

**TEXT BOOK
OF
ZOOLOGY**

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TEXT BOOK OF **ZOOLOGY**

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PREFACE TO SEVENTH EDITION

The authors could not find the suitable words which can express their deep gratitude and appreciation to their colleagues concerned with teaching "General Zoology" in the different Egyptian, Arab and other Foreign Universities for their warm and effective reception of any edition of this book.

These overwhelming feelings have stimulated the authors to issue this seventh edition of "Text Book of Zoology",

Perhaps one of the main reasons which has ensured the continuity of this book is that the authors have always done their best in amending it and providing it with any possible new knowledge or information in these areas within the appropriate limits for its adequacy and convenience to its intended goals.

We hope that this edition will be also fortunate enough to be met with the same acceptance and encouragement as its predecessors.

Needless to add that any comments on this book will be highly welcomed.

The Authors

July, 1994

PREFACE TO FIRST EDITION

The long-standing need for a standard text book of Zoology, written in simple English for premedical and science students in Egyptian and other Arab Universities and High Institutions, has urged us to write this book. The book is primarily designed to introduce new approaches and modern trends in studying major topics and fundamentals of Zoology by students interested in Biological Sciences. Thus, in writing its various chapters, the authors have adopted the most recent advancements and theories relevant to the different fields of Zoology covered in the syllabus.

The syllabus currently applied in most Egyptian Universities includes the following topics : Cytology, Histology, Systematic Zoology, Vertebrate Anatomy and Physiology, Embryology and Animal Genetics. Some of these topics, *viz.* Histology and Embryology, are only introductory and usually treated in an abridged form. This principle has been followed in the present book, where only fundamentals of these subjects are given.

Being aware of the great importance of Cytology as an essential basis for applied Biology and Medical Sciences, the authors have given much emphasis on the recent studies by light, phase and electron microscopy of the cell and cell structure.

Other topics are covered in more detail in this book. In the chapter on Systematic Zoology, many representative animal types have been selected, on the basis of the phylogenetic relations of various animal groups, from Protozoa through Arthropoda and among the Chordata. Animal types which the student is already familiar with, from his previous secondary school education, are briefly described here. Other new types are given in more detail, and special emphasis is laid on parasitic Protozoa, helminthic worms and arthropods of medical importance, their biology and host-parasite relationships.

In studying Vertebrate Anatomy and Physiology, some universities use the Egyptian toad, while others prefer the rabbit as the representative vertebrate to be studied. The anatomy and physiology of both examples are des-

cribed in this text. Attention is given to the functional morphology and physiology of the organs and organ systems of these vertebrates, as a prerequisite to the understanding of advanced animal and human physiology.

The section on Genetics deals with Mendel's fundamental laws in Heredity, and the inheritance of several common characters in man and animals. The gene - interaction and sex-linked characters are reviewed in a more comprehensive way. Special emphasis is given to the modern molecular genetics, particularly to the structure and function of genes and the role of nucleic acids in heredity.

Needless to say that all suggestions and criticisms from instructors and students using this book are most welcomed by the authors.

September 1972

The Authors

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INTRODUCTION

Zoology (Greek : Zoo'n = animal; logos = discourse) is the science which deals with the study of animal form, function, mode of development, and transmission of hereditary characters between successive generations. It also includes the mode of interaction of the different existing and pre-existing forms with each other, and with the surrounding environment. The science dealing with similar aspects of plant life is called **Botany** (G. botane = herbs). Both Zoology and Botany constitute the science of **Biology** (G. bios = life).

Zoology includes the following branches :

- Morphology** : is the study of form and structure of animals.
- Histology** : deals with the microscopic structure of animal tissues.
- Cytology** : deals with the fine structure and function of cells.
- Physiology** : deals with the modes of functioning of the body organs.
- Embryology** : is concerned with the development and growth of individuals.
- Genetics** : is the science dealing with the transmission of hereditary characters between successive generations.
- Ecology** : deals with the relation between animals and the surrounding environment.
- Taxonomy** : is concerned with the identification and classification of animals.
- Palaentology** : is the study of animals which were living in ancient geological times, and are now fossils.

Besides these, there is a number of other branches, such as zoogeography, parasitology, cytochemistry, histochemistry, protozoology, etc.

Nature and manifestations of life

What is life ? All definitions given for life are still far from being satisfactory. However, it can be generally said that life is a phenomenon character-

rized by certain features, such as the ability for nutrition, respiration, locomotion, etc., and when one or more of these properties are lost, the organism is said to be no longer living, or dead.

Such characteristics or principal **manifestations of life** are summarized as follows :

1. **Protoplasm**

This is the material of which all living beings are built-up. It furnishes the physical basis of life since all vital activities, such as digestion, respiration, secretion, etc. take place in it. In brief, no life can exist without protoplasm and no protoplasm can exist without life.

2. **Organization**

The bodies of all living organisms are composed of certain structural units, the **cells**, which are grouped to form body **tissues**, and these form the body **organs**, which in turn comprise the different **organ systems** of the individual.

3. **Metabolism**

This includes the different biological activities which take place in the protoplasm. These are of two main categories :

a) **Anabolism** : is the building up of new living material from the food stuffs, in the presence of energy. Anabolism starts with the intake of food or **ingestion**. This food cannot be utilized by the body as such, but it must be first transformed into soluble material which can diffuse through cell membranes, so that the animal can make use of it.

The change of complex food materials into simple soluble ones within the body is known as **digestion**. It takes place mainly through the help of certain organic catalysts known as digestive enzymes. Digestion is followed by **absorption** which means the diffusion of the soluble food materials into the cells. Inside the body cells, these substances undergo a process known as **assimilation**, i.e. they are transformed into materials similar to those of the living cells in which they are deposited. Thus, digested substances absorbed by the liver cells, for example, are transformed into material similar

to that found originally in the liver cells, and those absorbed by the kidney cells are converted into material similar to that originally existing in the kidney cells, and so on. Assimilation takes place by the help of certain enzymes known as synthesizing enzymes.

Some of the food taken by the animal cannot be digested. Such substances are usually harmful to the body, which thus gets rid of them by expelling them to the exterior as faeces. This process is known as **egestion**.

b) **Katabolism** : includes all the processes that break down the assimilated food materials for the liberation of energy, which is necessary for the body to carry out its vital activities. These processes take place in the presence of oxygen and are collectively known as **respiration**. Energy is liberated in the form of heat as a result of this process which is catalyzed by a large number of respiratory enzymes and coenzymes found in the animal cells.

There is a continuous breakdown of the living material in the body. And since many of the cellular substances contain nitrogen, some nitrogenous products, such as urea, are produced as a result of their breakdown. These substances are poisonous to the body, which therefore gets rid of them by a process known as **nitrogenous excretion**. Elimination of carbon dioxide and water resulting from respiration is sometimes referred to as **carbonaceous excretion**.

It should be emphasized, however, that there is a difference between egestion and excretion. Egestion means getting rid of certain substances which were not digested and were not utilized by the body in the formation of new cellular material. But excretion means the elimination of certain waste products which were formed as a result of the breaking down of certain cellular material.

4. Growth

Means the addition of new substances to the living material of the body. If the rate of katabolism equals that of anabolism, no growth takes place. But if anabolism is greater than katabolism, new materials are added to the body.

Growth also takes place in non-living material, e.g. the formation of crystals. But there is a marked difference between growth in a living matter

and that in the non-living material. In the former case, growth takes place by the lodging or interposition of new material within that already existing in the organism, a process known as **intussusception**. On the other hand, growth in non-living material is known as **accretion**, which means the accumulation of new material around the pre-existing material.

5. Irritability (Sensitivity)

It is the capacity of the living organism to react to the changes which take place in the surrounding medium. Such changes act as **stimuli** which result in certain **response** of the organism in a suitable manner. Stimuli are either external or internal. External stimuli may be physical, such as heat, cold, pressure; or chemical, as acidity, alkalinity or salinity. Internal stimuli include hunger, anger, fear, etc.

Irritability takes place mainly by certain specialized parts of the body, namely the nervous and sensory organs, such as the eyes, nose and ear. The response of the organism to a stimulus is not permanent and may disappear when the stimulus is stopped. This is unlike the response of non-living material to different stimuli, in which case the material may be permanently altered in shape, size or structure, as in case of bending a rod of iron by heating.

6. Reproduction

This is the ability of living organisms to produce new individuals similar to the original parents, thus keeping the race from extinction. Reproduction takes place by different methods which may be either asexual or sexual :

(a) **Asexual Reproduction** : Takes place in lower animals and plants in one of the following ways.

(i) **Binary Fission**. In which the individual divides into two halves usually similar to each other. These separate from each other and each half grows into a new individual similar to the parent.

(ii) **Budding**. In this case, a small protrusion, known as the **bud**, develops on the individual and grows gradually into a new individual. This either separates from the original parent to lead an independent life, or remains attached to the original individual. The latter case results in the production of colonies of many individuals as those familiar in sponges and coelenterates.

(iii) **Sporulation.** This process is well illustrated in *Plasmodium*. In this case, the nucleus divides repeatedly, and each daughter nucleus becomes surrounded by a part of the cytoplasm. The resulting cells are called **spores**. These spores separate from each other and each grows into a new individual.

(iv) **Regeneration.** Certain animals have the ability to replace or regenerate lost parts of their body. For example, if an earthworm is cut into two or more pieces, each of them can grow into a complete worm. Starfishes, crabs and some other animals can regenerate lost arms or other parts of the body.

b) **Sexual Reproduction :** This mode of reproduction is frequent in a large variety of living organisms. The process involves certain specialized parts of the body known as the sexual organs or **gonads**; those found in the male individuals are called **testes**, and those found in females are the **ovaries**. Testes and ovaries produce germ cells known as **spermatozoa** and **ova** respectively.

During reproduction, a spermatozoon fuses with an ovum, and a fertilized egg or **zygote** is produced. This soon undergoes gradual development resulting in the formation of a new individual.

There are certain animals in which both male and female organs are found in one individual. These are known as hermaphrodite or **monoecious** (G. monos = one; oecium = house) animals. On the other hand, individuals in which sexes are separate are known as **dioecious** (di = two) animals.

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CHAPTER I

CYTOLOGY

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CYTOLOGY

INTRODUCTION

Cytology is a specialized branch of biology which deals with the study of cells (cyton = cell; logos = science). Cells are now regarded as the units of structure and function of living organisms. The discovery of the cell is closely related to the compound microscope which was invented by Leeuwenhoek in 1591. In 1665, Robert Hooke noticed, during his examination of a piece of cork with the compound microscope, that it consisted of small compartments very much similar to the cells of the honey-bee comb. Hence, Hooke applied the name **cell** to identify each of these compartments. Since the time of Hooke, microscopic techniques and methods of study of cells have been actively progressing and providing a profound knowledge of the cellular organization, not only as it appears in the non-living cells, but also as it is seen in the living condition. Of these methods, tissue culture has been so well developed that a culture of living fibroblasts could be made to survive for more than 30 years. Also, the device of the micromanipulator enabled the dissection or injection of cells and their examination under high magnifications. Besides, there are the X-ray diffraction microscope, phase contrast microscope and ultraviolet fluorescent microscope which are of great value in the study of cells.

In addition, there are now various methods of staining and visualization of the different parts of the cells. However, the most important invention, which caused a great revolution in the field of cytology, is the **electron microscope**. This apparatus has brought into vision many of the detailed cellular structures which were never known before. The electron microscope differs from the normal light microscope in the fact that the electron microscope has no lenses and uses a beam of electrons as a source of illumination, instead of light which is used in the normal light microscope. The

electrons pass through the specimen, and are then received upon a highly sensitive photographic plate, where they produce an image of the specimen. Electron microscopes produce a degree of magnification which is 10,000 - 200,000 times the original size of the specimen.

In spite of the fact that cytology is a newly born branch of biology, yet it is now a very important element in most biological studies, as it is nowadays believed that the cells are concerned with most of the vital processes of the body.

Cytology is strongly related to Genetics that deals mainly with the hereditary material found in the chromosomes which are important constituents of the cell. These branches are therefore usually referred to by the common name **Cytogenetics**.

Cytology is also closely allied to taxonomy. Modern taxonomy is mainly based on differences in number and form of the chromosomes.

Moreover, Cytology is strongly related to Embryology and Physiology. Besides, there is a close relation between cytology on one hand and pathology and medicine on the other hand. Many diseases are primarily attributed to certain disturbances in cellular and tissue activities. One of the well known diseases, namely cancer, is essentially nothing but uncontrolled growth of the cells. All these and other similar findings led Goddard in 1958 to say : "When we truly understand the cells, we will understand life itself".

CELL THEORY

Following the discovery of the cell by Hooke in 1665, his work was repeated by several authors on different plant tissues, and in 1838, Schleiden declared that all plant tissues were composed of cells. Schleiden is thus regarded as the founder of the **cell theory** though he did not use this term in his work. Later, this term was applied for the first time by Schwann in 1839, who confirmed the findings of Schleiden and extended them to the animal tissues. According to this theory, *"The cells are organisms, and animals as well as plants are aggregates of these organisms arranged in accordance with definite laws"*.

During that period, most of the studies carried out on the cells were mainly concerned with the cell walls, but later, at the beginning of the 19th century, Robert Brown in 1831 noticed the presence of a spherical body in the cell which he called the **nucleus**. Purkinje in 1840 and Von Mohl in 1846 observed a slimy substance enclosed by the cell wall in plant and animal cells respectively. This substance was first given different names, but later, it became known as the **protoplasm** (primary or essential substance). Since that time, it was realized that the protoplasm is the principal component of the cell.

The protoplasm has been a fertile field of study for numerous investigators who discovered several cytoplasmic and nuclear structures : Altmann in 1890 reported the presence of minute organelles in the cytoplasm, the **mitochondria**; Waldeyer in 1890 discovered the **chromosomes** in the nucleus; Golgi in 1898 described a net-like structure in the cytoplasm which became later identified as the **Golgi apparatus**, etc.

THE PROTOPLASM

The protoplasm is the living substance of which all organisms, whether plants or animals, are composed. The structure of the protoplasm as well as its physical, chemical and biological properties show some differences from one organism to the other, as they also differ in the different parts of the same organism. The protoplasm is usually a greyish, translucent and jelly-like substance.

Chemical structure of the protoplasm

The protoplasm is a complex substance. Its exact chemical constitution has not been exactly determined. This is due to the fact that this living substance must be killed first and then analysed. Such procedures bring about certain changes in the chemical composition of the protoplasm. Nevertheless, the protoplasm is known to be formed of several chemical substances which may be classified into three main categories :

1 — Organic substances

2 — Inorganic substances

3 — Water

1 — Organic substances

Organic substances are those essentially containing carbon in addition to one or more other elements. These substances constitute about 9 - 10 % of the protoplasm. The most common organic components of the protoplasm are the following :

a) **Carbohydrates** : These substances consist mainly of carbon, hydrogen and oxygen, with the latter two being in the ratio of 2 : 1. They include a large variety of substances such as sugars, starch, cellulose, etc. The simplest forms of carbohydrates are the **monosaccharides** (e.g. glucose). Two molecules of monosaccharides form a **disaccharide** such as sucrose, and more than two molecules form a **polysaccharide**, as glycogen, starch and cellulose. Carbohydrates serve mainly to supply the body with energy.

b) **Lipids (fats)** : Lipids are organic substances containing carbon, hydrogen and oxygen, with the latter two existing in a ratio different from that found in the carbohydrates. Examples of lipids are olive oil, waxes, fish liver oil, etc. Lipids are formed of simpler substances, namely **fatty acids** and **glycerol**. They are also utilized by the body to give energy.

c) **Proteins** : These include substances formed of carbon, hydrogen, oxygen and nitrogen besides other elements such as sulfur, phosphorus, iodine, magnesium, manganese, iron, etc. Proteins are composed of simpler substances known as **amino acids**.

Proteins are commonly known as the tissue-builders since they are used in building up new tissues in the body or in repairing the tissues which are torn out during the daily body activities. Besides, they enter in the formation of various parts of the body, such as muscles, hair, bone, blood, etc.

d) **Nucleic acids** : These are complex organic substances formed of simpler units known as **nucleotides**. Each nucleotide is made up of a sugar molecule to which a molecule of phosphoric acid is attached on one side and a molecule of certain compounds known as the nitrogenous bases is connected to the other side. Nucleic acids are two main varieties, namely **deoxyribonucleic acid** (DNA) containing the sugar known as deoxyribose, and **ribonucleic acid** (RNA) which contains the sugar ribose.

Nucleic acids play a principal role in the process of protein synthesis

in the cells and in the determination and transmission of the hereditary characters.

2 — Inorganic substances

These substances exist in the protoplasm in the form of free ions or salts, or in combination with organic substances. Inorganic materials are found in excess in certain parts of the body, such as in the skeleton where they exist in the form of calcium carbonate and calcium phosphate. Other salts, such as sodium chloride and potassium chloride, are very important for the proper functioning of the animal cells, particularly in cell permeability, muscle contraction, heart beating, etc.

3 — Water

Water constitutes the largest proportion of the protoplasm. It forms 10 - 90 % of the body weight. Water is an essential constituent of the body fluids, such as blood and lymph. It acts as a solvent for many inorganic and some organic substances in the body. In general, water plays an essential role in different functional activities such as digestion, secretion, excretion, etc.

The amount of water differs in different tissues of the body. It also varies in the same tissues at different ages. It is markedly abundant in the embryonic stages, and undergoes a gradual decrease with ageing.

Physical properties of the protoplasm

Chemical substances are classified into two main categories. One type includes the substances which dissolve in water, pass through semipermeable membranes, and on evaporation, give crystals of definite shapes. Such substances, as sugars, sodium chloride, etc., are called **crystalloids**. The other category, exemplified by starch, gelatin and egg albumen, are known as **colloids**. The latter substances form suspensions in water, do not pass through semipermeable membranes, and yield shapeless masses on evaporation.

The protoplasm is a typical colloidal substance of the type known as **emulsoid**. Emulsoids are those colloids in which both the dispersed phase and the dispersion or continuous medium are liquids, as in case of milk in

which particles of fat are suspended in water. The other type of colloids are the **suspensoids** in which the dispersed phase is a solid material and the dispersion medium is liquid. Indian ink is an example of suspensoids.

The protoplasm, as an emulsoid, consists of fine protein particles suspended in water, which also contains many other dissolved substances including certain organic compounds. In the living condition, the protoplasm is sometimes seen to exhibit a streaming movement within the cell. In many cases, this movement takes place in a wriggling manner described as the **Brownian movement**.

Emulsoids, in general, have a certain property known as **reversible solation and gelation**. This phenomenon is illustrated by the following example : gelatin in water forms a colloidal solution, which at a certain temperature exists in a semisolid form, with the gelatin representing the continuous phase and water forming the dispersed phase. If temperature is raised, the mixture becomes fluid or liquifies. The first case (semisolid phase) is known as the **gel phase**, and the second (liquid phase) is known as the **sol phase**. If the mixture is cooled, it reverts to the semisolid condition again. These reversible changes ($\text{gel} \rightleftharpoons \text{sol}$) are produced under the effect of several factors, including temperature, pH of the medium, pressure, etc. Solation and gelation are very important for the various cellular activities. This is clearly marked during cell division in which there are continuous changes in the viscosity of the protoplasm. Also, in unicellular organisms, the reversible solation and gelation is sometimes responsible for locomotion, as in *Amoeba*.

CELL STRUCTURE

Cells differ markedly in form and structure according to their location and functional activities. Some of them have variable forms, such as the white blood cells which are known to exhibit amoeboid movement. Other cells, as the egg cells, sperm cells and nerve cells, have fixed forms.

Also cells show marked variation in size. Those of human beings range in size from $200\mu^3$ to $15,000\mu^3$ ($1\mu = 0.001\text{ mm}$). In birds, there are cells, as the egg cells, which can be seen with the naked eye. The egg cell of the ostrich reaches 30 cm in diameter. Furthermore, there are cells, such as the nerve cells of some large animals, which are several feet in length.

Cell contents

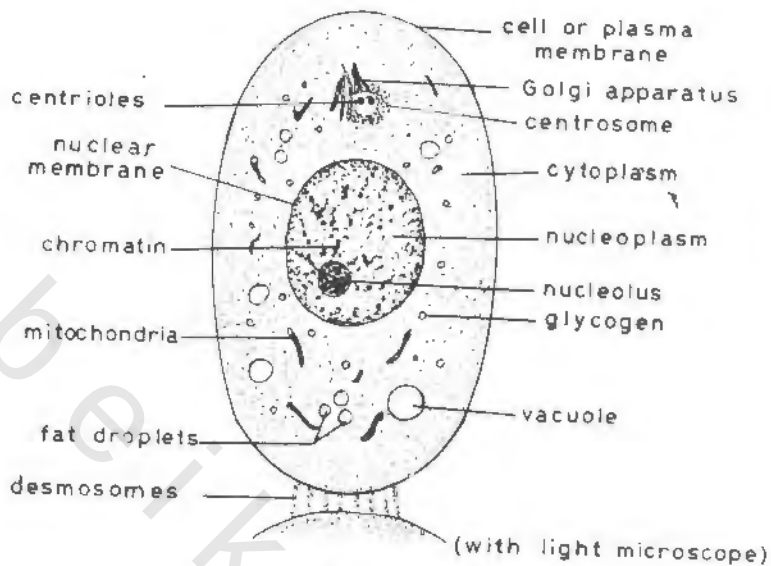
The protoplasmic mass of the cell is differentiated into two main portions; that of the nucleus is called the **nucleoplasm**, and the other one surrounding the nucleus is identified as the **cytoplasm**. The nucleus is bounded by a thin membrane, the **nuclear membrane**, and the whole cell is limited externally by another membrane, the **plasmalemma** or **cell membrane**. These membranes do not only serve to protect the internal parts of the cell, but also function as means of interaction and regulation of exchange of materials between the nucleus and cytoplasm on one hand, and between the whole cell and the surrounding medium on the other hand.

The cytoplasmic region contains a variety of living structures known as the **cytoplasmic organelles**, as well as non-living substances commonly identified as the **metaplasm** or **deutoplasm**. To the first category belong such structures as the **mitochondria**, **Golgi apparatus** and **plastids**. The second category includes **storage materials** such as glycogen, starch, fat granules, oil droplets, as well as other substances such as pigments, secretory materials and excretory products.

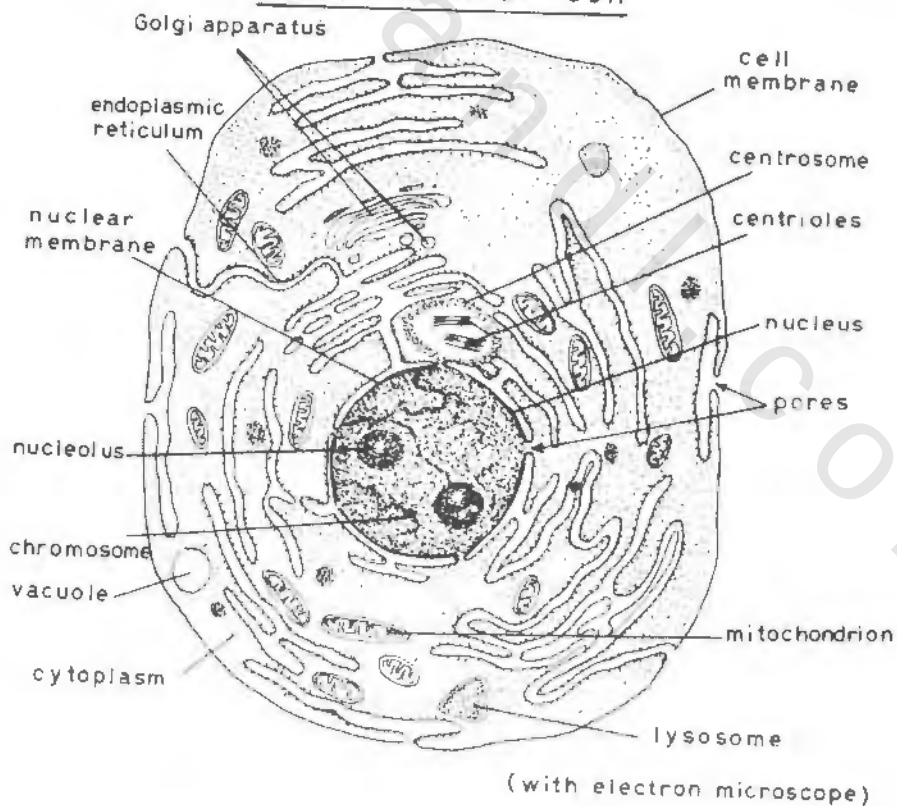


Animal cell

C. cell membrane; GER. granular endoplasmic reticulum; GO. Golgi apparatus; M. mitochondrion; N. nucleus; R. ribosomes.



Typical animal cell



THE CELL MEMBRANE

Structure

Experimental studies carried out on different varieties of cells showed that each cell is bounded by a very thin membrane formed of lipids and proteins. This information was obtained from the observation that lipid substances and many substances soluble in lipids diffuse easily into the cell or outside the cell. This was a clear indication that the cell membrane contains a layer of a lipid material. Accordingly, the more such substances are soluble in lipids or lipid solvents, the more easily they penetrate into the cells. For example, urea and ether, which are more soluble in lipids, penetrate more rapidly than glycerol which shows moderate solubility. Further chemical investigations indicated the existence of a proteinic fraction in the cell membrane.

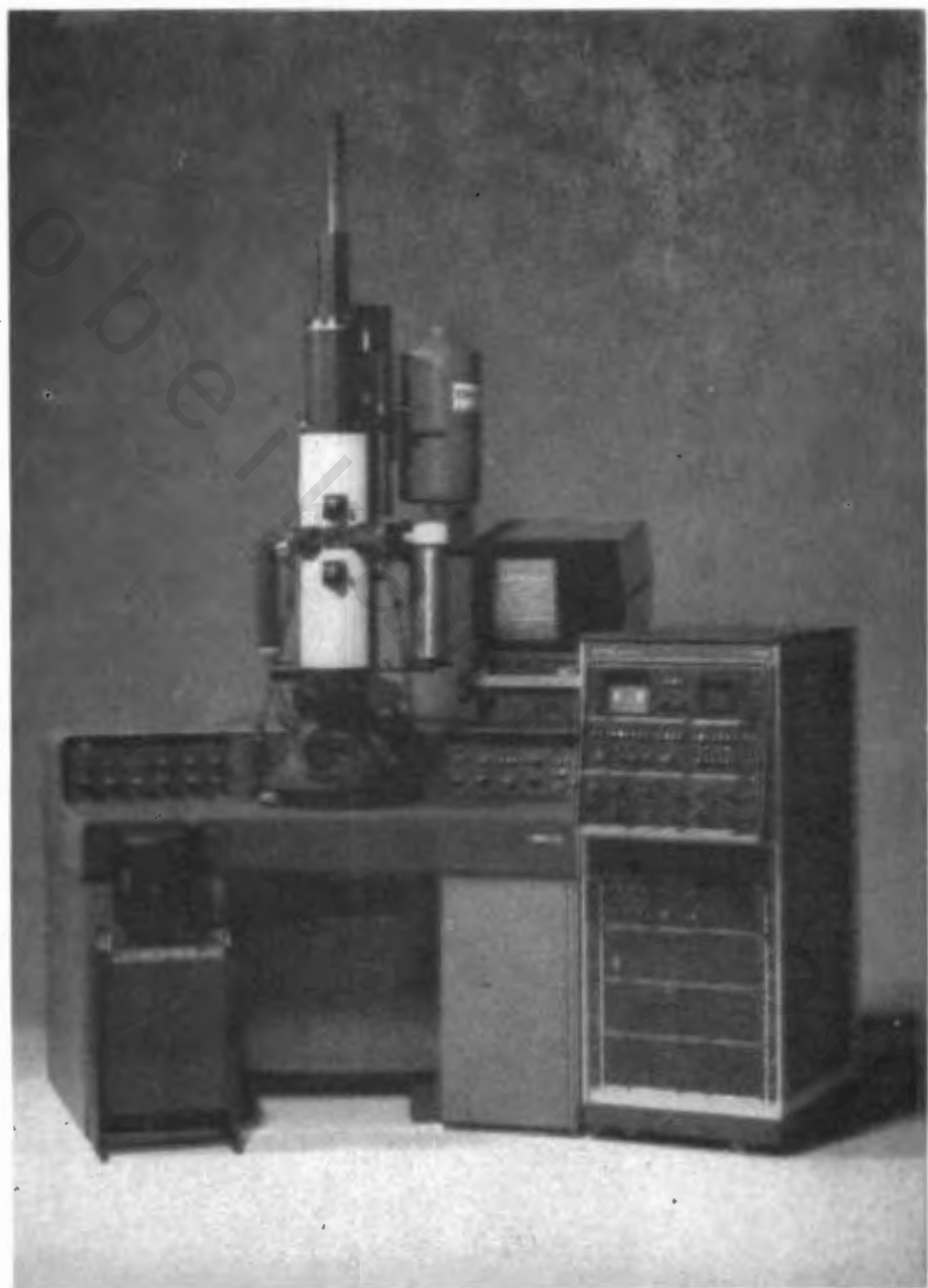
In certain cases, as in some epithelial cells, the cell membranes of adjacent cells are connected together by **desmosomes**. These are thickened fibrillar projections of the membranes of neighbouring cells.

Molecular organization

Lipids and proteins are disposed in the cell membrane according to a definite pattern. Lipids are found in the form of a double row of molecules sandwiched between two layers of protein molecules. Danielli in 1954 described the presence of minute pores in the cell membrane. The existence of these pores was later confirmed and clearly demonstrated by the electron microscope. Recently, it has been found that these pores are electrically charged; some of them carry positive charges while others have negative charges. This electrical property controls to a large extent the passage of different ions in and out of the cell.

Functions

The cell membrane acts primarily to control the passage of dissolved substances between the cell and the surrounding medium. This property



The Electron microscope

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is collectively known as **permeability** which can be defined as "the rate of movement of a substance through a permeable layer under a certain driving force". Permeability is of fundamental importance as it is the mechanism which regulates the entrance of certain substances that are essential for the synthesis of the living material. The cell membrane also regulates the outflow of excretory and secretory products as well as of excess water which is to be eliminated outside the cell.

Cellular permeability depends on many factors such as the physiological state of the cell, tonicity of the surrounding medium, temperature, etc. (e.g. temperature increases the rate of cell permeability).

Cellular permeability and cellular metabolism

There is a strong relation between permeability and the metabolic processes of the cell. The passage of a material is much facilitated when it is needed to be utilized in cellular metabolism. For example, an amino acid passes more easily when it is needed to be incorporated into the cellular proteins. Also, in case of sugars, molecules of glucose diffuse with great ease, while other sugars diffuse with difficulty. This is due to the fact that glucose is strongly and continuously needed for the general metabolic activities of the cell and is mostly utilized as soon as it enters the cell. Also, oxygen, which is required in large amounts by the cells, has a great ability of diffusion.

On the other hand, permeability of the cell membrane plays an important role in the control of the outflow of the products of the various metabolic activities of the cell. The first products of glucose metabolism in contracting muscle cells, *viz.* glycerol derivatives which are valuable to the cells, are not allowed to escape easily. During muscle work, lactic acid is produced. This would be toxic if left to accumulate inside the cells. Thus the cell membrane allows such a substance to escape freely to the surrounding blood vessels. This phenomenon is also well illustrated by certain substances, such as menthol and bromobenzene, which are eliminated from the cells to the neighbouring blood vessels, then filtered off by the glomeruli of the kidney, and are never reabsorbed by the cells of the kidney tubules, i.e. they become totally eliminated outside the body.

Lysis of the cell membrane

The cell membrane is easily affected by certain agents which may cause

its degeneration and destruction. Examples of such agents are the antibodies, heavy metals, X-rays and lipid solvents.

THE ENDOPLASMIC RETICULUM AND THE RIBOSOMES

In 1945, Porter noticed, during his studies with the phase contrast microscope, that the ground substance of the cell, or **hyaloplasm**, contains a system of branched cavities surrounded by delicate membranes to which he gave the name **endoplasmic reticulum**. The presence of this structure was later verified by the electron microscope, and was found to exist in almost all kinds of nucleated animal and plant cells.

Structure and occurrence

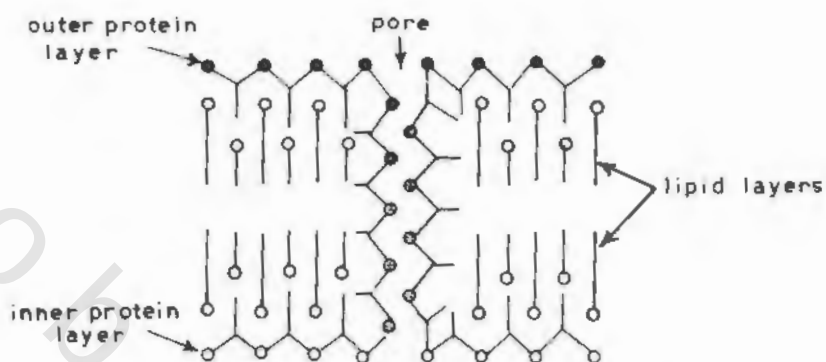
The endoplasmic reticulum shows some variations in the different types of cells, though it always consists of a system of membrane-enclosed spaces which are connected together so as to form a continuous structure in the cell. These spaces, also known as the **cisternae**, appear tubular or irregular. Owing to the great thinness of the sections studied with the electron microscope, the cisternae usually appear as separate or independent rounded, oval or elongate spaces. These apparently separate structures are actually parts of the continuous endoplasmic reticulum of the cell and their shape varies according to the plane of sectioning.

It is assumed that the membranes of the endoplasmic reticulum, by enclosing internal spaces, separate in the cytoplasm an inner part or inner phase from an outer part represented by the continuous cytoplasm or the cytoplasmic matrix.

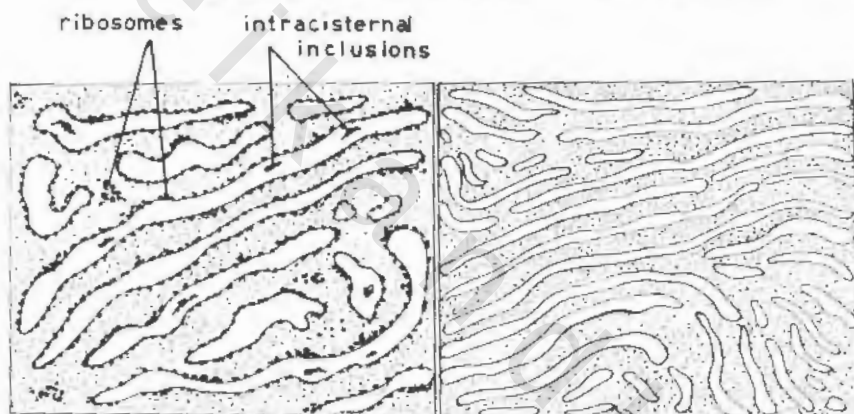
There are two types of endoplasmic reticulum :

1 — Granular or rough endoplasmic reticulum

This type is characterized by the presence of numerous minute particles on its outer surfaces. These particles are rich in ribonucleic acid (RNA) and proteins; hence they are known as **ribonucleoprotein particles (RNP)** or **ribosomes**. The presence of these ribosomes is not only confined to the



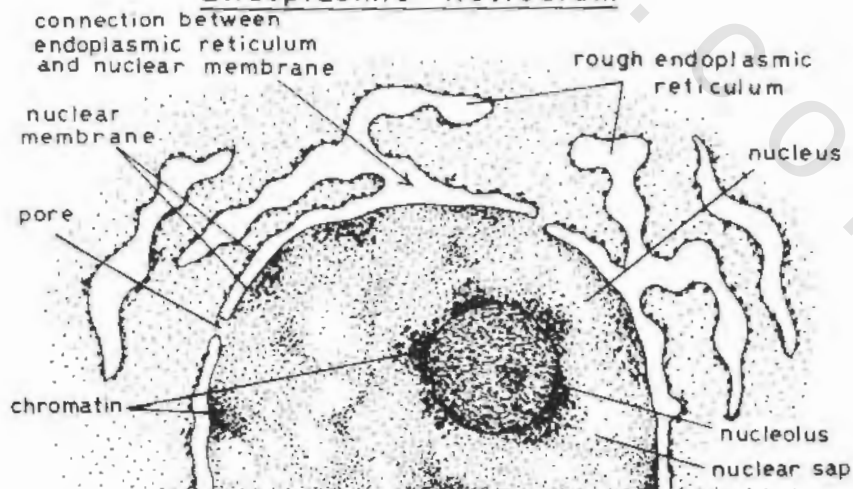
Molecular structure of cell membrane



Rough

Smooth

Endoplasmic Reticulum



membranes of the endoplasmic reticulum, but there are aggregates or clusters of such particles inbetween the membranous structures of the endoplasmic reticulum.

Ribosomes represent the sites of protein synthesis in the cell; hence they are markedly abundant in the actively protein-synthesizing cells, such as those of the liver and pancreas.

The rough endoplasmic reticulum is mainly concentrated in the basal region of the secretory cells. The cavities of this reticulum usually contain certain accumulations of material known as the **intracisternal inclusions**.

2 — Agranular or smooth endoplasmic reticulum

This type is devoid of ribosomes. Its existence is limited to a small variety of cells, e.g. the pigment epithelial cells of the retina of the eye and the striated muscle cells. In such cells, these smooth elements appear to play a role in nerve conduction.

