The hooks are used for anchoring the embryo. Then, it passes into the lymph and blood stream and finally comes to lie in the voluntary muscles where it becomes encysted in the connective tissue between the muscle bundles. The parasite loses its hooks, increases in size and forms a bladder full with fluid and is called bladder worm (Fig. 171) or cysticercus (3-10 mm. in diameter). The wall of the cysticercus becomes tucked at one spot forming a pouch, on the inner wall of which develops the suckers of the future scolex. This is called the proscolex. The cysticerci (7.5 — 9 mm. long) are usually found in the tongue, larynx, diaphragm, muscles of the back, jaw, and legs and also in the heart, peritoneum, liver, lungs and even brain. The bladder worm is called **cysticercus bovis** as it is found in cattle. It can live in the muscles of an ox for eight months.

When meat containing the cysticerci is eaten raw or insufficiently cooked, the gastric juice dissolves the outer wall of the bladder worm. In the small intestine the scolex evaginates and attaches itself to the mucous membrane by its four suckers. The bladder is thrown off and digested. The proglottids begin to be formed from the generative zone (neck) behind the scolex. It takes 2 — 3 weeks for a mature worm to develop.

2 — *TAENIA SOLIUM*

(Pork liver-fluke)

It is similar to *T. saginata* in many respects, but differs in the following :

1. The intermediate host is the pig where the bladder worm called *Cysticercus celleulosae* develops.

2. The scolex (Fig. 168) is provided with four suckers and an anterior cone-shaped rostellum provided with two rows of hooks, an inner ring of hooks which are larger than those of the outer ones.

3. It reaches about 2 — 4 meters long.

4. The number of proglottides ranges from 100 — 1,000.

5. The genital papillae alternate, more or less, regularly between the

right and left margins of the worm. In *T. saginata* the alternation of the genital papillae is irregular.

6. The uterus of the gravid proglottis possesses 8 — 12 lateral branches on each side, each branch has numerous ramifications. In *T. saginata* there are 20 — 30 lateral branches, but with less ramifications.

7. The gravid proglottides are separated in groups of 4 — 6. They are passed passiveley with the faeces. Thus they are unable of active movement.

8. Sometimes man becomes infected with the onchosphere either when taking it with the food, or when a broken up proglottis from the adult worm is carried back to the stomach by reverse peristalsis (self infection). The liberated hexacanth embryos may migrate to any organ such as the liver, muscles or even brain. The disorders caused by the cysticerci formed are called **cysticercosis** which may lead to epilepsy and even death.

Control of Taenia

1. Meat inspection in slaughter houses.
2. Latrines and manure pits should be removed from close the proximity of pastures.
3. Handling of meat should be carried out with care, especially pig meat where the cysticerci can stick to the hands and a risk of **cysticereosis.**
4. Avoiding eating raw or poorly cooked meat.
5. Preservation of meat by cooling or salting kills the bladder worms.

3 — *ECHINOCOCCUS GRANULOSUS*

(Dog-tapeworm)

The adult worm lives in the intestine of dogs, wolf, fox, monkey, kangeroo and other wild carnivorous mammals. The larvae live in more than forty species of animals including man, monkeys, sheep, cat and cattle. Man, thus serves as an intermediate host. It is found all over the world.

Morphology and life cycle

The adult is about 3 — 8 mm long and consists of a scolex, neck and four proglottids, the first is immature the second proglottis is mature,while

the third and fourth are gravid. The scolex bears four suckers and a rostellum with two circular rows of hooklets.

The eggs are discharged with the faeces. When the eggs are swallowed by the intermediate host, the hexacanth embryo is liberated inside the intestine. It bores its way through the intestinal wall and enters the portal vein where it is carried mainly to the liver or even to the various organs through the blood circulation. When the hexacanth embryo settles in an organ it forms a **hydatid cyst** which is in the form of a bladder whose inner side develops **brood capsules** with a large number of scolices (Fig. 172). When the hydatid cysts are ingested by the definitive host (dog) they grow inside the small intestine into the adult worms.

When man acts as an intermediate host by swallowing the eggs during contact with dogs or other infected animals, the hexacanth embryo is liberated inside the intestine. This embryo then bores the wall of the intestine

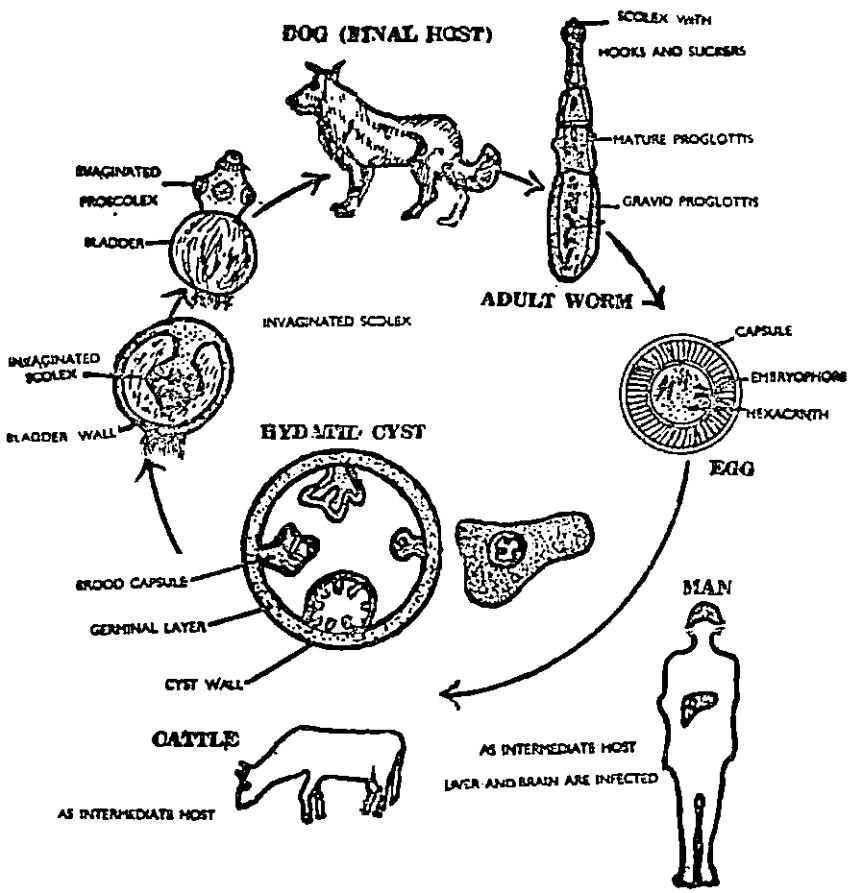


Fig. 172 — Life cycle of the dog tapeworm; Echinococcus granulosus

and passes to the various organs mainly liver, lungs or even the central nervous system. Inside these organs the hexacanth embryo is transformed into the hydatid cyst which may reach 5 — 8 cm. in diameter. The cyst grows slowly by the continuous formation of brood capsules each of which buds off many scolices nternally. The cyst is surrounted by an outer cuticular layer and an inner germinal layer and is filled with the hydatid fluid. The cyst becomes surrounded by a fibrous layer formed as a reaction of the host. The cyst causes pressure on the organs where it is present and the symptoms vary according to the place of the cyst.

PHYLUM ASCHELMINTHES

This phylum includes the largest number of pseudocoelomates. The large body cavity, which is filled with a fluid, is not coelomic as it is not lined by mesodermal cells. The mesoderm is either associated with the body wall or gut. The development of a body cavity is probably associated with the increase in animal size. As the volume of the body increases, a solid structure becomes less efficient physiologically. The presence of a body cavity gives more space for accomodation of coiled or looped internal organs, and the fluid in the cavity may aid in waste removal and in the circulation of food materials and oxygen.

This phylum has reached the organ-system level where there are complete systems. The digestive system is a complete tube provided with a mouth and anus. Thus the digestive products and waste food are not mixed. This will give a chance of rapidity of growth and size increase found in higher forms. The digestive tract is mainly endodermal, thus differs from that of higher forms which contain mesoderm as well. The tube within tube plan first appeared in this phylum. There is neither a circulatory nor a respiratory system but protonephridia are often found.

Most aschelminthes are small, even microscopic. Some parasitic members may reach a length of more than a meter. The body is often elongated round or cylindrical, although it is distinctly flattened in some members. There is no distinct head and the body is covered with a scleroprotein cuticle. The number of cells or nuclei forming the various organs is remarkabely constant. This number is characteristic of the species and differs from one species to another.

Aschelminthes are distributed in all kinds of habitats, fresh, marine water, terrestrial habitats and even in the most unexpected places as vinegar (vinegar eels) and petrol. A small amount of mud from the bottom of a pond may contain hundreds of these worms. Many species are parasitic

either in man, animals or plants. Thus, this phylum is of great medical and economic importance. The number of known aschelminthes to-day is only exceeded by Protozoa and Arthropoda.

The name **Aschelminthes** is derived from the Gr. askos = cavity; and helmins = worm. Member of this phylum has a body cavity known as pseudocoel. The nature, development and origin of the pseudocœl is known when studying the embryology of this phylum. During the formation of the gastrula, the archenteron appears, and the blastocoele (cavity of the blastula) does not disappear; but remains as an internal body cavity which surrounds the internal organs. Thus the pseudocoel originates from the blastocoel which arises between the ectoderm and endoderm.

Phylum Aschelminthes includes many classes among which are :

Class **I Rotifera** (Fig. 173) which includes minutes aquatic animals characterised by having anterior ciliary organ or corona which when beating gives the appearance of a rotating wheel and hence their name wheel animalcules. (L. rota = wheel; ferre = to bear).

Class **II Nematoda** (Gr. nema = thread; eidos = form). These are aquatic, terrestrial or parasitic worms, with cylindrical elongated unsegmented body covered with a thick cuticle. There are about 500,000 species.

Class **III Gastrotrichia** small aquatic animals, with cilia, cuticle covered with short curved dorsal spines, with a posterior forked end.

CLASS NEMATODA

It is the largest class of aschelminthes and contains most of the widespread and numerous of all multicellular animals. Free living nematodes are found in the sea, freshwater and in the soil. They occur from the polar region to the tropics in all types of environments, including deserts hot springs, high mountain elevation and great ocean depths. Most nematodes are free living, but there are many parasitic species. They infest plants, animals and man himself. About fifty species are parasitic on man of which are the hookworm (*Ancylostoma*); trichina (*Trichinella*), filaria (*Wuchereria*) and *Ascaris*.

All nematodes are remarkably similar having elongated cylindrical bodies pointed at both ends and covered with a thick cuticle without any cilia. Nematodes possess a longitudinal muscle layer, there is no circular

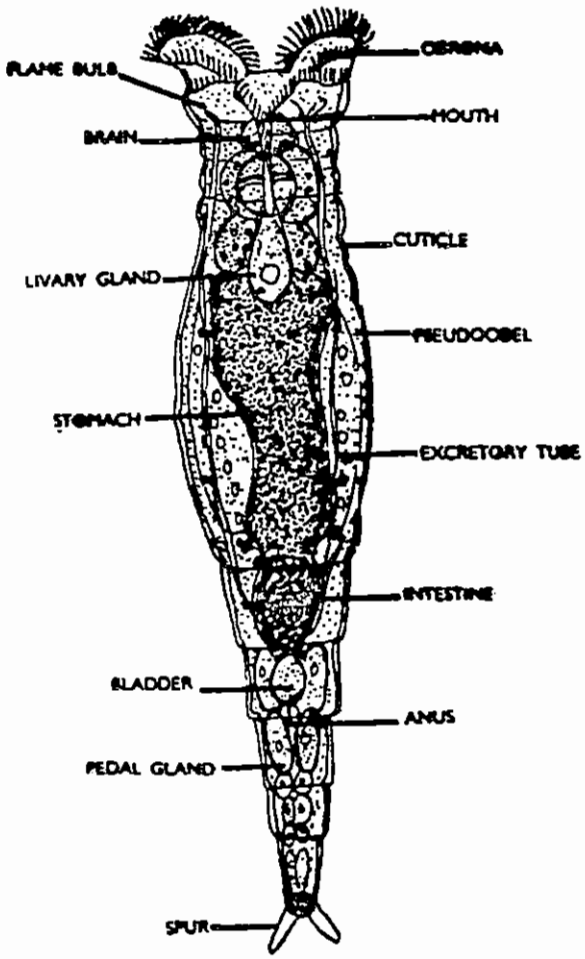


Fig. 173 — The common rotifer Philodina

muscle layer, hence they can only bend in a dorsoventral plane. The longitudinal muscles are antagonized by the force exerted upon the cuticle by the pressure of the body fluid.

GENERAL CHARACTERISTICS OF NEMATODES

1. Nematodes are tripoblastic animals, with round elongated bodies, hence their name, round worms.

2. The cuticle is flexilble but inelastic thus preventing the worm from changing length and thickness. It is composed of several layers having different chemical composition and different structural arrangement. It

is made up of protein and not chitin. The cuticle contains several layers of diagonally-crossed inextensible fibres.

3. The body is bilaterally symmetrical, but the mouth is surrounded with radially symmetrical sensory papillae and lips.

Body wall

It is covered with a thick complex cuticle which is resistant to digestive juices of the host. It is permeable to salts and water. The cuticle is secreted by an underlying **cellular** or **syncytial epidermis.**

The epidermis (hypodermis) expands in the pseudocoel to form four longitudinal lines; the middorsal, midventral and two mid-lateral lines. Underneath the epidermis there is a primitive muscle layer composed of longitudinal fibres arranged in four bands being separated by the four longitudinal lines. The muscle layer is composed of myoepithelial cells. Each cell is composed of an outer contractile portion made up of longitudinally striated spindle-shape muscular part and an inner greatly vacuolated non-contractile protoplasmic portion (Fig. 174). The latter which contains the nucleus and network of supporting fibrils, gives a process (muscle tail) which runs to the nerve trunk in either the dorsal or ventral longitudinal cords, a means by which each myoepithelial cell is innervated. Circular muscles are entirely absent from the body wall.

The pseudocoel

It is the perivisceral cavity between the outer muscle layer and the internal organs. It is filled with a clear protein-rich fluid and contains fibrous tissue and a limited number of fixed highly vacuolated cells called giant cells, the **pseudocoelomocytes.** The perivisceral body cavity, pseudocoel, is formed as a result of fusion of the vacuoles of these cells.

In parasitic nematodes there is a single pseudocoelomocyte which is highly branched and found dorsal to the pharynx. The pseudocoel is not lined by mesoderm. Its main function is to distribute digested food and collects waste products as there are no circulatory or respiratory systems. In addition the fluid inside the pseudocoel and cuticle forms a **hydrostatic skeleton.**

Nutrition

Many free living nematodes are carnivores feeding on other small animals. Other nematodes especially marine species feed on algae and diatoms. A large number of terrestrial species are parasitic on plants,

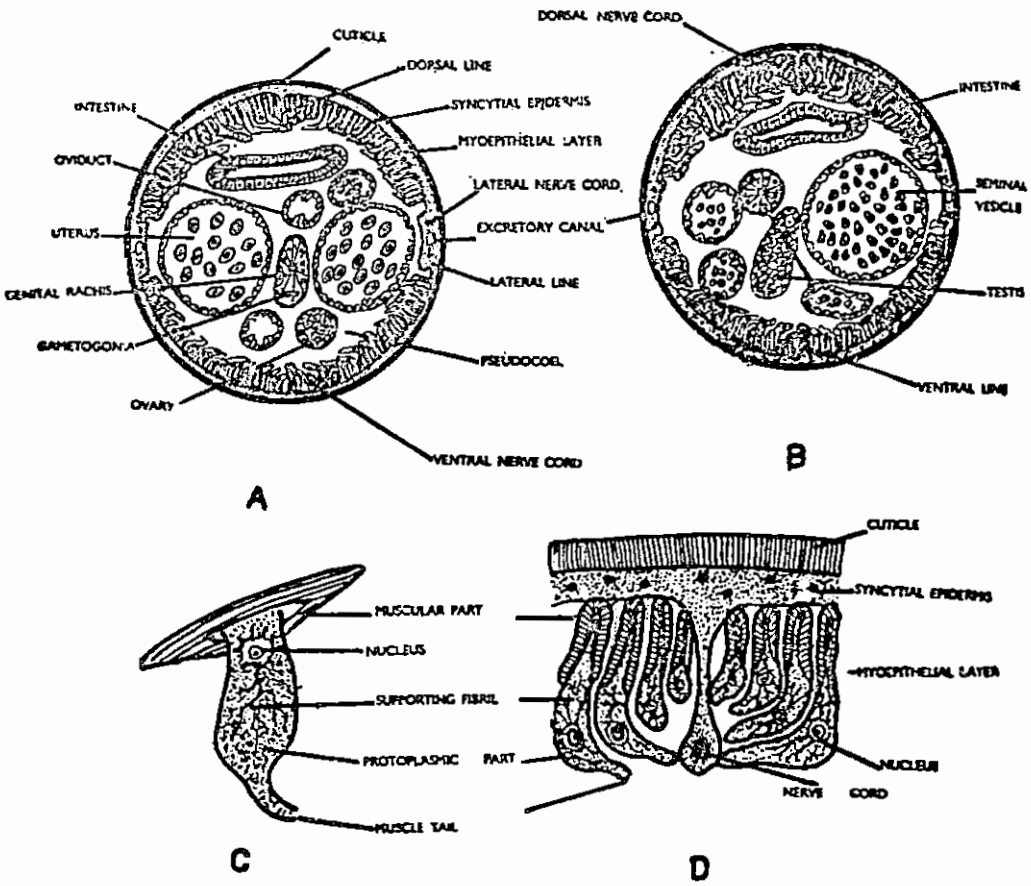


Fig. 174 — Ascaris : A) T.S. of female; B) T.S. of male; C) myoepithelial cell; D) part of the body wall.

they pierce the cells or plant roots and suck out their contents. Other nematodes live on dead organic matter.

Parasitic nematodes (as *Ascaris*) suck their food which is partly digested by means of a well developed muscular pharynx. In *Ascaris* the pharynx is provided with three large pharyngeal glands. Digestion is extracellular and the soluble food is digested through the intestinal wall then it is distributed to the various tissues by the pseudocoelic fluid.

Excretory system

In primitive marine nematodes (e.g. *Rhabditis*) the excretory system is composed of one or two renette glands, (Fig. 175 A) which are located ventrally in the pseudocoel near the junction of the pharynx and intestine.

Each gland has a duct which joins its partner to open by the excretory pore on the ventral midline.

In most nematodes the excretory system is tubular and H-shaped formed of two lateral longitudinal canals which extend inside the lateral longitudinal cords (Figs. 175 B and C). A transverse canal connects the two lateral canals and opens to the outside by a short common excretory canal which opens by the excretory pore. There are no flame cells, cilia or internal openings. In *Ascaris* (Fig. 175 C) the anterior limbs of the "H" are reduced and the transverse canal is branched in the form of a network from which arises the common excretory canal which opens by the excretory pore that lies ventral and posterior to the lips. The excretory canals are lined by a firm membrane covered by a cytoplasmic layer. The lumen of the excretory canal is considered as the intracellular cavity of a single giant cell whose nucleus is found in the transverse canal (Fig. 175 B).

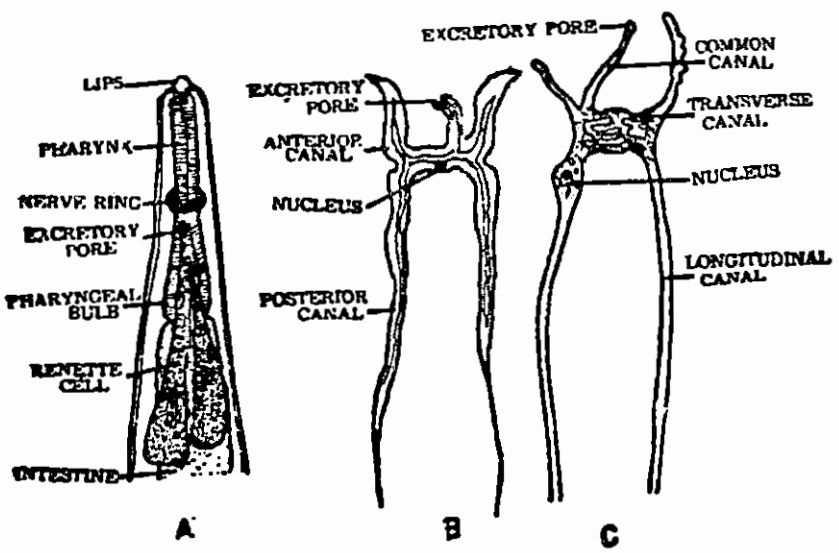


Fig. 175 — Excretory system in nematodes : A) in Rhabditis; B) H-type tubular system; C) in Ascaris

Nervous system (Fig. 176).

It is composed of a circumpharyngeal nerve ring (brain) with a lateral ganglion on either sides of the ring. From the brain extends six anterior papillary nerves each provided with a nerve ganglion, innervating the sensory organs in the anterior region (sensory papillae and amphids). From the nerve ring six longitudinal nerves extends posteriorly and run within the longitudinal lines. The largest is the ventral nerve cord which

originates as a double cord then fuses to a ganglionated chain which ends with the anal ganglion innervating the tail region. The dorsal nerve which is a non-ganglionated motor nerve has only a small dorsal ganglion near its origin. The dorsal and ventral nerves are connected by commissures which pass in the hypodermis.

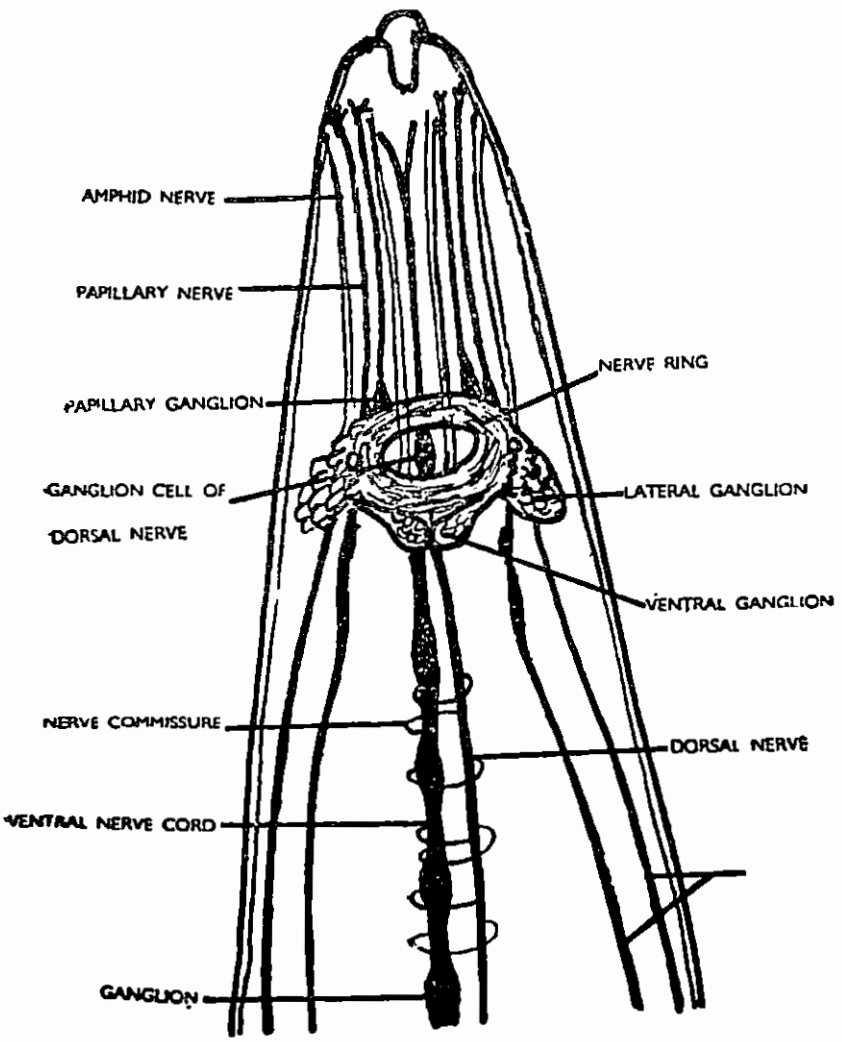


Fig. 176 — Nervous system in a nematode

A pair of lateral nerves arise from each of the lateral ganglia of the brain. These lateral nerves run on either side of the excretory canal. They are sensory and ganglionated. A visceral nervous system exists which is composed of pharyngeal and rectal divisions which innervate the phary-

ngeal and rectal regions. The number of nerve cells in the ganglia is small and remarkably constant.

Sense organs

In free living nematodes sensory organs are well developed. These include the papillae, bristles, amphids, phasmids and eyes. The papillae include the cervical papillae which are cuticular structures found in the cephalic region (Fig. 177 B). Each is flask-shaped and lies below the cuticle. The labial papillae are sensory and are found on the lips. The genital papillae which are tactile lie anterior and posterior the cloacal opening, of the male.

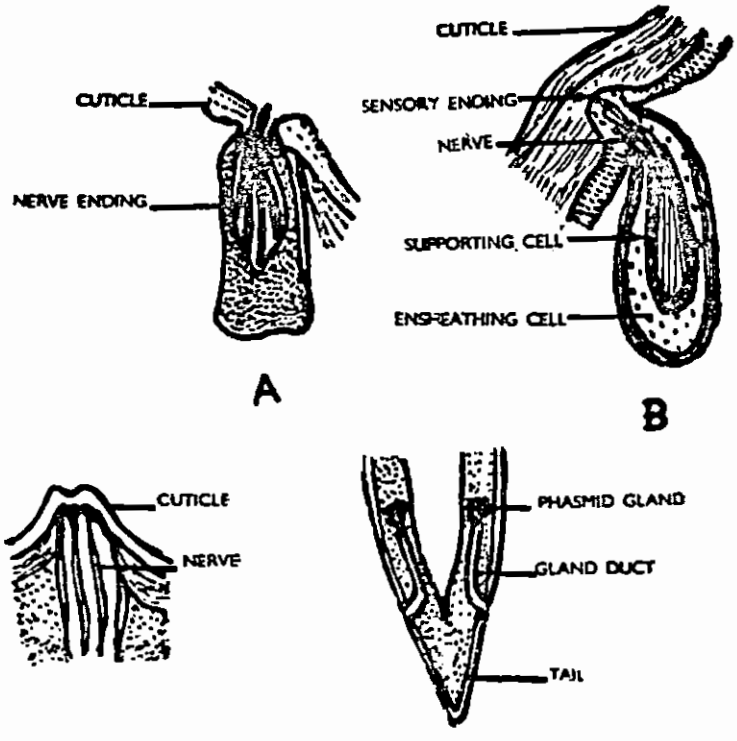


Fig. 177 — Sensory organs in nematodes : A) amphid; B) cervical papilla; C) anal papilla; D) phasmid

The **sensory bristles** are scattered over the surface of the body. The **amphids** (Fig. 177 A) are cuticular exacavations of small size and supplied by a nerve. A pair of amphids is found in the head region. These are believed to be olfactory chemoreceptors. They are well developed in marine nematodes and of small size in parasitic worms.

In the tail region there is a pair of unicellular glands known as **phasmids** (Fig. 177 D), which open separately by a short canal on either side of the tail. Phasmids are glandulosensory structures which are highly developed in parasitic nematodes.

Respiration

Respiratory and circulatory systems in nematodes are lacking. In free living nematodes respiration takes place by diffusion of respiratory gases through the cuticle. In parasitic nematodes as *Ascaris* anaerobic respiration takes place. The worm obtains its energy by the break down of glycogen into carbon dioxide and fatty acids which are formed instead of lactic acid which is harmful when accumulating in large quantties The waste products are excreted through the cuticle. *Ascaris* can use oxygen when available, for oxygen is not present in any appreciable quantities in the intestine of the host. However, the small amount of a peculiar haemoglobin (which has a high affinity to oxygen) in the body wall of the parasite (*Ascaris* or *Ancylostoma*) and in other parts of the body and in the pseudocoelic fluid can take oxygen even when present in a low tension. In certain species of *Ascaris* (*A. suis* in the pig) two kinds of haemoglobin were discovered, an outer in the body wall and an inner haemoglobin in the body fluids. The former retains oxygen 2500 times, and the inner 10000 times longer, than the pig's own haemoglobin. This arrangement is found to be the most efficient system as ideal oxygen carrier in a habitat with considerable oxygen deficiency. In addition *Ancylostoma* can obtain oxygen from the blood on which it feeds.

I. ASCARIS LUMBRICOIDES

It is a common endoparasite living in the small intestine of man, pig and other animals. It takes its nourishment from the chyme and not apparently from the host's tissue. The waste products of their anaerobic metabolism, mainly fatty acids, are considered partly responsible of the disease symptoms which include abdominal pains, vomiting, general restlessness and insomnia. The sensitivity to the excreta of the worms varies greatly from one person to another. When in large numbers *Ascaris* may migrate to the bile ducts, pancreatic duct, appendix, nasal sinuses and even up the oesophagus and out through the nose causing serious damage.

Ascaris is the largest intestinal roundworm parasitising man. Its body is stout and cylindrical with pointed ends, the anterior end being thinner than the posterior (Fig. 178). The worm is whitish yellow, the female

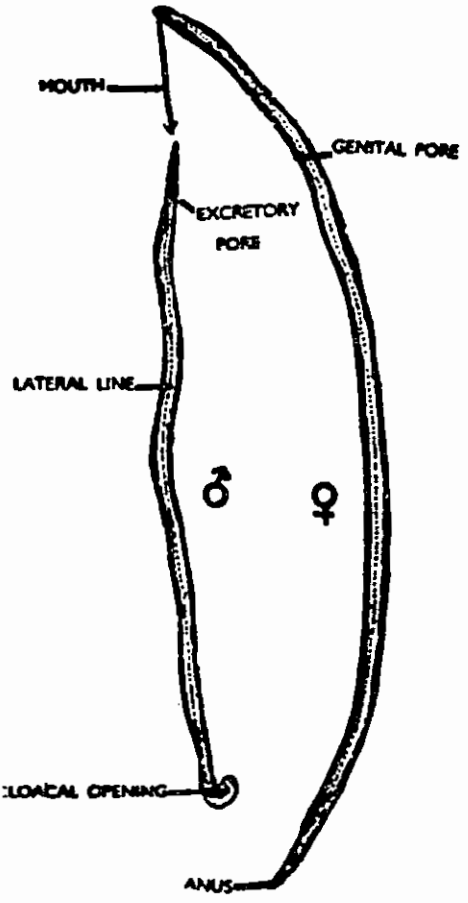


Fig. 178 — Adult Ascaris lumbricoides

being longer (20 — 40 cm. long) than the male (15 — 30 cm. long). Its diameter ranges from 2 to 5 mm. It has been estimated that 644 million persons are infected by this worm (STOLL, 1947).

The body is covered with a thick cuticle with marked fine striations. The male can be distinguished from the female by its smaller size and by the sharply curved posterior end which carries a pair of copulatory spicules projecting from the cloacal opening (Fig. 197 B). The posterior end of the female is conical and straight and the genital pore is situated on the ventral surface about the anterior third of the body.

At the anterior end there is a triangular mouth opening surrounded by three finely denticulated lips, a dorsal and two lateroventral lips (Fig. 179) A). Each lip is provided by a pair of sensitive papillae. The anus

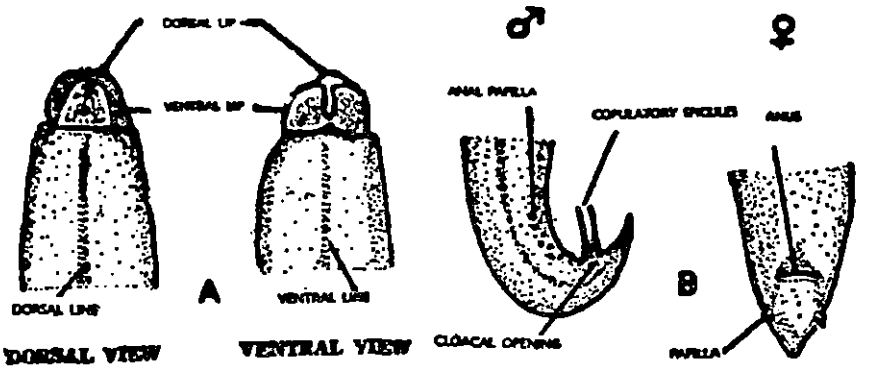


Fig. 179 — Ascaris lumbricoides; A) anterior end; B) posterior end

(in the female) or cloaca (in the male) is a ventral slit found a short distance from the posterior end.

Digestive system (Fig. 180).

It consists of stomodaeum, mesenteron and proctodaeum. The stomodaeum (fore gut) is composed of a short ectodermal muscular suctorial pharynx ending into an end bulb. The pharynx is cylindrical with a characteristic Y-shaped lumen, provided with three longitudinal grooves and lined with a cuticle.

The mesenteron (mid-gut) is a thin walled and long intestine lined by simple columnar epithelial cells with an outer striated border which may represent fused cilia. The intestine is covered by a thin cuticle. There is no muscle layer or digestive gland cells.

The hind-gut or proctodaeum constitutes a short narrow rectum with few muscle fibres. It is lined with a thin cuticle. The rectum opens to the exterior by the anus in the female. In the male it leads into the cloaca which opens by the cloacal apreture.

The fore and hind-guts are ectodermal in origin and originate by the inward invagination of the body wall. Thus they have muscle fibres. The mid-gut is endodermal in origin and its cells are not glandular or digestive. They are absorptive cells.

Ascaris feeds on partly digested food and semifluid material which is sucked from the intestine of the host by the suctorical pharynx. Digestion is extracellular. The digested food is absorbed in the intestine and is circulated by the locomotory movements of the animal through the fluid in the pseudocoel which acts as a circulatory system. The undigested food is

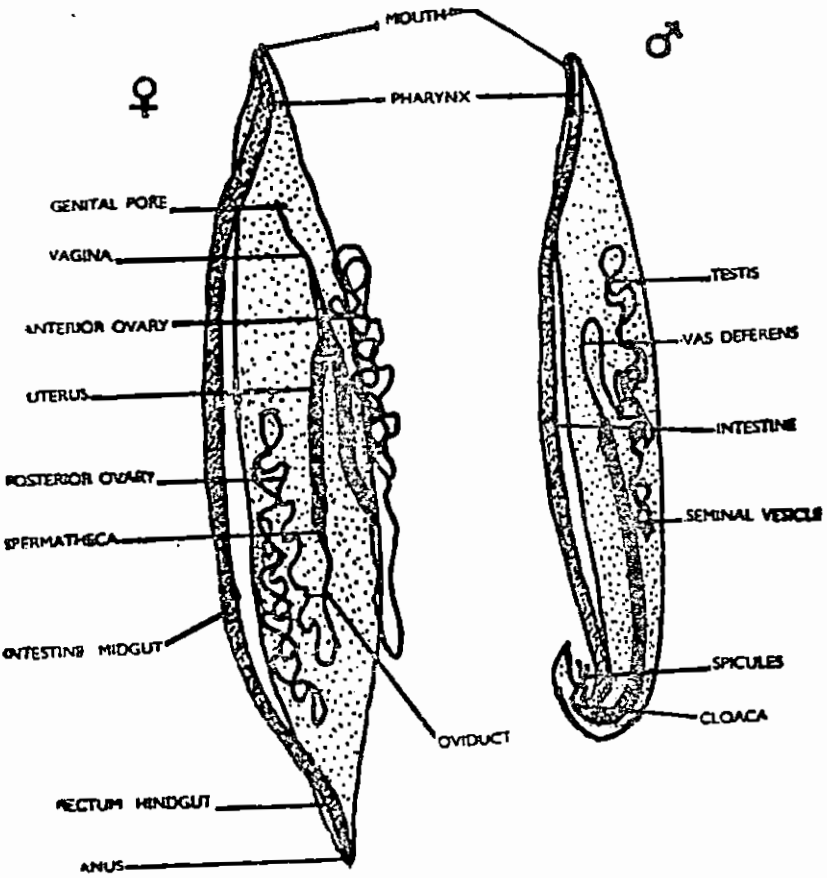


Fig. 180 — Ascaris lumbricoides : Internal anatomy

eliminated through the anal or cloacal opening. The pseudocoel contains an irritant fluid containing a toxin **ascarase** which is a primary albumose (proteose). This substance causes allergy to infected human beings or even those who handle the worms and work on them.

Reproductive system

The reproductive organs are tubular structures which are highly coiled and lie freely in the pseudocoel except when they connect the digestive system. They are connected with the genital pore in the female and cloaca in the male.

The **male reproductive organs** (Fig. 180) are situated at the posterior region and consist of :

A single coiled thread-like **testis** which passes gradually into a vas deferens used for carrying sperms. The vas deferens leads into a wide long seminal vesicle for storing sperms. The seminal vesicle joins a short narrow muscular ejaculatory duct used for discharging the sperms into the cloacal opening. On the dersal side of the cloaca there is a pair of muscular sacs known as spicule or penial sacs. Each sac contains a penial seta which is a cuticular structure with a cytoplasmic core. Both penial setae (spicules) protrude from the cloacal opening during copultation serving to bring the male and female apertures together (Fig. 181 B) and helping in transferring the sperms to the female. Their function is aided by a chitinous plate, the gubernaculum found in the wall of the cloaca.

The sperms of *Ascaris* are simple round cells without tails (Fig. 181 A) They are set free in the vas deferens, they are passed to the seminal vesicle where they are stored. When they are transferred to the female they exhibit amoeboid movement

The **female reproductive organs** (Fig. 180) consist of : A pair of ovaries which occupy the posterior two thirds of the body. Each ovary leads into an **oviduct** which joins a wide muscular uterus. The two uteri run parallel to each other and unite anteriorly to form a short median muscular vagina lined with cuticle. The vagina opens by a transverse gonopore or vulva which is found on the ventral surface at the anterior third of the body. The first part of the uterus where it joins the oviduct, acts as a seminal receptacle used for storage of the sperms and where fertilization takes place. The rest of the uterus is used for the storage of fertilized eggs. Its lining secretes the yolk material and egg shell. The uterine wall is composed of outer thin oblique muscle fibres and an inner thicker circular muscle layer.

The structure of the gonads (testis or ovaries) is built on the same plan. The proximal end is formed of a solid mass of germ cells and this zone is called germinal zone. Posteriorly at the growth zone the gametogonia arrange themselves around a central cytoplasmic rachis (Fig. 174) from which they obtain their nourishment. In the last portion of the gonad the gametocytes are set free and hence they develop to form the gametes (eggs or sperms).

Life cycle (Fig. 182).

The two sexes copulate and the sperms are stored in the seminal receptacles of the female where fertilization of the eggs takes place. The fertilized egg is provided with yolk material in its cytoplasm and is sur-

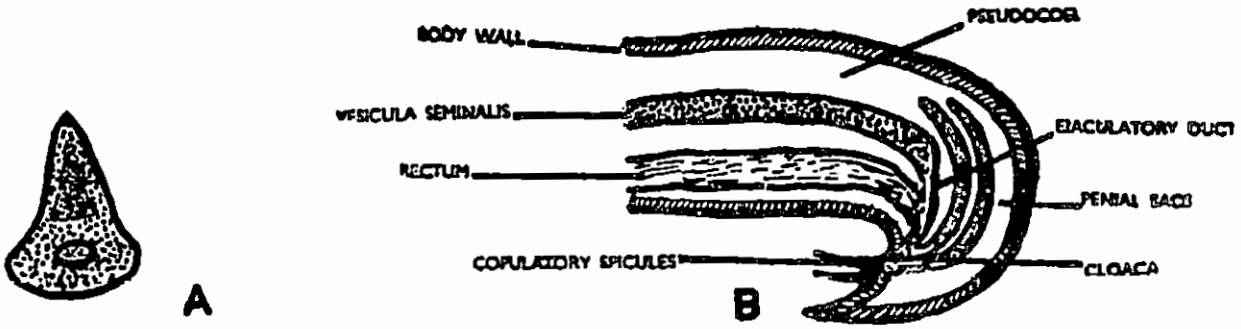


Fig. 181 — Ascaris lumbricoides : A) sperm; B) posterior region of male

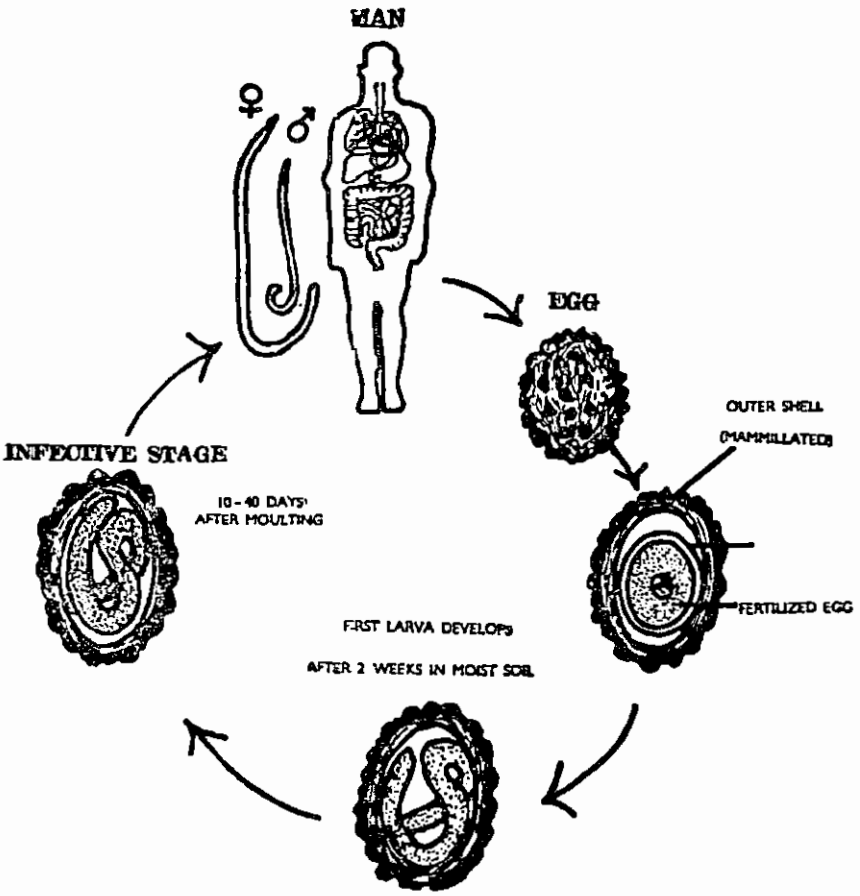


Fig. 182 — Life cycle of Ascaris lumbricoides

rounded by a thin clear inner shell formed of a double membrane and made up of lipoid material (Fig. 182). While passing through the uterus the egg is covered by an oval mammillated outer shell which is secreted by the uterine wall. This shell is made up of an albuminous protein. The eggs are laid by the female in the small intestine where they become yellowish in colour because they are stained with the bile in the intestine. A single female *Ascaris* may lay up to 200,000 eggs a day. It has been estimated that a mature female *Ascaris* may produce 21 million or even 60 million eggs per year.

The eggs are passed to the exterior with the faeces where they can live in moist soil for five years. *Ascaris* eggs are exceptionally resistant to external environmental conditions. They can live even in sandy soil or on green plants. Ascaris eggs were found alive in dilute formalin solutions. Also

they can remain alive in disinfectants used for sterilization. Eggs were found alive even in river water after the discharge from sewage works.

Fertilized eggs are round or oval in shape measuring 60 — 75 μ in length and containing large conspicous unsegmented ovum with a clear crescentic area at each pole. Unfertilized eggs, on the other hand, are elongated more elliptical about 80 μ long with a thinner shell and contain small disintegrated ova with masses of refractile granules of various sizes, Newly laid eggs are not infective unless they undergo a period of development under favourable conditions such as presence of oxygen, absence of putrefaction, moisture and a suitable temperature above 16°C. The eggs are killed within few seconds at 50-75°C.

Under favourable conditions the embryo develops in the soil into a larva within the egg shell in about two weeks depending on the atmospheric temperature and humidity. This larva moults during the next week giving a second stage larva inside the egg shell. This larvae is called the **'rhabdiform larva'** which is the infective stage. The development of the embryo to give rise to the infective larva requires 8 — 50 days depending on the external temperature.

When the ripe eggs are swallowed by a human being with food, drink or raw vegetable, or by accidental transfer of soil containing ova, the eggs pass unaffected in the stomach. Inside the first part of the duodenum the egg shells are weakened by digestive juices which stiumlate the larvae into activity. The eggs hatch within few hours after ingestion and rhabiditiform larvae are liberated in the upper part of the small intestine. The liberated larvae measure about 0.25 — 3.0 mm long. These larvae penetrate through the intestinal wall and enter the veins and lymph vessels which take them to the mesenteric vesses which carry them to the hepatic portal vein then to the liver. They live in the liver for a period of 3 - 4 days. During their passage in the liver the larvae cause cloudy swellings, fatty degeneration and necrosis. Few larvae may penetrate directly from the wall of the duodenum through the abdominal organs then bore through the outer capsule of the liver. From the liver the larvae are carried to the heart through the hepatic and postcaval veins. From the right ventricle of the heart they are carried by the pulmonary arteries to the lungs. In the lungs the larvae grow and increase in length from 0.3 mm to 2 mm. long and moult twice giving the third and fourth larvae (the first moult on the 5th or 6th day, the second after the 10th day). When in the capillary network of the alveoli the larvae burrow through the wall of the alveoli, leave the blood stream and enter into the cavities of the

alveoli (air sacs) of the lung. The migration of the larvae in the lung is accompanied by fever, inflammation of the lungs and eosinophilia. The time taken for migration in the lung is about 10 to 15 days.

From the lung alveoli the larvae are carried passively or may crawl up the bronchioles, the bronchi and trachea up to the pharynx. They are aided by the ciliary current of the respiratory tract. Then the larvae are swallowed into the oesophagus where they pass to the stomach and then the upper part of the small intestine. In the intestine the fourth larva undergoes the last or fourth moult to become the fifth larva. This larva becomes sexually mature within $1^1/_2 - 2$ months without further moulting. The adult *Ascaris* lives inside the host for about one year. The time required for the whole development from hatching of the egg till reaching the adult stage takes place in about 6 — 10 weeks.

Mode of infection

Infection takes place by swallowing ripe embryonated eggs containing the infective stage (the second larva). Infections takes place by :

(*a*) Eating raw vegetables planted on a soil fertilized by infected human faeces.

(*b*) Drinking water obtained from water supplies contaminated with the infected eggs which are carried to it either directly or through sewage works.

(*c*) In places where soil pollution is common, eggs may be carried directly by the dirty fingers.

(*d*) By inhalation of dust containing embryonated eggs.

Control of Ascaris

In order to prevent infection the following measures should be taken :

1. Manuring of the soil should be done only by sprinkling clarified sewage.
2. Vegetables should be washed throughly.
3. Education of population to use sanitary laws of hygiene.
4. Treatment of infected persons by oil of chenopodium and tetrachloroethylene.
5. Proper disopsal of human faeces.

2. *ANCYLOSTOMA DUODENALE*

(The common hookworm)

It is a common parasite living in the small intestine of man especially the jejunum, less often in the duodenum and rarely in the ileum. It is commonly found in tropical and subtropical countries wherever the temperature and humidity are favourable for the development of the larvae in the soil. It is found in Africa, Europe, Ceylon, Central and North China and Southern States of America. The New World hookworm *Necter americanus* is the common species in America and it has been introduced from Africa. These worms are commonly known as hookworms because the male has a hook-shaped body.

The hookworms occur mainly in areas which lie between latitude 30° South and 40°North. It is the most dangerous nematode parasite in man as it becomes attached to the mucous membrane and sucks the blood and body fluids of the host. In massive infections anemia occurs due to deficiency of iron and to prolonged illness. *Ancylostoma* may cut holes in the intestinal wall. In children it may retard mental and physical growth.

Ancylostoma is similar to *Ascaris* in its organisation but some differences are to be mentioned.

General morphology

Sexes are separate. The adult male is 8 — 11 mm long and 0.5 mm diameter, and the adult female is 10 — 18 mm long and 0.6 mm diameter. When freshly passed the worms have a reddish colour due to the ingested blood inside their intestine. The mouth is antero-dorsal without lips and is surrounded with a well developed cup-shaped buccal capsule (Fig. 183). The buccal capsule is lined with a hard cuticle and carries two pairs of curved teeth or plates on its ventral border, and one pair of triangular teeth or plates on its dorsal border. These teeth are used for attachement and cutting holes in the mucosa of the intestine. While the posterior end of the female is pointed, that of the male is expanded to form a bilaterally symmetrical trilobed copulatory bursa (bursa copulatrix). The bursa is supported by six chitinous rays in each lobe, and a small dorsal ray divided at its tip (Fig. 183). A pair of long delicate copulatory spicules is also present. The female genital opening is situated at the junction of the posterior and middle third of the body. The male genital opening is posterior and opens into the cloaca.

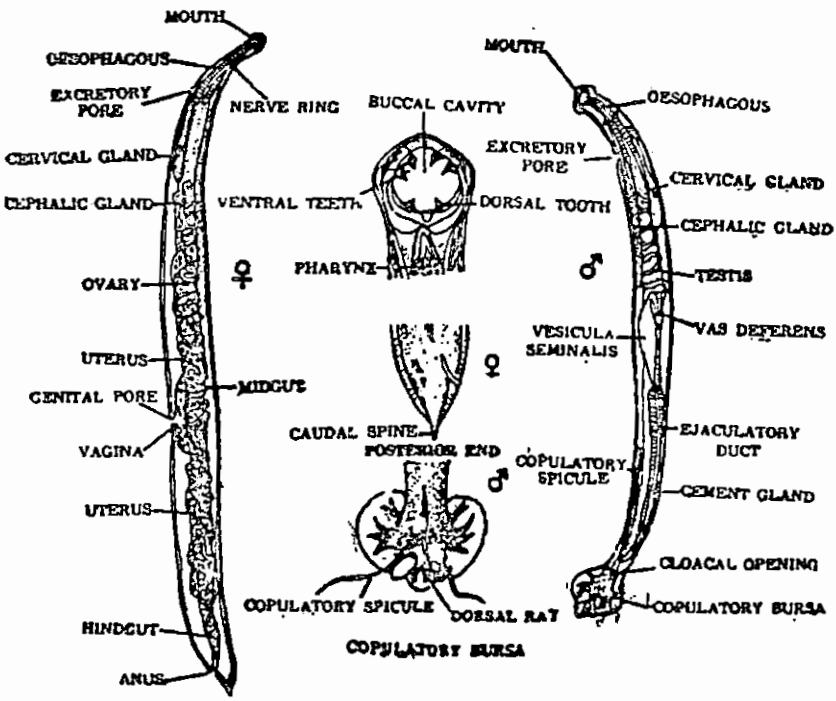


Fig. 189 — Ancylostoma duodenale

The adult worm can live in the intestine of human being about 3 to 4 years.

Nutrition

Ancylostoma feeds on the blood and tissue fluids of its host. It is adapted structurally for attachment to the mucosa of the intestine by its buccal capsule which is provided by strong teeth. In addition its pharynx is a muscular suctorial organ which sucks continuously the fluids of its host which are expelled from the anus. To facilitate their feeding *Ancylostoma* secretes anticoagulins from a special cephalic gland which prevents blood from clotting thus ensuring a continuous flow of arterial blood. They often take more blood than they need and hence their faeces contain mainly undigested red blood corpuscles. A single worm may withdraw about 0.3 — 0.8 ml. of blood in 24 hours and 500 worms remove about 300 ml. of blood daily. Usually the worm leaves a bleeding wound after feeding thus resulting in considerable loss of blood. In severe infections anemia may take place. A worm moves from one place to another causing serious damage to the mucosa of the intestine.

Life cycle

Copulation takes place between two adult worms. The ejaculatory duct of the female is surrounded by two multicellular glands which secrete an adhesive substance serving to cement the bursa of the male to the body of the female during copulation. During this process the female is held by the male bursa at the level of the female genital pore, thus assuming a Y-shaped figure (Fig. 184).

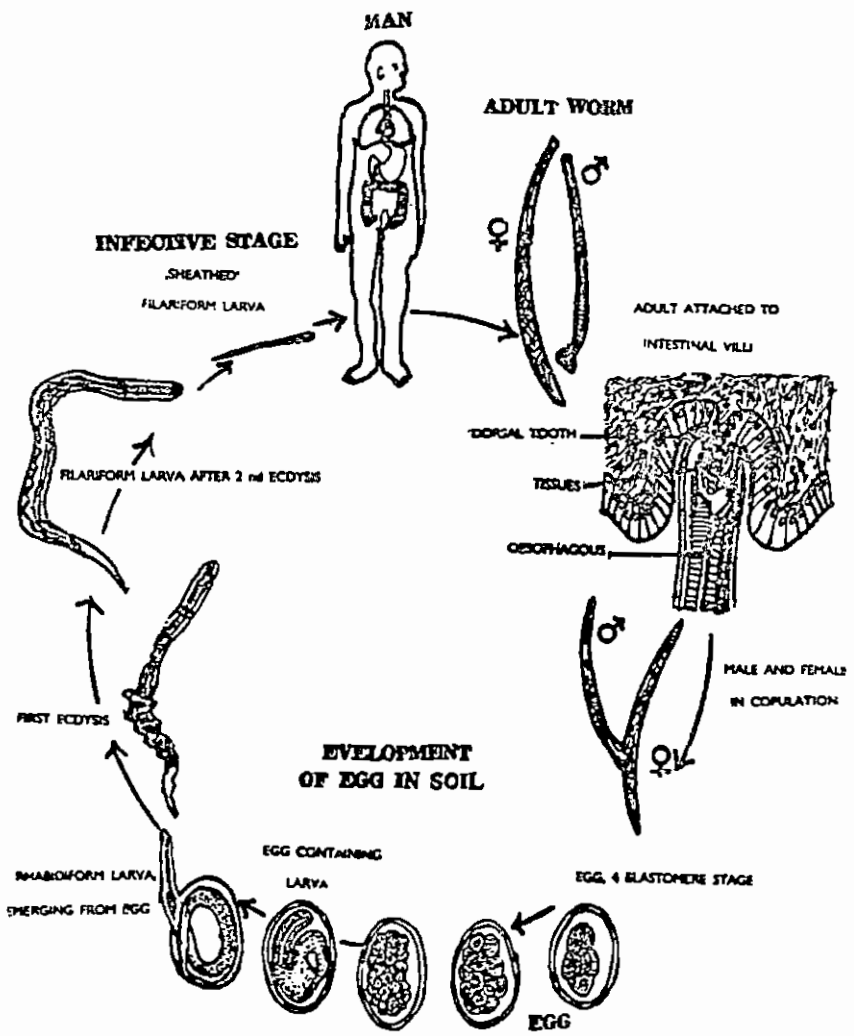


Fig. 184 — Life cycle of Ancylostoma

After copulation the female lays several thousands of eggs daily which may reach 35,000 eggs. The eggs are passed out with the faeces. The egg is elliptical in shape about 65 μ long, covered with a thin transparent smooth shell-membrane. They appear in form of glassy clear to yellowish tone. When laid the eggs are unsegmented but segmentation proceeds during their passage through the intestine. When passed out with the faeces the eggs are usually in the 4 - cell stage with a clear space between the shell and ovum. The freshly passed eggs are not infective to man. They can withstand temperatures between 10 to 45°C. The eggs can survive and develop under certain limits of moisture and temperature. Periods of droughts or spells of cold or very hot and sunny weather kills large numbers of eggs and larvae. Thus the hookworms are restricted to parts of the world where favourable environmental conditions for the development of the eggs and larvae prevail.

Under favourable conditions of enough oxygen, sufficient atmospheric moisture, moderately high temperature (more than, 16°C) and preferably darkness, development of the larvae in the eggs take place. Hatching occurs within 1 — 2 days at 23 - 30°C. The hatched larvae (**first larvae**) resemble a nematode of the genue *Rhabditis* hence they are called **rhabditiform larvae** which are about 250 μ long.

The rhabditiform larvae feed and grow on bacteria and within 3 — 6 days moult twice giving rise to the second and third larvae. The third larvae are surrounded by their old skin and are called sheated **filariform larvae** because of their resemblance to a nematode of the genus *Filaria*. The skin of the second larva remains as a loose sheath around the third larva to protect it from the unfavourable environmental conditions. This filariform larva is the infective stage which is not a feeding stage. It is negatively geotropic and thigmotropic ascending through the soil and is a very active stage. The larvae can live in warm moist soil for 4 — 8 weeks and in cool moist soil for 6 months. The larvae are killed in dry soil or when exposed to direct sunlight.

The filariform larvae are attracted to the moist skin of human being who walks bare-footed, baths or washes his hands in the water containing these larvae; a normal habit in warm countries. The infective stage can infect a human being by entering his mouth with his food or drink. Once coming in contact with human skin the larvae bore through it and enter by the way of a hair follicle. This process of penetration of the skin is aided by special penetrating apparatus. They usually enter the skin in the region between the toes, dorsum of the feet of inner side of the sole or any part where the skin is thin. On reaching the subcutaneous tissue the larvae enter into the lymphatics and small venules from where they are carried

by the venous circulation to the right side of the heart. Then they are carried to the lungs by the pulmonary arteires. The larvae remain in the capillary network of the lung for sometime then they break their way out of capillairies of the lung, and enter into the air sacs or alveoli of the lung. From the alveoli the larvae are carried upwards with the stream caused by the cilia lining the bronchioles and bronchi. From the bronchi the larvae migrate through the trachea to reach the pharynx where they are swallowed into the oesophagus, then the stomach and to the intestine. This migration from penetrating the human skin till the larva reaches the intestine, takes about 3 — 7 days. During migration the larva undergoes its third moult and a buccal capsule is formed. In the intestine the fourth moult takes place and the buccal capsule is changed into a "provisional buccal capsule" with the mouth opening directed dorsally but without teeth. On the fifteenth day the "provisional buccal capsule" is cast off. Then the larva assumes the adult form and becomes attached to the intestinal wall. In the male the adult buccal capsule and bursa appear. In 3 — 5 weeks it becomes sexually mature. The fertilized females begin to lay eggs in the faeces. The time taken from penetration of the skin by the larvae till the appearance of the eggs in the faeces is about 5 — 6 weeks.

Control of Ancylostoma

1. **Attack of adult parasite** by mass treatment of infected persons.
2. **Attack of the larvae** by : (*a*) Preventation of soil manuring by human faeces; (*b*) Proper control of sewage disposal; (*c*) Disinfection of faeces or soil.
3. **Personal protection to prevent** the entry of the infective larvae through the human skin or mouth. This is most effective measure of controlling the disease because man is the main if not the only host of this worm. The following measures can be followed:

(*a*) Wearing boots or gloves when coming in contact with infective places.

(*b*) Using adequate sanitary arrangements.

(*c*) Not to drink water from infected areas unless boiled, or heated above 75°C.

3. *ENTEROBIUS* (*OXYURIS*) *VERMICULARIS*

(**The pinworm or threadworm**)

It is very common parasite found all over the world especially in warm countires. In some communities about 40 or even 100% of

the children are infected. It has been estimated that more than 209 million persons are infected by this worm (STOLL, 1947).

The adult worms live in the caecum, colon and appendix of human beings. It is generally attached to the surface of the mucosa and in some cases it may encyst in the submucosa.

Enterobius is commonly known as the threadworm on account of its resemblance to a small piece of thread.

Morphology

The sexualey mature females are longer than the males being 10 — 12 long with an elongated pointed tail end. The males are much smaller being 3 — 4 mm long with a blunt curved tail and provided with a single copulatory spicule. Males are usually few and rare because they die soon after copulation. Gravid females die after 2 — 3 weeks. At the anterior end of both sexes there is a pair of wing-like expansions called cevical alae (Fig. 185), which are used for attachement to the mucous membrane. The mouth is surrounded by three small lips. There is no buccal cavity and the oesophagus is characterised by the presence of a conspicuous globular bulb at its posterior end.

The threadworm feeds on the contents of the large intestine but sometimes blood of the host is found in its gut. One person may be infected by thousands of this worm.

Life cycle

After fertilization, the females whose uteri are full with eggs cannot fix themselves to the mucosa of the intestine. They are expelled to the rectum from where they creep out of the anus at night to lay their eggs on the perianal skin. Egg laying is stimulated by contact with air. The female bursts, lays eggs within few minutes and then dies. A female may lay about 10,000 — 15,000 eggs.

The egg (Fig. 185) is colourless asymmetrical in shape with a flattened ventral surface and a convex dorsal surface. It is surrounded by a transparent shell and is 50 — 60 long. The egg develops on the surface of the skin within 5 — 6 hours to give rise to a small larva within the shell. This is the infective stage which when swallowed hatches in the small intestine through the dissolution of the egg-shell by the action of the digestive enzymes. The larva soon invades the glandular crypts and penetrates

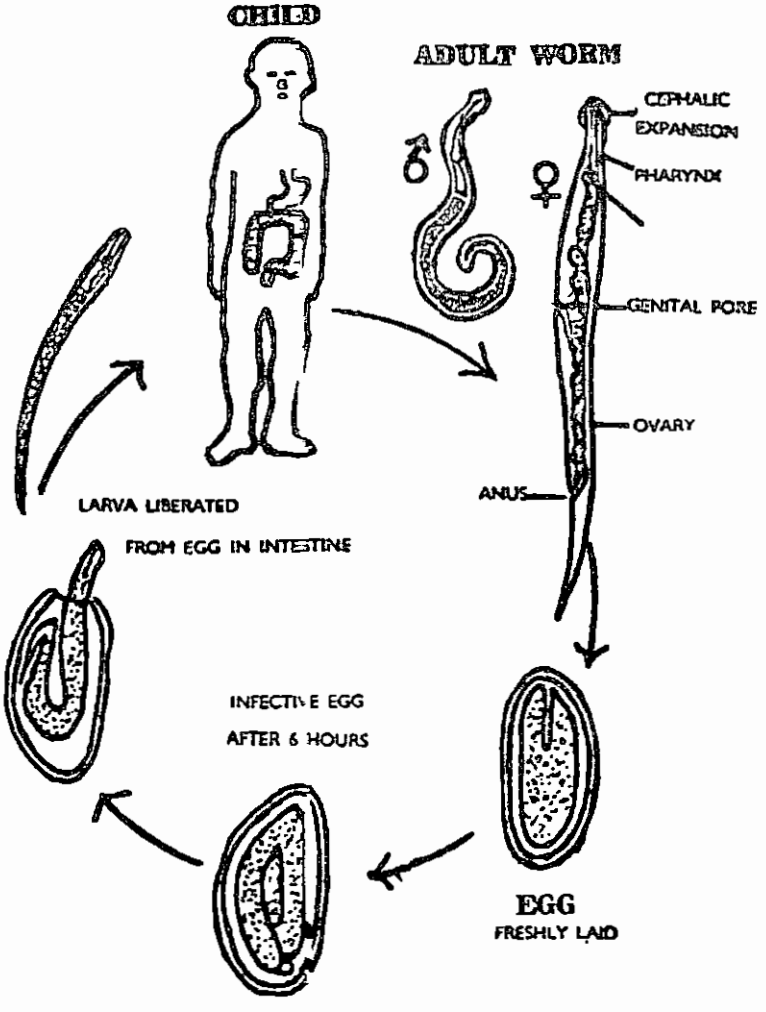


Fig. 185 — Life cycle of the pinworm, Enterobius vermicularis

into the glands and stroma where it coils up. After two months the larvae pass from he small to the large intestine and caecum where they become sexually mature.

Persons usually reinfect themselves (autoinfection) by scratching the skin where the eggs are laid. The eggs are sticky and thus the fingers become contaminated with them from where they enter into the mouth. There is no intermediate host and the eggs are infective few hours after being laid.