Relation between endoplasmic reticulum, nuclear envelope and cell membrane

The endoplasmic reticulum is closely associated with the nuclear envelope. This envelope consists of two membranes, the outer one being continuous with the neighbouring elements of the endoplasmic reticulum. Porter in 1960 postulated that the nuclear envelope is the essential part of the endoplasmic reticulum and that the cytoplasmic parts of the reticulum are derivatives or extensions of that envelope. This explains why the endoplasmic reticulum is present in young nucleated red blood cells and is lacking in mature red blood cells which have lost their nuclei.

In most cells, the endoplasmic reticulum is also continuous with the cell membrane; hence it actually extends from the nuclear envelope to the cell membrane. In such cells, the channels of the endoplasmic reticulum open into the intercellular spaces. In plant cells, in particular, the endoplasmic reticulum of one cell seems to connect with that of adjacent cells through what are known as **plasmodesmata**.

Chemical structure

The membranous parts of the endoplasmic reticulum consist of lipids

and proteins combined together forming a lipoprotein complex.

Biological role

The endoplasmic reticulum, particularly the rough type, plays a major role in protein synthesis and cell secretion, mainly by incorporating various amino acids into proteins. This is indicated by the presence of zymogen granules (raw material of enzymes) within the cavities of the endoplasmic reticulum. Also, in the hen's oviduct, the albumen substance was found concentrated within the endoplasmic reticulum. Moreover, Wissig in 1960 noticed that the cavities of the endoplasmic reticulum of the thyroid gland cells were filled with the colloidal secretion of the cells.

Another probable function of the endoplasmic reticulum is that its channels serve as routes for transportation of materials between the different parts of the cytoplasm, from the nucleus to the exterior of the cell, or from the exterior of the cell to the cytoplasm and even directly to the nucleus.

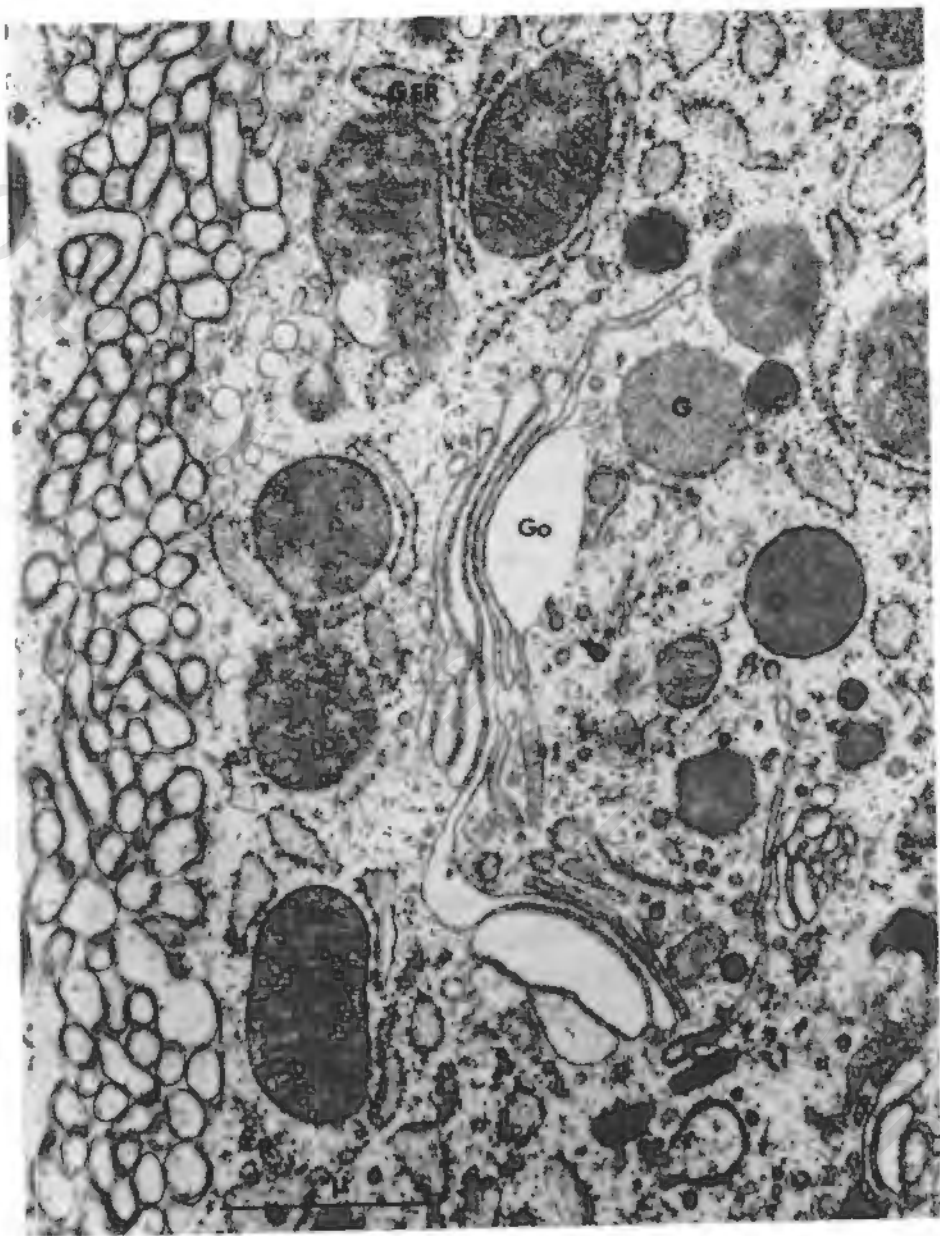
THE GOLGI APPARATUS

This cellular organoid was described for the first time by Camillo Golgi in 1898 in the nerve cells of cats and some birds. Golgi demonstrated this apparatus as a network on which silver nitrate and osmium tetroxide are heavily precipitated. This structure was later proved to exist in a large variety of animal cells, whence it became known as the **Golgi network** or **Golgi apparatus**. At present, there are some indications of the existence of similar Golgi bodies in a variety of plant cells also.

Occurrence

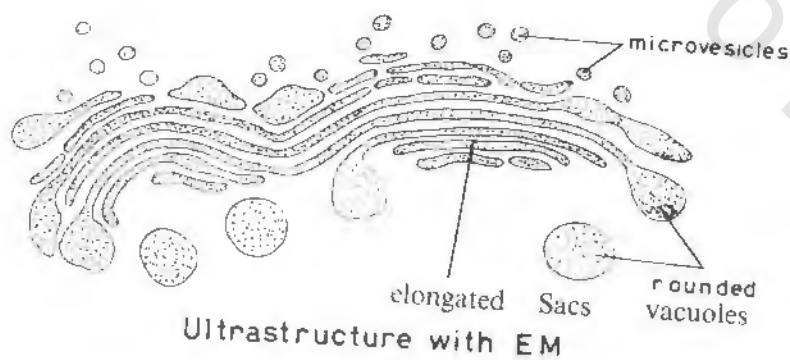
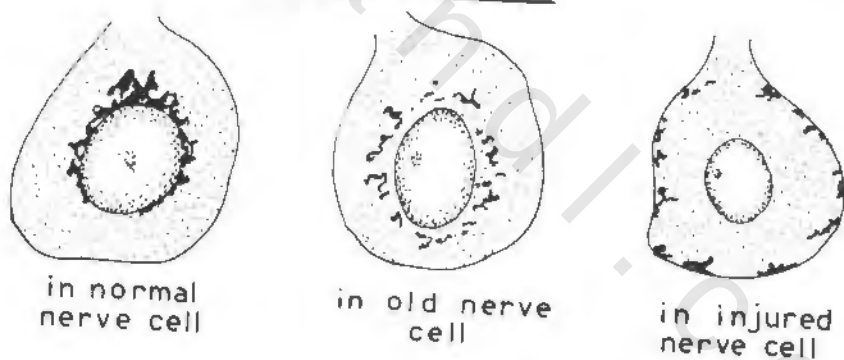
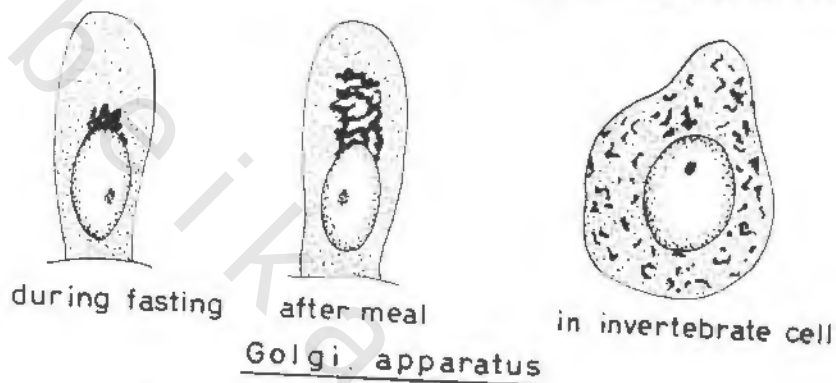
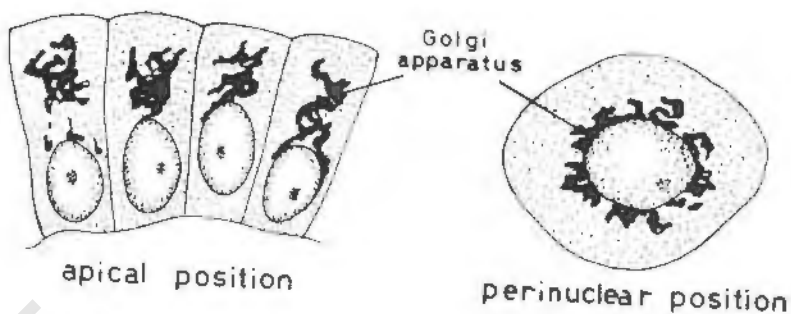
The Golgi apparatus exists in different types of vertebrate animal cells, with the exception of the germ cells, in the form of a network. But in the vertebrate germ cells, in all invertebrate cells and in plant cells the apparatus exists in the form of curved elements known as the **dictyosomes**.

The position of Golgi apparatus is almost characteristic for each cell



Golgi apparatus

G, Golgi products; GER, granular endoplasmic reticulum; GO, Golgi apparatus; M, mitochondrion; R, ribosomes.



type. For example, in some secretory cells, such as those of the exocrine pancreatic cells, it is always located within the secretory pole of the cell, between the nucleus and the free border of the cell. In nerve cells, the Golgi apparatus has a perinuclear location.

The form of Golgi apparatus varies also according to the physiological state of the animal. Thus, in the intestinal epithelial cells of hungry animals, the Golgi apparatus appears as a small dense body lying in a narrow cytoplasmic area. After feeding, the Golgi structure enlarges gradually and extends over a wide cytoplasmic area. Besides, numerous granular particles, manufactured by the Golgi apparatus, are seen in the Golgi region in the latter cells.

The Golgi apparatus also undergoes considerable alterations in form accompanying development and ageing, especially in the nerve cells. In nerve cells of young animals, the Golgi apparatus forms a small net-like structure lying in the axon pole of the cell. This structure grows gradually during development until it acquires a perinuclear position. Later, in ageing animals, this structure undergoes progressive fragmentation until it transforms into discrete granules scattered in the cytoplasm.

Ultrastructure

As seen in electron micrographs, the Golgi apparatus consists mainly of three parts: a) a number of thin-walled elongated sacs running parallel to each other, b) a group of large rounded vacuoles limited by thin membranes and lying near the margins of the elongated sacs, and c) a small group of microvesicles.

Chemical structure

The Golgi apparatus consists of proteins and lipids combined together forming a lipoprotein complex. The lipid portion is found in a masked or invisible form, being surrounded by protein films. These lipids can be made visible or unmasked by treating the cells with any proteolytic enzyme that acts to digest the protein material. Unmasking of the lipid portion of the Golgi complex takes place naturally in certain cells of ageing animals as well as in some pathological conditions.

Functions

The Golgi apparatus is closely associated with the elaboration of secretory materials, such as zymogen, bile, mucus, hormones, vitamin C, etc. Acid and alkaline phosphatases are usually found accumulated in the Golgi region of the epithelial cells, a fact which indicates that the Golgi apparatus plays a principal role in the formation of these enzymes.

The Golgi complex is also considered to be engaged in other cellular activities, such as the formation of the acrosomes of sperms, the elaboration of the synovial fluid in joints, and the formation of the enamel of teeth.

Pathological changes

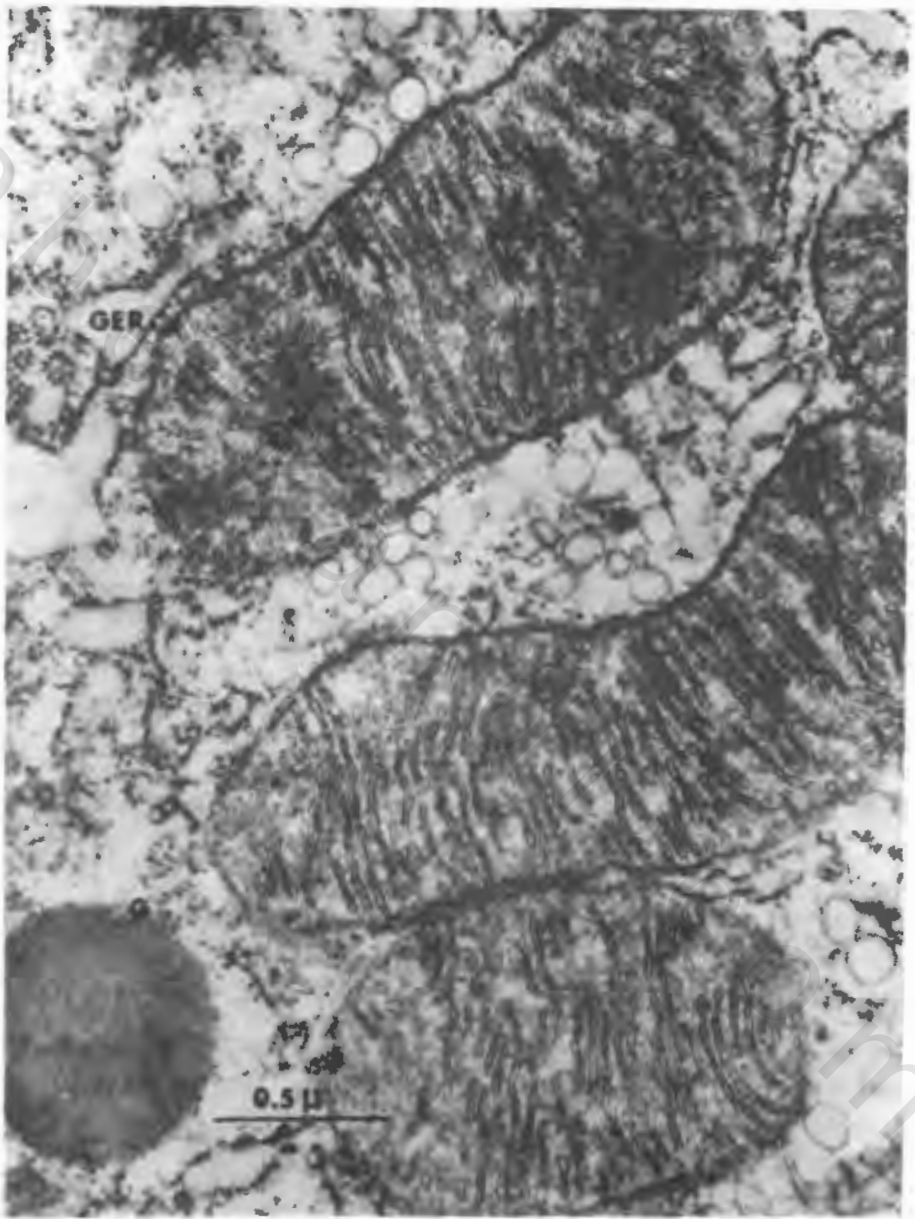
The Golgi apparatus was noticed to be affected in some pathological conditions in various organisms. Moussa in 1956 has shown that when a nerve is cut or injured, the Golgi apparatus in the corresponding nerve cells undergoes marked degeneration. Insecticides, morphine, phosphorus, vitamin B-deficiency and other agents also have marked effects on the Golgi apparatus.

THE MITOCHONDRIA

Mitochondria are living organelles which are of universal occurrence in different organisms, ranging from the unicellular ones as *Amoeba* to the most complicated animals and plants. They were described for the first time by Flemming in 1882 who gave them the name "fila". The same structures were described later by Altmann in 1890 who called them "bioblasts" (or living bodies). Benda in 1897 was the first to identify these structures as the mitochondria.

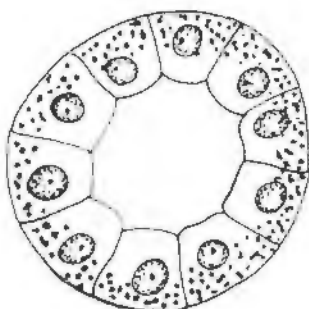
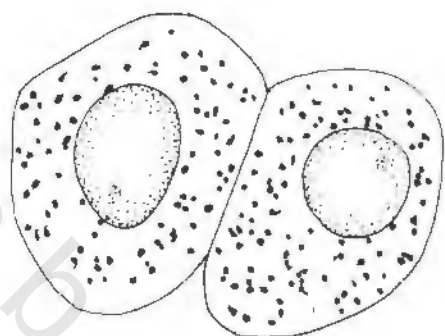
Occurrence

Mitochondria exist in different cells in the form of some granules, short rods or threads. They range in length from 0.5 to 1μ , but the thread-like

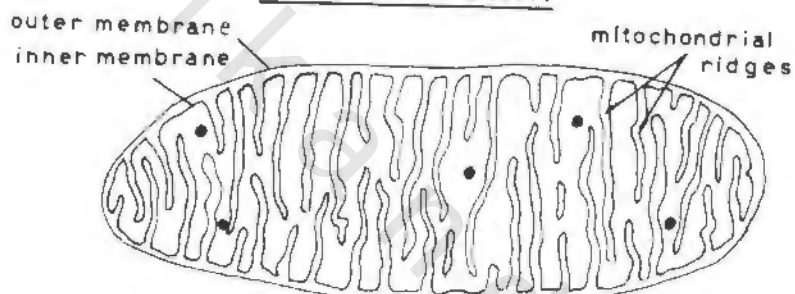


Mitochondria

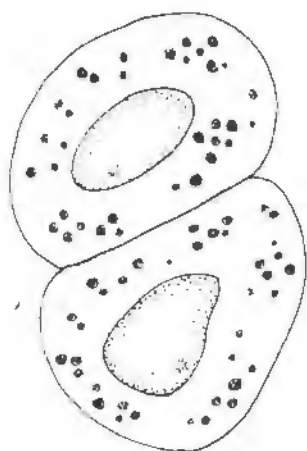
G, Golgi products: GER, granular endoplasmic reticulum.



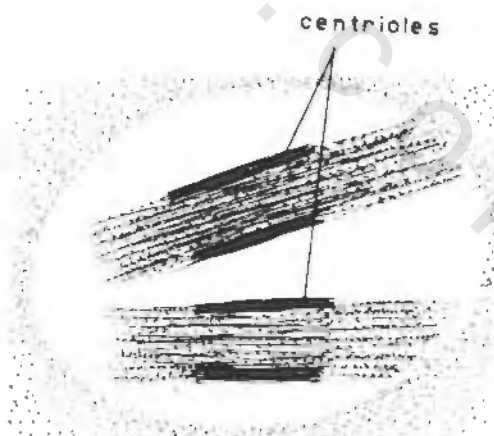
MITOCHONDRIA



Ultrastructure with EM



LYSOSOMES



CENTROSOME
with EM

ones may reach $10-12\mu$. One or more of such mitochondrial types may be found in the same cell.

The number of mitochondria is almost constant for each cell type. e.g. in *Amoeba* there are about 500,000 and in rat liver cells there are nearly 2,500 mitochondria per cell. In hepatoma(cancer liver) cells, the number falls to 175 - 800. Generally, mitochondria are more numerous in more specialized cells, such as those of the liver and kidney, than in the less specialized or less active cells, such as those of the thymus gland.

In the majority of cases, the mitochondria are homogeneously scattered in the cytoplasm, but in some cell types they are restricted to certain regions of the cell. In the kidney cells, for example the mitochondria are mainly located in the basal regions of the cells, mostly in the neighbourhood of the blood capillaries supplying these cells.

Mitochondria are not easily seen with the normal light microscope since they have a low refractive index due to their lipid constituents. However, the living mitochondria are clearly demonstrated with the phase contrast microscope. They can be supravitaly stained with Janus green. This substance becomes deeply coloured under the effect of the oxidative enzymes which are abundant in the mitochondria. In fixed preparations, the mitochondria are permanently stained with acid fuchsin and iron alum haematoxylin.

Ultrastructure

Mitochondria are seen in electron micrographs as sac-like structures, each being bounded by two membranes. The outer membrane is smooth; the inner membrane extends inwards forming a number of septa or partitions known as the **internal ridges** or **cristae mitochondriales**. These ridges divide the mitochondrion incompletely into a number of compartments.

The mitochondrial ridges are either laminar or lamellar in form, though in certain cells they exist as tubular structures or as microscopic villi. They carry numerous small aggregates of enzyme particles. The presence of these ridges is considered to provide a larger internal surface area, enough for the intra-mitochondrial activities. This is clear from the fact that the mitochondria of flight muscle cells, which are very active cells, possess larger numbers of ridges.

Chemical structure

Mitochondria consist mainly of lipids and proteins, in addition to other organic materials, mineral salts and vitamins. Recently, minute particles of DNA were also described in the mitochondria of some cells. Moreover, the mitochondria are the chief containers of the respiratory enzymes in the cells, such as cytochrome oxidase, succinic dehydrogenase, etc. That is why the mitochondria are identified as "batteries of enzymes".

Functions

Mitochondria are also known as the "powerhouses" of the cells. This is because many chemical reactions, which involve the oxidation of food stuffs and the release of energy, occur in the mitochondria. These reactions take place under the effect of the intra-mitochondrial enzymes. Green in 1961 found that even when mitochondria were broken into small fragments, they were still capable of carrying on some oxidative processes. Besides, it was also noticed that cyanide, which is known to inhibit respiratory processes, prevents the mitochondria from carrying on their respiratory functions.

Mitochondria are also strongly related to the general metabolism of the cells, particularly to fat and amino acid metabolism. They are responsible for the formation of the tail sheath of sperms.

Pathological changes

Mitochondria are markedly affected in the different pathological conditions of the organisms. In most cases, they either coalesce and transform into fatty particles, or break down into small fragments which disappear gradually from the cells. Among the agents which produce pronounced effects on the mitochondria are cyanide, phosphorus, insecticides, and X-ray irradiation.

THE LYSOSOMES

Lysosomes were first discovered by de Duve in 1955 in mammalian liver cells. Later, they were found to exist in the great majority of animal cells, and to a lesser extent in plant cells.

Form

Lysosomes appear under the normal light microscope as small vesicular bodies, slightly smaller in size than the mitochondria. In electron micrographs, lysosomes appear as small sac-like structures, each bounded by a single thin membrane.

Chemical structure

Lysosomes are formed of a lipoprotein complex. Their internal cavities contain a number of important digestive enzymes, including acid phosphatase, cathepsin, ribonuclease, deoxyribonuclease, etc. The name lysosome itself refers to the richness of these particles in such hydrolytic enzymes, and also implies that those enzymes go into solution when the lysosomal membranes are disrupted. When this happens, the liberated enzymes destroy the cell constituents, bringing about complete dissolution of the cell. Hence, these particles are also known as the "suicide bags".

Functions

Lysosomes take an active part in a variety of cellular activities, such as intracellular digestion, carbohydrate metabolism, etc. Hence, they are markedly abundant in the cells engaged in carbohydrate metabolism such as those of the liver, kidney and small intestine.

Lysosomes also play an important role in the removal of some cellular and tissue contents under certain conditions. For example, during metamorphosis in the Amphibia, there is occasional destruction and degeneration of considerable numbers of cells, as happens when the tadpole tail degene-

rates. This activity and other similar ones are undertaken by the lysosomal enzymes which are assumed to be discharged outside the cells for this purpose in order to exert their lytic effects.

Pathological changes

Lysosomes are affected by different physiological and pathological conditions. Fasting and ageing produce marked diminution in the number of lysosomes. X-rays cause the disruption of the lysosomal membranes, and this results in a progressive loss of these particles. Insecticides were also found to produce marked alterations in the lysosomal particles. In some malignant tissues, e.g in hepatoma cells, the lysosomes are markedly fewer than in healthy liver cells.

THE VACUOLES

Cells, particularly those of plants, possess certain vacuoles filled with a fluid material. Similar vacuoles are also found in some protozoa, such as the **contractile vacuoles** which play an important role in osmoregulation.

Immature plant cells usually contain a number of small vacuoles, which gradually enlarge and fuse together until they form a single large vacuole. As a result, the cytoplasm is pushed aside to form a thin peripheral layer.

THE CENTROSOME

The centrosome is a small cellular organoid located just outside the nucleus. It is found in the great majority of animal cells, except those which have lost their capacity to multiply, such as the fully-grown nerve cells. Centrosomes are absent from plant cells, except in very few primitive forms.

Form

The centrosome is seen under the normal light microscope as a small

dark body surrounded by a clear zone known as the **microcentrum**, followed by a dense zone called the **centrosphere**, from which the astral rays or **astrosphere** radiate out in dividing cells. One or two **centrioles** (diplosomes) are usually found in the centrosome of each cell.

Ultrastructure

The centriole appears in electron micrographs as a cylindrical structure, the wall of which contains 9 groups of small rods or tubules oriented parallel to the axis of the cylinder. Each group consists of three rods or tubules.

Function

Centrioles play an important role in cell division. The two centrioles move apart to the two opposite poles of the cell during division, but they remain connected with each other by certain threads, known as the spindle fibres, on which the chromosomes become arranged.

Centrioles are also closely associated with the ciliary movement in ciliated cells and ciliated organisms, and are moreover involved in a special manner in the formation of sperm tails.

NISSL BODIES

These are cytoplasmic inclusions specific for the nerve cells. They exist in the form of small granules or flakes of different forms and sizes, which are scattered in the cytoplasm and dendrites of the nerve cells. They stain intensely with basic dyes.

Nissl bodies are composed of protein and ribonucleic acid in addition to traces of iron. They are believed to play a role in the storage of oxygen or energy in the nerve cells since they were noticed to disappear during hard exercise and fatigue, then re-appear at rest. Marked alterations in form of these bodies were also observed in various physiological and pathological conditions. They may disappear partially or totally then re-appear when conditions return to normal, and sometimes they are completely lost.

THE FIBRILS

In some specialized cell types, the cytoplasm appears modified in various ways, thus giving rise to specific fibrillar structures, e.g. the neurofibrils in nerve cells and the myofibrils in muscle cells.

Neurofibrils exist in nerve cells in the form of intermingled threads extending from the various cell processes to the cell body. They are closely related to the nervous activities of these cells, particularly to nerve conduction.

Myofibrils are fine thread-like structures extending along muscle cells (or fibres). They represent the contractile machinery of muscle cells, i.e. they are the elements responsible for muscle contraction. They appear homogeneous in the visceral (involuntary) muscles, but in the skeletal (voluntary) muscles they show dark and light cross striations.

THE NUCLEUS

The nucleus is a permanent structure in the great majority of animal and plant cells. Its presence is essential for life since the persistence of the cell depends on the metabolic interactions which take place between the nucleus and the cytoplasm. Cells which have lost their nuclei, such as mature red blood cells, live for short periods after which they disintegrate. Experimentally, when *Amoeba* was sectioned into two parts, one containing the nucleus and the other devoid of the nucleus, the first part survived normally whereas the other part degenerated.

In some primitive animals, a typical nucleus is not found; it is only represented by a number of granules of nuclear material scattered in the cytoplasm, as in the case of certain flagellates. No proper nuclei were demonstrated also in bacteria, only some scattered granules with microchemical characteristics of a nucleus. The electron microscope has recently brought into vision some nucleoid bodies in bacteria not enveloped by a

nuclear membrane. In viruses, no definite nuclei are seen but chemical analysis has shown the presence of nucleoproteins which are regarded to represent the nuclear substance.

The nucleus passes during the course of its life through two successive periods; an interphasic or metabolic period (erroneously identified previously as the resting period) and a dividing or mitotic period.

Interphasic Nucleus

Shape

The shape of the nucleus is usually related to that of the cell, i.e. if the cell is isodiametric (spherical, cubical or polyhedral), the nucleus is almost spherical. On the other hand, in cylindrical, prismatic or fusiform cells, the nucleus is elliptical, and in flattened cells it is filamentous. Irregularly-shaped nuclei are found in the white blood cells, in which case they may be horse-shoe shaped or multilobed. Branched, moniliform, pyriform and lanceolate forms of nuclei are also found in different kinds of cells.

Size

The nuclear size is much variable, but in general it bears some relation to that of the cytoplasm. This relation is expressed by what is known as the nucleocytoplasmic index "NP".

$$NP = \frac{\text{Volume of nucleus } (V_n)}{\text{Volume of cell } (V_c) - (V_n)}$$

This fixed relation indicates that when the volume of the cell increases, a corresponding increase will take place in the nucleus. The lack of maintenance of the "NP" ratio seems to act as a stimulus for cell division.

Number

Almost all cells are mononucleate, but binucleate cells are sometimes found in the liver, cartilage and certain nervous tissues. Polynucleate cells are also found, as in the osteoclasts of bone marrow. Syncytia are also examples of polynucleate cells. A syncytium is a mass of protoplasm containing numerous nuclei, e.g. striated muscle cells.

Location

The position of the nucleus is variable, but is usually characteristic of each cell type. In embryonic cells, it almost lies near the central area, but as the cells become differentiated, the nucleus becomes often displaced to one end, especially in storage and secretory cells due to the accumulation of reserve and secretory substances in their cytoplasm. For example, in adipose cells, yolk-rich cells and in mucus-secreting cells, the nucleus usually occupies a peripheral position.

Structure

The nucleus consists mainly of the following parts :

1 — **The nuclear membrane or karyotheca**, is a definite structure limiting the nucleus and having certain chemical and physical characteristics. It controls the exchange of material between the nucleus and the cytoplasm.

In electron micrographs, the nuclear membrane is shown to be formed of two layers, the outer layer of which is continuous with the endoplasmic reticulum. The membrane is also perforated by minute pores. It is suggested that large molecules pass through these pores, while small molecules and ions pass by diffusion through the membrane itself. It is also thought that the nuclear membrane is selectively permeable, but its permeability is different from that of the cell membrane, i.e. some materials which can diffuse through the cell membrane may not be allowed to pass through the nuclear membrane.

2 — **The nuclear sap or karyolymph**, is a colourless fluid which almost completely fills the nuclear space where other nuclear structures are found.

3 — **The nucleoli**, are more or less spherical structures, usually of considerable size. They may be single, double or multiple.

4 — **The chromatin or chromocentres**, appear in the form of fine and lightly stained granules, or coarsely clumped and darkly stained bodies. The chromatin bodies seen in the interphasic nuclei are regarded as parts of chromosomes. The latter are only visible during cell division when they appear as darkly stained thread-like structures. They are regarded as the material basis of genetics.

5 — **The Barr body** : In 1949, Barr and Bertram described a small darkly-stained particle of chromatin in the nerve cells of female cats, but not seen

in those of male cats. This body, which was later found in the great majority of the interphasic nuclei of other female animals, occurs in the form of a lenticular structure lying against the inner surface of the nuclear membrane. This structure is now known as the **Barr body**.

This body is regarded as a diagnostic feature for the sex of the embryo before birth. Within the pregnant mother, the amniotic fluid in which the embryo floats contains a lot of epithelial cells which are shed off from the skin of the embryo. A drop of this fluid can be obtained from the mother by abdominal puncture or through the cervix of the uterus. By this technique, the sex of the embryo can be distinguished as early as 15 – 16 days after conception. It is used not only to satisfy curiosity, but also to predict any possible diseases or abnormalities related to the sex of the individual.

Chemical structure

The nucleus consists mainly of a complex nucleoprotein formed of nucleic acids combined with some basic proteins, such as protamines and histones. Nucleic acids include DNA and RNA. DNA is found as an essential constituent of the chromatin material. On the other hand, RNA is mainly found in the nucleoli, and to a lesser extent in the chromatin. Small fractions of lipids and certain enzymes are also reported in the nuclei of some cells.

CELLULAR CHANGES DURING SENESCENCE

Cell senescence is usually accompanied by certain cytological and cytochemical changes. The most marked of these is the accumulation in the cells of **senility pigments**, or the so-called "wear and tear pigments", which are considered to be derived from the oxidation of unsaturated lipids. These pigments are frequently observed in nerve cells, and sometimes in the cells of the liver, kidney, ovary and thyroid gland. They do not dissolve in fat solvents although they stain well with Sudan stains.

During senescence, the nucleus stains more intensely than normal, decreases progressively in size and finally loses its structural details. This phenomenon is collectively known as **nuclear pyknosis** (pykno = dense); it ends with the death of the cell.

Normal senility, especially in nerve cells, is also accompanied with retraction of the cell boundaries, loss of transparency of the nuclear sap, and a notable diminution in the chromatin substance of the nucleus. Furthermore, the Golgi apparatus becomes fragmented and transforms into lipid droplets. Occasionally the nucleus divides by amitosis.

In some organs, as in the thyroid gland, senility is indicated by fibrosis, i.e. the transformation of the organ into a fibrous tissue. In the liver, however, fibrosis does not occur and giant nuclei with intranuclear inclusions are commonly seen.

Death of the cell

Cell senescence eventually leads to cell death which is generally defined as the irreversible cessation of its vital processes. The gradual changes which take place during cell senescence and lead to cell death are known as **catabiosis** (kata = down; bios = life). However, death may occur very rapidly by agents that cause instantaneous coagulation or precipitation of the protoplasm, as the death produced by tissue fixatives or by heat.

In nature, cessation of cellular processes usually takes place in a gradual manner. A cell may undergo an irreparable injury, but may retain its

activity for some time. For example, if the cell boundaries are artificially destroyed (e.g. by grinding), some metabolic processes, such as oxygen consumption, fermentation and glycolysis, may continue, but they usually decline rapidly with time, until they stop.

Other features of cell death are the lack of growth, movement and reproductive capacity. Acidosis is also noticed in dead cells, indicating certain oxidation-reduction disturbances.

Dead cells are recognized with the help of certain vital stains, such as neutral red, methylene blue and Janus green. Their cytoplasm is diffusely stained and their nuclei stain more densely than those of living cells.

POST-MORTEM CELLULAR CHANGES

1 — Cytoplasmic changes

In many cells, death is immediately preceded by a shorter or longer period of marked disturbances in normal metabolism and of some degenerative changes. The post-mortem modifications generally result from the activity of the intracellular hydrolytic enzymes, which begin their action after death. They attack or break down large molecules of the protoplasm, particularly protein molecules. Also lack of oxygen, after cell death, favours anaerobic fermentation and the formation of various acids, especially lactic acid. Moreover, the accumulation of small molecules and ions in the decaying cell increases the osmotic pressure and causes the passage of water inside, resulting in the swelling of the cell. Another phenomenon following death is the irreversible coagulation of the protoplasm. This may persist for a long time, but is generally followed by the digestion and liquefaction of the cell.

The liquefaction of dead cells is frequently preceded by its swelling and by the appearance of protein granules in the midst of its cytoplasm, a phenomenon known as **cloudy swelling**. This process may also occur in living cells under the influence of toxins, infectious diseases, etc. The cloudy swelling is immediately preceded by the accumulation of acids in the protoplasm and thus by the lowering of the pH (acidosis). This accumulation of ions increases the imbibition of water, and at the same time brings about

precipitation of the proteins of the ground cytoplasm in the form of fine granules. Minute droplets of fat also appear, resulting from the dissociation of lipoproteins.

The mitochondria are also markedly affected by cell death. These elements are rapidly fragmented after death and are transformed into granular materials which undergo swelling. The mitochondrial swelling, however, is different from the cloudy swelling. The granular appearance of the cytoplasm in the former case is due to mitochondrial changes, while in the latter case it is due to the precipitation of proteins in the ground cytoplasm.

2 — Nuclear changes

The nucleus also undergoes some post-mortem changes which are different from those of the cytoplasm. The nuclear structure and staining properties resist autolysis for a longer period than the cytoplasm; in many cases the stainability of the nuclei may even increase.

Dead or pyknotic nuclei have shrunken boundaries and do not show structural detail, but they often stain darkly with basic stains. During pyknosis, the DNA content of the nucleus does not show any significant decrease at the beginning. But later, it starts decreasing progressively as the protein content of the cells is markedly decreased. This indicates that, after death, proteins are lost first (proteolysis), and this is followed by the breakdown of nucleic acid molecules under the effect of nucleases. Finally, the nucleus loses its staining properties and disintegrates (karyolysis), either with or without previous nuclear fragmentation (karyorrhexis).

CHAPTER II

CYTOGENETICS AND GENETICS

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CYTOGENETICS

Cytogenetics is a new branch of biology which is based on the inter-relations between cytology and genetics. The two branches are inter-related since chromosomes are the carriers of the genetic factors. Any changes which take place in the chromosomes are reflected in the genetic constitution of the resulting offspring.

THE CHROMOSOMES

Chromosomes were named for the first time by Waldeyer in 1888, though they had been described by Hofmeister 40 years earlier.

A chromosome may be defined as a nuclear component with special organization, individuality and functional activity. It is also capable of self-reproduction and of maintaining its morphological and physiological properties throughout successive cell divisions. Chromosomes are the principal vehicles which carry the hereditary factors or genes. They have thus gained great importance because of the fundamental role they play in heredity, multiplication, variation, mutation, etc.

Chromosome numbers

Chromosomes can be seen only during cell division. Their number varies in the different kinds of organisms. A fixed number of chromosomes is characteristic of each species. The smallest number of chromosomes is found in *Ascaris megalocephala* (2 chromosomes). The highest number is found in some protozoa (300). The chromosome numbers of some common animals and plants are shown in the following table :

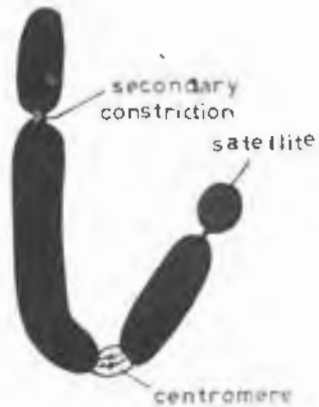
Species	Chromosome number	Species	Chromosome number
<i>Ascaris megalocephala</i>	2	<i>Oryctolagus cuniculus</i>	44
<i>Culex pipiens</i>	6	<i>Homo sapiens</i> (Man)	46
<i>Drosophila melanogaster</i>	8	<i>Cebus</i> sp.	54
<i>Musca domestica</i>	12	<i>Bombyx mori</i>	56
<i>Pisum sativum</i>	14	<i>Bos taurus</i>	60
<i>Allium sepa</i>	16	<i>Equus caballus</i>	66
<i>Zea maitiva</i>	20	<i>Camelus dromedarius</i>	70
<i>Apis mellifica</i> (female)	32	<i>Canis familiaris</i>	78
(male)	31	<i>Gallus domesticus</i>	78
<i>Mus musculus</i>	40	<i>Eupagurus ochotensis</i>	254

Chromosomes mostly occur in double numbers, or **diploid sets**. In humans, the diploid number of chromosomes is 46. This means that each somatic cell of the human body contains 46 chromosomes, known as the **somatic chromosomes**. This number or diploid set is referred to as "**2n**", i.e. in humans $2n = 46$ chromosomes. Each diploid set is formed of 2 **haploid sets**, each of which is denoted by "**n**". Hence, in humans $n = 23$ chromosomes. The two haploid sets of each diploid one are exactly similar in every respect, hence they are described as **homologous chromosomes**.

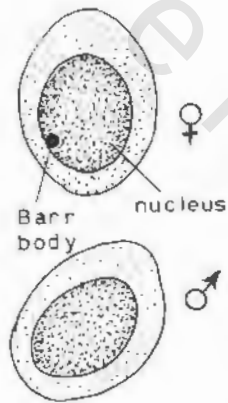
During gamete formation, every two homologous chromosomes separate from each other; one of them goes to one gamete and its homologue goes to another gamete. In other words, each gamete (whether sperm or egg) possesses only one haploid set of chromosomes known as the **gametic chromosomes**; the corresponding haploid set is contained in another gamete. Thus, in humans, each sperm or egg contains 23 chromosomes only. Later, during the formation of a new embryo, the sperm and egg fuse together and the fertilized egg or zygote comes to possess 46 chromosomes. The zygote grows into a new individual, in which every cell possesses the same number of chromosomes (46). Thus in each individual one haploid set of chromosomes is contributed by the father through the sperm and the other set is contributed by the mother in the egg. Those coming from the father are known as **paternal chromosomes** and those contributed by the mother are known as **maternal chromosomes**. Thus, every somatic cell in a human being contains a haploid set of paternal chromosomes and another haploid set of maternal chromosomes.

acrocentric

metacentric



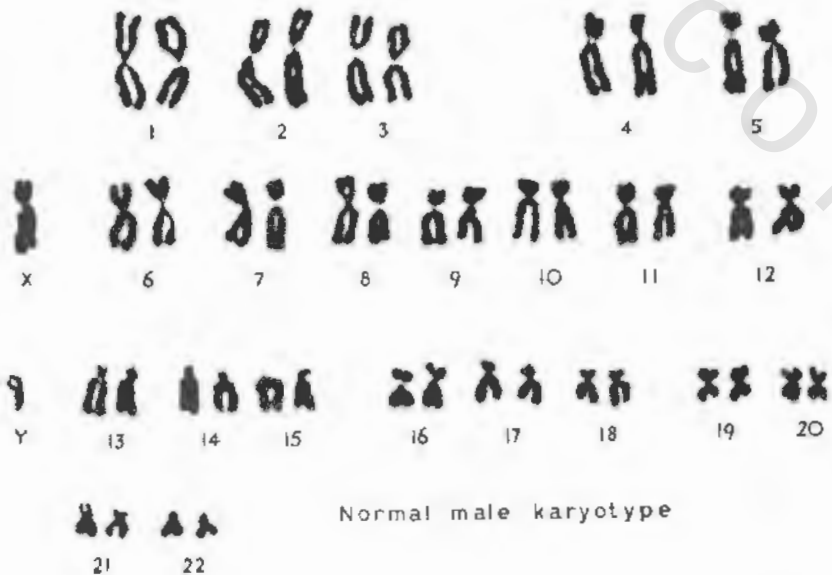
submetacentric



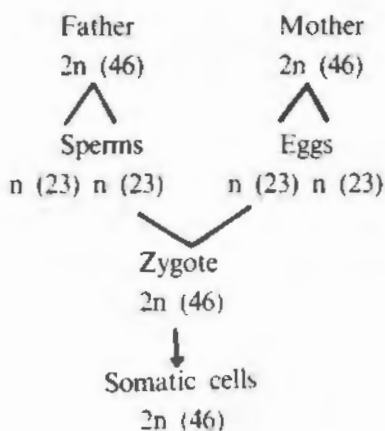
BARR BODY



CHROMOSOMES



Normal male karyotype



Form

The size of each chromosome is relatively constant for the species and is important for the identification of the different chromosomes. The length varies from 0.2 to 50μ , and the diameter ranges from 0.2 to 2μ . In humans, the length ranges between 4 and 6μ .

The chromosome structure is best studied during the stage of cell division known as the metaphase stage. At that stage, each chromosome appears as a rod-like or cylindrical body showing a number of constrictions. One of these constrictions, known as the **primary constriction** or **centromere**, appears as a clear zone containing a small granule or spherule. The centromere is functionally related to the chromosomal movements which occur during cell division. Besides, the chromosome possesses some small constrictions, known as the **secondary constrictions** the number of which is characteristic for each chromosome.

Another important part of the chromosome is the **satellite**. This is a round or elongated portion which is found at one end of the chromosome and is connected to the rest of the chromosome by a delicate chromatin filament. The dimensions of the satellites are very important in differentiating between various chromosomes.

Three main types of chromosomes are distinguished :

1 — **Acrocentric chromosomes**, are rod-like chromosomes, each formed of a single arm. The centromere is found near one end of the chromosome.

2 — **Submetacentric chromosomes**, are L-shaped chromosomes, each with two unequal arms. The centromere is found at the junction of the two arms.

3 — **Metacentric chromosomes**, are V-shaped chromosomes, each with two equal arms joined by the centromere.

The chromosomes of each cell are of two kinds **autosomes** and **sex chromosomes**. There are usually 2 sex chromosomes in each cell. These may be similar to each other and referred to as **XX** chromosomes, or dissimilar and known as **X Y**. In some cases one of these chromosomes may be missing, a case referred to as **X O**.

The **Barr body** (p. 51) appears only in cells containing two **X** chromosomes. In human beings, cells with a single **X** chromosome, e.g. cells of normal males, do not show this body, but men suffering from Klinefelter's syndrome (**XXY**, p. 121) show a Barr body in their cells. On the other hand, females showing **Turner's syndrome** (**X**, p. 546) do not have this body, and abnormal females (with **XXX**) show 2 Barr bodies in their cells.

Karyotype

The word karyotype means the group of characteristics which may be taken into consideration in identifying the chromosomal complex of a species. These characteristics include shape, length, and diameter of the chromosomes, number and location of their constrictions, position of their centromeres, etc. The karyotype is characteristic for each individual, race, genus or large grouping of living beings. It is usually represented by a diagram known as the **idiogram**. In this idiogram, each 2 homologous chromosomes are arranged beside each other, and each pair is given a certain number that is agreed upon universally.

Chemical structure

Chromosomes consist of proteins and nucleic acids. Proteins are mainly histones, and nucleic acids are mostly DNA. Traces of RNA and alkaline phosphatase were also reported by some biologists in certain chromosome types.

CELL DIVISION

The body of each living individual consists of a large number of cells. Each multicellular organism starts its life as a single cell, the fertilized egg or zygote. This cell undergoes successive divisions giving rise to the whole individual. Two main types of cell division take place in higher organisms, namely **mitosis** and **meiosis**.

A third type, known as **amitosis**, occurs in the macronucleus of ciliated Protozoa as well as in the cells of some animals under certain pathological conditions. In amitosis the nucleus divides into two parts at random, without showing division spindles or chromosomes.

MITOSIS

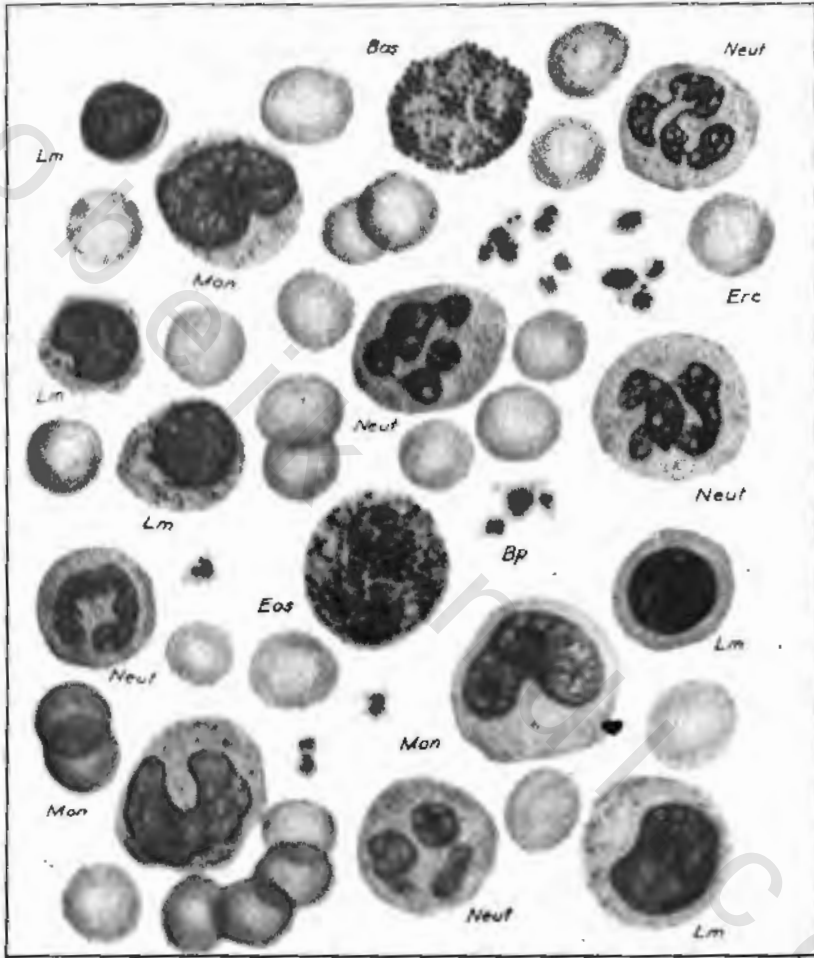
Mitosis, or mitotic division, is the type of cell division common among somatic cells. It is a complicated process that includes a number of successive steps or stages. These stages are :

1 — Prophase

This stage includes all the changes which take place in the interphasic nucleus to prepare it for division.

In the interphasic or intermitotic nucleus, no chromosomes are visible; the nucleus contains only chromatin and nucleoli. This chromatin or chromocentres represent certain condensed parts of the chromosomes. At the beginning of the prophase, the chromosomes become visible in the nucleus in the form of long coiled threads intermingled with each other. They gradually shorten and thicken, and their affinity for stains is markedly increased. Each chromosome appears formed of two exactly similar elements which lie very close to each other. These are the **chromatids** or **daughter chromosomes**. The two chromatids of each chromosome are separate except at the region of the centromere.

At the same time, the centriole, if single, divides into two centrioles which separate and move apart towards the two opposite poles of the cell. The cytoplasm surrounding each centriole is modified to form short radiating threads called **astral rays**. The cytoplasm between the two centrioles also

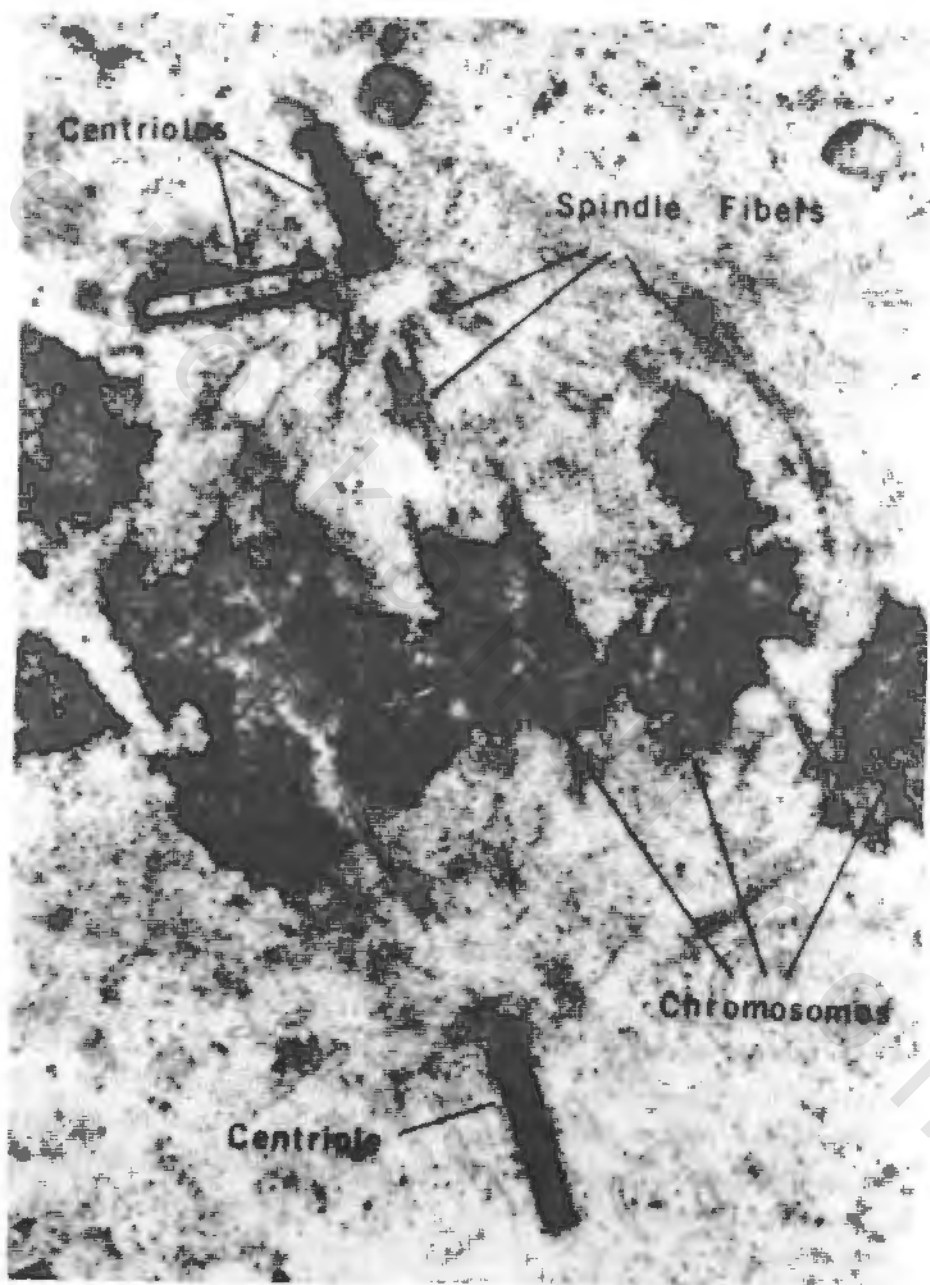


كريات الدم في الإنسان (مصبوغة صبغة رايت)

Blood cells in man (stained by Wright's stain)

Lm	كروية لمفية	Bp	صفائح الدم
Mon	كروية كبيرة	Eos	كروية بيضاء محبة للحمض
Neut	كروية بيضاء متعادلة	Erc	كروية حمراء
Bas	كروية بيضاء محبة للأساس		

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Mitotic spindle

modifies to form a number of fibres known as the **spindle fibres**, which collectively form what is known as the **spindle**.

The nucleoli disappear and the nuclear envelope disintegrates.

At the end of the prophase stage, the chromosomes appear connected to the spindle fibres.

2 — Metaphase

During this phase, the chromosomes become arranged in a linear series along the equatorial plane of the cell.

3 — Anaphase

This stage starts with the splitting of the centromeres connecting every two chromatids. Thus, the two chromatids of each chromosome separate from one another, and each is moved towards the corresponding pole of the cell. It is assumed that this process takes place under the effect of two forces : a force of repulsion between every two chromatids, and a force of attraction at the centrioles by which each centriole pulls the chromatids facing it.

4 — Telophase

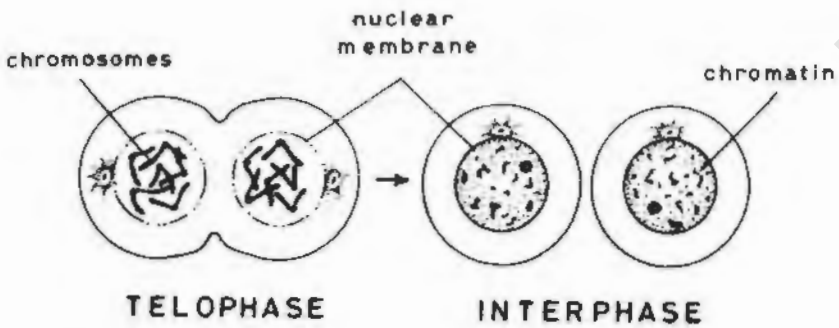
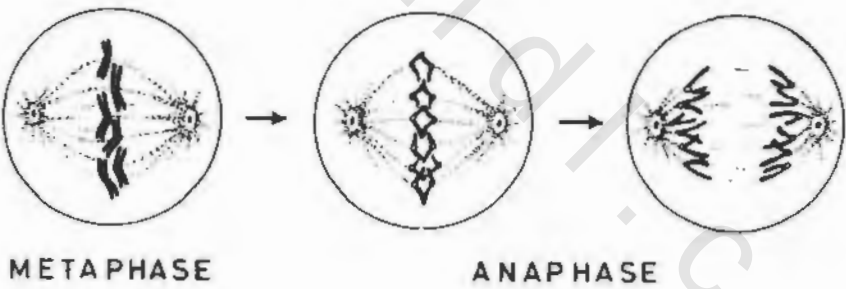
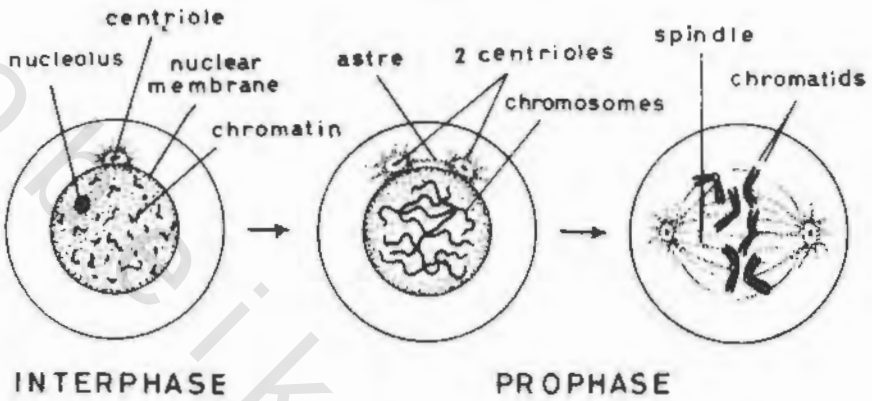
Each set of chromatids (now known as chromosomes) reach the corresponding pole of the cell. The chromosomes become thinner, more elongated and faintly stained. A nuclear membrane is developed around each set of chromosomes so that two daughter nuclei are formed. The nucleoli develop and the spindle fibres disappear.

This process is accompanied by **cytokinesis**, or division of the cytoplasm. A constriction appears in the cell and deepens gradually until the cell is divided into two, each containing one of the two daughter nuclei.

Worthy of notice is that during mitosis, each chromosome divides into two equal and exactly similar halves. Since the chromosome is the carrier of the genetic information, then each of the two resulting copies will carry the same genes.

The frequency of mitotic divisions is also dependent on the state of the cells. Mitotic figures are more frequent during embryonic development, repair of injury, in tumours, etc.

MITOSIS



The duration of mitosis is almost fixed for each cell type. For example, in the cells of the fruit fly, mitosis takes about 9 minutes, whereas in the cells of the chick it takes 100-200 minutes.

The different types of body cells in fully mature individuals differ as regards their capacity for cell division. In this respect, they are classified into 3 main categories :

a) Some cells divide continuously throughout the life span of the individual, such as the cells of the Malpighian layer of the skin.

b) Other cells, such as the liver cells, usually stop division at maturity, but under certain conditions (e.g. hepatectomy, liver injury, etc.) they regain their capacity to divide.

c) The third category includes cells which seem to have completely lost their capacity for division. This capacity is not regained under any condition, such as the nerve cells.

MEIOSIS

This type of cell division takes place only during the formation of sexual cells or gametes. It is a special type of cell division in which the chromosomes divide once whereas the nucleus divides twice. It differs from mitosis in the fact that the resulting cells contain only half the number or the haploid number of chromosomes, hence it is also known as **reduction division**.

Meiosis comprises two successive divisions referred to as the first and second meiotic divisions :

I. First Meiotic Division

This takes place in a manner comparable to that of mitosis, though its prophase stage is rather complicated.

1 — Prophase I

This includes the following stages :

a) **Leptotene stage** : In this stage, the chromosomes appear as long filaments that usually look like strings of beads of a rosary.

b) **Zygotene stage** : Each 2 homologous chromosomes arrange side by side, or come together in pairs. This pairing occurs in a definite manner and is known as **synapsis**. The process starts at the regions of the centromeres, then extends along the whole length of the 2 pairing chromosomes.

c) **Pachytene stage** : After pairing is completed, the chromosomes contract lengthwise so that they appear as short thick rods. The nucleus at this stage appears as if it contains only the haploid number of chromosomes. But each of its chromosomes is, in fact, double and formed of 2 chromosomes lying very close to each other. Such paired chromosomes are known as **bivalent chromosomes**. Since each chromosome has its own centromere, a bivalent has 2 centromeres lying close to one another. The two components of a bivalent usually twine among themselves forming a spiral structure.

About the middle of this stage, each component of a bivalent shows its two chromatids connected together by one centromere. Thus, the chromosomes are seen in the form of **tetrads** by the end of this stage.

Some transverse breaks appear in the two internal chromatids of the tetrad. These breaks occur at the same levels in every pair of homologous chromatids. Exchange of the corresponding parts of these homologous chromatids then take place. This process is known as **crossing over** and is very important for the exchange of hereditary factors.

d) **Diplotene stage** : After the exchange of parts, the two chromosomes of each bivalent, which has been so far intertwined in a spiral, start to separate from each other. The separation is not yet complete. Every two chromosomes remain in contact with one another for some time, touching at certain points known as the **chiasmata**. The number of chiasmata is reduced gradually as the two chromosomes continue their separation along their whole length. This process, in which the chiasmata decrease in number and disappear gradually from the centre towards the two ends of the chromosomes, is known as **terminalization**.

e) **Diakinesis** : Terminalization continues in this stage until all the chiasmata disappear and the two chromosomes of each bivalent separate completely from each other. Meanwhile, the separating chromosomes contract; every chromosome is now formed of a pure chromatid and a mixed one. The centrioles also separate and a mitotic spindle is formed. The

MEIOSIS

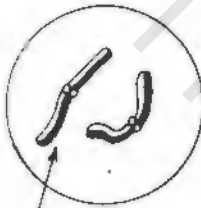


Leptotene

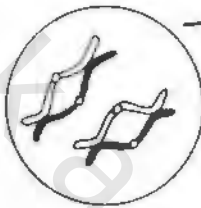


Zygotene

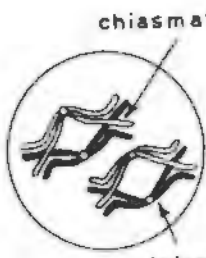
synapsis



bivalent

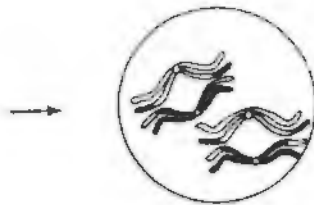


Pachytene



chiasmata

tetrad

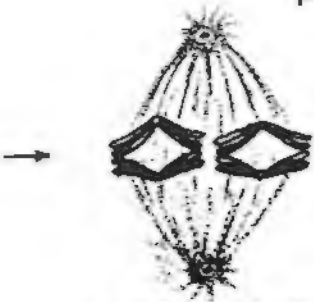


Diplotene



spindle

Diakinesis



METAPHASE I



ANAPHASE I

PROPHASE I



TELOPHASE I

INTERPHASE

End of first meiotic division



PROPHASE II

METAPHASE II



ANAPHASE II

TELOPHASE II

nuclear membrane disappears and the chromosomes become associated with the spindle fibres.

2 — Metaphase I

The bivalent chromosomes arrange along the equator of the cell, one just above the equatorial line and its partner below that line. Each member of a bivalent appears formed of two chromatids which are still held together by their centromere.

3 — Anaphase I

The two chromosomes, each still consisting of two chromatids, are drawn apart and pulled towards the two opposite poles of the cell.

4 — Telophase I

Each set of chromosomes at one pole is surrounded by a nuclear membrane, thus two daughter nuclei are formed, each containing half the original number of chromosomes (n).

This stage is followed by a short period called **interphase**, and this is soon followed by the second meiotic division.

II. Second Meiotic Division

This process takes place in each of the 2 resulting nuclei. It comprises the following stages :

1 — Prophase II

Each centriole divides into two, and these travel to the opposite poles of the cell. The spindle is formed, the nuclear membrane disappears, and the chromosomes become associated with the spindle fibres. Each chromosome is still composed of two chromatids held together by a centromere.

2 — Metaphase II

The chromosomes become arranged along the equatorial plane of the cell.

3 — Anaphase II

The centromere binding every 2 chromatids splits, so that they separate from each other and move away towards the corresponding poles of the cell, each chromatid being now an independent chromosome.

4 — Telophase II

Each set of chromosomes are grouped together near the corresponding centriole. The chromosomes elongate, become thinner, and lose their entity. A nuclear membrane is formed around each group, and two nuclei are thus produced, each containing half the original number of chromosomes (n).

It is clear that meiosis, as described above, comprises two successive divisions. In the first division, half of the chromosomes pass into each daughter nucleus. In the second division, each chromosome divides into two chromatids. Therefore, at the end, 4 nuclei are produced from the original dividing cell, each containing the haploid number (n) of chromosomes. In other words, 4 gametes are developed each gamete (sperm or ovum) contains (n) chromosomes.

During fertilization, fusion takes place between the sperm and egg; a zygote is thus produced with the diploid number ($2n$) of chromosomes. Without this reduction division, the number of chromosomes would be duplicated at every fusion of gametes.

Another significance of meiosis is the exchange of genes which takes place during crossing over. This process also allows the zygote to receive a supply of genetic factors from both the male and female parents.

CHROMOSOMAL ABERRATIONS

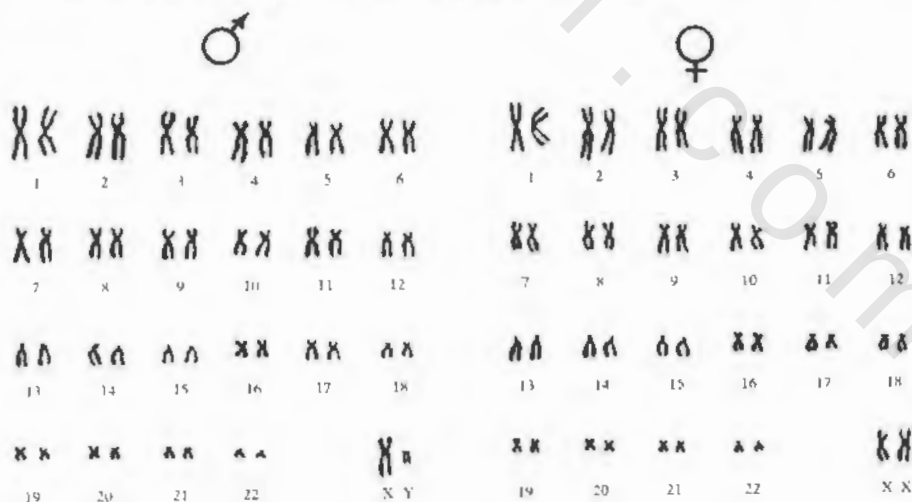
Microscopic changes in the structure or number of chromosomes are known as aberrations. These include:

A) **Deficiency or deletion**, is defined as a chromosomal aberration in which a segment of the chromosome is lost. The separated segment does not survive if it lacks a centromere. But, if it has a centromere it survives and may be included as a new chromosome.

Heterozygous deficiency indicates that one chromosome is normal while its homologue is deficient. **Homozygous deficiency** results in the death of the organism because of the lack of a complete set of genes.

B) **Variations in chromosome numbers**, as in the following cases:

1 — **Haploidy**: Some plants and animals have a monoploid set of chromosomes, i.e. one haploid set of genes. This means that the homologous chromosomes and genes are absent. Examples of this case are seen in insects, e.g. drones (males) of ants, wasps and bees.



Normal Karyotype of a man (on the right side)
and a woman on the left side .

2 — **Polyploidy**: This means the presence of more than two haploid sets of chromosomes. Cases of this sort may be **triploids**, **tetraploids**, **pentaploids**, etc. Cells showing reduplicated chromosomes are frequently met with in certain pathological conditions and can be induced by certain substances as colchicine, or under the effect of heat or cold. These factors prevent the formation of the spindle, thus cell division does not come to its end. After some time, the cells resume the process again, but after they have developed the double number of chromosomes.

3 — **Aneuploidy**: In this case, one or more chromosomes reduplicate, and the organism is said to be **polysomic**. This case is caused by the failure of the chromosomes to separate during meiosis. One of the chromosomes, together with its homologue, move towards the same pole and go into the nucleus of the same gamete. This phenomenon is also called **nondisjunction**. When such gamete unites with a normal gamete, an individual, called a **trisomic** individual, is produced ($2n + 1$), and this results in certain genetic changes, as happens in mongolism in humans.

4 — **Allopolyploidy**: This type of chromosome variation is produced in crosses between 2 species that have different sets of chromosomes. The number of chromosomes in the resulting hybrid differs from that of either parents. Such individuals are sterile and never reproduce, e.g. the mule.

5 — **Extra chromosome number 21 (Trisomy chromosome 21) – Down's syndrome**: This represents the first case of known chromosomal aberrations. Its symptoms were discovered for the first time by Down (1866) and it was known formerly as "Mongolism" since the features of the individual suffering from it represent those of Mongolian race. This syndrome appears as a result of an increase of one somatic chromosome. In other words, one of the chromosomes, namely chromosome number 21 exists as three members instead of the familiar double number (2 chromosomes). This means that this individual possesses 47 chromosomes instead of the usual 46 chromosomes.

Individuals with this syndrome differ markedly from normal ones. They are dwarfs (about 4 feet height), with thick hands, relatively long tongue, loose joints, plain facial features, flat nose, small ear lobes, curved fifth finger and his finger prints are obviously different from the usual type, as they are also mentally retarded. These individuals usually die at early stages.

This syndrome was estimated to occur once in every 700 births in Europe, that is in the ratio of 7.3 in one thousand births. One sixth of such individuals die usually during their first year of age, though some were recorded to live until they reach 16 years of age.

Although such persons suffer mental disorders, yet they can be trained for certain mechanical abilities. The United States are estimated to spend about one billion dollars for the care of such cases.

It was found that there is a strong relation between the appearance of this syndrome and the age of the mother. Women up to age 25 years have the probability of $\frac{1}{1500}$ to produce such cases; $\frac{1}{100}$ for women of 40 years old and $\frac{1}{40}$ probability when the age of the mother reaches 45 years. It is clear that this tendency increases with the increase of the age of the mother. It is also noticed that these ages are much shorter than those recorded 100 years ago. This may be attributed to the relative increase of many pollutants which can produce this syndrome, such as irradiation, insecticides, etc...

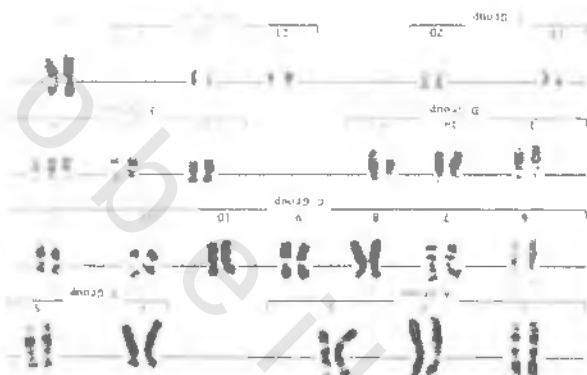


Down's syndrome

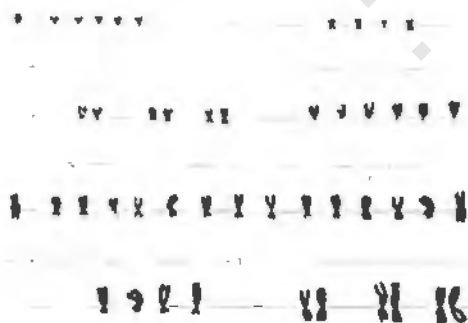
6 — Trisomy of chromosome 18: This case is characterized by an increase in the number of chromosome 18; three chromosomes exist instead of the usual pair of this chromosome. Hence, the total number of chromosomes will be 47.

This aberration is reflected on the newly born infant which has a small mouth, tiny nose, incomplete and backwardly retreated palate. He is idle, mentally retarded, and most, if not all, of his body organs are abnormal. The great majority of these infants usually die during 6 months after their birth.

Aberration of chromosome 18

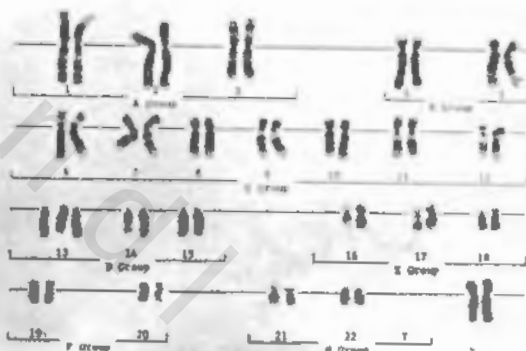


Karyotype of Down's syndrome



7 — Trisomy chromosome 13: This aberration includes the existence of an extra chromosome number 13, and hence the total number of chromosomes is 47. This syndrome was discovered for the first time in 1960 and it was estimated to occur in one for every 2000 births approximately. This case is rarely observed in young children and is never seen in adults since its possessors die during the first three months following their birth.

Symptoms of this syndrome appear in the suckling infants as bent foot, curved toes, heel protruding pronouncedly backwards and with a very small rear. The brain is very small and with mental retardation. Infants are also clearly deaf. Besides, the lips and palate are clefted, there is an extra finger, and the heart is abnormal structurally and functionally.



Aberration of chromosome 13

8 — Aberrations of one chromosome: In such cases, the number of chromosomes is normal (46), but there are certain changes in the structure of one of the chromosomes. Examples are:

a) Aberration of chromosome 5 (Cri-du-chat); This aberration is so called because its carrier cries like cats. The cause of this case is due to certain changes in the structure of the chromosome number 5. Besides their crying

like cats. infants suffering from aberration are small in size, with a weak body, broad facial features, curved nose, wide eyes and suffer from mental deficiency. There is no chance for the transmission of this syndrome to the following generations since infants of this type die very early, i.e. before adolescence.

b) Aberration of chromosome 3: This case is characterized by a change in morphology and structure of the chromosome number 3. This aberration causes early abortion of infants during pregnancy i.e. early before their birth, though some cases were recorded to live until they reached 6 years of age. Such individuals have an abnormal head, with thick eyebrows, long eye lashes, small nose, marked prognathism and gorged blood vessels. A skin fold is also found on both sides of the neck. Such infants, if born alive, cannot sit or lie on their sides, cannot eat any solid food and find great difficulty in suckling or swallowing.