Mode of transmission

1. Autoinfection especially in children, when as a result of itching at the anus, the sticky eggs stick to the fingers which transfer them to the mouth.
2. Direct contact between an infected and healthy person.
3. By taking in eggs which get into the air, in the dust from the beds. By this way a whole family is usually infected by inhalation. Infection can be carried through bed clothes, furniture and kitchenware.

   The eggs of the threadworm are not very resistant. They are killed by drying or direct sunlight so a high percentage of eggs in the air contains dead larvae.
4. The eggs may hatch on the skin round the anus and the hatched larvae re-enter the anus and develop normally.

The threadworm while moving in the anal region causes severe itching of the anus (anal prurities).

4. *TRICHINELLA SPIRALIS*

(Trichina worm)

It is one of the smallest human parasites whose development takes place in one and the same host. The adult lives in the walls of small intestine (duodenum) of man, pigs, cats; dogs and rodents (hogs, mice and rats). It causes a serious disease known as trichinosis (trichiniasis) which is common in Enrope, United States and some parts of Africa, China and Syria. About 27 million persons in all the world are infected by trichina-worm.

Infection takes place when one animal eats the flesh of another animal which contains the infective stage. Thus although one individual acts as a definitive and intermediate host, two hosts are required to complete the life cycle.

General Morphology

The adult worms are slender with the body tapering towards the anterior end. The pharynx is long with an anterior muscular portion and a posterior glandular region. Females which are 3 — 8 mm long

are ovaviviparous thus discharging larvae instead of eggs. Eggs develop and hatch inside the uterus. Adult males are smaller measuring about 15 mm long with a pair of conical papillae at the posterior end. There are no copulatory spicules. The adult worm lives for 2 to 5 weeks, males live longer than the females.

Trichiniasis when severe may cause prolonged illness or leads to death. The larvae and adult causes damage to the intestinal wall manifested by vomiting, diarrhoea, nausea and abdominal pain. The encysted larvae cause, however severe intoxication and allergy accompanied by oedema (chiefly in the eye-lids), high fever and eosinophilia. In muscles it causes rheumatic muscular pains, pneumonia, kidney failure and even degeneration of muscles.

The chief source of human infections are the pigs. By eating raw or insufficiently cooked meat in the form of sausage or mincemeat containing the cysts.

Life cycle (Fig. 186).

When a human being eats uncooked or partly cooked pig's meat (pork) containing encysted larvae, the cyst is digested in the stomach and duodenum. The larvae emerge in the small intestine. The larvae may penetrate the intestinal mucosa and return to the lumen of the intestine. During this migration they cause serious damage to the intestinal wall.

The larvae become sexually mature within 5 — 7 days. After copulation the female bores through the intestinal wall as far as the muscularis where it gives birth to about 1,000 — 2,000 larvae for about 30 — 40 days afterwhich the female dies. The liberated larvae reach the lymphatic vessels or veins from which they are carried by the venous circulation to the right side of the heart. Then they reach the lungs, then to the left side of he heart from where it is carried to the various parts of their host. Many larvae die in the tissues in which they cannot live, but most of them survive in the skeletal (voluntary) muscles especially the muscles of the jaw, neck, eyes, tongue or diaphragm. In the muscle the larvae grow, coil up and become surrounded by a capsule formed as a result of the reaction of the host (Fig 186). The larvae can live inside the cyst for 10 or even 20 years and eventually die inside the capsule which usually becomes calcified.

Pigs, rats, dogs and cats get infected by eating pork scraps containing encysted larvae. To prevent infection with trichna-worms man have to avoid eating raw or unsufficiently cooked pork meat. This must be throughly cooked or refrigerated at — 15°C for at least 20 days, in order to kill the cysts.

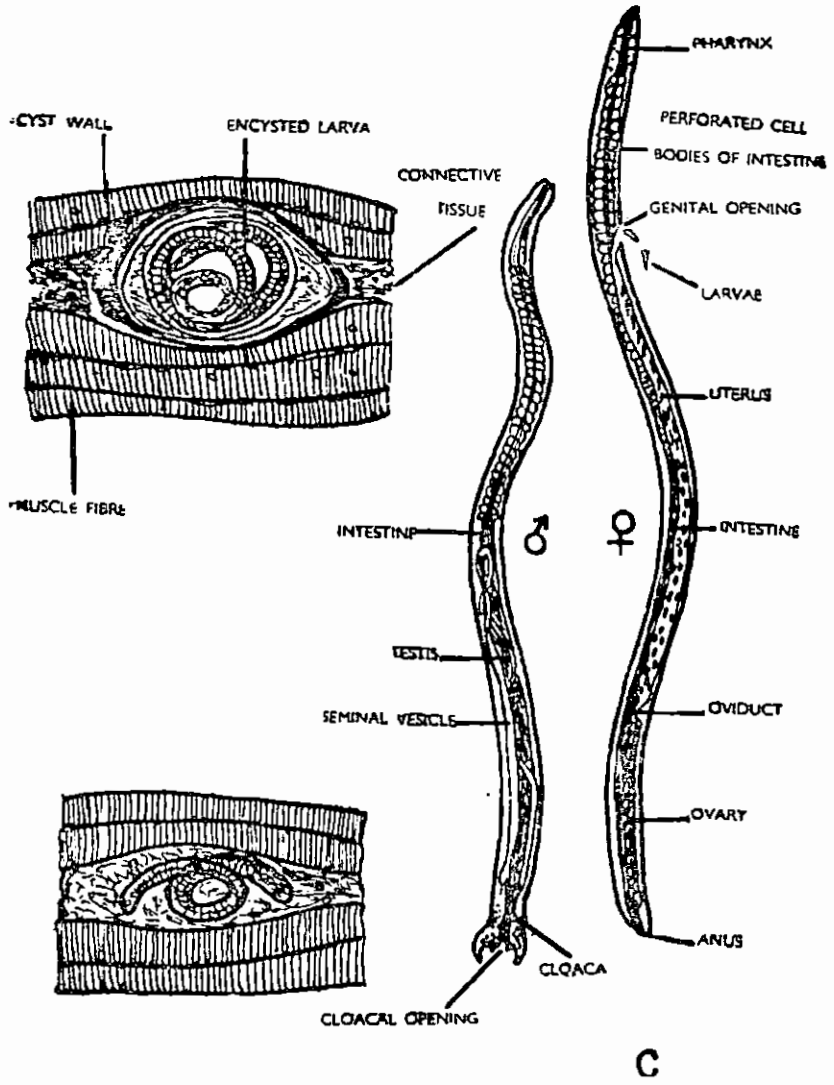


Fig. 186 — Trichinella spiralis : A) encysted larva inside connective tissue and between muscle fibres; B) larva between muscle fibres, not encysted; C) adult worm

5 *WUCHERERIA BANCROFTI*

(**Bancrofti's filarial worm**)

This parasite is mainly confined to tropical and subtropical countries, occurring in the Mediterranean region (Nile Delta, Southern Spain, Turkey); South America, Central Africa, Southern China and India.

The adult worms live in the connective tissue, lymphatic vessels, lymph nodes and glands where they obstruct the flow of the lymph producing a disease called elephantiasis. It involves and excessive growth of the connective tissue and enormous swelling, enlargement and thickinning of the affected parts such as legs, arms and scrotum. Man is the only definitive host of this parasite while various species of blood-sucking mosquitos act as intermediate hosts STOLL (1 47) estimated that about 189 million persons of the world population are infected by Bancrofti's filarial worms.

Morphology

The adult worms are transparent, long hair-like with tapered ends. The female is long being 8 — 10 cm with a narrow abruptly pointed tail. The male is smaller, measuring 2.5 to 4 cm. long with a curved tail provided with two unequal spicules. The adult worms live in the lymph vessels and glands especially those of the reproductvie organs, arms, legs or the pelvic region. Male and females are coiled together, the male being less numerous than the females. The adult worms can live for several years.

Life cycle (Fig. 187)

The female lays eggs containing larvae, their egg-shell forms a sheath around them. These sheathed larvae are called **microfilariae** (Fig. 187) which measure about 127 — 320 microns long. The microfilariae are discharged into the lymph where they are carried by blood vessels and circulate with the blood and lymph. The microfilariae do not undergo further development in man unless they are taken by the suitable blood sucking mosquito (*Culex* or *Aedes* or *Anopheles*). If not taken by the mosquito the larvae die within 70 days.

During night the microfilariae migrate to the peripheral blood vessels (blood vessels of the skin and outer parts of the body), so that night feeding mosquitos can suck them with the blood while they are feeding. In places where mosquitos are active during day the microfilariae are found during night in deeper vessels (capillaries of lungs, kidnies, heart, etc). and during day in peripheral blood vessels. This change in migration may be related to the night or day feeding habits of its intermediate host. However, in certain regions (Pacific Islands) the microfilariae do not show any periodicity as they appear in the blood during day and night.

When the mosquito sucks the blood of an infected person, it takes the

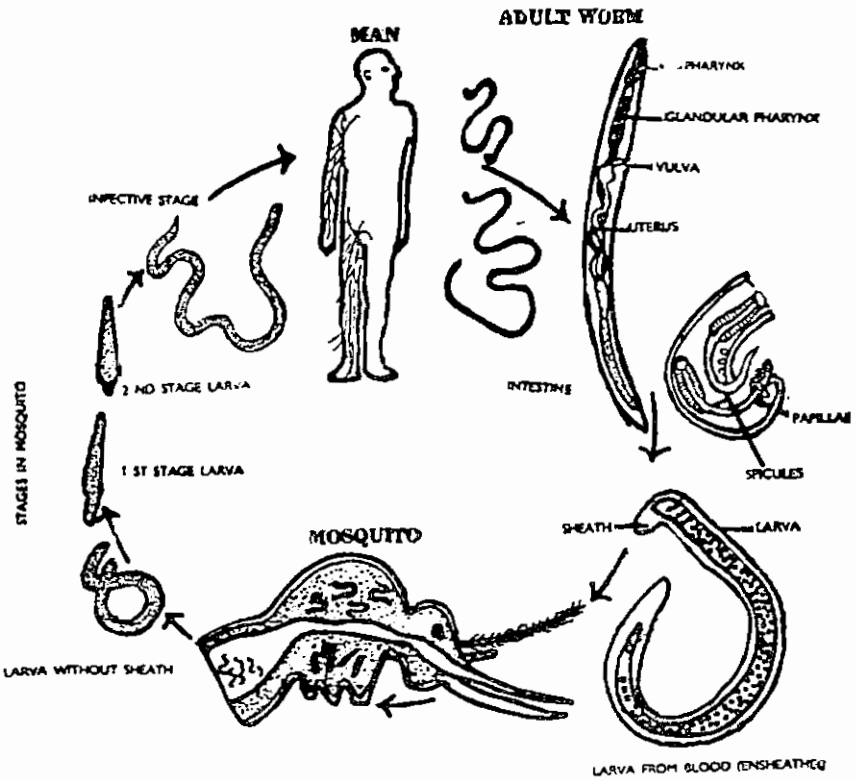


Fig. 187 — Life cycle of Filaria : Wuchereria bancrofti

microfilariae with its food. In stomach of the mosquito the larvae lose their sheaths within 2 — 6 hours. Then they bore through the intestinal wall and migrate to the thoracic muscles within 4 — 17 hours, where they develop into the infective stage after moulting twice giving rise to the third larval stage. This infective stage is about 1.4 — 2 mm long. Then these larvae migrate to the sheath (lower lip) of the proboscis of the mosquito which becomes infective. The formation of the infective larvae takes 10 — 11 days after they have been taken the mosquito.

When the mosquito bites a human being, the larvae leaves the proboscis and either actively penetrate the skin or they enter the puncture made up by the mosquito mouth parts. These larvae pass to the lymph vessels and glands where they become sexually mature after about 9 months.

THE EUCOELOMATA

It includes a large group of triploblastic animals characterised by the presence of a body cavity known as **coelom.** The coelom appears in the mesoderm and is lined by mesodermal epithelial cells called the peritoneum, the outer layer being the **somatopleure,** and the inner one covering the alimentary canal and is called the **splanchnopleure.** The coelom is filled with coelomic fluid which gives the body its rigidity and protects the internal organs. In addition the coelom allows independent movements of the muscles of the alimentary canal and those of the body wall. The presence of a wide coelomic cavity makes it necessary for the appearance of circulatory and respiratory systems. The circulatory system which connects the respiratory surface with other parts of the body, is made of blood vessels which contain blood plasma and cells. The respiratory pigment is either dissolved in the plasma or contained in blood cells.

The coelom is formed during development either by a splitting within originally solid masses of mesoderm (as in annelids and arthropods) or by pouches that bud off from the original gut cavity — archenteron — as in chordates (Fig. 188). Thus successives pairs of mesodermal pouches are formed. Each pair grows and surrounds the alimentary canal, leading to the formation of dorsal and ventral mesenteries which are double sheets of peritoneum. Thus the mesoderm is segmented and the successive coelomic cavities are separated by transverse septa (Fig. 188). Such segmentation is clear in annelids, and the external segmentation of the body into segments or annuli corresponds to the internal segmentation of the mesoderm. All the segments are similar, and all the body organs — musculature, blood vessels, nerves, excretory organs and gonads — are repeated in each segment. This condition is termed **metamerism,** and each segment is called **metamere.**

In most coelomates, however, no transverse septa are present between the segments in the adult animal. The coelomic cavity being continuous throughout the length of the body, and in higher vertebrates traces of segmentation can be seen in the spinal nerves, vertebrae, etc.

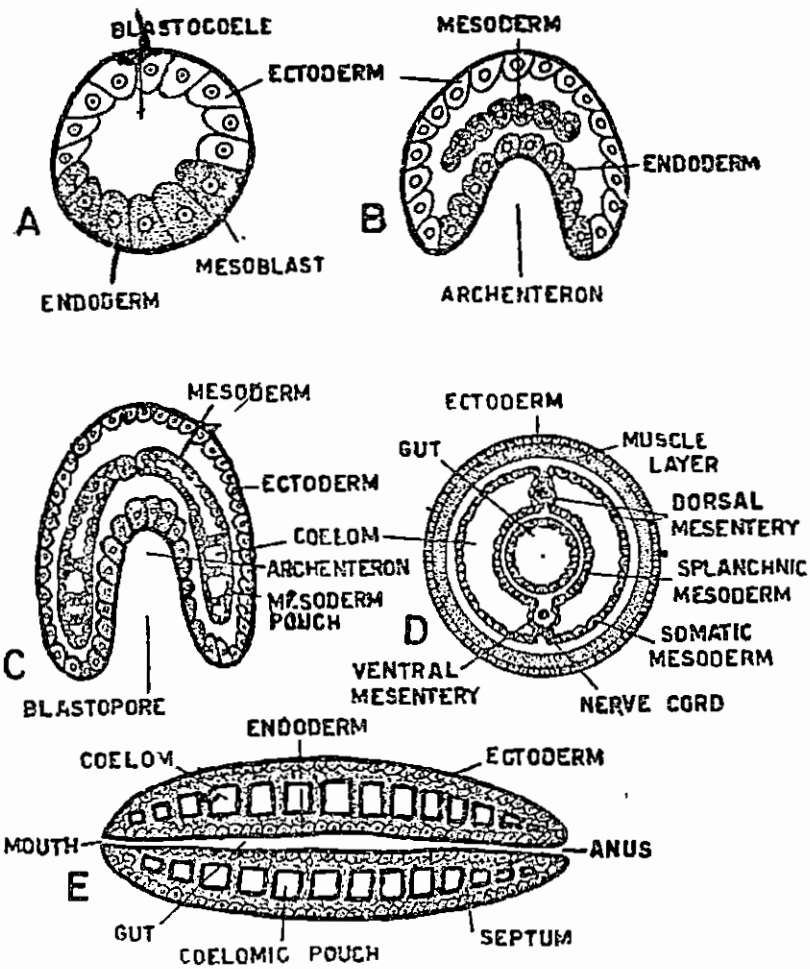


Fig. 188 — Development of coelom in annelids : A) formation of a blastula whose cells are differentiated to form the ectoderm, endoderm and mesoderm; B) gastrula, with outer ectoderm, inner endoderm and middle mesoderm; C) mesoderm forms two bands surrounding the endoderm, notice the first appearance of mesodermal pouches separated by septa; D) T.S. of a late embryo showing coelomic pouches united to form dorsal and ventral mesentries; E) advanced embryo, with the mesoderm forming compartments with a coelomic cavity.

PHYLUM ANNELIDA

The annelids are worms whose bodies are divided into similar segments or annuli and hence their name annelids (annelus; little ring). The phylum is characterised by metameric segmentation. The external segmentation

may coincide with the internal segmentation. However, in some annelids, (e.g. leech), each segment is divided into many annuli (Fig. 189 B).

Annelids are divided into classes, primarily on the basis of the presence or absence of parapodia, setae, metameres and other morphological features. Of these classes, the following may be mentioned.

Class — **Oligochaeta** (Gr., oligos = few; chaite — bristle), no parapodia, few setae, small head, hermaphrodite; presence of clitellum, no larval stage.

Example : Earthworms (*Allolobophora* and *Lumbrius*, Fig. 189 A).

Class — **Polychaeta** (Gr., poly = many; chaite = bristle), parapodia numerous, bristle-like setae, well developed head with eyes; tentacles and

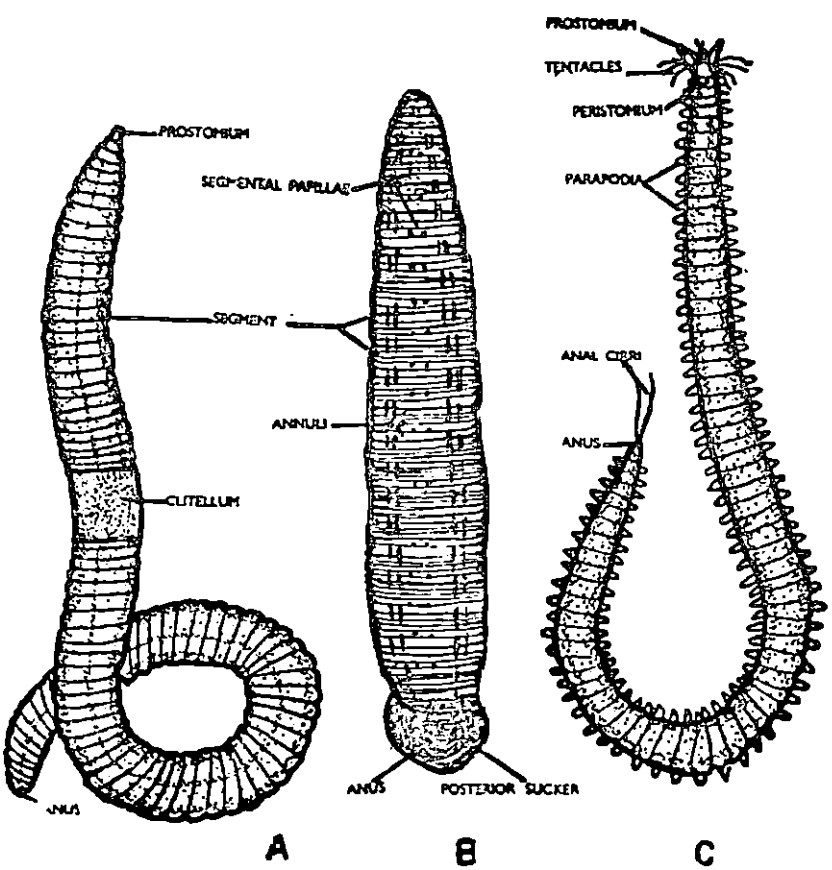


Fig. 189 — Representatives of annelids : A) an earthworm; B) a leech (Hirudo); C) a sandworm (Nereis)

palps, no clitellum; sexes separate, trochophore larva is usually found.

Example : Sandworms (*Nereis*, Fig. 189 C).

Class **Hirudinea** (L. hirudo, leech). Body with fixed number of segments, each segment may be divided externally into a number of annuli, no parapodia or setae; anterior and posterior suckers, coelom reduced by connective tissue and muscles; hermaphrodite with no larval stage.

Example : Leeches (*Hirudo*, Fig. 189 B).

GENERAL CHARACTERS OF ANNELIDS AS SHOWN BY THEIR ORGAN SYSTEMS

Body wall (Fig. 190). The body wall of the earthworm is covered with a thin transparent cuticle which is secreted by the epidermal cells. The cuticle is provided wih cross striations which give it an iridescent appearance due to refraction of light which produces various colours. The epidermis is formed of simple epithelial cells which contain unicellular glands which open by pores on the cuticle. Sensory and small basal cells are also found in the epidermis. Beneath the epidermis there is the basement membrane which is followed by the continuous muscle layers; an outer circular and an inner longitudinal muscle layers. The muscle layer is followed by the **somatic mesoderm** (parietal peritoneum) which is

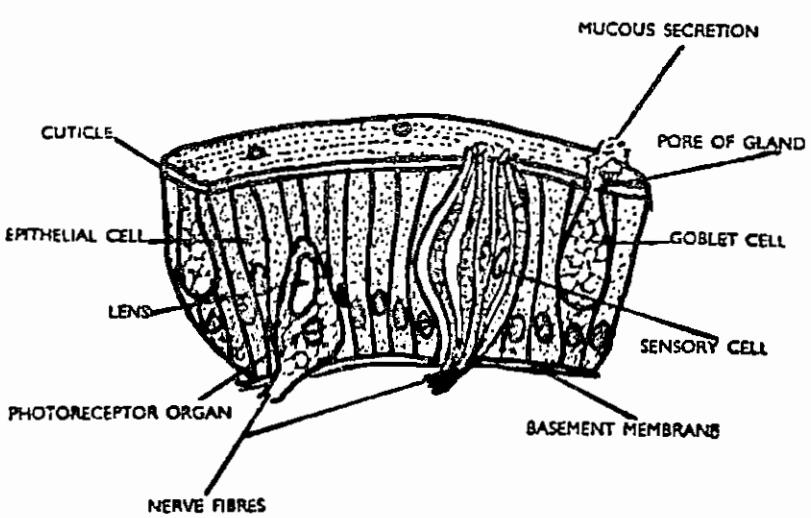


Fig. 190 — Diagram of a transverse section of the epidermis of the earthworm showing sense organs

formed of squamous epithelium and lines the large coelomic cavity The body wall contains **setagenous cells** which secrete setae (Fig. 191) used to anchor the worm when moving. Certain pigments as protoporphyrin are also found in the body wall

The longitudinal muscle fibres are long enough to extend through two or three segments, thus the segments are linked in small groups. The arrangement of muscle layers which can exert a pressure on the coleomic fluid ensures the formation of an elaborate hydrostatic skeleton which shows great flexibility and speed of response.

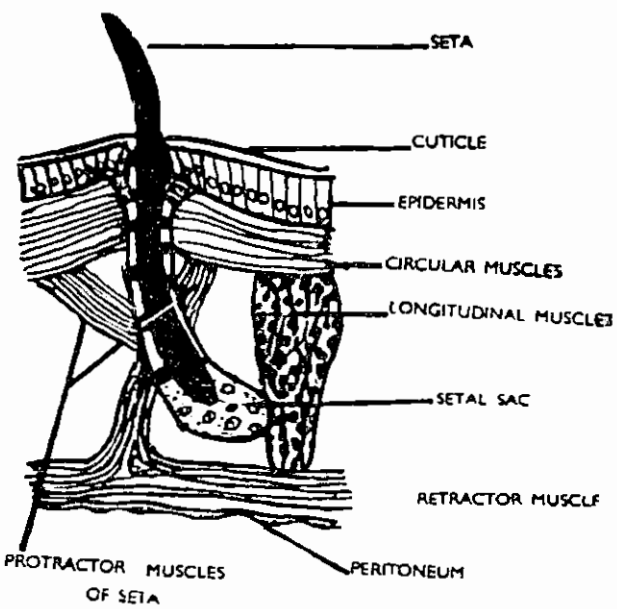


Fig. 191 Transverse section through the body wall of the earthworm in the region of a seta

Digestive system

In the **earthworm, Allolobophora,** the digestive tract (Fig. 192) consists of: 1. The **mouth** which is overhung by a fleshy prostonium, leads into a **buccal** cavity located in somites 1 to 3. 2. The buccal cavity connects a thick muscular sucking **pharynx** (in somites 4 to 5) provided with **pharyngeal glands** which secrete mucin used for lubrication of food. The pharynx leads to a narrow straight **oesophagus** (in somites 6 — 14) provided with three pairs of **calciferous glands.** 3. The oesophagus is connected to a large thin walled **crop** (in somites 15 and 16) which is used

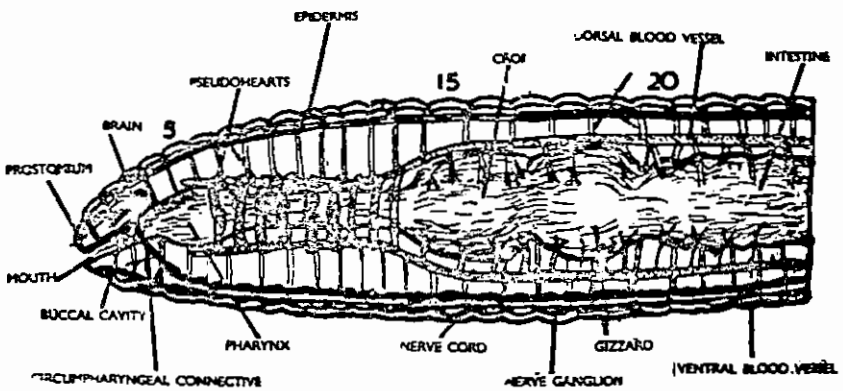


Fig. 192 - Internal structure of some of the organs of the anterior region of the earthworm

for storage of food. 4. The crop opens into a thick muscular **gizzard** located in somites 17 and 18. The gizzard is lined with cuticle and used for grinding the food by the aid of sand grains. 6. The long intestine follows the gizzard. The intestine is provided with a deep dorsal longitudinal fold, the **typholosole** which is used to increase the digestive and absorptive surfaces. The intestine is lined by simple columnar epithelium followed by longitudinal and circular muscle layers. The intestine is covered by special **yellow** or **chloragogen cells** which are peritoneal cells which fill the typhlosole. The chloragogen (chloragogue) cells play a role similar to the vertebrate liver as they serve : (*a*) storage of food material; (*b*) elimination of waste; (*c*) may convert protein into fat. When dividing, the portion of the chloragogen cell laden with the fat constricts to form a wandering **elocyte** which distributes fat to various parts of the body; (*d*) deamination of proteins, formation of ammonia and synthesis of urea.

The intestine opens to the exterior by the anus located at the tip of the last segment.

In the **medical leech** (*Hirudo*) the triradiate mouth is surrounded by the oral sucker. The mouth opens into a short buccal cavity provided with three jaws. The jaws which are covered with minute denticles are provided with muscles and salivary papillae. The buccal cavity leads to a thick-walled muscular **pharynx** located in somites 6 to 8. The pharynx is surrounded with a mass of unicellular **salivary glands** which open between the denticles of the jaws. The saliva contains an anticoagulant called **hirudin** or **anticoagulin** which prevents blood from clotting during blood sucking. *Hirudo* is an external parasite and feeds by sucking the blood of vertebrates.

The pharynx is connected with the thin walled well developed crop (Fig. 193). The crop is provided with eleven chambers each is provided with a pair of lateral pouches or caeca, the eleventh pair of lateral pouches or caeca being the longest and extends till the 22nd segment The crop is

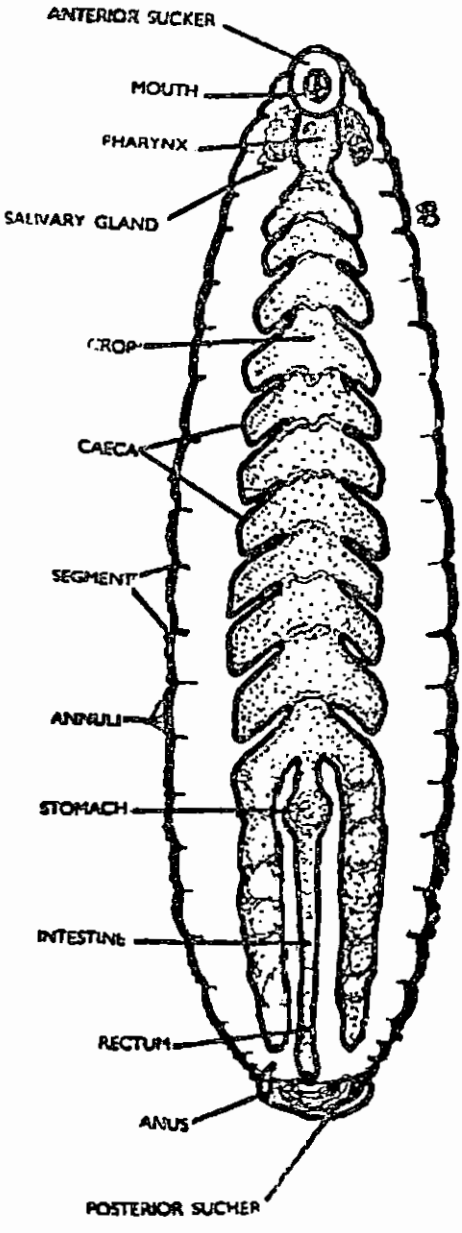


Fig. 193 — Digestive system of Hirudo

used for the storage of blood of the host. The food may be stored for ten to twelve months or more. The crop opens by a narrow opening into a globular **stomach** with both secretory and absorptive cells. The stomach leads to a short **intestine** which is followed by a short **rectum** which opens by the anus on the dorsal surface above the posterior sucker.

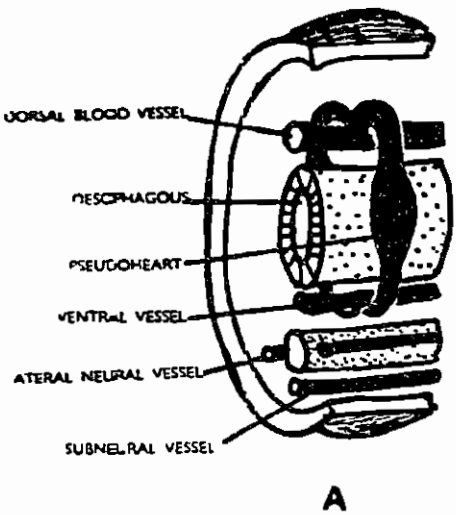
Feeding and digestion

Earthworms normally feed on dead plant and animal remains, leaves, vegetation and mud rich in organic material. The food which is made moist by the secretions of the pharyngeal glands is sucked by the suctorial pharynx. The prostomium helps in handling food. The calciferous glands secrete calcium carbonate to neutralize the acidic food. The food is passed to the crop where it is stored. Then it passes to the gizzard where it is ground up into a fine state. The mucin secreted by the pharyngeal glands aids in the passage of the food while the proteolytic enzymes start the digestion of proteins. The digestion is completed in the intestine which secretes digestive enzymes: **amylase** and **invertin** which act upon carbohydrates; **cellulase** acting upon cellulose; **lipase** which splits fats and **pepsin** which acts on proteins. Digested food is absorbed in the intestine where it is carried by the blood to the various organs. Some of the food is absorbed into the coelomic fluid which aids in its distribution. Undigested food is egested through the anus.

Leeches (as **Hirudo**) live as ectoparasites on warm blooded animals. The leech becomes attached to its host by the oral sucker and by the aid of its jaws forms a triradiate wound. The saliva containing the anticoagulant is secreted to prevent blood from clotting. By the action of the suctorial pharynx large amounts of blood are pumped into the crop. In the crop the red blood corpuscle are haemolysed (burst) and haemoglobin spreads in the plasma which becomes dark red in colour. Then blood passes gradually into the stomach through a sphincter. In the stomach the blood becomes green and is digeseted. The digested blood passes into the intestine where absorption takes place. Undigested food is rejected through the anus.

Circulatory system (Figs. 192 and 194).

In the earthworm the blood system is of the closed type where blood flows in blood vessels having their own distinct walls. The circulatory system consists of five main longitudinal vessels; a number of transverse vessels and numerous, branches and capillaries. The main longitudinal vessels include : 1. a **dorsal blood vessel** which extends dorsal to



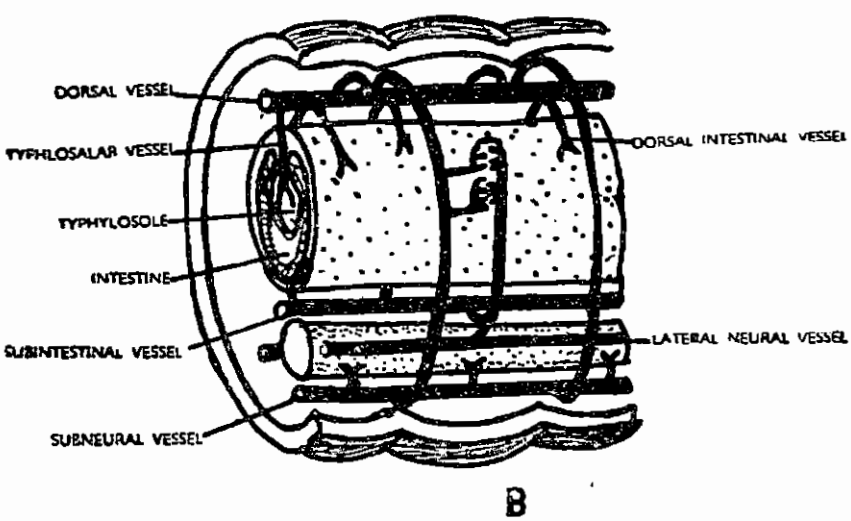


Fig. 194 — Diagrams showing the circulatory system of the earthworm : A) in the region of a pseudoheart; B) in the intestinal region

the digestive tract; 2. a **ventral blood vessel,** ventral to the digestive tract; 3. a **subneural blood vessel** ventral to the nerve cord; and 4. two **lateral neural blood vessels** on either side of the nerve cord. The transverse vessels include : 1. the **pseudohearts** which connect the

dorsal and ventral vessels. There are 6 pairs in *Allolobophora*, 2. the **subneural dorsal vessels** (parietal vessels) which connect the dorsal and subnerural blood vessels (Fig. 194). From the various vessels extend numerous branches which supply the various parts of the body the typhlosolar blood vessels, the ventrointestinal and dorsointestinal vessels, etc...

The blood is forced along the vessels by the peristaltic action of the muscular walls of the blood vessel especially the dorsal blood vessel which is considered as the "true heart". Valves in the vessels and pseudohearts prevent the backflow of the blood. In the dorsal blood vessel the blood flows forward, while in the ventral blood vessel the flow is forward anterior to the pseudohearts, and backwards posterior to the hearts. The direction of the blood in the dorsal and ventral blood vessels in annelids is the reverse of that in chordates.

The blood is made up of a liquid **plasma** which contains amoeboid cells, the **blood corpuscles.** In the plasma the respiratory pigment **erythrocruorin** is dissolved. The latter substance is similar to haemoglobin and gives the blood its colour. Erythrocruorin aids in the transport of respiratory gases. The blood carries absorbed food and transports waste products and respiratory gases.

Respiration

In earthworms there is no special respiratory system but gaseous exchange takes place through the moist skin which is well adapted for this process. The epidermis is sufficiently thin to permit diffusion of gases. Beneath the thin permeable cuticle and epidermis there is a rich network of blood capillaries where oxygen can combine with erythrocruorin of the plasma then it is carried to the various tissues. In earthworms the skin is kept moist by the coelomic fluid, nephridial excretion and mucous glands. Once the cuticle becomes dry respiration ceases and the worm dies of suffocation.

In leech the blood capillaries penetrate among the epidermal cells. In aquatic annelids (polychaetes) respiration takes place by the parapodia which are hollow, and the mobile lateral extensions of the body surface or by gills which are rich in blood capillaries.

Excretory system

Excretion takes place by segmental paired **nephridia** which are found in most of the segments. Each nephridium. (Fig. 195), consists of a **ciliated funnel** or **nephrostome** which is found in one segment. The nephrostome leads to a **ciliated tubule** which pierces the intersegmental septum and becomes greatly coiled forming several loops which are surrounded by two capillary networks. The ciliated tubule leads to a wide **non-ciliated**

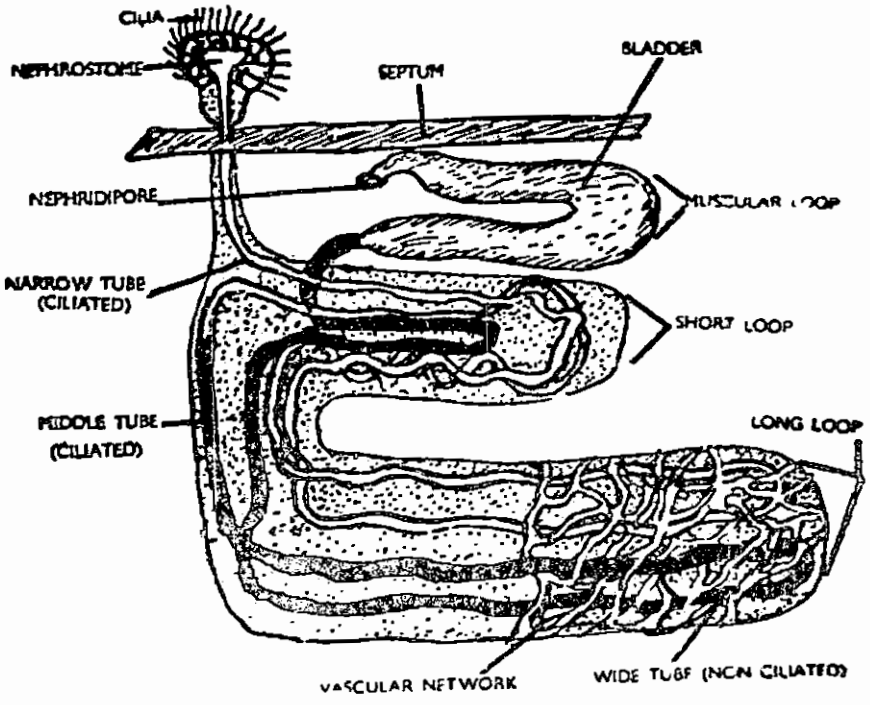


Fig. 195 — Diagram of the nephridium of an earthworm

tubule which expands to form a **bladder-like** structure which opens to the exterior by the **nephridipore.** Different regions of the tubule are specialized for different processes.

Excretion takes place as follows :

(*a*) by means of cilia wastes from the coleom are drawn into the nephrostome and tubule.

(*b*) in the glandular region of the nephredium wastes in the blood are removed and passed in the lumen of the tubules. The nephridia not only remove waste material (urea, etc.), but also serve for : 1. salt and water balance, which is of great importance in aquatic and terrestrial environment. A considerable reabsorption of salts takes place in the nephridia. In the terrestrial earthworms reabsorption of water by the nephridia is essential in water conservation especially when the soil becomes dry; 2. the nephridia are used in the removal of products of erythrocuroin destruction.

In addition to the nephridia the chloragogen cells surrounding the alimentary canal, extract waste products and salts from the blood. These waste products are deposited in these cells which are released in the coelom

as free cells, the **eleocytes.** These cells either break up and pass through the nephrostome, or they are destroyed by amoeboid cells in the coelomic fluid

Nervous system (Fig. 196).

The nervous system is more advanced than that of acoelomates. It shows a high degree of metameric arrangement. It consists of the central system and peripheral nerves. The central system consists of :

A pair of suprapharyngeal ganglia (the brain; inhibitory center) just above the pharynx, a pair of circumpharyngeal connectives which pass around the pharynx to the subpharyngeal ganglia (center of motor control and vital reflexed stimulatory center), a **ventral nerve** cord with a pair of fused ganglia in each somite. The ventral nerve cord is formed of two closely united cords

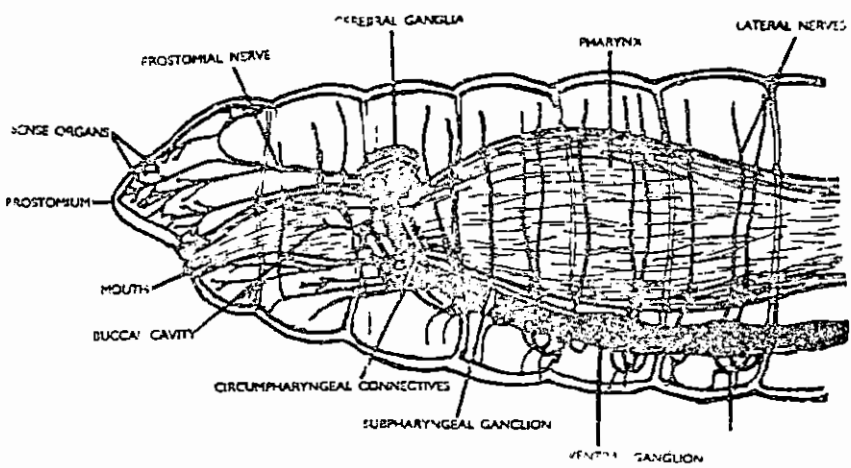


Fig. 196 — Anterior region of the earthworm showing the nervous system

The **peripheral nervous system** consists of nerves which arise from the central system. Each pair of ganglia gives off three or four pairs of lateral nerves which innervate the muscles, epidermis, nephridia, and setae in each somite. Each nerve consists of both **sensory** and **motor nerves,** as found in higher animals. The sensory fibrers come from special sensory cells in the epidermis, while motor fibers run from the cells in the ganglia to muscles or glands. The peripheral nervous system is composed of element which have definite connect on in the nerve cord, thus it differs from the simple nerve net of *Hydra.*

In addition, the brain may contain **neurosecretory cells** and the segmental ganglia have **chromaffin cells** which have an endocrine function. The nerve cord of earthworms is provided with five **giant fibers,** the axons of which are fused end to end at inter-segmental synapses which allow rapid transmission of nerve impulses (at a rate of 100 feet/second; in other nerves 20 feet/second). These giant fibers are used for rapid escape movements.

There is a **visceral nervous system** (entire nerve system) which consists of **pharyngeal ganglia** and nerves which innervate the muscles of the gut.

Behaviour

Earthworms are adapted for their mode of life. Although they do not possess specialized sense organs, they react to various stimuli such as light, contact, moisture, chemicals; sound; etc. Most oligochaetes are negatively phototropic to strong light and positive to weak light. Earthworms react positively to moderate vibratory mechanical stimuli. They also respond to various chemical stimuli. Their chemical responses aid them in the choice of food.

Experimental studies showed that earthworms have some learning ability. This type of learning is usually associated with a reward. An earthworm is trained to turn into the dark by receiving an electric shock if it moved into the lighted region. The dark is its **'preferred'** environment and provides the reward.

Locomotion

Locomotion in the earthworm is carried by extension, contraction and flexion of the body caused by the muscle layers, and also by the use of setae. By action of the retractor muscles the seta are drawn into their sheath. Protractor muscles (Fig. 191) cause the setae to protrude and can be moved forward and backward thus acting as little levers. The setae serve to propel the body in either directions within the burrows.

Reproductive system of the common earthworm, Allolobophora

Allolobophora is hermaphrodite. **The female organs** (Fig. 198) consist of : (*a*) a pair of small ovaries lying in segment no. 13. Each **ovary** is pear-shaped and is attached to the posterior surface of the anterior septum of the segment; (*b*) a pair of **oviducts** which open by ciliated **ovarian funnels** in segment **no. 13.** Each ovarian funnel leads into an enlarged

ovisac which joins a short oviduct to open to the exterior by the female genital opening on segment no. 14. In the ovisac the eggs mature; (*c*) a pair of rounded **spermathecae** (seminal receptacles) in segments no. 10 and 11 which opens to the outside in the grooves between segments no. 10 and 11 and 11 and 12 (Fig. 197). The spermathecae receive sperms from the other worm.

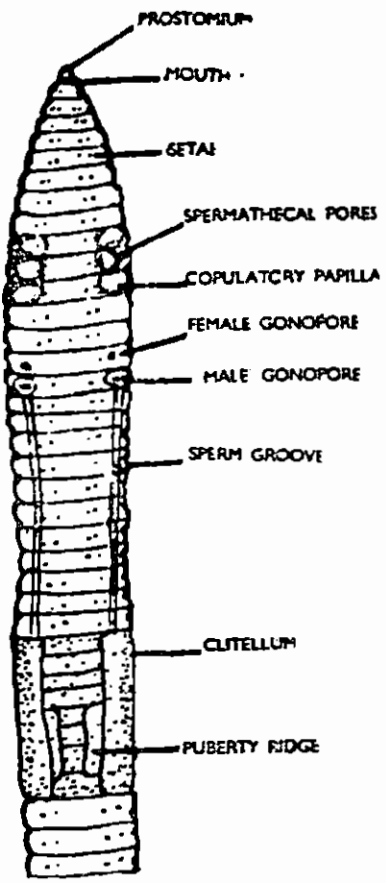


Fig. 197 — The common earthworm, Allolobophora caliginosa, antero-ventral view

The **male reproductive organs** are composed of :

(*a*) Two pairs of glove-shaped **testes** found in segments no. 10 and 11.

(*b*) Opposite each testis there is a ciliated **seminal funnel** which leads to a fine **vas efferens** which penetrates the septum and joins the vas efferens of the posterior testis. The two vasa efferentia unite to form

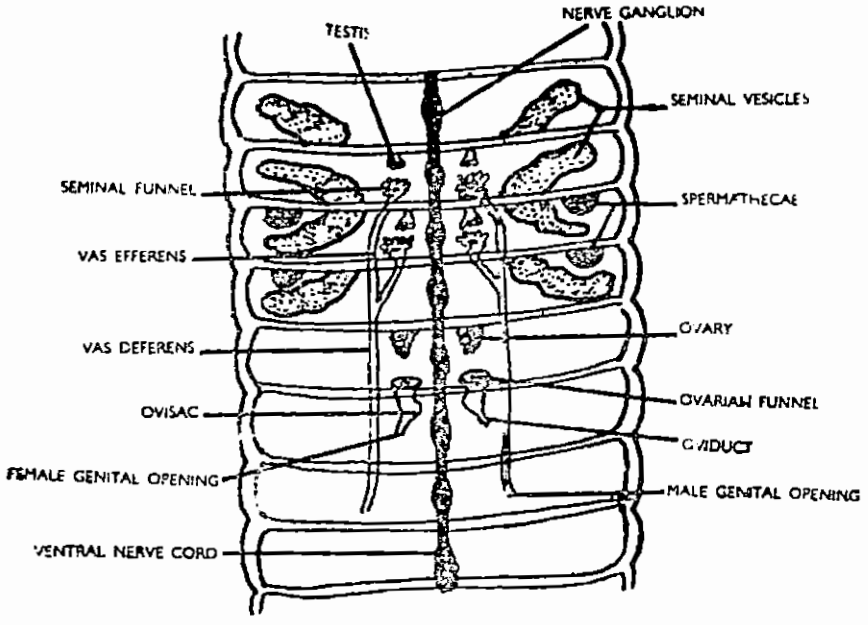


Fig. 198 Allobophora caliginosa Diagram showing reproductive system

the vas deferens The two vasa deferenita open by the male genital pores on the ventral surface of segment no 14.

(*c*) Four pairs of **seminal vesicles** lie on the sides of the oesophagus in segments 9 – 12

Life cycle

The sperm cells are produced in the testis, matured in the seminal vesicle and passed out through the vas efferens and vas deferens. Eggs are set free in the coleom and are collected by the ciliated funnels leading to the oviducts. Mature ova are stored in the ovisacs.

Copulation takes place between two worms in such a way that the anterior ends are in opposite directions (Fig. 199) and the two ventral surfaces are in contact. The clitellar region of one worm lies opposite the spermathecal region of the other. The worms are held together by slime tubes secreted by the clitellar and skin glands, and may also by the genital setae (modified ventral setae).

The sperms of one worm pass to the seminal receptacles of the other through the canals formed by the opposite **seminal grooves** (Fig 199) on the ventral surface of the two worms The movement of the sperms

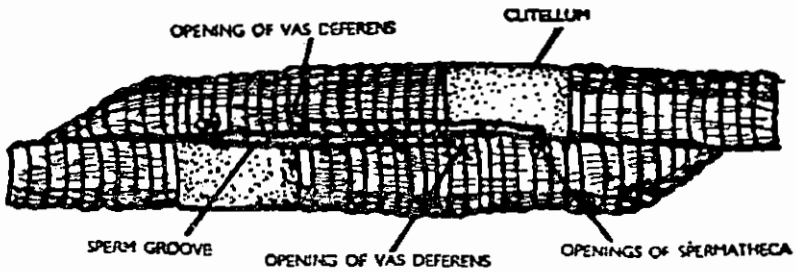


Fig. 199 — Diagram representing copulation in the common earthworm

along the seminal grooves is aided by the contraction of the muscles forming the groove.

After copulation which lasts for to three hours the two worms separate. Few days after copulation the clitellum secretes a band-like cocoon for the deposition of the eggs. The cocoon is formed of chitin-like material which surrounds the clitellar region. Then the clitellar glands secrete albumin in the space between the clitellum and cocoon. The worm then drags itself backwards and as the cocoon passes over the worm it receives eggs from the female gonopores and sperms from the seminal receptacles. As the coccon slips over the anterior end of the worm, it becomes free and its two ends constrict and close (Fig. 200). Fertilization takes

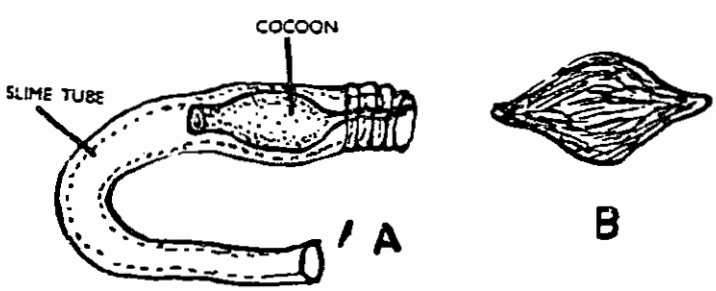


Fig. 200 — The earthworm : A) slime tube containing cocoon; B) cocoon

place after the cocoon is slipped over the head. The cocoon is left in the soil, and the fertilized eggs develop into embryos which are nourished by the albumen inside the cocoon. The cocoon contains two to twenty eggs. When hatching the young is similar to the adult.

Regeneration and grafting

Earthworms have considerable power of regeneration. They are able to regenerate lost or cut segments. If an earthworm is cut into two between

segments 15 and 18, the anterior piece will regenerate a tail, and the posterior piece, a new head. No more than five new segments will regenerate at the anterior end. No head will regenerate if the cut part is posterior to segment 18. In such cases a worm develops with two tails, such worm will starve and eventually dies. It has been shown that regeneration of missing posterior segments depends on the presence of the cerebral ganglia. The suboesophageal ganglia seems to be essential for regeneration. However, the ganglia are associated with removal of certain blood vessels that carry neurosecretory products from the cerebral ganglia. These products are essential for regeneration.

Leeches have little or no regenerative power. Regeneration of the earthworms seems to follow the axial gradient therory which emphasises the physiological dominance of the anterior end.

Earthworms can be grafted, and several pieces from different worms can be grafted together to form a long worm. By grafting a two-headed or two-tailed worm can be made by joining together suitable parts of several worms. Grafting is done until they become united.

Relation of annelids to man

Earthworms are used by anglers as bait for catching fish. They also form food for certain birds. The activities of earthworms have beneficial effects on the soil. They increase the fertility of the soil by making burrows which help in the following manner : (*a*) increase soil drainage and aeration; (*b*) make the soil loose and more porous; (*c*) mixing of the soil; (*d*) help the roots of plants to penetrate deep into the soil; and (*e*) aid nitrogen fixing bacteria to make use of nitrogen.

Earthworms bring up the subsoil to the surface as castings and mix it with the toposil, while organic material is moved to lower levels. It has been estimated that earthworms bring up about 7.5 to 18 tons of earth per acre annually. The worm feeds on the soil and vegetable debris which passes through the intestine and egested through the anus as castings. In doing so the leaves of plants and organic matter are ground up in the gizzard into fine particles. Then these pass into the intestine where digestive enzymes are secreted. The egested substances enrich the soil with valuable nitrogenous products as well as metabolic products. An earthworm is able to ingest its own weight of the soil every 24 hours. Earthworms bring nutritive salts which are found in the subsoil such as potassium and phosphorous to the top-soil.

Due to the importance of earthworms many authors recommend their culture in the soil in order to build up fertility of any soil. Extensive studies

are necessary to select the type of earthworm suitable for culturing. After culturing, worms and their eggs are introduced into the soil.

Then use of the medical leech (*Hirudo medicinailis*) is known by doctors in early times, and one day the practice of medicine was spoken as "leechery". Leeches were used to suck the blood of sick persons as it was believed that there was an upset in the balance of body fluids. Nowadays in many countries barbers keep leeches for this purpose.

Leeches may live on land, in humid tropical regions, or in streams. They may attack human beings dwelling these areas, attach themselves to their skin and suck an appreciable amount of their blood. If a large number of these leeches attacked a human being death may occur resuling from loss of his blood Man may get attacked by leeches if he swims in infected streams. These leeches may enter the urinary passages where they hang on for months.

PHYLUM ARTHROPODA

The Arthropoda is the most extensive group of animals in the animal kingdom, including more than three-fourths of all known species (about 800,000 species). It includes the crustaceans (prawns, crabs, lobsters, water fleas; cyclops; etc); spiders, millipedes, centipedes, ticks; mites and insects. Arthropods live in a greater variety of habitats than any other phylum. They are adapted for life in and on land, in water and in the air. They are often found in places where no other forms could survive. Some arthropods are parasitic on plants and animals, although parasitism is not dominant in this group. The social organization of insects is not represented in any other invertebrate group. The gregarious termites, ants and bees have worked out marvelous systems of division of labour of great ingenuity and complexity.

The word "arthropod" referred to the paired jointed-appendages characteristic of this phylum. Arthropods are means of greatest competitors contending for food supplies and spreading serious diseases. However, some arthropods are useful; lobsters, crabs, shrimps are used sa food; the silkworm furnishes clothing; insects are necessary for cross-polination of plants, bees furnish honey and beewax, and other insects yield useful drugs and dyes.

General characters

1. Bilaterally symmetrical, triploblastic coelomate animals. The coelom is greatly reduced and is only represented by the cavity of gonads and excre-

tory organs. The body spaces of arthropods are sinuses or spaces filled with blood and hence called **haemocoele.**

2. The body is metamerically segmented, but the body cavity is not segmented. All the segments or some of them carry paired jointed appendages which may be similar or are modified to perform certain functions. Thus the appendages round the mouth form the mouth parts which help in feeding.

3. The body is covered with a unique external skeleton; the exoskeleton which is secreted by the hypodermis.

4. The circulatory system is of the open type where blood flows in blood sinuses.

5. Excretion takes place by coxal glands or malpighian tubules or both.

6. Respiration may be by gills, tracheae or lung books which represent an efficient breathing mechanism.

7. Presence of striated muscles ensuring rapidity in movement.

8. The nervous system and sense organs are highly developed.

STRUCTURAL AND PHYSIOLOGICAL CHARACTERS

1. **Exoskeleton** (Fig. 201).

It is a nonliving, noncellular substance secreted by the underlying epidermis. It is a protein-carbohydrate compound and is composed of several different substances. It consists of two layers :

1. The **epicuticle** is a thin outer layer composed of proteins and lipids but lacks chitin.

2. **Procuticle** which is a much thicker layer and contains chitin. It is composed of an outer **exocuticle** and an inner **endocuticle.** Chitin is an acetate of the polysaccharide that contains glycosamine as the most important constituent. In Crustacea the procuticle may be impregnated with mineral salts (calcium carbonate and phosphate). The procuticle is an impermeable covering, but in certain areas when it is thin it allows the passage of gases or absorption of water. The cuticle is secreted by a one layered **hypodermis** which contains dermal glands specialized in the secretion of the moulting fluid. The hypodermis is followed by the **basement membrane.**

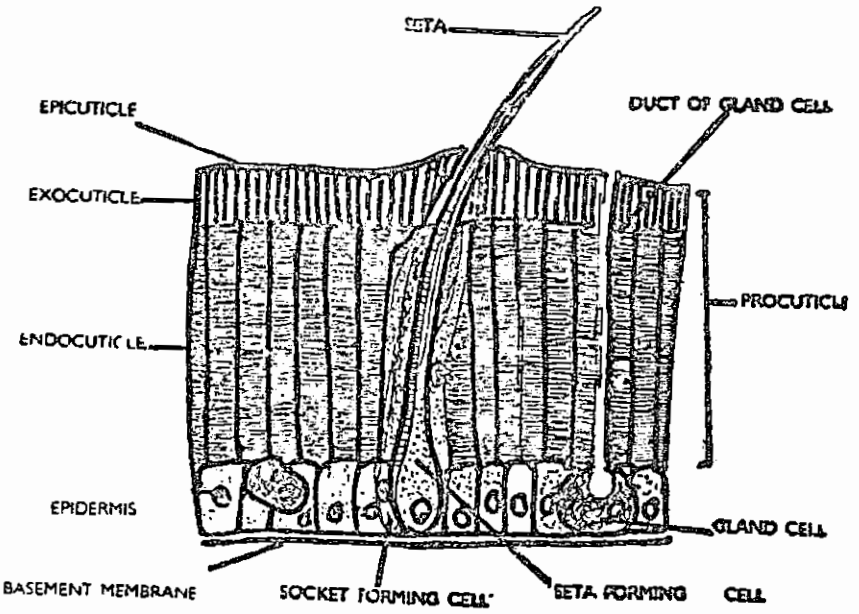


Fig. 201 — Section of insect integument

This hard exoskeleton is adapted to perform many functions :

1. attachment of muscles,
2. protection of the delicate internal organs,
3. serving as levers and centers of movement,
4. preventing the entrance and loss of water,
5. affording maximum amount of protection without sacrificing mobility, and
6. elaboration of complex sensory receptors especially the unique compound eyes.

The presence of the exoskeleton leads to many of the special characters of arthropods such as :

1. The presence of **joints** and **jointed appendages.** Since the exoskeleton is hard so movement is impossible if it is formed of a continuous sheet. Movement, however, is made possible, by the fact that the cuticle is laid into separate plates or **sclerites** which are connected together by **articular** or **arthrodial membranes.** In this membrane the cuticle is very thin and flexible where the middle hard layer of the cuticle is absent. The cuticular skeleton of the appendages is made up of tube-like segments

connected to one another by **articular membranes**. Thus each appendage has a **joint** at each junction.

2. **Ecdysis (moulting).** Due to the presence of hard exoskeleton, the gradual increase in size is impossible. In order to grow, the arthropod must shed its exoskeleton at intervals, and growth takes place while the new exoskeleton is still thin and flexible. This process is called **ecdysis.** Just before moulting the epidermal glands secrete a **moulting fluid** which contains enzymes which digest the chitin and proteins of the inner layers of the old cuticle thus separating the cuticle from the hypodermis. Under the old cuticle a new soft, flexible and folded epicuticle is secreted which is imprevious to the secreted enzymes. The animal may swallow water or air to aid in swelling up and bursting the old cuticle. Moulting is under the control of hormones secreted by the sinus gland in the eye stalk, and the **juvenile hormone** secreted by the corpora allata in insects (see page 490).

3. **Muscles.** The presence of a hard exoskeleton formed of plates and jointed appendages necessitates the presence of separate muscles forming a complex system to render movement possible. The muscles are of the striated type and are attached to the inner surface of the exoskeleton across the joints. This arangement is quite different from that found in vertebrates where the muscles are attached to the endoskeleton. In an annelid the muscles form two cylinders lying beneath the epidermis.

In arthropods the muscles are attached to the procuticle by special fibers inserted on the inner surface. Flexion and extension plates are affected by the contraction of these muscles.

Nervous System

The nervous system has reached a high degree of cephalization. The increase in the brain size is correlated with the well developed sense organs such as the eyes and antennae. In addition, there are special nerves such as the optic, auditory, and olfactory nerves.

Respiratory System

Respiration takes place either by gills, lung books or tracheae. In many arthropods especially insects the respiratory system is highly developed to meet the need of oxygen for great movements. The tracheal system of land arthropods is made of highly efficient system of air tubes which deliver the oxygen directly to the cells This makes possible the high metabolism characteristic of active insects.

The tracheal tubes consist of a single layer of cells lined with cuticle

which is shed out at moulting. The larger tubes are covered by spiral threads of chitin which prevent them from collapsing. The finer air tubes or tracheoles are connected directly to the tissues to deliver oxygen and carry away carbon dioxide. In addition, there are several air sacs in the abdomen, which pump air in and out of the tracheal system by the alternate expansion and contraction of the abdomen. The tracheae open to outside by the spiracles.

CLASSIFICATION OF ARTHROPODA

The classification of the arthropods is complex. The main classes are as follows :

Class 1 **ONYCHOPHORA**

Arthropods with a thin cuticle and a soft muscular body wall. e.g. *Peripatus*.

Class 2. – **TRILOBITA**

Fossil arthropods with body moulded into three lobes; one pair of antennae, e.g. *Olanus*.

Class 3. — **CRUSTACEA**

Aquatic arthropods with two pairs of antennae, e.g. *Penaeus* (Prawn).

Class 4. – **MYRIAPODA**

Terrestrial arthropods with one pair of antennae and many pairs of walking legs, e.g. *Julus*.

Class 5. — **ARACHNIDA**

Terrestrial and aquatic arthropods with the first appendage chelate, not antennate, e.g. *Buthus* and *Limulus*.

Class 6. — **INSECTA**

Three pairs of walking legs, e.g. *Periplaneta americana* (the cockroach).

CLASSIFICATION OF CLASS HEXAPODA (INSECTA)

Insects are classified into two subclasses according to the presence, absence and development of wings and the type of metamorphosis. The following is the classification of insects with a description of the main orders.

Subclass I **Apterygota** (**Ametabola**) (Gr., a, not; pterygotos, wing). It includes primitive wingless insects, with little or no metamorphosis, usually with style-like appendages on pregenital abdominal segment in addition to cerci. It includes the **silver-fish** (*Thermobia aegyptiaca*), **cotton springtail** (*Lepidocyrtinus incertus*) and the **banana springtail** (*Entomobrya muscatica*).

Subclass II **Pterygota** (**Metabola**) (Gr. pterygotos, winged) Insects of this class are winged, but if wingless the condition is secondarily, there are no abdominal appendages except cerci and genitalia. This subclass is divided into two divisions :

Division I. **Expoterygota** (**Heterometabola**), (Gr. exo, outside; pterygotos, winged). It includes insects with wings which develop externally as outgrowths of the thorax; with slight, incomplete or gradual metamorphosis. The larval stage is a nymph with the full number of segments and which changes into adult after few ecdyses. This division includes about 17 orders, the most important of which are :

Order **Orthoptera** (orthos, straight; pterin, wing). Its members with two pairs of wings, the anterior pair is thickened and the hind wing is soft and can be folded under the forewing, incomplete metamorphosis and biting mouth parts. This order includes **locusts** (*Schistocera gregaria*); **grasshoppers** (*Homorocoryphus nitidulus*), **crickets** (*Gryllotalpa gryllotalpa*) and the **cockroach** (*Periplaneta*).

Order **Isoptera** which includes **termites.** They are often called wrongly white ants. Insects of this order are characterised by presence of similar wings, biting mouth-parts and gradual metamorphosis. They are social and polymorphic insects which live in communities. The common Egyptian termite is *Holotermes ochraceus*.