Aberration of chromosome 3

CHROMOSOMES AND SEX-DETERMINATION

It is now well known that the male and female characteristics are transmitted from one generation to the next in the same way as for any other hereditary character. The sex of the individual is determined as soon as the zygote is formed. Studies in this respect showed the presence of two kinds of chromosomes in the cell : the common chromosomes or **autosomes** and other special chromosomes known as the **sex chromosomes**. The majority of diploid sexual organisms have a pair of sex chromosomes. One of the sexes has a pair of identical sex chromosomes "XX", and the other sex has a single chromosome which may be unpaired "XO", or paired with a Y chromosome "XY". Sex is accordingly determined in different ways, the most common of which are the following :

XX-XY : This case is found in mammals including man, and in certain insects as in *Drosophila*. In humans, the female is homogametic having 44 autosomes + XX, and the male is heterogametic with 44 autosomes + XY. Thus, only one kind of eggs is produced, each containing 22 autosomes + X, but 2 types of sperms are developed, sperms with 22 autosomes + X, and others with 22 autosomes + Y.

If an egg is fertilized by a sperm containing Y, it develops into a male. But, if it is fertilized by a sperm containing X it grows into a female.

XY-XX : In other animals, as in fishes and some birds, the female is heterogametic (with XY) and the male is homogametic (with XX). This method is sometimes referred to as the ZW-ZZ for the female and male respectively.

XX-XO : In some insects, sex chromosomes are of the XO type in the males and of the XX type in the females. Females of ants, wasps and bees, for example, possess XX chromosomes, whereas males possess one X chromosome and the other is missing. The males contain haploid sets of chromosomes. In the squash bug, for example, females have 22 and males have 21 chromosomes, the former including 2 X chromosomes, whereas the latter have one X chromosome. Each egg contains 11 chromosomes, while half the sperms possess 11 chromosomes (one of

which is the X chromosome and the other half contain 10 chromosomes only as they lack the X chromosome. If the egg is fertilized by a sperm containing 11 chromosomes it develops into a female, but if it is fertilized by a sperm containing 10 chromosomes it will have a single X chromosome and grows into a male.

Parthenogenesis

This process well-illustrates the role of chromosomes in sex determination. In bees and ants, for example, eggs containing the haploid number of chromosomes (n) are produced as usual. If such eggs are fertilized, the resulting zygote contains ($2n$) chromosomes and develops into a female. But the same eggs can grow without fertilization (parthenogenically) into a male with the haploid number of chromosomes. Parthenogenesis is either natural, as in the above mentioned example, or artificial, being induced by certain mechanical, chemical or physical factors, as by pricking the egg surface with a needle or putting the eggs in certain solutions.

Gynandromorphism

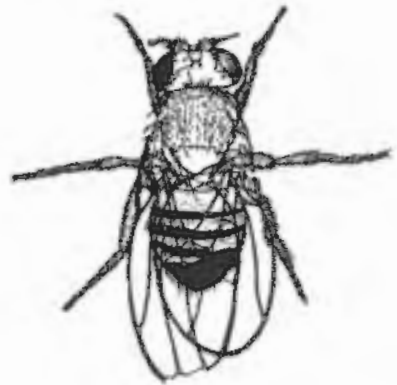
This is another phenomenon which illustrates the role played by the chromosomes in sex determination. This case is well represented in the fruit fly, *Drosophila melanogaster*, where it happens in the ratio of 1 : 2000. A **gynandromorph** is an individual with a part of its body showing male features and the other part showing female characteristics.

In bilateral gynandromorphs, one side is male and the other is female. The male side usually contains 2 testes and the female one contains 2 ovaries. Since, in *Drosophila*, the male fly is shorter than the female, the body of such gynandromorph appears curved towards the male side. Cells in the male region were found to possess only one X chromosome, whereas each cell in the female region possesses XX chromosomes.

This case results from certain chromosomal disturbances which take place during early embryonic development. The resulting individuals are considered produced by zygotes which contain XX chromosomes. These were presumably developing into females, but during cell division, one cell happens to lose one X chromosome, so that all the cells produced from it contain a single X chromosome. These cells lead to the development of male tissues and organs.

If such chromosomal disturbance takes place during the first cleavage or fission of the fertilized egg, it will lead to **bilateral gynandromorphism**. If it occurs during the second fission, only one fourth of the individual will be male, and if this disturbance happens during the third fission, one eighth of the individual will be male, and if this disturbance happens during the third fission, one eighth of the individual will be male and the remaining part will show female characteristics.

Bilateral gynandromorphism
in *Drosophila*



GENETICS

Genetics is the branch of biology which deals with the transmission of hereditary characters from one generation to the next.

It was previously thought that blood was the principal agent in heredity. However, it was realized later that the embryo does not arise from the blood of the parents, but is formed by the union of two sexual cells, the egg from the mother and sperm from the father. It followed that the sexual cells are the principal vehicles for carrying hereditary characters from the parents to the offspring. Some characters are acquired by the embryo from the mother through the egg, while other characters are acquired from the father through the sperm.

Recent advances in cytological studies demonstrated that hereditary characters are determined by certain factors, **traits** or **genes** located on the chromosomes. Each gene is found in a fixed position on a particular chromosome. At present, the gene is regarded to represent a certain length of a molecule of the deoxyribonucleic acid (DNA) found in the chromosome. It contains enough information to produce a certain form of ribonucleic acid (RNA). This particular RNA, known as messenger RNA, serves to produce a certain protein or enzyme. The proteins and enzymes are regarded to interpret the phenotypic constitution of the individual. In other words, modern genetics is explained in terms of proteins and enzymes. The term **genotype** or **genome** refers to the collection of inherited information, or genes, of the individual. The extent to which an inherited character appears in the offspring differs from one individual to another. The final expression of all inherited information in the individual, or its total characteristic features, is called the **phenotype**.

In each organism, paired or **homologous chromosomes** are present, there are 2 genes for every character; one gene on each homologue. The cells of the organism divide by reduction division to give the gametes. Each gamete contains only one chromosome of the paired or homologous ones. Consequently, in each gamete there is a single gene for every character. But when

these gametes unite together to form zygotes, each zygote will again have the diploid number of chromosomes, i.e. will contain the doubled genes of the different hereditary characters. For example, in some species, the height of the individual is a character controlled by 2 genes; one acts to bring about tallness and the other acts to bring about shortness. These 2 genes occupy two corresponding locations on 2 homologous chromosomes in that species. These two contrasting genes are called **allels** or **allelomorphs**.

When the 2 members of a given pair of alleles are alike (i.e. both of them act to produce either tallness or shortness), the individual is said to be pure or **homozygous individual**, or simply a **homozygote**. On the other hand, when the 2 members of a certain pair of alleles are different from each other (i.e. one acts to produce tallness and the other produces shortness), the individual is called a hybrid or **heterozygous individual**, or simply a **heterozygote**.

GREGOR MENDEL

THE FOUNDER OF MODERN GENETICS

Modern studies of heredity began in the second half of the nineteenth century by the Austrian monk Gregor Mendel (1822-1884) in the gardens of an Augustinian monastery at Brunn, Austria (now in Czechoslovakia). Mendel carried out several experiments on the garden pea, *Pisum sativum* and published his results and observations on the hybridization of that plant in 1865. Unfortunately, Mendel's findings were overlooked by people of his time, who were much occupied with the theory of the "Origin of Species" of Darwin that was subject to great controversial discussions during that period.

Mendel died in 1884 unrecognized and bitterly disappointed, but he was much aware of the great importance of his work and was sure that the time would come when his work would receive due consideration. That was what actually happened later in the period 1900-1910 when three famous scientists from different nations rediscovered the work of Mendel and revealed its great importance. These scientists were De Vries from Holland, Correns from Germany, and Von Tschermak from Austria. Since that time, Mendel became known as the father of modern genetics.

MENDEL'S MONOHYBRID CROSSES

Principles Of Segregation

Mendel discovered some basic rules which laid the foundation for all later advances in genetics. He carried out his experiments of hybridization, or crossing, on the edible pea, *Pisum sativum*. He noticed that individuals of that plant varied in 7 pairs of contrasting characters. These were : the height of the stem (which may be long or short), the colour of the flower (red or white), the nature of the seed surface (smooth or wrinkled); the colour of the unripe pods (yellow or green), the position of the flowers (axial or apical), the colour of the seed (yellow or green), and the structure of the pods (even or segmented).

Mendel examined these different pairs of characters concentrating on one pair of characters at a time, and followed the inheritance of such characters over successive generations. He used to carry on his experiments of hybridization or crossing by removing the stamens from the flowers of one plant and fertilizing it artificially with pollen grains from another plant. He was careful to prevent insects from reaching the artificially fertilized flowers so as to avoid their contamination with other pollen grains.

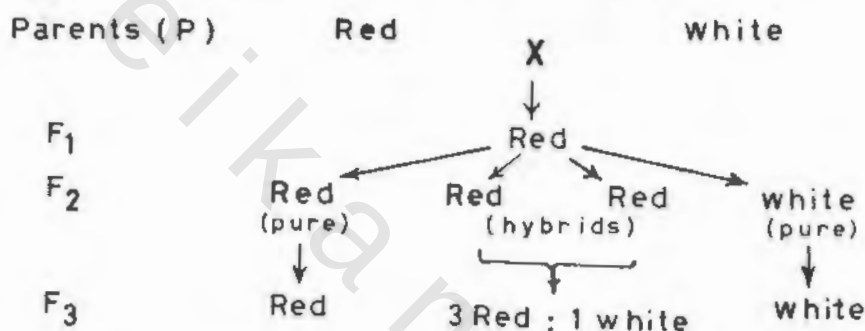
In some other experiments, Mendel left the flowers to perform self-fertilization in the usual manner. Then he collected the resulting seeds and cultivated them to find out the nature of the resulting progeny.

In one of his experiments, Mendel made cross fertilization between a plant carrying red flowers and another plant with white flowers; these plants are referred to as the **parental generation (P)**. When the resulting seeds were cultivated, all of them were found to grow into red-flowered plants. The resulting individuals are designated as the **first filial generation (F_1)**. It is clear that in this experiment, one character only (red colour) expressed itself in the first filial generation, whereas the second character (white colour) did not appear. The red colour of the flower in this case is called the **dominant character**, and the other suppressed character (white colour) is known as the **recessive character**.

Individuals of the F_1 generation were left to carry on self-fertilization, i.e. they were left to interbreed. When the resulting seeds were cultivated,

the **second filial generation** (F_2) produced by them was found to consist of red-flowered and white-flowered plants in the ratio of 3 : 1. In other words, only 25 % of the F_2 generation showed the recessive character, while 75 % of that generation carried the dominant character.

When the red-flowered plants of that F_2 generation were left to interbreed; the seeds of one-third of them gave red-flowered plants, and those of the remaining two-thirds gave red and white-flowered plants in the ratio of 3 : 1. The white-flowered plants of the F_2 generation were found to **breed true** for this character, i.e. they continued to produce white-flowered individuals, generation after generation. This can be expressed as follows :



Explanation of Mendel's experiments

Mendel's findings were explained on the assumption that each character is represented by a factor or gene which is usually given, as symbol, the first letter of the word describing that character. The dominant character is symbolized by a capital letter and the contrasting recessive one is represented by the same letter written in small. Thus, in case of the above mentioned experiment of Mendel, R refers to the dominant red colour and r represents the recessive white colour.

A pure red-flowered plant which contains the diploid number of chromosomes is represented by RR, and the pure white-flowered plant by rr. When these plants produce gametes, they undergo reduction division, and each gamete produced by the red-flowered plant contains only one factor R, and each gamete produced by the white-flowered plant contains only one factor r. When the 2 gametes fuse together during fertilization, they give red-flowered plants with Rr.

These plants, which form the F_1 generation, are heterozygotes or hybrids.

Each, in this case, is described as a **monohybrid** because it is the result of a cross between parents differing in a single gene or character. These hybrids grow and in turn produce gametes by reduction division. The allelic genes segregate or separate from each other during the process of gamete formation, i.e. half of the gametes will contain R and the other half contains r.

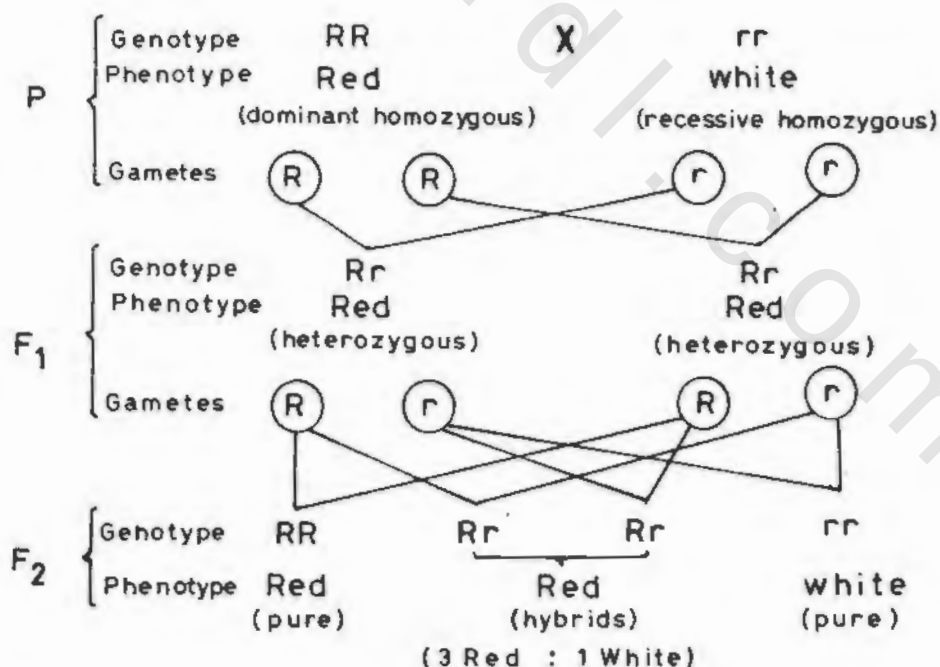
Since gamete fusion takes place at random, the following different combinations can possibly take place as a result of such a **monohybrid cross** :

1 — Male gametes containing R fuse with female gametes containing R producing zygotes containing RR, and these will grow into red-flowered plants.

2 — Male gametes containing R fuse with female gametes containing r producing zygotes containing Rr, and these will grow into red-flowered plants.

3 — Male gametes containing r fuse with female gametes containing R giving zygotes with Rr, which will also grow into red-flowered plants.

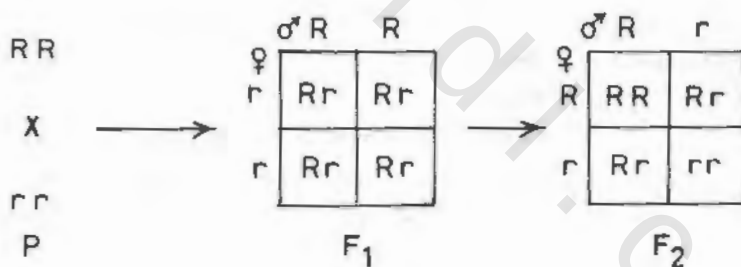
4 — Male gametes containing r fuse with female gametes containing r giving zygotes containing rr, which will grow into white-flowered plants.



It is clear from this example that plants containing RR do not contain any factor for whiteness, and are thus red-flowered. The Rr plants contain a gene for red colour and a gene for white colour, and since R is dominant over r, these plants are also red-flowered. The third group of plants containing rr do not contain a factor for redness, and are thus white-flowered.

Worthy of notice also is that there are 2 types of red-flowered plants in the F_2 generation. One group is homozygous containing RR, and the other is heterozygous containing Rr. Plants of the 2 groups are said to be **similar phenotypically** (because both have red flowers) but **different genotypically** (because they have different genetic constitution).

Mendel's findings can be expressed in another way, by the checker-board plan or the so-called Punnett square. This is a square divided into a number of small squares equal to the number of gametes involved in the cross. Gametes of one parent are arranged outside the horizontal edge of the large square and gametes of the other parent are arranged outside the vertical edge. The zygote formed by the fusion of every two gametes is inserted in the corresponding small square as follows :



These findings were summarised by what is now known as Mendel's first law, **the law of segregation of hereditary factors**. According to this principle : *"Genes do not blend, but behave as independent units. They pass intact from one generation to the next, where they may or may not produce visible characters or traits, depending on their dominance or recessiveness. Genes segregate at random, thereby producing predictable ratios of traits in the offspring. Thus, if a cross is made between a male and a female differing in a pair of allelomorphous characters, only one character appears in the resulting offspring. This character is known as the dominant character and the other one is known*

as the recessive character. The recessive character does not disappear completely, but re-appears in the second filial generation in a fixed ratio which is approximately one-fourth of the generation".

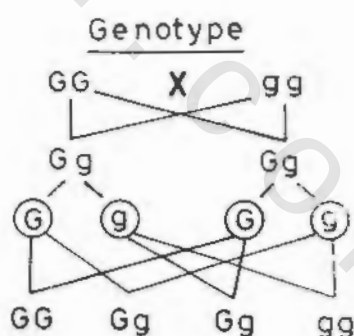
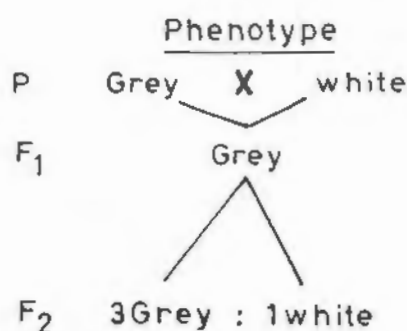
Such a case, in which only one character appears and dominates in the first generation, is known as **complete dominance**.

COMPLETE DOMINANCE

Many characters are inherited in animals according to Mendel's principle of dominance and recessiveness, i.e. with only one character dominating in the first generation, a case described as complete dominance. For example, in mice, grey colour dominates over the white one. When a grey mouse was crossed with a white one, all individuals of the F_1 generation were grey, and the F_2 generation consisted of grey and white mice in the ratio of 3 : 1.

Thus the F_2 is supposed to include :

- 25 % grey mice (homozygotes),
- 50 % grey mice (heterozygotes), and
- 25 % white mice (homozygotes).



Other examples of complete dominance of simple (monohybrid) characters are found in cattle, horses and cats. In cattle : Black skin is dominant over the red one, absence of horns is dominant over the presence of horns, and red and white spots are dominant over black and white spots.

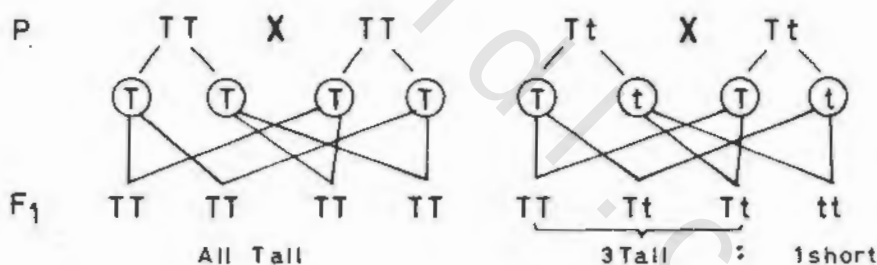
In horses : Black skin is dominant over brownish skin. In cats : short hair is dominant over long hair.

Identification of pure and hybrid dominants

It is very important, especially from the economic point of view, to differentiate between pure and hybrid organisms, i.e. between homozygous and heterozygous individuals. For example, tallness is a dominant character in peas. But a tall plant may be either pure (TT) and breeds true, or may be a hybrid (Tt). To identify its genotype, a **test cross** is carried out. Two main procedures are usually applied for this purpose, namely interbreeding and reciprocal crossing.

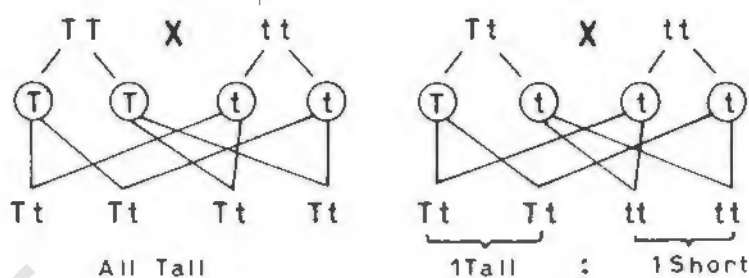
1 — Interbreeding

Two individuals of the examined plant are crossed with each other. If they are homozygotes, the resulting offspring will consist of tall individuals. If short individuals appear among their progeny, the tested plants are hybrids.



2 — Reciprocal crossing

In this case, the tested individual is crossed with a recessive tt . If the offspring consists of tall plants only, the individual is pure. But, if the offspring consists of tall and short plants (1 : 1) the examined plant is a hybrid.



Complete dominance in human beings

There are many characters in human beings which are inherited in accordance with Mendel's first principle of dominance and recessiveness. These include : Brown eyes are dominant over blue or grey eyes, Dark hair is dominant over light hair, Curly hair is dominant over straight hair, Yellow colour is dominant over white colour, Normal colour is dominant over albino colour, and Nose with pointed tip is dominant over nose with flat tip.

Besides, many abnormalities and diseases are also inherited in a similar way. Short fingers, prognathism (protruding jaw), polydactyly (extra-finger), hypertension (high blood pressure without organic cause) club foot, chondrodystrophic dwarfism are examples of such characters, all of which are dominant over normal characters. The following illustrate the mode of inheritance of some of these characters in man:



Polydactyly

1 — Inheritance of idiocy

In idiocy, the symbol i is used to designate the gene which produces this abnormality. This gene is a recessive one. Its normal allele is represented by $+$. A person who is hybrid for idiocy may appear perfectly normal. If such a person marries a normal woman of the pure normal type, all his children will be normal.

	Man genotype			Woman genotype
P	$i / +$	$\times$		$+ / +$
F ₁	$i / +$ $i / +$			$+ / +$ $+ / +$
	Normal (carriers)			Normal (pure)

It is clear that all the children will receive the $+$ allele from the mother. Half of them will get the i allele of the father and the other half will get the other allele $+$ of the father.

It should be noticed that, although the children will appear normal, yet half of them are carriers of the gene of idiocy. If these carriers, or hybrids, marry pure normal wives, all the children will again appear normal. Thus, the gene for idiocy might exist for a number of generations without expressing itself. But if one member (carrier) of this family marries a woman with a similar family history, a quarter of the children will be idiots.

P	$i / +$	$\times$	$i / +$
F ₁	i / i $i / +$ $i / +$		$+ / +$
	Idiot	Normal (carriers)	Normal (pure)

If a hybrid man marries an idiot woman or vice versa, half of the resulting offspring will be idiots and the other half will be carriers.

P	$i / +$	$\times$	i / i
F ₁	i / i $i / +$		$i / +$
	Idiots		Normal (carriers)

The last case is that illustrated by the marriage of a normal man with an idiot woman, or the opposite. In this case, all the resulting offspring is normal, though the individuals carry the gene of idiocy.

P		+ / +	×	i / i
F ₁	i / +	i / +		i / + i / +
	All normal (carriers)			

2 — Inheritance of myopia (near sightedness)

Myopia is attributed to a dominant gene. If one parent has myopia, and the other is normal, then half of the children would have myopia and the other half would be normal.

	Myopic		Normal
P	M / +	×	+ / +
F ₁	M / + M / +		+ / + + / +
	Myopic		Normal

If two hybrid myopic persons marry, their children are expected to be :
25 % pure myopics, 50 % hybrid myopics and 25 % normals.

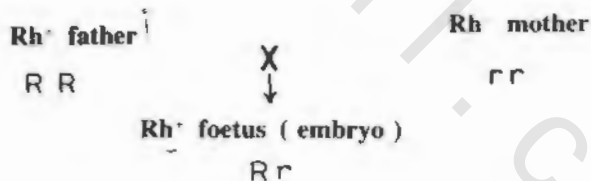
P	M / +	×	M / +
F ₁	M / M	M / + M / +	+ / +
	Pure myopics	Hybrid myopics	Normal

3 — Inheritance of Rhesus (Rh) factor

If a man with Rh⁺ blood marries a woman whose blood is Rh⁻, the embryo will be Rh⁺ since this factor is a dominant one. This factor will reach the blood of the mother and induces it to produce certain antibodies which will in turn reach the blood of the foetus (see p. 566). As a result, blood agglutination takes place in the foetus. These are known as the **blue babies**; they may be born dead, or seriously ill, in which case all their blood can be replaced. In this case, the gene responsible for producing the Rh factor is represented by R, while the Rh⁻ is represented by r. An Rh⁺ individual may be either pure (RR) or hybrid (Rr) for this character. On the other hand, there is only one genotype for the Rh⁻ individual, namely rr. The inheritance of this factor may be illustrated as follows.

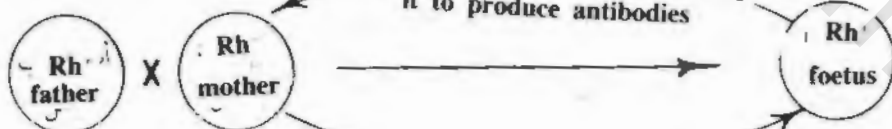


Blue baby suffering from Rhesus factor



Reaches mother's blood and induces

it to produce antibodies



Antibodies reach blood of foetus
Causes blood agglutination .

FAMILY PEDIGREE

The study of hereditary characters in human beings is very difficult as it is not easy to subject human beings to experimentation. Besides, the number of individuals produced after each cross or marriage is very small, and the period between successive generations is too long.

The inheritance of one character in a family of human being can be illustrated diagrammatically by a chart known as the **family pedigree**. Charts of this sort are useful to follow the inheritance of certain characters, particularly those related to diseases, and to predict on the probability of appearance of such characters in future generations. This is of particular importance in marriage advisory bureaus.

In family pedigree charts, the males are represented by squares and the females by circles. The squares or circles representing individuals carrying a certain character are blackened, while those referring to individuals not showing that character are left blank. The symbols of the parents are joined together by a horizontal line known as the **marriage line**. The children are represented below them, being connected to the marriage line of the parents by small vertical lines. Each generation is represented by a Roman figure and the individuals are represented by Arabic numbers. The group of sons and daughters produced by 2 parents is called a **sibship**, and the children themselves are called **sibs**.

Family pedigrees of some human traits

1 — Albinism

This phenotype is characterized by a marked deficiency or complete absence of pigment in the skin, hair and iris of the eye. It is due to a recessive gene represented by the letter *a*. Homozygotes *aa* are albinos, whereas *AA* and *Aa* are normally pigmented.

In one family of six individuals two albinos have occurred. The parents are normally pigmented, but they are presumably carriers *Aa*, and hence a combination of recessive genes *aa* occurred in the two albino sons. When one albino married a normally pigmented woman, they got 2 albino daughters and one normal son.

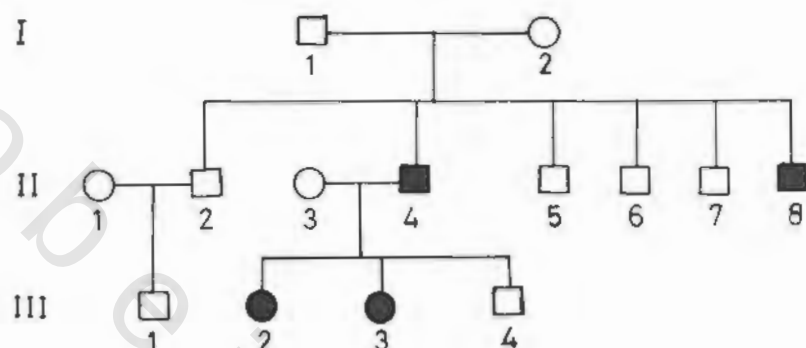


Albinism



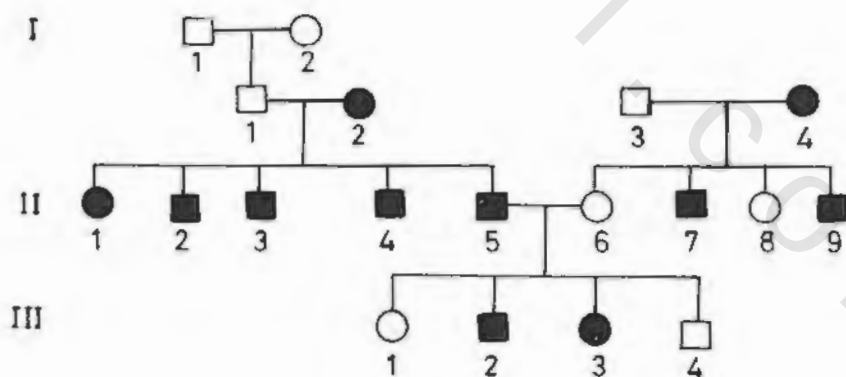
Three brothers born to two black parents carrying albinism
in a recessive manner

The inheritance of this trait is shown by the following pedigree chart.

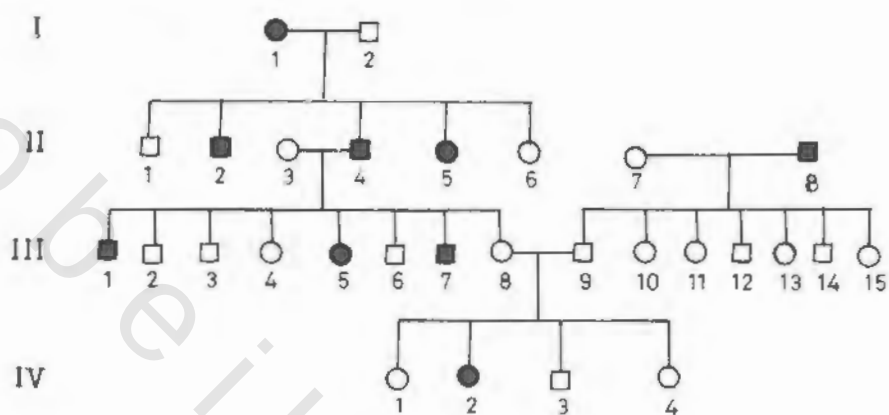


2 — Eye colour

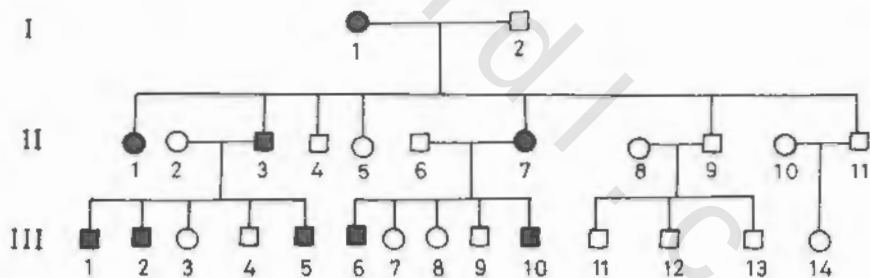
In human beings, brown eyes are dominant over blue eyes. The following chart shows the mode of inheritance of this human trait in one family.



3 — Left-handedness



4 — Polydactyly

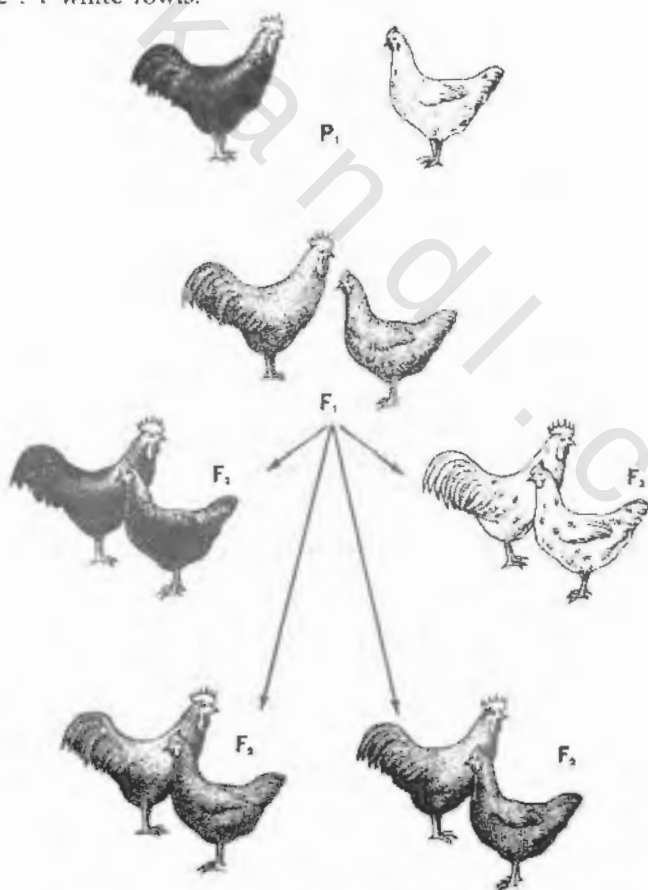


LACK OF DOMINANCE

In some cases of inheritance, the heterozygous individual may not show the same character as the homozygous dominant, but shows a phenotype intermediate between those of the two parents. In this case, the genes are said to exhibit incomplete dominance. Examples of this mode of inheritance are the following :

1 — Inheritance of feather colour in fowls

This case is clearly illustrated by the Andalusian fowls. When a black fowl is crossed with a white one, the F_1 generation shows a new colour not found in either parents. All members of this generation are dark blue in colour. This new colour is a blend between black and white. When two of the F_1 generation interbreed, the F_2 generation will consist of : 1 black : 2 dark blue : 1 white fowls.



Incomplete dominance in Andalusian fowls

From this example, it is clear that dominance of the black colour is not complete over the white one; a case known as **incomplete dominance** or **lack of dominance**.

P	Black BB	×	White bb
F₁	Bb	Bb	Dark blue
F₂	BB Black	Bb Dark blue	Bb Dark blue
		bb White	

2 — Inheritance of skin colour in cattle

Another example of incomplete dominance is found in certain cattle known as shorthorn cattle. When a red individual mates with a white one, the F_1 generation consists of roan individuals (roan is a blend between red and white).

P	Red RR	×	White rr
F₁	Rr	×	Rr
		Roan	
F₂	RR	Rr	Rr
			rr
	1 Red	2 Roan	1 White

In such cases of incomplete dominance, the pure strains are easily recognized externally from the hybrid ones, and there is no need to test their genotype. Black fowls and red cattle are pure; the dark blue fowls and roan cattle are heterozygotes.

3 — Inheritance of M-N blood types

When human blood is injected into the blood vessels of rabbits or any other mammal, certain antibodies are formed in the serum of these animals. These antibodies cause agglutination or clumping of human blood if mixed with it later. Blood of such animals is said to have been immunized against human red blood cells.

This phenomenon is due to the presence of certain substances in the

human erythrocytes known as **antigens**, which are of 2 types (M & N). Either one of these antigens or both may be found in a person. Thus, human beings are divided into 3 blood types according to the presence of one or two of these different antigens. These types are referred to as : M, N and MN groups.

People belonging to group M carry the antigen M in their red blood cells. These cells can be agglutinated by immune sera of rabbits injected with the blood of other M persons, i.e. by anti-M serum. Those of group N have the antigen N in their red cells, and their cells are agglutinated by anti-N serum. The third group of individuals, MN, possess both M and N antigens in their red blood cells, and these cells are agglutinated by both anti-M and anti-N sera.

Studies carried out on this subject, showed that the inheritance of the antigen M is due to a gene designated by the symbol M^n and that of the antigen N is symbolized by an allele of this gene, M^m . These 2 alleles differ from the other Mendelian traits in the fact that they do not show dominance over each other. Heterozygous persons $M^n M^m$ possess both M and N antigens in their erythrocytes and belong to group MN.

The different possibilities for the inheritance of these antigens are illustrated as follows :

a) Both parents of M group : P $M^n M^n \times M^n M^n$
 F_1 $M^n M^n$
 All M group

b) Both parents of N group : P $M^m M^m \times M^m M^m$
 F_1 $M^m M^m$
 All N group

c) One of M group and the other of N group :
 P $M^n M^n \times M^m M^m$
 F_1 $M^n M^m$
 All MN group

d) One parent of M group and the other of MN group :
 P $M^n M^n \times M^n M^m$
 F_1 $M^n M^n$ $M^n M^m$
 M group MN group

e) One parent of N group and the other of MN group :

P	$M^n M^l$	×	$M^m M^n$
F	$M^n M^n$		$M^n M^n$
1			
	MN group		N group

f) Both parents of MN group :

P	$M^n M^n$		×	$M^m M^n$
F	$M^n M^n$	$M^n M^n$		$M^n M^n$
1				
	M group	MN group		N group
	1	2		1

INCOMPLETE DOMINANCE

In such cases, the dominance of one allele is not complete over the other allele, but somewhat weak. Hence, the second allele also exerts its effect to a certain extent as shown in the following case:

Sickle cell anaemia

Sickle cell condition is the condition when the red blood cells exhibit a sickle or half-moon appearance. They have abnormal haemoglobin identified as haemoglobin-S whereas normal haemoglobin is known as haemoglobin-A. This abnormal haemoglobin contains the amino acid valine instead of glutamic acid which is an essential amino acid in normal haemoglobin. It is also characterized by its disability to hold oxygen, which is the important function of normal haemoglobin.

This disease is attributed to a recessive gene (s) whereas the gene for the normal condition is symbolized by (S+). The gene (s) for sickling has a lethal effect when found in a homozygous condition (ss). The homozygus usually dies of a fatal anaemia before reaching sexual maturity, though some may survive.