Order **Anopleura** (Gr. anoplos, unarmed; oura, tail). Small wingless dorsoventrally flattened insects, with piercing and sucking mouth parts and no metamorphosis. They are ectoparasites on birds and mammals. This order includes the **Lice**, *Pediculus humanus*; *Phthirius pubis* (**pubic louse**).

Order **Hemiptera** (Gr. hemi, half; pteron, wing). The forewings are thickened and leather-like at the base, and membranous at the distal half, with piercing and sucking mouth parts and with gradual metamorphosis. It includes the bugs; the **bed-bug** (*Cimex*), the **green cotton bug** (*Nezara viridula*), and the **water bug** (*Lethocerus niloticum*).

Division II. **Endopterygota** (**Holometabola**) (Gr. endon, inside). Insects with complete metamorphosis including larval and pupal stages, their wings develop from inside.

Order **Diptera** (Gr. di, two). It includes insects characterised by having only two wings, the hind wings are modified into halteres, with piercing and sucking mouth, part. It includes long-horned flies, **mosquitos** (*Culex*), **moth flies** and **black flies.** Short-horned (antennae 5 or less segmented) include the **fruitfly,** *Ceratitis capitata*; *Drosophila melanogaster*; the **housefly** *Musca*; and **fleshfly,** *Sarcophaga.*

Order **Siphenaptera** (**Aphaniptera**). It includes the **fleas** which are small, wingless laterally compressed ectoparastic insects, with legs adapted for leaping. Compound eyes are lacking, mouth parts of the piercing and sucking type, with complete metamorphosis. Examples are the **man flea** (*Pulex*), the **rat flea** (*Xenopsylla*), and the **cat flea** (*Ctenocephalus felis*).

Class — INSECTA

THE COCKROACHES

These are common pests of storerooms, kitchens, sinks. bakeries, sewage and places where warmth, darkness and food are available. The cockroaches are spread all over the world. They are noctural animals, hiding in holes and crevices during day and come out at night to feed. Cockroaches are fast runners, though they can fly.

In Egypt there are four common kinds of cockroaches :

Periplaneta americana; *Blatta orientalis*; *Blatta germanica* and *Rhyllodromia supellectilium*

PERIPLANETA AMERICANA

It is one of the largest cockroaches reaching up to 4 cm. long. The body is elongate, 20 segmented and dorsoventrally flattened It consists of the head, thorax and abdomen (Fig. 202). The head is connected to the

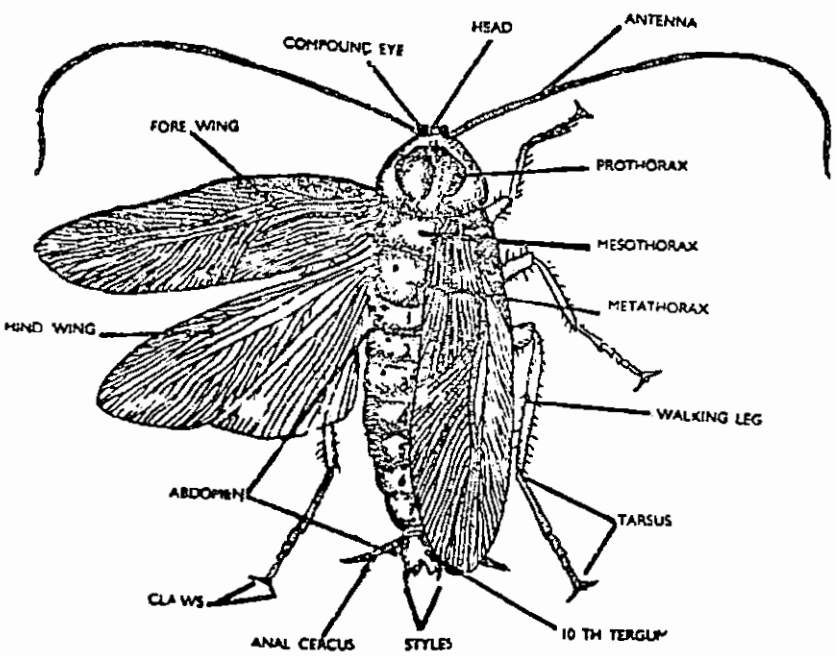


Fig. 202 — Periplaneta americana. Dorsal view of adult male

thorax by a slender and soft neck. The head is usually bent beneath the thorax. The body is covered with hard brown-coloured exoskeleton. The exoskeleton of each segment is made up of plates called sclerites which are joined by thin flexible articular or arthrodial membranes which permit movement freely. There are four main sclerites in each segment, a dorsal tergum, a ventral sternum and a pleuron on each side.

Head

The **head** is oval in shape, flattened and broader than long. It lies at a right angle to the long axis of the body. It is highly mobile in all directions on account of the flexible neck. The exoskeleton enclosing the head is called **head capsule** and is made up of several sclerites (Fig. 203). The sutures between these sclerites are obliterated. The top of the head is covered by the **epicranium** which is formed by the fusion of two epicranial plates separated in the nymph by a Y-shaped **epicranial suture.** The topmost part of the epicranium is called **vertex.** Posterior to the vertex on the back of the head lies the occiput. Below the epicranium there is the frons which is connected to a ventral plate, the **clypeus.** The lower part of the clypeus is membranous and from it hangs the **labrum** or **upper lip.** The lateral sclerites are the **genae** or cheeks.

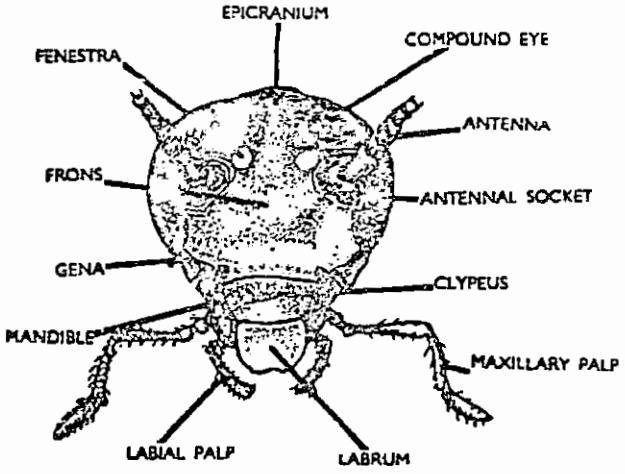


Fig. 203 — Periplaneta americana. Front view of the head

On the laterodorsal sides of the head there is a pair of large compound eyes. Each eye is made up of a large number of visual units, the **ommatidia.** The cornea covering the eye is in the form of hexagonal facets each of which represents the upper surface of an ommatidium. In the angle

between the eyes there are two small oval areas called **fenestrae** which represent undeveloped **ocelli** (simple eyes). At the posterior end of the head there is an occipital foramen connecting the cavity of the head with that of the body.

The head is made up of six segments, the first and third segments are devoid of appendages. A pair of long filiform many-jointed **antennae** arise from membranous antennal sockets each lying below the eye in a sclerite called **fossa.** Each antenna consists of a large basal **scape,** a smaller **pedicel** and a long filamentous many-jointed **flagellum.** The other three appendages of the head are modified to form the biting mouth parts (Fig. 204) which consist of the **mandibles, maxillae** and **labium.**

The **labrum** or upper lip is a flat oblong plate lying in front of the mouth and covers the anterior surface of the mandibles. The labrum does not represent an appendage. The **mandibles** are stout dark strongly

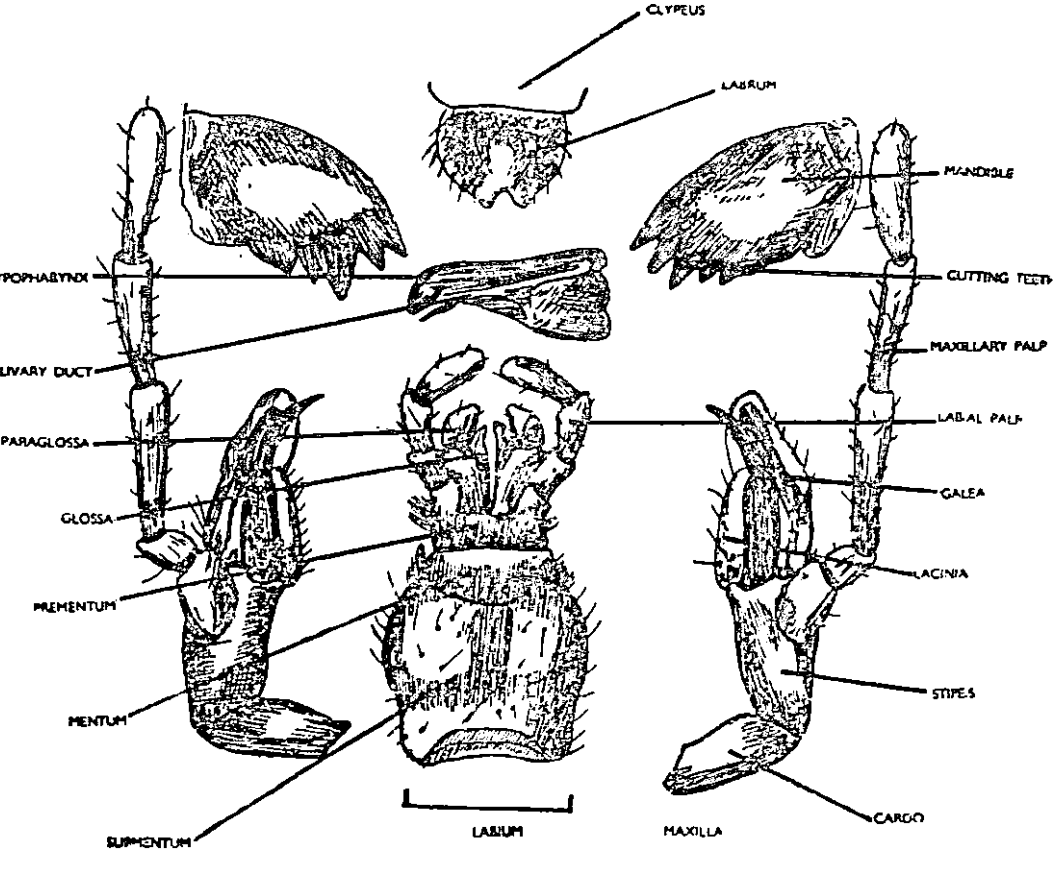


Fig. 204 — Periplaneta americana Mouth parts

chitinized jaws with inner toothed cutting edges and crushing surfaces which work against one another laterally. There are two **maxillae,** each consisting of a basal part made up of a **cardo** and a **stipes.** The latter carries at its outer edge an elongated five - jointed sensory **maxillary palp.** On the inner side of the stipes arises an outer hook-like elongated **galea,** and an inner flat blade, the **lacinia** ending into two sharp claw-like projections. The inner surface of the lacinia is covered with short bristles. The maxillae are used to hold the food by the claws of the lacinia and bring it to the mandibles for mastication. The **labium** or lower lip consists originally of the second pair of maxillae which are fused at the base. The proximal portion of the labium consists of a large **submentum** and a small **mentum.** The distal portion is a paired structure fused at its base. It is made up of a bilobed **prementum,** a pair of outer-three-jointed sensory **labial palps** and four lobes in between the labial palps; two median small **glossae** and two outer larger **paraglossae.** The labium takes no active part in feeding but the glossae and paraglossae prevent the loss of food particles from the mandibles. The **hypopharynx** is a flat cylindrical tongue-like structure which projects from the mouth, with the opening of the salivary duct at its base.

Thorax

The thorax is composed of three segments, **prothorax, mesothorax** and **metathorax.** The **prothorax** is covered with a large shield-like tergum, the pronotum which extends forward to cover the neck and head. The terga covering the mesothorax and metothorax are smaller and are called **mesonotum** and **metanotum** respectively. The thorax carries three pairs of walking legs (Fig. 205) which articulate with the thoracic segments between the pleuron and sternum by a basal coxa. The latter is followed by a small articulating **trochanter**; a long broad **femur**; a slender tibia covered with stout bristles and a five-jointed **tarsus.** The joints of the tarsus are movable and terminate with two curved claws and, a median short hollow lobe, the **pulvillus.** The latter is an adhesive organ for holding on smooth surfaces.

The **mesothorax** and **metathorax** bear a pair of wings (Fig. 202). The fore wing arises from the anterolateral margins of the tergum of the mesothorax. It is called **tegmina** and is dark coloured and heavily chitinzed. The tegmina covers and protects the delicate hind wing when in folded stage. The hind wings arise from the mesothorax, They are membranous and larger than the fore wings, and when rest they lie folded below the tegmina. The wings arise as double, membranous outgrowths of the integument strengthened by a network of ridges, the veins or nervures which are strongly chitinzed and enclose fine tracheae

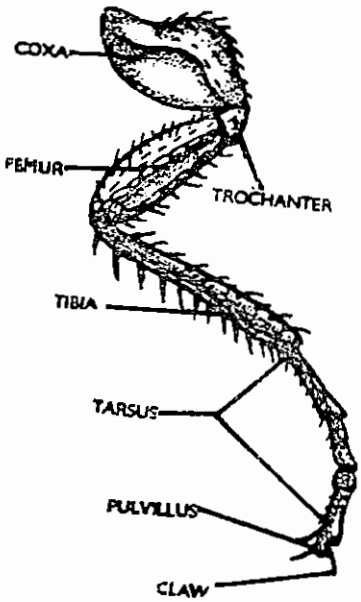


Fig. 205 – Periplaneta. Walking leg

Abdomen

It consists of ten segments in the adult and eleven segments in the embryo. The anterior seven terga are visible externally while the 8th and 9th are narrow and telescoped or overlapped by the tergum in front. The 10th tergum is large, shield-shaped and notched posteriorly. The **podecal plate** bears a pair of many jointed movable anal **cerci.** Each cercus bears a sense organ receptive to sound. The anus lies beneath the 10th tergum in between a pair of podical plates which may represent the vestiges of the 11th segment. The posterior end and the structures it carries differ in both sexes.

In the **male** (Fig. 206) the posterior end is rather narrower than that of the female. Nine sterna are visible externally. The 9th sternum carries a pair of unjointed slender **styles.** On the ventral surface of the 9th sternum there is a concavity which forms a pouch which contains the **genital opening** and holds the complex **genital apparatus** made up of chitinous hooks and plates, the **gonapophyses.**

In the **female** the broad abdomen has seven externally visible sterna (Fig. 206). The rest are modified in relation to the reproductive organs and are hidden by the 7th sternum. The latter is prolonged posteriorly into a boat-shaped structure which is divided lateraly into two halves and forms the lower wall of the **genital pouch.** This pouch is enclosed in the 7th sternum and belongs to the 8th and 9th segments. The genital pouch

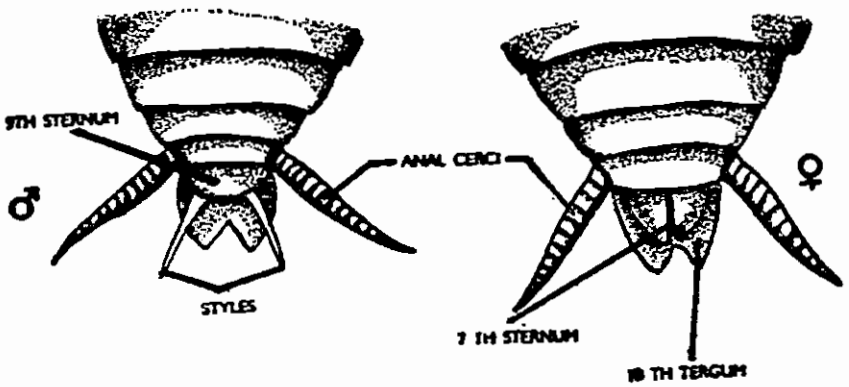


Fig. 206 — Periplaneta. Ventral view of the posterior end

contains the female genital aperture and three pairs of curved appendages, the **gonapophyses.**

There are ten pairs of respiratory openings, the **spiracles,** two on the thorax and 8 on the abdomen. The first thoracic spiracle is large and lies between the pleura of the pro- and mesothorax; the seond pair between the meso-and metathorax. The abdominal spiracles lie on the first eight segments, the first pair of abdominal spiracles lies dorsally on the first abdominal tergum, the remaining seven pairs on the pleura of segments 2 — 8.

INTERNAL ANATOMY

Alimentary canal (Fig. 207).

It consists of three regions; **stomodaeum** (foregut); **mesenteron** (midgut) and **proctodaeum** (hindgut). The stomodaeum and proctodaeum are ectodermal in origin and are thus lined with a thin chitinous cuticle which is continuous with that of the exoskeleton. The mesenteron is short and is lined with endodermal cells.

The **stomodaeum** consists of a pre-oral food cavity, mouth, oesophagus, and crop. The pre-oral cavity is not a true buccal cavity as it lies in front of the mouth. It is surrounded by the labrum in front, the labium from behind and the mandibles and maxillae on the lateral sides. The hypopharynx lies into the pre-oral cavity and receives the opening of the **common salivary duct** at its base. The mouth opens at the base of the pre-oral cavity and is followed by a long **oesophagus** which dilates into a large thin-walled **crop.** The latter extends in the abdomen and opens into a thick walled muscular, globular **gizzard** or **proventriculus.** The cuticular

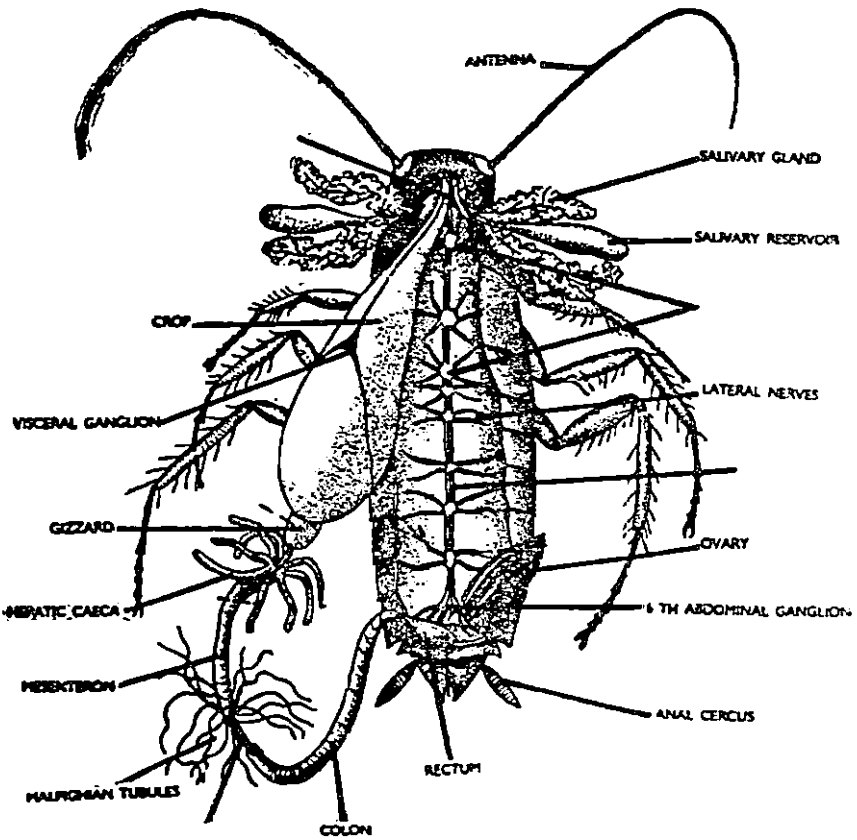


Fig. 207 — Periplaneta americana. Digestive and nervous systems

lining of the gizzard is in the form of 6 teeth-like plates with deep grooves in between which are provided by fine bristles. In the gizzard the food is ground up by the aid of the teeth and then strained by the bristles, and only fine food particles pass on the mid gut.

The **mesenteron** is a short narrow tube where digestion and absorption is completed. The endodermal cells lining the mesenteron break down while secreting their contents. Attached to the anterinr end of the midgut are 7 — 8 **hepatic** or **mesenteric caeca** which play a role in digestion and absorption.

The mesenteron leads into a looped proctodaeum which consists of an anterior short narrow ileum, a longer and wider colon and a short and dilated rectum. The latter opens posteriorly by the anus below the 10th tergum. The lining of the rectum is in the form of 6 longitudinal folds.

At the junction of the mesenteron and ileum there is a large number of very fine greenish yellow **Malpighian tubules** which are concerned with excretion.

At the anterior end of the alimentary canal there is a pair of **salivary glands** lying alongside the crop in the thorax. Each gland consists of two glandular lobes and a **reservoir** (Fig. 208). From each **glandular lobe** arises a duct which joins its follow from the same side to form a common duct. The left and right common ducts unite to form one duct which joins the common duct arising from the two reservoirs. Both ducts unite to form a larger **common salivary duct** which opens at the base of the **hypopharynx** (Fig. 208). The ducts of the glands and reservoir have spirally thickened cuticular lining.

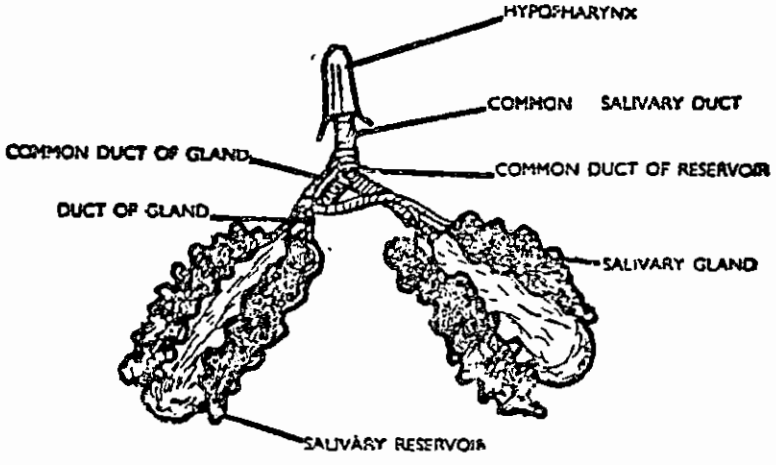


Fig. 208 — Periplaneta americana, salivary apparatus

Food and digestion

Cockroaches are omnivorous insects that feed on any kind of animal or plant origin. They feed on dead insects, vegetable remains and even its own cuticle after it is shed. The maxillae pick up and carry food to the mandibles which crush and chew the food by the aid of their strong inner teeth. The maxillae and labium then push the food into the pre-oral cavity from where it goes into the mouth. The function of the hypopharynx is obscure. The food which is mixed with the saliva in the pre-oral cavity passes from the mouth into the oesophagus and then to the crop. The saliva contains an enzyme amylase which acts upon the carbohydrates changing them into glucose. In the crop digestion of other food substances takes place by the action of enzymes which pass into the crop from the

midgut through the grooves of the gizzard. In the gizzard food is crushed and only fine particles are passed into the mid gut. The mid gut and hepatic caeca secrete enzymes that act upon proteins and fats in an acid medium. In the cockroach all classes of enzymes are produced except that represented by pepsin which is characteristic of vertebrates. Digestion in the midgut proceeds in a thin chitinous tube, the peritrophic membrane which is secreted by special cells lining the gizzard. The peritrophic membrane is permeable to enzymes and digested food. It protects the lining of the midgut from hard food particles. Digested food is absorbed in the midgut and hepatic caeca. In the rectum water is absorbed from undigested food, a means of conservation of water in insects. Some of the absorbed food is stored as reserve food in the form of glycogen, fat and albuminous substances in the fat **bodies** lying in the haemocoele.

Respiratory system

The respiratory system of the cockroach consists of :

1. a series of paired respiratory openings, the **spiracles,** on the sides of the body. The spiracles are guarded by valves which can open and close by special muscles to regulate the flow of air.

2. a system of longitudinal tubes which extend throughout the length of the body on each side forming **dorsal** and **ventral trunks.** These trunks are connected with the spiracles and with one another and anastomose to form a network of **tracheae** which send branches to every part of the body (Fig. 210).

3. a series of muscles and skeletal structures by which the insect can pump air in and out of the system of tracheae. By alternate expansion and contraction of the abdominal cavity, alternation of inflow and outflow of air takes place.

A trachea (Fig. 209) is covered with a single layer of thin epithelial cells, and is lined by a thin cuticle called **intima** which in large tracheae forms spiral thickinings to prevent them from collapsing. Each trachea ends into a stellate **end cell,** the tracheal cell from which arises a number of fine **tracheoles** which are lined with a very thin cuticle without spiral thickenings. The tracheoles are less than 1 micron in diameter and they are connected directly to tissue cells where they surround the cells and end blindly within them. Thus, the cells obtain their oxygen from the air directly and not through the blood.

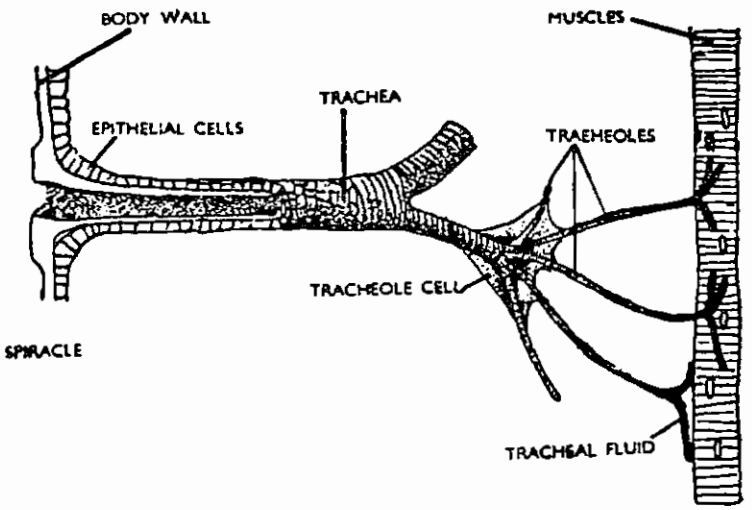


Fig. 209 — Diagram showing relationship of spiracle and tracheoles to trachea

Mechanism of respiration

When resting air enters passively into the spiracles. When active the abdominal muscles move causing air to enter the spiracles. Air then passes into the tracheoles where it dissolves in the water filling them by the force of capillarity. Thus the cells obtain their oxygen directly from the air dissolved in the tracheoles. During great activity (flying or running) water is withdrawn from the tracheoles to the tissue fluids, the spaces left in the tracheoles become filled with air moving along them. Since oxygen diffuses much more rapidly through air than through water, the effect of this is to improve the supply of oxygen to the cells.

In **expiration** carbon dioxide may pass through the cuticular covering of the body. Carbon dioxide may dissolve in the blood plasma and reach the body surface which is permeable to gases and thus carbon dioxide passes out. In addition some carbon dioxide may pass through the spiracles.

Respiratory movements are coordinated by nerves in each segment. These nerves receive impulses from the thoracic ganglia which control the respiratory movements.

The first thoracic and first abdominal spiracles remain open all the time for expiration, while the other 8 pairs of spiracles open during inspiration and close during expiration, a means by which respiratory gases are not mixed.

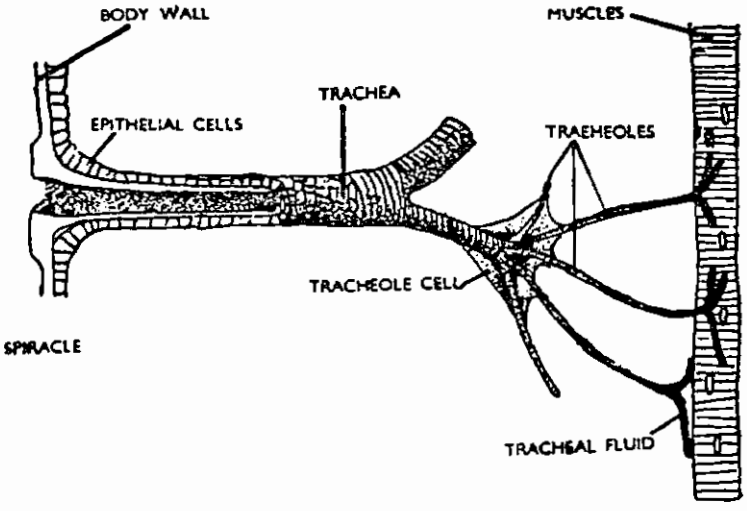


Fig. 209 — Diagram showing relationship of spiracle and tracheoles to trachea

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The circulatory system consists of: 1. a tubular **heart** situated mid-dorsally along the thorax and abdomen, just under the body wall. The heart consists of 13 chambers, 3 in the thorax and 10 in the abdomen. Each chamber has a pair of **ostia,** one on each side. The ostia are guarded by valves which permit the passage of blood into the heart. A large **pericardial sinus** formed by a delicate dorsal diaphragm surrounds the heart. The wall of the heart is made up of a single layer of cells having muscles; 2. anteriorly the heart passes into a narrow **dorsal aorta** which extends into the head region; and 3. haemocoele which is made up of spaces surrounding the various tissues, the largest cavity being the **perivisceral sinus** which forms the main body cavity surrounding the various organs.

Blood is pumped into the dorsal aorta by a series of rythmic contractions which begins at the posterior chamber and moves forward. From the aorta blood passes slowly into the haemocoele. The blood moves backwards from the haemocoele and passes into the pericardial sinus through holes in the dorsal diaphragm. The blood enters into the ostia aided by the contraction of paired alary muscles attached to the diaphragm.

Both the perivisceral and pericardial sinuses are filled with a loose mass of whitish tissue forming the fat body. The latter consists of vacuolated cells rich in fat. This tissue serves as a store for food material and as an excretory organ as it contains considerable amount of nitrogenous waste in form of urates.

Excretory system

It consists of a large number of long, unbranched blind-ending, fine **Malpighian tubules** attached to the beginning of the hindgut and hang freely in the haemocoele. Each tubule is lined with a single layer of large secretory cells which have the power to extract waste nitrogenous products (urates and uric acid) from the blood.

Recent studies showed that in the distal end of Malpighian tubule, water, nitrogenous waste products and dissolved salts pass into the lumen by a process involving active secretion. In the proximal end of the tubule and the rectum, water and some essential salts are reabsorbed and a concentrate containing uric acid crystals and urates pass into the hindgut to be excreted with the faeces. Thus **Malpighian tubules** are adapted for water conservation, an adaptation to full terrestrial life of arthropods.

Excretion may be carried by the **fat bodies** where waste uric acid is stored. **Nephrocytes** which are groups of cells found along the heart may store nitrogenous products which are removed later by the blood.

Nervous system (Fig. 211).

The nervous system of the cockroach consists of :

1. a pair of **supraoesophageal ganglia** (**brain**) on the dorsal side of the head which are formed by the fusion of three pairs of ganglia. The brain is concerned mainly with sensory functions. It supplies nerves to the eyes, antennae and labrum.

2. a pair of **circumoesophageal connectives** which pass around the

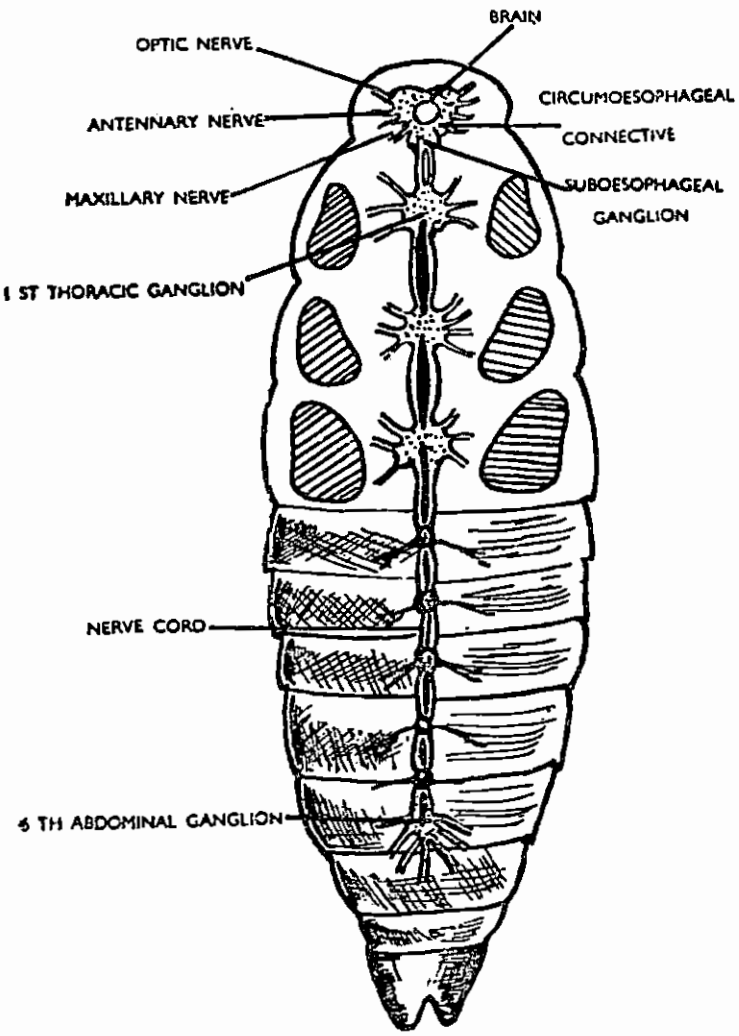


Fig. 211 — Periplaneta. Nervous system

oesophagus to connect the supraoesophageal ganglia with the suboesophageal ganglia.

3. a **suboesophageal ganglion** which lies below the oesophagus. It is formed by the fusion of three pairs of ganglia, and is the main motor centre which controls the movements of muscles, wings, mouth parts and legs. From the suboesophageal ganglion nerves arise to supply the mandibles, maxillae and labium.

4. a double **ventral nerve cord** extends from the suboesophageal ganglion and passes backwards along the ventral side of body. The two cords are fused together and contains three thoracic ganglia, and six **abdominal ganglia.** The last abdominal ganglion is large and is formed by the fusion of several ganglia. From it arises five pairs of peripheral nerves which innervate the last five abdominal segments. From each of the other ganglia several pairs of nerves supply the various parts of their respective segments.

There is a **sympathetic nervous system** which consists of: (*a*) a **frontal ganglion** in front of the brain; (*b*) two **oesophageal ganglia** behind the brain; (*c*) a large **visceral ganglion** lying on the top of the crop, and (*d*) nerves which connect these ganglia with the brain and supply the muscles, alimentary canal and spiracles. The main nerve is the **stomatogastric nerve** which runs on the dorsal side of the crop.

Sense organs

These include the compound eyes and various receptors sensitive to light, sound, touch, temperature change; taste and smell. These receptors are calld **sensillae** (Fig. 212). Each sensilla consists of a modified bristle, two or more **trichogen cells** which are modified hypodermal cells, and

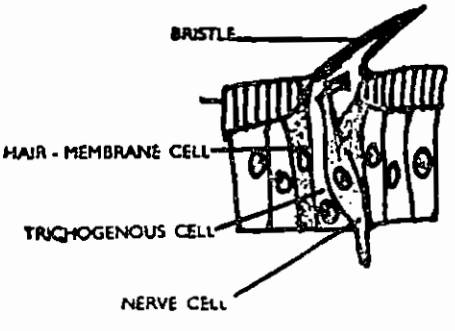


Fig. 212 — Tactile sensilla

a nerve cell ending in a nerve fibre. The sensillae of touch, taste and smell are simple and isolated. Those of hearing are formed of aggregations of sensillae forming elaborate organs. The **tactile sensillae are** located on the hairs of antennae, palpi, legs, cerci and body surface **Olfactory sensillae** are found mainly on the antennae and certain parts of the body. **Taste sensillae** are located on the maxillae, while auditory sensillae are found on the cerci which can detect sounds which the human ear cannot hear.

The **compound eye** consists of visual units called **ommatidia** which are arranged radially and are covered by hexagonal cuticular facets called the **cornea.** An ommatidium (Fig. 213) consists of (*a*) a **lens** (**cornea**) which is a biconvex thickened transparent part of the cuticle; (*b*) **corneagen cells** which are clear cells that secrete the lens; (*c*) **vitrellar or cone cells,** a group of four cells which surrounds the **crystalline cone** that they secrete. The crystalline cone acts as a lens for the refraction of light on the sesnitive retinular cells; (*d*) **retinular cells,** a group of seven **photorecepor cells** which secrete a median spindle-shaped refractive body, the **rhabdome** which is formed of seven **rhabdomeres.** The

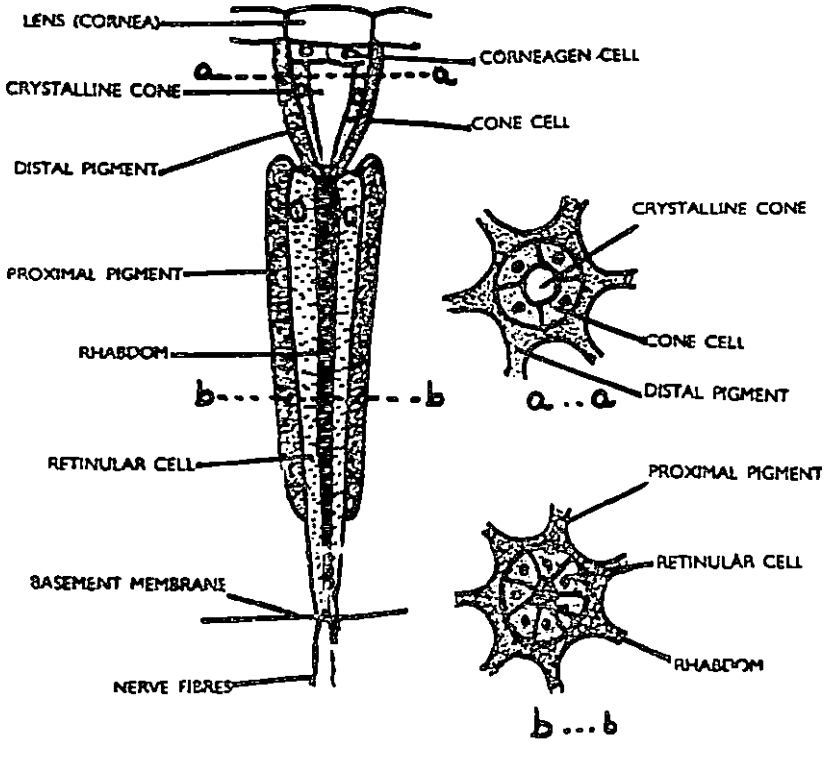


Fig. 213 — L.S. and T.S. of an ommatidium of an insect

visual pigment is probably located with the rhabdome; (*e*) **pigment cells** which separate the adjacent ommatidia. These include proximal and distal pigment cells surrounding the retinular cells and cone respectively. In the cockroach the pigment cells are not retractable. Each ommatidium rests on a basement membrane through which passes nerve fibres from retinula cells to join the optic nerve.

In the cockroach the retinular cells and rhabdome are widely separated from the crystalline cone. Such eye is called **superposition eye** in which ommatidia are not separated from one another by pigment. Each ommatidium is stimulated by light that has entered through a number of ommatidia lenses. Thus overlapping images of the object are seen. Such overlapping images called **superposition images** are not very distinct but they enable the eye to detect movements of objects at once. Eyes of certain insects can distinguish different colours, but not all the colours of the spectrum.

Reproductive system (Fig. 214 A).

Sexes are separate and can be distinguished externally. The **male reproductive organs** consist of: (*a*) a pair of small **testes** which lie below the terga of the 5th and 6th segments being embedded in the fat body. The testes are difficult to be seen in adult males since the sperms are formed at an early stage and stored in the **utricular tubules** of the mushroom-shaped gland. From each testis arises a vas **deferens.** The two vasa deferentia lead to the **seminal vesicles** which are bulbous whitish tubules filled with sperms. The seminal vesicles are covered dorsally by a large

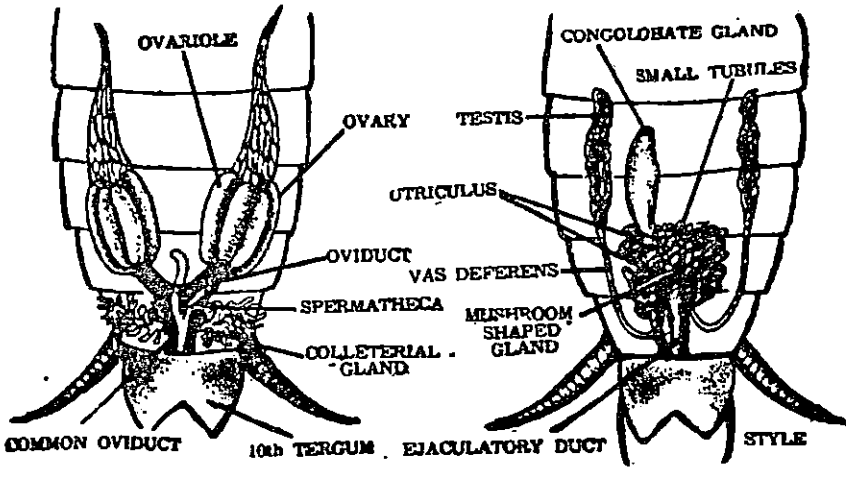


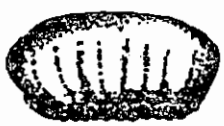
Fig. 214 A — Reptcroduive system of Periplaneta, female and male

white-coloured **utricular gland** which is in the form of long and short tubules comprising the **mushroom-shaped gland.** From the seminal vesicles a single muscular **ejaculatory duct** leads to exterior, opening medially between the 9th and 10th sternum. Opening close to the genital aperture is the duct of the **conglobate gland.** The latter is a slender tubule extending below the ejaculatory duct. The **conglobate gland** may take part in the formation of the outermost layer of the **spermatophore.**

The **female reproductive organs** consist of two **ovaries** which lie in the lateral region of segments 4-6 (Fig. 214 A). Each ovary is formed of eight tubes or **ovarioles,** which are narrow anteriorly and broad posteriorly as the contained eggs become larger. The ovarioles of each side join together posteriorly to form a short wide **oviduct.** The two oviducts unite to form a median **vagina** which opens on the 8th sternum by the **gonopore.** The gonopore lies inside the genital chamber which receives the opening of the **colleterial** glands on its dorsal side. There is a pair of branched colleterial glands, the left gland is large and the right is small. The ducts of the two colleterial glands unite to form a common duct which opens into the genital chamber. There is a pair of **spermathecae** of unequal size, which unite to form a common duct which opens into the genital chamber. The spermathecae receive the sperms from the male during copulation, where they are stored. The secretions of the colleterial glands form the egg-case in which the eggs are laid.

Reproduction and life history

Males copulate with the females by their posterior ends. The sperms which are stuck together to form pear-shaped spermatophores pass from the ejaculatory duct of the male into the spermathecae of the female where they are stored. The eggs are laid alternately from the ovaries and pass from the vagina into the genital chamber where fertilization takes place. The colleterial glands secrete the purse-shaped **egg-capsule** or **ootheca** (Fig. 214 B) which contains 16 fertilized eggs arranged in two rows. The ootheca is formed of dark brown scleroprotein and is about 12 mm long. The ootheca is carried by the female for several days afterwhich it sticks them into dark dry places.



OOTHECA

Fig. 214 B — Ootheca of Periplaneta

The eggs hatch in the form of **nymphs** which are similar to the adult but smaller in size, paler in colour and devoid of wings and the gonads are immature. The nymphs feed on the same food as the adult. They grow and undergo six or seven ecdyses to become adults in about one year. During this period the nymph grows, formation of wings takes place and the gonads become mature. This type of metamorphosis is called **incomplete metamorphosis.**

ORDER ANOPLEURA

THE BODY-LOUSE

PEDICULUS HUMANUS CORPORIS

It is a small apterous insect which lives as an ectoparasite on man where it lies its eggs in his clothes or body hairs.

External features

The adult is dorsoventrally flattened with a conical distinct large **head** (Fig. 215 A). The head has a pair of reduced compound **eyes,** a pair of short 5-jointed antennae but no ocelli. The mouth parts are highly adapted for **piercing** and **sucking** and are not seen externally when not in use as they are withdrawn in a stylet sac within the head.

Mouth parts and feeding mechanism.

The **mouth parts** consist of two tubes (Fig. 215 B). An upper **pharyngeal** tube which opens upon a short projection called the **rostrum** which is armed with small teeth on its inner surface. The lower tube is a backward extension of the front end of the upper tube. This tube contains one pair of stylets each of which is paired at the posterior end. The salivary duct runs between the stylets. When not in use the stylets are withdrawn into a ventral stylet sac.

When the louse is about to suck the blood, the rostrum is evaginated and the teeth maintain a firm hold of the skin of the host. Then the stylets are pushed into the skin aided by special muscles. A puncture is thus formed where the saliva is poured to prevent blood clotting. By the aid of certain muscles the pharyngeal tube is inserted into the wound and the blood of the host is sucked up by the pumping action of the pharyngeal muscles through the blood-channel which is formed when the stylets come together.

The **thorax** is small, apterous and its segments are fused. It carries

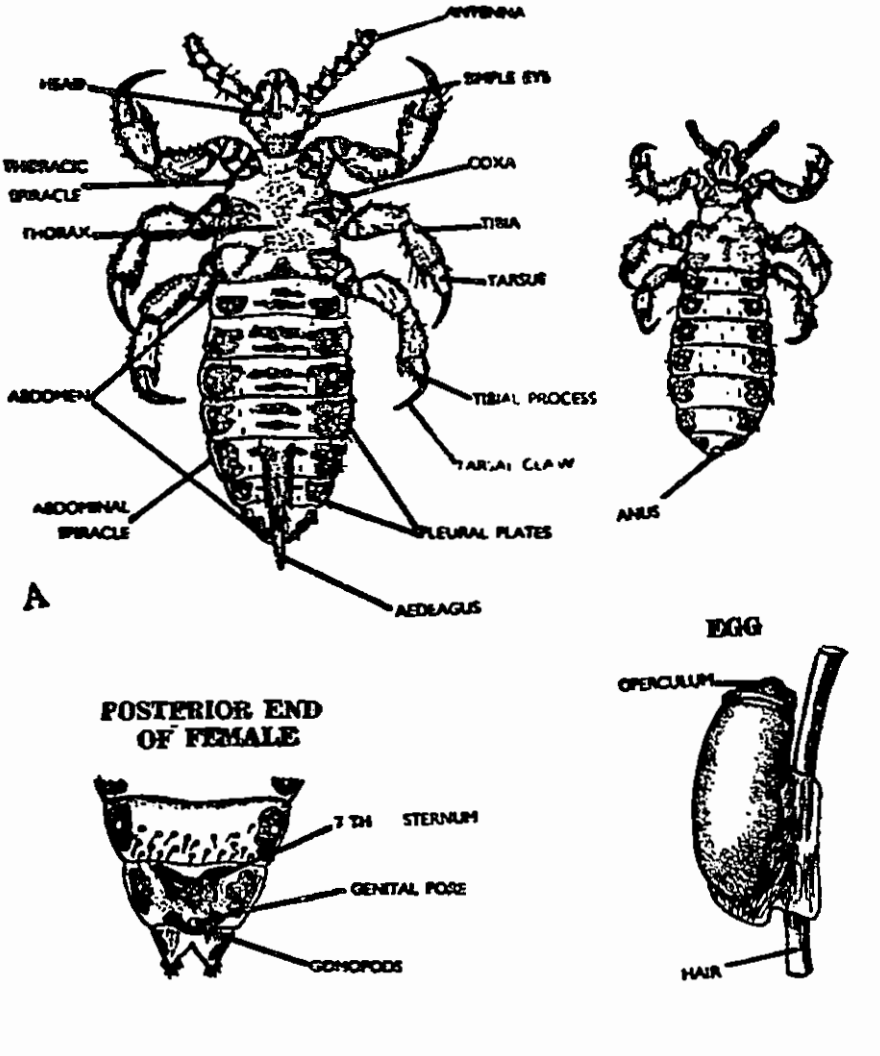


Fig. 215 — Pediculus humanus corporis : A) life cycle and B) diagramatic longitudinal section of head (lower)

three pairs of legs, each with a one-jointed tarsus which ends in a single powerful movable curved claw.

The claw works against a process of the tibia to form a chela-like structure used for clinging to the body or to clasp hairs of its host firmly. One pair of thoracic spiracles is found between the first and second pairs of legs.

The **abdomen** is broad and 9-segmented; the first two abdominal segments are fused while the 9th segment is small. The terga and sterna are thinly chitinized but the pleura are well chitinized and pigmented forming the **pleural plates.**. The 6 pairs of abdominal spiracles open on the pleural plates of segments 2-7.

In the **female** (Fig. 215) the abdomen is broader than that of the female. The 8th abdominal segment is deeply clefted. The female genital opening is on the 8th sternum and is surrounded by a pair of gonopods which are used to hold the cloth fiber (or hair) while laying eggs. The anus is located near the cleft of the terminal segment dorsal to the genital opening.

In the **male** the posterior end is round and directed upwards so that the anal and genital apertures are dorsal in position. The male genital organ which is well developed is in the form of a pointed grooved **aedeagus** (**penis**) which usually projects beyond the posterior end.

Internal anatomy

The **mouth** leads into a suctorial **pharynx** which joins a tubular **oesophagus.** There are two pairs of **salivary glands** located in the thorax and open into the mouth by the **common salivary duct.** The oesophagus opens into a large **stomach** which is bilobed anteriorly. The stomach leads into the **intestine** which joins a short **rectum.** The four **Malpighian tubules** open at the junction of the stomach and intestine.

Life cycle

After copulation the female lays eggs or **nits** at a rate of 8 — 12 eggs daily. An adult female can lay up to 300 eggs during its life which may last for five weeks. The **egg** is ovoid and provided with an operculum (Fig. 215). It is usually fixed to the hair or a cloth fibre by a cement substance.

The egg hatches after a week into a **nymph** which undergoes three moults within 10 — 12 days. The **nymph** is smaller than the adult with three-jointed antennae in the first instar, and lacks the genital organs.

At the third moult the nymph changes into the adult, 14 days after leaving the egg. Thus there is no metamorphosis.

Types of human lice

Two subspecies of the human common louse are known :

1. *Pediculus humanus corporis*, the body louse. It lives in the folds of clothes, but goes to the skin to feed. The eggs are laid on clothes or body hairs. This subspecies is larger in size and paler in colour than the other subspecies, its antennae are more slender and the divisions of abdominal segments are less distinct.

2. *P. humanus capitis*, the head louse. It lives among the hair of the head on which it lays its eggs. It is smaller and darker than the former species. The antennae are thicker and the divisions of abdominal segments are marked.

ORDER HEMIPTERA

THE BED-BUG

CIMEX LECTULARIUS

It is a common blood-sucking ectoparasite of man and probably attacks rodents and birds. It is usually found in dirty crowded places especially bed-rooms where it hides during the day in crevices of the walls, furniture and floors, and emerges during night where it feeds on the blood of man after piercing the skin. There are two species of *Cimex* which are cosmopolitan : *Cimex rotundatus* which is common in Asia and Africa and *C. lectularius* which is found in Europe and America.

Cimex belongs to order **Hemiptera** which is characterized by piercing and sucking mouth parts, absence of palps and anal cerci and the presence of two pairs of wings which may be absent in some bugs. This order includes water bugs, bed-bugs stink-bugs etc.

External features (Fig. 216).

The body is ovoid dorsoventrally flattened and reddish brown in colour. The **head** is large and broad and is partly lodged in lateral extensions of the prothorax. The head bears well developed compound eyes and a pair of 4-jointed long antennae. The ocelli are absent and the clypeus is distinct. The mouth parts are in the form of a 4-segmented proboscis which is bent

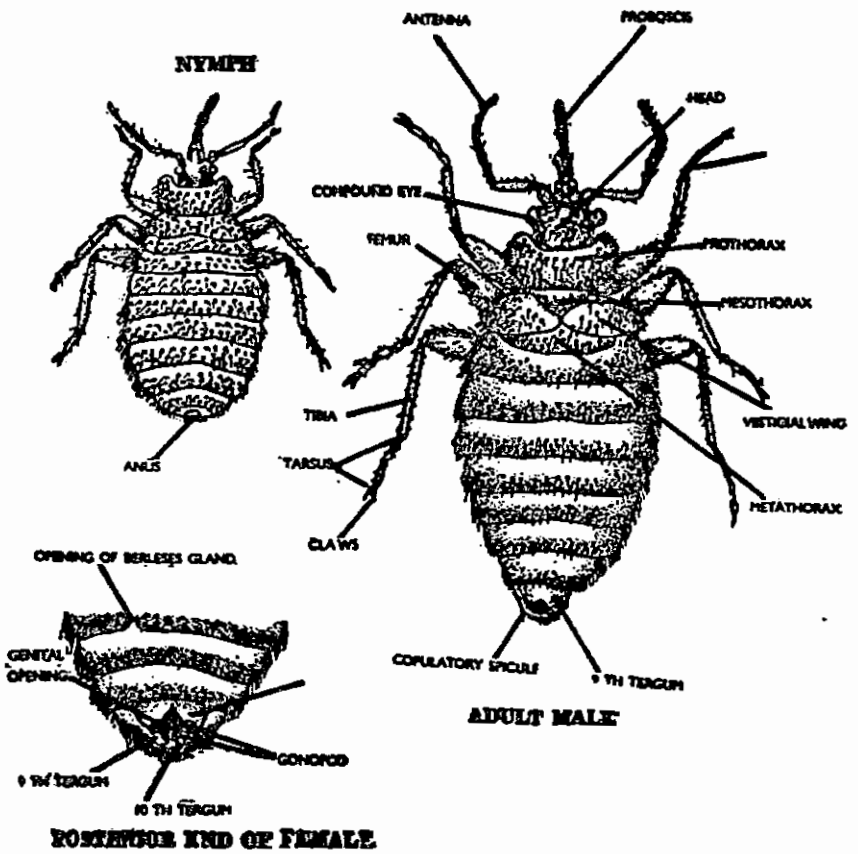


Fig. 216 — Cimex lectularius. The bed bug

under the head in a ventral groove and projects up to bases of the first pair of legs.

Mouth parts and feeding mechanism.

The **mouth parts** are of the **piercing** and **sucking** type (Fig. 217). The labium is 4-segmented with a deep elongated groove on its dorsal side where two pairs of needle-like stylets, the **mandibles** and **maxillae** are lodeged. The two pointed maxillae lie inner to the mandibles which have serrated tips. Each maxilla has two longitudinal grooves on its inner surface. When the two maxillae are fit together, two canals are formed between them; a dorsal large **food canal** for sucking the blood, and a ventral **salivary canal** (duct) through which saliva passes into the wound (Fig. 217). The food canal is connected with a suctorial pharynx

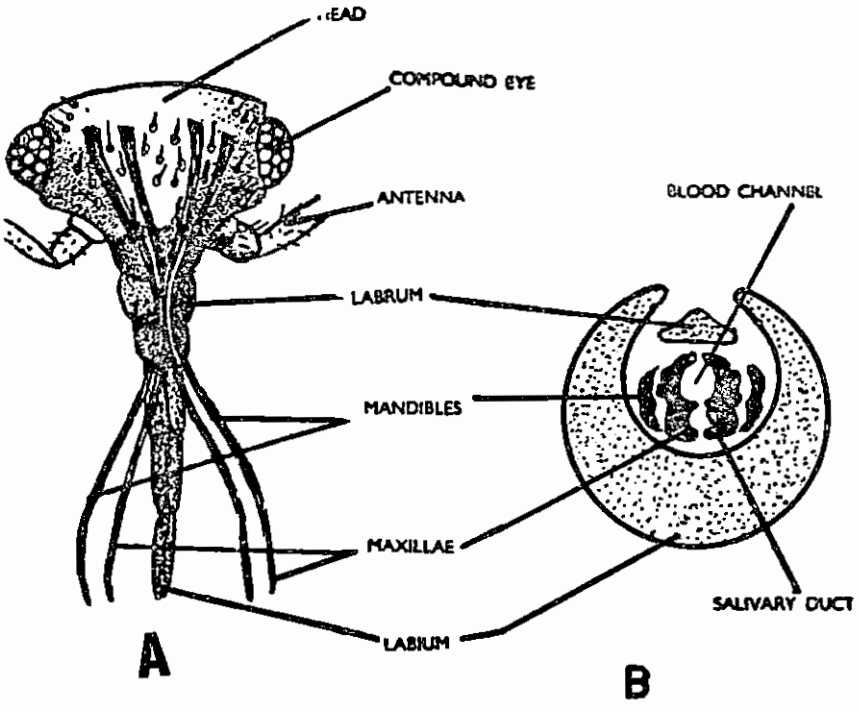


Fig. 217 — Cimex; A) mouth parts; B) T.S. of the mouth parts

which aids in sucking the blood. The mandibles are serrated to pierce the skin. The **labrum-epipharynx** is in the form of a dorsal flap which covers the proximal part of the labium. There are no maxillary or labial palps. When not in use the maxillae and mandibles are kept in the groove of the labium which acts as a sheath. Just at the base of the labium is a fine pointed **hypopharynx.**

When feeding the proboscis is extended and is directed downwards. The ensheathing labium is folded to allow the mandibles and maxillae to be pushed into the skin of the host. Then the saliva is poured through the hypopharynx into the wound through the salivary duct in order to prevent blood coagulation. By the action of the suctorial pharynx blood is sucked up through the food channal then into the alimentary canal. The bite of the bed-bug causes a swelling and irritation of the skin. Bed-bugs can survive without a meal for 6 months or more.

The **thorax** consists of a large **pronotum** (**prothorax**), a small triangular **mesothorax** which has a pair of **vestigial forewings** (Fig. 216), which cover the greater part of the mesothorax. There are three pairs of

long **walking legs**, each with a 3-jointed tarsus terminating with two very sharp claws.

The **abdomen** is 10-segmented, the first being fused with the second, while the 10th segment is small and surrounds the anus. Seven pairs of spiracles are found on the ventral surface of segments 2 to 8.

The posterior end of the abdomen in the female is somewhat broad and rounded as compared to the bluntly pointed posterior end of the male. The 5th sternum of the female has a cleft on its right side where **Berlese's organ opens**. The spermatozoa which are introduced by the aedeagus of the male into this opening, bore through Berlese's organ and pass into the haemocoele from where they reach the oviducts via the blood stream. The female genital opening lies ventrally at the posterior end and is surrounded by small triangular plates the **gonopods (gonapophyses)**. There are no cerci.

From the left side of the 9th sternum of the male protrudes the grooved **copulatory spicule** or **aedeagus** which is used for copulation. The sterna of the 8th and 9th segments are somewhat asymmetrical.

Internal anatomy

The **oesophagus** leads to a tubular **stomach** which leads to the **intestine** and a short **rectum** where the **Malpighian tubules** open. There are two pairs of **salivary glands** which secrete an anticoagulant to prevent the blood from clotting. At the anterior end of the abdomen there are **stink glands** which open, in the adult, on each side of the mesothorax. In the young stage these glands open on the dorsal side of the abdomen. The stink glands secrete a substance which gives the bug its characteristic repellent smell.

Life cycle

The female lays **eggs** in cracks of the walls, floor and furniture, in sleeping places. The egg is yellowish-white in colour, barrel-shaped with a raised lid and contains a **micropyle** at one end. The egg is elongated about 1 mm long. The eggs are laid in patches of 200 — 500 eggs, and a female can lay eggs throughout the year in warm countries.

The eggs hatch within 8 days and a nymph emerges. The **nymph** is yellowish in colour and is smaller than the adult (Fig. 216). It lacks the fore-wings and genital organs. The tarsi of the nymph are two segmented. The nymph moults five times, and within 7 — 24 weeks becomes an adult.

ORDER DIPTERA

It includes insects with a single pair of functional wings, the hind pair is represented by knobbed balancers called halteres. The mouth parts are sucking but may also be piercing or biting usually elongated to form a proboscis. The three thoracic segments are fused, prothorax and metathorax are small. Metamorphosis is complete and the larvae are without legs (apodous) and with a reduced or retracted head. The pupa is either free or enclosed in the hardened larval skin (puparium).

Diptera includes highly specialized insects such as *Culex*, *Anopheles*, *Aedes*, *Musca*, *Glossina*, *Stomoxyx*, etc. Many of these insects have great importance because they harbour and transmit pathogenic organisms causing diseases to man and various animals. These diseases are malaria, sleeping sickness, elephantiasis, yellow fever, dangue, encephalitis, dermatobia, etc.

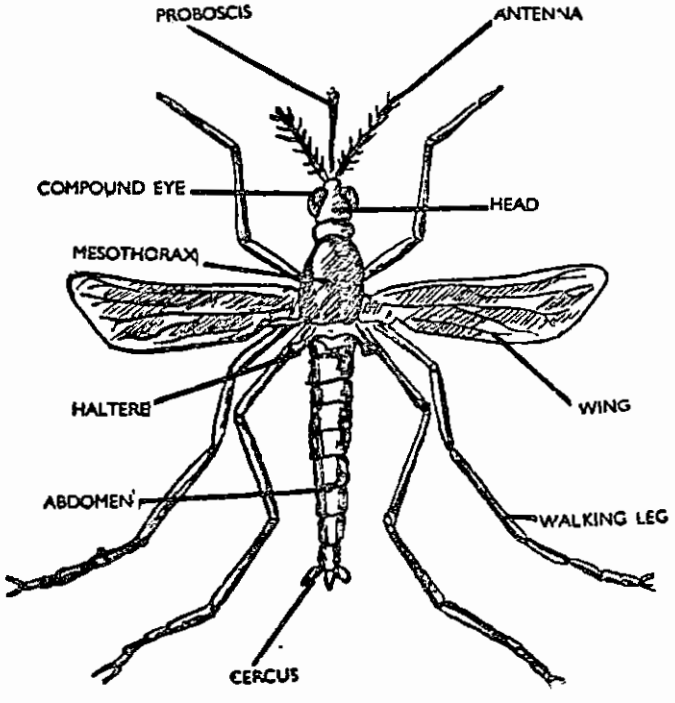


Fig. 218 — A female mosquito

Order **Diptera** includes many families among which are :

1. Family **Culicidae** which includes mosquitos.
2. Family **Anthomyidae** — house fly.

1 — MOSQUITOS

These include *Culex pipiens* (house mosquito); *Anopheles* sp., *Aedes aegyptia* and many others. Mosquitos are commonly known as gnats. Their body is formed of head, thorax and abdomen.

The **head** is provided with a pair of large **compound eyes,** and a pair of long **antennae** which are many jointed and covered with sensory hairs. They provide an easy way of distinguishing between male and female mosquitos. While those of the male carry long hairs (**plumose antennae**) which give them a bushy appearance; those of the female are short and like slender threads (**pilose antennae**).

The mouth parts are modified for piercing and sucking. While the female uses its proboscis for piercing and sucking, the male uses it for sucking only. It is the female that sucks the blood of mammals, the males feed on the juice of plants.

Mouth parts of mosquitos (piercing and sucking types, Fig. 219).

In the female the **labrum** and **epipharynx** are combined to form a sucking tube. The **mandibles** and **maxillae** are elongated slender organs acting as stylets and used for piercing. The mandibles are finer than the maxillae, but both have saw-like edges at their tips. The **food canal** is made by the almost rolled up sharp **labrum-epipharyx** and the elongated lanceolate **hypopharynx.** The salivary duct runs through the hypopharynx to open at its tip (Fig. 220). The saliva contains an anticoagulant which prevents blood from clotting. The labium which represents the fused second maxillae, forms a sheath in which the other mouth parts lie when not in use. The distal end of the labium is provided by a pair of small tactile **labellae** which represent the reduced labial palps.