Heterozygous carriers (S s) are estimated to contain 25-45% abnormal haemoglobin. Thus, the single gene for sickling shows some degree of expression of this characteristic. These heterozygotes also suffer from some degree of sickling when exposed to conditions of extremely low oxygen concentration such as when they travel to a high altitude. In this case, anaemia might develop. Such heterozygotes are usually known to have the sickle cell trait.

Sex - influenced traits

In some cases, the dominance or recessiveness of certain genes in the male differ from those in the females under the effect of sex hormones, i.e. sometimes a gene may be dominant in the male but behaves as a recessive in the female. A gene of this sort is described as being sex-linked or sex influenced. It should be noted that these genes are carried on the normal body chromosomes or autosomes, not on the sex chromosomes. **Baldness** in human beings is an example of this case. It is an inherited character caused by a certain gene B which is dominant in the male and recessive in the female. Its recessive allele for normal hair is represented by b and is recessive in man but dominant in woman. Thus :

Genotype	Man	Woman
BB	bald	bald
Bb	bald	normal
bb	normal	normal

Examples showing the mode of inheritance of this character are illustrated in the following :

a) A marriage between a normal (non-bald) man and a homozygous bald female : In this case all the resulting sons will be bald, while all the resulting daughters will be normal.

P	Man	Woman
	bb	BB
	(Normal)	(Bald)
F₁	Bb	Bb
Result :	Sons	- All bald.
	Daughters	- All normal.

b) A marriage between a homozygous bald man and a heterozygous normal woman : In this case all the resulting sons will be bald, whereas half of the resulting daughters will be bald and the other half will be normal.

P	Man	Woman
	BB	Bb
	(Bald)	(Normal)
F₁	BB	Bb
Result :	Sons	- All bald.
	Daughters	- 1 bald ; 1 normal.

c) A marriage between a heterozygous bald man and a homozygous normal woman : In this case half of the sons will be bald and the other half will be normal, while all the female offspring will be normal.

P	Man	Woman
	Bb	bb
	(Bald)	(Normal)
F₁	Bb	bb
Result :	Sons - 1 bald : 1 normal.	
	Daughters - All normal.	

d) A marriage between a heterozygous bald man and a heterozygous normal woman : In this case $\frac{3}{4}$ of the resulting sons will be bald and $\frac{1}{4}$ will be normal. On the other hand, $\frac{1}{4}$ of the resulting daughters will be bald and $\frac{3}{4}$ will be normal.

P	Man	Woman
	Bb	Bb
	(Bald)	(Normal)
F₁	BB Bb	Bb — bb
Result :	Sons - 3 bald : 1 normal.	
	Daughters - 1 bald : 3 normal.	

From these data one understands why baldness is more common among men than among women.

Another example is illustrated by the length of the second (index) finger. The gene concerned with the abnormally short index finger is dominant in man and recessive in women.

In animals, the effect of sex-influenced genes is illustrated by the possession of horns in domestic sheep. The genes for the horned condition are dominant in males and recessive in females.

Sex-limited genes

These are the genes responsible for the appearance of certain characteristics in either the males or the females which are commonly known as secondary sexual characters. These genes are not necessarily located on the sex chromosomes, but may be found on any other chromosome.

An example of a characteristic in human beings controlled by such genes is the **beard** in man. The beard-producing genes are also found in women, but women do not usually have a beard. If some abnormalities occur in hormone secretion, a woman becomes bearded. Typical masculine hair will appear on her face and chest.

Similarly, a feminine **breast** is a characteristic of women, but if a man suffers from a disbalance in hormone secretion, he will have a feminine breast.

Such secondary sexual characters and other ones as the deep masculine voice and masculine musculature in man appear only in presence of the male sex hormones. In women, the genes responsible for such characteristics as the high pitched feminine voice and feminine musculature are capable of producing their effects only in the absence of male sex hormones, but the presence of female sex hormones is not necessary in such cases. Hence, when the testis is removed from a male (castration) so that no male sex hormones become available, that male will show the above mentioned feminine characteristics in spite of the absence of female sex hormone. However, the development of a breast in females necessitates the presence of the female sex hormones. It is therefore clear that some sex-linked genes can produce their effects only in the presence of the specific sex hormones and others produce their effects in absence of such hormones.

In animals, particularly in cattle, an example of sex-limited characters is illustrated by **milk production**. Genes responsible for this character occur in both males (bulls) and females (cows), but the character itself (milk production) is a characteristic of females only.

PROBABILITY IN GENETICS

It is of prime importance in the study of genetics to point out that the genetic ratios listed in the above mentioned crosses are only expressions of probability, but do not necessarily exist as such. Genetic ratios are essentially based on the laws of chance or probability. For example, if two heterozygous black guinea-pigs are mated, it is not necessarily that three of the offsprings will be black and one white in accordance with the typical Mendelian ratio 3 : 1. All might be black, or white or a mixture of black and white.

This can be explained by the laws of probability according to which if one tosses a coin, there is a chance or probability of $\frac{1}{2}$ or 50 % for either the head or the tail of the coin to come on the upper side. If two coins are tossed at the same time, the chance that the two heads will be on the upper surface is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ or 25 %.

In the above mentioned example of the two heterozygous guinea-pigs, the chance that any given sperm will possess the gene B is $\frac{1}{2}$ and the chance that it will possess the gene b is also $\frac{1}{2}$. This is also the same for the eggs. Therefore, the chance that an egg with B will be fertilized by a sperm with B is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ or 25 %. In other words, the probability of getting zygotes with BB is only 25 %. Similarly, the expected ratio for zygotes with bb is 25 %. On the same basis, the chance for the production of heterozygotes with Bb is 50 %. Hence, the expected ratio of BB : Bb : bb is 25 : 50 : 25 or 1 : 2 : 1.

If the above mentioned relation is applied in the case of marriage between a man and a woman who are heterozygous albinos, the chance to have an albino child is $\frac{1}{4}$ or 25 %. The expected ratio of albinos to non-albinos in the offsprings is 1 albino : 3 non albinos. This does not mean that this couple must have four children; they may have one, two or three children only. The probability of the first child to be albino is $\frac{1}{4}$ or 25 %. The chance for the second child to be also albino is $\frac{1}{4}$ or 25 %. The probability that both children are albinos is $\frac{1}{4} \times \frac{1}{4} = 1/16$.

The following equation can be generally applied to calculate the probability percentages in monohybrid crosses :

$$(P + q)^2 = P^2 + 2Pq + q^2$$

where P represents the frequency of one gene and q the frequency of its allele. Thus, if 50 % of gametes in a given cross carry gene P and 50 % carry its allele gene q, then this will result in 25 % of the offspring with PP, 50 % with Pq and 25 % with qq.

MENDEL'S DIHYBRID CROSSES

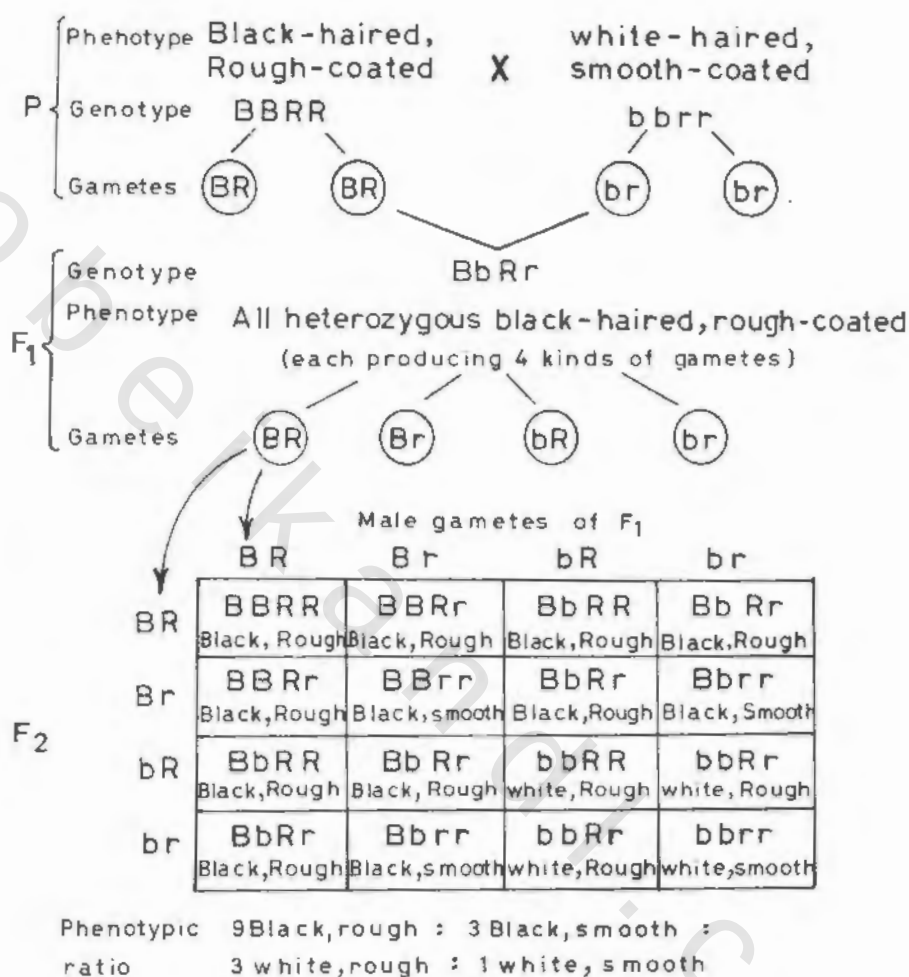
(Inheritance of two independent genes)

This case represents the mode of inheritance of two pairs of allelomorphous characters. A **dihybrid individual** is the result of a cross between two parents differing in 2 genes or 2 characters, each character is inherited independently of the other. In animals, this case is represented by the following example.

In guinea-pigs, 2 different pairs of alleles are present, namely black hair and rough coat, which are dominant over white hair and smooth coat respectively. If mating takes place between a male and female differing in these 2 pairs of alleles, the F_1 consists of individuals with black hair and rough coat. When a male and a female belonging to the F_1 generation mate with each other, the F_2 generation consists of the following :

- | | | |
|-------------------------------|---------------------|----------------------------|
| 9 black-haired, rough-coated | ————— | like the dominant parent. |
| 3 black-haired, smooth-coated | } New combinations. | |
| 3 White-haired, rough-coated | | |
| 1 white-haired, smooth-coated | ————— | like the recessive parent. |

The following checker-board shows the possible 16 combinations produced in the F_2 generation, with the gene for blackness represented by B and its recessive allele of whiteness by b; that of coat roughness is represented by R and its recessive allele by r.

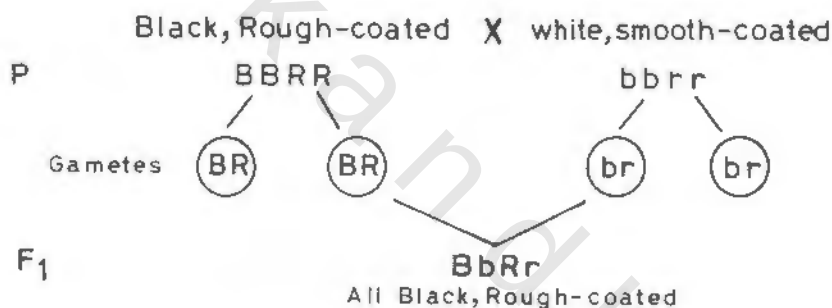


By considering each pair of characters separately, it is clear that the total number of black individuals in the F₂ generation is 12, whereas those showing the recessive white colour are 3, i.e. blackness appears in the ratio of 3 black : 1 white. Also, the rough-coated individuals are 12 while the smooth-coated ones are 3, with the same ratio of 3 : 1. It is thus obvious that each pair of alleles is still segregated or assorted in a manner totally independent of the other characters, and in the ratio of 3 : 1.

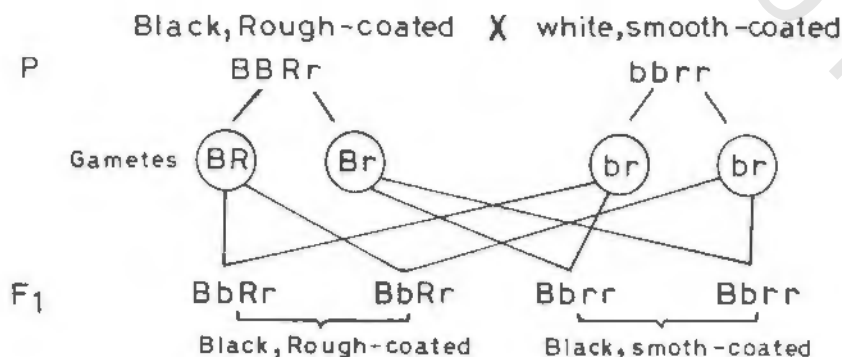
Identification of homozygous and heterozygous individuals in dihybrid crosses

In the above mentioned example, the individuals showing the 2 dominant characters (black-haired, rough-coated) may be either pure for both characters, or hybrids. They may be also pure for the first character and hybrid for the second, or vice versa. To identify these different types of individuals, they are back-crossed with a **double recessive** individual, i.e. an individual showing the 2 recessive characters. The possible results are :

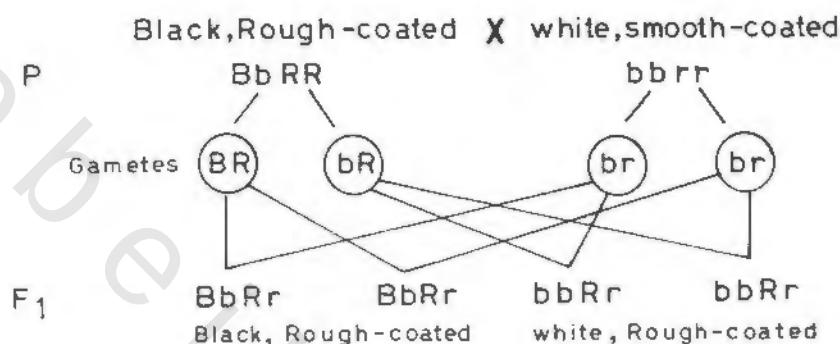
1 — If the resulting offspring consists totally of black-haired, rough-coated individuals, this indicates that the tested animals are pure for both characters.



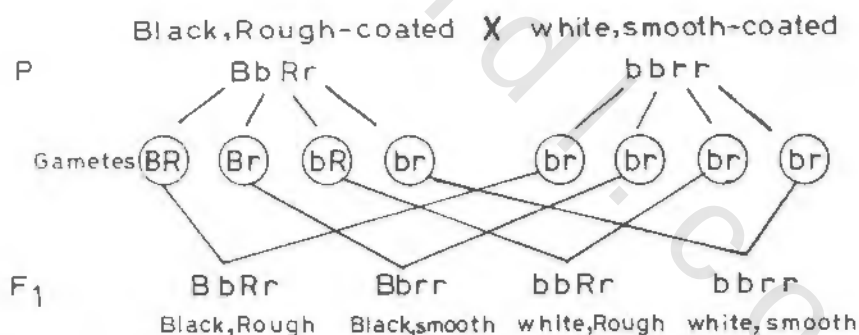
2 — If the tested individuals are pure for black hair and hybrids for rough coating, the offspring will consist of black-haired rough-coated and black-haired smooth-coated individuals in the ratio 1 : 1.



3 — If the black colour is not pure while rough coating is a pure character, the resulting offspring will consist of black-haired, rough-coated individuals and white-haired, rough-coated ones in the ratio 1 : 1.



4 — If the tested individuals are hybrids for both characters the resulting offspring will consist of black rough, black smooth, white rough, and white smooth in the ratio 1 : 1 : 1 : 1.



GENE INTERACTION

It has been nowadays realized that Mendel's laws of segregation and independent assortment of characters is not applicable to all hereditary characters in all sorts of organisms. In fact, the classical Mendelian ratios, such as 3 : 1 and 9 : 3 : 3 : 1, etc., do not apply as such to all genetic characters.

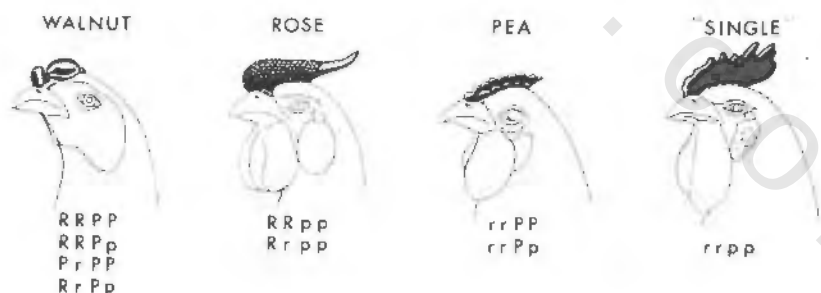
Genes are chemical units, each playing a special role in the basic biochemistry of the cell and of the organism. The influence of one gene may be reflected in many characteristics. Although each gene has a single action, yet the specific actions involved in basic chemical processes may have various effects on the organism. This concept of interaction in phenotypic expression emphasizes the importance of distinguishing clearly between genes and characters. The following are examples of gene interaction in animals:

Inheritance of combs in fowls

In this case, 2 pairs of alleles work together, or interact to produce a single character. This is the opposite of the usual cases of dihybrid crosses in which one pair of alleles produces its effect on a particular character of the organism while the second pair acts on another character.

Three types of combs are familiar in fowls namely pea, rose, and single types. Each character is pure and breeds true. The rose is dominant over the single, and crossing between individuals with these two characters results in all rose in F_1 , and 3 rose : 1 single in F_2 . The same is also true for the pea and single characters, the pea being dominant over the single.

But, when the pea is crossed with rose, the F_1 generation shows a new type of combs called the walnut type. The F_1 consists of : 9 walnuts : 3 rose : 3 pea : 1 single.

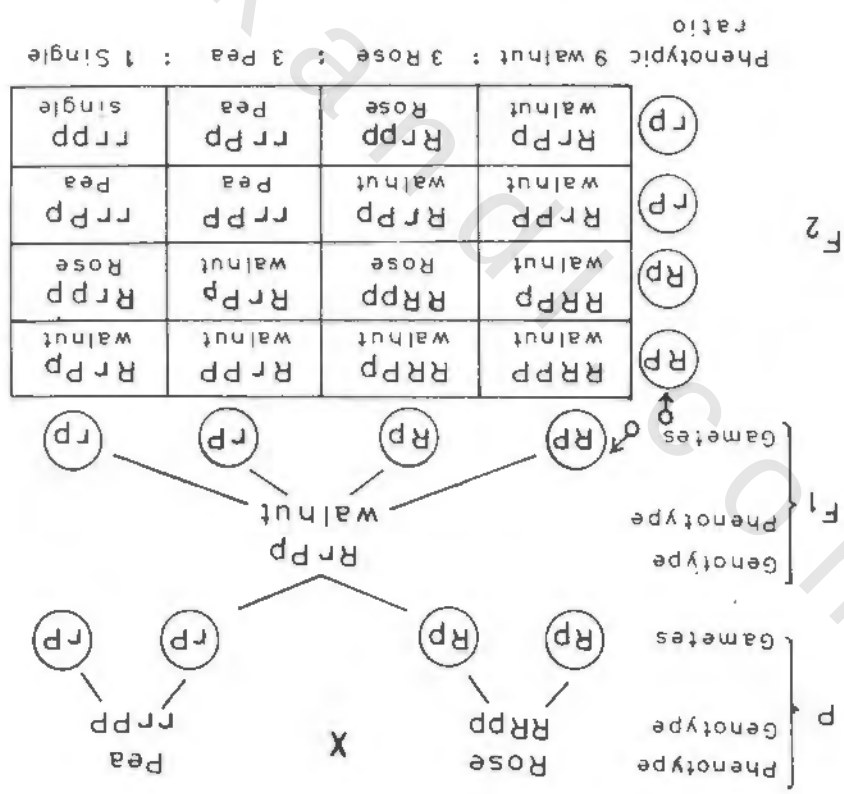


This clearly indicates that 2 pairs of alleles are involved in the inheritance of these characters. Studies carried out on this subject revealed the presence of 2 factors referred to by P and R. When the first is present alone, the comb is of the pea type, and if absent the comb is of the single type. On the other hand, if R is present the comb is of the rose type, and if absent the

comb is of the single type. If both factors P and R are present together, they produce the walnut comb. In other words, the walnut type is produced by the interaction between both factors. Such crosses are represented in the following manner, with the genotype of the rose comb designated as $RRpp$, that of the pea type as $rrPP$ and that of the single type as $rrpp$.

**Pea****Walnut****Rose****Single**

Structure of combs in fowls



INHIBITING FACTORS

In fowls of the leghorn type, there is a strain with white feathers and another strain with black feathers. Each strain breeds true for its character. But if a black fowl mates with a white one, the resulting offspring carries white feathers with black spots. After a certain time, the black spots disappear and the feathers become white. Such a case cannot be regarded as complete dominance because of the appearance of black spots in the early feathers. Also, it cannot be considered as a case of incomplete dominance since the intermediate character (white with black spots) is not a permanent one; it disappears after some time.

This case of inheritance is explained as follows : Feathers which are apparently white are in fact, coloured but their colour does not make its appearance due to the presence of a certain factor which acts to inhibit the gene producing that colour.

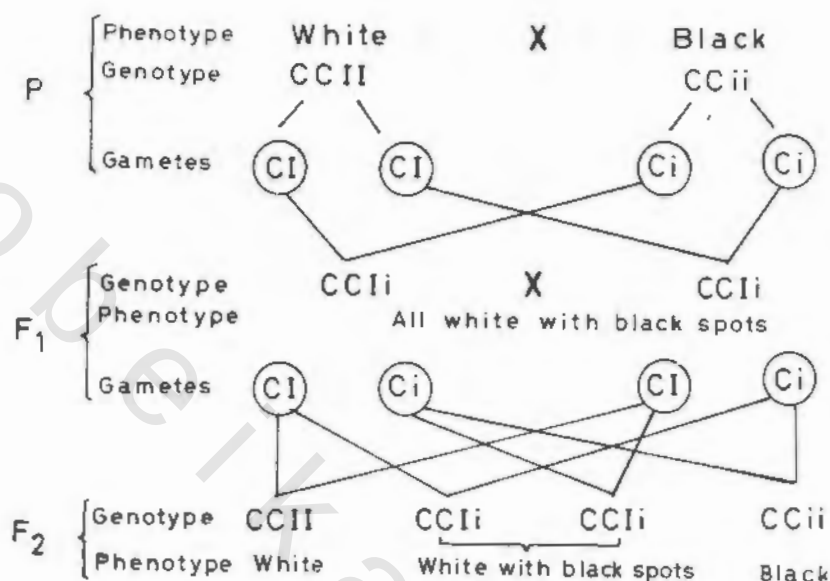
Thus, if C represents the colouring factor of the feathers and I represents the inhibiting factor, the genotype of the white fowls is represented as CCII. Black fowls resemble the white ones in having the 2 factors for black colour CC, but differ in carrying the recessives ii of the inhibiting factors which have no effect on the black colour. Thus the genotype of black fowls is represented as CCii.

In F_2 , 25 % of the individuals carry the inhibiting factors II in a homozygous form. They are white since these 2 factors act together to inhibit the black colour and prevent its appearance.

50 % of F_2 carry the inhibiting factor in a heterozygous form, i.e. Ii. These are white with black spots; a colour which soon disappears and the feathers become white. This is explained by the fact that the effect of a single inhibiting factor is weak and slow. That effect disappears after some time and the feathers become all white.

The remaining 25 % of F_2 do not carry the inhibiting factors, but carry their recessives which have no effect on the colour and therefore, such individuals possess black feathers.

This case of inheritance is represented as follows :



LETHAL AND SEMILETHAL GENES

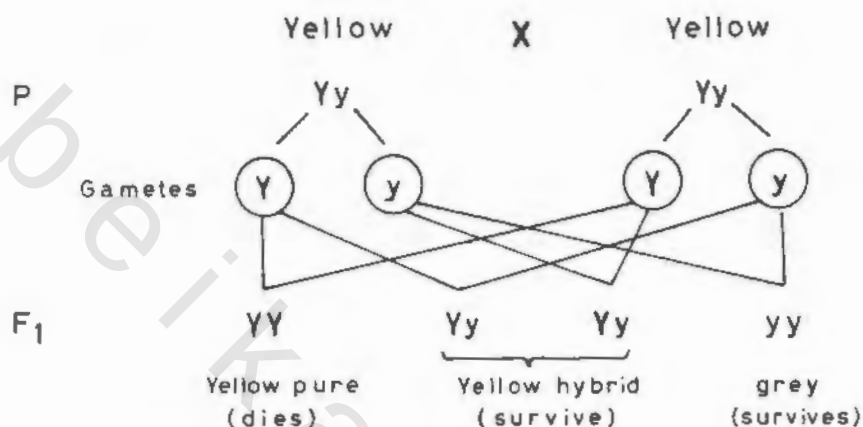
A lethal factor is one which, when present in a homozygous form, i.e. when contributed by both parents, causes the death of its carrier.

When the lethal factor is found in a single or heterozygous form, i.e. when contributed by one parent only, the individual may continue to survive, but it will transmit the fatal factor to the following generations.

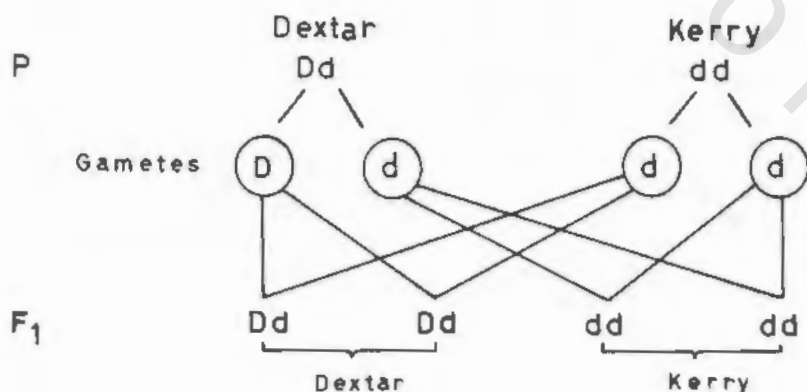
1 — The first known case of lethal factors was reported in mice. It was noticed that yellow mice never breed in the usual manner. When 2 yellow mice mate, their offspring is not all yellow as it is the usual case with homozygotes. The offspring consists of 2 yellow and 1 non-yellow (grey). When a yellow mouse is crossed with a grey one, the result is 1 yellow and 1 grey. These results clearly indicate that the grey colour is a recessive character, the yellow colour is a dominant character and that yellow mice are always hybrids. However, even if this is true, the ratio in F_1 should be 3 yellow : 1 grey (1 pure yellow — 2 hybrid yellow — 1 grey), and not 2 : 1 (2 hybrid yellow — 1 grey) as actually happens. This led to the conclusion that the pure or homozygous yellow must have disappeared in a certain way. Dis-

section of the uterus of the mother mouse showed the presence of the missing pure yellow individual dead at an early stage of development.

This is explained in the following manner in which Y represents the dominant yellow colour and y stands for the recessive grey colour.



2 — Another example of inheritance of lethal factors of economic importance is illustrated in the dextar cattle. This is a black Irish strain, with shorter legs than normal cattle. This type arose as a mutation from the original long-legged cattle known as kerry. The characters of dextar are dominant, and those of kerry are recessive. When a dextar mates with a kerry, the result is 1 kerry and 1 dextar a fact that shows which dextars are always hybrids.

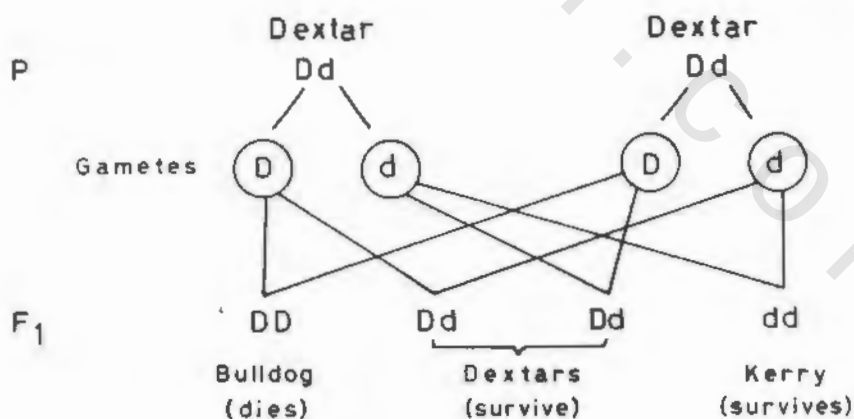


Dextar cattle carry a lethal factor designated as D . When this lethal factor occurs in a heterozygous manner Dd , the individuals are short-legged. Those which carry this factor in a homozygous form DD die just before birth. They possess much shorter legs and a very deformed shape. Such individuals are known as bulldogs.



Bulldog

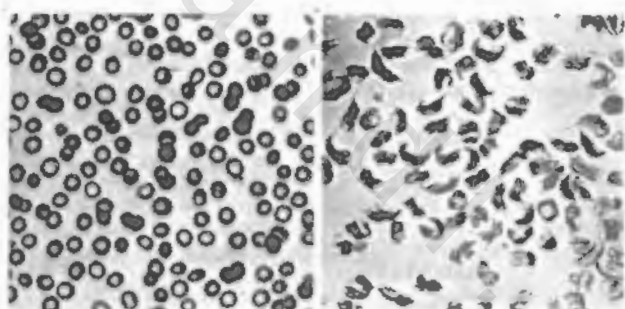
When 2 dextars interbreed, $1/4$ th of the resulting offspring are bulldogs and die before birth. Half of the individuals are dextars with short legs and survive normally. The remaining $1/4$ th are long-legged animals that live in a normal way, their offspring are always long-legged and never give bulldogs.



For this reason, animal breeders never allow the mating of two dextars; a dextar is allowed to mate only with a kerry.

3 — In man, the disease known as **amaurotic idiocy** well illustrates the effect of lethal genes. If the gene causing this disease is found in a homozygous manner (contributed by both parents), the infants appear to be quite normal at birth, but their eyesight fades gradually between the age of 4 - 7 years and eventually blindness occurs. This is accompanied by deterioration of mental and physical powers and death finally occurs.

4 — **Sickle - cell anaemia** is another example of the diseases associated with the lethal genes in Man. When this disease occurs, the red blood cells, under insufficient oxygen conditions, acquire a sickle (half moon) shape and become very fragile. This disease is brought about by a dominant lethal gene. The homozygotes usually die of a fatal anaemia before attaining sexual maturity. Heterozygotes look healthy, though they may show mild anaemia. Unfortunately, such cases cannot be identified by the microscopic examination of the blood, but the production of an offspring with the homozygous fatal anaemia could be avoided by preventing marriages between the carriers of this gene.



Normal erythrocytes

Sickle cells



Fingers of a child with sickle anaemia

5 — Another interesting example of the lethal genes is also provided by the syndrome known as **Phenyl ketonuria**. In this syndrome, the patients produce urine which gives a deep bluish-green colour on addition of a few drops of a 5% solution of ferric chloride. This test indicates the existence of phenyl pyruvic acid which is excreted in the urine of the patients, but metabolized in healthy individuals. The enzyme responsible for the metabolism of this acid is lacking in diseased individuals. Such patients also show certain mental disorders as well as fading in the colour of their skin and hair. They have a reduced life span and rarely have children.

6 — **Brachyphalangy** or shortened segments of the second fingers and toes is another example of lethal genes in man. It has a lethal effect if both parents carry it, leading to a homozygous condition with respect to that factor. A homozygous child usually dies one year after birth.

7 — **Thanatophoric dwarfism**, a genetic disorder in which the chest is much smaller in size than the belly. It is caused by a recessive lethal gene, which causes the death of their carrier at an early age when it exists in a double (homozygous) manner.



Thanatophoric dwarfism



Inherited dry skin

8 — **Congenital ichthyosis**, is also a genetic disease characterized by a very dry skin. It is also due to a recessive lethal gene which causes the death of the infant, when it is found homozygous, during the first week after birth.

Elimination of lethal genes

Recently a technique has been developed by which an individual with homozygous lethals in its gonads can be created and used in breeding. This happens as follows : two yellow mice for example are mated, then after the embryos have started their development, the abdomen of the pregnant female is opened and the embryonic mice are removed. Those which are homozygous for the lethal gene will show certain deformities that distinguish them from the normal ones. The ovaries are removed from the female homozygous embryos (YY) and are transplanted into the bodies of the newborn normal yellow heterozygous female individuals (Yy) from which the original ovaries had been removed. These females will grow and develop normally. All the cells in their body will possess Yy except the cells of the ovary which will possess YY. When a female of this sort reaches maturity, it will produce eggs which contain a Y factor. When such females are allowed to mate with grey males yy, the resulting offspring will be yellow mice having the genotype Yy and will live normally.

A similar operation is performed on embryonic calves. In this case, the ovary is removed from a bulldog (homozygous lethal, DD) and is transplanted into a female dextar Dd (See p. 109) This female grows with every somatic cell in its body containing Dd, but with the cells of its ovary containing DD. At maturity, the ovary produces eggs, each containing the factor D. When this female is allowed to mate with a male kerry dd, dextar individuals Dd are produced. In this way, the advantage of getting offspring of the big-sized dextar cattle is achieved without any losses possibly produced under the effects of the lethal genes.

Semilethal Genes

These genes, unlike the lethal genes which are sometimes called the complete lethals, cause the death to less than 100% of their carriers, but still more than 50% of these carriers usually die. An example of these genes is the gene responsible for the disease known as **epiloia** that is characterized by mental retardation, abnormal outgrowths on the skin and tumours in the internal organs. Some of the carriers of these genes die early during childhood whereas others survive and can even have children.



Epiloia

POLYGENES

(MULTIPLE OR CUMULATIVE GENES)

It is to be recalled that in case of Mendelian characters, each character (e.g. skin colour of mice, eye colour in man, etc.) is controlled by two genes and the traits produced by these genes show conspicuous and sharp differences as regards the quality of the character (e.g. grey and white mice; brown and blue eyes in man, etc.). Inheritance of such characters is known as **qualitative inheritance**.

Some characters, however, may be controlled by more than one pair of genes, which are located on different chromosomes. Each gene contributes only a certain quantity of the character. The more the number of genes involved, the more the character is intensified in the progeny. The effect of the genes in this case is obviously additive or cumulative, and this type of inheritance is known as **quantitative inheritance**. The hybrids produced in such cases are not all alike, but exhibit a gradual series of variations from one another. Examples of quantitative inheritance are those concerned with body weight, intelligence, meat yield, milk yield, resistance to certain diseases, fertility, etc.

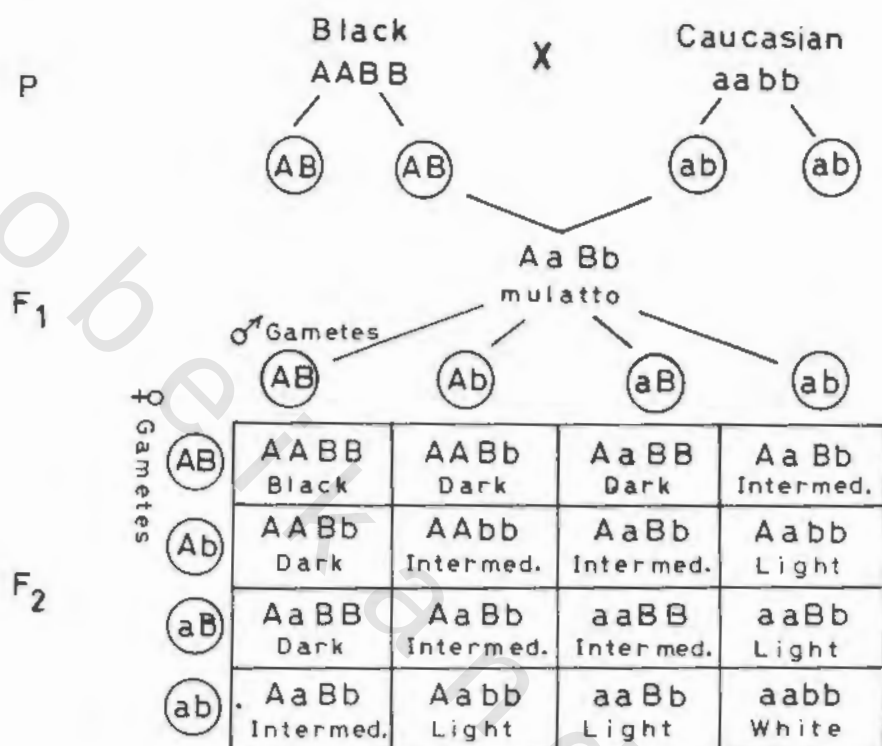
Inheritance of skin colour in man

A simple example is illustrated by the mode of inheritance of skin colour in man. Davenport, one of the first investigators of the skin colour problem in human beings, considered 2 pairs of genes to account for the difference in pigmentation between "Black" and "Caucasian" people. He found that the black pigment melanin, which is found in "black" people, was also present in varying amounts in the so-called "white" people, as well as in those with mixed ancestry.



An arbitrary scale was developed in terms of percentage, with albino people designated 0%, and the most heavily pigmented people as 100%. The average white individuals were found to have about 5-10% of melanin. The class with 10-25% of pigment was identified as light; 26-40% as medium (mulatto); 41-55% as dark, and 56-78% as black, although some black people may have up to 100% pigmentation.

Davenport's analysis was based on the presence of 2 pairs of alleles, each producing the same amount of pigment. Using the gene symbols A and B, the cross could be represented as follows :



Phenotypic ratio 1 Black : 4 Dark : 6 Intermediate : 4 Light : 1 White

It is therefore clear that if one parent is white and genetically pure $aabb$, the children would not be genetically darker than the other parent.

If, however, each parent carries one or 2 of the genes of pigmentation, combinations produce more intense pigment than that shown by either parents.

Inheritance of blood group alleles in man

Studies on the distribution of the blood groups (see p. 466) in the offspring of parents of known blood groups have shown that inheritance of these groups is determined by a series of 3 allelic genes, I^A , I^B , i .

I^A gene for group A

I^B gene for group B

i gene for group O

Both I^A and I^B are dominant over i . But I^A and I^B do not show any dominance over each other. A heterozygote with the genotype $I^A I^B$ belongs to group AB.

Also, the genotype for group A is either $I^A I^A$ or $I^A i$.

The genotype for group B is either $I^B I^B$ or $I^B i$.

The genotype for group AB is $I^A I^B$.

The genotype for group O is ii .

Determination of these factors is very helpful in many cases such as the disputed parentage or the accidental interchange of newly-born babies in hospitals.

The following table shows the possible as well as the impossible relations between parents and offspring as regards blood groups :

Parents	Children	
	Possible	Not possible
O O	O	A, B, AB
O A	O, A	B, AB
A A		
O B	O, B	A, AB
B B		
A B	O, A	
	B, AB	
O AB	A, B	O, AB
A AB		
B AB	A, B, AB	O
AB AB		

Child	one parent	Other parent	
	known to be	May be	Cannot be
O	O	O, B	
	A	O, B	AB
	B	O, A	
A	O		
		A, AB	O, B
	B		
B	O		
		B, AB	O, A
	A		
AB	A	B, AB	O, A
	B	A, AB	O, B
	AB	A, B, AB	O

Accordingly, if both parents belong to group O, they can never have a baby belonging to group A, and a couple of groups O and AB cannot possibly have a baby of group O, etc.

TWIN STUDIES IN GENETICS

The production of twins by many animals, and occasionally by human beings, provided useful models for the study of inheritance of several genetic characters.

There are two kinds of human twins : identical twins and fraternal twins. **Identical or homozygous twins** arise from a single zygote formed by the fusion of an egg and a sperm. The fertilized egg divides during early cleavage, by some sort of developmental accident, giving two separate embryos instead of one. In this case the resulting twins will have the same genotype, i.e. they will be of the same sex, have similar physical and physiological characters, and have practically the same mental abilities.

Fraternal or dizygous twins come from two different eggs, each being fertilized by a different sperm; hence they have different genotypes. They usually arise as a result of the simultaneous release of two eggs from the mother's ovaries, which are fertilized by two different spermatozoa.



Identical twins (3 months and 19 years old)



Fraternal twins

In animals like dogs, cats, mice, etc, multiple ovulation is the rule. This also happens in some human races (Japanese). Identical twins, on the other hand, appear sporadically in man and some other animals, and the causes of such accidents are not understood. In Armadillos, at least, a single egg regularly produces four embryos resulting in four identical individuals, and the process is thus under genotypic control.

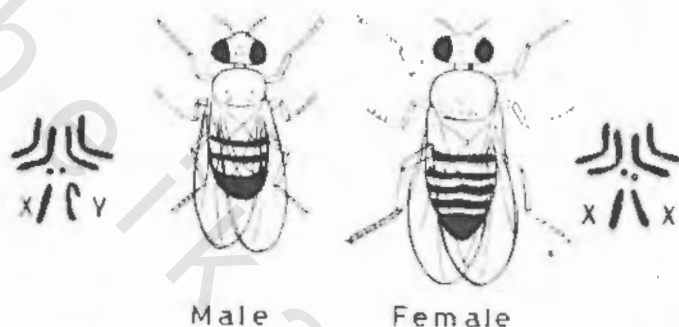
GENETIC DETERMINATION OF SEX

Previously, it was thought that the fertilized egg may develop into a male or a female according to certain external factors such as the type of the food taken by the mother, her health, or other physiological conditions. Also, some people were of the opinion that the left ovary gives females and the right one gives males. This is not true, simply because the mother can give males and females after the removal of one ovary.

Now, it is well established that sex is determined at the time of fertilization, or in other words, the time of mixing of the male and female chromosomes.

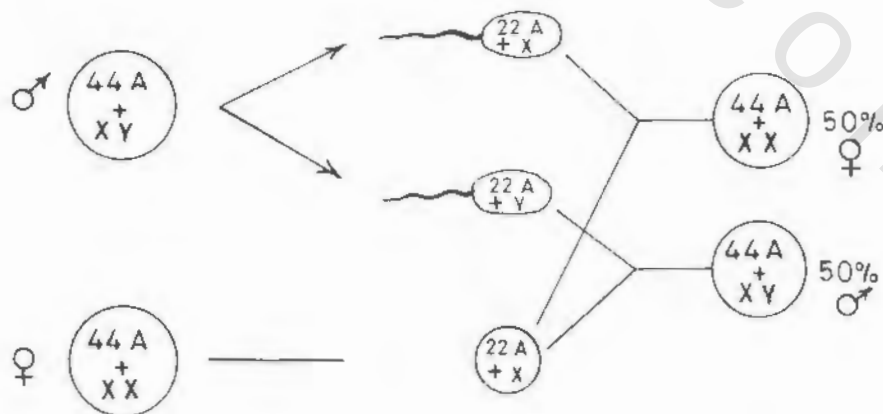
With advances in cytology, it became known that chromosomes are of 2 kinds : ordinary chromosomes, or **autosomes**, and other special chromosomes called **sex chromosomes**. The latter ones are concerned with the determination of sex.

In man and in some animals as the horse, monkey and the fruit fly *Drosophila*, there are 2 sex chromosomes which are exactly similar in every respect in the female, each being identified as the X chromosome. In the male, there is one X chromosome; the other one differs in shape and structure and is known as the Y chromosome. Thus, the male has XY chromosomes. The female has XX chromosomes and is thus described as being **homogametic**, while the male is **heterogametic**.



In man, all gametes produced by the female are alike, each containing 22 autosomes + X chromosome. But the male produces 2 types of sperms : one with 22 autosomes + X chromosome, and the other with 22 autosomes + Y chromosome.

When an egg is fertilized by a sperm containing X chromosome, the zygote will contain XX chromosomes, and will grow into a female. On the other hand, if the egg is fertilized by a sperm containing Y chromosome, the zygote will contain XY chromosomes and will grow into a male.



Probability in sex determination

The application of the principles of probability in genetics helps in obtaining some predictions as regards the sex of the offspring. All the eggs in human beings possess an X chromosome, whereas 50 % of the sperms possess an X chromosome while the other 50 % have Y chromosomes. Hence, there is a chance of $\frac{1}{2}$ or 50 %, for the offspring to be a boy, and the other $\frac{1}{2}$ chance to be girl. In case of two children, the chance for both to be boys is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$, and similarly, in case of three children the chance is $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = (\frac{1}{2})^3 = 1/8$. This means that in a survey of a number of families, each having only three children, it is to be expected that in 1/8th of these families all the three children are boys. Similarly, it is expected that in 1/8 th of these families, the three children are girls. The remaining 6/8 th of these families, each will have boys and girls together. In 64 families with six children each, there is a chance of $(\frac{1}{2})^6$ for families to have all their children boys. In other words, only $(\frac{1}{2})^6 \times 64 = 1$ family will have all their children boys. Similarly, only one family of these 64 families is expected to have all its children girls and the remaining 62 families have mixed boys and girls.

Sex determination and sexual abnormalities

The determination of the sex of the offspring is now believed to be controlled by certain genetic factors carried on the body chromosomes or autosomes and on the sex chromosomes. The type of sex is now regarded to be the resultant of the action of two opposed sets of genes, one set tends to produce the female characteristics while the other acts to produce the male characteristics.

a) In *Drosophila* : the male determining genes are found on the autosomes and the female determining genes are carried on the X chromosomes. The Y chromosomes are considered to be of no importance in this respect, except in the elimination of one of the X chromosomes in case of the female offspring. The male producing genes in the autosomes are more effective than those found in one X chromosome. Hence, the existence of a single X chromosome in the zygote (either XO or XY) results in a male. Nevertheless, males produced as a result of the existence of a single X chromosome are sterile, which shows that the Y chromosome plays a role in fertility.

On the other hand, the effect of genes of the two XX chromosomes overcomes the effect of the male-producing genes in the autosomes, and hence the zygote XX develops into a female. Thus, it is clear that the sex is decided by the genetic balance between the male and female genes in each individual. Flies with 2 X chromosomes and a Y chromosome produce normal fertile females. It is therefore clear that the Y chromosome does not affect the development of feminine characteristics.

It is regarded that a Single X chromosome contains female-influencing genes with a strength relatively estimated as 1.5, while a haploid set of 3 autosomes (which occur in the egg or sperm and are referred to as the autosomal genome) contains male-stimulating genes with a relative strength of 1.0. The strength of the Y chromosome = 0 as it has no sex-affecting genes. Hence a zygote with 6 autosomes (2 haploid sets or 2 autosomal genomes) and 2 X chromosomes will have male and female-determining genes in the relative strength ratio 2:3. The strength of the female-affecting genes is therefore greater and this zygote will accordingly develop into a female. A similar result is obtained from a zygote with 6 autosomes + XXY. On the other hand, a zygote with 6 autosomes + X + Y chromosomes possesses the strength of 2 for masculinization and 1.5 for feminization and this gives a male.

In cases of non-disjunction in which 2 X chromosomes remain together in one pole of the egg cell during cell division and are fertilized by a sperm containing an X chromosome, a zygote with 6 autosomes and 3 X chromosomes is produced with the ratio of the male to female strength 2 : 4.5. These develop into **super females** which, contrary to what their name may imply, have low viability, are rather sterile and have underdeveloped sexual characters.

A fly containing the Y chromosome, but not the X chromosome usually dies early as it lacks the genes on the X chromosome which are essential for the completion of their development. On the other hand, a zygote with 6 autosomes and a single X chromosome will survive, but it will give a sterile male.

In case of zygotes containing 3 haploid sets of autosomes (9 autosomes or 3 autosomal genomes) + XX chromosomes produce individuals referred to as **intersex** in which the strength ratio is 3:3, i.e. intermediate between the two sexes. Those containing 9

autosomes + X + Y chromosomes (sex ratio 3:1.5) will give what are known as **supermales**.

All these different cases are summarized in the following table:

Chromosome complement	Sex ratio	
	(male : Female)	Type of sex
6 autosomes + xx	2:3	Normal Female
6 autosomes + XXY	2:3	Normal Female
6 autosomes + XY	2:1.5	Normal male
6 autosomes + XXX	2:4.5	Superfemale
6 autosomes + Y	2:0	(Dies)
6 autosomes + X	2:1.5	Sterile male
9 autosomes + XX	3:3	Intersex
9 autosomes + XY	3:1.5	Supermale

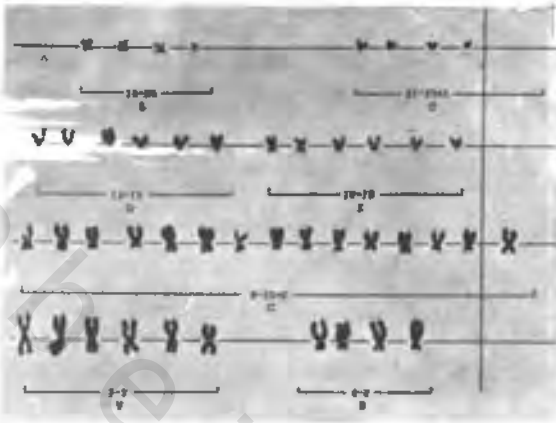
b) In man : the Y chromosome differs essentially from that of *Drosophila* in containing potent male - determining genes which are capable of predominating the effects of the female - determining genes found in the X chromosomes. Without the Y chromosome maleness is never produced.

The existence of one Y chromosome even together with 2X chromosomes (XXY) in a zygote will produce a male, but this male is always sterile. This abnormality is known in Genetics as **Klinefelter's syndrome**. This syndrome was named after its discoverer Klinefelter (1942). It is estimated to occur in the ratio of 1 : 10000 of male births. Individuals with this syndrome are tall, possess a masculine phenotype, but their testes are much smaller than normal and their semen is devoid of sperms. This syndrome is occasionally associated with mental retardation, as they also have female-like hair and fat deposits together with some degree of breast development. These individuals possess 47 chromosomes. It is regarded that the Y chromosome in man contains some male-stimulating genes but their effects are not fully expressed and the 2 X chromosomes lead to the suppression of male characteristics and the initiation of female characteristics.

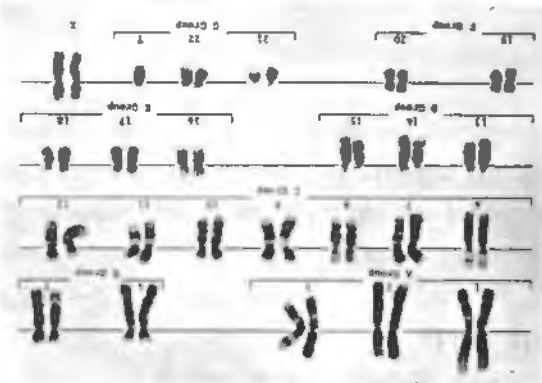
The existence of a single X chromosome and the absence of the Y chromosome in human zygotes leads to the development of females with small body size and infantile mammary glands. Their gonads are vestigial or



Turner's syndrome



Klinefelter's syndrome



completely absent and they never menstruate. Such a case is known as **Turner's syndrome** after the name of Turner who noticed it for the first time in 1938. This syndrome was found to occur in the ratio of 1 : 3000 births, though 90% of these cases die before birth. However, this syndrome occurs in the ratio of 1 : 5000 of the living persons. The X chromosome can bring about the development of the female body, but the presence of the two X chromosomes are required for the development of normal ovarian tissue and the secretion of hormones essential for completion of femaleness development.

Hormones and sex-determination

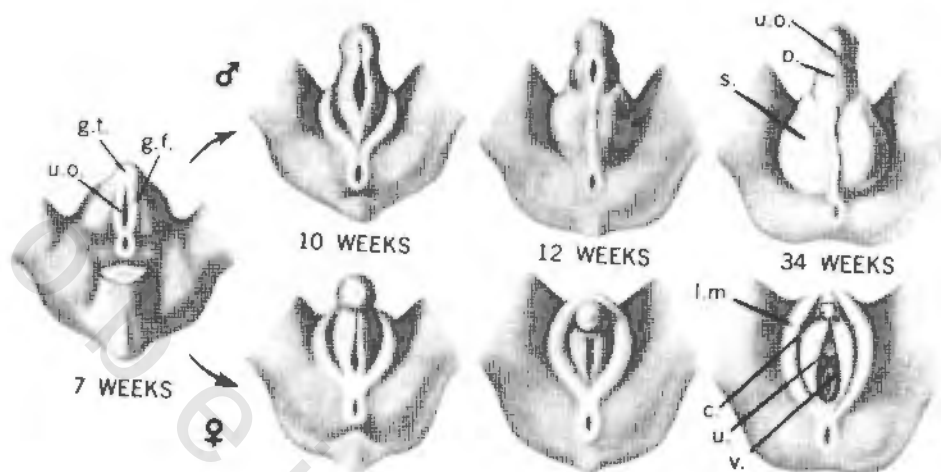
A. In human beings

The type of sex of the individual is essentially determined by the sex chromosomes. Nevertheless, there are certain factors, namely the sex hormones, that also play an important role in the attainment of sexual characteristics. These hormones are secreted by the male and female gonads. The influence of the sex hormones is clear from the fact that the removal of the testes (castration) from boys before reaching adolescence results in suppression of male characteristics, e.g. no beard is developed and their voice and musculature are not masculine-like. Also, the removal of the ovaries (ovariectomy) from young females will not allow the expression of feminine characteristics.

In general, each animal contains genes capable of producing male traits and genes responsible for production of female traits. These genes, together, with other factors, act to influence sexual development. It is therefore clear that animals possess a genetic ability to develop into males or females.

In some animals, such as different groups of worms, the genes of maleness (masculinizing genes) have equal strength to the feminizing genes. In such cases, and in the absence of other factors, the animal will be hermaphrodite (contains both male and female sexual organs).

The integration of the role of sex chromosomes and sex hormones in this respect can be explained briefly as follows : In the early embryonic development, the genitalia are the same in human embryos of both sexes. There is a small protruding genital tubercle, a small uterus, a small vagina.



Development of genitalia in human beings

c. = clitoris

g.f. = genital fold

g.t. = genital tubercle

l.m. = labia majora

Development of genitalia in man

P = penis

S = scrotum

U = uterus

u.o. = urinogenital opening

V = vagina

a urinogenital opening and two genital folds of skin on either side of the vagina. Two gonads, usually known as the **ovotestes**, are found. Each is differentiated into an inner testicular tissue and an outer ovarian tissue. Embryos resulting from an XY combination are supposed to develop into males. Hence, the testicular tissue enlarges in size and secretes the male hormones which stimulate further development of the testicular tissue and inhibits growth of the ovarian tissue in the ovotestis. In this case, the genital tubercle enlarges to form the penis and encloses the urinogenital (urethral) opening. The two genital folds on either side of the vagina enlarge to form the scrotum which encloses the testes when they descend from the body cavity after birth. In this case, the rudimentary uterus remains undeveloped. These changes usually take place at the end of the second month of embryonic development. It is clear that the female sex organs represent the basic type of sexual development.

On the other hand, the embryo developed from a zygote containing XX chromosomes develops into a female. The ovarian tissue in the

ovotestis enlarges and inhibits the testicular tissue which persists as rudimentary protions in the centre of the ovary. The genital tubercle remains small forming the clitoris, but it does not surround the urinogenital (urethrel) opening as in males. Meanwhile, this opening is divided to form the openings of the urethra and vagina. The vagina and uterus continue their development and attain their functional maturity at puberty. The two genital folds on either side of the vagina develop into the outer lips of the female genitalia and are known as labia majora.

B. In other mammals

In some other mammals, in which experimental work can be carried out on embryonic development and differentiation, it was postulated that there is a hormone-like substance secreted by the whole cells of the body and plays an essential role in sex-differentiation. In this case, the sex chromosome balance in the body cells determines whether these cells will secrete male or female stimulating substances. These substances, in turn, stimulate the early development of the gonads into male or female ones. When the gonads reach a certain degree of development they start to take the role of further sexual differentiation and complete the whole process leading to full expression of sexual characteristics. Therefore, the early removal of the ovary from a developing young female fowl resulted in the loss of feminine characteristics and even in the appearance of the testes. Also, the removal of the testis (castration) from a young male sheep prevented the development of the horns.

Sex reversal

It is now clear that sex determination is a result of combination of chromosomal and hormonal factors. In some cases in which chromosomal or hormonal effects become unbalanced, several degrees of sex intergrades will appear. Examples are the intersexes in *Drosophila* (p. 543) and Klinefelter's and Turner's syndromes in man (p. 545).

As previously mentioned, it is apparent that the female sex organs represent the basic type of sex differentiation. This is clear from the fact that these organs will develop in spite of the non-existence of any sex

hormones. But these organs do not complete their development and become sexually mature unless the female hormones are present. Nevertheless, male hormones can produce an alteration of the basic female organs, and male organs can be formed. This phenomenon sometimes takes place incidentally as a result of hormonal unbalance in the body. For example, an old hen which has been known to lay eggs regularly and normally for several years starts suddenly to display male characteristics. Spurs appear together with development of a male comb, begins to crow and is inclined to mate with females. It also can produce fertile sperms which ensure proper fertilization. It is clear that certain changes have taken place in the body which caused such hen to release the inhibition caused by female hormones which has long suppressed the effects of genes responsible for maleness. Consequently, male-stimulating genes become active and are capable of producing male characteristics.

This was explained by the fact that birds have only one ovary, the left one, which contains a central portion of testis-like tissue. In normal conditions, the ovary produces the female hormones which bring about the full expression of female characters and inhibit those of maleness. In some cases, the ovary becomes infected and is consequently destroyed. As a result, the testicular tissue included in it is released from the inhibiting effects of female hormones and starts to produce male hormones. Thus, it enlarges and secretes further amounts of hormones that cause the reversal of sex from a typical female to a typical male.

Sex reversal can also be carried out surgically by removal of the ovary leaving the inner testis-like structure, or removal of the whole ovary and transplanting a testis instead. In a few months following the operation, the bird attains the full male characteristics. Similarly, the removal of the testes from an immature male and their substitution by an ovary will result in sex reversal and the rooster becomes a typical hen.

The same is also true for mammals in which sex reversal is successfully produced by removing the gonads surgically from one sex and its substitution by gonads of the opposite sex. In human beings, if the ovary is removed from a young girl followed by treatment with male hormones, she will change into a person with complete



Bearded lady

masculine appearance and is even indistinguishable from typical males. However, in such cases. It is not expected to find complete change in the genital organs which have reached an advanced stage of development since birth time. Nevertheless, they show a great extent of variation from typical females.

Gynanders in human beings

Gynandromorphism is a phenomenon recorded in some insects and is concerned with the existence of a male tissue on one side of the body and a female tissue in the other (p. 76). The first part contains XY chromosomes in the constituent cells, whereas XX chromosomes are found in the female tissue cells.

A similar case is also noticed in human beings and is referred to as human gynanders (half man and half woman). Such a person shows curious peculiarities; a masculine chest on one side and a feminine breast on the other side, a hairy muscular leg on one side and a delicate smooth leg on the other and even he can talk with a deep masculine voice from one side of the mouth and then can change to a higher — pitched feminine voice from the other side.

Pseudohermaphrodites

There are several cases of intersexual conditions in human beings with characteristics of both sexes in one body. These cases are referred to as pseudohermaphrodites, to be distinguished from hermaphrodite animals which normally have male and female organs in their bodies and produce sperms and eggs. A hermaphrodite human has the complete sex organs of both sexes and shows secondary sexual characteristics which are intermediate between the two sexes.

An interesting case was recorded in this respect. A baby was born to two normal parents who were told by physicians that they had a baby girl. On reaching adolescence, this person decided not to be a girl but a boy and started to behave like a boy. At the same time, masculine characters developed, though not to the usual extent found in a normal man. This person married a normal woman at the age of 24 and lived a normal married life. Later, he was examined at the age of 42 and it was found that he had fully developed sex organs of both sexes. The breast development was that of a girl of about 15 years old and the musculature and voice were intermediate between the two sexes. He had a normal beard but his hair was not heavy.

Other cases were reported in which a pseudohermaphrodite can decide to be a male or female. In this case, an operation can be made to remove the ovarian or testicular tissue and it was recorded that two years following a similar operation the person has gained full characteristics of the chosen sex.

Such phenomena are attributed to the occurrence of unbalance in hormonal secretions but not in the chromosomes.

SEX-LINKED CHARACTERS

The genes located on the X or Y chromosomes are known as **sex-linked genes** and the characters they control are called the **sex-linked characters**. Such characters are not only those concerned with sex determination, but include some other body characters, such as colour blindness, night blindness, haemophilia, etc. **Colour blindness** is a disease characterized by the inability to differentiate between colours, especially the red and green ones.

Night-blindness is the disability to see clearly in the dim light. **Haemophilia** is a disease in which the blood of the patient fails to coagulate properly when a wound or cut occurs in the body. This causes haemorrhage which may lead to serious results.

Sex-linked genes are double in the homogametic sex, but are single in the heterogametic sex. The Y chromosome does not contain any genetic factors of considerable importance apart from those necessary for the determination of maleness in human beings.



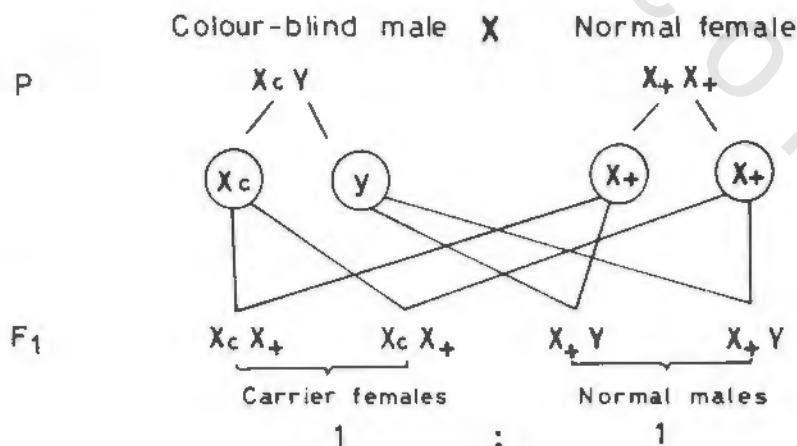
Haemophilia

Inheritance of colour blindness

In the inheritance of sex-linked characters in general, it should be remembered that the Y chromosome comes to the male from the father, and the X chromosome from the mother. Thus, sex-linked characters in males are derived from the mother only.

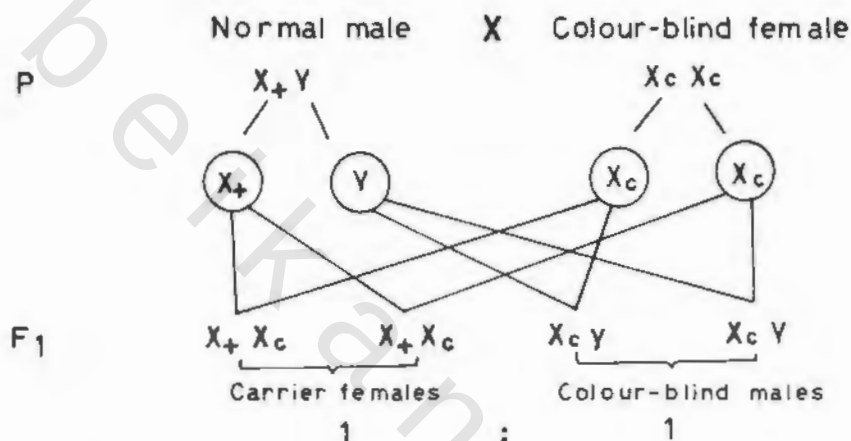
Colour blindness is a recessive character. It appears in the female only when it is carried on the 2 X chromosomes. But in the male, the disease appears when it is carried on the X chromosome of the male. Hence, this disease is more familiar in males, and rare in females.

The possible modes of inheritance of such character are :

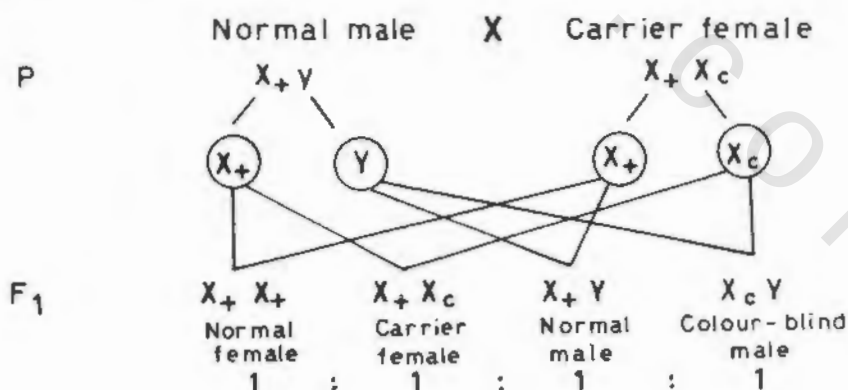


1 — If a diseased man marries a healthy woman, all the offspring will be healthy but the females are carriers of the disease. This case is illustrated as follows, provided that c denotes colour blindness and $+$ represents normal vision.

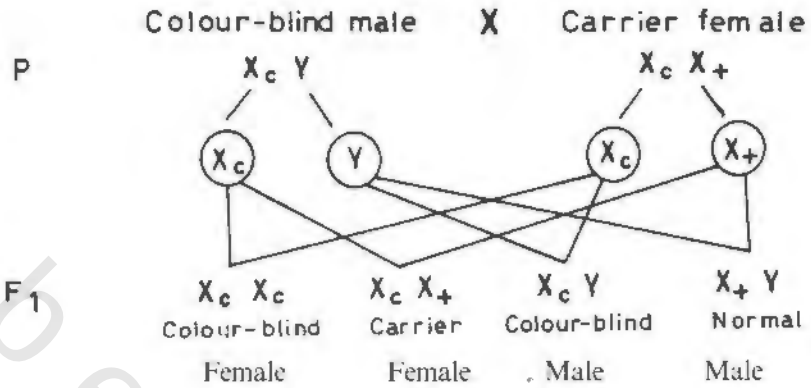
2 — When a healthy man marries a diseased woman, the female offspring is healthy but carry the disease, while the males are all diseased.



3 — If a healthy man marries a female carrying the disease, half of the males are diseased and the other half are healthy. All the females are healthy, but half of them are carriers of the disease.



4 — In case of marriage between a diseased man and a carrier female, half of the female offspring are healthy and the other half are carriers. Also, half of the males are diseased and the other half are healthy.



Inheritance of hairy ears

Genes responsible for this trait are located in the Y chromosome. Hence, its presence is only confined to men.



Inheritance of hairy ears

LINKAGE

Linkage in genetics involves the study of inheritance of genes located together on one chromosome. Such genes are called **linked genes**. The different chromosomes carry variable numbers of genes. In the fruit fly, *Drosophila melanogaster*, for example, there are 4 chromosomes carrying hundreds of genes; chromosome 1 carries about 500 genes, and chromosome 4, which is the smallest one, carries about 10 genes. Linked genes are transferred together from the parent to the offspring. Inheritance of these genes differs in its mechanism from the inheritance of free or independent assortment of genes which involves genes located on different chromosomes.

A clear example of linkage is provided by *Drosophila melanogaster*, in which the grey colour G is dominant over the black colour g , and the character of long wings L is dominant over vestigial wings l . The 2 factors concerned with the body colour and length of wings are linked together on one chromosome.

When a grey fly carrying long wings $GGLL$ is crossed with a black fly with vestigial wings ggl , the resulting offspring consists of grey flies with long wings $GLgl$.

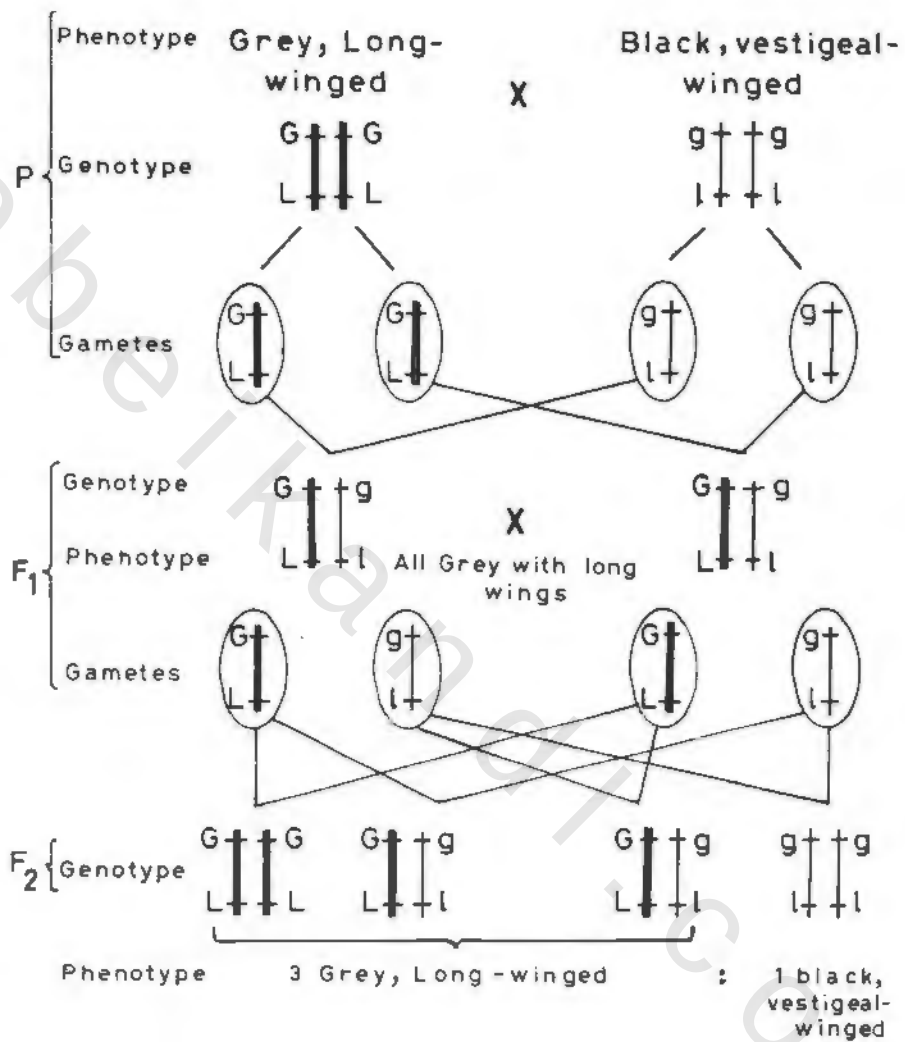
When two F_1 individuals interbreed, they produce gametes of 2 kinds only, not 4 kinds as in case of independent assortment; the gametes formed are GL and gl . (If it was a case of independent assortment, the gametes formed should have been : GL, Gl, gL and gl)

The second generation or F_2 , thus consists of :

- 3 individuals with grey colour and long wings, and
- 1 individual with black colour and vestigial wings.

In every case, the gene of colour is always linked with the gene of wings and they pass together from generation to generation.

This case is diagrammatically illustrated as follows :



CROSSING OVER

As indicated above, linkage exerts severe restriction upon the possible variability among organisms. But such limitation is compensated for by another mechanism which acts to increase the variability. This mechanism is known as **crossing over**. Crossing over may be defined as the mutual exchange of blocks of homologous genes, located on the two members of a homologous pair of chromosomes, during meiotic division.

When a dihybrid heterozygous grey female *Drosophila* with long wings (Glg) is back-crossed with a double recessive male black fly with vestigial wings (ggl), the resulting offspring will consist of :

Grey long : Black vestigial : Grey vestigial : Black long

41.5 % 41.5 % 8.5 % 8.5 %

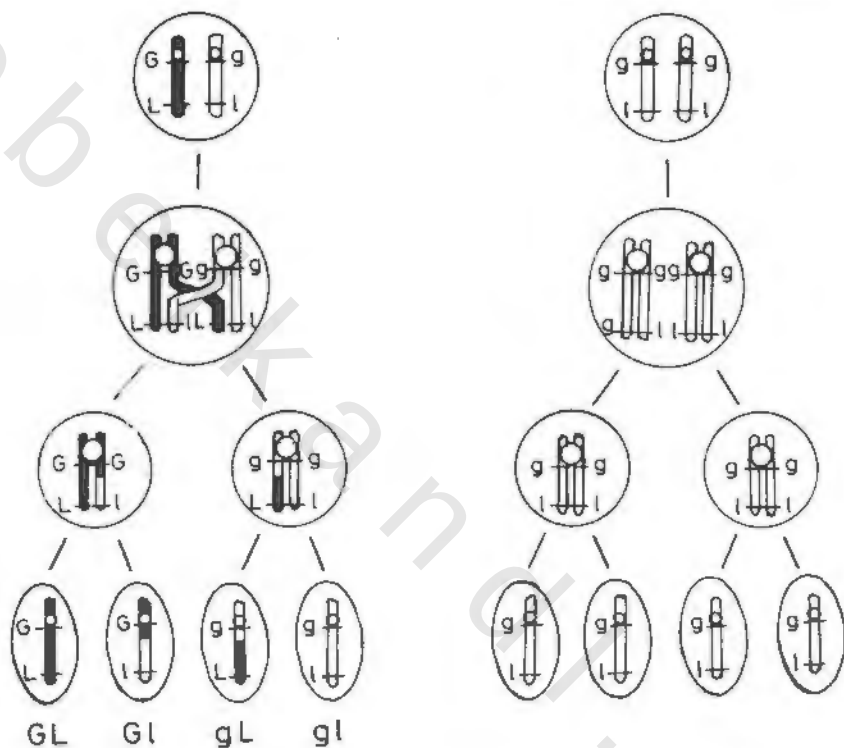
This ratio is different from the 1 : 1 : 1 : 1 ratio which is usually obtained in normal back-crosses. The original combinations (Grey, long) and (black, vestigial) make up only 83 % of the total offspring, instead of 50 % in case of independent assortment. The rest of the offspring are new combinations which make up 17 % of the total number. Such new combinations are known as recombinations or **crossovers**.

The 17 % new combinations are produced as a result of interchange of parts, or crossing over between the 2 chromatids of the hybrid. It should be emphasized that crossing over takes place only between the 2 internal chromatids of 2 homologous chromosomes; no crossing over occurs between the 2 outer chromatids.