The labium and other structures which it contains are collectively known as **proboscis** which is a long straight tube. Outside the proboscis there is a pair of **maxillary palps.** The shape of the maxillary palps differs in both females and males. In male *Culex* the maxillary palps are long, 5-jointed stiff structures provided with many bristles and are usually as long as the proboscis. In male *Anopheles* the five-jointed maxillary palps

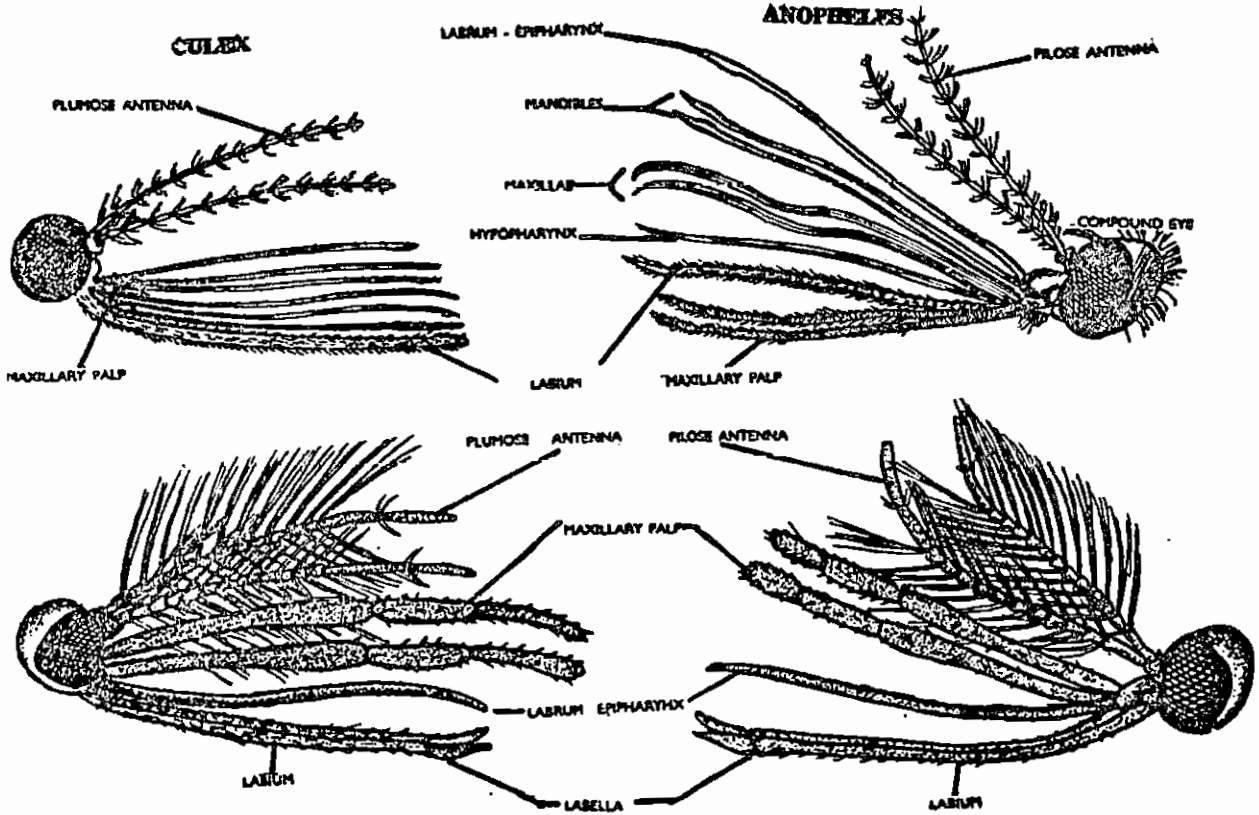


Fig. 219 — Diagram showing mouth parts of male and females Culex and Anopheles

are longer than the proboscis and the terminal two joints are flat and broad, being club-shaped. In female *Culex* the three-jointed maxillary palps are short. In *Anopheles* the maxillary palps of the female are long slender five-jointed structures, usually as long as the proboscis.

In **male mosquitos** the labrum-epipharynx and labium are the same as those of the female, the mandibles and maxillae are very short and functionless, and the hypopharynx is fused with the labium. The maxillary palps are present.

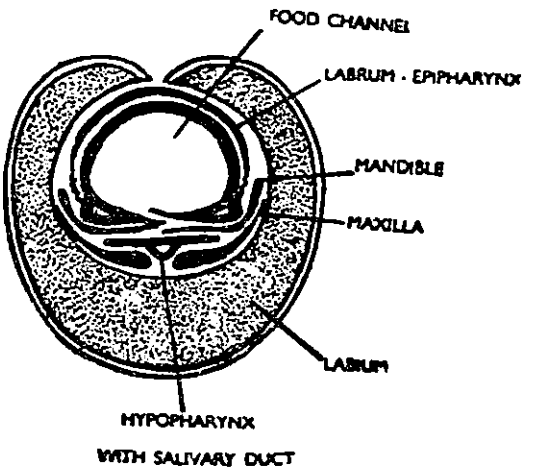


Fig. 220 — T.S. of the proboscis of female mosquito

Feeding mechanism

The mouth parts of mosquitos are adapted for piercing and sucking. The normal food of both sexes are the juices of plants and necter of flowers. However, females can obtain blood from vertebrates on account of their mouth parts which are adapted for that purpose. A female mosquito stands on the skin of a vertebrate, on which it presses its labellae. The labellae act as a guide for the piercing stylets (mandibles, maxillae, labrum-epipharynx and hypopharynx). The stylets are pushed into the skin while the labium is bent back. The saliva is secreted to prevent blood coagulation, and by the sucking action of the pharynx, the blood is sucked up through the food channel. Mosquitos are provided with three oesophageal food reservoirs in addition to the stomach. The reservoirs are usually used to store plant juices and not the blood which passes directly to the stomach.

The thorax

It is separated from the head by a flexible neck The **pro, meso,** and **metathorax** are fused together the prothroax and metathorax are very small. Each segment is provided with a pair of long slender legs The leg consists of a short **coxa, trochanter, femur, tibia** and a long five-jointed **tarsus** terminating into a pair of simple **claws** with a pad-like **pulvillus** below each claw.

The mesothorax bears a pair of wings joined to the anterior region of the dorsal sclerite. The wing is a membraneous fold of the skin in which the epidermis has practically disappeared and the two layers of the cuticle have come together. The wings are strengthened by branched ridges known as **"veins"** or **"nervures".** The veins are hollow and each contains a trachea and a nerve. Wings are used for flight. Simple up and down movements of the wings are sufficient to account for the elementary phenomenon of insect flight.

The metathorax is devoid of wings which are represented by a pair of small knob-like structures, the **halteres** which may assist the insect in maintaining its balance during flight. The halteres vibrate 300 times per second during flight and if removed flight becomes difficult and even impossible.

The abdomen

It consists of ten segments, the first is vestigial and fused with the thorax, while the ninth and tenth are partly telescoped into the eighth. The postrior end of the abdomen is different in both the male and female. In the male a pair of **claspers** and **aedeagi** project posteriorly. The female 10th segment is blunt and carries a pair of **cerci.**

Internal anatomy

It is more or less similar to that of the cockroach. The alimentary canal consists of the **pharynx,** which leads to the **oesophagus** which passes through the neck into the thorax where it divides into two branches a branch connected to the food reservoir which is formed of three **oesophageal diverticula,** the other branch leads into the **midgut** formed of a tubular region leading to a dilated chamber, the **stomach.** The food reservoir is used for storage of food as it is sucked up and is emptied gradually. The stomach leads into the **intestine** in which five long **Malpighian tubules** open. The hind intestine is made up of the distal

intestine and **rectum** which is provided with six papillae.

The salivary glands are situated in the throrax. Each gland is trilobed and opens by the **common salivary duct** which passes to the base of the hypopharynx. The salivary secretion is expelled down the salivary groove at the apex of the hypopharynx.

Life history (Figs. 221 and 222)

Mosquitos lay their eggs on or near the surface of water either fresh or brackish. Different species require different environmental conditions as certain size of a pond, temperature, hydrogen ion concentration, salinity, etc. The number of eggs laid by a single individual varies from 40 — 100 eggs in *Anopheles*, up to 300 or more in *Culex pipens*. While *Anopheles* lays its eggs singly, *Culex* eggs are laid in a compact mass which form boat-shaped rafts which float on water. *Culex* eggs are cigat-shaped tapering at one eud. The eggs of *Anopheles* (Fig. 222) are pointed at both ends, each is provided with a pair of lateral floats and lie borizontally.

Larva

The eggs hatch within 1 to 3 days into legless active larvae which swim beneath the surface of water by wriggling movements of the whole body. The larvae feed on minute food particles in water by means of the brush-like structures which continually sweep a current of water into the mouth. The larva grows and moults four times. It lives from 3 to 14 days depending on the water temperature.

The larva consists of a large chitinous **head** provided with a pair of **larval ocelli** and a pair of the developing compound eyes of the adult (Fig. 221). The head bears a **labrum,** small toothed **mandibles,** a pair of **maxillae, labial plates** and a pair of jointed **antennae.** The head carries a pair of dense tufts of stiff bristles forming the **food brushes.** The throax is globular and its segments are fused. The slender abdomen is nine segmented. The seven anterior abdominal segments and the thorax carries paired tufts of bristles. The anal segment is surrounded at its apex by four **anal papillae** which are small. Most spiracles are closed but two main tracheal tubes open on the eighth segment of the abdomen. In *Culex* the two spiracles open at the tip of a tubular **respiratory siphon** which projects from the eighth segment and is provided by two **pectens** (Fig. 221). In *Anopheles* larva the siphon is lacking and the two spiracles open on a slightly raised quadrilateral plate (Fig. 221). The two spiracles are surrounded by five leaf—like flaps which close the piracles when the larva is under water. When coming to the surface the flaps spread out on the

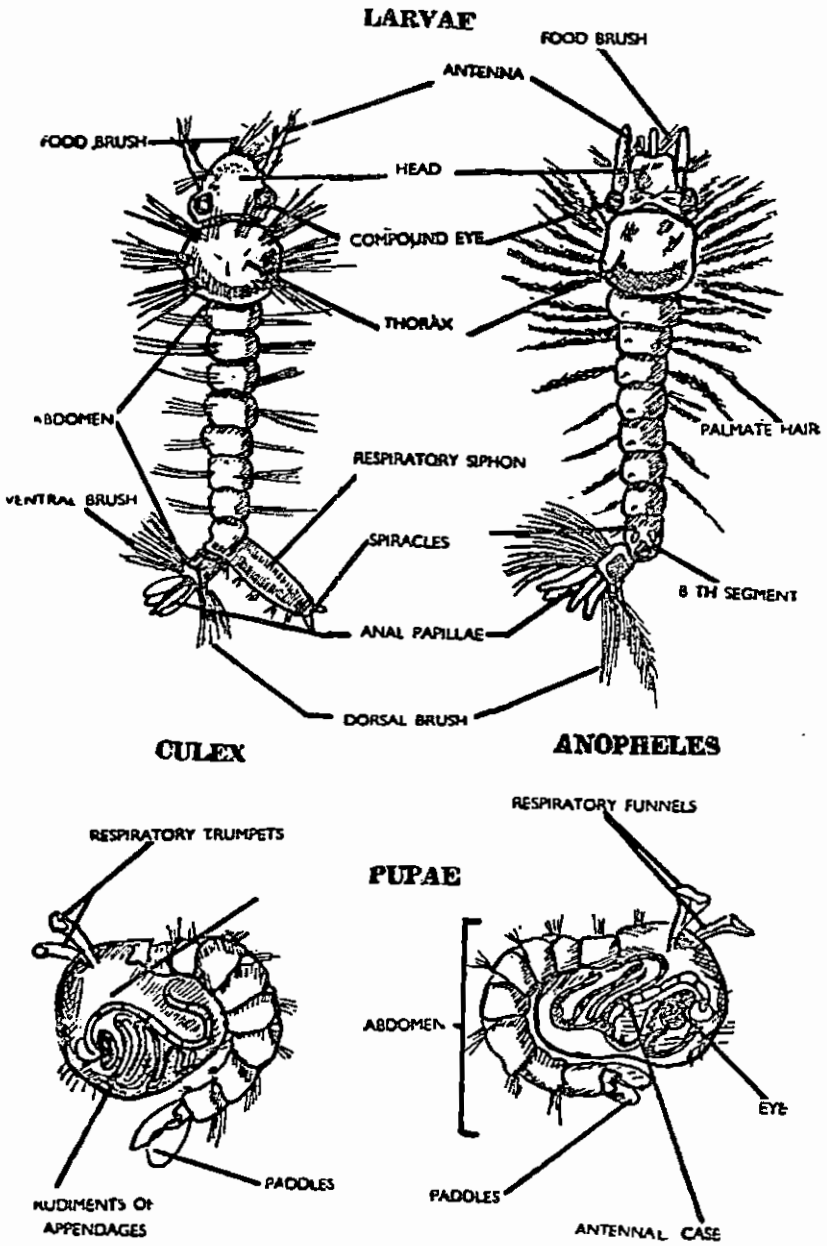


Fig. 221 — Larvae and pupae of Culex and Anopheles

surface film thus exposing the tracheal openings to the air. The nineth segment is slender and is provided by four leaf-like **anal papillae.** These structures were formerly known as gills, but it is now known that they are organs through which water can enter or leave the body, according to the osmotic pressure of the medium; they are also capable of active uptake of ions. The degree of development of anal papillae depends on the salinity of the medium in which the larvae live. The papillae are large in fresh-water forms. The anal segment is covered by a dorsal chitinous plate. It is provided with dorsal and ventral tufts of bristles forming the dorsal and ventral brushes.

The anopheline and culicine larvae can be distinguished by their position in water. Where the former floats horizontally just beneath the surface film, the latter is inclined at an angle of the surface film.

Pupa (Fig. 221).

After four months the larva changes into a comma-shaped pupa. While the formation of the pupa in *Culex* takes from 3 to 15 days, that of *Anopheles* takes 2 to 4 weeks. The pupa can swim but it does not feed. Respiration takes place by a pair of **breathing trumpets** situated on the mid-dorsal side of the cephalothorax. The trumpets communicate with an anterior pair of **thoracic spiracles.** While the trumpets of *Anopheles* pupa are short and broad with a large terminal opening, those of *Culex* pupa are longer and cylindrical with a broad distal end. The pupa floats at the top of the water where it hangs by means of the trumpets (Fig. 222).

The body of the pupa consists of a large **cephalothorax** formed by the head and thorax. Inside the cephalothorax, cases containing the compound eyes, one pair of ocelli, antennae, wings and legs of the adult are found. The ventrally flexed **abdomen** follows the cephalothorax The abdomen is nine segmented with the first being very small The last segment bears a pair of chitinous leaf-like paddles by which the **pupa** swims in the water. Each of the abdominal segments of *Culex* pupa is provided with a pair of tufts of fine branched bristles. On the other hand *Anopheles* pupa has a pair of peg-like spines at the posterior ends of all but the last segment. In addition the abdomen is more curved than that of *Culex* (Fig. 222).

The pupal period lasts from two to seven days druing which remarkable changes take place in the pupa and the adult insect being formed. When fully formed the adult now called **gnats** emerges into the air through a mid-dorsal split between the trumpets. The adult head merges first followed by the body and appendages. It stands on the floating pupal skin until its own has hardened. The adult matures in a week.

Adult Anopheles can be distinguished from *Culex* by the fact that they settle with the proboscis and the long axis of the body in one straight line In *Culex*, the abdomen is usually parallel with or inclined towards the surface upon which the insect rests (Fig. 222).

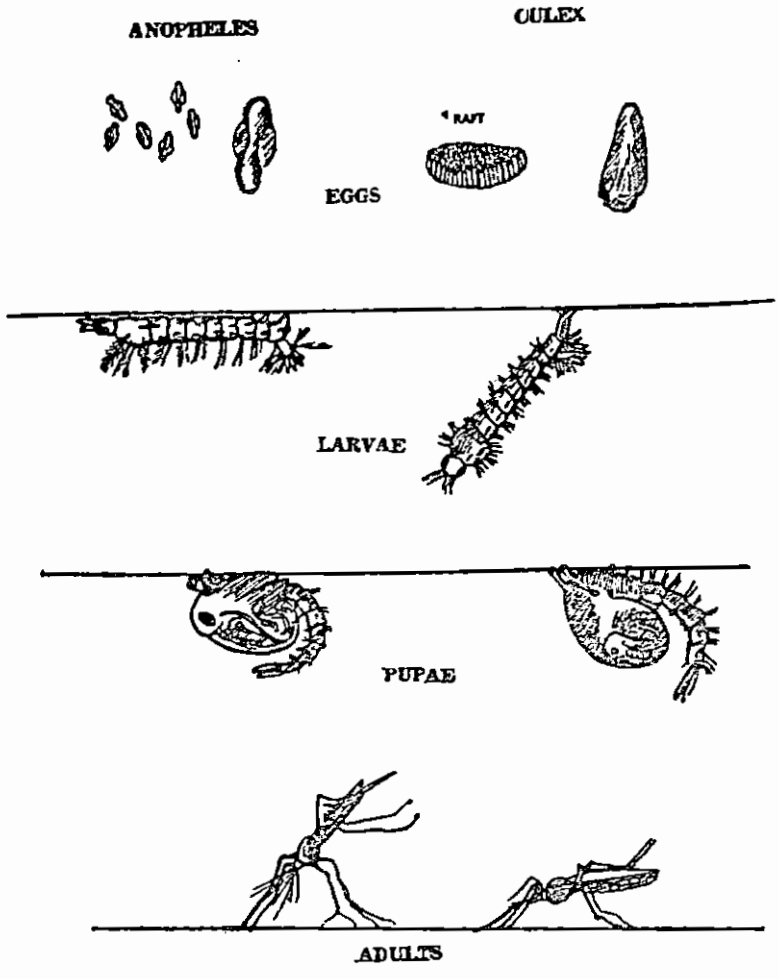


Fig. 222 — Life cycle of Anopheles and Culex

2 — THE COMMON HOUSELY

MUSCA DOMESTICA VICINA

It is the most common housefly in Egypt and many oriental countries. Other species of *Musca* are widely spread all over the world where they are abundant and active during summer and rainy season.

External features

The body is composed of a large mobile head, thorax and abdomen. The **head** bears two large **compound eyes,** three **ocelli** on the epicranium on a triangular ocellar plate and a pair of short three-joined **antennae** lying in a depression. The last joint of each antenna is longer than the rest and is provided with a long plumose bristle called **arista** .The atennae can be raised above the head or withdrawn into the depression.

The **mouth parts** are in the form of an elongated **proboscis** lying under the head (Fig. 223). The proboscis consists of three parts; a basal **rostrum,** a middle **haustellum** and a distal **labella.** The rostrum which is cone-shaped is covered anteriorly with the clypeus. Morphologically the rostrum is a part of the head and carries a pair of one-jointed **maxillary palps.** A chitinous **fulcrum** which encloses the muscular pharynx is found inside the rostrum.

Mouth parts and feeding mechanism

The haustellum is hinged to the rostrum. It is composed of a large ventral (posterior) **labium** provided with a deep anterior groove where the **labrum-epipharynx** and **hypopharynx** are found. The food channel is made up by the grooved labrum-epipharynx and hypopharynx (Fig. 223). The hypopharynx has the **salivary duct.** At the point where the pharynx joins the food channel there is a micro-shaped sclerite, the **prepharynx** which helps to keep the lumen of the pharynx distended. There are two strong chitinous rods, the **stipes** which articulate with the sides of the labrum-epipharynx and rostrum. The stipes and maxillary palps represent the maxillae.

The **labellae** are two large fleshy lobes whose surfaces contain a series of channels, which are kept open by incomplete chitinous rings, thus they look like tracheae and hence called **pseudotracheae.** The pseudotracheae open externally by fine holes through which liquid food is taken in. All the pseudotracheae converge into a mouth lying in between the labellae. The mouth (oral pit) is surrounded by small **prestomal teeth** which act as a file to rasp solid food into very fine particles on which saliva is poured. The mouth parts lack the mandibles, and labial palps.

The mouth parts of the housefly are adapted to feed on organic liquid food which they lap by the aid of the pseudotracheae, hence the mouth parts are called the sponging type. When feeding the labellae are placed into the liquid food which is sucked by the action of the suctorial pharynx. Liquid food or very fine particles pass through the pseudotracheae then

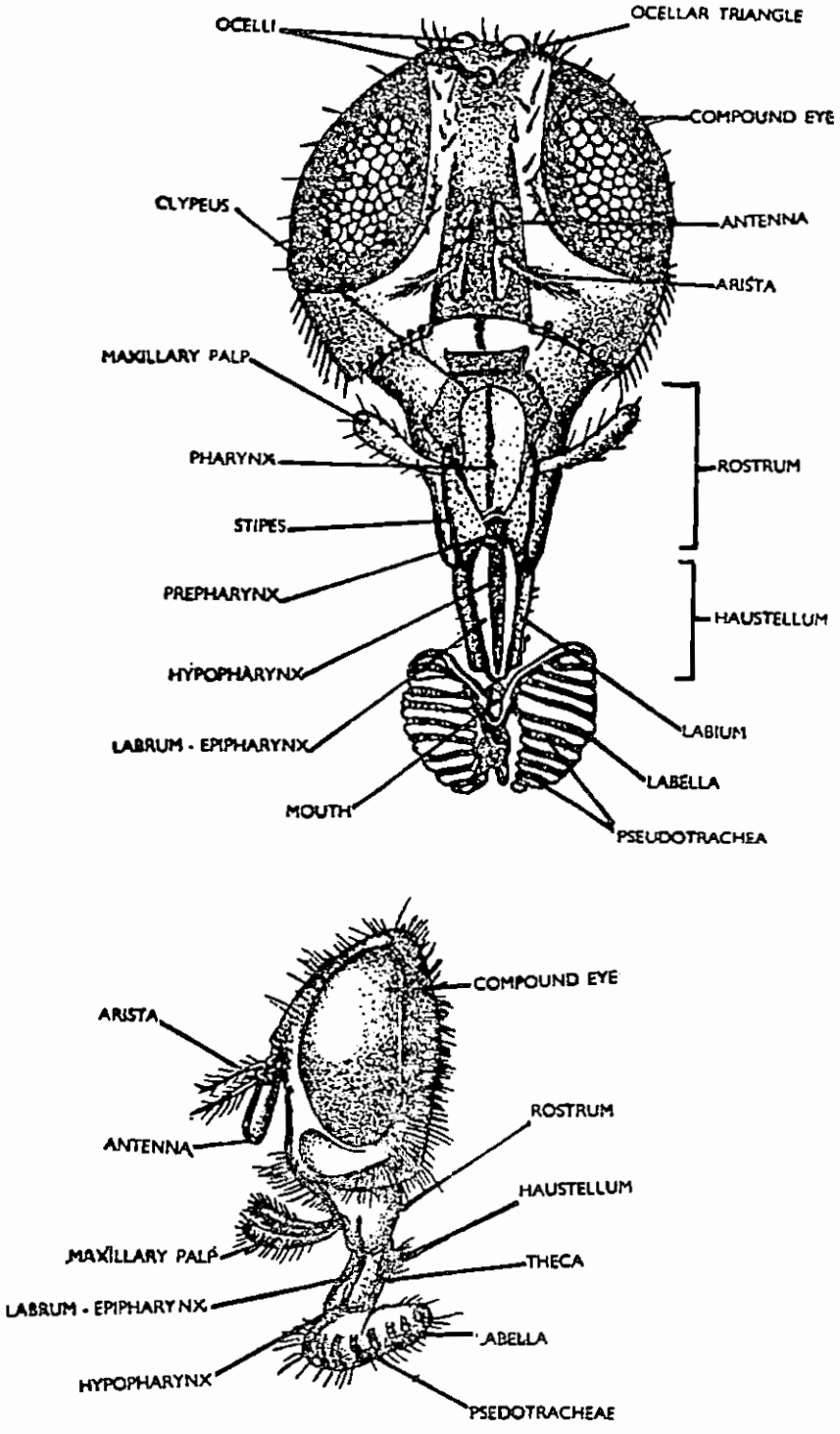


Fig. 223 — Musca domestica. Head and mouth parts, anterior view (upper) : lateral view (lower)

into the mouth from where they are carried up the food channel then to the pharynx, oesophagus and stomach. When the food is a solid substance like sweets or sugars, saliva from the salivary glands and a drop of liquid which is regurgitated from the alimentary canal are poured on to the solid food to liquify it. Then it is sucked up through the pharynx.

Thorax

It consists of three segments, the **mesothorax** being the largest while the **prothorax** and **metathorax** are small. The mesothorax carries a pair of large transparent wings while the metathorax bears a pair of modified wings, the **halteres** which are believed to be balancing organs. The thorax carries three pairs of legs each ending into a five-jointed tarsus which terminates with two claws and two pad-like pulvilli. The latter secrete a sticky fluid by the help of which the fly can rest and move on smooth surfaces, and ceilings without walking.

The **abdomen** is broad in the middle and tapers towards the apex. It is formed of ten segments but only four are visible, the rest are either atrophied or reduced. Five pairs of spiracles are found on the ventral edge of the abdomen.

Life history (Fig. 224)

After mating, the female lays eggs on any decomposing organic matter like stable manures, faeces, horse-dung, etc. The eggs are laid under favourable conditions of moisture and temperature. They are laid in masses of 120 — 150 eggs at one time. A female housefly can lay four to six patches of eggs during its breeding season.

The **eggs are** cylindrical, whitish and about 1 mm. long. At favourable temperatures the eggs hatch within 8-24 hours. The **larva** which is called **maggot** is apodous (i.e. without appendages) and 12-segmented (Fig. 224). At the anterior pointed end there is a vestigial head provided with a pair of **oral lobes** carrying **sensory papillae,** and two **mandibular sclerites** used to cut the food. The thorax is three-segmented and the abdomen is eight-segmented. Both are covered with a thin soft cuticle and are devoid of appendages. However, paired spiny **locomotory pads** are found on the ventral surface of the abdominal segments. These are used for locomotion. The spiracles are reduced in number and there are two pairs of spiracles, a pair on the mesothorax, which appears after the first moult, and a larger pair on the dorsal side of the last abdominal segment.

The larva is an active feeding stage which feeds, grows and moults

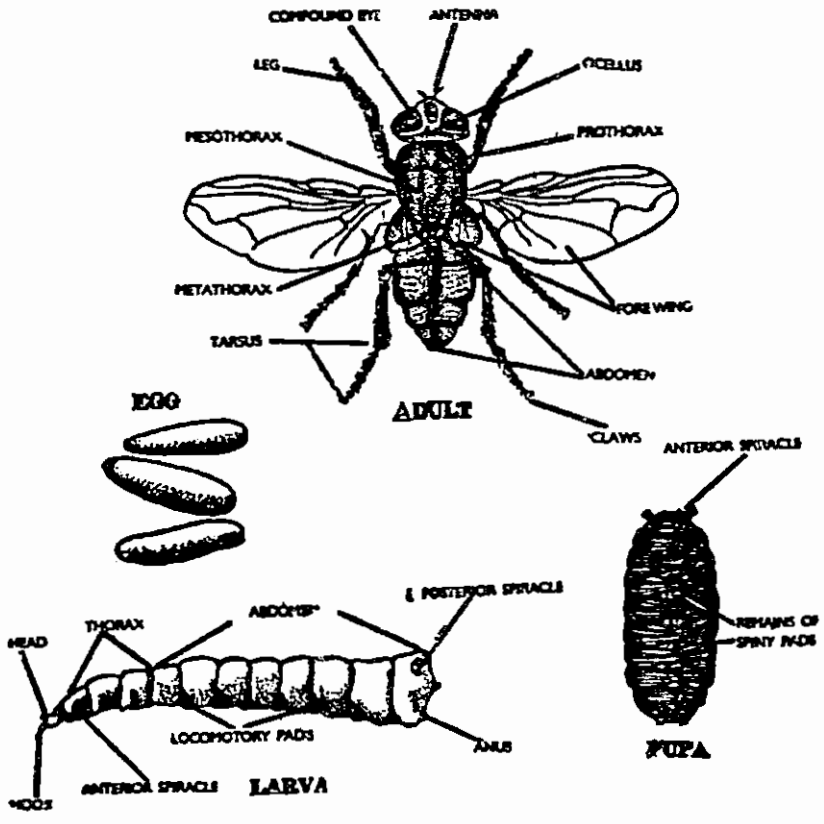


Fig. 224 — Musca domestica. Life cycle

twice. The larva prefers moist dark places, where it feeds on liquid organic matter and tiny solid particles. The larva moults twice and after 4-6 days it is changed into a pupa.

The **pupa** is formed after the second moult of the larva which contracts and becomes covered with the last larval skin which hardens to form a barrel-shaped dark-brown **puparium** in which the pupa develops (Fig. 224). The puparium shows signs of larval segmentation, spiracles and spiny pads. It is provided with two pupal-spiracles which project between the 5th and 6th segments of the puparium.

The pupa is an immobile non-feeding stage which lasts from 4-5 days during which internal changes take place. At the end of the pupal stage the adult fly emerges out of the puparium. This is aided by a blood-filled bladder the **ptilinum** which is formed on the head of the adult. By forcing

the pitilium from the head the puparium splits transversely and the **imago** (adult) emerges out. The wings are left to dry, and the adult flies become sexually mature within a week. The pitilium is withdrawn in to the head.

THE FLEAS

PULEX IRRITANS

These are small bilaterally flattened insects which live as ectoparasites on birds and mammals by sucking their blood. The human, flea, *Pulex irritans* has a small triangular head with a pair of simple eyes, a pair of short stout 3-segmented antennae lying in depressions, the antennal pits, fonud in the side of the head (Fig. 225). The antennae of the male are larger than those of the female and are used for grasping the female during copulation. In certain species of fleas (the dog flea, *Ctenocephalides*) the head is provided with a thick row of strong curved spines pointing downwards from the head and forming the genal comb or ctenidia. A similar row the pronotal comb projects posteriorly from the prothorax. The ctenidia enable the flea to hold firmly on to the host, both these combs are lacking from *Pulex*.

Mouth parts and feeding mechanism

The **mouth parts** are modified for **piercing** and **sucking** (Fig. 225). The **labrum-epipharynx** is long with a ventral groove. The **mandibles** are in the form of long blades serrated distally and are grooved along their inner surfaces. The labrum-epipharynx fits between the mandibles to form the **blood canal** through which blood is sucked up. When the mandibles are opposed together they form the **ejection-tube** at their posterior end through which saliva is poured into the wound. The **hypopharynx** is small and attached to the base of the mandibles. The **maxillae** are in the form of triangular lobes on each side of the mouth, with a pair of 4-segmented **maxillary palps.** The **labium** is reduced into a basal plate with a pair of 5-segmented **labial palps.** The latter are slightly concave at their inner sides to form a short sheath which surrounds the mouth parts.

When feeding the flea punctures the skin of its host by its serrated mandibles. Saliva is poured into the wound, and blood is sucked up through the suction tube aided by the suctorial pharynx. Fleas are provided by a mechanism which prevents regurgitation of the contents of stomach while

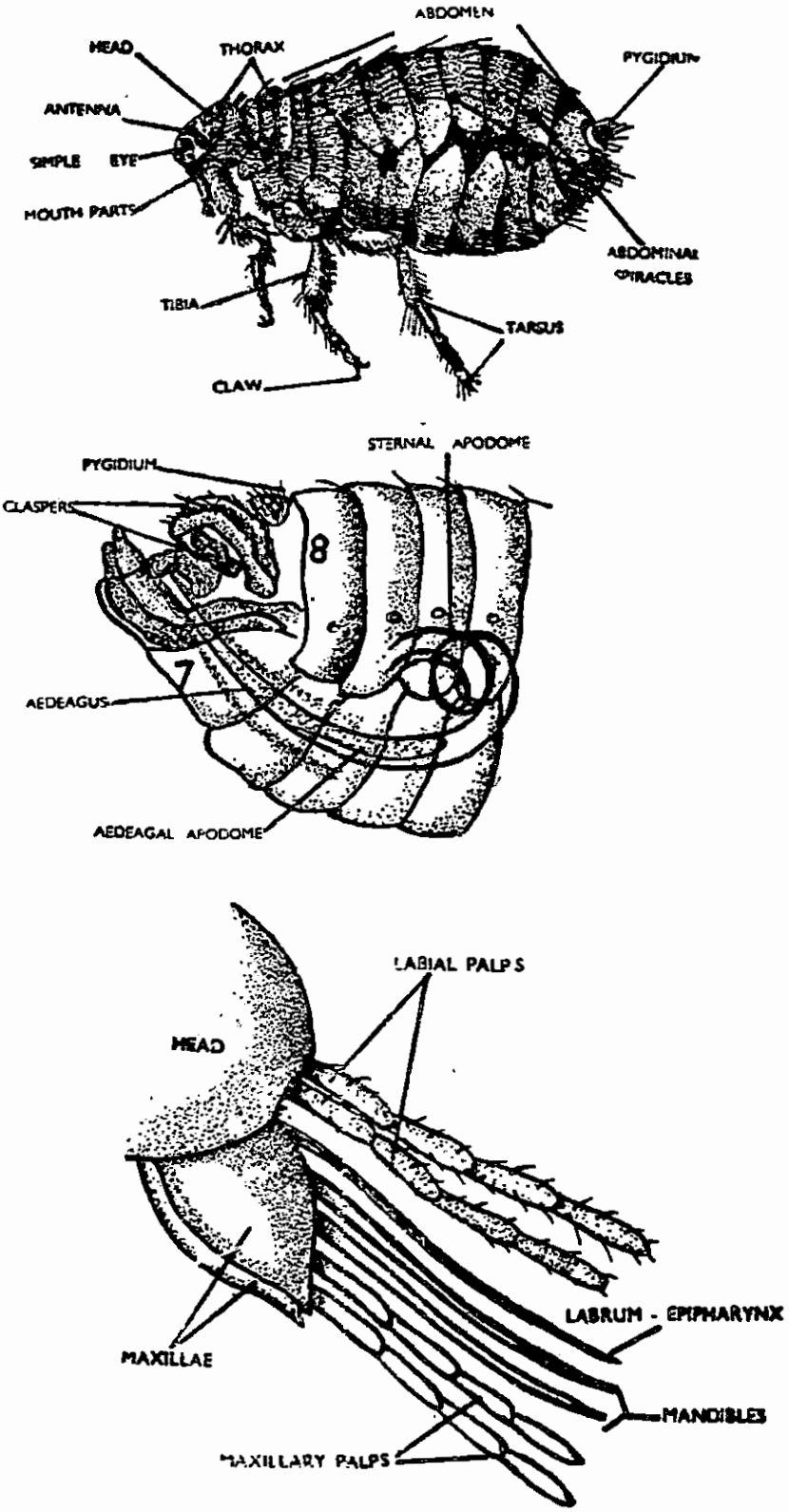


Fig. 225 — Pulex, adult female (upper); posterior end of male (middle) and mouth parts (lower)

the pharynx is sucking the blood. This feature plays an important role in the spread of diseases such as plague which are transmitted by some species.

The **thorax** consists of three distinct segments, the metathorax being the largest. There are three pairs of 5-segmented legs each ending in a 5-jointed tarsus with a pair of claws. The legs are well developed and are adapted for jumping. The coxae are large and stout while the femur and tibia are short. The hindmost pair of legs is well developed and gives the flea its well known jumping power. There are two thoracic spiracles.

The **abdomen** is 10-segmented. In the female the 8th segment has the genital aperture, the 9th tergum bears a dorsal sensory plate, the **pygidium.** Internally there is the **spermatheca** which appears as a comma-shaped structure near the posterior end of the abdomen.

In the male (Fig. 225) the **pygidium** is found on the 9th tergum which protrudes at both sides to form complicated finger-like projections, the **claspers.** A long **aedeagus** (**penis**) projects anteriorly from between the claspers. While the posterior end of the male is directed upwards, that of the female is round and not directed upwards. There are 8 pairs of abdominal spiracles on segments 1-8.

The body of a flea is difficult to hold even if it is caught. This is because the chitin of which the cuticle is formed is smooth and slippery, and the bristles on the segments are directed backwards.

Life history (Fig. 226).

After fertilization the female lays its eggs in the cracks of floors, under carpets and sleeping-places of the host. A female can lay about 6 eggs daily. The egg is oval in shape and whitish in colour. After 3-10 days the eggs hatch into a caterpillar-like, apodous and wingless **larvae** (Fig. 225). The larvae move forward by the help of bristles which cover their bodies, and by hook-like structures the **anal struts.** The larva is 13-segmented with a small head devoid of eyes and provided with a pair of tiny antennae. The larva is a free living stage which feeds on organic debris. It undergoes two ecdyses in about 12 days, after which it is changed into a **pupa** which is surrounded by a **silken cocoon** which is spun by the larva. After one or two weeks, depending on the moisture, temperature and mechanical stimuli, the adult emerges from the pupa.

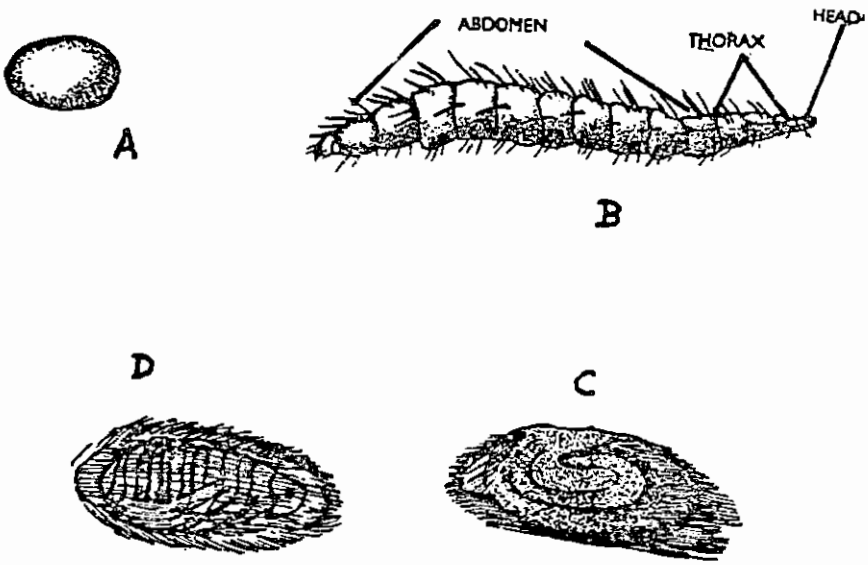


Fig. 226 — Pulex. Life history: A) egg; B) larva; C) larva in cocoon and D) pupa in cocoon

MEDICAL IMPORTANCE OF INSECTS

Insects are responsible for transmitting serious diseases to man and his domestic animals. Many insects act as intemediate hosts or vectors for the parasite, others act as mechanical transmitters of the disease from man to man or from animals to man. Some examples are given in table 2.

LICE

Both body and head liee are considered as the primary transmitters of three serious diseases.

1. **Relapsing fever** which is caused by the spirochaete *Borrelia recurrentis* where transmission takes place by breaking or crushing the lice and inoculating the bites with the infective fluid.

2. **Epidemic typhus** which is caused by *Rickettsia prowazeki*, an organism which lives between the cells and causes typhus fever. The organism is transmitted as a result of contamination of the bites or scratches by the faeces of an infected louse, or even from inhalation of the dried faeces which may remain infective for over two months.

3. **Trench fever** which is transmitted by the louse faeces and is caused by *Rickettsia quintana*.

BUGS

Although it is believed that bedbugs transmit many diseases to man but there is no proof for this. However, mechanical transmission of certain diseases may take place by bedbugs from man to man. It was found that pathogeneic microorganisms such as spirochaetes, rickettsias, typhoid and plague may remain in the bodies of bugs for days or weeks. Infection may take place when bites or scratches of these bugs are contaminated by the faeces or crushed bodies of the bugs.

The kissing bugs, *Triatoma* spp. and *Rhodnius* spp. which are winged bugs act as intermediale hosts of **Chagas' disease** caused by *Schizotrypanum cruzi* (*Trypanosoma cruzi*). These species usually defaecate while biting which results in contamination of the bites with the faeces containing the infective stage. Also infection may occur when rubbing the faeces with the eyes.

MOSQUITOS

These transmit serious diseases to man caused by different organisms and these are :

1. Diseases caused by viruses such as **yellow fever** and **dengue "breakbone fever"** which are mainly transmitted by *Aedes aegypti*. Encephalitis is a dangerous disease which is transmitted by *Culex spp.* i.e. *C. pipens*; *C. tarzalis*.

2. Malaria which is caused by *Plasmodium* spp. and is transmitted by species of *Anopheles*.

3. **Filariasis** or **elephantiasis** which is caused by nematodes, *Wuchereria bancrofti* and *W. malayi* the former being the most common parasite in Egypt and is transmitted by *Culex pipens*.

FLIES

These are among the insects which cause widespread diseases in many parts of the world. The housefly, *Musca domestica*, is an important transmitter of diseases especially those affecting the eyes and alimentary canal. Houseflies transmit **typhoid, amoebic** and **bacillary dysentry** and virus of **poliomyelitis**. Helminth eggs can also be carried externally and

Table 2 — **Examples of Diseases transmitted by insects**

Disease	Causative organism	Carried by (Vectors)	Order
Human yellow fever	Virus	Mosquito (*Aëdes aegypti*)	*DIPTERA*
Human malaria	*Plasmodium* (Protozoa)	Mosquito (*Anopheles*)	
Encephalitis	WEE and SLE viruses	Mosquito (*Culex pipens*)	
Elephantiasis	*Wuchereria bancrofti* (Nematode)	Mosquito (*Culex pipens*)	
African sleeping sickness	*Trypanosoma gambiense* (Protozoa)	Tsetsefly (*Glossina palpalis*)	
Rhodesian sleeping sickness	*T. rhodesiense* (Protozoa)	Tsetsefly (*Glossina morsitans*)	*DIPTERA*
Typhoid	*Salmonella* (Bacteria)	Housefly (*Musca domestica*)	
Amoebic dysentry	*Entamoeba histolytica* (Protozoa)	Housefly (*Musca domestica*)	
Bacillary dysentry	*Salmonella* (Bacteria)	Housefly (*Musca domestica*)	
Leishmaniasis			
Visceral (Kala-Azar)	*Leishmania donovani* (Protozoa)	Sandfly (*Phlebotomus periciosus*)	

Table. 2 — **Examples of Diseases transmitted by insects** (*Cont.*)

Disease	Causative organism	Carried by (Vectors)	Order
Cutaneous (Oriental sore)	*Leishmania tropica* (Protozoa)	Sandfly (*Phlebotomus papatasii*)	*DIPTERA*
Bubonic plague of rats and man	*Pasteurella pestis* (Virus)	Fleas (*Xenopsylla* and others)	*SIPHONAPTERA*
Murine (endemic) typhus	*Rickettsia mooseri* (= *R. typhi*) (Virus)	Rat flea (*Xenopsylla cheopis*)	
Dwarf tapeworm	*Hymenolepis nana* (Cestode)	Fleas and lice	*SIPHONAPTERA AND ANOPLEURA*
Dog tapeworn	*Dipylidium caninum* (Cestode)	Lice (*Trichodectes*) and fleas	
Relapsing fever	*Borrelia recurrentis* (Spirochate bacteria)	Lice (*Pediculus humanus*)	*ANOPLEURA*
Human (epidemic) typhus fever	*Rickettsia prowazeki* (Virus)	Lice (*Pediculus humanus*)	
Trench fever	*Rickettsia quintana* (Virus)	Lice (*Pediculus humanus*)	
Chagas disease	*Schizotrypanum cruzi* (Protozoa)	Bug (*Triatoma*)	*HEMIPTERA*

also internally, so houseflies could be a factor in causing **hydatid infection.**

The blood-sucking tsetse flies (*Glossina* spp) act as vectors of trypanosome infections of man and his domestic animals, which cause the **African** and **Rhodesian sleeping sickness.**

Sandflies of the genus *Phlebotomus* are of great importance as transmitters of leishmaniasis. *P. papatasii* is the principal vector of **Oriental sore** or **cutaneous leishmaniasis.** *P. perniciousus* and *P. longicuspis* are the main species transmitting the **visceral leishmaniais** or **Kala-azar** in the Mediterranean area where dogs are the reservoir hosts.

FLEAS

In addition to the human flea, *Pulex irritans* which is an ectoparasite on man and other mammals, there are other kinds which are of medical importance and act as vectors which transmit dangerous diseases to man. The rat-flea *Xenopsylla cheopis* is responsible for the transmission of **plague** which is a bacterial diseases caused by *Pasteurella pestis.* Infection takes place by contamination of the bite either by the faeces or regurgitated bacteria while sucking the blood. *Pulex irritans* transmits the plague bacteria from man to man.

Fleas are also responsible for the transmission of the **endemic** or **murine typhus** caused by the virus, *Rickettsia mooseri* (= *R. typhi*). Infection takes place by contamination of the wound caused by the bite of the flea, with the faeces containing the virus.

In addition fleas act as intermediate hosts of the **cysticercoid larvae** of two tapeworms, the dwarf tapeworm, *Hymenolepis* of rats, mice and man; and the dog tapeworm, *Dipylidium caninum* which infects dogs, cats and sometimes children.

METAMORPHOSIS IN INSECTS

Many insects pass through successive stages which are different from one another. This change from larva to adult is called **metamorphosis.** Three types of metamorphoses are known :

1. **Ametabolic metamorphosis (Ametabola, Apterygota, direct or incomplete metamorphosis).**

It occurs in wingless primitive insects (silver-fish, springtails) in which the eggs develop into a young which is similar to the adult in all respects, except its small size. The adult stage is reached gradually after several moultings and growth.

2. Heterometabolic metamorphosis (Heterometabola)

The egg hatches into a nymph which resembles the adult insect with compound eyes, the same mouth parts but no wings, usually with a large head and small thorax and abdomen. The nymph is adapted to the habitat it lives in. The nymph is voracious and grows rapidly. After successive moults the nymph reaches the adult stage. Growth is a gradual process in which the appednages, mouth parts and antennae grow directly into those of the adult. The wings appear as small external outgrowths of the thorax (hence they are called **expterygota**) that enlarge at successive moults. The reproductive organs mature gradually. This type of metamorphosis may be :

(*a*) **Gradual metamorphosis** where the nymph lives in the same habitat as that of the adult as in cockroaches crickets, and grasshoppers.

(*b*) **Incomplete metamorphosis, (Hemimetabola)** where the nymph is adapted for life in a different environment from that of the adult. The nymph of the dragonfly lives in water, feeds on aquatic animals and respires by tracheal gills. It is called a **naiad.** The adult insect lives on land.

3. Holometabolic metamorphosis (Holometabola, indirect or Complete metamorphosis).

The egg hatches into worm-like segmented **larva** with head, thorax, abdomen, no wings, often no legs and no compound eyes. These larvae may be given different common names according to the type of insect. They are called **caterpillar** in butterflies and moths; **maggots** in flies, and **grubs** in beetles. The larvae are different from the adult in structure, body form, mouth parts and mode of life. They feed voraciously, crawl and grow by moulting several times. Each larval **instar** becomes a larger larva. The last larval stage changes into a resting, quiescent instar called **pupa** which may be surrounded by the last larval skin, or a **puparium** or a **cocoon** secreted by the labial glands of the larva.

During the pupal stage many larval organs-except the central nervous system and developing reproductive organs — are broken down and resorbed by phagocytic cells, a process called **histolysis.** These are used as building materials for the development of the adult organs. Each part of the **adult** or **imago** (eyes, wings, legs, etc.); develops from a group of cells called **discs** which develop directly from the eggs and remain quiescent during the larval stages. During the pupal stage these discs grow and differentiate into adult structures and remain folded. On hatching out

from the pupal case, blood is pumped into the folded structures, which unfold and inflate and the adult emerges.

Complete metamorphosis occurs in mosquitos, house flies, fleas, etc.

Factors controlling metamorphosis

Experimental studies have shown that growth, moulting and metamorphosis are controlled by **hormones.** The production and release of these hormones are controlled by internal and external environmental factors. Two hormones are involved in metamorphosis.

1. **Juvenile hormone** which is secreted by a special gland the **corpus allatum** which lies behind the brain dorsal to the pharynx (Fig. 227). The juvenile hormone controls larval growth and moulting till the end of the larval period. It inhibits metamorphosis and is not secreted during the last larval stage thus permitting pupation to take place. If the **corpora allata** are removed from the larva it quickly transforms into pupa stage.

2. **Growth and differentiation hormone** which is secreted from the **prothoracic glands.** This hormone stimulates growth and differentiation of tissues. It is secreted under the influence of a hormone secreted by the **neurosecretory cells** in the **intercerebral gland** found in the brain ganglia (Fig. 227). The hormone secreted from this gland passes along the axons of the cells to their expanded tips which form the **corpus cardiacum.**

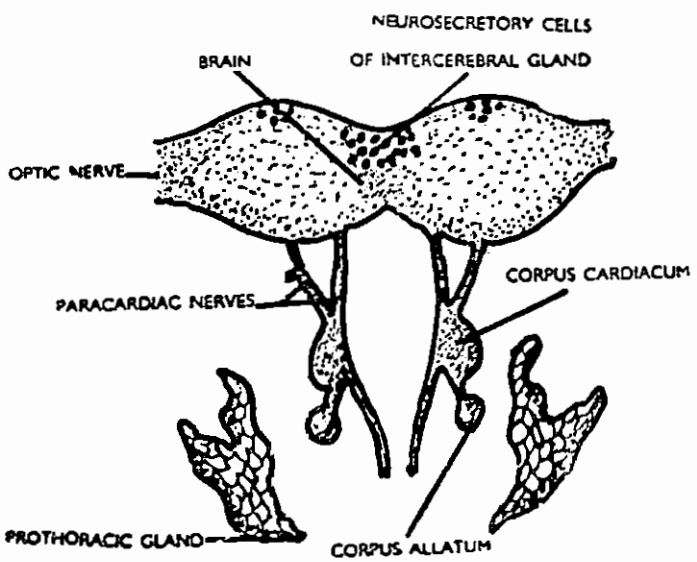


Fig. 227 — Endocrine glands of an insect.

The latter secretes a **prothoracicotropic hormone** which stimulates the prothoracic gland to secrete the growth and differentiation hormone. This hormone was isolated and called **ecdysone.** It causes the epidermis to secrete the moulting fluid and thus leads to moulting and metamorphosis.

When both hormones are secreted, moulting of the larvae takes place and adult characters are suppressed. When ecdysone is secreted alone, the larva will moult into pupa and the pupa into adult. The absence of either the brain hormone or prothoracic hormone prevents metamorphosis into the adult.

Class CRUSTACEA

Crustacea are aquatic arthropods. The body is divided into head and trunk. The head is formed of five fused segments and an anterior embryonic segment which carries no appendages in the adult. The trunk with a variable number of segment which may be divided into thorax and abdomen. The abdomen may end in an unsegmented part called telson. The telson may carry caudal furca or rami. In many forms the head may fuse with one or more thoracic segments to form the cephalothorax covered with a carapace.

The appendages of the body are either of biramous or phyllopodium type. The appendages are variously modified according to their functions as jaws, legs, fins or accessory reproductive organs.

The exoskeleton is a hard cover formed of an outer thin non-chitinous epicuticle and an inner chitinous hardened endocuticle.

Respiration takes place either by the general surface of the body or by gills which develop from the thorax or abdomen or their appendages.

The excretory organs are modified coelomoducts which may take the form of either the maxillary glands opening on the second maxilla or of the antennary glands opening on the second antennae.

Sexes are separate or united. sexual dimorphism is common,. parthenogenesis sometimes occurs. Development passes through a nauplius larva.

Daphnia, (or water flea, Fig. 228), lives in fresh water; the carapace is in the form of a bivalved shell enclosing the trunk. The antennules are very small and sensory. The antennae are long biramous and used for locomotion. The thorax carries five pairs of appendages of phyllopodium type. These appendages are used for collecting the food and for respiration. The female shows a brood pouch in which the eggs are kept and develop directly to young. Daphnia has the ability to reproduce by parthenogenesis.

Cyclops (Fig. 228)

Small fresh water crustacea The head and the first two thoracic segments are fused together. There is one median eye Antennules are long uniramous and used as clasper in males. The abdominal segments are apodal. The eggs are carried in two egg-sacs on the sides of the abdomen of the female. The body ends in a telson and two caudal furca The egg hatches into a nauplius larva which develops to the adult stage.

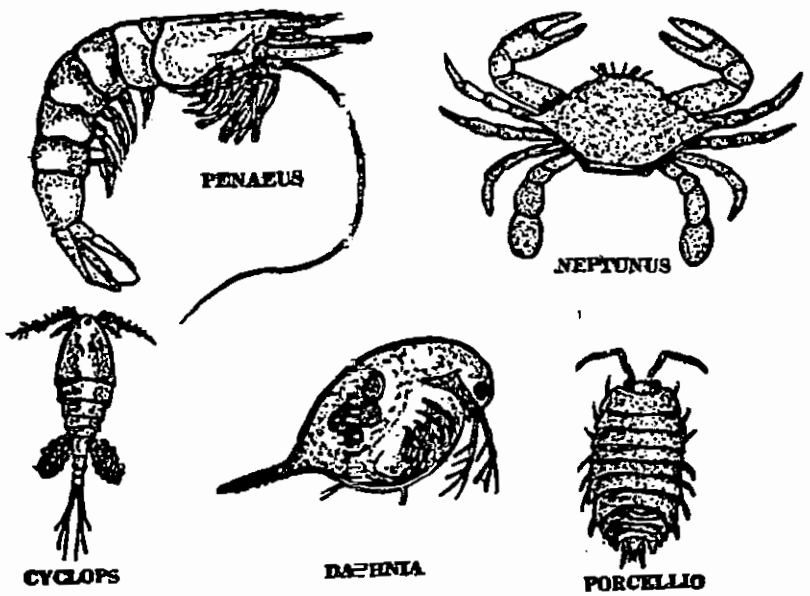


Fig. 228 — Examples of crustacean arthropods

Porcellio (Fig. 228)

This is a terrestrial form, lives hidden under stones and dead tree leaves. The head carries two sessile compound eye The antennules are reduced, antennae are long uniramous. The first thoracic segment is fused with the head and its appendages form the maxillipeds. The seven free thoracic segments carry similar uniramous legs for walking on soil. The five anterior abdominal appendages are biramous and plate-like and used for respiration. The last pair of the abdominal appendages are biramous cylindrical and known as uropods. The 6th abdominal segment is fused with the telson.

The eggs are laid and kept in the brood pouch formed on the ventral surface of the first five free thoracic segments, development is direct.

Penaeus (Fig. 228)

This is a marine crustacean. It is an edible prawn which is common in our sea shores. The head and thorax are fused together forming the cephalothorax which is covered by the carapace. Respiration is carried out by gills in the thoracic region.

The antennules and antennae are long and biramous. The thoracic appendages are used for seizing and cutting the food and for walking. The abdominal appendages are used for swimming. The telson together with the uropods form the tail fan.

Sexes are separate, fertilization is external in the sea. The fertilized eggs hatch into nauplius larvae. The nauplius larva undergoes a process of metamorphosis and passes through different other forms of larvae until it reaches the adult stage.

Neptunus (Fig. 228)

This is a marine edible crab. The cephalothorax is broader than long. The abdomen is reduced and bent forwards and closely applied to the sterna of the thorax. The abdomen is broader in the female than in the male. The first pair of walking legs is provided with strong chela and the fifth pair is broad and flattened to help in swimming.

The eggs are attached to the abdominal appendages until hatching into zoaea larvae which develop to the adult.

Class MYRIAPODA

Terrestrial arthropods with head and trunk. The head is provided with one pair of many jointed antennae, eyes in the form of groups of ocelli, or two pairs of maxillae. The trunk is elongated and segmented. Each segment carry one or two pairs of legs. Respiration by takes place by branched tracheae which open by a series of stigmata. The excretory organs are in the form of Malpighian tubules which open into the hind gut. The gut is without digestive glands. Sexes are separate, female lays eggs which hatch and into young similar to the adult but with few segments.

Scolopendra (Fig. 229)

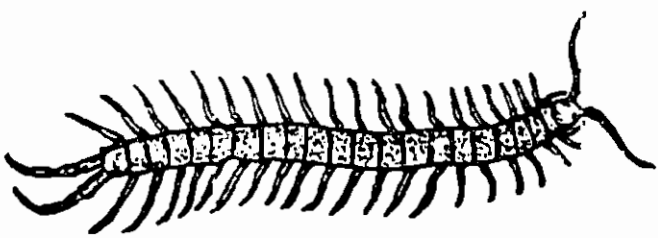
Found in soil under stones. Carniverous with dorsoventrally flattened body. Each trunk segment carries a pair of jointed walking legs. The

appendages of the first trunk segment are modified to a pair of poison claws. The genital opening is situated at the posterior end of the body.

Julus (Fig. 229)

Vegetarian, whose body is cylindrical. Each trunk segment has two pairs of legs and 2 pairs of ganglia indicating the fusion of the body segments in pairs. There are no poison claws. The genital opening lies anteriorly on the third trunk segment

JULUS



SCOLOPENDRA

Fig. 229 – Examples of myriapodous arthropods; a diplopod Julus; and a chilopod, Scolopendra.

Class ARACHINDA

The members of this class have no antennae or proper jaws. The body is divided into two regions : the prosoma and opisthosoma. The prosoma consists of eight segments which carry the median eyes, paired chelicerae, pedipalps, and four pairs of walking legs. The eighth segment which is called the pregenital segment carries no appendages.

The opisthosoma consists of twelve segments and a telson. This number is changed in some forms, this region may be diferentiated into two parts called mesosoma and metasoma. It begins by the segment carrying the paired genital opercula.

Arachnids include land and aquatic forms. Respiration takes place by gill-books in the aquatic forms and by lung-books or tracheae or both in the terrestrial forms. Sometimes there are no special respiratory organs and the exhange of gases takes place through the skin.

Excretion takes place by Malpighian tubules and coxal glands. The alimentary canal with a digestive gland and sexes are separate. Larval forms are found in some forms as **Argas.** This class includes the scorpions, spiders, ticks and mites, (Fig. 230).

Buthus (Fig. 230)

This is the common terrestrial poisonous scorpion. The prosoma consists of 8-segments, mesosoma of 6-segments and metasoma of 6-segments. The chelicerae are small and chelate and pedipalps are large and chelate. The second segment of the mesosoma carries a pair of sensory pectines. Respiration takes place by means of four pairs of lung-books found on the third to sixth segments of mesosoma.

Oecubis (Fig. 230)

This is the spider commonly found in houses and other places. The prosoma and opisthosoma are joined together by a narrow pedicle. The chelicerae are subchelate and with poison glands. The pedipalps are simple and they carry the palpal organs in the males Respiratory organs are lung-books or both lung-books and tracheae. Eggs are kept in silken cocoons.

Argas (Fig. 230)

It is an ectoparasite on domestic animals as fowls, dogs and camels. The body is not segmented and shows no division into prosoma and opisthosoma

The median hypostome and the chelicerae are elongated and serrated and used for cutting or piercing with a sucking channel formed between them. The pedipalps are sensory. Respiratory organs are the tracheae which open by a pair of spiracles situated laterally near the bases of the fourth pair of walking legs. Metamorphosis occurs during the life cycle.

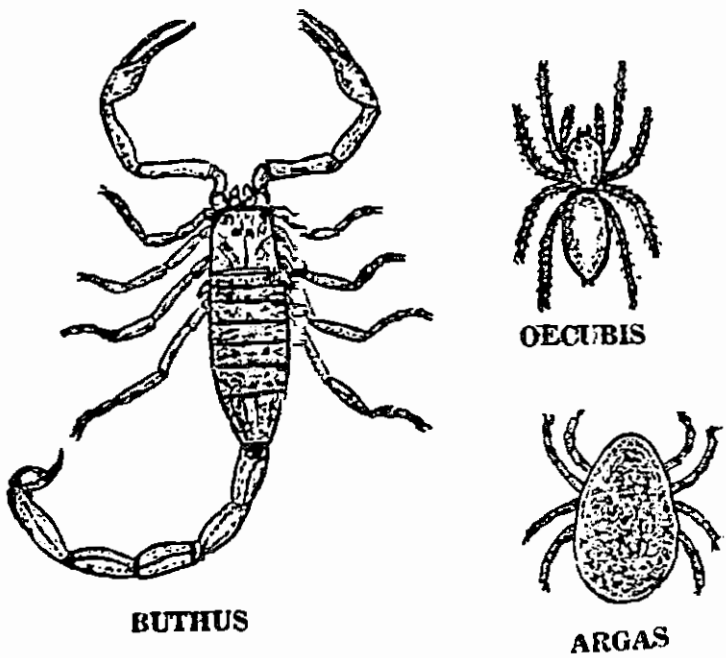


Fig. 230 — Examples of arachnids, a scorpion (Buthus); a spider; Oecubis and a tick (Argas)

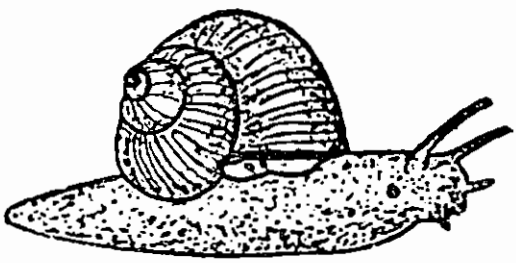
PHYLUM MOLLUSCA

Mollusca are bilaterally symmetrical, unsegmented coelomate animals; with a head, foot and a visceral hump covered with a mantle which secretes a calcareous shell of different forms. Two ctenidia for respiration are placed in the mantle cavity into which open the anus and kidneys. The gut is provided with a radula, salivary glands and a digestive gland. The perivisceral body cavity is partly haemocoelic and partly coleomic. The

coelom varies in development and is represented by the cavities of the kidneys, gonads and pericardium. The nervous system is concentrated into a circumoesophageal ring connected to a number of ganglia. The larvae are often of the trochophore type.

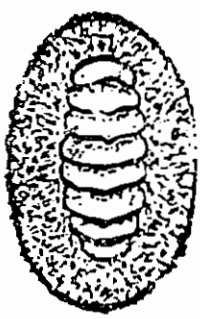
Acanthochiton (Fig. 231)

Lives sticking on to the stones of the sea shores. The shell is formed of eight plates. Head without tentacles or eyes.

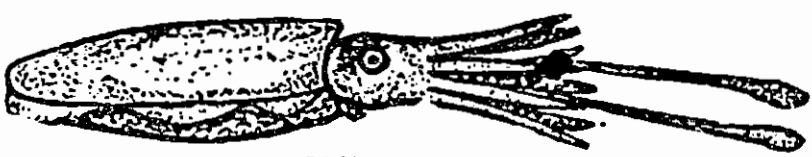


EREMINA

UNIO



ACANTHOCHITON



SEPIA

Fig. 231 — Examples of molluscs, a snail (Eremina); a clam (Unio) coat-of-mail shell (Acanthochiton), and cuttlefish (Sepia)

Eremina (Fig. 231)

Terrestrial animal, head bearing two pairs of tentacles and one pair of eyes. The visceral hump is spirally coiled. The shell is of one piece and coiled. Hermaphrodite, development is direct.

Unio (Fig. 231).

Fresh water mollusc whose body is laterally compressed and covered by the mantle. The shell is formed of two valves joined dorsally by a ligament and hinge and closed ventrally by two transverse adductor muscles. The head is rudimentary, eyes, tentacles and radula being absent. Foot is wedge-shaped and development with metamorphosis.

Sepia (Fig. 231)

It is a marine animal with a well developed head and two large and highly developed eyes. The foot is modified to a funnel and ten arms with suckers. The shell is internal Development is direct.

PHYLUM ECHINODERMATA

The echnioderms are coelmate marine, bilaterally symmetrical as larvae and radially symmetrical as adults. Body wall contains calcareous plates or ossicles which may be referred to as internal skeleton. This skeleton carries spines, hence the name echinoderm or spiny skin. The body is prolonged as five arms forming the radii and the regions between them as the interradii. Attached to the spines and in the spaces between them there are many small bodies known as pedicellariae. These are sets of 2 or 3 calcareous jaws arranged to bite together as pincers. They are used for defense, for catching food and for protection of dermal gills. Respiration is performed through a variety of structures as the dermal gills, tube feet and respiratory tree. No nephridia for excretion which is performed by amoebocytes. The nervous system is simple. Sexes are separate, fertilization is external. Development shows free swimming larvae which are bilaterally symmetrical.

Astropecten (Star-fish, Fig. 232)

Star-shaped echinoderm, with five arms not sharply marked off from the central disc. On the oral surface which faces downwards, there are 5

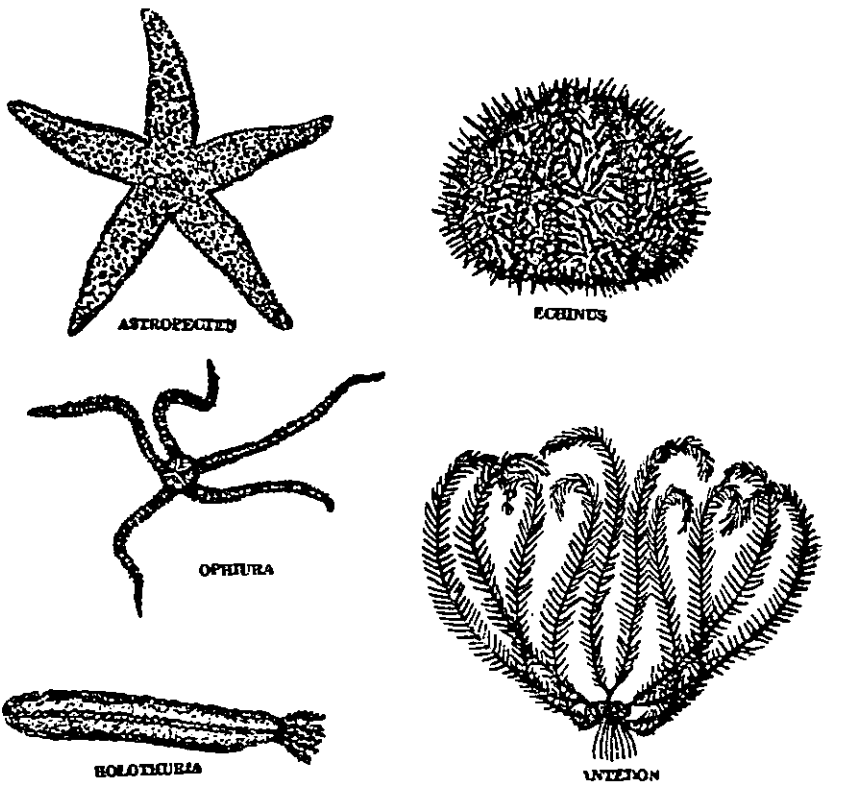


Fig. 232 — Examples of echinoderms, a starfish (Astropecten) a sea urchin (Echinus); a brittle star (Ophiura); a sea cucumber (Holothuria, and a sea lily (Antedon)

ambulacral grooves containing tube feet. This species lives in the sand near the sea-shores. It has got no anus and no suckers on the tube feet.

Ophiura (Brittle-star, Fig. 232)

Star-shaped with five arms which are sharply marked off from the central disc. The tube feet are not locomotory and without suckers. Locomotion by the movement of the arms . The arms are provided with calcareous pieces called vertebrae. Dermal gills, anus, pedicellariae and ambulacral grooves are absent.

Echinus (Sea-urchin, Fig. 232)

Globular in form, without arms, provided with numerous spines and pedicellariae, tube feet with suckers. The dermal ossicles are attached together to form a shell.

Holothuria (Sea-cucumber, Fig. 232)

This is cylindrical in shape, without arms. Some of the tube feet are modified around the mouth in the form of a ring of tentacles. The body wall is muscular and provided with scattered ossicles but without spines, or pedicellariae or ambulacral grooves.

Antedon (Feather-star, Fig. 232)

With a central disc and five branched arms bearing pinnules. It is fixed to the substratum by a number of jointed cirri. The tube feet are without suckers. Spines and pedicellariae are absent.

PART SEVEN

PHYLUM CHORDATA

INTRODUCTION

The phylum Chordata includes the vertebrate animals (mammals birds, amphibians, fishes; and cyclostomes) and a number of marine forms that are not generally known except to zoologists. All of these animals are characterised at some stage in their existance by :

1. a skeletal axis, the notochord.

2. by paired slits connecting the pharynx with the exterior.

3. by a central nerve-cord dorsal to the alimentary canal and containing a cavity or system of cavities, the neurocoele.

In many respects the chordates differ widely from one another, and it is customary to separate them into four subphyla :

I — Subphylum **CEPHALOCHORDATA** in which the notochord extends throughout the whole length of the body, from the tip of the snout to the tip of the tail, e.g. *Amphioxus*.

II — Subphylum **HEMICHORDATA** in which the notochord is found in the anterior end of the body, e.g. *Balanoglossus*.

III — Subphylum **UROCHORODATA** in which the notochord is restricted to the tail, e.g.*Ascidia*.

IV — Subphylum **CRANIATA** or **VERTEBRATA** in which the notochord is found only in the embryonic stages, later on it becomes replaced by the vertebral column. The notochord in the vertebrate embryos extends anteriorly as far as the middle of the brain only. The vertebral column is made up of a series of bodies called vertebrae, and the notochord disappears before the adult stage is reached. The vertebrates are the **lampreys, sharks, rays, bony fishes, frogs, toads, lizards, snakes, crocodiles, turtles, birds, whales, seals, bats, monkeys,** and **man.**

Seven classes of vertebrates are recognized :

I — Class **Cyclostomata.**

II — Class **Chondrichthyes.**

III — Class **Ostechthyes.**

IV — Class **Amphibia.**

V — Class **Reptilia.**

VI — Class **Aves**

VII — Class **Mammalia.**

SUBPHYLUM CEPHALOCHORDATA

The animals related to this subphylum are translucent and fish-like in appearance and proportions. They are found in shallow marine water in various regions of the world and sometimes locally abundant. As the shape suggests, they can swim readily, but because of poor development of fins they spend their time with the body buried in the sands of the bottom, with merely the anterior end projecting. In spite of their fish-like appearance, they are far more primitive than any fish. They show all the main chordate characters. The **notochord** extends the entire length of the body projecting beyond the nervous system to the tip of the snout. They have a dorsal **tubular neural tube** without a definite brain. **Pharynx** is large with numerous gill clefts opening into an ectoderm-lined **atrium.** The pharynx has an **endostyle** and ciliated tracts, which are concerned with ciliary feeding. **Metamerism** is well marked and even the gonads are segmented. There is a definite **coelom.** Excretory organs are segmental **nephridia.**

AMPHIOXUS LANCEOLATUS

Amphioxus, the lancelet may be also termed Branchiostoma. It has a wide distribution from the Mediterranean to the North Sea, in the Atlantic coast of America and in the Indian Ocean. On the Chinese coast, it is found in such abundance that it is sold as food. Its body ranges from one to three inches in length. The animal burrows in sand near the shore, with greater part of the body buried and only a fringed anterior oral hood projecting into water.

External Features

The body of *Amphioxus lanceolatus* (Fig. 233) is compressed laterally and pointed at both ends. Its dorsal surface is sharp but the ventral one, for

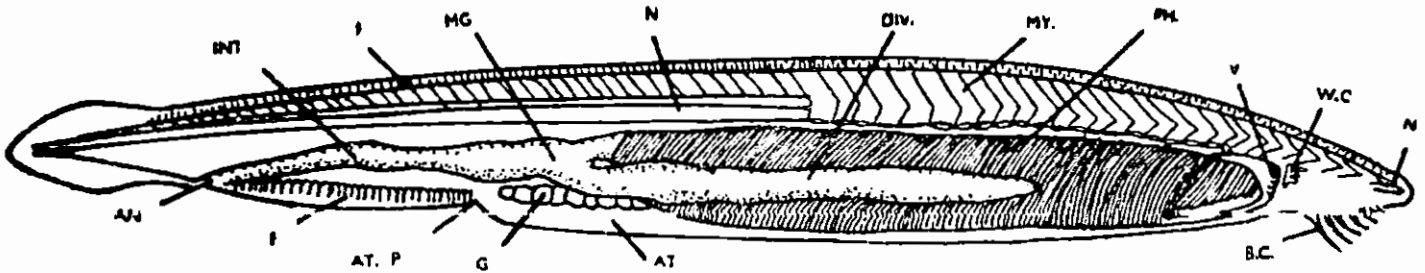


Fig. 233 — Amphioxus lanceolatus dissected An, anus; AT atrium; A.T.P., atriopore; buccal or oral cirri; DIV. diverticulum; F, fin ray boxes; G. gonads; INT, intestine; MG, mid-gut; My, myctomes, N. notochord; PH, pharynx; W.O. wleel organ; V. velum.

the greater part of its length, is flattened The anterior end (Figs. 234 and 235) represents a poorly developed, somewhat degenerated head, whose ventral part consists of an expanded membrane. the **oral hood,** which

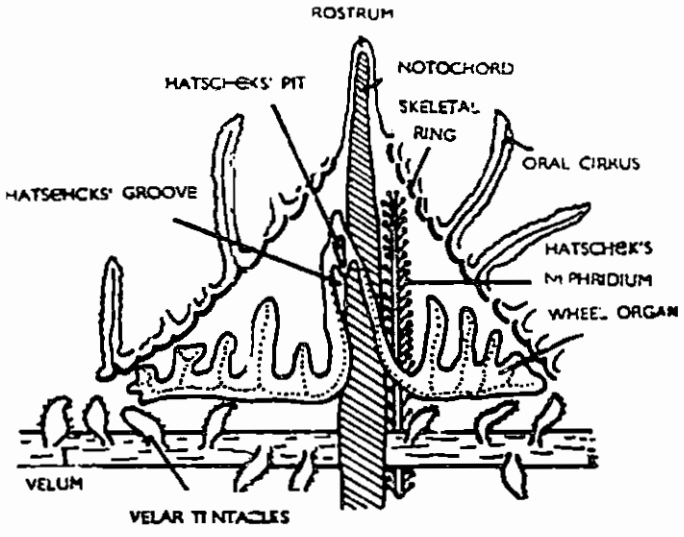


Fig. 234 — Ventral view of anterior end of Amphioxus.

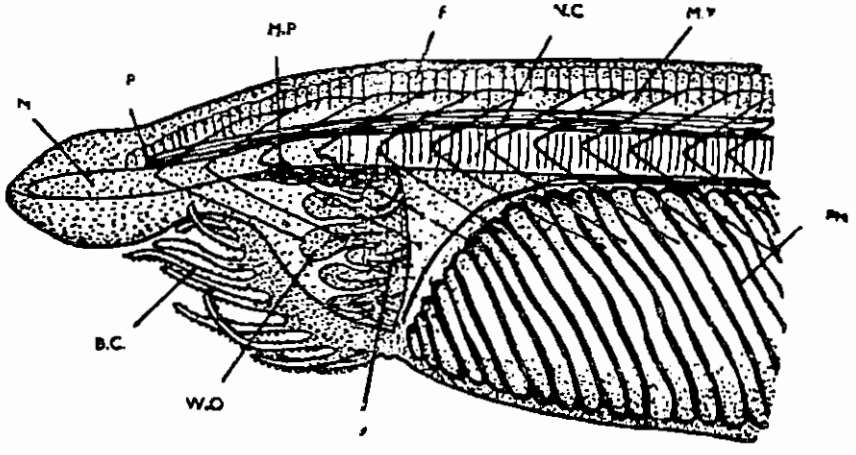


Fig. 225 — Anterior end of Amphioxus. B.C., buccal or oral cirri F. fin ray boxes · H.P.. Hatchek's pit , MY, myotomes *N. notochord* N.C. nerve cord: P. pigmen spot PH, pharynx V velar tentacles, W.O.. wheel organ.

encloses a cavity, the **vestibule,** at the bottom of which the mouth is located. The borders of the oral hood are expanded into a series of stiff tentacles or **oral cirri** (twenty or more).

The flattened portion of the ventral surface is bounded laterally by two membranous folds, the **metapleural folds,** or **lateral fins,** extending posteriorly from the oral hood. These folds meet behind the **atriopore.** From this point a median membranous fold, the fin, passes to the posterior end of the body, around to the dorsal side, and forward along the dorsal one to the anterior end.

The slightly wider portion of this fin which surrounds the pointed posterior end is the **caudal fin;** that along the dorsal side, the **dorsal fin.** The anus is situated to the left of the midventral line near the posterior end, just behind the point where the fin widens.

Along the sides of the body there are the longitudinal series of V-shaped muscle segments or **myotomes,** separated from each other by **myosepta.** The **myotomes** extend nearly to the anterior tip, diminishing in size above the oral hood. The number of myotomes is about sixty. Immediately below the ventral ends of the myotomes there are the gonads.

In the vestibule, inside the oral hood, the epithelial lining has finger-shaped patches of ciliated grooves and ridges known as Muller's organ or wheel organ (Figs. 234 and 235). Each patch of the wheel organ has a groove ending in a pit anteriorly, the median dorsal patch has a long glandular and ciliated **groove of Hatschek** which secretes mucus. It has a small depression slightly to the right called **Hatschek's** pit which may be sensory. At the posterior end of the vestibule is a vertical partition called **velum** which bears many sensory velar **tentacles** forming a strainer. The velum has a circular aperture, the **enterostome.**

Body Wall (Fig. 235)

There is a thin outermost perforated cuticle covering an epidermis, which is made of a single layer of columnar epithelial cells. In between the epidermal cells are some sensory cells, but there are no glands or chromatophores. A thin layer of tough fibrous connective tissue forms a cutis below the epidemis. Below the cutis is a subcutis made of a gelatenous material containing fibres and cutaneous canals. Below the subcutis, are myotomes lined internally by a layer of parietal peritoneum, except in the region of the pharynx where this peritoneum is restricted to small tracts only.

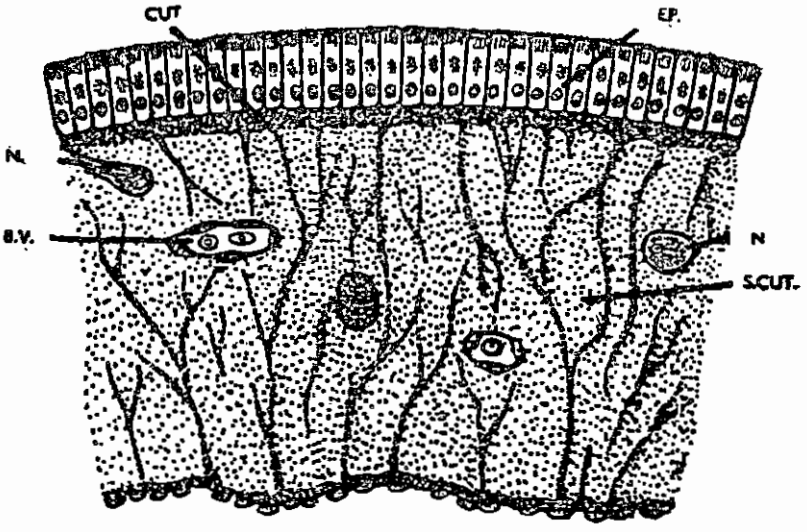


Fig. 236 — Vertical section of the skin Amphioxus. B.V., blood vessel; CUT. cutis; EP., epidermis; N. nerve; S. CUT., subcutis.

Skeleton

The most important skeletal structure of Amphiouxs sp. is the notochord. This elastic rod extends dorsal to the gut and ventral to the nerve cord. It is formed of large alternate fibrous and gelatenous cells which make the notochord hard and turgid. The notochord is enclosed in the notochordal sheath. The oral hood is also supported by a ring made of

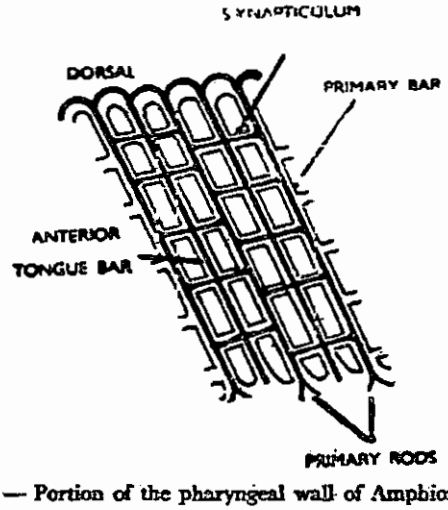


Fig. 237-A) — Portion of the pharyngeal wall of Amphioxus to show, the skeletal elements.

gelatenous substance resembling **soft cartilage.** This ring is made of pieces lying end to end and each piece gives out a rod forming the axis of an oral-cirrus. The gill bars of the pharynx are supported by **skeletal rods** made of elastic gelatenous substance (Figs. 237 A, B and C). The dorsal fin is supported by a single row of **fin rays** and the ventral fin has a double row of supporting fin rays. These **fin rays** are made of connective tissue containing a gelatenous substance inside.

Digestive Tract (Figs. 233, 234, 235 and 238).

The mouth cavity is surrounded by a circle of stiffened projecting cirri. The pharynx is greatly elongated, extending about half the total length of the body. Behind the pharynx, the gut extends as a straight tube with little sign of division into successive chambers. There is a large pouchlike outgrowth which is generally compared to a liver although the homology is dubious. As in vertebrates the tube ends at the anus.

The pharynx is highly specialized for collecting food. **Amphioxus** lives on particles gathered from the sea water: these are taken in through the mouth by ciliary action and strained out from the water as it passes out of the body through the gill slits. The number of gill slits is more than

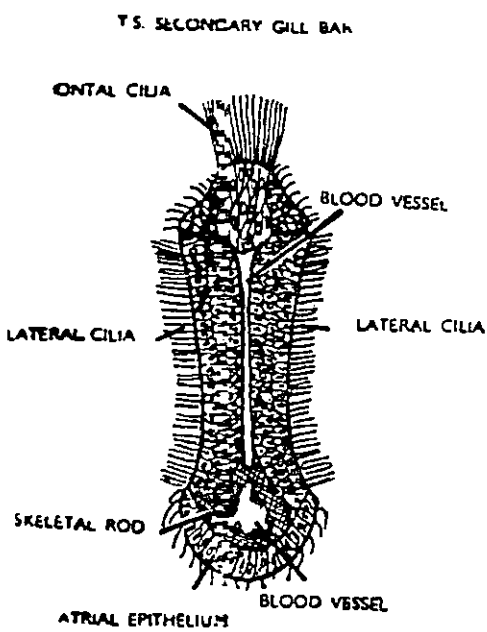


Fig. 237. B) — Transverse section of a primary gill bar of Amphioxus (highly magnified)

150 pairs which bear no gills. The gill clefts are metameric, vertical apertures when first formed in the larva, but each gets divided into two. New gill slits are added with age at the posterior end of the pharynx, hence their number varies in different specimens. Between the gill clefts, the wall of the pharynx is known as gill bars or gill lamellae. The gill bars are of two types, primary gill bars and secondary gill bars or tongue bars (Fig. 237). They alternate regularly and differ in their structural and mode of development. A primary gill bar is fromed of the tissue between two successive gill clefts after they have perforated to the exterior. It is composed of the wall of the pharynx and the body wall of the larva. The secondary gill bars arise as downgrowths of the dorsal wall of the larval gill cleft; the wall grows downwards dividing the original gill cleft into two halves vertically. Both primary and secondary gill bars are covered on their outer surfaces by ciliated ectodermal or ciliated atrial epithelium, but on their inner, anterior and posterior surfaces by endodermal pharyngeal epithelium which is heavily ciliated. In the middle, each gill bar has a mesodermic core of connective tissue, blood vessels and gill rods.

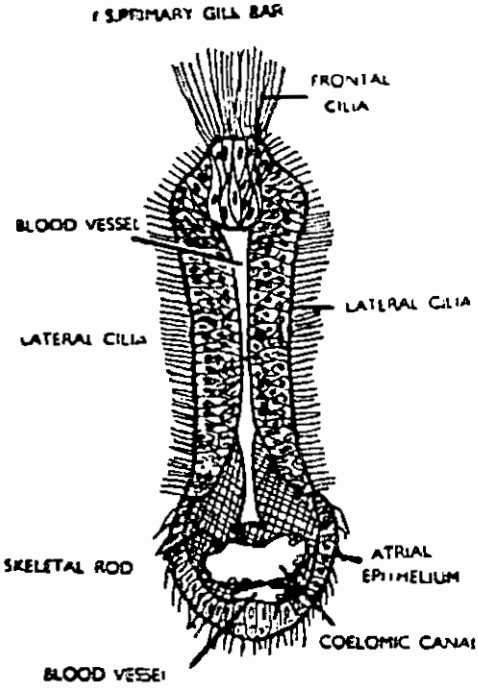


Fig. 237, C — Transverse section of a secondary gill bar of Amphioxus (highly magnified)

The gill bars are supported internally by gelatenous skeletal rods. All the gill rods are united dorsally, but ventrally, their free ends are forked in the primary gill bars and unforked in the secondary gill bars. The gill bars are connected by transverse **synapticula** which also contain gelatenous rods and blood vessels. The synapticula develop only after the gill clefts have been completed. The primary gill bars contain a narrow coelmic canal and three blood vessels in each running lengthwise. These secondary gill bars with simple gill rods have no part of the coleom and only two blood vessels, run through each of them. Beside the cilia which are found on the gill bars there are other ciliated tracts in the pharynx. As shown in Fig. 238, there is a mid-dorsal ciliated **epibranchial** groove which leads into the opening of the oesophagus. In the mid-ventral wall of the pharanx is a shallow groove calld **endostyle.** The endostyle is lined with secreting mucous gland cells. The gland cells which are found in tracts are separated by ciliated cells of which the median row bears very large cilia. At the anterior part of the pharynx there are two ciliated **peripharyngeal** bands which join the epibranchial groove and endostyle.

Respiratory System

At the early stages, the gill-slits correspond to the segmentation of the body, but during development more and more of them are formed (up to 180) and the correspondence is lost. The gill-slits are separated from each other by the gill-bars which are strongly ciliated (Figs. 237 A and B). These cilia force water through the slits into the atrium. In case of Amphioxus sp., exchange of gases between the water current and blood through the gill clefts appears doubtful, since the blood contains no respiratory pigments. It appears more probable that an exchange of gases occurs over the whole surface of the body and particularly in the walls of the atrium.

Atrium

The atrial cavity is formed by **metapleural folds** and lined with ectoderm. The metapleural folds grow down and unite by a transverse shelf so that a cavity is enclosed with the body (Fig. 238). The atrium surrounds the pharynx and anterior part of the intestine both laterally and ventrally. It extends back on the right side as a blind pouch which runs almost up to the anus. Near the end of the pharynx, the atrium gives two conical pouches, which project in front into the coelom on either side of the pharynx, and are hence called **atrioccelomic** canals. They are of unknown function. The atrium opens externally by a small **atripore.**

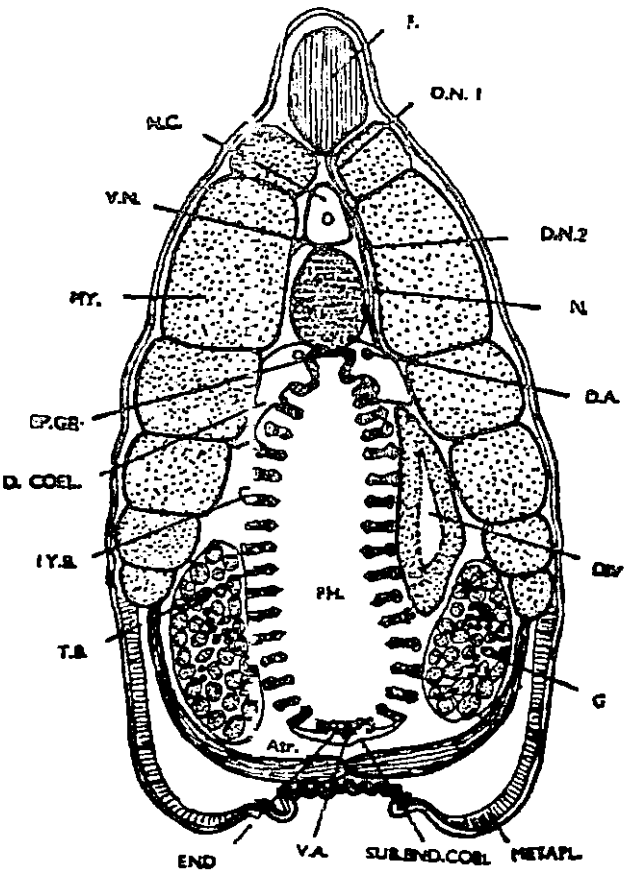


Fig. 238 — Tranverse section of the pharyngeal region of Amphioxus. ATR., atrium; D.A., dorsal aorta; D. COEL., dorsal portion of coelom; DIV, intestinal diverticulum; D.N.1 and D.N.2, branches of dorsal nerve root; END. endostyle; EP.GR, epibranchial groove; F., fin ray box; G, gonad; I Y.B., primary gil bar containing coelom; M.Y., myotome; METAPL., metapleural fole.; N., notochord; N.C., nerve cord; PH. pharynx; SUBEND COEL, subendostylar coelom; T.B., tongue bar; V.A., ventral aorta; V.N., ventral nerve root.

Coelom

In the region of the pharynx the coelom is much reduced due to formation of gill-slits, though in the larva it surrounds the pharynx all around except mid-dorsally. In the adult, the pharyngeal coelom is reduced to three spaces which are the **subendostylar coelom,** two **dorsolongitudinal coelomic canals** which enclose the atriocoelomic canals and minute vertical **coelomic canals** which pass through the primary gill-bars and connect the sub-endostylar coelom with the dorsal coelmic canal on each side of the pharynx.

Behind the pharynx there is a wide coleomic cavity around the mid gut and hind gut. The intestine is suspended in the coelom by a dorsal mesentery. At the right side of the hind gut, the coelom is reduced due to the presence of the posterior extension of the atrium.

Circulatory System (Fig. 239)

The circulatory system lacks a heart and is composed of vessels and tissue channels forming a continuous circuit. The contractile vessels have muscular walls, but the others consist of only a thin membrane. There is no histological distinction among the smaller vessels between arteries, veins and capillaries.

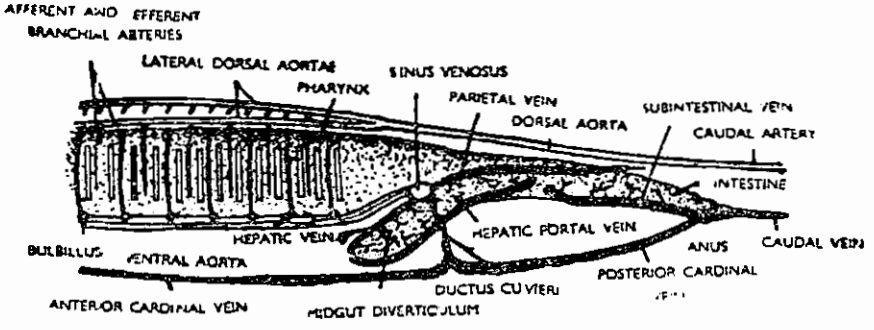


Fig. 239 — Lateral view of the circulatory system of Amphioxus.

The blood is colourless and devoid of corpuscles. It may be found also in lymph spaces around fin rays and in metapleural folds. From a junction point which is sac-like and corresponds to the **sinus venosus,** situated at the posterior end of the pharynx, a contractile vessel, which is known as the **ventral aorta,** runs forward beneath the endostyle and gives branches to both sides into the primary gill-bars. At the commencement of each branch, there is a contractile swelling known as **bulbillus** which also pumps blood. The paired branches of either side which are known as **afferent branchial arteries,** ascend the primary gill-bars with two secondary vesseles which spring from each **bulbillus.** The three branches as they pass through the primary gill-bars give two branches to each secondary gill-bar through the **synapticula.** These latter **afferent branchial vessels** are connected indirectly wtih the **ventral aorta.** Each nephridium receives branches from the vessels in the secondary gill bar. Blood is collected from the gill bars and nephridia by paired **efferent branchial vessels.** The efferent branchial vessels of each side open into a **lateral dorsal aorta** lying on one side of the **epibranchial**

groove. Shortly behind, the two aortae unite into a **single dorsal aorta** which continues backwards, and is known as the **caudal artery** in the tail region. From the lymph spaces of the intestine blood is collected into a **subintestinal vein.** It runs below the intestine The blood in the tail is collected in the **caudal vein** which runs forward and at the anus joins the sub-intestinal vein and forks into the posterior **cardinal veins.** Small vessels in the anterior part of the mid-gut unite to form a hepatic **portal vein** which runs along the ventral border of the mid-gut diverticulum and ramifies in its wall, thus forming a system which is not strictly comparable with, but which may be a sign, of the hepatic portal system of vertebrates. Small blood vessels from the mid-gut diverticulum unite to form a short hepatic vein running along the dorsal border of the mid-gut diverticulum. The hepatic vein enters the sac which was previously mentioned as corresponding to the **sinus venosus.** The posterior cardinal veins run forward inside the myotomes and opposite the **sinus venosus.** They join the similar anterior cardinal veins which run back from the anterior half of the body. The anterior and posterior cardinal veins of each side enter a **ductus cuvieri** just behind the pharynx. The two ductus cuvieri pass inwards through the atrium to join the **sinus venosus.** A renal portal circulation and a true hepatic portal circulation are absent because of the absence of the kidneys and a true liver. However the primitive characters of the circulatory system of Amphioxus indicates that this animal is a primitive one, i.e. related to the original ancestors from which all chordates evolved.

Excretory System

The excetory organs of Amphioxus are the nephridia (Figs. 240

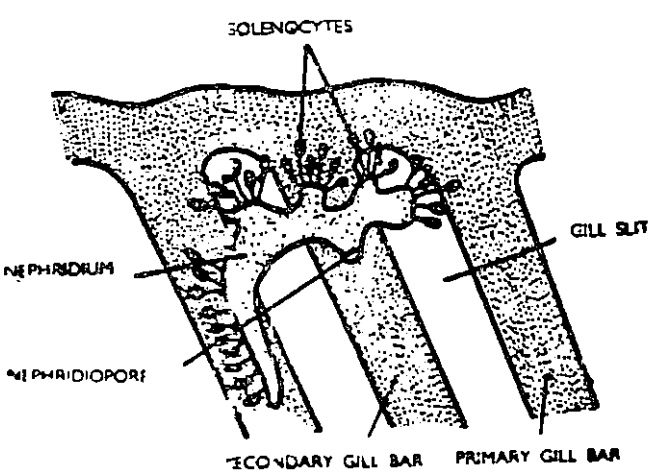


Fig. 240 — Nephridium with a portion of the pharyngeal wall of Amphioxus

and 241). The nephridia lie over the gill slits and project into the dorsal coelomic cavity and extend a short way down the coelomic canals in the primary gill bars in the form of small bent tubes. Each nephridium bears bunches of flame cells or solenocytes, like hollow pins with a flagellum hanging down inside from the head, and serving to flush out the contents. There is no internal opening to the nephridia, which derive the products which they excrete from the blood-vessels and coleomic fluid by diffusion.

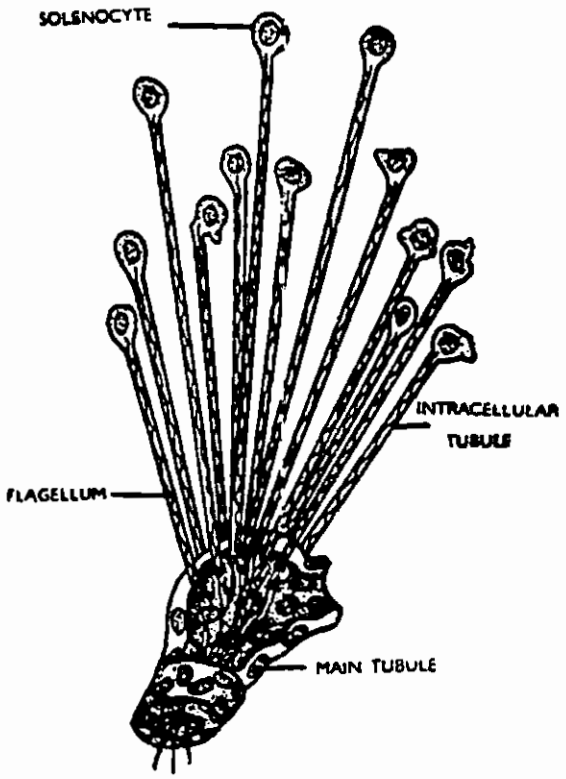


Fig. 241 — Solenocytes of Amphioxus showing the nuclei, long flagella and the openings into the main excretory canal leading to the atrium.

The nephridia open into the atrium by small pores situated near the top of the secondary gill bars. They are segmented in origin. There is another nephridium at the front of the animal, lying dorsal to the oral hood near the middle line. It opens into the pharynx, just behind the mouth. It is known as **Hatschek's nephridium** (Fig. 234).

Reproductive System (Figs. 233 and 238)

Sexes are separate although males and females are alike externally. The gonads lie in the ventro-lateral part of the body wall projecting into the

atrium. There are 26 pairs of gonads. They are metamerically arranged and begin from the 10th. tc the 36th. segments. They do not lie in the atrial cavity, but are separated from it by the body-wall. When the gonads are ripe, the germ cells burs: out of the pouches and pierce the body wall. Then, they pass from the atrium to the cutside through the atripore.

Nervous System

The central nervous system (Fig. 242) consists of a straight tube running dorsal to the notochord and ventral to the dorsal fin-rays. The olfactory pit on the left sice of the snout represents the spot where the cavity of the tube opens o the extreior at earlier stages (the **neuropore**). The cavity of the nerve tube is enlarged at its front end forming the brain vesicle. At the same time, the external diameter of the tube remains the same; its walls are therefore thinner.

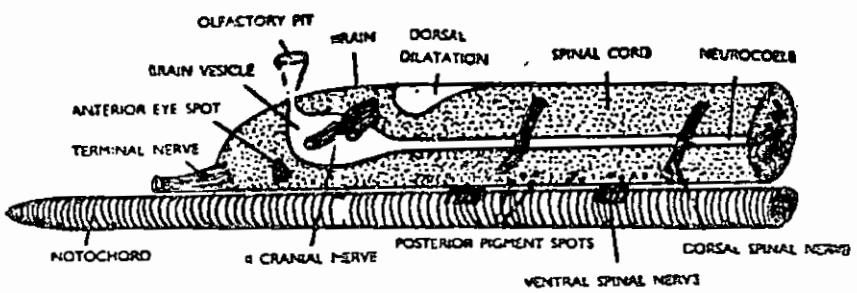


Fig. 242 — Neural tube of Amphioxus

From the anterior part of the neural tube arise two pairs of sensory nerves going to the oral hood, cirri and sense organs. The body behind the cerebral vesicle receives the spinal nerves. Each spinal nerve has a dorsal root with afferent sensory fibres entering and a ventral root made of several separate efferent motor fibres leaving the neural tube. The dorsal roots come from the skin and the ventral roots go to the myotomes. The dorsal and ventral roots do not unite to form a mixed spinal nerve as is the case in higher chordates. Also a dorsal root of a spinal nerve is slightly posterior to its ventral root and the spinal nerves of the two sides do not correspond. There is an **autonomic nervous system** which controls the unstrined muscles of the gut.

Sense organs

At the front end of the nerve-tube there is an eye spot (or pigment spot) which is supposed to be a visual organ. There are also other pigment spots

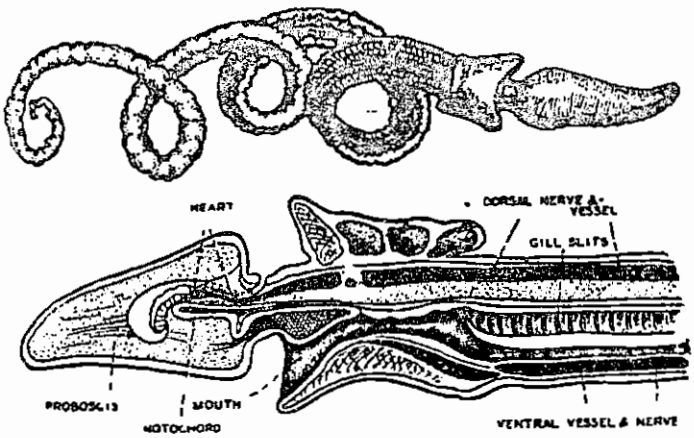


Fig. 243 — Balanoglossus of subphylum Hemichordata. Observe chordate characteristics : gill slits, dorsal notochord, and dorsal nerve in section below. (from Beover)

along the entire length of the neural tube. They are arranged in definite tracts and are also sensitive to lgiht. The olfactory pit is also referred to as the **Kolliker's pit.** It is probably not an olfactory sense organ since it has no specialized sensory cells. In addition there is an infundibular organ represented by a depression in the floor of the cerebral vesicle. It is lined by long ciliated cells and detects changes in the pressure of the fluid in the neural tube. However, papillae are sensory to touch and those of the velar tentacles are also chemoreceptors, having an olfactory function. Each of the sensory cells which are scattered all over the epidermis has a nerve fibre at its lower end and a hair-like sensory process, projecting from the cuticle, at the outer end.

Subphylum-HEMICHORDATA

BALANOGLOSSUS

This is a worm-like, simply organised animal possessing a structure which is commonly regarded as of the nature of a rudimentary notochord (Fig. 243). The body is divided into three regions, a **proboscis, a collar,** and a **trunk.** Paired lateral **gill slits** are present in the anterior part of the trunk. The mouth opens on the anterior surface of the collar region, and the anus is situated at the posterior end of the trunk. The proboscis and collar possess cavities which become filled with water through ciliated

pores. When in a swollen condition, the proboscis and collar are forced into the sand or mud, and consitute, effective burrowing instruments. The **notochord** is a supporting organ consisting of a hollow tube of cells. It opens posteriorly into the alimentary canal. The alimentary canal is straight, and the mud in which the animal lives is taken into the mouth and forced slowly through the digestive tube, where nutriment is extracted from the organic matter contained in it. The gill slits open into the anterior portion of the alimentary canal and supply water to the tongue-like respiratory organs. There is a dorsal blood vessel ending anteroirly into a **contractile heart** which lies in a pericardial cavity. A ventral blood vessel is connected with the dorsal blood vessel in the collar region by two lateral tubes. The other blood vessels are simply spaces in the tissues. **Excretory products** appear to be extracted from the blood by the **glomerulus** or kidney, which lies on the posterior wall of a cavity in the proboscis. The excretions pass out throngh the proboscis pore when water is expelled from the proboscis cavity. The **nervous system** is not concentrated. A layer of nerve fibres just beneath the ectoderm makes the entire surface sensitive. Thickenings occur along the mid-dorsal and mid-ventral lines, of the trunk just poterior to the collar. A **neural tube** is formed by the dorsal thickening. The **coelom** which arises from the primitive digestive tract, very much as in Echnioderms, is represented by a proboscis cavity, two collar cavities, and two trunk cavities. The **sexes** are separate, two ovaries or testes form a double row in the anterior trunk region, and the germ cells reach the exterior through pores in the body wall.

The inclusion of the Sub-phylum Hemichordata in the Phylum Chordata is an arrangement the propriety of which is universally admitted and is carried out here partly to obviate the incenvenience of ereting to class into a separate phylum On the whole, however, there seems to be sufficient evidence for the view that, if not the existing representataives of ancestral Chordates, they are at least a greatly modified branch, taking its origin from the base of the chordate tree. The presence of the presumed rudimentary representative of a notochord and of the gill slits seems to point in this direction. It should, however, be stated that, by some of these zoologists by whom the members of this group have been most closely studied, their chordate affinities are altogether denied. If the Hemichordata are primitive Chordates, he fact is of special interest (that they how remarkable resemblances in some points to a phylum, like that of the Echinodermata, which has been the custom to place very low down in the invertebrate series. The larva of Balanoglossus is so much like that Echinodermata, that a remote evolutionary connection between Echinodermata and Hemichordata is suggested, but the presence of the notochord

gill slits, and the dorsal portion of the nervous system are the basis for classifying the latter as Chordata.

Subphylum UROCHORDATA

ASCIDIA

The adult urochordates or tunicates bear no resemblance to vertebrates, but their tadpole-like larva exhibits pronounced chordate characteristics, as will be described below.

External Features

A tunicate, such as **Ascidia,** is an oval sac-like creature which is scarcely recognisable as an animal (Fig. 244 and 245). It is permanently attached to rocks or other objects, by its base which is generally irregular in form. Its free end bears two openings called **siphons.** When the animal is gently squeezed, jets of water are observed to squirt from these siphons; hence the name "sea squirt" properly applied to these animals. The upper siphon is the **oral** or **incurrent siphon** and is the degenerate anterior end of the animal. The lower siphon is the **atrial** or **excurrent siphon** or **atripore.** It represents the posterior end. The antero-posterior axis of the tunicates is bent into a U-shape. The region of the body between the two siphons is therefore dorsal, and the remainning and much larger part of the surface is ventral. The siphons are operated by circular and longitudinal muscles. The outer covering of the animal is a thick, tough and sometimes gelatenous membrane which is generally referred to as the **tunic** or **test.** This test is secreted by the underlying epithelium and attached to the enclosed body only at the siphons.

Internal Anatomy (Figs. 244 and 245).

Beneath the test, is the soft body wall which is also called the **mantle.** It consists of an outer epithelium and inner connective tissue. It encloses the viscera, to which it adheres considerably. The oral siphon leads into a large thin-walled bag, the **phhrynx.** The cavity between the pharynx and the mantle, is the **atrium,** which opens to the exterior by way of the **atrial siphon or atriopore.** The lower end of he pharynx narrows into a short oesophagus which opens into the widened stomach. The stomach leads into the intestine, which immediately doubles back to form a loop parallel to the stomach and then extends straight upward toward the atrial siphon, terminating by an **anus** situated in the atrium In the dorsal part

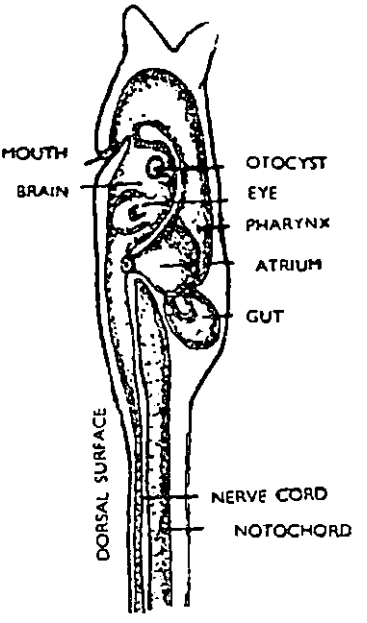


Fig. 244 — Diagram of the structures of a solitary Ascidia, as seen in the free swimming larva (head end above and only a short section of the tail figured). The otocysts is a simple ear structure.

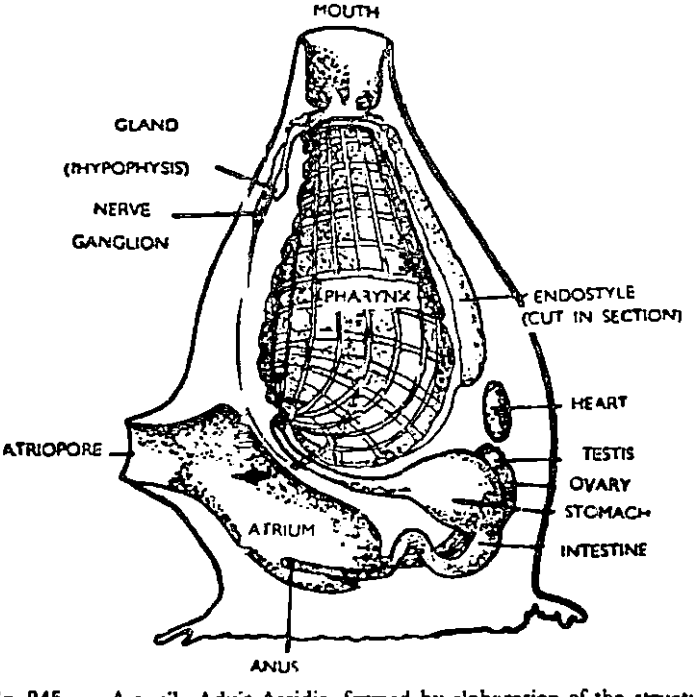


Fig. 245 — A sessile Adult Ascidia, formed by elaboration of the structures at the anterior end of the larval body. Water, passing through the lattice work gills of the pharynx, enters the atrium and, as indicated by the arrow, streams out through the atriopore.

of the mantle between the two siphons is found an elongated mass, the **ganglion,** which constitutes the **central nervous system** of the adult tunicate. Nerves may be seen extending from its ends to the siphon.

In the mid-ventral line of the pharynx there is a white cord, the **endostyle** or **hypobranchial groove,** composed of glandular and ciliated cells. Directly opposite the endostyle in the mid-dorsal line of the pharynx there is the dorsal **lamina,** which is either a deliacte membranous fold or a fringe-like row or projections called **languests.** At the junction of the pharynx and oral siphon, there generally occurs a circlet of tentacles or irregular processes.

Chordate Features of Tunicntes

Tunicates pass through a larval stage termed the **tadpole.** It resembles in shape the frog tadpole (Fig. 246) which represents an early stage where the tail is diagrammatically chordate. Under the simple dorsal epidermis, is seen the neural tube which is widened anteriorly into a **brain.** Below the neural tube, in the tail, is located the **notochord,** composed of large cells, and below that structure is the **endoderm** of the future intestine. It is enlarged anteriorly into the future pharynx. The notochord terminates anteriorly, just behind the brain vesicle. Both the notochord and neural tube are formed embryologically as in vertebrates. There is no trace of segmentation.

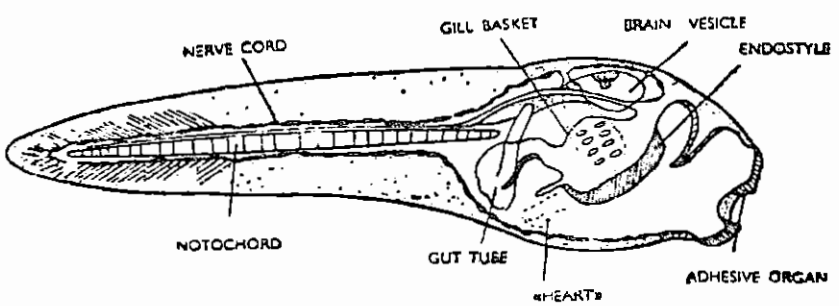


Fig. 246 — A swimming larva of a tunicate

The tadpole usually swims about for a few hours, attaches to some objects by **papillae** and then undergoes metamorphosis. The tail with its chordate features is partly cast off and partly absorbed. The brain also disappears. But, earlier, a portion of it is constricted off, persists and forms the adult **neural canal** and **duct.** The larval pharynx enlarges and differentiates. The **atrium** arises as a pair of pouches which grow in from the outside and eventually fuse to form a simple cavity. The **neural gland**

is a small mass near the ganglion, opening into the pharynx by a delicate duct whose mouth may be much convoluted or folded into a structure termed the **dorsal tubercle.** This whole apparatus is of nervous origin. There is some evidence that it is the homologue of the posterior lobe of the pituitary of vertebrates.

Subphylum VERTEBRATA (or CRANIATA)

Vertebrates, as the name implies, are those chordates which possess a vertebral column or backbone. This consists of a series of skeletal elements embedded in the great muscles of the back and replaces the notochord of the less complex chordates and of the vertebrate embryo. Animals which have a backbone always have other skeletal structures, particularly those developed around the brain and sense organs to form a cranium. Such chordates are therefore termed **craniates,** an alternative name for vertebrates.

In some vertebrates, certain animals possess jaws bordering the mouth. Such vertebrates are grouped together to form the **Gnathostomata** to distinguish them from those, **Agnatha,** which do not possess jaws, and in the modern representatives of which (the Cyclostomata), the mouth is round and suctorial. The gnathostomes, too, invariably possess outgrowths from the body termed limbs, and these have their particular skeletal structures forming the limb skeleton with which are associated limb girdles. Most of the other chordate features are clearly recognisable in vertebrates. The hollow **central nervous system** is always well developed and the anterior part enlarged to form **brain,** the remainder constituting the **spinal cord.** The ventral **heart** is contained in a pericardial cavity and leads into a ventral aorta from which arises a series of aortic arches passing along visceral arches to dorsal aorta above the pharynx. The **respiratory system** always includes a respiratory surface developed in relation with the pharynx, either gills (in aquatic forms) or lungs (in terrestrial animals). The **excretory organs** of vertebrates are the kidneys. The **gonads** are compact bodies and their ducts are closely associated with those of the kidneys.

Sub-phylum **Vertebrata** is subdivided into several **classes** which are :

I — Class **Cyclostomata.**

Without true jaws and without limbs. Extinct forms, a large group of primitive fishes armoured with large scales, **ostracoderms.** Existing

forms, without such scales, the **Lampreys.**

II — **Chondrichthyes.**

With cartilaginous skeletons and exposed gill slits, e.g. sharks and rays.

III — Class **Osteichthyes.**

With bony skeletons and with gill slits covered by an operculum e.g., common fresh-water and marine bony fishes.

IV — Class **Amphibia.**

Semi-terrestrial and aquatic forms, skin usually soft and moist, respirataion usually by gills in the larvae and by lungs in the adult, e.g. salamanders, frogs and toads

V — Class **Reptilia.**

Terrestrial or secondarily aquatic forms, covered with scales or bony plates, e.g. lizards, snakes and turtles.

VI — Class **Aves.**

Terrestrial forms, adapted for flight and covered with feathers,e.g. birds.

VII — Class **Mammalia.**

Terrestrial or secondarily aquatic forms, covered with hair, e.g. mammals.

Class CYCLOSTOMATA

PETROMYZON

(The Lamprey)

As shown in (Fig. 247), **Petromyzon** is an elongated animal, the length of which varies from a few inches to about four feet. There is a defined head with a brain. The body is cylindrical but, posteriorly, it is compressed laterally. On the head and sides of the body are open pores of the lateral-line system though a proper lateral line is absent. There are no scales and paired fins are absent. There are two dorsal fins, the posterior of which is continuous with the caudal fin. They are supported with cartilaginous fins rays. At the anterior end is a round, ventral, suctorial **buccal funnel**

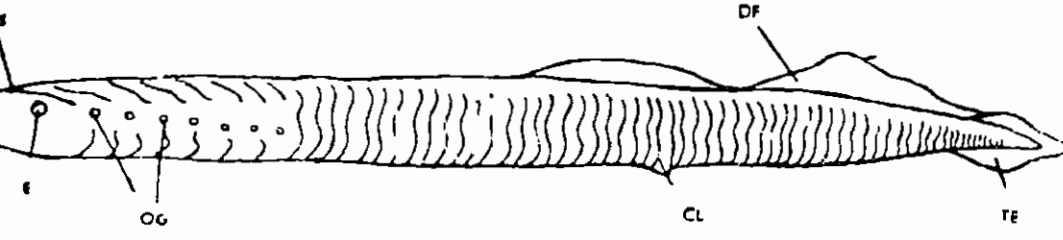


Fig. 247 — Lateral view of Petromyzon CL, cloacal aperture (urinogenital); DF, dorsal fin; E, eye; OG, openings of gill pouches; NS, nostrils; TF, tail fin.

having a mouth at the bottom of the funnel (Fig. 248). The lips of the buccal funnel have soft papillae and inside the funnel are horny epidermal teeth arranged in definite rows. Protruding through the mouth into the funnel is a rasping tongue with horny teeth. The teeth are cone-shaped and are replaced continuously when worn out. The tongue is used for rasping flesh and the funnel for sucking blood and mucus. A so-called salivary gland opens into the mouth cavity below the tongue.

There is a **median nasal aperture,** behind which is the **pineal eye** which is senstitive to light (Fig. 249). There are other photosensitive cells in the skin which are abundant on the tail. The paired eyes are covered with transparent skin but without eyelids. There are seven pairs of **gill slits** which lead into gill pouches. These pouches open into the pharynx. In front of the tail, on the ventral side, is an **anal aperture** and a **urino-**

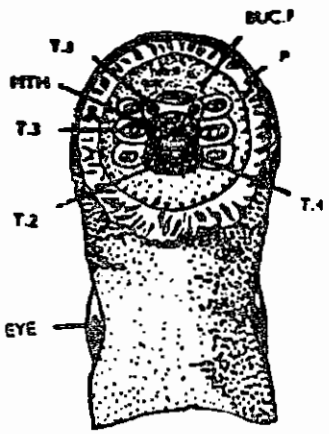


Fig. 248 — Ventral view of the head of Petromyzon. BUC. F., funnel; MTH, mouth; P. papillae; T1-T3, Teeth of buccal funnel T4, teeth of tongue.

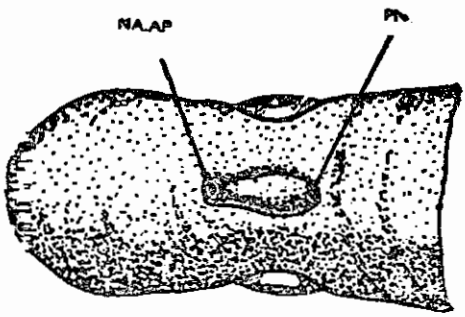


Fig. 249 — Dorsal view of the head of Petromyzon. NA.AP, nasal aperture; PN, pineal area.

genital aperture. In the male there is a **copulatory** papilla.

The **skull** is primitive and the **skeleton** is made entirely of cartilage. The visceral sketeton is known as the **branchial basket.** The **vertebral column** has incomplete vertebrae and the **notochord** is a persistant rod.

In the **alimentary** canal there is no indication of a curved and enlarged region which is known in all higher forms, as the stomach. There is also a liver connected to the intestine by a bile duct. The **excretory organs** are of the typical structure of a vertebrate kidney. The tubules which form them are of mesodermal origin coming from the coelomic epithelium and are sharply distinguished from the nephridia which are ectodermal in origin.

There is a muscular pump which is the **heart** (Fig. 250). It is formed of a **sinus venosus** into which the hepatic and other veins enter, leading on to a thin-walled **auricle** and a thick walled **ventricle.** The entry to and exit from the ventricle, which does the propelling of the blood, are guarded by valves so that blood cannot flow in the reverse direction. The length of the structure composing the heart is greater than that of the space (**pericardium**) in which they lie and consequently the heart is slightly bent on itself into the form of an S The blood is red owing to the presence of haemoglobin in corpuscles and there is no **spleen.**

The anterior end of the **nerve tube** (or nerve cord) **is** modified and enalrged in connection with the paired sense organs to form the **brain.**

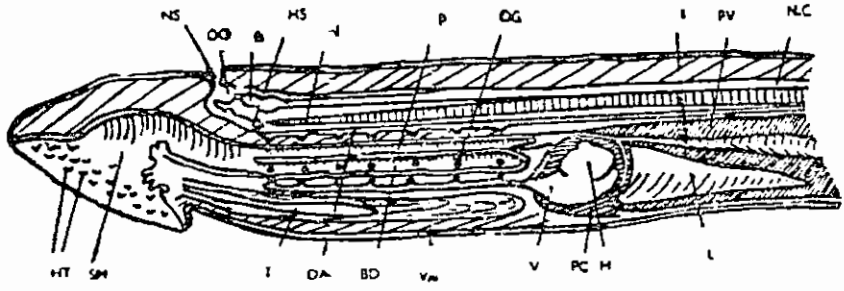


Fig. 250 — Median longitudinal section through the anterior region of an adult Petromyzon. (See lettering under Fig. 165)

In **Petromyzon,** there are two important primitive features to note in connection with the nerves. One is that the dorsal and ventral roots of each segment do not join together, but remain separate. The other is that the nerves are simple and non-medullated.

The young lamprey is known as **ammocoete larva** (Fig. 251). This larva is of special interest, because it shows striking similarities with **Amphioxus,** and because it is a very primitive and generalized vertebrate, it may regarded as a connecting link between **Amphioxus** and **Cyclostomes.**

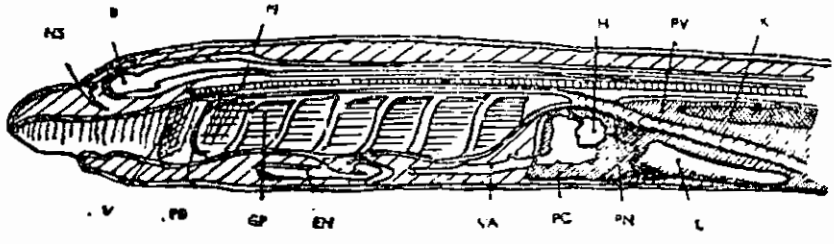


Fig. 251 — Median longitudinal section through the anterior region of the body of an Ammocoete larva.

Lettering for Figs. 250 and 251 : B, brain ; BD, branchial duct ; DA, dorsal aorta ; EN, endostyle ; GP, gill pouch ; H, heart ; HS, hypophysial sac ; HT, horny teeth ; H, intestine ; K, kidney ; L, liver ; N, notochord ; NC, nerve cord; NS, nostril ; OO, olfactory organ ; P, pharynx ; PB, perivisceral cavity ; SM, sucking mouth ; T, rasping tongue ; (in Fig. 250), ventricle ; V (in Fig. 251), velum ; VA, ventral aorta.

The following characters are shown by **Petromyzon** and absent in **Amphioxus** :

1. Formation of a distinct head, brain and skull.
2. Formation of a distinct heart.
3. Formation of a definite liver.
4. Formation of pro- and meso-nephric kidneys.
5. Epidermis several cells in thickness.
6. Rudimentary vertebral column.
7. Myotomes W-shaped.
8. Rudimentary sympathetic nervous system

Class CHONDRICHTHYES

They are Gnathostomata adapted for aquatic mode of life. The organs of respiration are gills which take up oxygen dissolved in water. While in Amphioxus and Petromyzon there are only median fins, the cartilaginous fishes possess not only median fins but also paired fins. There are typically two pairs of paired fins, the anterior are called the pectoral fins, and the posterior the pelvic fins.

SCYLLIUM

(The dogfish)

As shown in Fig. 252, the dogfish possesses an elongated body with a distinct head and tail. The latter is provided with a tail-fin of which the ventral lobe is larger than the dorsal one. The most obvious advance over **Petromyzon** condition is the possession of paired fins, of which there are two pairs : a pectoral and a pelvic. The body consists of three regions : head, trunk and tail.

The **head** (Fig. 253) is dorso-ventrally compressed, and has on its ventral surface the large crescentic mouth which is bounded by the upper and lower jaws. Each jaw carries several rows of teeth which are directed backwards and possess pointed ends. The nostrils are found in front of the mouth, and are connected with it by two **naso-buccal** grooves. The eyes are situated at the sides of the head. Close to each eye is found a small rounded opening, the **spiracle,** which leads to the pharynx. Posterior to each spiracle, and nearer to the ventral surface of the head are found five vertical openings which are called gill slits, which lead also to the pharynx. Behind the head the trunk becomes gradually flattened.

The anus lies in a cloaca in the midventral line behind the pelvic fins and on each side of its is the small abdominal pore which communicates with the coelom. In the male there is a pair of claspers on each side of the cloaca.

SKELETAL SYSTEM

Exoskeleton

The whole body is covered all over with small sharp spines, with the points directed backwards which are the placoid scales (Fig. 254) chara-

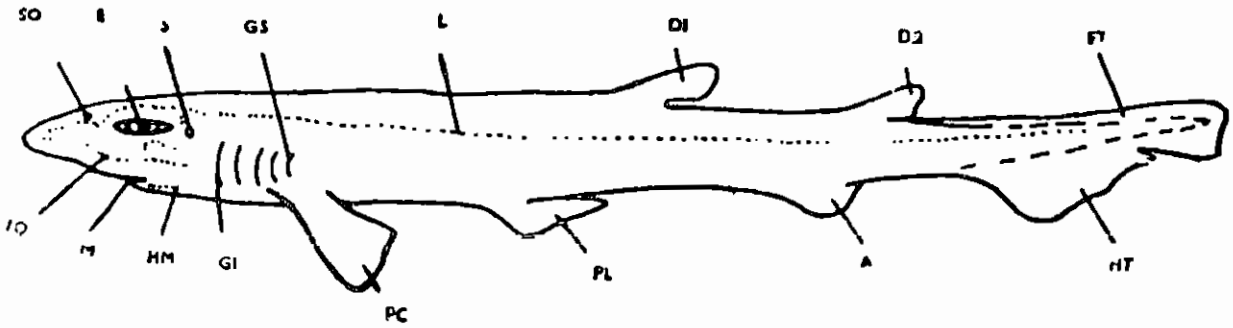


Fig. 252 — Lateral view of Scyllium (The Dogfish). A, anal fin; D1, D2, first and second dorsal fins; E, eye; ET, epicaudal (dorsal) lobe of heterocercal tain-fin; G1, G5. first and fifth gill slits; HM, hyomandibular lateral line canal; HT, hypocaudal (ventral) lobe of tail fin; 10, infraorbital leateral line canal; L. lateral line canal; M, mouth; MC, pectoral fin; S. spiracle; SO, supraorbital lateral line canal.

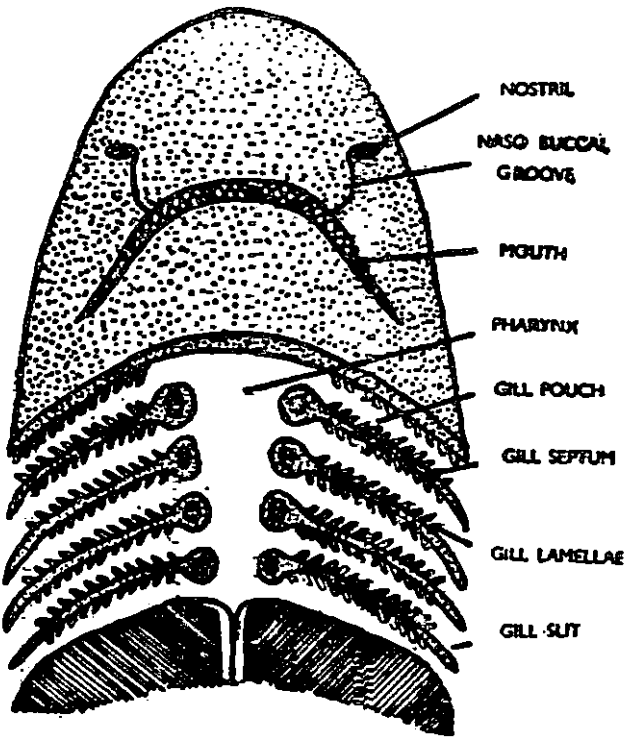


Fig. 253 — Ventral view of the head of Scyllium, with its gill region dissected.