Thus, 4 types of gametes are produced by the heterozygous female : GL, Gl, gL and gl. On the other hand, one kind of gametes are produced by the male, namely gl, as follows :

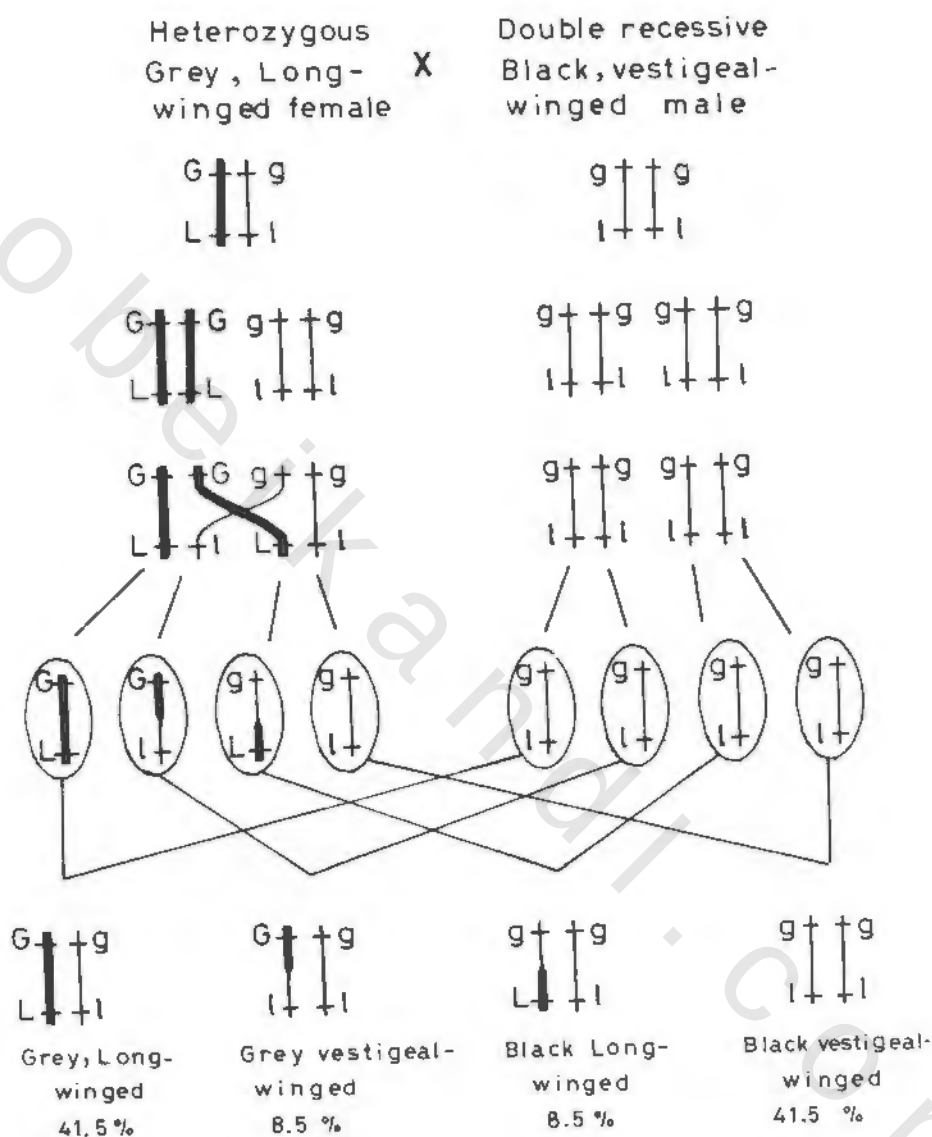
Heterozygous
female: Grey,
Long-winged

Double recessive
male: black
vestigial-winged



Production of gametes, with crossing over during meiosis in the female gametes only.

The whole case is represented as follows :



It has also been found that when 2 genes are located very close to each other in the same chromosome, the chances of crossing over between them is small; they tend to remain linked together. But when the genes are far apart from each other, there will be a greater chance for crossing over to take place between them. For such genes, there are always certain fixed ratios for crossing over. This percentage is equal to half of the average fre-

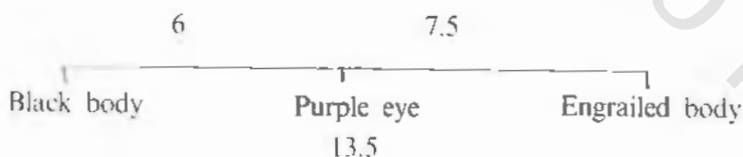
quency for crossing over between the 2 genes. This is because in crossing over, only 2 of the 4 chromatids interchange.

The case of *Drosophila*, in the above mentioned example in which there are 17% recombinations, it is assumed that there is a distance of 17 units between the 2 genes. The frequency of crossing over in this case is 34%.

CHROMOSOME MAPS

The different gene combinations were thoroughly studied by Morgan and his collaborators. They found it more convenient to represent the results graphically by the construction of maps for each chromosome showing the topography and respective locations of the genes on it. Chromosome maps have been constructed for maize, hen, mouse, sweet pea and other organisms. Also, in human beings, a series of genes were mapped on the sex chromosome.

Mapping the genes on a chromosome is illustrated in *Drosophila*, for example, in the following manner. In this fruit fly, there are 2 recessive genes, namely black (body colour) and purple (eye colour), both on chromosome 2. The crossover ratio of these 2 genes is 6%. A third gene "engrailed" (body character) lies on the same chromosome as the other 2 genes. Its crossover ratio with purple is 7.5%. The ratio of crossover between black and engrailed is 13.5%, which is the sum of the two other ratios. These 3 genes may be arranged on a graph or chromosome map as follows :



MUTATIONS

A **mutation** is defined as a new character, not known before, appearing due to a sudden change which takes place in the corresponding gene. Thus, mutations include all the changes which occur in the hereditary material and are capable of altering the phenotype of the individual. Such changes include the alterations which take place in the minute particles of the genes, as well as those which take place in the structure and number of the chromosomes. The new phenotypes arising in these cases are called **mutants** and the new characters are inherited in successive generations.

Mutation may be so severe that it produces a drastic change in the form of the individual, or it may be very weak appearing only when associated with other genes.

Types of mutations

Mutation may occur in cells and at any stage in the cell cycle. The immediate effect of mutation and its ability to produce phenotypic changes is determined by its degree of dominance, the type of the cell in which it occurs, and the stage in the life of the cell when it happens. Thus, mutations are classified into the following types :

1 — Somatic mutations

This is the type of mutation which takes place in a somatic cell, which in turn produces other cells like itself. In this case, the mutant change will only appear in the organs that arise from the original cell in which the mutation occurred, e.g. the delicious apple has resulted from mutation that occurred in somatic tissues.

2 — Germinal mutation

If dominant genes occur in germ cells which have the ability to reproduce the whole organism, the effects may be expressed immediately in the offspring.

If such genes are recessive, their effects may be observed by other genes. But if they are dominant, their effects will appear directly in the resulting offspring.

In order to be transmitted through the usual sexual process, a mutation must be in the germ cells. Germinal mutations, like somatic mutations, may occur at any stage in the cycle of the organism but they are common in certain stages, particularly during the division of the chromosomes. If the mutation arises in one of the gametes produced by the individual, a single member of the resulting offspring may receive the mutant gene. On the other hand, if a mutation occurs during an earlier stage of gamete formation, several gametes may receive the mutant gene, and therefore, many individuals may contain it.

In any case, the dominance of the gene and the stage in the cycle of the cell when the mutation occurs are important factors in determining the extent to which the mutation is distributed in the following generations.

The earliest recorded germinal mutation in domestic animals was observed by Wright in 1791. He noticed a peculiar male lamb with unusually short legs in his flock of sheep. He thought it would be an advantage to have a whole flock of the short-legged sheep, which could not get over the low stone fences. Therefore, he used this new short-legged male in breeding. The next season, he got 15 lambs. Two of these lambs were short-legged. Short-legged sheep were then bred together. The mutation that gave rise to the short-legged sheep was obviously of the germinal type because the cell carrying the mutation had the capacity to produce an entire organism.

3 — Zygotic mutations

These mutations occur just at the time of fusion of the male and female gametes to produce the fertilized egg or zygote. The resulting mutation appears in the individual produced by this zygote.

Spontaneous and induced mutations

Mutations are produced in two ways, *viz.* spontaneously and artificially :

1 — Spontaneous mutations

These are the mutations which appear suddenly in animals or plants without any induced agents. Examples are the short-legged lamb which appeared in Wright's flock of sheep. The Dextar cattle is also a mutation which resulted from Kerry individuals. Also, in the early 20th century, a worker discovered a branch on his orange tree which bore a peculiar type of oranges without seeds. This variety was also a spontaneous mutation which was the beginning of a new trait of this type of oranges. Another example of a plant mutation which is of value to man is the seedless grape.

2 — Induced mutations

These are the mutations which result under the effect of certain physical or chemical agents. One of the well known scientists in this field is Müller (1927). He showed that the mutations of *Drosophila* could be markedly increased by treating the flies with X-rays. The mutations thus produced were similar to those produced spontaneously, but they were much more numerous. These mutations occur as a result of certain destructions which take place in the chromosomes under the effect of X-rays. In *Drosophila*, the gene for the red eye pigment can be mutated in a certain way to produce a white pigment. Gamma-rays and ultraviolet-rays are also capable of producing mutations.

Certain chemical agents have also been shown to produce and increase mutations. These include mustard gas, methyl cholanthrene, phenol, ethyl urethane, etc. Formaldehyde, which is used commonly as a preservative for materials in zoological laboratories, has also certain mutagenic effects.

Two factors usually govern the effects of chemical mutagenic substances. These are :

a) The ability to penetrate the cells.

b) The ability to alter in some way the chemical structure of the genetic material within the cell.

These physical and chemical agents act to produce certain changes in structure and number of the chromosomes. Part of the chromosome may be broken and lost from the cell, or may be translocated to another chromo-

some. In some cases, a whole chromosome may be lost. The loss of a part or of a whole chromosome is known as **chromosome deletion**, and the changes which take place in the treated chromosomes are known as **chromosomal aberrations**.

In another case, the mutagenic agents produce certain disturbances in the arrangement of the chemical particles forming the different genes, and thus causing the production of mutation. This case is rather something like changing the orientation of the particles forming a monosaccharide to form another monosaccharide with the same particles.

Significance of mutations

A mutation may be of advantage to the individual or may be disadvantageous. It is useful when it makes the individual much more suited to the surrounding conditions. Some mutations are also of economic importance such as those which lead to the production of more eggs, more milk, or more meat, etc. The advantages can be increased by selection, and breeding.

On the other hand, a mutation may be harmful to the individual bearing it. Examples are the absence of eyes or horns, reduction of wings, albinism, idiocy, total colour blindness, haemophilia, etc. Some of these mutations are lethal to the individuals.

MEDICAL GENETICS

Besides the various examples of human characteristics mentioned in the foregoing pages, there are still several other ones which are of great importance in the studies of human heredity. The following table includes a list of some human traits with reference to their mode of inheritance :

Trait	General notes on its nature	Mode of inheritance
Hair	— Dark , dominant over red hair.	Dominant gene.
	— Hypertrichosis (excessive amounts of hair on the body).	Dominant gene
	— Heavy, bushy eyebrows	Dominant gene
	— White forelock (a tuft of white hair in the centre of the forehead).	Dominant gene
	— Mid-digital hair (existence of hair on the middle joint of the fingers).	Multiple genes.
Eyes	— Astigmatism (abnormality in vision due to unequal curvature of the cornea which causes objects in one plane to be in sharper focus than objects in the other plane).	Dominant gene.
	— Glaucoma (the fluids within the eye chamber exert pressure which causes the destruction of the optic nerve causing blindness. This disease starts in middle ages and can be prevented by surgery).	Dominant gene.
	— Optic atrophy (degeneration of optic nerve leading to blindness).	Recessive, sex-linked gene.
	— Cataract (development of an opaque condition of the lens or cornea).	Dominant gene.
	— Red-green colour blindness.	Recessive, sex-linked gene
Eyelids	— Cryptophthalmos (the two eyelids remain attached in the embryo and the baby fails to open its eyes).	Recessive gene.
	— Ptosis (or dropping eyelids, being unable to use the muscles that raise the upper eyelids which therefore remain dropped over the eye).	Dominant gene.
Ears	— Attached ear lobes.	Recessive gene.
	— Deafness.	Two recessive genes.
Nose	— High convex bridge of the nose.	Dominant gene
	— Straight or concave bridge of the nose	Recessive gene.
	— The wings (which spread out from the point of the nose) :	
	* The widespread wings.	Dominant gene.
	* The narrow wings.	Recessive gene.
Lips	* The higher wings (in which the openings of the nostrils are clearly visible from a side view).	Dominant gene
	* Upturned tip of the nose	Recessive gene.
	— Harelip (clefted upper lip as in the mouth of hares).	Recessive gene.
	— Absence of some of the upper incisors and molars.	Dominant gene.
Teeth	— Absence of enamel.	Sex-linked dominant gene.
	— Brown enamel of the teeth.	Sex-linked recessive gene.
	— Looped tongue	Dominant gene.

Trait	General notes on its nature	Mode of inheritance
Chin and checks	— Reduced chin. — Elongated chin. — Dimple in cheeks. — High Cheek bones.	- Recessive gene - Multiple genes. - Dominant gene. - Dominant gene.
Fingers and toes	— Arachnodactyly (extreme long fingers and toes — spider-fingered). — Short index (second finger).	Dominant gene.
	— Crooked fingers. — Left handedness. — Clubfoot (an inward turning of the foot so that the person walks on the outer side of the foot).	- Sex-influenced (dominant in man and recessive in women). - Recessive gene. - Recessive gene. - Recessive gene.
Skin	— Flat foot. — Vitiligo (unpigmented spots on the skin). — Freckles (small dark spots due to accumulation of pigments). — Xeroderma pigmentosum (extreme sensitivity of skin to sunlight leading to malignancy). — Epiloen (butterfly rash, accompanied by tumours and death before maturity but some may survive). — Anidrotic ectodermal dysplasia (absence of sweat glands).	- Recessive gene. - Dominant gene. - Dominant gene. - Recessive gene. - Semilethal. Dominant gene. - Sex-linked dominant gene.
Skeleton	— Chondrodystrophic dwarfism (normal head and trunk, but limbs greatly reduced). — Atelotic dwarfism (all parts of skeleton reduced in size in a proportional manner). — Osteo-chondrodystrophy (normal limbs, but shortened trunk). — Osteopsathyrosis (very fragile bone leading to bone abnormalities) and accompanied by otosclerosis (defect in ear bones leading to deafness) and white sclera. — Exostoses (cartilagenous and bony outgrowths). — Rickets	- Dominant gene. - Recessive gene. - Sex-linked, recessive. - Multiple dominant effects of a single gene. - Dominant gene. - Dominant gene.
Muscles	— Pseudohypertrophic muscular dystrophy (gradual wasting away of the muscles leading to death in early stages. It is not known in girls).	Recessive gene.
Nervous System	— General intelligence. — Schizophrenia (tendency to retire from the world of reality).	- Multiple genes. - Dominant gene with intermediate expression
Blood	— Anaemia (pernicious anaemia). — Varicose veins (Bulging of veins under skin of legs).	- Recessive gene. - Dominant gene.



Looped tongue



Muscular dystrophy



Short index

Trait	General notes on its nature	Mode of inheritance
Diseases	— Diabetes mellitus. — Allergy (Those who develop allergies early in life are homozygous for a gene that makes them easily sensitized. Those who develop allergies after puberty are heterozygous and those who do not become easily sensitized are homozygous for the normal allele). — Some types of Cancer. — Gout (excessive production of uric acid with attacks of arthritis, and chalky deposits in the cartilages of the joints).	Recessive gene. Multiple alleles Dominant gene.



Attached earlobe



Normal ear lobe



Dwarfism



Tall and short finger



Twisted foot



Spider fingers (arachnodactyly)



chondrodystrophic dwarfism

EUGENICS

Eugenics is mainly concerned with the application of the principles of heredity to improve the mankind. Several aspects are taken into consideration in this respect.

Medical treatment

The recent advances in the field of medicine in general and surgery in particular have made it possible to overcome the serious effects of many inherited genes. A baby suffering from erythroblastosis foetalis (blue baby) as a result of marriage between an Rh- father and an Rh- mother would survive normally if his blood is extracted and replaced by new blood. Also, a baby with an inherited abnormality in his heart in which deoxygenated blood can be mixed with oxygenated blood, would die, but with surgical treatment, this deformity can be corrected and the person leads a normal life.

Controlled segregation

In many serious cases concerned with lethal inheritance or mental diseases, marriage is to be prevented so that such persons carrying these genes do not get children. This will control the propagation of defective genes among human population. If such marriages can not be avoided, sterilization of such people is necessary. In such cases, they can experience a normal marital life, but they will not have children that might suffer from these dangerous effects of such harmful genes.

Birth control is also very important in this respect. It can be achieved by the use of several kinds of contraceptives.

Consanguineous marriages

Since a long time, it has been realized that marriages between close relatives is liable to result in weak generations with various defects. This can be explained by the fact that a considerable number of the harmful genes are recessive, and in marriages between closely related individuals, such genes have greater chances to express their effects.

Genetic counselling

Genetic counselling clinics are commonly found in many parts of the world. Specialists in these centres can offer advice to people suspecting the occurrence of any genetic defects in their offspring as a result of the existence of such defects in members of the family. In such cases if a man knows that there is a probability that his children might have the abnormality or disease he may seriously think about applying any restrictions to having children.

MOLECULAR GENETICS

Structure and function of genes

Genes were usually identified as unit factors of heredity which are found in certain locations on the chromosomes and are responsible for the determination of the phenotypic characteristics of living organisms. The actual nature of genes and their precise role in heredity remained unknown for a long time. Recently, with advances in biological studies, it became known that genetic characteristics are the end products of certain biochemical reactions taking place inside the living cells. Hence, a new branch of science known as **Molecular Genetics** has been formulated to deal with the chemical and physical nature of the genetic material, and with the mechanism by which genes act to control the phenotypic characteristics of the individual.

It is now known that genes control the different chemical reactions which take place in the cells. They even act in certain ways to control the production of the different enzymes necessary to catalyze those reactions and control the synthesis of body proteins. These different reactions finally interpret the phenotypic constitution of the individual. In other words, modern gene-

tics is now explained in terms of enzymes, proteins, and the chemical reactions taking place in the cells.

What is a gene ? A gene or "genome" is now identified as a certain length of the **deoxyribonucleic acid (DNA)** molecule, the essential constituent of the body chromosomes, which specifies the amino acid sequence of a specific protein

DEOXYRIBONUCLEIC ACID (DNA)

DNA is now regarded as the principal hereditary material in the living cells. It is the material which stores the genetic information in the cell and transmits it from one generation to another. This is clear from the following example : Pure DNA extracted from a particular strain of bacteria characterized by a special feature (e.g. having a sugar-containing capsule) was added to a culture of another strain of bacteria lacking this feature. The latter strain was left to reproduce and the resulting offspring was examined. A considerable number of the offspring was found to acquire that new character and to transmit it to the following generations.

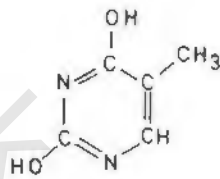
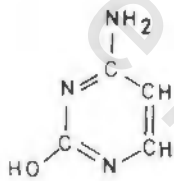
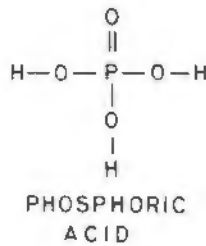
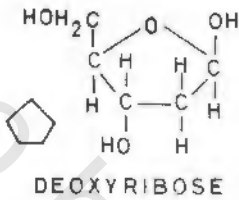
Chemical structure of DNA

DNA usually constitutes the major part of the body chromosomes; in some instances it forms 90-95 % of the substance of the chromosome. Other chemical substances entering in the composition of chromosomes are ribonucleic acid (RNA), histones, and nonhistone proteins.

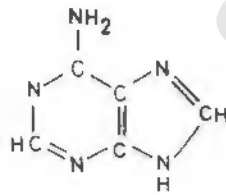
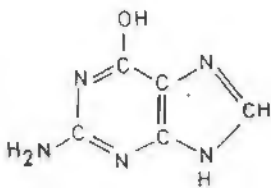
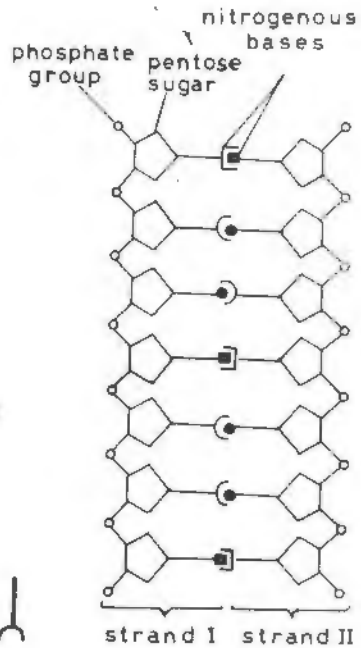
DNA is an organic substance built up of simpler units called **nucleotides**, hence it is also known as a **polynucleotide**. Each nucleotide consists of 3 molecules : a **pentose sugar (deoxyribose)**, to which a molecule of **phosphoric acid** is attached on one side, and a molecule of **nitrogenous base** on the other side.

Phosphoric acid-Pentose sugar - Nitrogenous base
(deoxyribose)

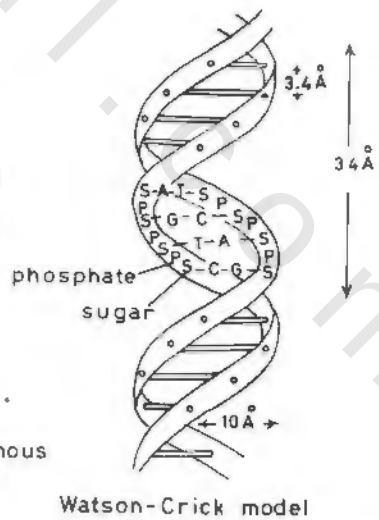
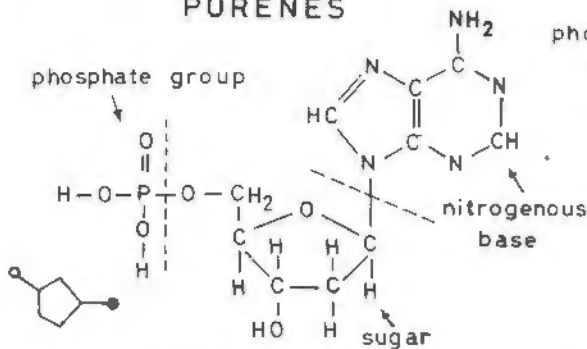
Generally speaking, the molecule of DNA is extremely long. Its molecular weight ranges from 500,000 to several millions. A single molecule of DNA may be built up of many thousands to several millions of nucleotides.



PYRIMIDINES



PURENES



STRUCTURE OF DNA

Two major kinds of nitrogenous bases are found in DNA, **purines** and **pyrimidines**. Pyrimidines are monocyclic, each having a six-membered ring; but purines are dicyclic, each consisting of two such rings. Purines include **Adenine (A)** and **Guanine (G)**, and Pyrimidines include **Cytosine (C)** and **Thymine (T)**. The ratios of purine and pyrimidine bases differ in different samples of DNA, but the total amount of purines equals the total amount of pyrimidines ($A + G = T + C$). It has also been found that the amount of adenine in the DNA molecule is equal to the amount of thymine ($A = T$); and that of guanine is equal to the amount of cytosine ($G = C$). DNA isolated from mammalian tissues was generally rich in adenine (A) and thymine (T), and relatively poor in guanine (G) and cytosine (C).

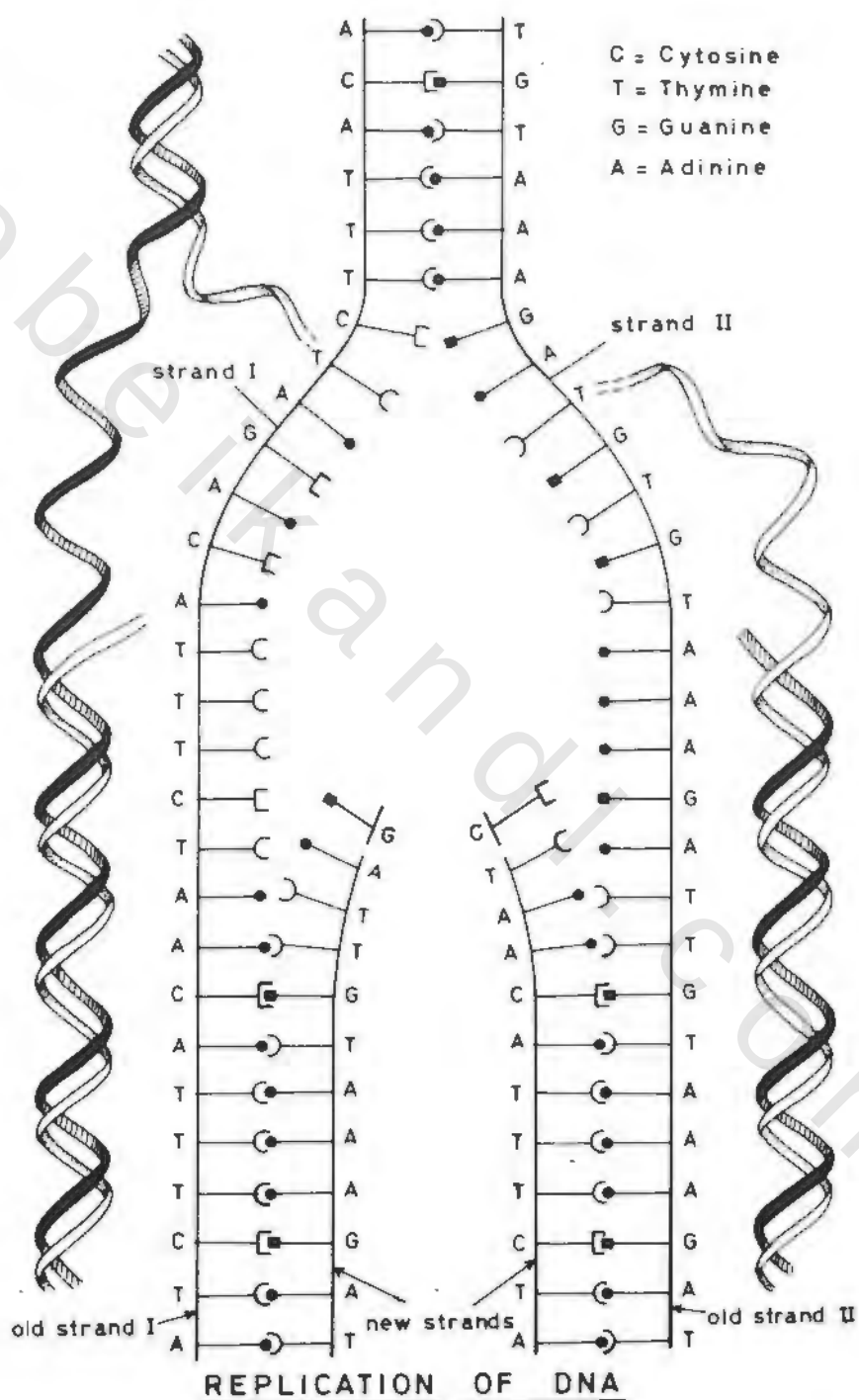
Molecular organization of DNA

Several studies have been carried out to reveal the molecular organization of DNA. The most satisfactory and acceptable findings are those of Watson and Crick (1953). These authors proposed a molecular model which has been widely accepted as representing the natural structure of the DNA molecule. Watson and Crick were given the Noble Prize in 1962 for their work, which marked the beginning of a new era of research in biology.

The model introduced by Watson and Crick consists of two pentose-phosphate chains arranged in a double entwined helical structure and bound together by pairs of nitrogenous bases linked by hydrogen bonds. In other words, the DNA molecule consists of two longitudinal strands bound together in the form of a double helix. Each strand is built up of a linear assembly of smaller molecules known as **deoxyribonucleotides**. Each of the deoxyribonucleotide molecules consists of : one of the 4 nitrogenous bases + deoxyribose sugar + phosphate group. Adjacent molecules of the deoxyribonucleotides are linked together to form a strand, with the sugar of one molecule joined to the phosphate of the neighbouring molecule.

There may be as many as 40 million deoxyribonucleotides along one strand of a single DNA molecule. This repeating pattern is observed at intervals of 24-34 Å, i.e. a complete turn occurs every such distance, and thousands of such turns are present in a single molecule.

Moreover, in each deoxyribonucleotide molecule, the base on one strand is linked to the base of the neighbouring strand by hydrogen bonds. Thus, the long DNA molecule can be regarded as resembling



a ladder in which the banisters or sides consist of alternate sugar and phosphate molecules, and the rungs or steps consist of nitrogenous bases joined centrally by hydrogen bonds. This ladder may be further imagined as twisted in the form of a compact double helix or spiral

Watson and Crick pointed out that the double-stranded structure of DNA is stabilized by the nitrogen bases (purines and pyrimidines) which point toward each other and unite together by hydrogen bonds. Furthermore, it was realized that each of the horizontal bridges holding the two strands of the double helix together consists of a purine and a pyrimidine. This was assumed on the basis that there is no enough space between the two strands for 2 purines (dicyclic) to occur together. Also the space between the two strands is too wide for 2 pyrimidines (monocyclic). Hence, each bridge must be formed of a purine and pyrimidine capable of forming hydrogen bonds in between them as follows :

Adenine-Thymine and Guanine-Cytosine

It follows that the sequence of the bases along one strand of a DNA molecule must be different from that of the opposite strand of the same molecule. Wherever there is an adenine (A) on one strand, there is a thymine (T) opposite to it on the other strand, and wherever there is a cytosine (C) on one strand, there is a guanine (G) on the other. That is why it is said that the 2 strands of a DNA molecule are complementary to each other. If the sequence of nucleotides in one strand is, for example -A T T T G T C C A-, it will be on the other strand- T A A A C A G G T-.

This model was proved correct by many techniques including X-ray diffraction, electron microscopy and other physical and chemical methods.

DNA replication

The amount of DNA is constant and characteristic for each cell type; and its amount in the diploid nucleus is double that of the haploid nucleus of the same species. In case of mitotic division, the 2 resulting nuclei possess the same amount of DNA. This is because the molecules of DNA are arranged lengthwise in the chromosomes, and they undergo longitudinal splitting accompanying the splitting of chromosomes during cell division.

Experimental studies with radio-active isotopes showed that, at the be-

ginning of cell division, the DNA molecules are replicated inside the chromosomes prior to the chromosome splitting. Replication begins by the unwinding of the two complementary strands of the DNA molecule. Then, each strand acts as a mold or a template for the synthesis of another complementary strand. Thus, during the formation of the new strand, (A) will come opposite to (T) found in the old strand and (C) will come opposite to (G), and vice versa. At the end of this process, 2 DNA molecules are formed, each of which consists of an old strand and a newly-synthesized complementary strand. Each of these molecules now forms a chromatid. The two chromatids separate from each other forming two daughter chromosomes. In *Entamoeba*, DNA replication was found to take place every 20-30 minutes.

That the two strands of DNA molecule separate from each other, was shown experimentally in test tubes. By heating the DNA molecule, the hydrogen bonds between the 2 strands are broken down and the 2 strands separate from each other. On slow cooling, the hydrogen bonds form again between the 2 complementary strands, but with fast cooling, the 2 strands remain separate and can be isolated by certain procedures.

Also, in the experimental field, it has been possible to prepare DNA artificially in the test tube by making a medium containing A, T, G, C, deoxyribose sugar, certain synthesizing enzymes, and a part of DNA molecule obtained from a living cell.

DNA and genetic information (Genetic code)

DNA is regarded as the store of genetic information in the living cells. This is because it acts to select and arrange molecules of different amino acids in special orders to form various protein molecules. This process is mainly controlled by the nitrogenous bases found in the DNA molecule and by the sequence of their arrangement along this molecule. The mode of arrangement of the nitrogenous bases in the DNA molecule defines what is known as the genetic code. It is according to this code that different amino acids are united together in a special manner to form certain protein molecules. A group of amino acids form a protein molecule, and the formed proteins are expressed in the phenotype of the organism. Any change in the arrangement of the nitrogenous bases in the DNA molecule leads to the formation of another type of protein, and this will be reflected in the phenotype of the organism.

As well known, information is communicated by words, and words are composed of letters. Words give a large variety of information, not only because they are composed of letters, but also because the same letters can be arranged in different sequences to give different words and convey different meanings, e.g. the 3 letters A, R and T can be arranged in different ways to give words of different meanings as RAT, ART, TAR, etc.

The DNA molecule may be similarly looked upon as having an alphabet consisting of 4 chemical letters : Adenine (A), Guanine (G), Cytosine (C) and Thymine (T). These letters form certain words which convey different information and can be written and arranged into long sentences, thus conveying considerable information. This is similar to the case of the language used in the transmission of telegraph messages in which two letters only are used; the dash and dot (—) forming what is known as the "Morse code". These two letters can convey all the messages which can be conveyed by the letters of any usual language. However, since genetic information is finally expressed in the form of proteins, and since there are nearly 20 amino acids, only a code of 20 letters is needed, each of which specifies a certain amino acid.

RIBONUCLEIC ACID (RNA)

The control of protein synthesis by DNA is indirect. It performs this role through another nucleic acid, namely **ribonucleic acid (RNA)**, which carries or transcribes the information contained in the DNA found in the nucleus to the cytoplasm, where these messages or information are translated into and used in building proteins and enzymes, which decide the phenotypic characteristics of the individual. The whole process can be summarized as follows :

a) The DNA carries within its molecule certain genetic information in a coded manner.

b) This information is transcribed into the RNA molecules which carries it to the cytoplasm.

c) The transcribed information is translated into different proteinic substances which collectively represent the actual genetic characteristics of the individual.

RNA is formed in the cell in a manner very much similar to that by which DNA is replicated. In other words, a strand of RNA is synthesized in the nucleus which is complementary to a strand of DNA, except that **uracil** (a pyrimidine) is found in RNA instead of thymine found in DNA, a **ribose sugar** is found in RNA instead of the deoxyribose sugar found in DNA.

From the above description, it is clear that :

- 1 — A molecule of RNA is formed of a single strand.
- 2 — The strand of RNA contains ribose sugar instead of the deoxyribose sugar found in DNA.
- 3 — Uracil is found in RNA in place of thymine found in DNA.

Types of RNA

Three main types of RNA are distinguished in the cell. These are :

1 — Messenger RNA (mRNA)

This is the first RNA to be formed in the cell. It is built up of molecules of different sizes. The basic composition of mRNA is complementary to that of the strand of DNA from which it is copied. The name messenger refers to its function, which is transcribing the genetic information from the DNA molecule in the nucleus and carrying it to a certain particle in the cytoplasm, a ribosome. The longer the molecule of mRNA, the longer is the message it carries from the DNA molecule.

2 — Transfer RNA (tRNA)

Transfer RNA is formed of short strands, each being formed of 75-80 nucleotides. The name transfer also refers to the special role of this RNA in the cell. Each molecule of tRNA carries the components of one amino acid molecule to the site of protein synthesis in the cytoplasm. One end of each tRNA has a special identifying sequence of nitrogenous bases which are specific for a certain amino acid. Thus, there are 20 types of tRNA, each

being specific for each of the known 20 amino acids in the body. For example, the molecule of tRNA which has the following sequence of bases at its end (ACA) becomes attached to the amino acid valine, and the molecule of tRNA having the sequence (CCU) becomes attached to the amino acid glycine, etc.

Each amino acid (AA) becomes attached to the corresponding tRNA and this AA-tRNA complex is carried on to a certain particle in the cytoplasm, namely a ribosome.

3 — Ribosomal RNA (rRNA)

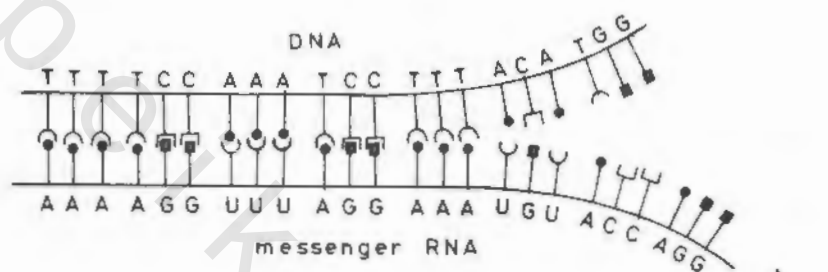
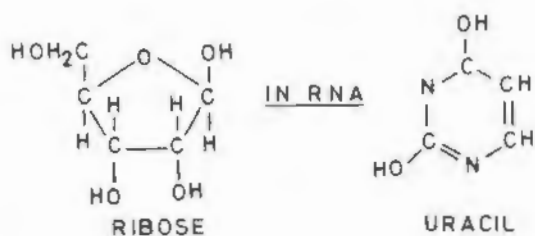
This is contained in the ribosomes which are scattered in the cytoplasm. The size of each ribosomal particle ranges from 150-200 Å in diameter. The ribosomes are the sites at which protein synthesis takes place in the cytoplasm.