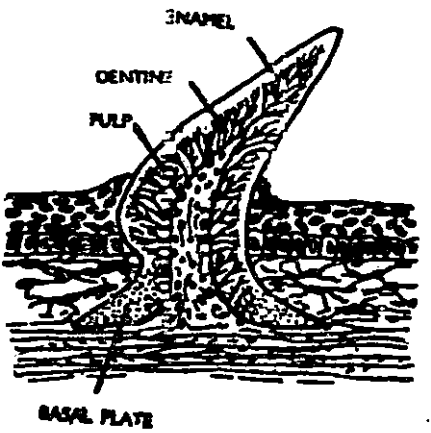


Fig. 254 — Vertical section of a placoid scale

eteristic of elasmobranch fishes. They give a rough texture to the skin and are embedded in the dermis as exoskeleton. A placoid scale has a flat four-

lobed or rectangular basal plate from which arises a pointed backwardly in oblique rows. They project from the epidermis forming a directed spine. The base is embedded in the dermis and the spine projects through the epidermis beyond the surface. In a vertical section, each spine is seen to be covered on the outside with a hard whitish shiny enamel-like material within which is the more spongy dentine. Inside the spine is a pulp cavity containing pulp made of connective tissue, blood vessels and a layer of odontoblast cells. The basal plate is made of calcified dentine and the spine has mostly dentine which is covered with a cap of hard modified dentine called **vitro dentine** (enamel). The basal plate and spine are both of mesodermal origin. Placoid scales and teeth of **gnathostomes** are homologous structures. This homology can be emphasized if we consider the development of the placoid scales.

Development of Placoid Scales (Fig. 255)

Stages of the development of the placoid scales are shown in (Fig. 255 A, B, C and D). During development, a group of cells known as **odontoblasts** collect in the dermis to form a **dermal papilla** which increases in size and projects upwards into the epidermis. Thus, it pushes the Malpighian layer before it. Then, the dermal papillae take the shape of a **basal plate** and **spine.** The odontoblasts secrete **dentine** all around forming the basal plate and spine of placoid scale. The dentine of the basal plate becomes calcified. The Malpighian layer of the epidermis in contact with the dermal papilla is known as **enamel organ.** This latter organ forms **vitro dentine** over the **dentine** of the spine. The dermal papilla forms **pulp** in the **pulp cavity** of the scale. As the superficial layers of the epidermis rupture, the spine emerges beyond it and the base remains embedded in the dermis.

The scales are constantly replaced by other new scales with the result that, in a vertical section of the skin, denticles in various stages of development can be seen.

Related to exoskeleton are the **dermal fin rays.** The fins are supported by stiff rays of dermal origin. In case of fishes, in general, there are four kinds of fin rays which are **ceratotrichia, actinotrichia, lepidotrichia** and **camptotrichia.** In case of cartilaginous fishes, the dermal fin rays are of the first type (**ceratotrichia**). These are slender, flexible, unjointed fin rays which consist of a fibrous material.

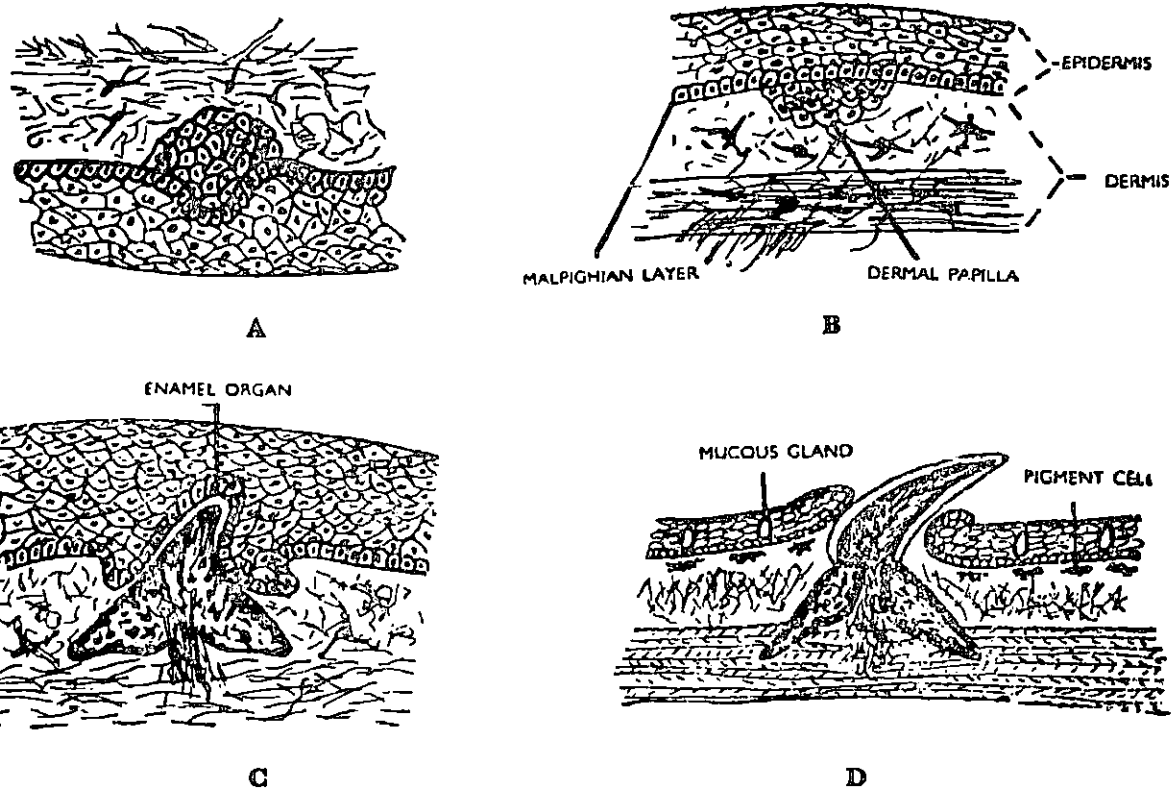


Fig. 255 — Development of a placoid scale

Endoskeleton

The internal skeleton is composed of the skull, vertebral column, ribs, pectoral and pelvic girdles and the skeleton of the median and paired fins. The endoskeleton is composed entirely of cartilage in which may be deposited calcium salts.

The skull

The cranium (Fig. 256) is a cartilaginous case, the wall of which is continuous throughout. Anteriorly, there is a pair of thin **olfactory capsules,** while posteriorly there is a pair of stout **auditory capsules,** both are firmly fused with the cranium. At the side of the olfactory and auditory capsules are the shallow **orbits.** The part of the roof of the cranial cavity behind and between the olfactory capsules is formed not of cartilage but of a tough fibrous membrane and the space thus filled in is termed the **anterior fontanelle.** In contact with the lower surface of the membrane is the **pineal body.** Over the orbit, there is a ridge-

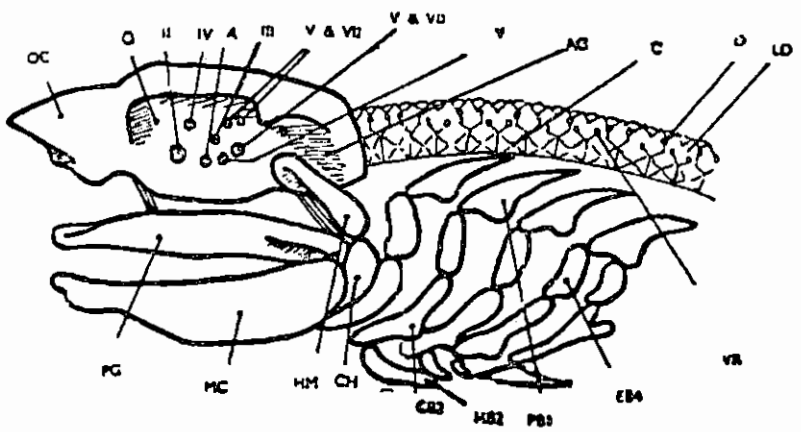


Fig. 256 — Scyllium. General view of the skull and visceral arches.

A. foramen for effereut pseudobranchial artery ; AC, auditory capsule ; C, centrum of vertabra ; CH, ceratohyal ; BC 2, ceratobranchial of second arch ; D, formen for dorsal spinal nerve-root ; EB 4, epibranchial of fourth each ; HB 2, hypbrachial of second arch ; HM, hypomandibular ; ID, interdorsals cartilage ; MC, Meckel's cartilage ; O, orbit ; OC, olfactory capsule ; PB I, pharyngobranchial of first arch ; PG, pterygo-quadrate cartilage ; V, foramen for pituitary vein ; VR, foramen for ventral spinal nerve-root ; II, optic nerve foramen ; III, oculomotor nerve foramen ; IV, trochlear nerve foramen ; V and VII, trigeminal and facial foramen ; V, and VII O, foramina of ophthalmic branches of trigemidal and facial.

like promonance which is the **supra-orbital crest,** terminating anteriorly and posteriorly in obscure processes termed respectively the **pre-orbital** and **post-orbital processes.** Below the orbit is a longitudinal **Infra-orbital ridge.** The cranial nerves all emerge through special holes or formina. The notochord disappears in the skull region and a definite joint is formed between the hind end of the skull and the front of the vertebral column.

Connected with the cranium are the **visceral arches.** The first is the **mandibular arch** which forms the jaws and separate the spiracle from the mouth. The upper and lower portions of this arch move on one another. The skeleton of the upper jaw is the **pterygoquadrate.** that of the lower jaw is **Meckel's cartilage.** The arches between the gill-slits also have cartilaginous rods. The **second visceral arch** or the **hyoid arch** separates the spiracle from the first gill-slit and is composed of a dorsal portion, the **hyomandibular,** a ventral portion, the **ceratohyal** and a median **basihyal.** The following visceral arches are made up of four pieces on each side which are from above downwards, the **pharyngo-, epi., cerato.,** and **hypobranchial.** There is also a median **basibranchial.**

Vertebral Column

The vertebral column does not come from the notochord, but it is formed around it. The notochord is thus, enclosed inside the centra, where it is readily located in the more primitive vertebrates. But in most vertebrates it is gradually squeezed down and more or less disappears. In the dogfish corresponding to each septum between two segments, there are paired **basidorsal** and **basiventral** cartilages (Fig. 257) surrounding

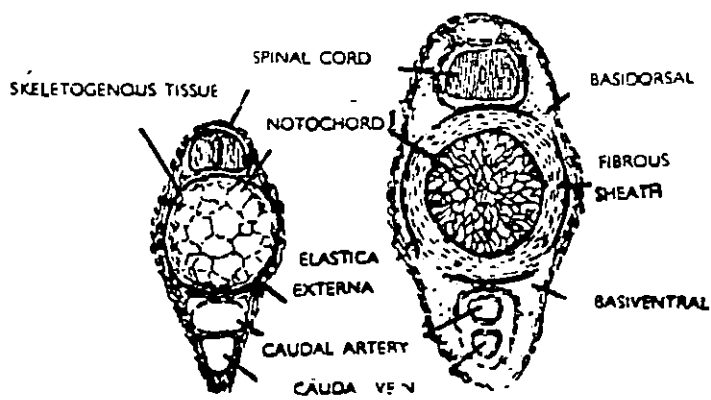


Fig. 257 — Transverse section of the vertebral column of the tail region of a young embryo before invasion (left) and the same of an older embryo showing invasion.

the notochord. The sheath of the notochord is penetrated by these cartilages which, together, form a bobbin-like ring or **centrum,** which constricts and interrupts the notochord. The centra articulate on one another end to end, and in this ways a vertebral column is formed. Arising up from the centra, are the **neural arches** which enclose the spinal cord in a canal. Alternating with these, are **interdosal** cartilages The ventral nerves emerge behind the neural arches, and the dorsal roots behind the interdorsal cartilages.

The vertebral column is distinguished into a trunk and a caudal region. In the trunk region, each vertebra consists of a **centrum, neural arch** (**basidorsal**) and a transverse process (**basiventral**). The distal portion of the latter forms a slender rib lying in the transverse septum. In the caudal region (Fig. 257), transverse processes instead of projecting lateral are bent inwards, beneath the centrum and fuse in the midventral line to form the **haemal arch** and thus ribs are absent. Within the haemal arch are found the caudal artery and caudal vein. The centra of all the veterbrae are **amphicoelous** (biconcave). Through the series of centra runs the constricted notochord, but it dialates in the large spaces formed by the opposition of the amphicoelous centra of adjoining vertebrae, where it forms a pulpy mass.

Fins (Fig. 258).

The median fins are supported by jointed cartilaginous rods or radials. In addition, the web of the fin is supported by horny dermal fin-rays, close under the skin on each side of the radials. These rays, or **ceratotrichia,** are more numerous than the radials.

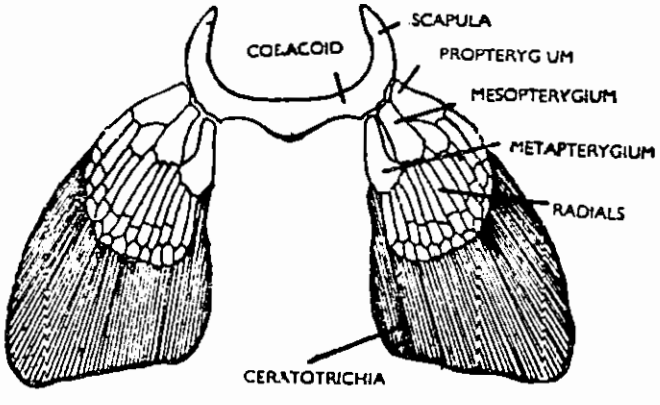
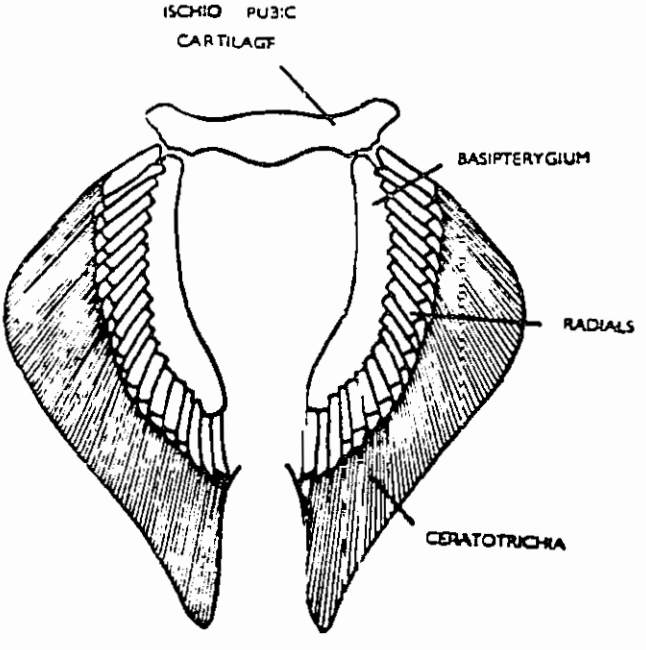


Fig. 258 A) — Pectoral girdle and skeleton of pectoral fin

The paired fins also have an internal skeleton of cartilaginous radials, and are anchored to the body by girdles lying in the body-wall The **pectoral girdle** is a half-loop of cartilage set transversely to the long axis of the body, with the free ends pointing upwards. On each side is a hollow, the glenoid cavity, in which the cartilages of the fins fit. The latter cartilages are the most proximal radials, which form three cartilages, the **pro-, meso-,** and **metapterygia.** The ventral portion of the pectoral girdle is termed the coracoid region from the glenoid cavity to the free tips which project dorsally the cartilage is known as the **scapular** region.

The **pelvic girdle** (Fig. 258 B) is formed by a transverse cartilage, at each end of which an elongated backwardly directed basipterygium is articulated. This basipterygium forms the axis of the pelvic fin, and bears a number of cartilaginous radials on its anterior border.

The pectoral and pelvic fins, as well as the median fins, have their webs supported by horny dermal fin-rays, the **ceratotrichia.**



258 B) — Pelvic girdle and skeleton of pelvic fin.

The Alimentary Canal (Fig. 259)

The mouth leads into the pharynx into which open the internal apertures of the branchial clefts and of the spiracle. The pharynx leads to the wide oesophagus which passes into the stomach. This latter is a U-shaped organ with a long left limb continuous with the oesophagus and a short right one passing into the intestine. At the pylorus, there is a slight constriction followed by a thickening. The intestine consists of small intestine which is very short and large intestine which is long and wide. The latter is divisible into the colon in front and the rectum behind. The former has a spiral valve which affords a more extensive surface for absorption. The rectum is narrower and opens behind into the cloaca.

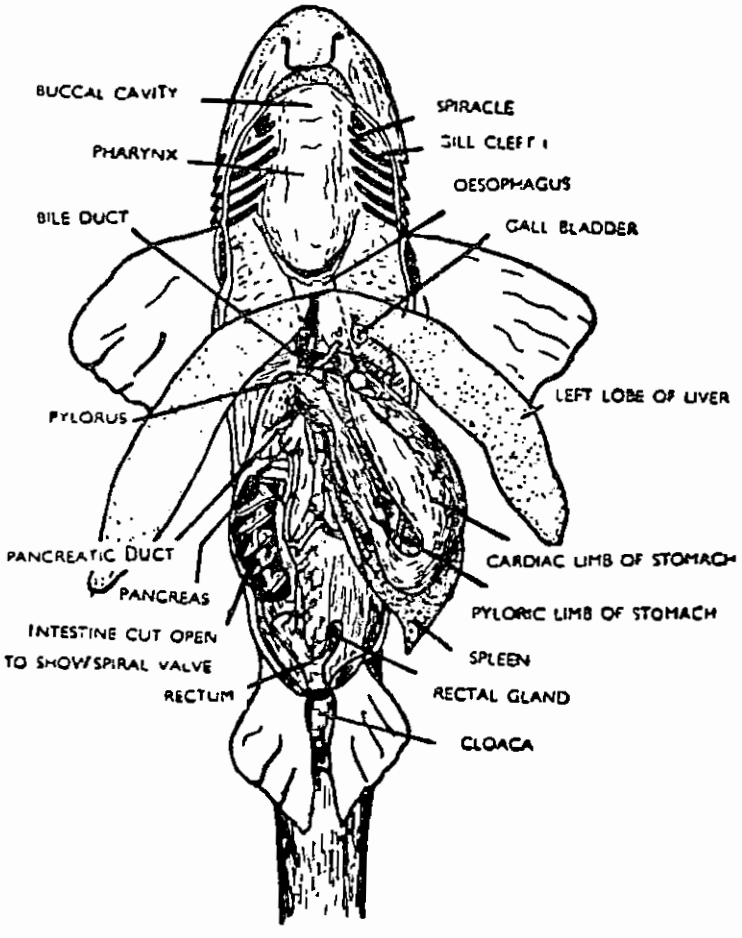


Fig. 259 — Scyllium dissected to show the alimentary canal.

Connected with the alimentary canal is a large liver which consists of the elongated lobes. In the left lobe there is embedded a gall bladder. The bile duct runs from the liver to the intestine.

The pancreas lies in the angle between the right hand limb of the stomach and the small intestine. Its duct enters the wall of the small intestine and runs in it for about half an inch, opening at the point where the small intestine passes into the colon. Also, there is a rectal gland which is connected with the rectum on its dorsal surface. There is a spleen attached to the stomach and has narrow lobe along the right-hand limb.

Respiratory System

There are five pairs of functional **branchial clefts** lying between the hyoid and successive branchial arches (Fig. 253 and 259). Each branchial cleft consists of an internal pharyngeal opening, a spaceous branchial or gill pouch, containing the gills and an external opening the gill **slit** or **cleft** on the surface of the head. Between successive clefts, there is present on the inner side, the **branchial arch** and extending obliquely backwards from the arch to the surface of the body, is an **interbranchial septum.** This septum is covered by epithelium and contains blood vessels and nerves. Arising from the arch and extending through the septum into the gill are the cartilaginous gill rays. The gill proper is formed of leaf-like foldings the septal tissue, each fold constituting a gill lamella or filament, the distal ends of which are free. From each branchial arch two groups of lamellae arise, one on the anterior and one on the posterior face of the septum, and each is termed a hemibranch, the two arising from the same arch, constituting a holobranch. Each of the first four pairs of branchial pouches contains a hemibranch on both the anterior and posterior wall, but the last pair has a hemibranch on the anterior wall only. In each spiracle a vestigial gill termed a **pseudobranch** is present. Within each gill lamella, there are sinusoids which receive blood from the **afferent branchial vessel** and passes it to the **efferent branchial vessel.** To maintain a continuous supply of oxygen, a current of water through the gill pouches is set up by movements of the pharyngeal wall. Water is taken into the buccopharyngeal cavity through the mouth, and when the mouth closes, the raising of the floor of the buccopharyngeal cavity forces the contained water through the internal openings of the branchial clefts into the gill pouches, bathing the gill lamellae and then to the exterior through the gill slits.

The Urinogenital System (Figs. 250 A and B).

The Urinary apparatus is a **mesonephros.** The excretory and genital systems are closely associated and should be treated together. In the dogfish, in the place of the single mesonephric duct on each side, there are typically two. One of these, the **Wolffian duct,** can be regarded as the original **mesonepfic duct,** and it continues to receive the tubules from the **Bowman's capsules.** The other is the **Mullerian duct** which opens into the coelom by the conjcined openings of the degnerated pronephric tubules and leads straight back to the cloaca without any connection with the mesonephric tubules. The degree of development of these ducts depends on the sex of the animal.

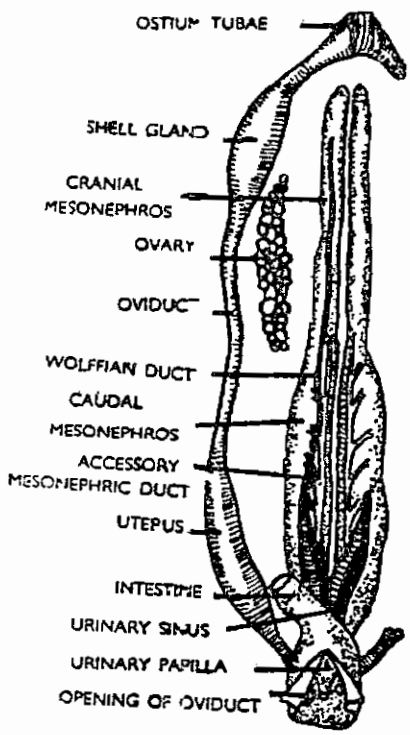


Fig. 260 A) — Female urinogenital system of Scyllium

The genital system is highly specialized to allow internal fertilization and the production of a few very yolky and well protected eggs. There is a single large ovary, from which the eggs are carried by the cilia of the peritoneum to a pair of funnels lying on either side of the liver behind the heart.

The testes are paired and sperms are collected at their front ends by vasa deferentia leading into the anterior or reproductive portion of the mesonephros. This consists of a much coiled, thick-walled, vas deferens, whose glands produce materials that aggregates the sperms into spermatophores. The vas deferens expands into a broader ampulla (seminal vesicle), which at its lower end gives off a forwardly directed blind diverticulum, the sperm sac.

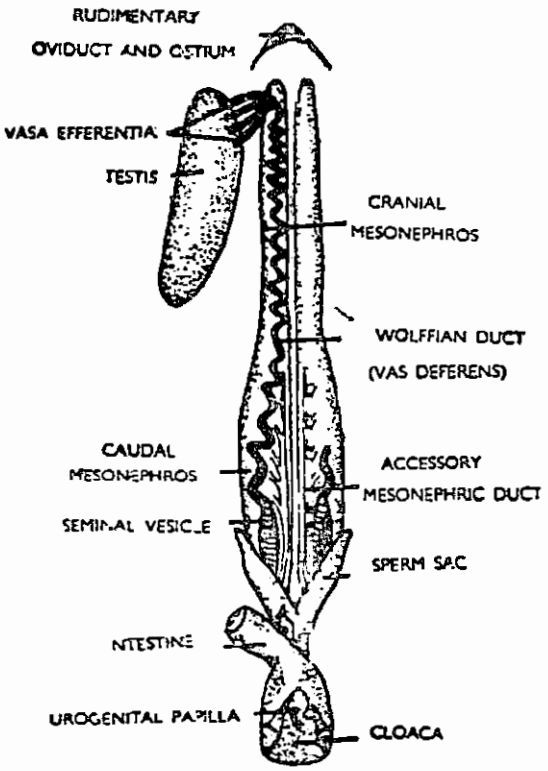


Fig. 260 B) — Male urinogenital system of Scyllium.

Transmission of the sperm is produced by a large and complicated pair of claspers. These are modified parts of the pelvic fins of the male, developed into scroll-like organs and containing a pumping mechanism and erectile tissue; they are inserted into the female cloaca. The mechanism of erection is operated by nerves and may involve the liberation of adrenaline. Experimental injection of that substance produces erection, and it is perhaps significant that the male possesses a reverse of adrenaline-producing tissue.

The Vascular System

The **heart** of the dogfish develops as a specialization of the subintestinal vessel between the place where it receives the veins from the liver and the body wall and the gills, which are to be supplied under high pressure. It consists of a **sinus venosus, atrium** and **ventricle** in addition to a conus **arteriosus** which is provided with valves and represents the most anterior chamber of the heart (Fig. 261). The blood circulates through the chambers of the heart in the following order : sinus venosus, atrium, ventricle, conus arterious. The conus arterious runs forwards as a median stout tube to be anterior end of the pericardial cavity where it gives off the **ventral aorta.** The latter gives each branchial pouch a pair of afferent branchial arteries.

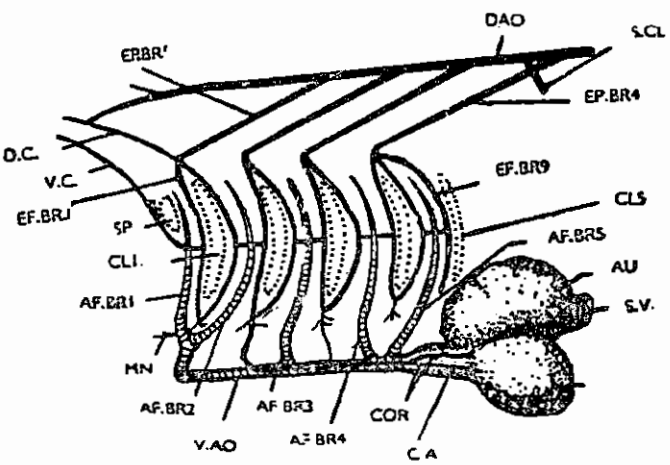


Fig. 261 — The heart and branchial arches of dogfish AF. DR. 1 — 5, branchial clefts; cor. coronary artery; DAO, dorsal aorta; D.C. dorsal carotid artery, EF. BR 1 — 9, efferent branchial arteries; EP. BR 1 — 4, epibranchial arteries; MN, mandibular artery; SP, spiracle; S. CL. subclavian artery; S.V., sinus venosus; V, ventricle; V.AO. ventral aorta; V.C., ventral carotid artery.

From the gills, the blood passes by means of the **efferent branchial** arteries which form a series of loops, one turning around the margin of each of the first four internal branchial clefts. A single vessel runs along the anterior border of the fifth branchial cleft and opens into the fourth loop. The efferent branchial vesseles are connected with **opibranchial vessels** which run inwards and backwards from the loops and unite in a large median dorsal aorta. A **dorsal carotid** artery is given off from the first effeerent branchial. Also the first efferent branchial vessel gives a hyoideann

branch which supplies the pseudobranch and then blood is taken up by the **ventral carotid.** The dorsal carotid and the ventral carotid run forwards to supply the head. The **dorsal aorta** runs backwards giving numerous branches and is continued as the caudal artery.

The **veins** (Fig. 262) are very thin-walled, and the larger trunks are remarkable for their dialated character, from which they have obtained the name of sinuses though they are true vessels. The venous blood is brought back from the head by a pair of **anterior cardinal veins** and from the trunk by a pair of **posterior cardinal veins.** At the level of the sinus venosus, the **anterior** and **posterior cardinals** of each side unite to form

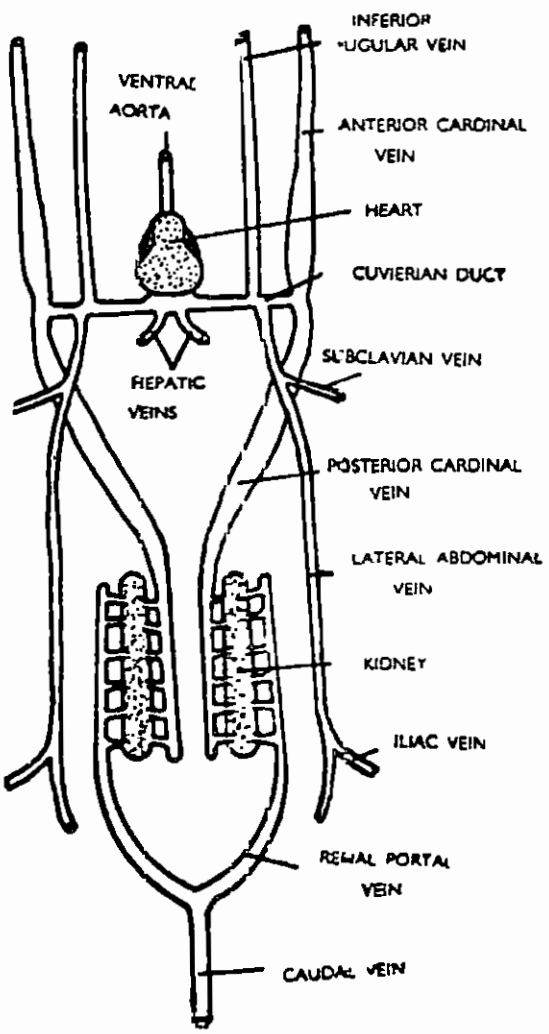


Fig. 262 — Scyllium: Diagrammatic ventral view of the venous system.

a transverse short vein, the **ductus Cuvieri** which is continued into the lateral extremity of the sinus venosus. Into the ductus Cuvieri, about its middle, opens an **inferior jugular vein** on either side which brings back the blood from the floor of the mouth and about the branchial region of the ventral surface. The two **posterior cardinal veins** extend backwards throughout the length of the body cavity. In front, they are enormosuly dialated and behind they lie between the kidneys. Anteriorly the lateral abdominal vein receives the corresponding **subclavian** vein, which brings the blood from the pectoral fin and adjacent points of the body wall. Posteriorly, the lateral abdominal vein receives the corresponding **iliac vein** which brings blood from the pelvic fin and adjacent parts of the body.

There are two **portal systems,** the renal portal and the **hepatic portal,** by which the kidneys and liver respectively are supplied with venous blood. The **caudal vein** which runs along with the **caudal artery,** divides on entering the abdomina cavity into right and left **renal portal veins** and it ends in a number of afferent renal veins supplying the kidneys.

The hepatic portal vein is formed by the confluence of veins derived from the intestine, stomach, pancreas, and spleen and run forwards to enter the liver. The blood from the liver enters the sinus venosus by two hepatic veins placed close together

Nervous System

The brain (Fig. 263) is divisible into fore-, mid., and hind regions and the fore and hind brains can also be divided into two. There are therefore five sections of the brain, whose names are: **telencephalon, diencephalon,** (also called **thalamencephalon**), **mesencephalon, metencephalon, and myelecephalon.** The first two division together form the forebrain or **prosencephalon,** the last two form the hind hrain or **rhombencephalon.** The sides of the telencephalon are greatly expanded, and bear the olfactory bulbs, on the floor is the **optic chiasma,** where the optic nerves cross over from one side to the other.

A transverse fold in the roof, the **velum transversum,** marks the beginning of the **diencephalon** (or between-brain). The sides are thickened and known as the **optic thalami,** the floor is depressed to form the **infundibulum** to which the pituitary is attached. The roof bears a projection the **epiphysis,** vestige of the **pineal eye.**

The floor sides and roof of the mesencephalon are thickened, so that its cavity is reduced and is known as the aqueduct of Sylvius. The roof forms the paired optic lobes.

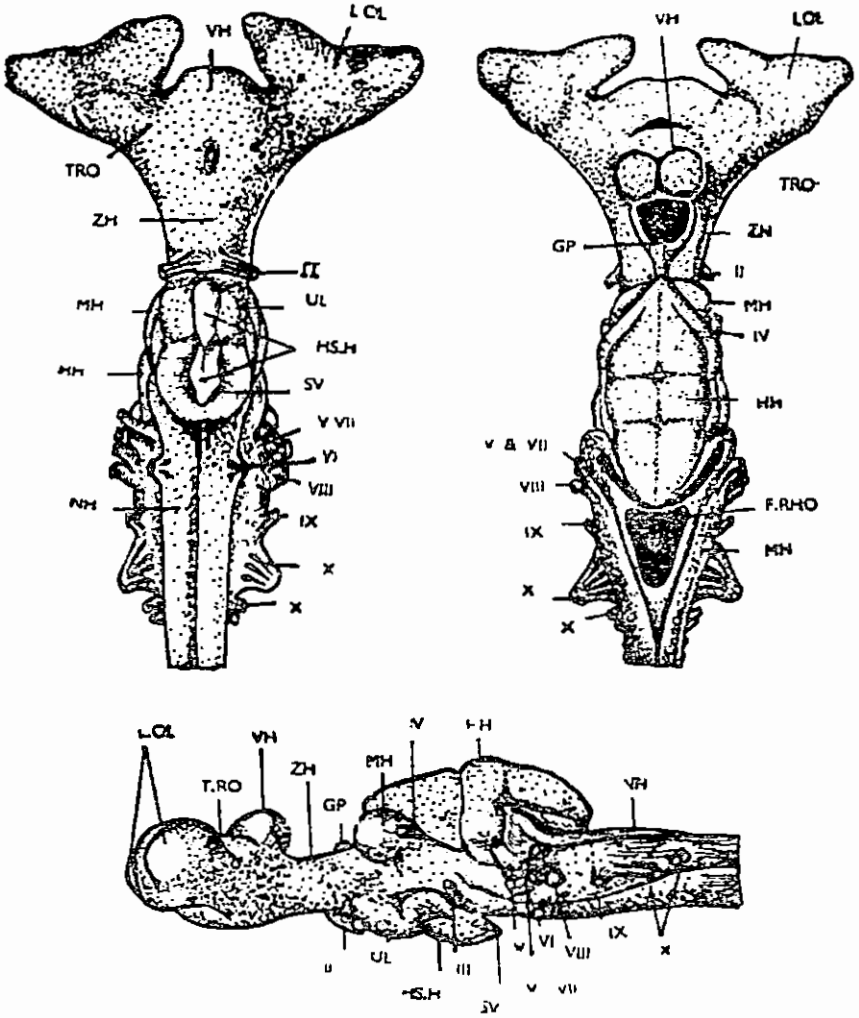


Fig. 263 — Brain of Dogfish : A) dorsal view; B) ventral view; C) lateral view, F. RHO, the fossa rhomboidalis (fourth ventricle); 2GP, epiphisys; HH, cerebellum. HS. H, hypophysis L. OL olfactory bulb; M, mid-brain; NH, medulla oblongata; Sv. sinus vasculosus; TRO, olfactory peduncle; UL, lobi inferiores; VH, prosencephalon; ZH. diencephalon; II. optic nerves : III. oculomotor; IV pathetic; IX, glossopharyngeal; X, vagus.

The roof of the mesencephalon is thick and forms the **cerebellum,** that of the myelencephalon is thin. To the sides of and behind the cerebellum are the restiform bodies.

The cavity of the forebrain is called the 3rd ventricle and that of the hindbrain the 4th ventricle.

The myelencephalon, or medulla oblongata, passes back gradually into the spinal cord. This is a tube with thick walls and a small central cavity, continuous of course with that of the brain.

Cranial Nerves

The **peripheral nervous** system consists of nerves connected to or arising from the central nervous system. It has cranial and spinal nerves. **Cranial nerves** are those which are joined to the brain. They are all paired and emerge through foramina of the skull. Except the first four pairs of cranial nerves, the rest arise from the medulla oblongata. There are ten pairs of crania nerves in anamniota and twelve pairs in amniota.

The cranial nerves are numbered I to X or I to XII. Cranial nerves I and II are different from the others. The first is formed by non-medullated fibres coming from the olfactory epithelium and going to the olfactory lobes. The second is not a true nerve but a tract of medullated fibres arising from the cells of the retina and going to the opposite side of the brain. The I, II and VIII are sensory nerves.

The parts of the body that are innervated by the cranial nerves are discussed below as represented in the dogfish.

I — **Olfactory nerve** (olfactory organs).

II — **Optic nerve** (retina of the eye).

III — **Oculomotor** nerve (superior rectus, inferior rectus, internal rectus and inferior oblique muscles of the eye).

IV — **Trochlear nerve** (superior oblique muscle of the eye).

V — **Trigeminal nerve** : it gives three branches : ophthalmic (snout), maxillary (upper jaw) and mandibular (lower jaw).

VI — **Abducent nerves** : (external rectus muscle of the eye).

VII — **Facial nerve** : It gives four branches : ophthalmic (snout), buccal (sides of head), palatine (roof of mouth) and hyomandibular (hyoid arch).

VIII — **Auditory nerve** : (internal ear).

X — **Glossopharyngeal** nerve (first branchial arch).

— **Vagus nerve** : It gives a lateral line branch (lateral line sense organs), branchial branches (branchial arches 2-5) and a visceral arch (viscera).

The following characters are present in **Scyllium** and lacking in **Petromyzon** :

1. Biting jaws.
2. Paired fins.
3. Denticles.
4. Definite stomach and pancreas
5. Mixed spinal nerves (dorsal and ventral roots joined).
6. Vertebral column constricting the notochord.
7. Myotomes separated into dorsal an ventral portions.
8. Mullerian and Wolffian ducts.
9. Seven segments included in the head.

Class OSTEICHTHYES

Bone is always present in the skeleton. Bony scales, in the form of flattened plates, are generally embedded in the dermis. The eggs are very numerous, of small size, and in most cases fertilization takes place externally.

TILAPIA NILOTICA

(Bolit)

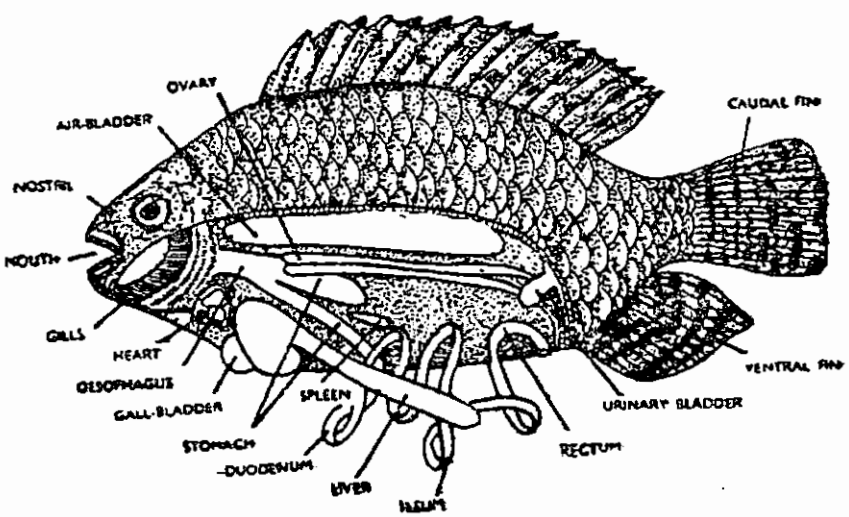


Fig. 264 — Tilapia nilotica. Dissected to show the general viscera.

As shown in Fig. 264, the body, as in Scyllium, consists of three regions head trunk and tail. It is laterally compressed, and provided with overlapping bony scales which are of different forms in different species. They may be ctenoid, cycloid and ganoid (Fig. 265). The mouth is termainl, and surrounded by upper and lower jaws. The eye is devoid of any eyelid. There is no external indication of the ear. On each side of the head, there is a large operculum which covers the gills.

The opereulum is attached distally with a thin membrane known as the **branchiostegal membrane.** At the margin of the operculum, there is a large crescentic gill opening. The trunck carries a pair of leaf-like

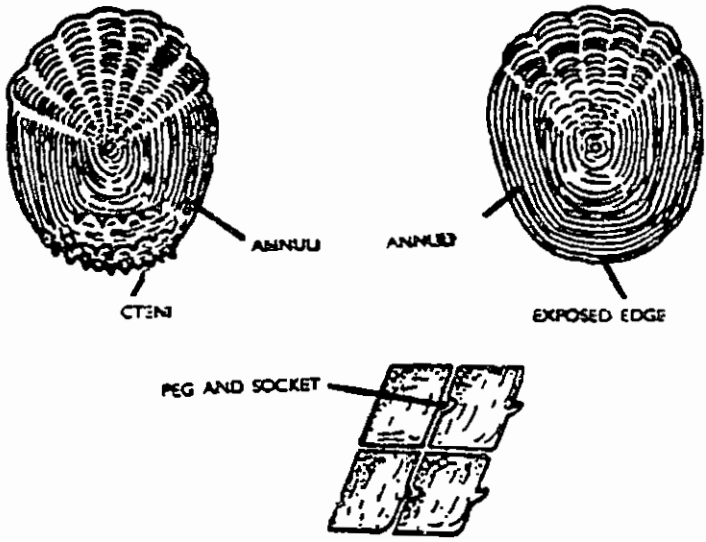


Fig. 265 — Different type of scales in bony fishes. A) Ctenoid, B) Cycloid, C) Ganoid.

pectoral fins lying near the operculum, and a pair of **pelvic fins** lying a little posterior, and more ventral. In male, the anus is followed by a urino-genital aperture found at the tip as a small urino-genital papilla. In female, the genital and urinary apertures are distinct from each other. The tail possesses a large **caudal fin**, and a **ventral fin** along its ventral margin. The dorsal fin extends on both trunk and tail regions.

Digestive system (Fig. 264)

The mouth of *Tilapia* leads to a wide pharynx which is perforated on each side by five elongated gill slits. These gills are fringed by teeth-like structures, the gill rakers. The pharynx leads to a short oesophagus which opens in the stomach. The stomach is composed of a narrow part which is continuous with the intestine, and is provided with a large closed caecum. There is no spiral valve in the intestine which is much coiled and is composed of three parts; the duodenum, ileum and rectum, and there are no sharp lines of demarkation between these parts. There is no cloaca, and the rectum opens to the exterior through the anus. The liver is large, and possesses a large gall bladder. The pancreas is diffused inside the liver, and part of it is found as patches of whitish tissue near the anterior end of the intestine. Above the alimentary canal is a large thin-walled sac known as the air bladder It develops as an outgrowth from the alimentary canal, and is attached with the alimentary canal by a thread of tissue

Respiratory System (Fig. 266).

There is no spiracle in *Tilapia*. The gills are four pairs found on both sides of the pharynx. The gills of each side are contained in a large gill chamber which is bounded externally by the operculum. Each gill consists of a gill arch which is a long, curved rod, and two rows of gill filaments. The gill arch contains inside it the **afferent** and **efferent vessels.** The gill filaments which are the actual respiratory elements, possess delicate walls through which exchange of gasses takes place.

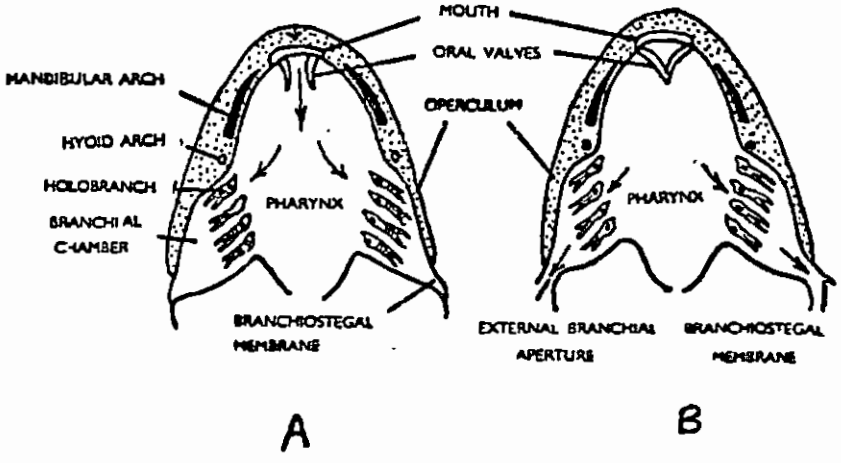


Fig. 266 — Respiratory organs of Tilapia, A) Inhalent, B) Exhalent.

Respiration is produced by a current passing in a single direction namely, in a the mouth and out over the gill lamellae. The pumping action is produced by a buccal pressure pump and opercular suction pumps resulting from side ways movements of the operculum, as follows :

When opercula are raised, the gill openings are closed by the branchiostegal membranes and this acts like a suction pump so that oral valves are opened and water is drawn into mouth. When opercula are lowered, the pressure of water in the buccal cavity and pharynx is increased, this closes the oral valves and opens the branchiostegal membranes. Thus, water is forced over the surface of gills and it passes out from the gill chamber. The gill lamellae take up oxygen and give out carbon dioxide.

Circulatory System (Fig 267).

The heart consists of hree chambers only, a **sinus venosus,** an **auricle,** and a **ventricle.** There is no conus **arteriosus.** Its place is occupied by an enlarged portion of the ventral aorta known as the **bulbus arteriosus** whose wall is composed of elastic fibres and unstriated muscles, and so it is not contractile as the **conus arteriousus** of Scyllium. The ventral aorta extends anteriorly in the mid-ventral line of the body below the pharynx. It gives off to the gills four pairs of **afferent branchial** vessels which carry to them the venous blood. Four pairs of efferent branchial vessels take away from the gills the oxygenated blood. They are collected by a circular blood vessel known as the **circulus cephalicus.** It sends forwards two carotid arteries to the head, and sends backwards a large, median **dorsal aorta** supplying the different parts of the body with oxygenated blood. The continuation of the dorsal aorta in the tail is known as the **caudal artery.**

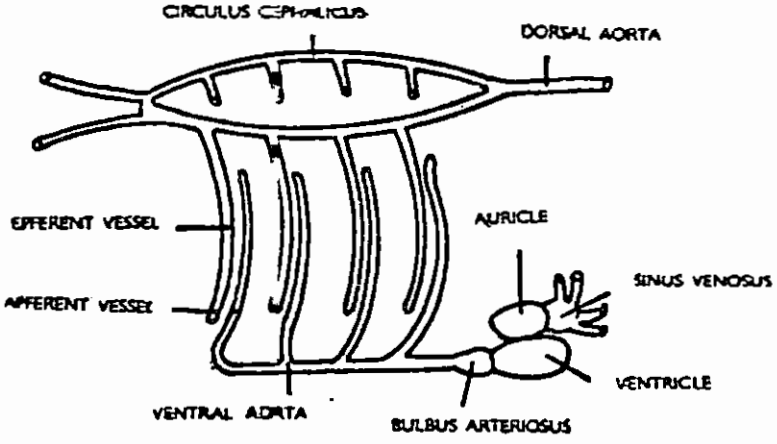


Fig. 267 — Lateral view of the heart and the branchial arteries of Tilapia.

Urinogenital System (Fig. 268).

There are two kidneys extending the entire length of the coelom. The posterior part of each kidney, contains masses of uriniferous tubules. From each kidney arises a ureter which joins its fellow to form a common urinary duct.

This duct becomes swollen giving rise to a urinary bladder and then opens to the exterior by a urinogenital aperture in the male and a urinary aperture in the female.

The male (Fig. 268 A) has two testes each testis leads into a genital duct. The two genital ducts unite to form a common genital duct. This latter duct unites in turn with the urinary duct to open through a urinogenital aperture.

In the female (Fig. 268 B) the excretory organs are the same as in the male. There are two hollow bag-like ovaries, each enclosed in an ovisac. The ovaries are broader than testes. Each ovisac is continued into an oviduct. The two oviducts unite posteriorly and open by a genital aperture between the anus and the urinary aperture.

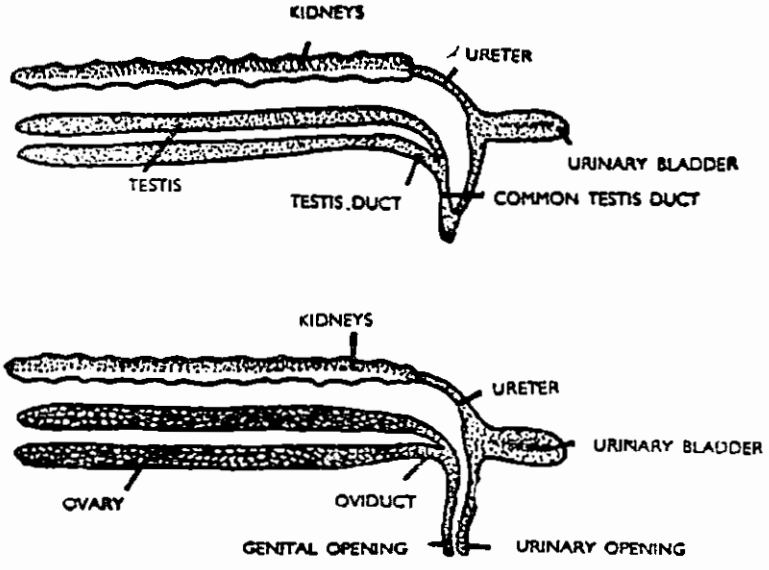


Fig. 268 — Urinogenital system of Tilapia, A) Male, B) Female.

Nervous System (Fig. 269.

The brain is formed of fore-, mid- and hind-brains. In the fore-brain, the **olfactory lobes** are small and have no olfactory **peduncles.** They are closely applied in front of the **cerebral hemispheres.** Both the olfactory lobes and cerebral hemispheres are olfactory. The **diencephalon** is small and hidden dorsally by the mid-brain, but the **pineal body** projectes in front because it has a stalk. On the ventral side the **diencephalon** has an **infundibulum** to which the **pituitary gland** is attached below. The infundibulum forms a pair of large **lobi inferiores** and a median **saccus vasculosus.** This latter has a thin highly vascular

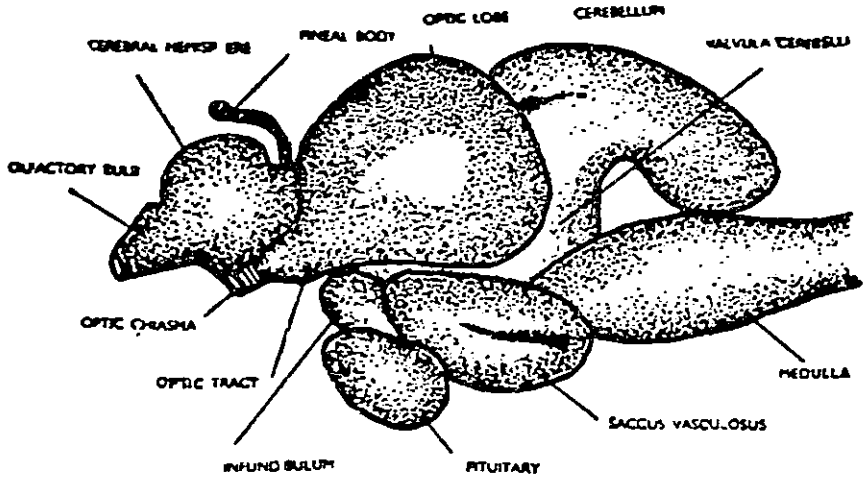


Fig. 26ᴮ Brain of Tilapia (lateral view)

wall and its function is not certain. It may be for secreting the cerebral fluid or for detecting the pressure of this fluid in the central nervous system.

The mid-brain is the largest part forming two large **optic lobes.** The **cerebellum** is large and bent upon itself. Its anterior part forms a **valvula cerebelli** which extends under the optic lobes. It is characteristic of bony fishes and controls active movements. The medulla oblongata is well developed with special lobes for entery of lateral line nerves. The cranial nerves are like those of dogfish.

IV -- Class AMPHIBIA

Amphibia are veretbrates in which the visceral arches of the larva almost always bear gills, which may be retained throughout life, though the adults normally possess functional lungs. When limbs are present, they have distinct digits. The unpaired fins frequently present both in larvae and adults, are without fin rays. In existing forms there is rarely any exoskeletion, but some extinct forms had an armour of bony plates. The skull has two occipital condyles. The heart is three-chambered, with two **auricles** and a **ventricle** and a **conus arteriosus.** The gut ends in a cloaca into which the ducts from kidneys and reproductive organs also open. The ova are small, numerous, usually pigmented, and with yolk towards one pole. They are almost always laid in water; there is usually metamorphosis in development.

Classification

Class Amphibia is divided into four orders :

I — Order **Anura** (taillnes Amphibia). The body is short and broad, the hind limbs are much longer than the fore limbs, the tail is lost in the adult, the gills are also lost in the adult. e.g., Frogs and Toads.

II — Order **Urodela** (tailed Amphibia). The body is elongated, the limbs are nearly equal in size, the tail is retained in the adult, some retain the gills throughout life, e.g., Salamanders and Newts.

III — Order **Apoda** (Gymnophiona). They are worm-like, there are no limbs or limb girdles, in some small scales are found in skin, the eyes are rudimentary, e.g., Coecilians.

IV — **Stegocephalia** (Labyrinthodonts). They are fossil Amphibia which were living in the past, some of them were of great size, the body was usually covered with scales and bony plates.

The most successful amphibians in Egypt are those belonging to the genus Bufo. There are different species related to this genus, the most common of which is *Bufo regularis.*

BUFO REGULARIS

(The Egyptian Toad)

External features

The body is short and broad and is composed of flat head and a plump trunk. There is no neck. The larval tail and both external and internal gills are lost during metamorphosis. The limbs are adapted for walking. Fore limbs are short and hind limbs are long. The hind limbs appear to have four sections instead of the usual three, beacause of the extraordinary elongation of the ankle. The digits do not possess claws and there are four fingers and five toes. The latter are united together by a web. There is a large mouth and there are two nostrils opening on the dorsal surface of the snout. The eyes are large and provide with an immovable upper eye lid and a lower movable eye lid corresponding to the nectitating membrane of higher animals. On each side of the head, behind the eye, there is an ear drum covering the middle ear but the ear drum remains flush with the surface. There is a pair of large glandular swellings (parotid glands) on the head behind the eyes and they apply in fact only to some membres of the family Bufonidae. At the posterior end of the body there is the cloacal aperture. Above the cloacal aperture lies a distinct prominence produced by the urostyle on each side of which there is a lymph heart.

Integument

The skin (Fig. 270) is loose, being attached to the muscles only at certain places by connective tissue septa which makes the boundaries

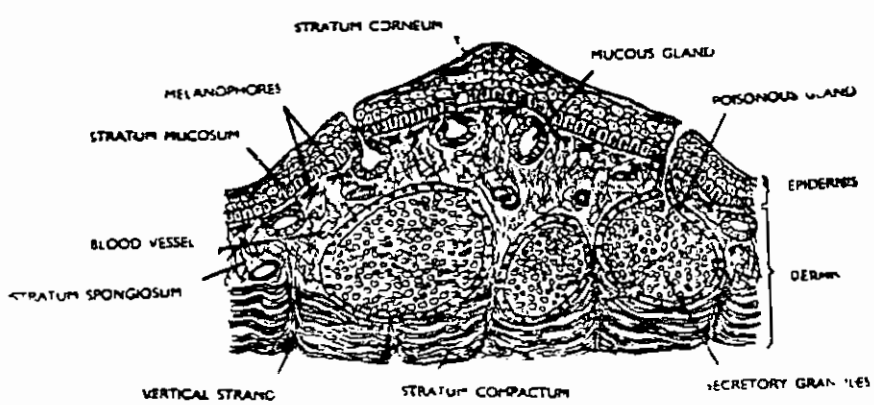


Fig. 270 — Vertical section of skin of Bufo regularis.

of the subcutaneous lymph spaces. It is moist and the only organ of respiration during hibernation. On the other hand the skin also shows a character typical of land animals in having heavily cornified outer layers.

The skin consist of two main layers, the epidermis and dermis. The epidermis consists of several layers of epidermal cells, the outermost are thin, flattened and keratinized, i.e. converted into a dead, hard horny material protecting against dryness and excessive loss of moisture and is termed **stratum corneum.** This **stratum corneum** is cast off and is replaced continuously by proliferation form below. Such a process of ecdysis is under the control of the pituitary and the thyroid gland. Local thickenings of the epidermis often occur and is a conspicuous feature of the warty skin of the toad.

Beneath the stratum corneum the cells gradually change from a flattened to a rounded and finally to a columnar shape. these layers constitute the **stratum mucosum.** However, the lowermost or basal layer of the stratum mucosum consisting of tall columnar cells, is the active portion of the epidermis and is known as the **Malpighian layer.** It continuosusly proliferates cells which are pushed outward, become flat and horny, and finally form part of the startum corneum.

Below the epidermis is a thin **basement membrane.** The dermis consists of fibrous connective tissue and is made of two layers, an upper loose **stratum spongiosum** and a lower, dense and compact **stratum compactum.**

The glands of the skin are of two types, **mucous** and **poison** glands. Both of these consists of little sacs of gland-cells, derived from the epidermis. The mucus serves to keep the skin moist, this being essential if the skin is, to respire. The secretion may perhaps also serve for temperature regulation.

The poison glands are more developed in Bufo than in Rana. They produce a mild but unpleasant poison which is protective.

Colours of Amphibia

The use of colour is highly developed in Amphibia. The colour is produced by three types of pigment cells. **melanophores** lying deepest, **guanophores** full of granules, which by diffraction produce a blue green colour, and yellow **lipophores** overlying these and filtering out the blue. Change of colour is produced by expansion of the pigment in melanophores. Movements in the other chromatophores can also affect the colour. The ability of the skin for changing colour to blend with the environment is well developed, through the colour change is very slow. The chromatophores are not directly influenced by the nervous system but are under the

control of the pituitary gland. In dark moist environment, toads become dark, while in lighted, dry environment they become yellow

THE SKELETAL SYSTEM

A) Axial Skeleton

a) **The skull** (Fig. 271 and 272).

The skull is divided into :

(*a*) cranium.

(*b*) sense capsules.

(*c*) jaws.

(*d*) hyoid apparatus.

The cranium is an elongate box which occupies the inside of the skull and in which the brain is lodeged and protected two exoccipitals occupy a postero-ventral postion. They are approximated to each other but a very narrow strip of cartilage is left between them dorsally. They embrace between them a large, more or le s circular opening called the **foramen magnum** for the passage of the spinal cord from the brain. Each exoccipital bears a conspicuous promonence called the **occipital condyle** The two condyles serve to articulate the skull with vertebral column behind. In

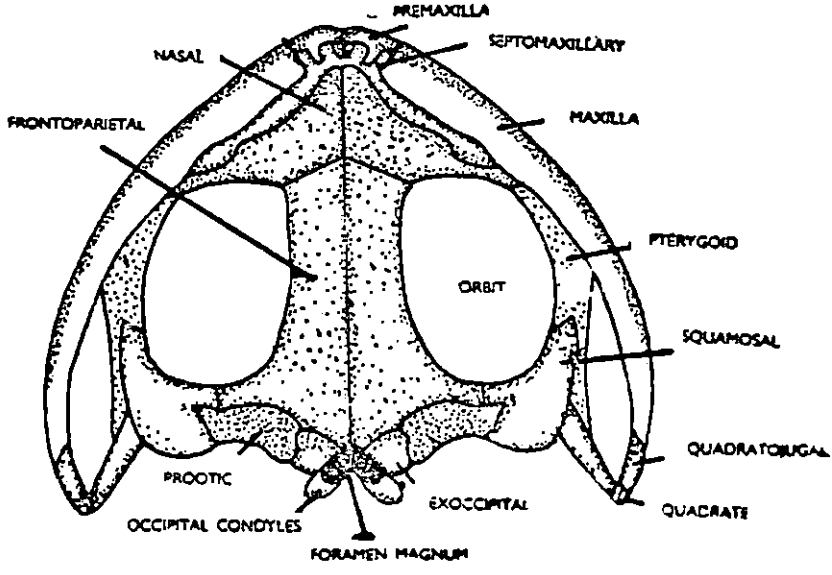


Fig. 271 — Dorsal view of the skull of Bufo regularis.

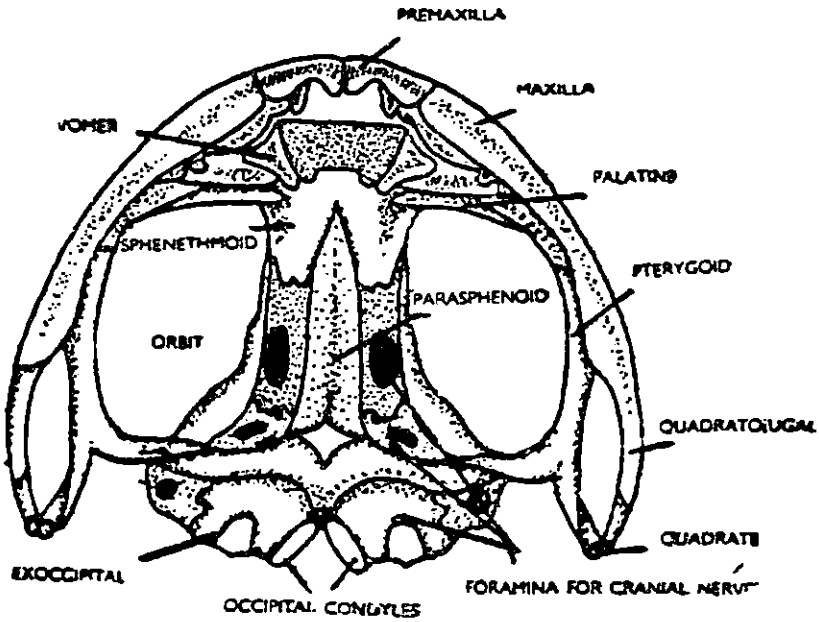


Fig. 272 — Ventral view of the skull of Bufo regularis.

the ventral surface of the exoccipitals, there is one foramen for the passage of the **vagus** and **glossopharyngeal** nerves.

The roof of the cranium is formed of two large bones, he **fronto-parietals,** which are separated from each other by a median suture. In the floor of the cranium, lies a bone known as **parasphenoid.** This bone is daggar-shaped. The median longitudianl arm is pointed anteriorly, the transverse limbs are also pointed at their distal extremities. In the anterior region of the cranium, there is the **sphenethmoid.** nternally, the sphenethmoid is divided by a transverse vertical partition which separates the cranium from the olfactory capsules in front. This partition is perforated by two **foramina** for the passage of the olfactory nerves.

The **sense capsules** are the **olfactory** and **auditory** capsules and the orbits.

The olfactory capsules lie in the sphenethmoid and are provided dorsally by two bones known as the **nasals.** The nasals are large and meet the bones of the upper jaw. Anterior to them, there is a cartilaginous area in which the **external nares** lie. In the ventral surface of the olfactory capsules, there are two small triangular bones known as the vomer which, unlike the nasals, do not meet but are widley separated.

In relation to the wall of the **auditory capsule** is a bone known as the **prootic.** The bone extends downwards and forwards to form part of the postero-median corner of the orbit. The prootic meets the exoccipital, and where these bones meet together there is a moderate depression into which the ear ossicle (columella auris) is received. The prootic bone is partly overlapped by a hammer-shaped bone known as the **squamosal.**

The orbit is surrounded medially by the bones of the cranium and laterally by the upper jaw.

The **upper jaw** is composed of a number of paired bones; which are attached to the sense capsules and form the outer borders of the skull. These are :

1. The **palatines** which are two thin plates extending from the sphenethmoid outwards; they are viewed from the ventral surface and form the anterior boundaires of the orbits.

2. The **pterygoids** are a pair of Y-shaped bones with the fork directed backwards and seen from the ventral size. The inner branch of the fork meets the transverse limb of the parasphenoid, while the outer underlies the squamosal. As the pterygoid and the squamosal meet each other at the posterior corner of the mouth, there lies a small cartilaginous piece known as 3. the **quadrate,** and by means of this system the upper jaw articulates with the lower jaw.

4. The **quadratojugal** is a short thin bone which meets the **quadrate** behind and the 5. **maxilla** in front. The maxilla is a large and slender bone lying along the outer border of the upper jaw. It extends forwards and meets the palatine and the 6. **premaxilla** in front. The premaxilla is a small bone which has a conspicuous backwardly directed process. The maxilla and premaxilla are concave on the ventral surface to receive the lower jaw.

The **lower jaw** is a simple curved bone consisting of two halves. Each half is formed of a small anterior **mentomeckelian** bone and two bigger ones : the **angulo-splenial** bone lying on the median side and the dentary on the outer side. The lower jaw, like the upper, does not carry teeth.

The **hyoid apparatus** (Fig. 273) is a framework mostly built of cartilage and lying in the floor of the mouth cavity. It consists of a flattened body bearing two pairs of small processes, anterior and posrteior, and two pairs of large cornua : the anterior cornua are long and curved to reach the **auditory capsules.** The potsterior cornua are short and are the only ossified pieces of the apparatus. They rest on the ventro-lateral surface of the laryngotracheal cavity.

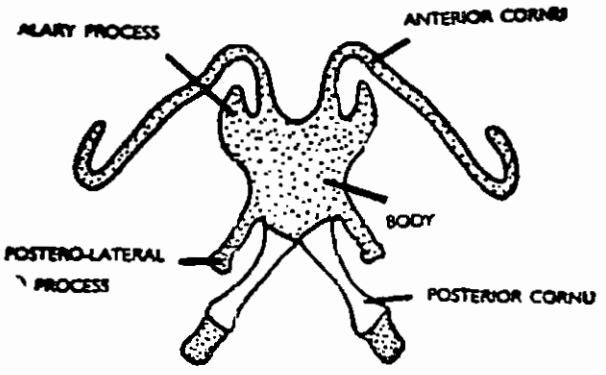


Fig. 273 — The hyoid apparatus of Bufo

ii) The Vertebral Column*

The vertebral column is composed of nine joined vertebrae succeeded by a long rod known as the **urostyle.** All the vertebrae are nearly alike except the first and last, which are modified, the first to articulate with the skull, and the last to articulate with the urostyle and pelvic girdle.

On the ventral side of each **ordinary vertebra,** there is a thick piece known as the centrum by means of which the vertebra articulates with the one in front and the other behind. The anterior surface of the centrum is concave, while the posterior is convex so that the convexity of one vertebra fits in the concavity of the one next behind. Such centrum is known as **procoelous.** Arching upon the centrum, there is a plate of bone known as the neural arch which bears on the dorsal surface a minute process called the **neural spine.** The neural arch embraces a space known as the **neural foramen** in which the spinal cord is lodged. The neural foramena thus produced by the nine vertebrae constitute the vertebral canal. At the anterior and posterior borders of the neural arch on each side there is a slight depression called the **intervertebral notch,** thus, the intervertebral notches on the borders of the neural arches in every two successive vertebrae constitute together an **intervertebral foramen** for the passage of a spinal nerve.

Arising from each side of the neural arch there is a **transverse process.** The neural arches of the adjacent vertebrae articulate with each other by certain facets known as **zygapophyses.** These are two pairs, a pair lying anteriorly and facing upwards and medianly known as the **prezygapophyses,** and a pair lying posteriorly facing downwards and

* For illustrations, see practical note-boobe.

laterally known as the **postzygapophyses,** thus, the postzygapophyses of one vertebra will overlap the prezygapophyses of the vertebra behind.

The first vertebra lacks a transverse process and there are two concave facets on the anterior surface of the centrum known as the **condylar facets** which articulate with the occipital condyles of the skull.

The last vertebra or the **sacral vertebra** possesses fanshaped transverse processes. The posterior wall of the centrum is doubly convex. The sacral vertebra articulates with the pelvic girdle by its transverse processes.

The **urostyle** is a long bone and is supposed to be formed of a number of vertebrae fused together. Its anterior wall bears two concavities, which receive the two convexities of the sacral vertebra. It is pierced through the anterior third by a longitudinal fine canal in which is situated the terminal part of spinal cord. On either side of the urostyle posteriorly there is a small foramen for the passage of the 10th spinal nerve. The urostyle bears at its tapering posterior end a small cartilaginous piece.

B) Appendicular Skeleton*

i) Pectoral girdle and Fore-limbs

The **pectoral girdle** is composed of an incomplete ring of bones. These are : In the middle line the two **epicoracoids** overlapping each other, the right lies ventral to the left, and each is broader posteriorly and articulates on the side with the **coracoid.** Anteriorly the epicoracoid articulates with the **clavicle.** The clavicle runs latero-posteriorly and thus they enclose a space between them known as the **coracoid foramen.** Laterally the clavicle and the coracoid meet a strong bone known as the **scapula.** Where these three bones meet together is a cup-shaped depression known as the **glenoid cavity** which receives the head of the **humerus.** On the dorsal surface of the girdle and articulating with the scapula, there is a broad plate known as the **suprascapula.**

Closely associated with the pectoral girdle, is the **sternum** and it is preferred to deal with it in connection with the girdle. The sternum consists of two pieces : 1. **xiphisternum** articulating with the epicoracoid in front, and 2. the **xiphoid cartilage** which is a more or less circular cartilaginous piece articulating with the xiphisternum behind.

The epicoracoids, xiphisternum, xiphoid cartilage and most of the suprascapular are cartilaginous and not osseous.

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* For illustrations, revise practical note-books.

The **fore-limb** is composed of the following bones :

1. **Humerus** is the bone of the upper arm and consists of a shaft bearing a head at the anterior extermity and a trochlea at the posrteior extremity. Along the inner side of the shaft there is a conspicuous **deltoid ridge.**

2. **Radio-ulna** is the bone of the fore-arm. It is a compound bone made of a **radius** and an **ulna** fused together; the inner being the radius which is also a little shorter, the outer being the ulna and is prolonged into a conspicuous **olecranon** process or elbow-bone. The radio-ulna articulates proximally with the trochlea of the humerus.

3. The **bones** of the hand are :

(*a*) **Carpals**; these are six small pieces arranged in two rows.

(*b*) **Metacarpals**; these are four elongate pieces, articulating distally with the digits.

(*c*) **Digits**; these are four, the first being lacking. Each of the second and the third is made up of two **phalanges**; the fourth and fifth of three. Thus, the number of phalanges can be represented by a **digital formula**; 2 : 2 : 3 : 3.

ii) **Pelvic Girdle and Hind-limbs**

The **pelvic girdle** articulates with the sacral vertebra on the transverse processes. It is composed of two long cylindrical bones, each called **ilium.** The ilium meets a wedge-shaped dorsal piece called **ischium** Between the postero-ventral part of the ilium and the ischium, there is a calcified cartilaginous piece called the **pubis.** As the three components meet, they take part in the formation of a cup-shaped depression called the **acetabulum** on either side of the girdle for the reception of the head of the **femur.**

The **hind limb** is composed of the following bones : —

1. **Femur** is the bone of the thigh. It is long, slightly curved and with two swollen ends; the proximal forming the head while the distal forming the condyles which articulate with the bone of the shank.

2. **Tibio-fibula** is, like the radio-ulna, a compound bone formed of a **tibia** and a **fibula** completely fused with each other. It is flattened and along its middle there is a groove indicating its compound nature.

3. The **bones** of the foot are :

(*a*) **Tarsals** consisting of two rows; one is formed of two long pieces called

the **astragalus** and the **calcaneum,** the former articulates proximally with the tibial end, and the latter with the fibular end of the **tibio-fibula.** The second row consists of two very small pieces.

(*b*) **Metatarsals** are six in number, one of which is very minute and corresponds to a sixth toe called the **prehallux** or **calcar.** The rest are elongate.

(*c*) **Digits** are built up of a number of phalanges. The digital **formula** is 2 : 2 : 3 : 4 : 3.

THE PENTADACTYLE LIMB

(Figs. 273 A and B)

The transition from water to the land during the phylogenetic history of vertebrates has resulted in great modifications in the bony skeleton, already possessed by fish-like ancestors, and in the appearance of an entirely different type of limb and limb skeleton. It is perfectly clear that the fin form of limb would scarcely fulfil the needs of a terrestrial animal, and so limbs of a very different pattern have been aquired by such creatures. The terrestrial animals, then, are provided with two pairs of limbs (from

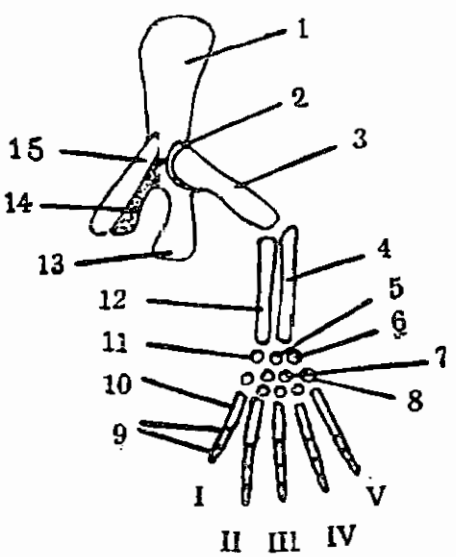


Fig. 273 A) — Diagram of pectoral girdle and fore limb of a Tetrapod, 1. scapula, 2. glenoid cavity, 3. humerous, 4. ulna, 5. intermedium. 6. ulnare, 7. two centralia, 8. five distalia. 9. phalanges, 10. five metacarpals, 11. radiale, 12. radius, 13. coracoid, 14. procoracoid 15. clavicle

which the name TETRAPODA is derived), all having a skeleton based upon a common schematic plan which is called the typical or, better the generalised PENTADACTYLE LIMB SKELETON, since the limb terminates in FIVE digits or fingers. Few existing animals have exactly this type of limb skeleton, and the special interest in the three animal types under consideration is to see how far the limb skeleton complies with, or depart from, this condition in accordance with the part of the limbs play in the life of the animal.

Externally, both fore and hind limbs are divided into regions movable on one another, the fore limb into upper arm, fore arm, wrist, and hand, and the hind limb into thigh, shank, ankle, and foot. Taking the fore limb first, the skeleton of the upper arm consists of a single long bone, the humerus, and that of the fore arm of two, the radius and ulna. In the wrist or carpus, however, nine small bones, the carpal bones are present, arranged in three rows. In the proximal row there are three bones, the radiale (in relation with the radius), the intermedium in the middle, and the ulnare (in relation with the ulna). The middle row consists of a single centrale (some authorities state that there were two bones here, but it is commoner to consider that there is one only). The distal row is made up of five bones, carpale one to five. In the hand (or

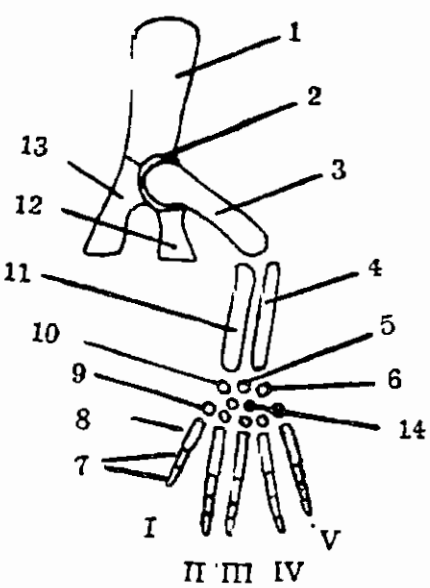


Fig. 273 B) — Diagram of pelvic girdle and hind limb of a Tetrapod. 1. ilium, 2. acetabulum, 3. femur, 4. fibula, 5. intermedium, 6. fibulare, 7. phalanges. 8. five metatarsals, 9. five distalia. 10. tibiale, 11. tibia, 12. ischium, 13. publis, 14. two centralia.

manus), two series of bone are found, first a series of five metacarpals (lying in the palm of the hand and all enclosed by skin and muscle) followed by a series of phalanges arranged in linear rows and forming the skeleton of separate digits or fingers The number of phalanges varies in the digits, the first or pollex having two and the others three each.

In the second limb the bones have precisely the same arrangement but are differently named. The thigh bone is the femur, the tibia and fibula lie in the shank. In the ankle, the tibiale, intermedium, and fibulare form a proximal row, centrale the middle, and tarsale one to five the distal row of tarsals. The bones of the foot or pes are termed metatarsals and phalanges respectively, and the first digit is called the hallux.

In both instances, the side of the limb which bears the first digit (that with two phalanges) is spoken of as the preaxial side or border and the other as the post-axial. These terms refer to the original or primitive relationships of the limb to the body in which the axis of the limbs was the right angles to that of the body, so that one margin of the limb was in front of, and the other behind, its axis so far as the orientation of the animal as a whole was concerned. These relationships become important when considering the ways in which limbs are modified.

THE CIRCULATORY SYSTEM

The Heart (Fig. 274).

The heart lies in a **pericardial cavity** and is enclosed in two membranes, an outer **percardium** and an inner **pericardium,** between the two membranes is a **serous** or **pericardial fluid.** The heart is composed of two **auricles,** one right and one left, the former is larger than the latter and both are separated by an **interauricular septum** of connective tissue and endothelium. A thin walled **sinus venosus** opens into the right auricle by an aperture guarded by two **sino-auricular valves.** A **pulmonary** vein opens into left auricle, but the opening has no valves. The auricles opens into a single ventricle by an **auriculo-ventricular** aperture bounded by two pairs of **auriculo-ventricular valves,** two of these valves have fibrous **chordae tendinae which** join the valves to the wall of the ventricle. Thus, they prevent a reflux of blood into the auricles. The ventricle has a thick muscular wall having ridges or **columnae carneae** with deep pockets between them which to some extent prevent mixing of the blood from the two auricles. From the upper side of the

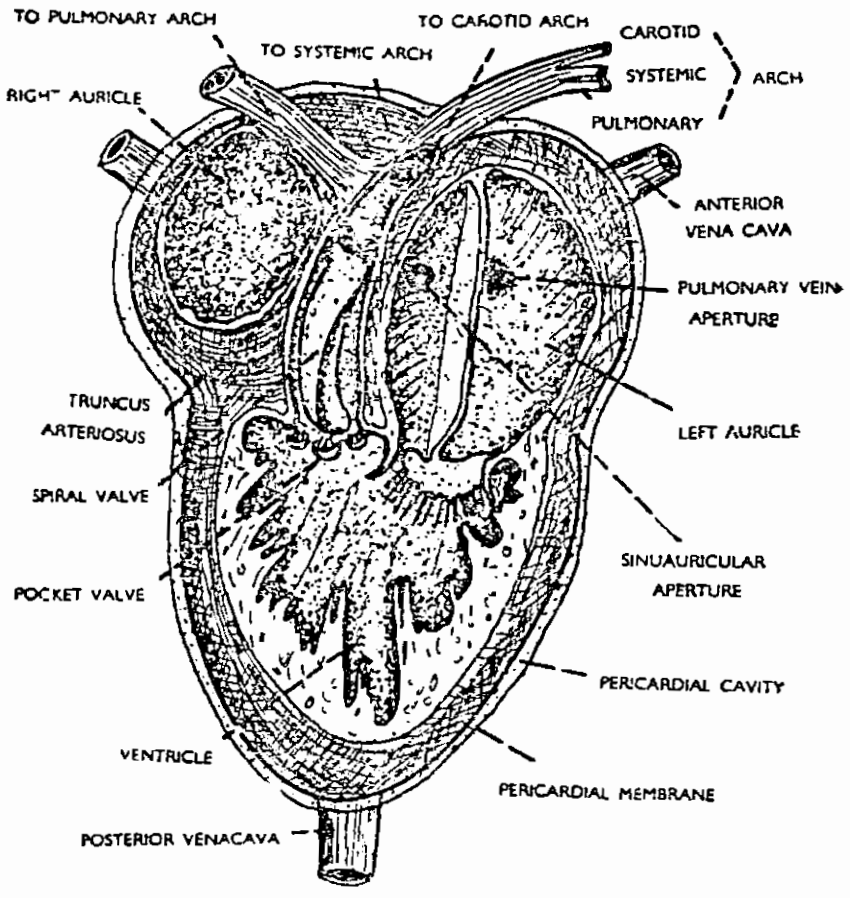


Fig. 274 — Heart of the Egyptian Toad, Bufo regularis, dissected.

ventricles arises a **truncus arteriosus,** its opening has three semilunar valves which prevent blood going back into the ventricle. The truncus arteriosus is formed from a basal **conus arteriosus** joining a much shortened ventral aorta. In the truncus arteriosus are two sets of semilunar valves, one set of three semilunar valves at the base and is already mentioned, and the other set at the junction of **conus arteriosus** and **ventral aorta.** One of these valves has been modified to form a large **spiral** valve. This valve incompletely divides the conus arteriosus into two passages : A cavum **pulmo-cutaneum** and a **cavum aorticum.** As shown in Fig. 276, the **truncus arteriosus,** then, divides into two halves each half having a **carotid arch,** a **systemic** arch and a **pulmocutaneous arch.**

The venous blood returns to the heart by the **proper venous system** and the **portal system** (Fig. 275). The main veins of the proper venous system are the **external jugular, innominate** and **subclavian.**

The main veins of the **portal system** are the **renal portal, hepatic portal** and **anterior abdominal.**

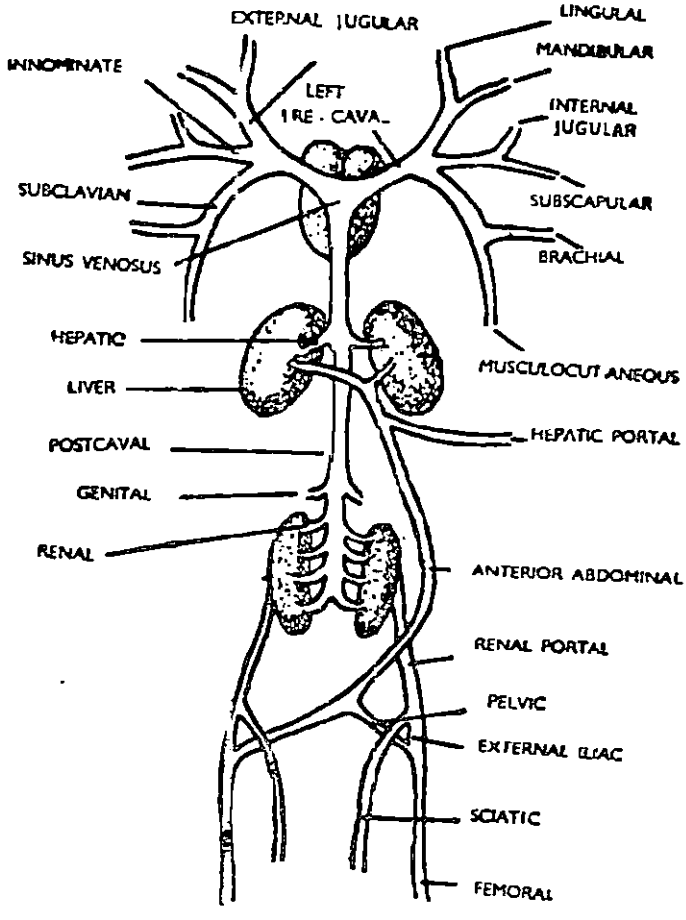


Fig. 275 — Venous system of the Egyptian Toad, Bufo regularis.

Circulation

In the toad, the lungs are not the only organs of respiration, but oxygenation of blood also takes place in the skin and mucous membranes of the buccal cavity. Oxygenated blood from the lungs comes to the left auricle. Blood coming through the musculo-cutaneous veins is mixed blood,

because blood from the skin is **oxygenated** and that from the muscles is **deoxygenated.** Blood returning from the buccal cavity is **oxygenated.** The blood together with mixed blood of musculo-cutaneous veins enters the sinus venosus (Fig. 275) and goes to the right auricle. The blood from the two auricles passes to the ventricle and is forced into the truncus arteriosus where all the blood is mixed but is almost all oxygenated. The blood passes first into the pulmonary arches (Fig. 276) because their opening lies in the cavum pulmo-cutaneum. The remaining blood goes to the systemic and carotid arches. The spiral valve takes no part in turning the blood, it only supports the conus arteriosus. The **carotid labyringth** does not raise the pressure of the blood but is sensory and detects pressure changes of oxygen in the blood. However, this circulation of blood is not accepted today.

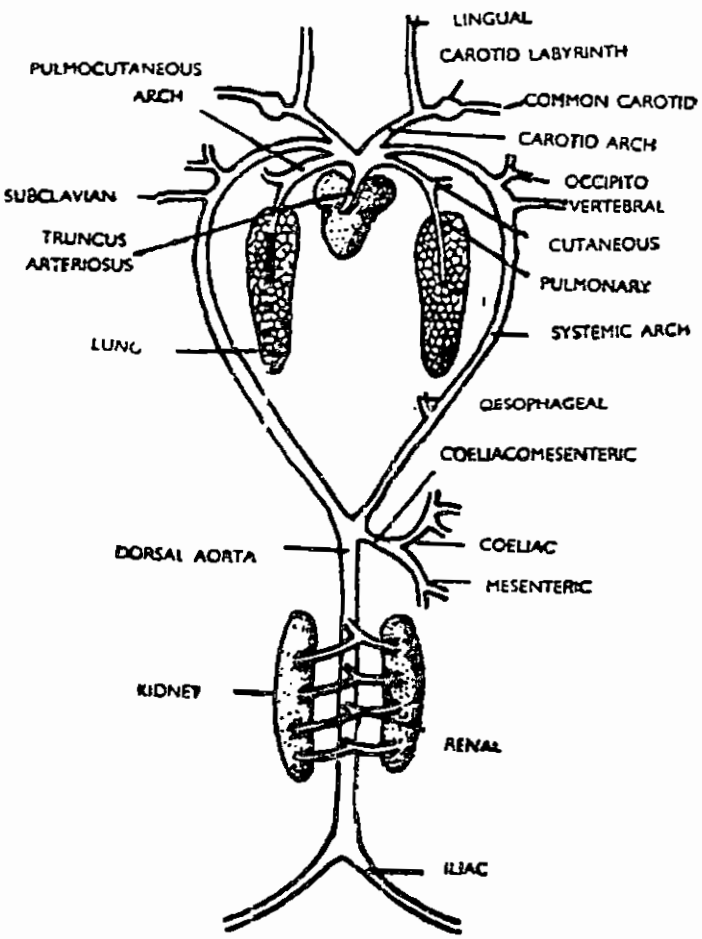


Fig. 276 — Arterial system of the Egyptian Toad, Bufo regularis

The Blood of Amphibia

The red blood corpuscles of Amphibia are much larger than those of mammals and are nucleated. The red cells are formed mainly in the kidney, and are destroyed, after a life of about 100 days, by the spleen and liver.

The haemoglobin of toad has a lower affinity for oxygen than that of mammals even when both are considered at the same temperature, and in this respect is notably less efficient. Also, although the power of blood to combine with carbon dioxide is great, there is a less delicate regulation of the reaction of the blood than in mammals.

The white cells of Amphibia are three types, **lymphocytes** with a large nucleus and small cytoplasm, **monocytes,** which are larger phagocytic macrophages, and **polymorphonuclear granulocytes.** These last may be **neutro-, eosino-,** or basiphilic and are migratory and phagocytic. The blood of the toad also contains numerous small platelets (**thrombocytes**) which probably break down when in contact with foreign surfaces to produce the **thrombin** that combines the **fibrinogen** of the blood plasma to produce **clotting.**

Respiration (Figs. 277 A and B).

The **lungs** of the frog are paired sacs, opening to a short **laryngeal chamber,** which communicates with the pharynx by a median aperture, the **glottis.** The glottis and laryngeal chember are supported by the **arytenoid** and **cricoid cartilages.** The arytenoids guard the opening of the glottis and are moved by special muscles. During **breathing** the mouth is kept tightly closed, the lips being so arranged as to make an air-tight junction (Fig. 277 B). Air is sucked in through the nostrils by lowering the floor of the mouth by means of the hypoglossal musculature, and can then, either be breathed out again or forced into the lung by raising the floor. The external nares are closed by a special pad on the anterior angle of the lower jaw, supported by the **mento-Meckelian** bones. This pad is thrust upwards and pushes the premaxillaries apart, so altering the position of the nasal cartilage so that the nostrils are closed. This is a special mechanism, found only among **anurans.** In **urodeles** the nostrils are closed by valves provided with smooth muscles. Such valves are present in the toad but are said to be functionless.

The movements of the floor of the pharynx (Fig. 277 B) are not continuosuly of the same amplitude. After a period of relatively slight

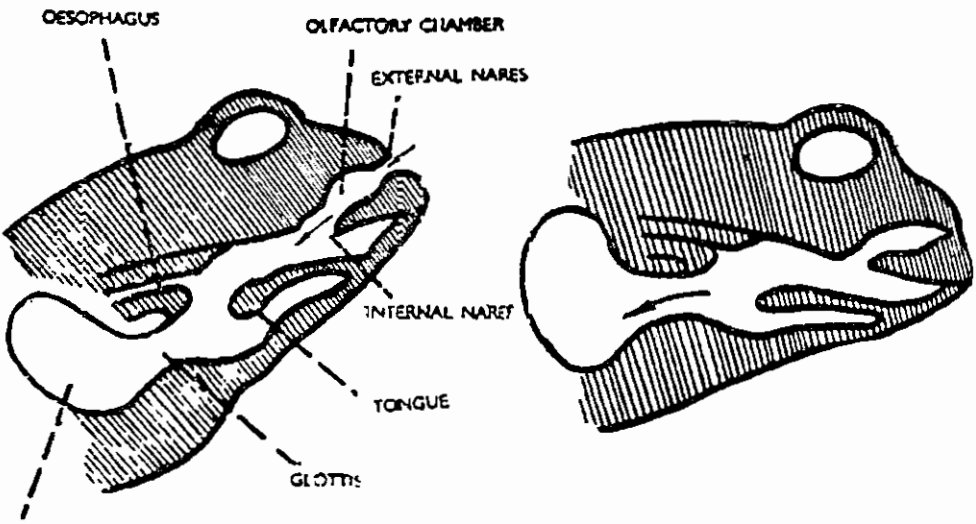


Fig. 277 — Respiratory movements of the Toad. A) Diagram representing the passage of air into the buccal cavity. B) Diagram showing how air is forced into lungs.

movements, the nostrils are kept closed while the throat is lowered. Air is thus, drawn from the lungs and then again returned to them, once or twice, before the nostrils are reopend. The whole procedure presumably ensures the maximum gaseous interchange for the minimum water-loss.

The **skin** is very vascular, and especially so in the buccal cavity. It plays a large part in respiration, actually serving to remove more carbon dioxide than do the lungs.

Digestive System (Fig. 278)

The mouth is terminal and wide. In the floor of the **buccopharyngeal** cavity, a protrusible **tongue** is present which is attached from its anterior end within the margin of the lower jaws an its end is directed backwards towards the pharynx. At the anterior end of the buccal cavity, are two internal nares. The lining epithilium of the buccopharyngeal cavity is richly ciliated and contains numerous **mucous glands.**

The pharynx is imperfectly delimited from the buccal cavity, but opening into it are the two wide laterally placed apertures of the **Eustachian tubes,** which lead to the tympanic cavity of the middle ear. In its floor the **glottis** opens into the **laryngeal chamber.** Dorsal to the glottis is the **gullet** which leads to the **oesophagus.** This latter is a short tube

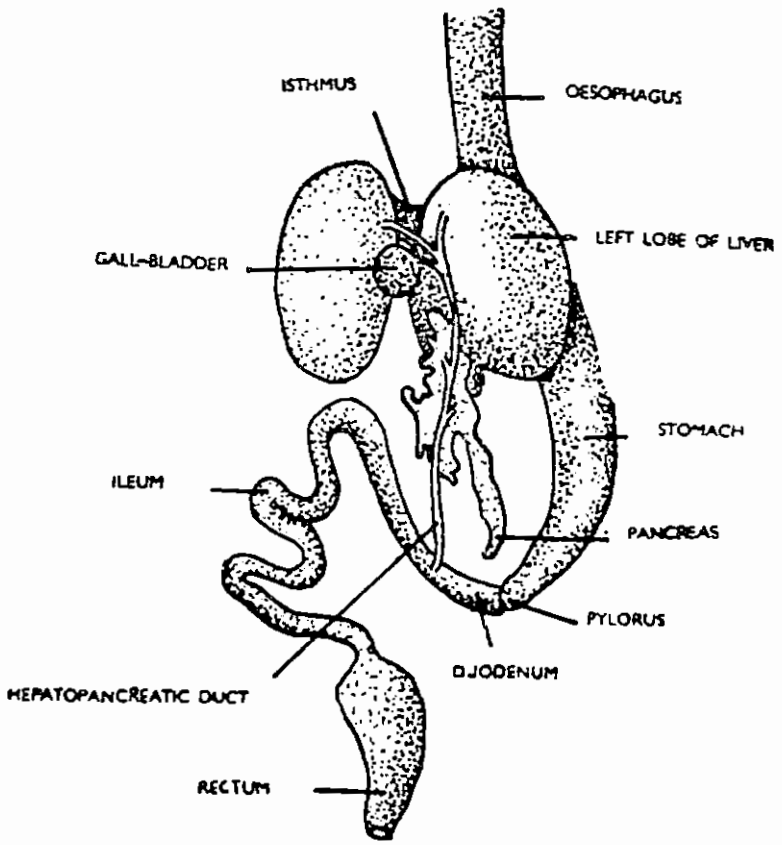


Fig. 278 — Digestive system of the Toad.

and its inner lining is folded longitudinally to allow the expansion during the passage of food along it to the **stomach.** The stomach lies in the left side of the body cavity. Its opening into the small intestine known as **pylorus** is marked externally by a constriction. The small intestine is composed of the **duodenum** and **ileum.** The duodenum extends anteriorly from the pylorus making with the stomach a U-shaped loop. The ileum is made of several coils and leads to the large intestine or **rectum,** which opens in the cloaca.

Connected with the alimentary canal are the **liver** and the **pancreas.** The liver is a large organ consisting of two lobes united together by a transverse **isthmus.** The left lobe is larger than the right and is notched posteriorly. Between the two lobes lies the **gall bladder** from which arises the duct, which also receives supplementary ducts from the liver

On its way backwards to the duodenum, the bile duct passes through the substance of the pancreas, the ducts of which open into it. The terminal portion of the duct which opens into the duodenum is therefore a **hepatopancreatic duct.** It conveys the products of both the liver and pancreas to the intestine. The pancreas lies in the mesentery between the stomach and duodenum.

The **spleen** is a dark red spherical body attached to the **mesentery** between the ileum and the rectum.

Urinogenital System (Figs. 279 and 280).

The kidneys are two elongated bodies and show some evidence of their segmental nature. They lie dorsal to the coelom in a lymph sinus. They are haemopoietic organs forming most of the red blood corpuscles. On the ventral surface of each kidney, there is the yellow **adrenal gland.** From each kidney arises a mesonephric or **Wolffian duct** which passes back to open into the cloaca. In the male toad the mesonephric duct dilates posterior to the kidney to form a **vesicula seminalis** in which sperms are stored. Thus the mesonephric duct is a urinogenital duct, but is

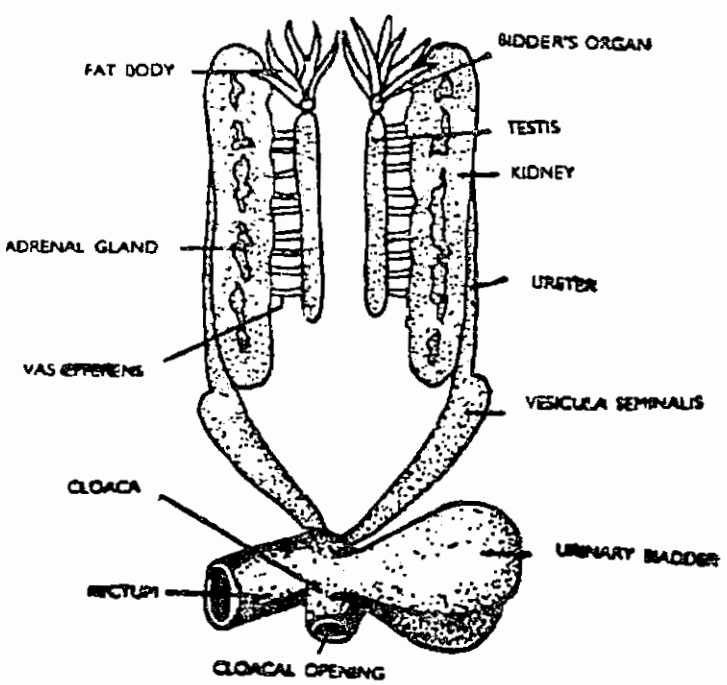


Fig. 279 — Urinogenital system of male Toad.

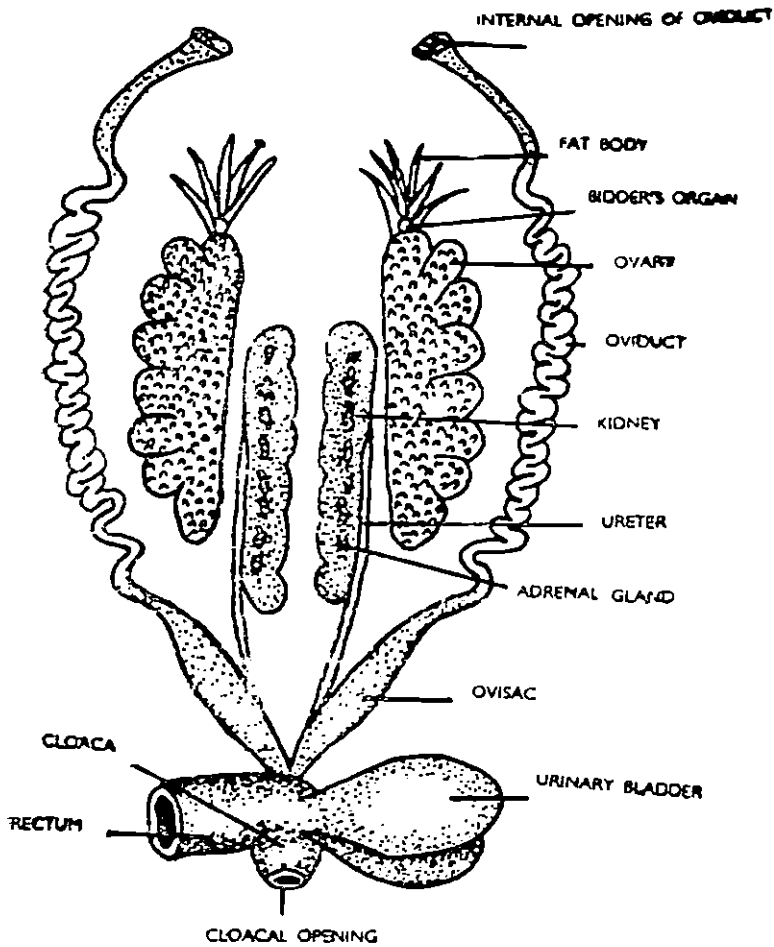


Fig. 280 — Urinogenital system of female Toad.

commonly called a ureter. From the floor of the cloaca arises a bilobed, thin-walled cloacal **urinary bladder.** A yellow oval testis lies near each kidney being suspended by **mesorchium.** In front of each testis there are the fat bodies. They are reserves of nourishment and become much smaller just before the breeding season. From each testis several thin **vasa efferentia** pass through the mesorchium and join the uriniferous tubules in the anterior part of the kidney

In the female there are two **ovaries** which become very large during the breeding season. Each ovary is saccular and its cavity is divided into compartments by septa. It is suspended by a **mesovarium.** On each side of the ovary is an oviduct or **Mullarian duct.** It starts near the base

of the lung by a thinwalled ciliated coelomic funnel then becomes coiled, thick-walled and glandular. Posteriorly each of the two oviducts forms a thin-walled dialated **ovisac.** They open by a common narrow aperture in the cloaca. Oviducts become much enlarged and coiled just before the breeding season.

Nervous System (Figs. 281 and 282).

The **fore brain** is large. The olfactory lobes are the anterior prolongation of the **prosencephalon** and are fused together in the median plane. The **cerebral hemispheres** are fully evaginated and the two hemispheres are separated by a longitudinal fissure. Each cerebral hemisphere has a large lateral ventricle which extends into the olfactory lobe. The **diencephalon** is short but optic fibres end in it. It has a vestigial **pineal body.** The anterior choroid plexus is thick and lies in front of the **pineal body.** Diencephalon has the third ventricle. Attached to the **infundibulum** is a well developed **pituitary gland.**

The **mid brain** forms two large optic lobes, each having an optic ventricle. Efferent fibres from the mid brain pass to the medulla and perhaps to the spinal cord, hence the mid brain has more connections than

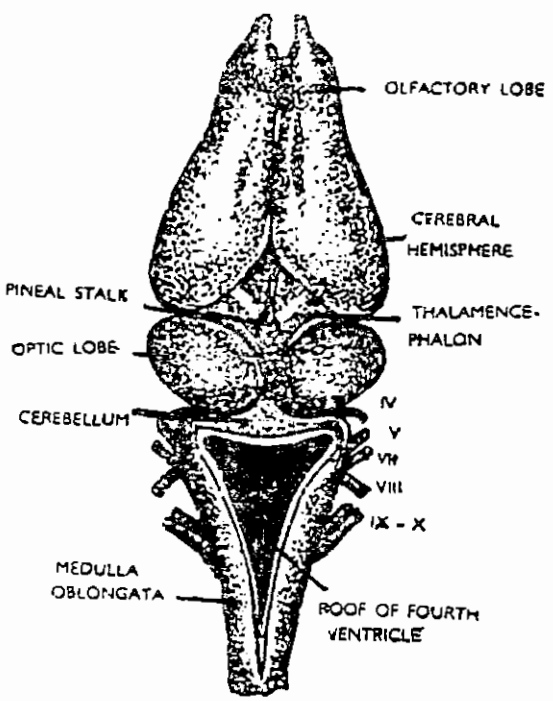


Fig. 281 — Dorsal view of the brain of the Toad.

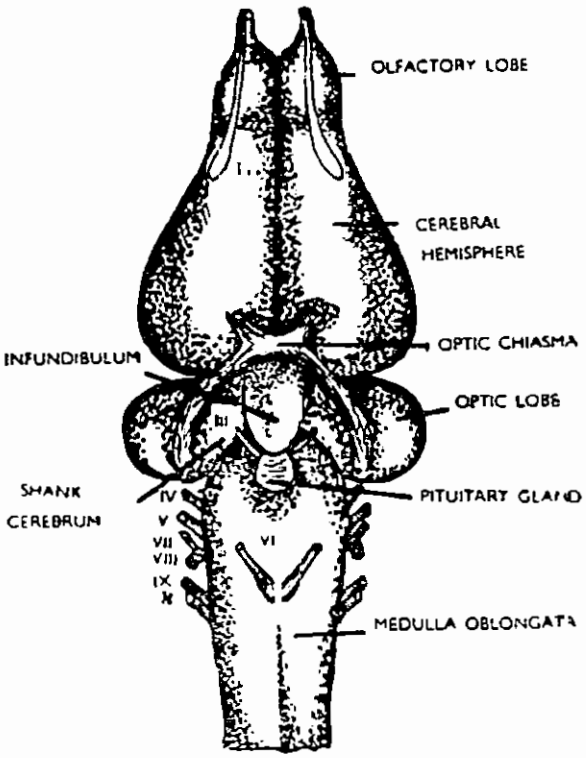


Fig. 282 Ventral view of the brain of the Toad.

any other part of the brain.

The **hind brain** is formed of the **cerebellum** and **medulla oblongata.** The cerebellum is very small because the toad is relatively inactive animal moving only in a single plane. The medulla oblongata is short and has a fourth ventricle below the posterior choroid plexus.

The **cranial nerves** arise from the brain and there are ten pairs of them in the toad.

The **spinal cord** is short and arises from it ten pairs of spinal nerves. Each one arises by a dorsal root and a ventral root which unite together after emerging from the vertebral column The dorsal root carries a spinal ganglion.

Sympathetic System

It consists of two sympathetic nerves running from the head to the end of the sacral region one on each side of the vertebral column. Each sympathetic nerve bears several ganglia which are connected to spinal nerves.

Class REPTILIA

Reptiles are ectothermal terrestrial or aquatic tetrapods. Generally, they have an exoskeleton of dry epidermal scales, below which, in some, there are also bony dermal plates. The **lungs** are the only respiratory organs with the exception of some aquatic Chelonia in which the cloaca is respiratory. The **ventricle** is divided either incompletely or completely and there is no conus **arteriosus.** The nitrogenous excretory matter is largely uric acid. There are twelve pairs of **cranial nerves.** The lower jaw consists of several bones and there is a single ear ossicle.

Reptiles are the first true terrestrial vertebrates, because along with birds and mammals they have evolved an egg which is laid and developed on land. Even aquatic pretiles come on land to lay eggs. Thus, there is avoided the necessity of any adaptation for water existence in the young. This egg type is the familiar one preserved in the reptiles. The shell offers protection and a large yolk furnishes an abundant food supply so that the reptilian young (unlike the tadople) can hatch out, at a fairly good size, as a miniature replica of the adult and thus avoids the necessity of prematurity foraging of its food. Most of the reptiles disappeared, few of them have persisted to the present day with little change, others evolved further and gave rise to modern living reptiles which are mainly consisting of **lizards, snakes, turtles** and **crocodiles.**

SCINCUS

(**The Lizard**)

External features (Fig. 283).

The reptilian body is divided into a head, neck trunk and tail. The **body, limbs** and also the head are covered with scales formed from the epidermis and called **corneoscutes.** On the head, the arrangement of the scales do not correspond with that of the underlying bones. Underlying the corneoscutes of the head there are ossifications of the dermis forming **osteoscutes** which fuse with the underlying bones of the skull. On the last phalanges of the fingers and toes, the scales form horny claws. The **eyes** have three eyelids. Behind the eye is the ear drum or **tympanic membrane.** The **nostrils** are on either side of the snout. There is a cloaca and the male has a pair of protrusible copulatory organs.

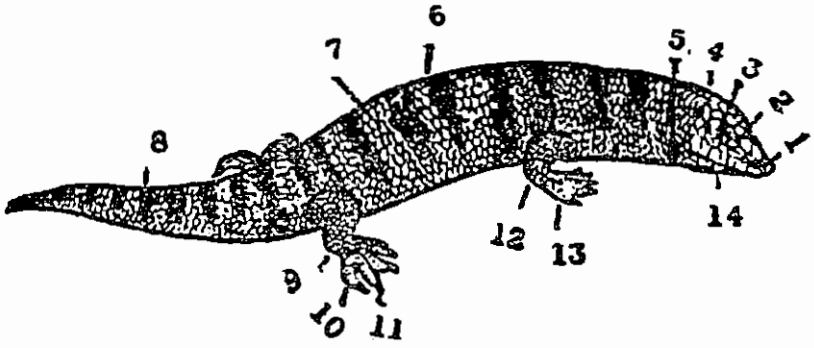


Fig. 283 — Lateral view of the lizard, Scincus 1. nostril, 2. head shields, 3. eye, 4. head, 5. ear opening, 6. trunk, 7. scales, 8. tail, 9. hind limb, 10. toe, 11. claw, 12. fore limb, 13. finger, 14. mouth.

Alimentary Canal (Fig. 284).

The upper and lower jaws, forming the boundary of the mouth, are each provided with a single row of small conical teeth, and there is a patch of similar tools (palatine teeth) on the palatine. On the floor of the mouth-cavity is the tongue which is a narrow elongated fleshy organ, bifid in front.

The **stomach** is a cylindrical organ but little wider than the oesophagus, and with thick muscular walls. At the point where the small intestine joins the large intestine or rectum, the latter is produced into a short caecum. The liver is divided into right and left lobes, and a gall-bladder lies at the lower margin of the right lobe. The pancreas is situated in the loop between the stomach and first part of the small intestine or duodenum. The stomach is attached to the body-wall by a fold of peritoneum, the **mesogaster,** the small intestine by a fold termed the **mesentery,** the rectum by a **mesorectum.** From the dorsal surface of the liver to the stomach extends a thin fold, the **gastro-hepatic omentum,** and this is continued backwards as the **duodeno-hepatic omentum,** connecting the liver with the first portion of the small intestine.

The Circulatory System

The **Heart** : **The heart** (Fig 285) is enclosed in a thin transparent pericardium. It is three-chambered in reptiles except **crocodilians** where it is four-chambered. Even this three-chambered heart shows an advance over that of amphibians. A **sinus venosus** is present but is greatly reduced due to its incorporation in the wall of the right auricle. The **sinu-auricular aperture** has no valves but is guarded by folds of the auricular

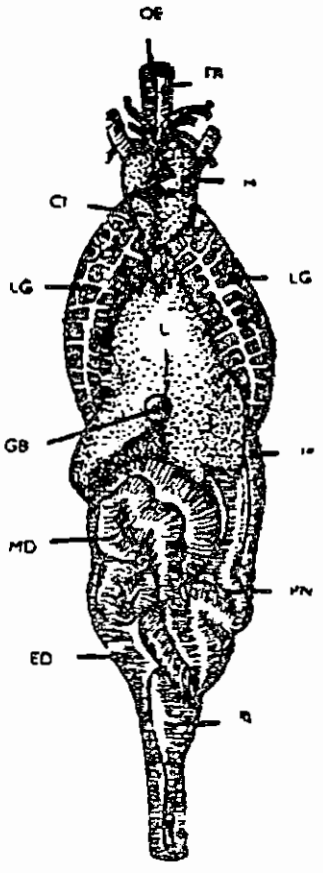


Fig. 284 — General viscera of Lacerta : BL. urinary bladder; CL, post-caval vein; ED, rectum; GB. gall bladder; H. heart; L. Liver; LG. lungs; PN. pancreas; TR. trachea.

wall. An **interauricular septum** separates a smaller left auricle from a larger right auricle. A single **pulmonary vein** opens into the left auricle, its opening has no **valve.** The two auricles open into a single **ventricle** by two openings having an **auriculo-ventricular** valve. The ventricle has an incomplete interventricular septum extending obliquely from the apex toward the centre, it divides the ventricle into a right **cavum ventrale** and left **cavum dorsale,** the latter is further subdivided into a left **cavum arteriosum** and a right **cavum venosum.** The **conus arteriosus** does not exist as such, but it has divided along with the ventral aorta into three trunks, each having a single valve at the base; the trunks are a **pulmonary aorta** arising from the cavum ventrale, a **right systemic arch** arising from the left cavum arteriosum. and a **left**

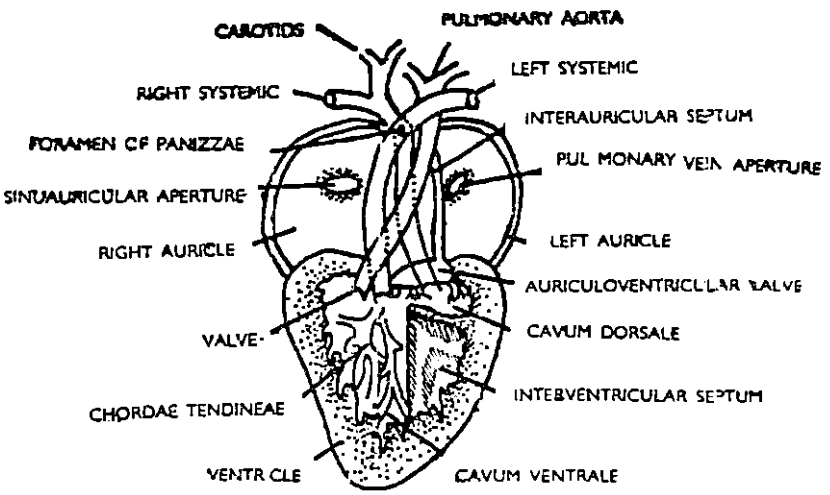


Fig. 285 — Heart of Lacerta dissected.

systemic arch arising from the right cavum venosum. The right and left systemic arches cross over to the opposite sides after leaving the heart. A small **foramen** of **Panizzae** connects the cavities of the two systemic arches where they cross each other. The **coronary circulation** has small coronary arteries arising from a branch of the right systemic arch, they take blood to the walls of the heart, a **coronary** sinus returns blood from the heart to the right auricle.

Circulation

Reptiles are the first vertebrates to become completely terrestrial and lungs are the only respiratory organs for which an efficient pulmonary circulation is necessary. Venous blood comes into the right auricle from the sinus venosus and oxygenated blood from lungs enters the left auricle. A sinuauricular node starts the heart beats, the muscles of the auricle and ventricle being continuous, the contraction of auricles travels to the ventricle. The blood coming to the ventricle in two blood streams from the auricle is kept separate by the incomplete **interventricular septum,** this separation is much more efficient than in amphibians. On contraction of the ventricle, the deoxygenated blood from the right auricle passes from the cavum ventrale into the pulmonary aorta and then, to the lungs, the mixed blood from the cavum venosum goes to the left systemic, and oxygenated blood from the left auricle comes to the cavum arteriosum from where it goes into the right systemic arch from which both carotid arteries arise and take the blood to the head. Some mixing of blood takes place in

the systemic arches at the **foramen of Panizzae** and again where the two systemic unite to form the dorsal aorta.

Classification

Subclass A. **Anapside** are the earliest primitive reptiles which arose in the Carboniferous age. The temporal region of the skull is not perforated.

Order **Chelonia** : In the members of this order, there is a short broad trunk which is enclosed in shields consisting of a dorsal carapace and ventral plastorn. The carapace and plastorn are made of outer epidermal scales and inner bony dermal plates. Jaws are strong and have no teeth but encased in bony sheaths. The humerus is turned forwards instead of backwards. In aquatic forms the limbs are modified into paddles. There is single penis and a longitudinal cloaca. They are oviparous. This order includes **turtles, tortoises** and **terrapins.**

Subclass B : **Lepidosauria** : Temporal region of skull has two fossae, one above and the other below, the suture joining the squamosal and post-orbital, quadrato jugal is absent. Such a skull is known as diapsid. The skin is covered with horny scales.

Order 1 : **Rhynchocephalia** are lizard-like in appearance, limbs are weak. Teeth are acrodont being fused to the summit of the jaws. Vertebrae are amphicoelus, there is a median parietal eye connected by a nerve to the brain and is sensitive to light. The sole living representative of the group is **Sphenedon.**

Order 2 : **Squamata** : Reptiles in which the skull has secondarily lost either one (Lacertilia) or both temporal vacuities (Ophidia). The surface is covered with horny epidermal scales, sometimes with the addition of dermal ossifications. The vertebrae are nearly always procoelous. The quadrate is movably articulated with the skull. The limbs when present are sometimes adapted for terrestrial locomotion (Lacertelia), sometimes for swimming (Pythonomorpha). There is always a wide cleft between the right and left divisions of the ventricular cavity. The optic lobes are approximated and the cerebellum is extremely small.

Suborder (*a*) **Lacertelia** are the lizards. Temporal fossae are reduced secondarily to one. They have movable eye lids. Girdles are always present though reduced in limbless forms. Tail breaks off by reflex action and is regenerated, e.g. **Uromastix, Varanus, Chamaeleon** and **Hemidactylus.**

Suborder (*b*) **Ophidia** or serpentes are the **snakes.** Temporal fossae are lost secondarily. Body is elongated. Girdles, limbs and sternum are lost, except rudiments of pelvic girdles and hind limbs in pythons. Eye lids are not movable. Ear opening, tympanic and Eustachian tubes are absent. Mouth is very expansible, even the upper jaw has movable bones. Teeth are fused to the jaws. In poisonous snakes salivary glands are modified to form poison glands. A bifid tongue is a sensory organ. There are only ten pairs of cranial nerves.

Subclass C : **Archosauria** : The skull is diapsid, interparietal bones and parietal formen are absent. They tend towards a bipedal locomotion with accompanying changes in pelvic girdle and hind limbs. Hind limbs are vertical below the body and tibia is long and strong. They include the living **crocodilians** and extinct **dinosaura.**

Order Crocodilia : These are the only living descendents of Archosauria. Skin has tough horny scales and bony plates and there is an abdominal sternum. Snout is elongated with external nares at the tip, they can be closed by valves. Tail is a powerful laterally compressed organ for swimming. Heart is four chambered but dorsal aorta receives mixed blood. There is a muscular but incomplete diaphragm. They are oviparous.

Class AVES

This class comprises birds which are warm-blooded vertebrates adapted for aerial life. Their bodies are covered with **feathers** which are produced by the epidermis of the skin. The **fore-limbs** are modified into wings which are used for flight. They are moved by the chest **muscles** which are very well developed. The **hind-limbs,** by means of which they move on land, are attached to the body much forward, thus enabling these animals to be well balanced on land. The bones are provided with numerous air-spaces, the presence of which lessens the weight of the body e.g. *Columba livia.*

Digestive System (Fig. 286).

The alimentary canal begins with the **mouth** which is large and

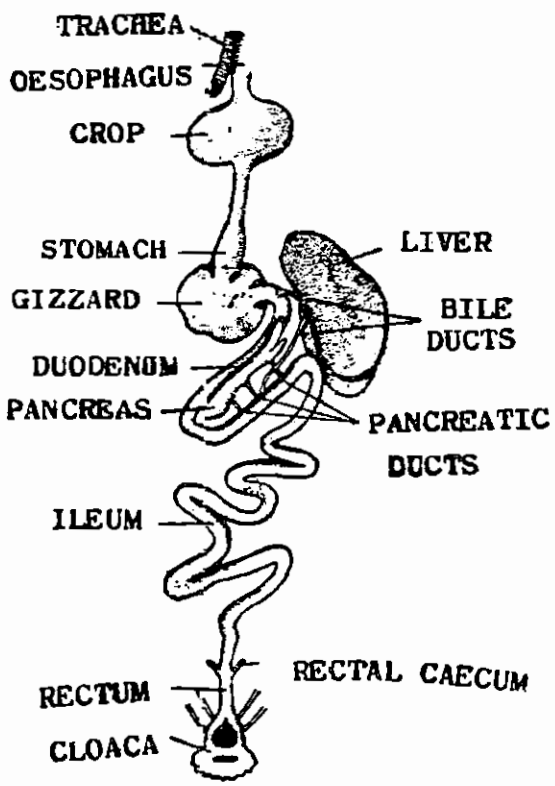


Fig. 286 — Digestive system of a pigeon.

contains no **teeth** inside it. The **oesophagus** is a long tube which becomes greatly dialated at the base of the neck forming a thin-walled sac, the **crop.** Inside the crop the food, which consists of grains, becomes macerated before it goes to the **stomach.** A short distance behind the crop, the oesophagus joins the stomach. It consists of two parts the **proventriculus** which secretes the gastric juice, and the **gizzard** which has the shape of a biconvex lens. Its walls are very thick and its cavity is small. This cavity contains small stones which are swallowed by the bird to help the gizzard in grinding up the food. The **duodenum** leaves the gizzard close to the entrance of the proventriculus. It forms a distinct loop enclosing the pancreas. Following the duodenum, is the ileum which is much coiled. It leads to the rectum and the junction between the two being marked by two small rectal caeca. The cloaca is divided into three chambers, the **coprodaeum** receiving the rectum, the urodaeum receiving the urinary and genital ducts, and **proctodaeum** opening to the exterior. Into the proctodaeum opens the **bursa Fabricii,** a gland of unknown function. The liver is large and bilobed. Each lobe joins the duodenum by its own duct. There is no **gall-bladder.** The pancreas is compact and discharges its secretion into the duodenum by three pancreatic ducts. The spleen is comparatively small and attached to the right side of the proventriculus.

Respiratory system (Fig. 287).

The glottis lies directly behind the tongue. It leads into the larynx which is supported by **arytenoid cartilage.** Unlike other vertebrates, the larynx does not act as an organ of voice. It leads into a very long **trachea which** is supported by complete bony rings. Its posterior end divides into right and left **bronchi** which are supported by incomplete cartilaginous rings. The organ of voice is the **syrinx** which is found at the junction of the trachea with the two bronchi. The syrinx is not present in any other vertebrate class. The **lungs** are comparatively small, spongy organs, not mere sacs as in Amphibia and many Reptiles. The bronchi not only give tubes which branch and form the spongy lungs, but also pass through these organs and are connected with a system of large **air-sacs.** These are nine in number; the cervicals found at the root of the neck, **anterior thoracic** and **posterior thoracic** closely adhering to the side walls of the body, **abdominals** among the coils of the intestine, and a single **interclavicular** between the lungs. The air-sacs are in communication with the air-spaces present inside the bones. This arrangement increases the efficiency of respiration and adds to the lightness of the bird.

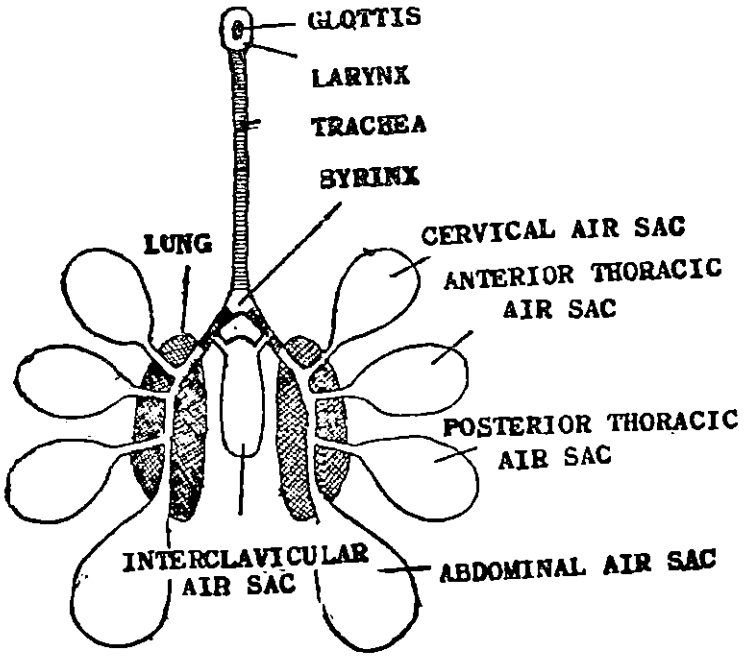


Fig. 287 — Diagramatic representation of the respiratory system and air sacs of a pigeon.

Circulatory system (Figs. 238 and 289).

The **heart** is comparatively large, consisting of four chambers. two **auricles** and two **ventricles** (Fig. 289). There is no **sinus venosus** or **conus arterious.** The right auricle receives the right and left **anterior vena cavae** and posterior vena cava. while the left auricle receives four large **pulmonary veins.** The right ventricle gives a single **pulmonary** artery which soon divdes into two. and the left ventricle gives the right **aortic arch.** The aortic arch curves to the right side and then extend backwards as the dorsal aorta. It gives at its apex two **innominate arteries** from each of which arise the common carotid and the subclavian. The latter soon divides into the branchial and pectoral arteries supplying the wing and pectoral muscles respectively. Owing to the position of the legs, the femoral and sciatic arteries arise more anteriorly The caudal artery is quite small. as the tail is much reduced.

Each **anterior vena cava** is formed by the union of **jugular,** a **branchial** and a **pectoral** vein (Fig 289). The two jugulars are in communication with one another by a transverse vessel The **caudal vein,** after receiving the large **coccygeomesenteric vein** from the cloaca and large

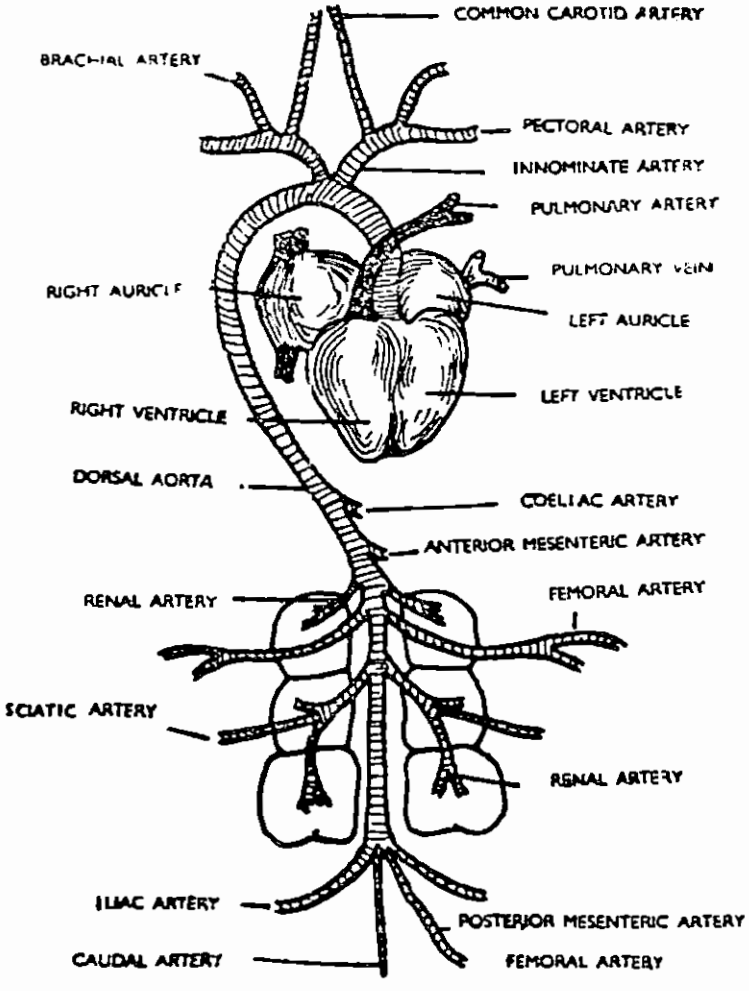


Fig. 288 — Arterial system of a pigeon.

intestine, bifurcates into two **renal portal veins.** The renal portal, instead of breaking up into capillaries inside the kidney, passes through it as a continuous vessel. Thus, there is no renal portal circulation. Each renal portal vein receives an internal **iliac** and a **sciatic** vein, and then joins the **femoral** vein from the leg forming the large **iliac vein.** The two iliacs unite together forming the posterior vena cava. Before reaching the heart, the **posterior vena cava** receives the hepatic veins, and thus there is a **hepatic portal circulation.**

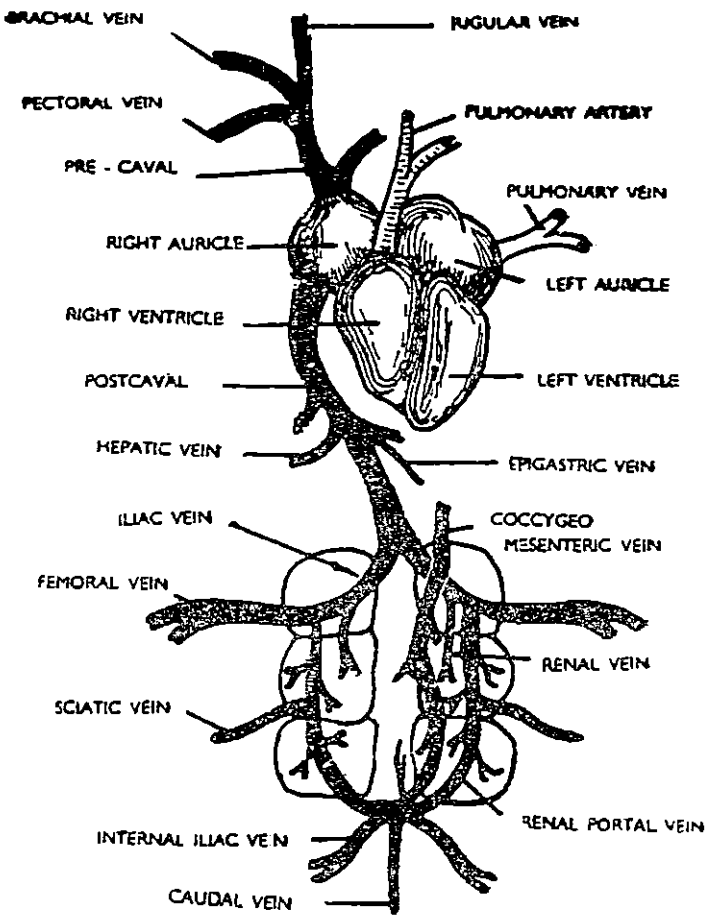


Fig. 289 — Venous system of a pigeon.

Urinogenital system (Fig. 290).

The **kidneys** are flattened, and each is divided into three lobes. The **ureters** are narrow and open into the middle chamber of the **cloaca** or **urodaeum.** In the male there are two oval testes, each is attached by a thin peritoneal membrane to the ventral surface of the anterior end of the kidney of its side. The vas deferens is a convoluted tube arising from the inner edge of the tesis. It extends posteriorly parallel with the ureter, to open into the **urodaeum** at the tip of a small papilla. Its posterior end is slightly swollen forming a seminal vesicle. There are no copulatory organs. In the female, there is only the left ovary, the right one has disappeared early in life. The right oviduct is rudimetnary and only a small part of it is left behind. The left oviduct is long and convoluted, its anterior end

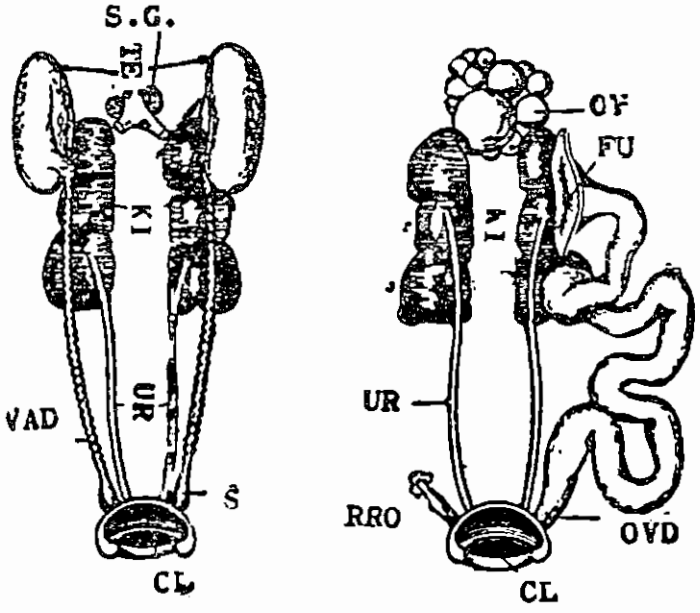


Fig. 290 — Columba, male and female urinogenital system (From Thomson).
CL, cloaca; funnel; KI, kidney; OV. ovary; OVD, oviduct PRO, rudimetary right oviduct; S.G., supra-renal glands; SV, seminal vesicle; TE. testis; UR, ureter; VAD, vas deferens.

is enlarged forming a wide funnel for the reception of the ripe ova, and its posterior end leads to the **urodaeum.**

Skeletal system*

1. **Endoskeleton**

The endoskeleton compirses the **skull, vertebral column pectoral** and **pelvic girdles,** and **fore-** and **hind-limbs.**

(*a*) **Fore-limb** (Fig. 291).

The **humerus** is strong. The **radius** is slender and nearly straight, but the **ulna** is shorter and slightly curved. There are two **free carpals,** the radiale and **ulnare.** Articulating with them is a bone called **carpo-metacarpus** consisting of two rods fused together at both ends. It is formed of the fusion of the distal carpo-metacarpus, the first consists of

(*) Students may consult other vertebrate text books for studying the remaining parts of this skeleton.

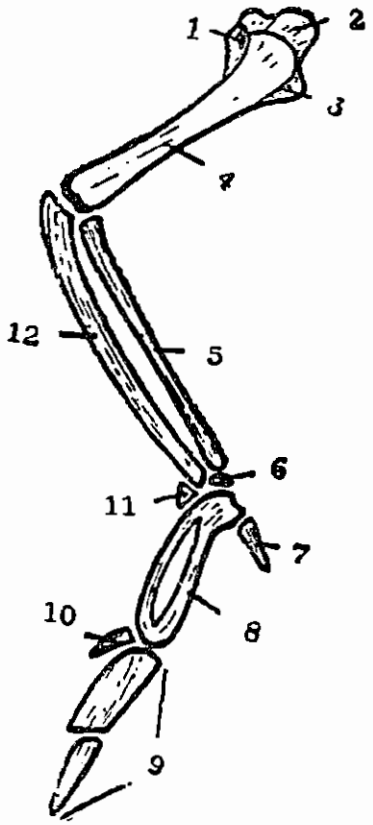


Fig. 291 — Fore-limb skeleton of Columba.

1. pneumatic foramen, 2. heac. 3. deltoid ridge, 4. humerus, 5. radius, 6. radiale, 7. phalanx of first digit, 8. carpo-mentacarpus, 9. phalanges of second digit, 10. phalanx of third digit, 11. ulnare, 12. ulna.

1 phalanx, the second of 2 phalanges, and the third o 1 phalanx. The digital formula is : 1 : 2 : 1 : 0 : 0.

(*b*) **Hind-limb** (Fig. 292).

The **femur** is comparatively short. A small bone, the **patella,** lies on the knee-joint. Articulating with the femur is a long bone which is the **tibio-tarsus** and which is formed by the fusion of the proximal tarsals with the tibia. The fibula is very small and slender. The distal end of the tibio-tarsus articulates with the tarso-metatarsus, formed by the fusion of the distal tarsals with the metatarsals. Four digits are present in the hind limb. The **digital formula** is : 2 : 3 : 4 : 5 : 0.

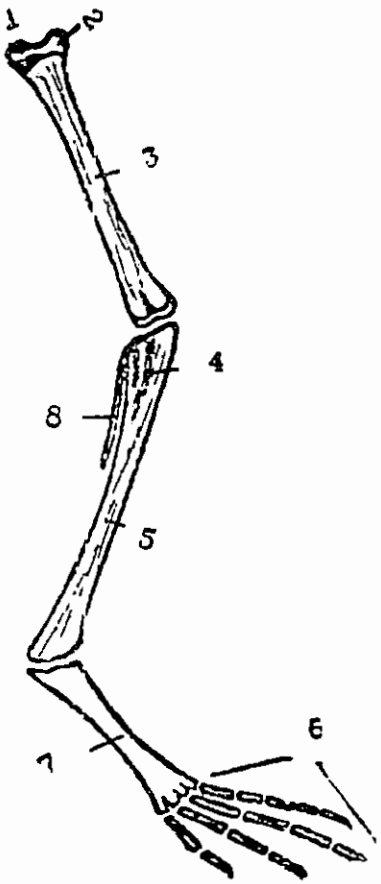


Fig. 292 — Hind-limb skeleton of Columba : 1. trochanter, 2. head, 3. femur. 4. cnemial crest, 5. tibio-tarsus, 6. phalanges of digits, 7. tarso-metatarsus, 8. fibula.

2. Exoskeleton

The exoskeleton consists of the feathers, beak and claws, with their horny sheaths, and the scales which cover the feet.

Feathers (Fig. 293).

There are three main kinds of feathers in birds: **contour, filoplume** and **down** feathers.

(*a*) **Contour feathers** (Fig. 293 C).

The conour feathers are of two types : (i) **flight** feathers whic are large in size and are found on the wing and tail; (ii) **covert** feathers which are smaller in szie and cover the body. A contour father of flight consists

Fig. 293 — Various types of feathers. A) Filoplume; B) Nesting down feather; C) Contour feather; D) Down feather.

of an **axis** which is the **stem** and a flat part which is the **vane.** The stem is made of two parts, the **quill** and the **rachis.** The quill is short hollow and has pith formed from the dry remains of the feather pulp. Its lower end is inserted into the feather follicle of the skin. At the lower end of the quill, is the opening of the **inferior umbilicus.** The **superior umbilicus** is found on the ventral surface of the quill at the point where it joins the rachis. From the superior umbilicus protrudes the **aftershaft.** The rachis has on its ventral surface the **umbilical groove.** On both sides of the

rachis are the **barbs** which constitute the vane. They are obliquely placed, parallel to each other and provided with side branches known as the **barbules** which posses **hooks.** Thus, the whole vanes is held together to form a single surface and offers reistance to air.

On the other hand, coverts are smaller than flight feathers and their hooks are poorly developed.

(*b*) **Filoplume feathers** (Fig. 293 A).

These are hair-like feathers with a long stalk carrying few terminal barbs. Hooks are absent and are found among the contour feathers.

(*c*) **Down feathers** (Figs. 293 B and D).

A down feather has a very small quill having barbs and barbules at its tip, but there are no hooks. In the adult the down feathers form powder down feathers from which powdery fragments are dropped. They are hidden by contour feathers and help in keeping the body temperature.

Nervous system Fig. 294

The **cerebral hemispheres** are well developed, and considerably larger than in the lower forms. The cortex of the brain is thin, and markedly different in this respect from that of the mammals. The **cerebellum** is also well developed as is the rule among animals which rely on a sense of balance, and its surface is thrown into ridges. The median portion of the cerebellum is known as the **vermis,** on each side of which is a conical projection known as the flocculus. The front of the cerebellum is in contact with the hinder surface of the cerebral hemispheres.

There are twelve pairs of cranial nerves, the spinal accessory and hypoglossal being included in the skull.

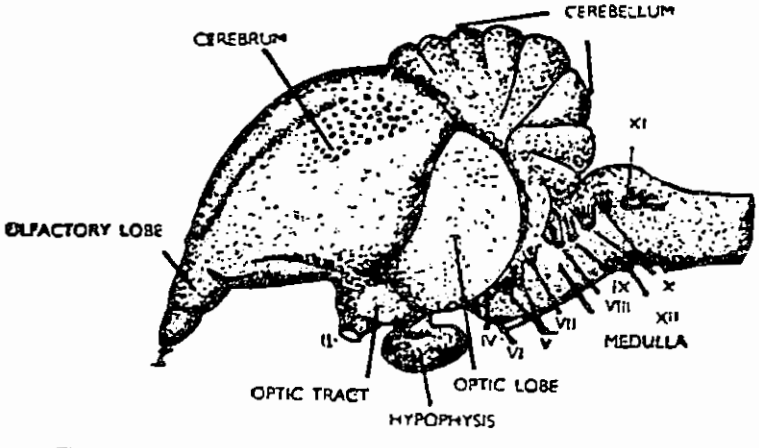


Fig. 294 — Columba. Lateral view of the brain. The roots of the cranial nerves are marked by roman numerals.

Class MAMMALIA

Mammals are craniates with a more complete adaptation to terrestrial life than any ohter animals, though a few have successfully reconquered the sea and fresh water and have become modified accordingly.

The mammalia as a class have some diagnostic characters and at some time there must have been animals with a mixture of ancestral reptilian and the beginnings of the modern mammalian characters. The Monotremata are still in some respects in this position.

The Characteristics of Mammalia

1. The skin is covered at least partially with hair which is found in no other vertebrates. However, a number of mammals are secondarily almost devoid of hairs, as **Cetacea, Sirenia, elephants** and **hippopotamus,** although the embryos of some of these posses a complete coat of hairs The scales of the reptelian ancestry are not fully despensed with, but may remain in some parts of the body, as the scales of the tail of the rat.

2. The skin is thick and waterproof having **sebaceous** and **sweat** glands, the latter control body temperature by evaporation of sweat.

3. The presence of **mammary glands** which are modified epidermal glands. They secrete milk for nourishment of the young.

4. There is a **diaphragm** which is a partition of muscular fibres with a tendinous centre separating the lungs and pericardium from the other viscera.

5. The **skull** has a large cranial cavity and the number of bones is reduced.

6. The bones of the **lower jaw** are reduced to one which is the **dentary.**

7. There are always **three auditory ossicles** in the **ear** and there is an **external pinna.**

3. Vertebrae are gastrocentrous and there are generally seven cervical vertebrae. The long bones and vertebrae ossify from three **centres, a central diaphysis** and two **terminal epiphysis.** This arrangement permits growth for long periods

9. The heart is completely four-chambered and the left **aortic arch** alone persists.

10. The **cerebral hemispheres** and **cerebellum** are very large with much increase in the grey matter.

11. Except in camels, the red blood corpuscles are round, biconcave and non-nucleated.

12. In most mammals, the testes descend into scrotal sacs in the adult.

13. Ovaries are small and have eggs in **Graafian follicels,** the eggs have no yolk, except in monotremes.

14. The embryo develops within the uterus, except in monotremes, having an **amnion** and an **allantois,** the latter along with the uterus forms a **placenta** which brings about nutrition, respiration and excretion of the **foetus.**

15. The young are nourished for some time after birth on milk, the secretion of the female mammary glands, a production peculiar to mammals.

THE RABBIT

External Features

The most obvious characteristic of the **rabbit** is the possession of hair, which, typically, forms a complete covering to the body (Fig. 295). Hairs are more or less cylindrical epidermal structures, seated in little pits or **follicles** at the base of each of which is a **papilla.** The epidermal cells, just above the papilla, multiply actively and contribute new material to the hair, which in this way grows in length. The central axis of the hair is called the **medulla,** and surrounding this is the **cortex** (which is often pigmented), and a **cuticle.** The function of hair is to prevent loss of heat from the body by radiation, for mammals are warm-blooded (**homothermous**). It also serves for protection, and sometimes as a sensory tactile organs, as in the case of the **vibrissae.**

The fingers and toes end in claws which are epidermal structures.

In the epidermis (Fig. 295) there is a great difference between the actively growing cells at the base (stratum Malpighi), and the flat horny cells on the surface (stratum corneum) which are continually being lost and replaced from the stratum Malpighi.

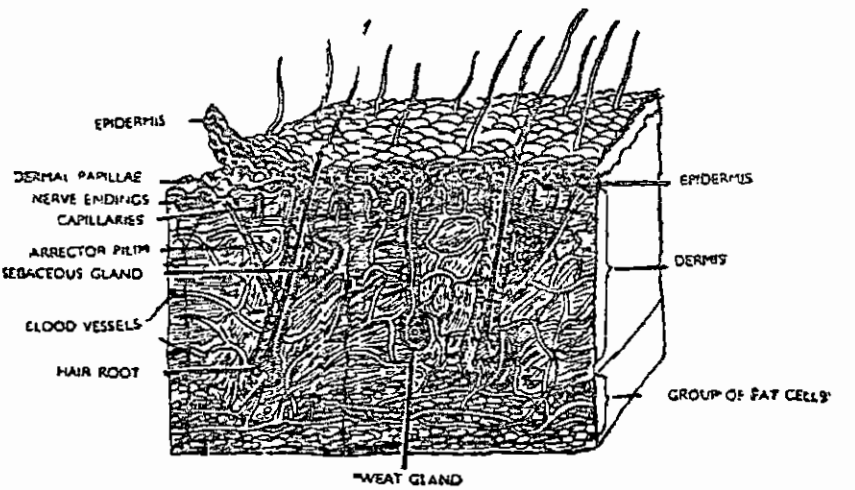


Fig. 295 A — Section of a mammalian skin to show hairs, glands and accessory structures

The dermis of the skin forms the basis of leather, and it commonly contains fat forming a layer which assists the animal in maintaining its internal heat. Beneath the skin are muscles which serve to move and shake it.

The skin is supplied with glands of epidermal origin, of which there are two kinds **sebaceous** and **mammary** (in other mammals there are also **sweat glands**).

The **sebaceous glands** branch repeatedly, and their secretion is intracellular greasy substances which are pushed out in the loaded cells themselves. These glands are usually found opening into the hair-follicles where the greasy secretion spreads over the hair. Other glands of this type, open to the surface along the edge of the eyelids, and into depressions at the sides of the anus (perianal glands). The secretion of the latter is responsible for the smell of the rabbit.

Mammary glands, or milk glands occur in both sexes, but are functional only in the female. They are branched tubes lying between the skin and the underlying muscles on the ventral surface of the body, and opening to the surface by nipples, of which there are in the rabbit about four pairs

The eyes have upper and lower eyelids and a small nictating membrane. A noteworthy feature is the presence of external ears, or pinnae, which assist the sense of hearing, by concentrating the waves of sound.

The **anus** is at the roof of the tail, and is separate from the urinogenital aperture, which is situated in front of it, and takes the form of a penis in

the male or a vulva in the female At the sides of the penis in adult males are the scrotal sacs which contain the testes This ventral position of the testes is a new feature peculiar to most adult mammals

Skull (Figs. 296 and 297).

The skull has two **occipital condyles,** formed from the exoccipitals. The floor is formed by **basioccipital, basisphenoid, presphenoid** and **vomer,** the latter representing the anterior portion of the parasphenoid of lower forms. The **mesethmoid** is perforated by a number of pores through which branches of the olfactory nerve run to the nasal sacs. Anteriorly, the mesethmoid extends as the vertical **septum nasi,** which separates the cavities of the nasal capsules.

The roof of **the skull** is formed by the **supraoccipital, parietals, interparietals, frontals** an **nasals.** The bones of the **auditory capsules** are fuse to form the **periotics,** which form the hinder part of the side of the brain-case. The remainder of the side is formed by the **squamosals, alisphenoids** and **orbitosphenoids.** There is a small **lachrymal bone** near the front of the orbit.

The margin of the **upper jaw** is formed by the **premaxillae** and the **maxillae.** From the maxillae the **jugals** extend backwards and meet a process (**zygomatic**) of the **squamosal** forming (with the jugal he "**cheek bone**". The **pterygoids** are small bones behind the palatines, and at the sides of the **basisphenoid.** The **vomer** representing the parasphenoid is covered over by the false **palate.** Large tympanic bullae lie beneath the **periotic** and contain the tympanic cavity.

The wall of the skull is pierced by a number of holes or foramina through which the nerves and blood-vessels pass out and enter

The lower jaw consists of a single bone, the **dentary,** which articulates with the skull by means of the **squamosal.** This method of articulation is characteristic of mammals, and differs from the articular-quadrate articulation of all other **Gnathostomes.** On the other hand, whereas other vertebrates have one single bone connecting the **tympanic membrane** with the **fenestra ovalis** of the auditory capsule, in the mammals there are three such bones. The one nearest to the **fenestra ovalis** is perforated and called the **stapes,** it is homologous with the columella auris and **hyomandibular** of lower forms. The next bone is the incus, which is in reality the **quadrate,** and the last bone is the **malleus** which is in reality the **articular.**

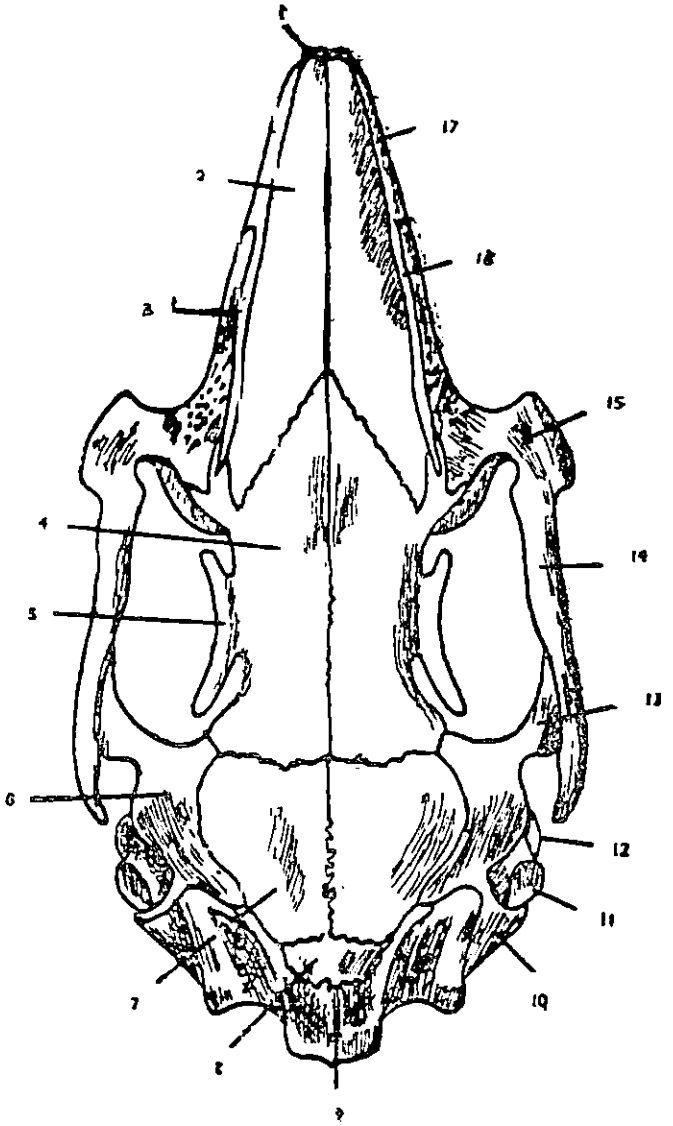


Fig. 296 — Dorsal view of the skull of rabbit.

1. Incisors. 2. nasal. 3. maxilla. 4. frontal. 5. supraorbital process of frontal. 9. supraoccipital. 10. periotic, 11. external auditory meatus. 12. tympanic bulla, 13. zygomatic process of squamosal. 14. zygomatic process of jugal. 16. nasal process of premaxilla, 17. premaxilla.

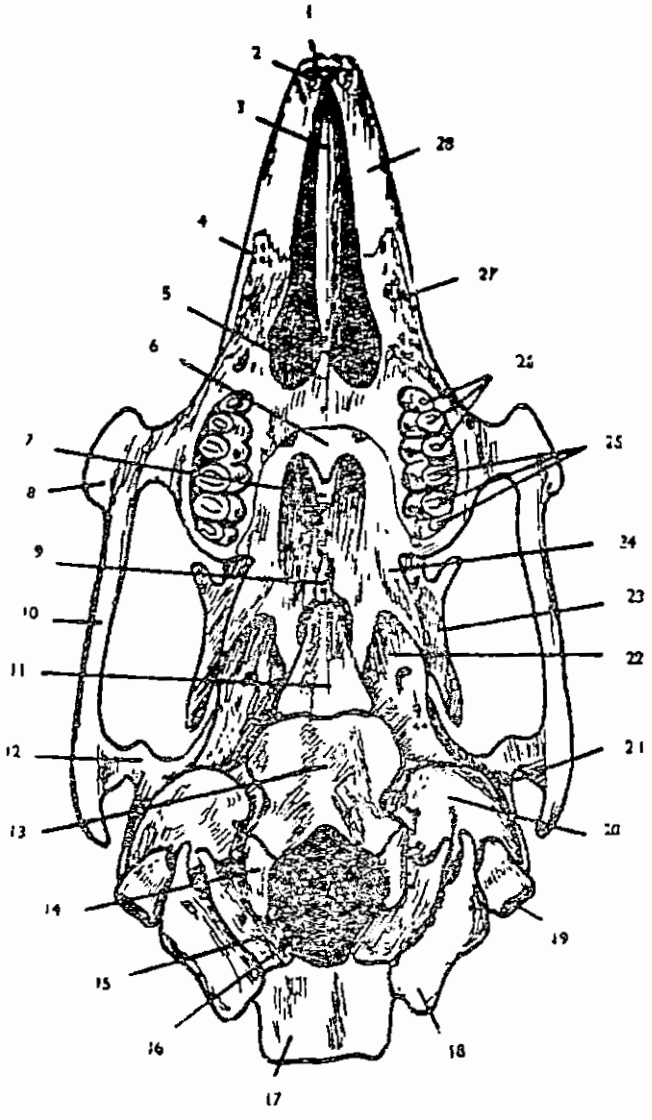


Fig. 297 — Ventral view of skull of rabbit.

1. anterior incisor, 2. posterior incisor 3. palatal process of premaxilla, 4. nasal process of premaxilla, 5. palatal process of maxilla, 6. palatal process of palatine, 7. vomer 8. jugal, 9. presphenoid, 10. zygomatic process of jugal, 11. basisphenoid, 12. zygomatic process of squamosal, 13. basioccapital. 14. occipital condyle, 15. exoccipital, 16. foramen. magnum, 17. supraoccipital, 18. periotic. 19 external auditory meatus, 20. tympanic bulla. 21. aqamosal. 22. pterygoid, 23. supraorbital process of frontal. 24. palatine, 25. molars, 26. premolars. 27 maxilla. 28. premaxilla.

Vertebral Column*

The number of cervical vertebrae is seven. The first is the **atlas,** and the second is the **axis** bearing the centrum of the atlas in the form of the **odontoid peg.** The **cervical vertebrae** have **vertebrarterial canals** formed by the fusion of the **tuberculum** of the rib to the transverse process of the vertebrae, and the **capitulum** of the rib to the centrum. The **thoracic** vertebrae are usually a dozen in number, and each is related to a pair of ribs with which it articulates by **tubercular** and **capitular facets.** Behind the thoracic region, are the **lumbar vertebrae,** usually seven in number, and characterised by their large transverse processes. Next comes the **sacral region** which is attached to the ilium of the pelvic girdle, and the **caudal region** with vertebrae which become simpler in structure as they approach the tip.

Fore Limb and Girdle*

The pectoral girdle is formed by the scapula, which bears a ridge, the **acromion,** and a small **coracoid process.** The **clavicle** is slender, and joins the **acromion** to the **sternum.** The arm is made up of the usual bones : **humerus,** radius, and ulna, three proximal carpals; one central carpal and four distal carpals make up the wrist. There are five metacarpals. and the phalanges are 2, 3, 3, 3, 3, in number on the respective fingers.

Hind Limb and Girdle*

The **pelvic girdle** is formed of the usual three bones : ilium, ischium, and pubis, on each side. The ilium runs forwards and upwards from the **acetabulum** to the **sacrum.** The pubis meets its fellow from the opposite side in the middle line, forming the **pubic symphysis,** and a large **obturator foramen** separates the pubic from the ischium of its own side.

The **femur** has a large **head,** which fits into the acetabular cavity of the pelvic girdle, and three processes or **trochanters** which serve for the attachment of muscles. The **tibia** is large, but the **fibula** is small and fused on the tibia. Covering the front side of the joint between femur and tibia is a small bone, the **patella** or **knee-cap.**

The priximal tarsal bones are two in number; the **astragalus,** and the **calcaneum** (heel-bone) There is one **centrale,** and theree distal **tarsals.** The foot has four toes, the first or **hallux** having disap-

(*) Students are advised to consult their practical note books including the illustrations of all parts marked by*.

peared. There are consequently four metatarsals, and the digital formula for the number of phalanges is 0, 3, 3, 3.

It is common to find small irregular bones on the under or palmar side of the joints of several of the fingers and toes, and covering certain joints of the arm and leg. These are the **sesamoid bones.** They arise in connection with the insertion of tendons on to bones. Examples are the **patella,** and the **pisiform** which underlies the joint between the ulna and the cuneiform bone of the wrist. Sesamoids are important functionally but, they have not much significance in comparative anatomy, since they are not constant from group to group.

Circulatory System (Figs. 298 and 299)

The **heart** contains four chambers, **two auricles** and **two ventricles.** The **truncus arteriosus** has been split into two right down to its base.

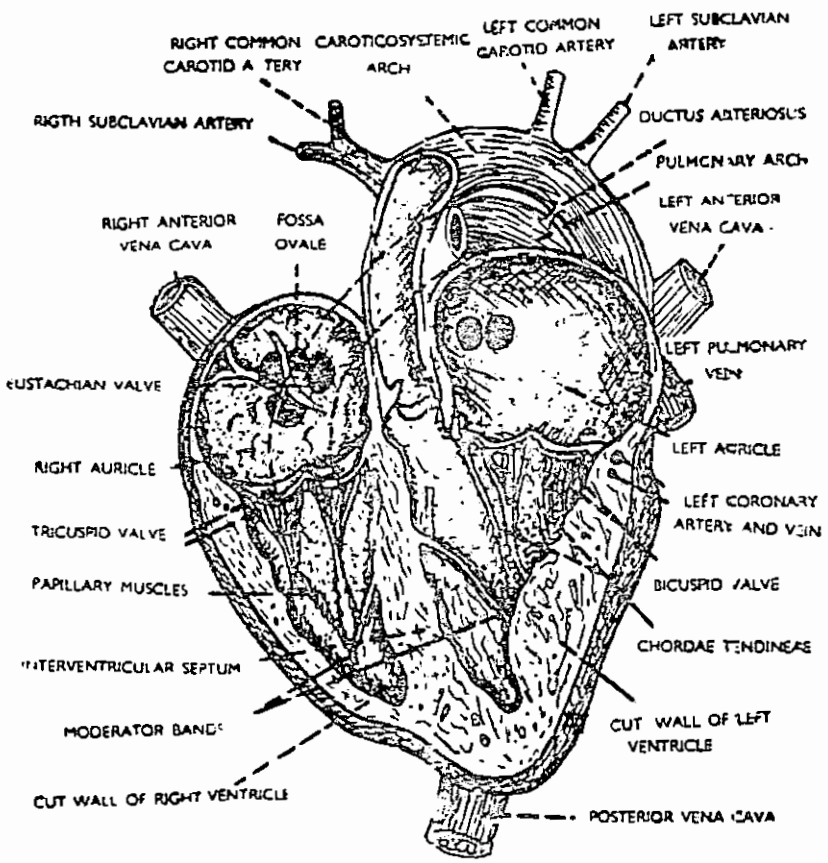
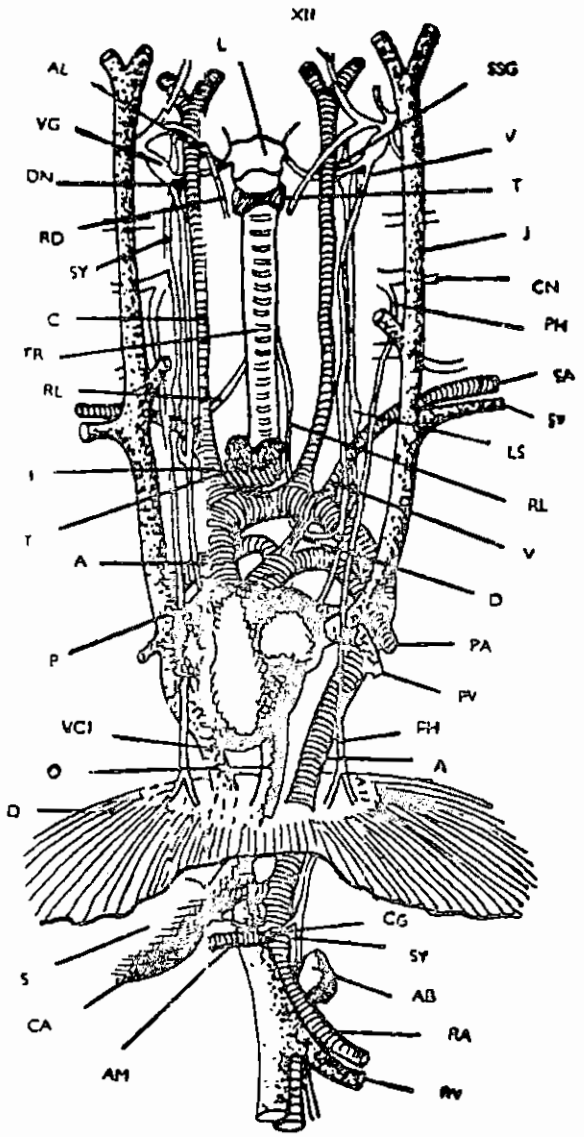


Fig. 298 — Mammalian heart dissected.



Fig, 299 — Dissection of the circulaory system af rabbit seen from the ventral side.

A) aorta; AB, adrenal body : AL, anterior laryngeal nerve (branch of vagus); AM, anterior mesenteric artery; C) carotid artery; CA, coeiac artery; CG, anterior mesenteric sympathetic ganglion; CN, cervical nerve; D, diaphragm; DA, ductus arteriosus; DN. depressor nerve (branch of vagus); I innominate artery; ISG, posterior cervical sympathetic genglion; J, jugular vein; L, arynx; O, esophagus; P, phlmonary trunk; PA, pulmonary artery; PH, phenic nerve; PV, pulmonary vein; RA, renal artery; RD, ramus descendens (branch of hypogiossal nerve); SL, recurrent laryngeal nerve (branch of vagus); RV. renal vein; S. stomach; SA subelavian artery; SSG, anterior cervical symphathetic ganglion; SV, subclavian vein; SY, sympathetic nerve-chain; T. thymus gland; TH, thyroid gland; TR, trachea; V vegus nerve; VGI vena cava inferior; VG. vagus ganglion; XII hypoglossal nerve

One of these vessels opens out of the right ventricle and leads to the lungs, it is the **pulmonary artery.** The other opens out to the left ventricle and is the **aorta** which leads to the **carotid arteries** and the **systemic arch.** The two superior **venae cavae** and the **inferior vena cava** open directly into the right auricle; there is no **sinus venosus.** The **pulmonary** veins opens into the left auricle. Guarding the opening between the right auricle and right ventricle is the **tricupsid valve**; the corresponding opening between the left auricle and left ventricle is guarded by the **mitral valve** The openings of the aorta and pulmonary artery are guarded by semilunar valves.

The systemic arch persists only on the left side. On the right, it is represented only by the short **innominate artery** from which the right **carotid** and right **subclavian arteries** arise. On the left side these two arteries arise from the systemic arch, which, passing back and up round the left, sie of the gut, becomes the **dorsal aorta.** The dorsal aorta gives off the coeliac, **anterior mesenteric** and **posterior mesenterie,** between the anterior and the posterior mesenteric arteries, the dorsal aorta also gives off the **renal arteries** to the kidneys, and the genital arteries to the gonads. In the case of males in which the testes have descended into the scrotal sacs, the latter arteries are of considerable length. Posteriorly the dorsal aorta divides into the iliac arteries which supply the hind legs, and the caudal artery.

The **superior vena cava** of each side is made up of the **jugular** and **subclavian** veins, and opens into the right auricle. In some forms the left **superior vena cava** is connected with the right by a transverse **innominate vein,** and so loses its own opening into the right auricle. The left superior vena cava also receives at its base the thoracic duct which connects with the system of lymphatic vessels. The posterior cardinal veins are represented by the **azygos** (right) and **hemiazygos** (left) veins of the **wall** of the thorax. The hemiazygos connects with the azygos, which opens into the right superior vena cava. The connection between the hemiazygos and the left superior vena cava has been lost.

The walls of the heart itself are drained by veins called **coronary veins,** which open into the right auricle.

The veins from the hind legs (iliac and femoral veins) run into the inferior vena cava, which also receives the genital vein from the gonads, the renal veins from the kidneys and the hepatic veins from the liver, and runs into the right auricle. Blood from the stomach and intestine is carried to the liver by the **hepatic portal vein** : there is no **renal portal vein.** The blood of the mammals differs from that of all other animals in that in the adult the red blood-corpuscles have **no nuclei.** Instead of being bicon-

vex, the red corpuscles here are **biconcave.** The source of supply of new blood-corpuscles in late embryonic and in adult life is in the **red marrow** which is situated in the central cavity of a number of bones. In addition, lymphocytes are produced in the lymph glands, which also serve as blood filters. It is possible that blood-corpuscles may also be formed in the **spleen.**

Urinogenital System (Figs. 300 and 301).

The kidneys are asymmetrically placed. They are metanephric structures, connected by the ureters with the urinary bladder.

The **ovaries** are close to the anterior end of the Müllerian ducts or oviducts, which open into the peritoneal cavity by the Fallopian tubes. The base of each oviduct is enlarged and specialised to form the **uterus,** in which the young embryos develop. The two uteri are close together, and they open into the single median **vagina.** The bladder is just ventral to the vagina and connects with it to form the vestibule which communicates with the exterior by the vulva.

The vestibule is dorsal to the **pubic symphysis,** and ventral to the anus, with which it has no connection. There is therefore no cloaca.

In the male, the **Müllerian** ducts disappear except for the **uterus masculinus,** which lies dorsal to the bladder. The testes are connected with the **epididymis,** representing the mesonephros of their own side. From the epididymis the vas deferens or **Wolffian** duct leads to the base of the bladder on its dorsal side, close to the prostate gland. The bladder and vasa deferentia lead into a tube, the **urethera** which runs through and opens to the exterior at the end of the **penis.**

The testes arise near the roof of the peritoneal cavity, suspended by mesenteries, they descend ventrally and backwards into the **scrotal sacs.** The **spermatic cords,** containing the artery from the dorsal aorta, show the path taken by the testes in their descent. The epididymis is connected with the scrotal sac by an elastic cord, the **gubernaculum,** which in early stages grows down into the scrotal sac and guides the testis higher in it descet.

Nervous System

The most important characteristics of the mammalian nervous system are to be found in the brain (Figs. 302 and 303). This brain consists, as usual, of fore-, mid- and hind-brains.

The Fore-brain

The **cerebal hemispheres** are so large that they completely over-

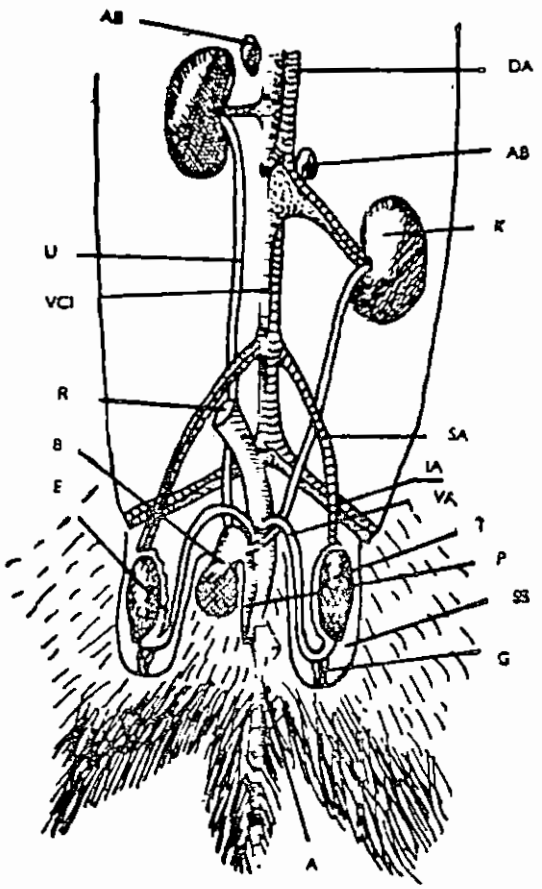


Fig. 300 — Male urinogenital system of rabbit.

A, anus; AB, AD, adrenal body; B. bladder; DA, dorsal aorta; E. epididymis; G. gubernaculum; IA, iliac artery; K, kidney; O, ovary; OA. ovarian artery; OD, oviducd; P. penis; R. rectum;RA. renal artery; SA. spermatic cord; SS, scrotal sac; T. testis; U, ureter UT. uterus; P. vestibule; VA, vagina; VCI, vena cava inferior; VD, vas deferens.

shadow the olfactory region and also project backwards and hide from view in the dorsal aspect, the **thalamencephalon** and part of the mid-brain. The **telencephalon,** then, consists of the cerebral hemispheres and the small olfactory lobes. The two cerebral hemispheres are separated from one another by the **median fissure,** though there are other fissures dividing the surface into regions. The shallow oblique **Sylvian fissure** divides each hemisphere into an anterior **frontal lobe** and a **lateral temporal lobe. On** the ventral side of the brain there is a longitudinal fissure which demarcates the **hippocampal** lobe. Posteriorly the olfactory lobes

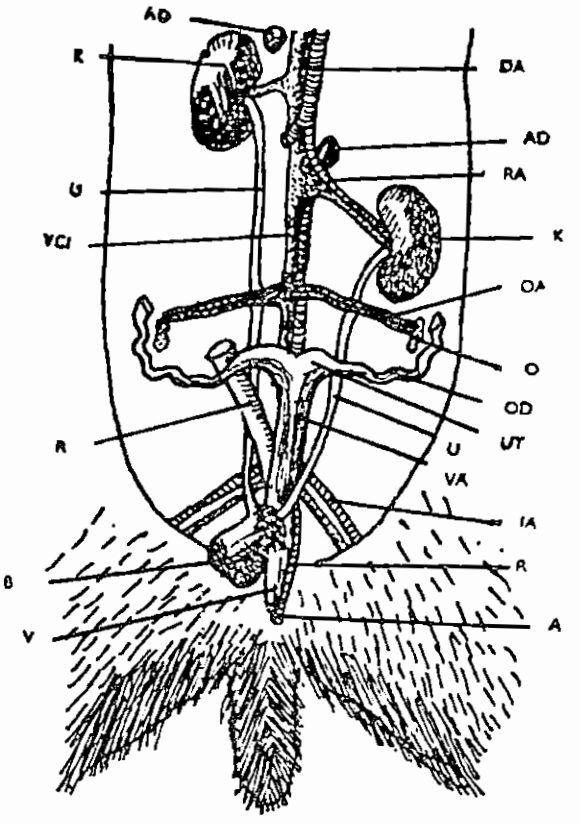


Fig. 301 — Female urinogenital system of rabbit.
(See lettering under Fig. 300)

continuous with the olfactory tracts, the outer margins of which are defined by the **rhinal fissure.** The thalamencephalon has the salk of the pineal body which arises from its dorsal surface, and on the ventral surface are found the optic chiasma and the pituitary body.

The mid brain

The optic lobes are represented by four rounded prominences, the **corpora quadrigemina,** on its dorsal surface. In lower vertebrates, there are only two **optic lobes.**

The hind brain

The **medulla oblongata** or **myelencephalon** is not very different from that of lower forms, but in the **metencephalon,** the cerebellum is much enlarged and dividible into a number of lobes. Its surface is thrown

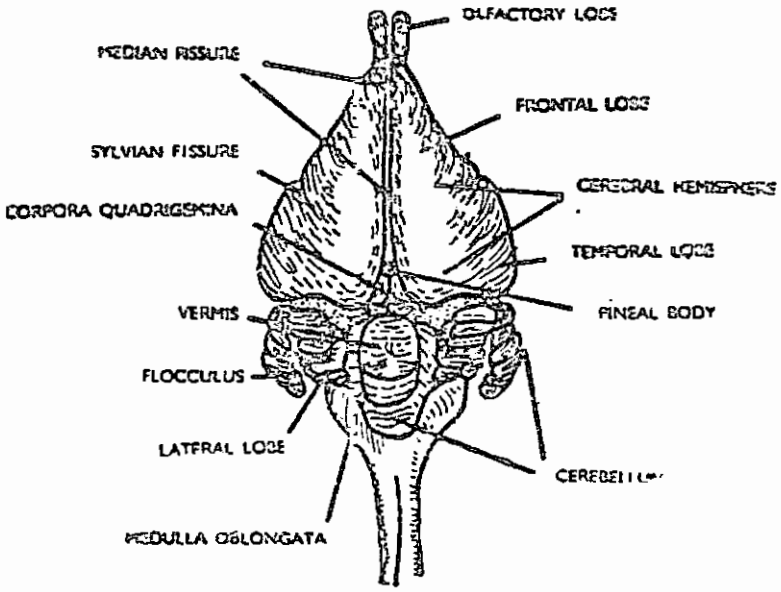


Fig. 302 — Dorsal view of brain of rabbit.

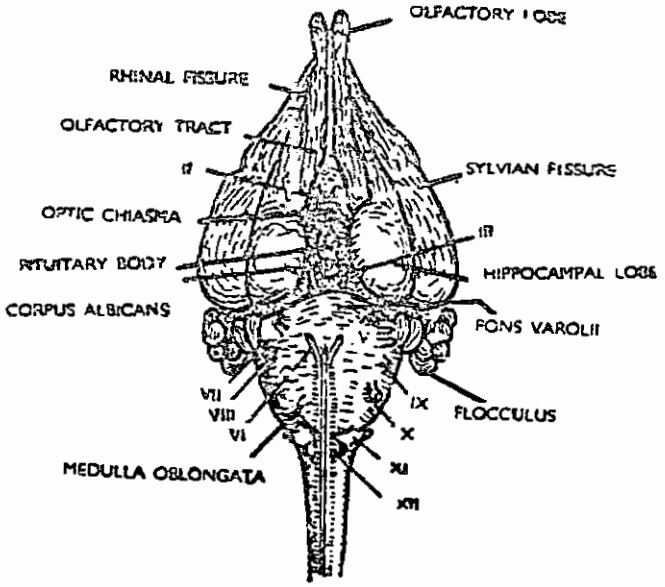


Fig. 303 — Ventral view of brain of rabbit.

into a number of folds, which increases the quantity of superficial grey matter or cortex which it contains. There is also a band of nerve-fibres which join the two sides of the cerebellum to one another passing

ventral to the rest of the hind brain; this is the pons Varolii, peculiar to mammals. The cavity of the 4th ventricle does not extend into the cerebellum, which is solid.

Meningeal Membranes

The brain is surrounded by the vascular **pia mater,** which projects into the lateral ventricles, the 3rd and the 4th ventricles, forming in each a **choroid plexus.** Outside the pia mater is the **arachnoid membrane,** and outside this again is the protective and hard **dura mater.** The cerebro-spinal fluid which fills the canal of the spinal cord and the ventricles of the brain communicates with the space contained by these meningeal membranes through an opening in the roof of the 4th ventricle.

PART EIGHT

EVOLUTION

INTRODUCTION

The term evolution which means change or development is an ever present factor in the world in which we live. It has been wisely stated that nothing is constant in the world except constant change. Evolutionary changes that are characteristic of the world and its inhabitants were first noted by the ancient Greeks, and these shrewd observers drew many accurate conclusions regarding evolution from the evidence that they saw around them. Between the time of the Greeks and the advent of the modern evolutionary theory of Darwin, educated men had mixed feelings about evolution, mainly because it was incompatible with the religion of the time.

The idea of evolution arose a number of times in the history of thought. Aristotle intuitively believed simple organisms might change in time to complex forms. However, the notion that complex animals, such as birds, could arise directly from inorganic objects, like mud, is mentioned no fewer than 40 times in very early scientific writings.

In 1801, Jean Lamarck, realizing that evolution had occurred, offered an explanation for it. Lamarck's notion is called the Theory of Acquired Characteristics. According to this theory, to cite an example, the long neck of giraffes supposedly came about by repeated stretching, and the stretching of the parents' necks was thought to be passed along to the offspring, who themselves improved upon it. This theory explains organic evolution by "use and disuse".

Charles Darwin introduced a genuinely scientific approach when he made a methodical examination of large quantities of data, he collected while travelling on H.M.S. Beagle as an official naturalist. Darwin's background for his work included reading the volumes by Lyell on geology and the essay of Malthus on population (1789); the latter pointed out that the geometrical increase of human beings would lead to disaster in a few hundred years if the rate of population increase continued. Alfred Russel Wallace, another naturalist, also read Malthus' essay. While travelling in Malaya and the East Indies during 7 or 8 years, Wallace suddenly advanced to the same point in his thinking which Darwin had quietly reached about 20 years before. Wallace wrote to Darwin of his deductions about evolution and natural selection, and he is accorded nearly equal status with Darwin for the idea. Because Darwin was able to present a well-documented account, however, accumulated over so many more years,

he has been given the honoured place as originator of the Theory of Natural Selection.

From Darwin's time to the present, the focus of attention among scientists has been upon the method by which evolution takes pace. For many years inheritable particles, genes, were not thought of — the gene concept arose in the twentieth century. Then, with a rediscovery of Mendel's paper in 1900, and advancement in thinking which came about from Darwin's book (1859) on the "Origin of Species by Means of Nautral Selection," the stage was set for a rapid synthesis of all ideas into one coordinated whole.

EVIDENCES OF EVOLUTION

There are various kinds of evidences, that gave rise to the evolutionary trend of thought, such as fossils, comparative anatomy, vestigial organs, comparative embryology, comparative body chemistry, georgraphic distribution, plant and animal breeding, mutations and artificial mutations.

Geological Evidence

We know that geologists were quite well informed about many of the evolutionary changes that had taken place inthe earth, since the beginning of time had convinced many people of this aspect of evolution at least 100 years before the advent of Darwinism Surface features of the earth in the form of mountains, volcanoes, inland seas, stratifications, earthquake faults and many other phenomena, all gave mute evidence of constant change. Fossils were and still are, some of the best and most indisputable evidence of evolution. Most fossils consist of the bodies of plants or animals which have gradually been mineralized by geological processes, or the imprints of such organisms that are preserved in rocks or some in other medium such as asphalt or amber. The majority of fossils are found in stratified rock which is the result of thousands or millions of years of sedementation. Successive stratifications that have been exposed by erosion present a veritable chromological fossil time-table for the trained paleontologist who is often able to read the fossil story almost as accurately as most of as would read a book. New methods of chronology have made possible much more accurate dating of such fossils than was formerly possible. Very old fossils can now be accurately dated by measuring the relative **radioactivity** of various materials embedded in the strata in which the fossil is found. Another method, the **radio-carbon** techniques, is a somewhat similar process that it used to determine fossils that go back

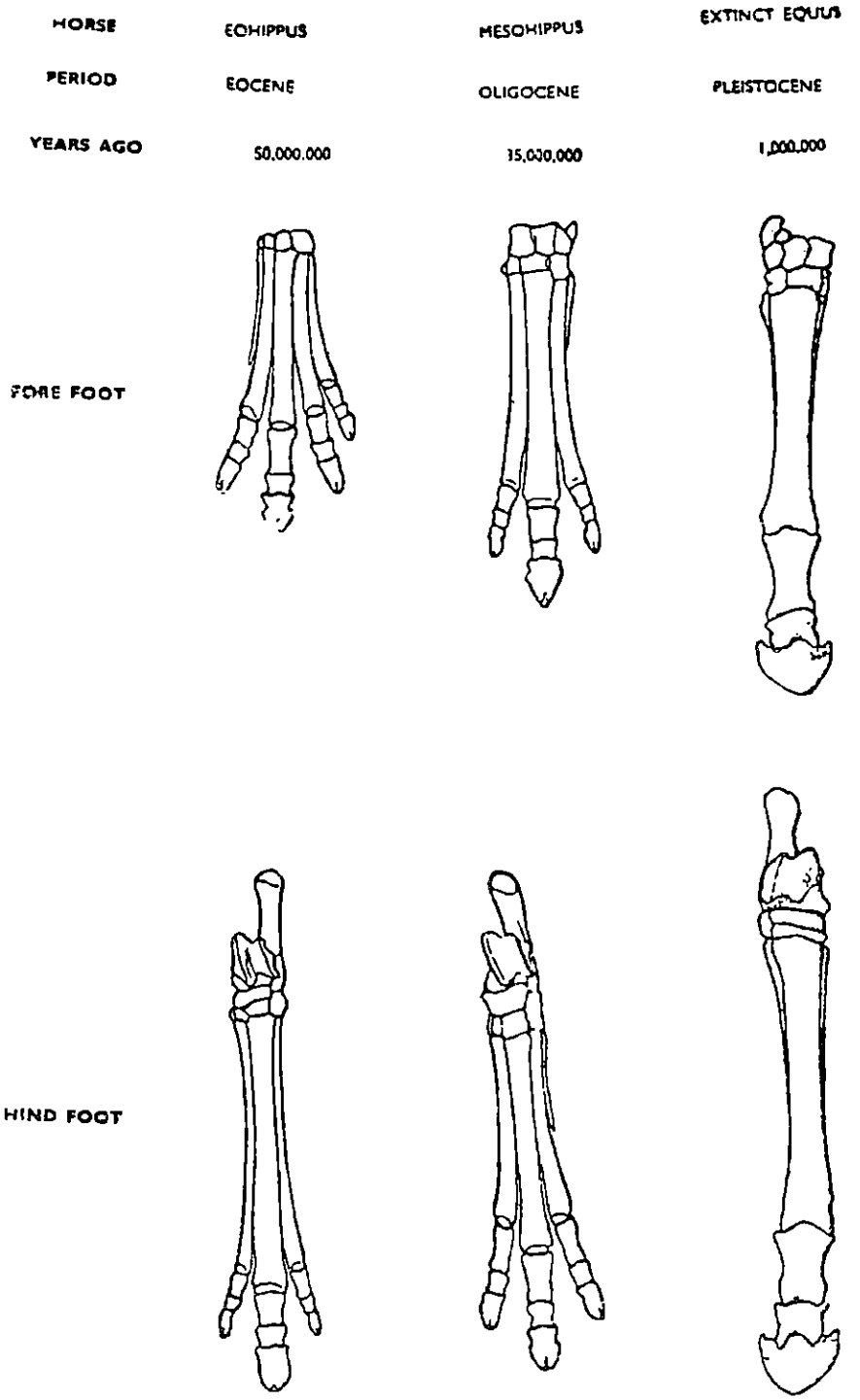


Fig. 304 — fossils of horse family.

no more than 35,000 years. The longer a piece of any plant or animal is exposed to the ravages of time, the less radio-attive carbon it will contain because the radio-active carbon has a known rate of deterioration. These two methods for determining the age of fossils, then, have made an already very accurate science even more precise, and have given evolutionists an evolutionary sequence of organic evolution that cannot be denied.

Comparative Anatomy

Anatomists have long been aware of the many structural similarities that exist between many seemingly dissimilar organisms, and animals and plants have been categorised into taxonomic groups on the basis of these homologies. The fore limb skeletons of Tenrek, Mole, Bat, Rhinoceros, Gazelle and Horse have homologous bones that give concrete evidence of organic evolution.

Vestigial Sturctures.

Many structures that have lost their function are present in numerous animals, especially Vertebrates. Man has many vestigial structures that point to definite changes that have occurred in his body as a result of evolutionary adaptations. The **appendix,** the **ear muscles,** the **nictitating membranes** of the eyes, and the **coccyx** are a few of the many such organs. **Vestigial hind legs** in whales and pythons, **vestigial ankle** and foot bones in horses, and the **vestigial wings** of ostriches and penguins can only be explained from the standpoint of evolution.

Comparative Embryology

A study of embryos quickly reveals basic similarities that could not hve happened by mere chance. For example, all vertebrate embryos develop **gill slits,** that are indicative of their fish-like ancestry. The development of the **heart, arteries** and **kidneys** of vertebrates, likewise, shows a similar fish-like influence that cannot be ignored. The discovery of these phenomena soon gave rise of the **recapitulation theory.** According to this theory, **ontogony** (the development of the individual) **repeats** or **recapitulates phylogeny** (the development of the race). This means that every animal went through all of the historical adult ancestral stages in its embryological development, and that new stages were added at the end of this chronological sequence. The modern version of the recapitulation theory holds that the ancestral stages manifested by the embryos of developing animals are fleeting images of the ancestors rather than of the adult forms

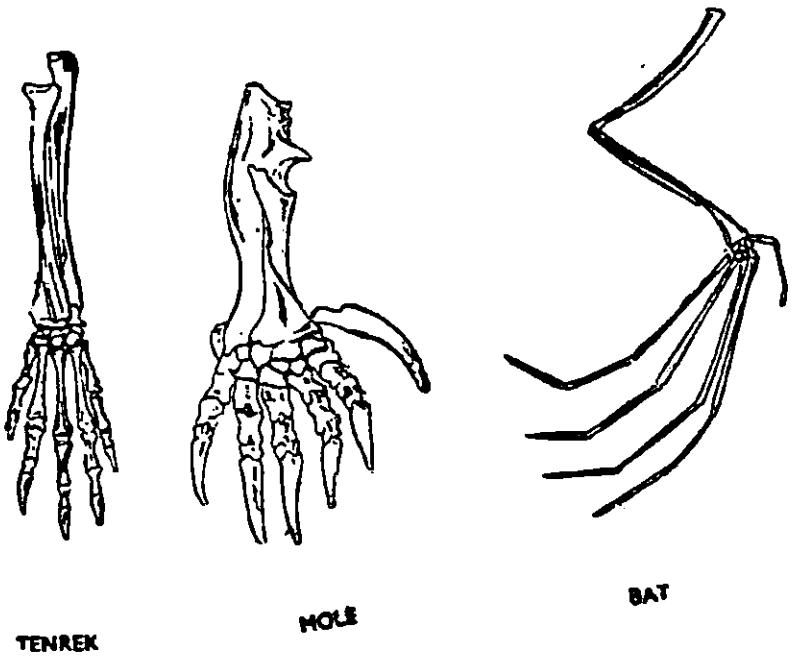


Fig. 305 — Fore-limb skeleton of different mammals.

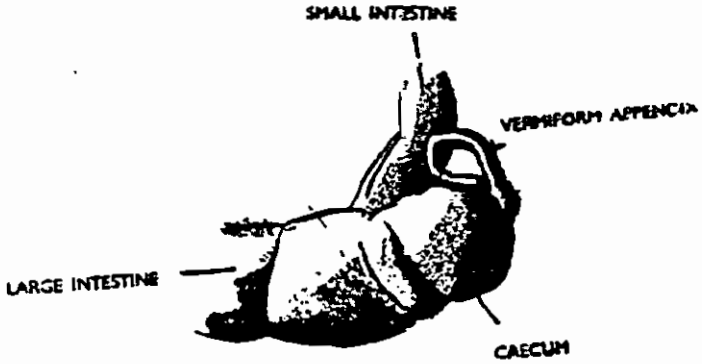


Fig. 306 — Vermiform appendix in Man.

Comparative Body Chemistry

Recent evidence indicates that evolutionary relationships can be determined by certain biochemical factors. One of these is blood compatibility. It has been proved that blood proteins of Mammals are basically similar to each other, and that the blood proteins of man more closely resemble those of the great apes than they do those of any other animals. Hemoglobin crystals are other blood components that prove to be more similar in closely related animals than in more distantly related form. The hormones produced by vertebrate animals are so similar, they can often be used interchangeably, thus giving evidence of a basic endocrine similarity between the veretbrates. This could not have developed by accidental means.

Geographic Distribution

Similarities between continental and adjacent insular species of animals furnished further proof of relationships that changed only because of the isolation that resulted from the separation of such islands from the mainland. These relationships formed part of the evolutionary fuel that generated that modern theory of evolution.

Plant and Animal Breeding

Man's application of artificial selection to domesticated plants and animals has resulted in the various and multiple forms that we have today. This was proof to thoughtful men that a similar type of selection in nature could have brought about somewhat similar changes through the action of natural forces extended over long periods of geological time.

Mutations

The fact that certain organisms suddenly changed their nature for some inexplicable reason and produced freakish forms, that could have been imported in the evolution of new species, gave rise to the **mutation theory** considering that this was due to changed genetic structure, and regarding such phenomenon as a prime factor in evolutionary development.

Artficial Mutations

Also the fact, that X-rays would cause a tremendous increase in genetic muntations, gave rise to further experimentation with radioactive materials and chemicals of various sorts. The results have proved that environmentat factors, such as these, can greatly accelerate the mutation rate, and that somewhat similar factors may have played an important role in genetic variation through the countless ages of the past.

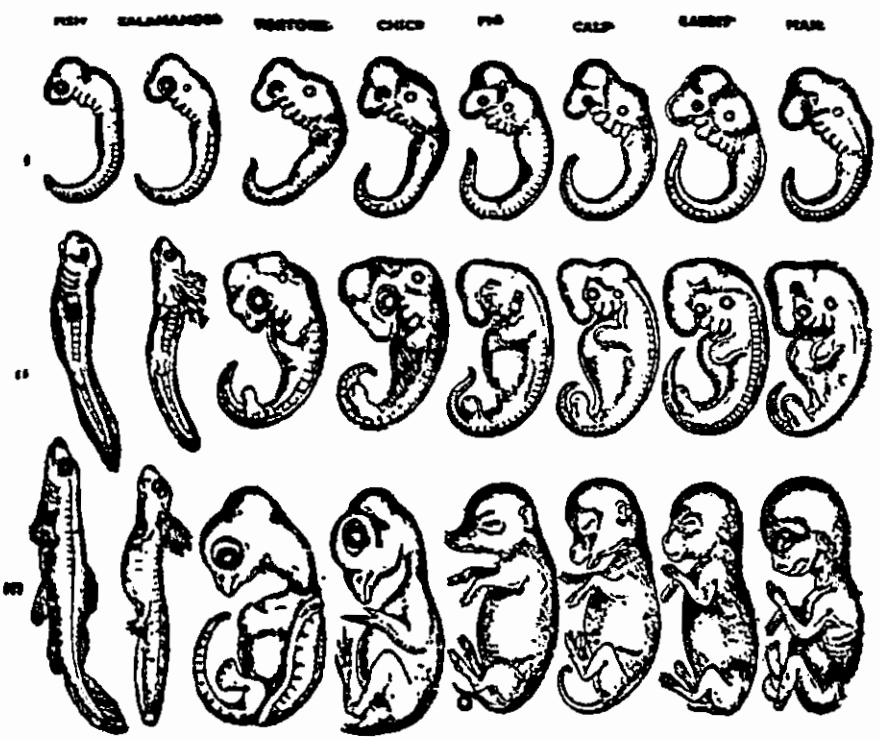


Fig. 307 — Embryological similarities in vertebrate animals.

EVOLUTION OF MAN

In common with the other primates, man's earlier stages were passed in tropical regions, and hence, well-preserved fossils are similarly scarce. Nevertheless, during the last several decades, a number of important findings have been made that contribute to both the numbers and particulars of man's ancestral types. **Only cranial portions, fragments of jaws,** or **isolated teeth,** unfortunately, are characteristically found as **fossils,** although a number of more or less complete skeletons have been encountered in the recent years. Since only fragmentary remains are typically all that provides the fossil basis of man's ancestry, the question may arise as to how anthropologists can be certain as to the identity of their specimens. To answer this inquiry, reference to the chief points of difference between man and the modern apes needs to be made.

Aside from the absence of hair on the body, which characteristically can scarcely be expected to fossilize, distinctive features of mankind are confined to his **upright carriage,** his **lack of prehensibility** in the feet, his **higher skull, flatter face,** lower **orbital ridge,** his **use of fire** and other tools, and especially the shpae of the dental arch. Since the last named trait is both among the most distinctive and most frequently fossilized body part, it is of particular value in establishing hominoid relationships. If the dental arch of any of the great apes is examined, it is found to resemble closely the same structure in monkeys. In all the anthropoids, save man, the molars on each jaws form rows that parallel one another, so that the dental arch resembles a capital letter U. That of man, on the other hand, is found too broadly rounded, more like the outline of a bowl than U-shaped; furthermore, the teeth are more closely set so that the whole arch is proportionately shorter. This trait, then, can serve as an absolute measure of human relationship, for no ape or monkey, past or present, possessed anything resembling its condition. However, it is logical to suppose that this trait, too, evolved gradually; so at the earliest stages, conditions intermediate between the pongid's and mankind's might be anticipated, but thus, far few fossils representing this early level have been encountered. Nevertheless, fossil forms with definitive human dental arches have been found that show either primitive or intermediate stages in the development of other peculiarities of modern man.

Although the story is fragmentary with large gaps in knowledge of particulars, sufficient details now exist to leave room for little doubt as to the fact of man's common origin with lower forms. That he is one with

the rest of the living world is, first of all, indicated by his cells sharing identical processes and enzymes possessed by all thier organisms. His oneness with the metazoa is undeniably indicated by the astral rays the animals alone display during mitosis. The prsence of anotochord, gill slits, and hollow dorsal nerve cord can suggest nothing less than actual relationship with the chordata; his **hairy coat,** though scant, h s **skeletal features, milk glands, diaphragm, heart,** and **brain structure** uniformly attest to his common derivation from a mammalian stock. And finally, his internal and external morphology, including many unusual features shared by all species concerned and no other, as well as functional and chemical trits, too, show that an ape like form was the common **progenitor,** of both modern apes and man. So man is thoroughly and completely an animal in all his physical aspects.

However, we should not think for a moment that man is just an animal, for he is not. He possesses innumerable qualities not found in any other living thing on earth, even over and obove the cultural objects his greatly brain has produced. An appreciation of beauty, his search for truth, and desire for merry and justice are attributes, no mere animal ever displays. Nor does nay other organism strive to make the world better for posterily or show evidence of possessing a belief in things divine or a spiritual life to come, other than man.

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