Nucleic acids and protein synthesis

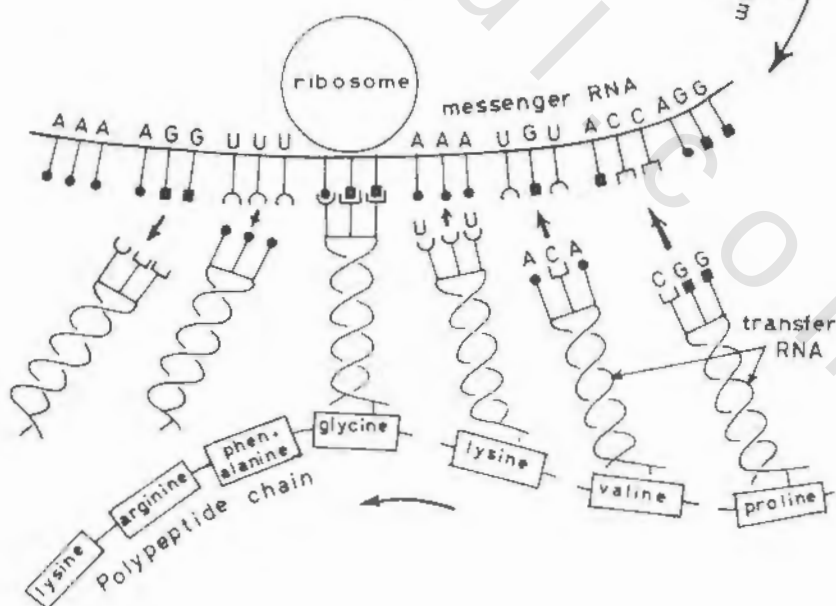
A vast amount of experimental work has been carried out on the role of nucleic acids in the process of protein synthesis in the living cells. This process is summarised as follows :

A molecule of mRNA is formed from a strand of DNA molecule carrying the genetic information in the nucleus. This mRNA leaves the nucleus and passes to the cytoplasm where it lies in the midst of a pool containing 20 types of amino acids. Each amino acid in the cytoplasm attaches to a certain tRNA identified by the three nitrogenous bases found at its end. These three nitrogen bases represent a word formed of three letters. The 3 letter-word in the mRNA calls for a corresponding 3 letter-word in a tRNA attached to an amino acid, and is thus complementary to it. Thus, the amino acid becomes attached to the tRNA at one end, and to the mRNA at the other end. This process continues so that, one by one, the different amino acids specified by the code along the original DNA strand, become linked both to the mRNA and to each other in a certain order.

Example : The amino acid valine is identified by the tRNA having the three letter-word ACA at its end. This will lie against the 3 letter-word UGU on a messenger RNA.



SYNTHESIS OF PROTEINS



Lysine is another amino acid identified by the tRNA having the the 3 letter-word UUU. This will lie against the 3 letter-word AAA on a messenger RNA.

At the end of this process a number of amino acids appear hanging down near each other and arranged beside one another in a certain manner which has already been determined by the arrangement of the nitrogen bases on the long molecule of mRNA. In 1962, Howard showed that the amino acids forming one molecule of haemoglobin can arrange themselves side by side in about 90 seconds.

Finally these amino acids become linked together by the help of certain enzymes forming special proteins required by the cell. The mRNA and tRNA are then broken down.

The following table shows triplet codes for amino acids in mRNA

Amino acid	Triplet code
Alanine	CGU, CCG
Arginine	CCG
Aspartic acid	CAA, GAU
Asparagine	CAU, AAU, AAC
Cysteine	GUU
Glutamic acid	GAA, GAU
Glutamine	AAC, AGG
Glycine	GGU
Histidine	CAC, CAU
Isoleucine	AUU
Leucine	CUU, GUU, AUU
Lysine	AAU, AAA
Methionine	GAU
Phenylalanine	UUU
Proline	CCU, ACC
Serine	CCU, CUU
Threonine	ACC, AAC
Tryptophane	GGU
Tyrosine	AUU
Valine	UGU

The role of nucleic acids in specifying the amino acids was experimentally shown as follows : A piece of DNA was used with known information, i.e. it has certain instruction for the synthesis of a certain type of protein. When one nucleotide, adenine (A), was added to it, it failed to synthesize the usual protein. When another adenine was added, it also failed. But when a third nucleotide (A) was added, the DNA resumed its ability to build up the protein. This is explained as such : when one or two nucleotides (A) were added, the usual arrangement of nucleotides in the DNA was disturbed, but when the third (A) was added and the 3 letters were arranged side by side (AAA), the specific protein was formed again.

SOLVING GENETIC PROBLEMS

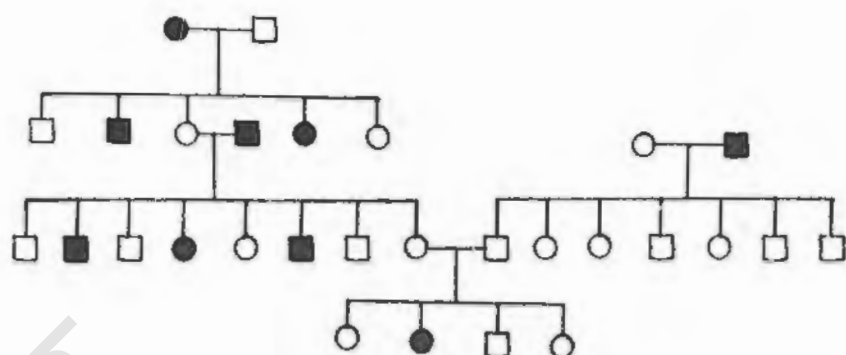
In solving genetic problems, the following procedure is recommended :

- 1 — *Define the symbols used for each gene. Select the first letter of the name of the character in question. Write this letter in capital to indicate the character if it is dominant, and in small if it is recessive. The same letter is used for the allele of this character. Polydactyly is a dominant character, hence, the first letter (P) is used to indicate it, while the same letter written in small (p) is used for the other allele, namely normal fingers.*
- 2 — *Write the phenotypes of the parents and the offspring as mentioned in the problem.*
- 3 — *Define the genotypes of the parents as deduced from the parents or offspring.*
- 4 — *Construct the Punnet square and list the different types of eggs on the horizontal or vertical line and the sperms on the other line.*
- 5 — *Write the corresponding combinations (genotypes) of the zygotes in the appropriate squares.*
- 6 — *Deduce the phenotypes of the different individuals according to their genotypes.*
- 7 — *Calculate the different ratios of the different homozygotes (pure) and heterozygotes (hybrid) individuals in the offspring.*

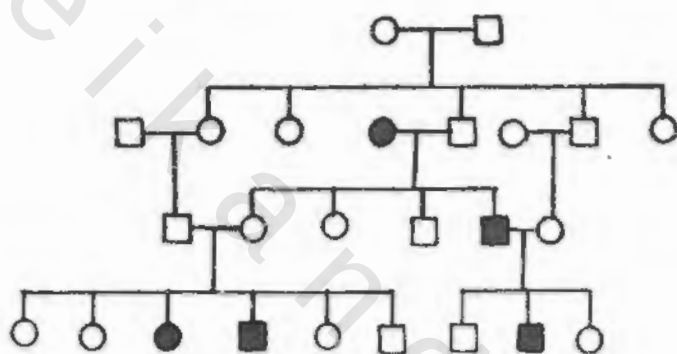
PROBLEMS

- 1 — 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 ?
- 2 — A blue-eyed man, both of whose parents were brown-eyed, marries a brown-eyed woman. They have one child, who is blue-eyed. What are the genotypes of all the individuals mentioned ?
- 3 — In a case of disputed parentage, the mother of an illegitimate child is blood type N, the child MN, and one suspected father is N and the other MN. How would you decide the case ?
- 4 — In marriages of albinos with Aa persons, what is the probability in families of 6 children of finding 3 Aa and 3 aa children ?
- 5 — A queen bee heterozygous for a dominant character mates with a drone that shows the same character. What characters would you expect the male and female offspring to show ?
- 6 — Two rough black guinea-pigs bred together have two offsprings: one of them rough white and the other smooth black. If these same parents were further bred together, what offspring would you expect for them ?
- 7 — In *Drosophila*, a gene called curly, causes the wings to curl up. When 2 insects with curly wings were crossed together, they gave 307 curly and 101 normal flies. Explain this result.
- 8 — In the above mentioned problem, how can you distinguish between homozygote and heterozygote individuals.
- 9 — What will be the comb character of the offspring of the following crosses, in which the genotypes of the parents are given :

a) Rr Pp, Rr Pp	d) Rr Pp, Rr pp
b) RR Pp, rrPp	e) Rrpp, rr Pp
c) rrPP, Rr Pp	f) Rr pp, Rr pp
- 10 — In the following pedigrees, state your opinion concerning the probability that the trait is dominant or recessive, and as far as possible, determine the genotypes of each individual in these pedigrees.



Taste blindness



Muscle atrophy

- 11 — Both parents are group A, but three fourth of the children belong to group A and one fourth to group O, determine the genotypes of the parents.
- 12 — A man and a woman, both of normal vision, have (1) a colour blind son who has a daughter of normal vision, (2) a daughter of normal vision who has one colour-blind and one normal son, and (3) another daughter of normal vision who has five sons, all normal. What are the probable genotypes of the grand parents, children and grandchildren? daughter of normal vision who has five sons, normal vision who has five sons, all normal. What are the probable genotypes of the grand parents, children and grandchildren?
- 13 — In cattle, short-legged animals of the Dexter-Kerry breed occasionally produce abnormal calves dead at birth or dying shortly thereafter.

Outline an experimental test of the hypotheses that such deaths are due to homozygosis for a lethal gene.

- 14 — In one family, the father and son are both haemophiliacs, but the mother is normal.
 - (i) what is the genotype of the mother ?
 - (ii) what is the chance of the daughters to be haemophiliac ?
- 15 — A mutant strain called dumpy is found in *Drosophila* in which the flies have obliquely truncated wings. When a normal female is crossed to a dumpy male, all the offspring have normal wings. When brother-sister matings are made between F_1 flies, an F_2 is produced containing 173 dumpy and 526 normal flies. When a F_1 female is back-crossed to the F_1 male, 97 dumpy and 106 normal flies are produced. Diagram such a succession of crosses. What conclusions can you draw to the inheritance of wing morphology in *Drosophila* ?
- 16 — In cattle, the polled, or hornless, condition P is dominant over the horned p. A polled bull is bred to 3 cows. With cow A, which is horned, a polled calf is produced; with cow B, also horned, a horned calf is produced; with cow C, which is polled, a horned calf is produced. What are the genotypes of the 4 parents, and what further offspring, in proportions, would you expect from these matings ?
- 17 — A rough black guinea-pig bred with a rough white one gives an offspring including rough black, rough white, smooth black and smooth white. what are the genotypes of the parents ?
- 18 — If the sequence of nucleotides of one strand of DNA helix is ACT GGC TACG, what is the sequence of nucleotides of the other strand ?
- 19 — A woman has 2 children, one by one husband and one by another. The M / N blood types of the children are : MM and NN What type of blood does the mother have ?
- 20 — In *Drosophila*, the genes for red, eosin, and white eye colour are alleles. The gene for yellow body is linked with white eye with a crossover value of 1.5 per cent. What is the probable crossover value between eosin and yellow ?
- 21 — In the following problem, the normal alleles of mutant genes are designated by + (wild type). The genes in each member of a pair

of chromosomes are written separately above and below a line.

Assume that genes a and b are linked and show 40 per cent of recombination. If a $\frac{+}{+} \frac{+}{+}$ individual is crossed with one that is $\frac{a}{a} \frac{b}{b}$ what will be the genotype of the F_1 ?

- 22 — In the preceding problem, what gametes will the F_1 produce and in what proportions?

If the F_1 is crossed with a double recessive, what will be the appearance and genotypes of the offspring?

- 23 — When 2 dextars are crossed, one - fourth of the offspring will die and one - half of the offspring will be dextars. Describe the reason for this, and explain the technique which could be performed to prevent such losses and acts to produce 100% dextars?

- 24 — Mrs Ahmed and Mrs Aly had babies at the same hospital and at the same time. Mrs Ahmed took home a girl and named her Fatma. Mrs Aly received a girl and named her Zeinab, but she suspected that this girl was not hers. Blood tests showed that Mr Aly was type O, Mrs Aly was type AB, Mr and Mrs Ahmed were both type B, Fatma was type A and Zeinab was type O. Had an exchange occurred.

- 25 — The mating of two black, short - haired guinea pigs produced a litter which included some black, long-haired and some white, short haired offspring. What are the genotypes of the parents?

- 26 — In the above problem, what is the probability of having black, short-haired offspring in the subsequent matings of the parents?

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CHAPTER III

HISTOLOGY

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HISTOLOGY

INTRODUCTION

Every organism, whatever complicated it may be, starts its life as a single cell which is the fertilized egg or zygote. This cell undergoes successive divisions giving rise to a large number of cells which become arranged into three layers known as the **primary germ layers**; an outer **ectoderm**, a middle **mesoderm**, and an inner **endoderm**. The cells in each layer are at first all alike, but later, they become differentiated in various ways to form groups of specialized cells. The cells of each group constitute what is known as a **tissue**. A tissue is defined as a group of cells similar in structure, perform the same function, and are bound together by a certain substance known as the **intercellular substance** or **matrix** produced by the cells themselves.

A group of tissues form an **organ**, and a number of organs form an **organ system**. The different systems form the whole animal body.

The study of tissues is called **Microscopic Anatomy** or **Histology**.

Animal tissues are usually classified into four main types :

Epithelial tissues.

Connective tissues.

Muscular tissues.

Nervous tissues.

I. EPITHELIAL TISSUES

Epithelial tissues are commonly known as the covering tissues. A tissue of this sort is usually found covering the outer surface of the body or of certain body organs, in which case it is called an **epithelium**. It may also be found lining certain hollow organs, in which case it is called an **endothelium**; or it may be lining the internal body cavity and is then known as a **mesothelium**.

Epithelial tissues are primarily responsible for covering and protection of the different parts of the animal body. But they may be modified to perform other functions such as secretion, sensation, reproduction, etc.

General characters

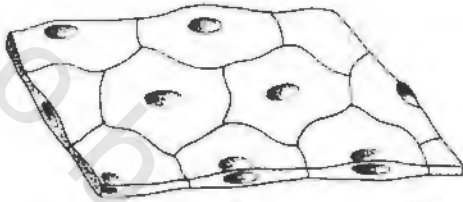
- 1 — They originate from any of the three primary germ layers (ectoderm, mesoderm, or endoderm).
- 2 — The cementing substance (intercellular substance or matrix) which binds their cells together is scanty.
- 3 — Their component cells rest on a very thin layer of connective tissue known as the **basement membrane**.
- 4 — They have the ability of multiplication to regenerate the cells which are worn out during the performance of various activities.

Epithelial tissues are either classified according to their structure, i.e. the shape and arrangement of their component cells, or according to their function.

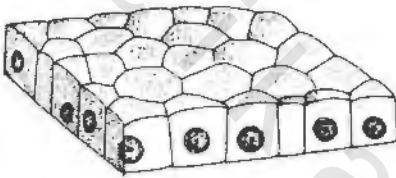
Classification of epithelia according to structure

Epithelial tissues are classified according to structure into two main categories :

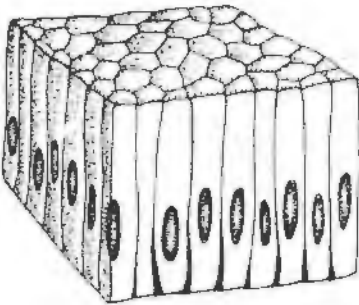
SIMPLE EPITHELIA



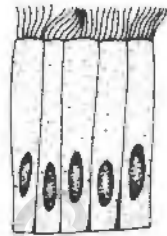
Squamous



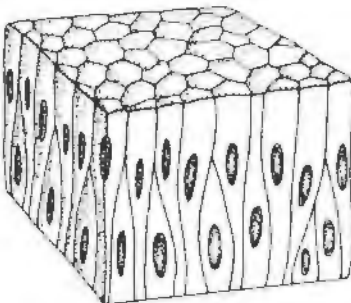
Cuboidal



Columnar



Ciliated
columnar



Pseudostratified



Ciliated
pseudostratified

A. Simple Epithelia

A simple epithelium consists of a single layer of cells arranged side by side on a basement membrane. Simple epithelia are distinguished into different types according to the shape of their component cells. These types include :

1 — **Squamous or pavement epithelium** : The cells in this epithelium are flattened or disc-shaped with smooth or wavy edges. They appear spindle-shaped in cross-section, each cell containing a nucleus in its widest part. This type of epithelium is found lining Bowman's capsules of the kidney, blood vessels (endothelium) and coelomic cavities (mesothelium). Besides, it forms the covering layer or serosa of the digestive tract.

2 — **Cuboidal epithelium** : The cells in this epithelium are square-shaped in cross-section, each containing a central round nucleus. Examples are seen in the kidney tubules and bile ducts.

3 — **Columnar epithelium** : This epithelium is built up of long pillar-shaped cells, each containing an oval or elliptical nucleus lying parallel to the long axis of the cell. This epithelium is found lining the mammalian digestive tract from the stomach to the rectum.

4 — **Ciliated columnar epithelium** : This epithelium is formed of columnar cells carrying on their free borders small vibratile protoplasmic processes known as **cilia**. These cilia beat regularly in one direction in order to create a current of air, drive a current of fluid, or help in the passage of food substances down the gut, or in driving certain objects like the eggs along the genital ducts. This epithelium is found lining the oesophagus, lungs and oviducts of the toad.

5 — **Pseudostratified epithelium** : This epithelium is built up of two kinds of cells; the first consists of tall cells with inner narrow ends resting on the basement membrane, and broad outer ends which reach the outer surface of the epithelium. The second kind includes small conical cells which are wedged inbetween the cells of the first type. Their outer tapering ends do not reach the surface of the epithelium. The cells of the first kind have their nuclei arranged in one level, whereas those of the second type are arranged in another level. Hence, this epithelium looks as if formed of two layers

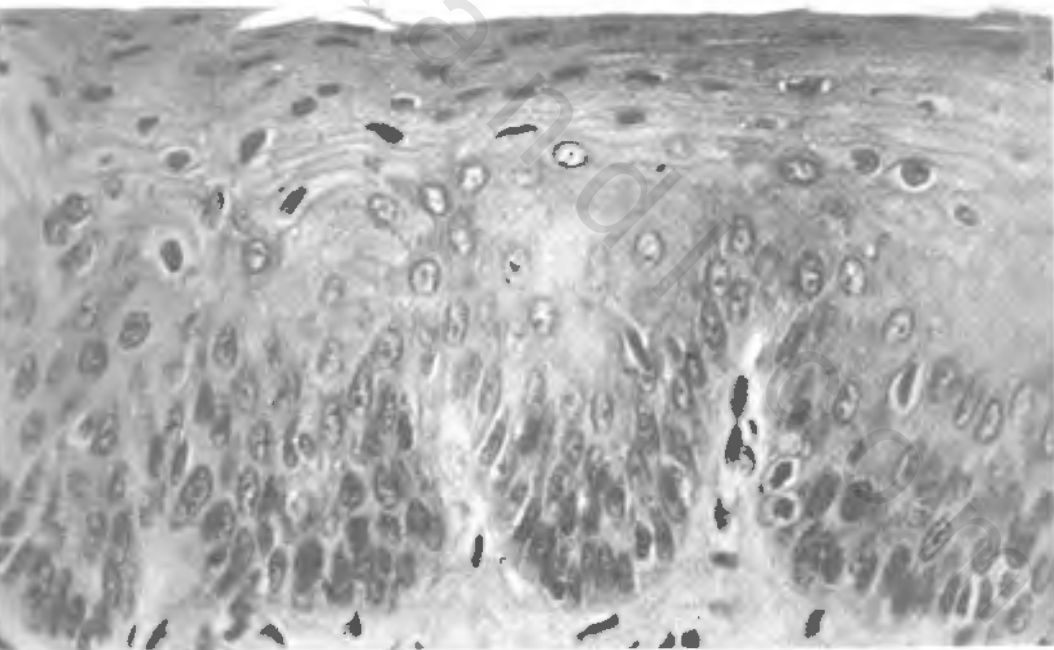
of cells. This epithelium lines the ducts of certain glands, such as the parotid gland.

6 — **Ciliated pseudostratified epithelium** : This is essentially similar to the preceding type, except that the tall cells carry cilia at their free ends. This epithelium is found lining the trachea.

B. Compound or Stratified Epithelia

A compound or stratified epithelium consists of more than one layer of cells; the lowermost layer rests on the basement membrane. Stratified epithelia are classified into several types according to the shape and structure of the outermost layer of their cells. These types are :

1 — **Stratified squamous epithelium** : The lowermost layer in this epithelium consists of cuboidal or short columnar cells and is known as the **germinative or Malpighian layer**. The cells of this layer divide continuously



Stratified squamous epithelium

giving rise to new cells which are pushed towards the outer surface of the epithelium. These cells are round or polygonal when first formed, but they become gradually compressed and flattened as they are pushed away from

the Malpighian layer. As they become displaced away from the food supply carried by the blood capillaries below the basement membrane, they die off and form a non-living **horny layer** at the surface. This layer is periodically peeled off the tissue, either in the form of small fragments as in mammalian skin, or in the form of a continuous layer as in snakes. The cells lying inbetween the Malpighian and horny layers constitute a special intermediate layer known as the **spongy layer**.

Stratified squamous epithelia are found in certain parts of the body which are exposed to friction, such as the epidermis of the skin, the lining of the oesophagus of mammals, etc.

2 — **Stratified cuboidal epithelium** : In this epithelium, the basal layer consists of low columnar cells, the outermost layer of cuboidal cells, and the intermediate layers of polygonal cells. An example of this tissue is found lining the cloaca of the toad.

3 — **Stratified columnar epithelium** : This is essentially similar to the preceding type except that the outer layer consists of columnar cells; e.g. the lining epithelium of some excretory ducts.

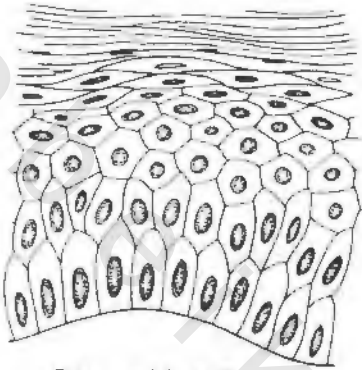
4 — **Ciliated stratified columnar epithelium** : This differs from the preceding type only in having cilia on the free borders of the cells of the outer layer, e.g. the epithelium lining the vas deferens in some mammals.

5 — **Transitional epithelium** : This epithelium lines certain organs which have elastic walls that have the ability to stretch and return back to normal size, e.g. the urethra and urinary bladder. When such an organ is stretched, as when the urinary bladder is filled with urine, its epithelial lining appears formed of few layers of small cells. When relaxed, the epithelial lining appears formed of several layers of cells, the outermost of which has cells with convex outer surfaces. This tissue is rich in its mucoid matrix, which allows for the sliding of the cells amongst each other when the wall of the organ is stretched.

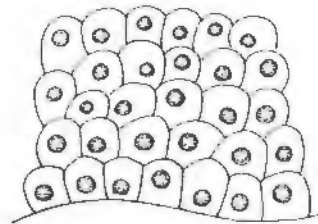
Modifications of epithelial tissues

Epithelial tissues undergo certain structural modifications which are either permanent or temporary :

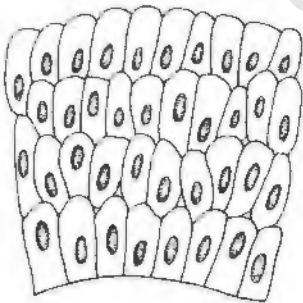
STRATIFIED EPITHELIA



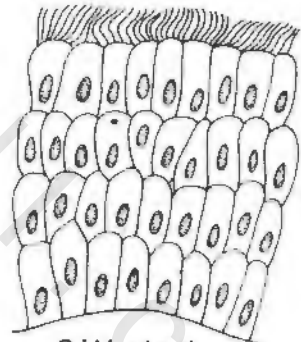
Stratified
squamous



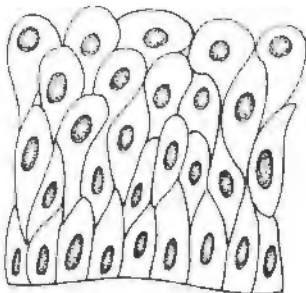
Stratified
cuboidal



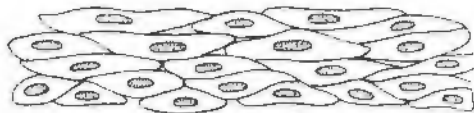
Stratified
columnar



Ciliated
stratified
columnar



(relaxed)



(stretched)

Transitional

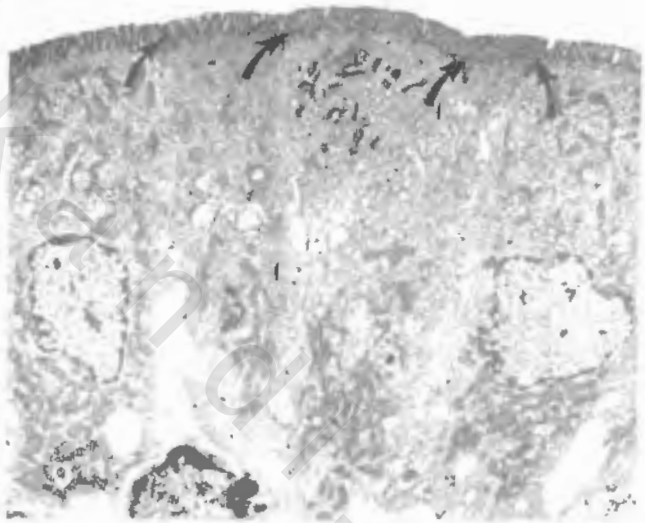
a) Permanent modifications :

1. **Brush borders.** The cells of certain epithelia, such as that lining the ileum, are absorptive cells which develop brush borders. This means that their free borders are produced into numerous microscopic finger-like processes or microvilli which serve to increase the absorptive surface.

2. **Pigments.** Some epithelial cells, e.g. the retinal cells of the eye and the cells of the Malpighian layer of the epidermis, contain various coloured pigments.



Ultrastructure of brush border of cells of micro villi .



Columnar cells with a brush border

b) Temporary modifications:

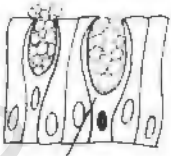
1. Transformation of one type of epithelium into another type, e.g. the change of the ciliated pseudost stratified epithelium lining the trachea into a squamous stratified epithelium in case of vitamin A deficiency.

2. Thickening of the horny layer of the squamous stratified epithelium due to vitamin B deficiency.

3. Deposition of large masses of glycogen in some epithelial cells due to excessive secretion of sex hormones.

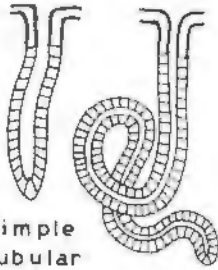
EXOCRINE GLANDS

Unicellular



Goblet cell

Multicellular glands

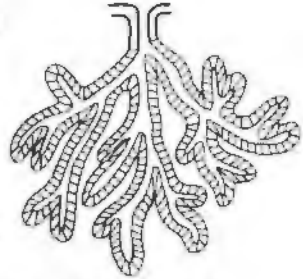


Simple tubular

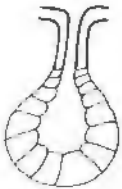
Coiled tubular



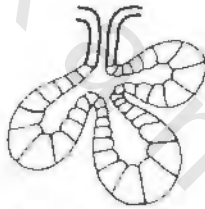
Simple branched tubular



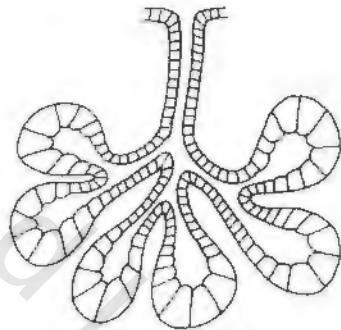
Compound branched tubular



Simple alveolar

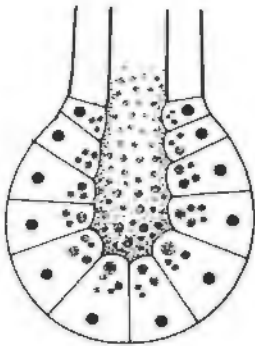


Branched alveolar

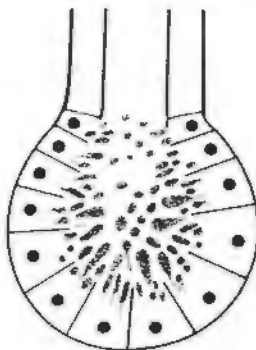


Tubulo-alveolar

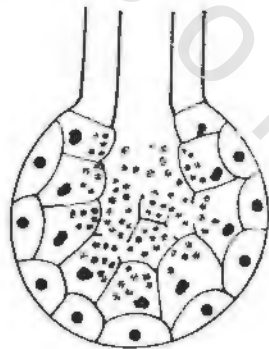
Methods of discharge of secretion



Merocrine



Apocrine



Holocrine

Classification of epithelia according to function

Epithelial tissues are also classified according to their function into :

- | | |
|--------------------------|-------------------------|
| A. Protective epithelia. | B. Glandular epithelia. |
| C. Cuticular epithelia. | D. Sensory epithelia. |
| E. Germinal epithelia. | |

A. Protective (Covering) Epithelia

These include the epithelia which mainly serve protection of the body and its different organs, such as the epidermis of the skin and the lining epithelia of the blood vessels.

B. Glandular (Secretory) Epithelia

These include the epithelia which are modified to perform a glandular or secretory function. These epithelia form glands of two sorts : endocrine glands and exocrine glands.

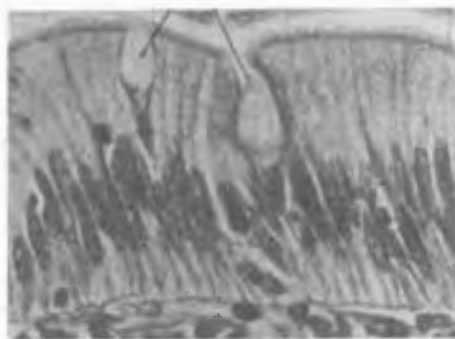
Endocrine glands : These glands have no ducts. Their secretions are passed from the cells directly into the blood or lymph, e.g. the adrenal and thyroid glands.

Exocrine glands : These glands have ducts for conveying their secretions. They are distinguished into the following types :

1 — Unicellular glands

Each of these glands consists of a single cell, e.g. the **goblet cell**. A unicellular gland starts as an ordinary epithelial cell, then certain secretory granules accumulate in its apical region. The nucleus and cytoplasm are pushed toward the basal region, and the cell, therefore, becomes pear-shaped

goblet cells



Columnar epithelium including goblet cells

or (goblet-like). The cell bursts at its apical end discharging its mucous secretion that spreads over the surface of neighbouring cells to moisten their cilia, thereby facilitating their movement. Secretions from unicellular glands also help in entangling dust particles in the respiratory passages, and in the passage of food material along the digestive tract.

2 — Multicellular glands

A multicellular gland consists of a large number of cells. These glands are either tubular or alveolar in form.

a) **Tubular glands** : These are tube-like; they may be simple, coiled or compound.

(i) **Simple tubular glands** : A gland of this type resembles a small test tube. It develops as an invagination of the simple epithelium covering the surface. This invagination deepens and increases gradually in length thus developing into a tube that penetrates deeply into the underlying tissues. The wall of this tube consists of a single layer of cells which become modified to perform a secretory function. Each simple tubular gland appears circular in cross section, with a thin wall built up of a single layer of columnar cells surrounding a narrow central cavity, e.g. the intestinal glands known as the crypts of Lieberkühn.

(ii) **Coiled tubular glands** : A coiled tubular gland has the form of a long coiled tube, e.g. the sweat glands in mammalian skin.

(iii) **Branched tubular glands** : These are branched and the branches of each gland open by a common duct, e.g. the gastric glands in mammalian stomach.

(iv) **Compound tubular glands** : Each gland consists of a large number of tubular branches which unite to open by a common duct, e.g. the liver and lacrymal glands.

b) **Alveolar glands** : These glands start developing in the same way as the tubular glands, i.e. as invaginations from the surface epithelium which penetrate into the underlying tissues. The inner part of each gland then enlarges to form a globular or rounded structure, while the outer region remains tubular. Accordingly, the gland looks like a flask. The globular part represents the glandular portion whereas the tubular part serves as a duct. Alveolar glands include the following types :

(i) **Simple alveolar glands** : Each of these glands consists of a single

flask-shaped structure. The globular part of the gland is formed of large glandular cells which are responsible for secretion, while the tubular part is formed of smaller cells and acts as a duct, e.g. the mucous glands found in the toad's skin.

(ii) **Branched alveolar glands:** The alveolar portion of each gland is made up of two or more parts which open by a common duct, e.g. the sebaceous glands in mammalian skin.

(iii) **Compound alveolar glands:** In this case, the gland is formed of two or more globular bodies which lead to the exterior by one common tubular duct, e.g. the parotid and mammary glands.

(iv) **Tubulo-alveolar glands:** Each of these glands resembles a compound alveolar gland in shape except that the cells of its tubular region also perform a secretory function, e.g. the exocrine glands of the pancreas.

Discharge of secretory products

Exocrine glands vary as regards the way in which they discharge their secretions. Accordingly, they are classified into three principal categories :

1 — **Merocrine glands :** Examples of this type are found in the pancreas and salivary glands. In this case, secretions diffuse through the outer tips of the cells.

2 — **Apocrine glands :** In this case, the apical parts of the cells are pinched off, thus liberating the glandular secretion. The cells then restore their apical portions, e.g. mammary glands

3 — **Holocrine glands :** This type is represented in the sebaceous glands found in the skin of mammals in which the glandular cells burst altogether, liberating their secretory products. The ruptured cells are then replaced by other cells produced through the division of non-secretory cells found in the outer wall of the gland.

C. Cuticular Epithelia

These are the epithelial tissues responsible for the secretion of a certain substance known as the **cuticle** which protects the underlying tissues. This type of epithelium is commonly found in invertebrate animals, e.g. the skin

of the earthworm. In some cases, certain salts are deposited in that cuticle, in which case the cuticle forms a hard outer covering or exoskeleton, such as that found in crustaceans and insects.

D. Sensory Epithelia

Some epithelial cells are modified to perform a sensory function. They receive stimuli and transmit them to the nervous tissues. The outer ends of these cells form one or more branched processes. This type is found in the skin, eyes, ears and other parts of the body.

E. Germinal Epithelia

These are the epithelia found in the sex organs, such as in the testis and ovary. They produce the germ cells, i.e. the sperms and eggs.

II. CONNECTIVE TISSUES

Connective tissues are the most important and most abundant of the body tissues. They serve to connect other tissues together and to the skeleton. They also form the skeletal support which gives the body its characteristic shape and helps in the movement of the animal.

General characters

- 1 — They originate from the middle germ layer, or mesoderm.
- 2 — Their cells do not rest on a basement membrane.
- 3 — They have an extensive intercellular substance composed of a solid or fluid ground substance known as matrix and fibres of a protein nature.

Connective tissues are classified according to the nature of the ground substance into the following types :

- A. Connective tissues proper, with a gelatinous ground substance.
- B. Skeletal tissues, with a solid ground substance.
- C. Vascular tissues, with a fluid ground substance.

A. CONNECTIVE TISSUES PROPER

These tissues are characterized by having an abundant intercellular substance composed of two kinds of fibres lying in a jelly-like ground substance. They are found almost everywhere in the body. The following types of connective tissues proper are recognized :

1 — Areolar Connective Tissue

This type is mainly characterized by the presence of certain spaces or areolae in between its cells giving it a network appearance. This tissue forms

a layer between the skin and muscles, binds the different muscles together, and exists in the digestive tract and many other parts of the body. The tissue contains different sorts of cells, and two main kinds of fibres :

Fibrocytes : These are secretory cells which are responsible for the formation of the connective tissue fibres. They are elongated cells with pointed ends, and each cell contains an oval nucleus.

Mast cells : These are large ovoid cells with central rounded nuclei and numerous darkly coloured granules scattered in their cytoplasm. These cells are responsible mainly for the secretion of the ground substance of the connective tissue. They also produce substances such as : heparin which prevents blood from clotting inside the blood vessels, histamine which is liberated in allergic conditions and causes dilation of the blood vessels, and serotonin which causes constriction of the blood vessels.

Macrophages : These are amoeboid or irregularly shaped cells, each containing a round nucleus. They have the ability to move within the tissue with the help of pseudopodia. They protect the body against various infections by engulfing bacteria and other foreign materials.

Eosinophils : These are white blood cells which have a strong affinity towards acidic stains. Each cell contains a nucleus, formed of 2 small lobes, and numerous cytoplasmic granules.

Lymphocytes : These are smaller cells which constitute another variety of the white blood cells. Each cell has a large round nucleus.

Plasma cells : These are small spherical cells with eccentric nuclei. They are believed to play a role in the production of antibodies as they increase in number under certain pathological conditions.

Adipose cells : These cells accumulate a reserve of lipid or fatty material in their cytoplasm. This material first appears in the cells as minute fat droplets which gradually increase in size and number and fuse together to form a large fat globule. The cytoplasm becomes restricted to a thin peripheral layer lining the cell membrane, and the nucleus is shifted to one side of the cell. These cells are especially abundant in fatty or adipose connective tissues.

In addition, connective tissues proper contain some undifferentiated

mesoderm cells which are star-shaped and have large nuclei. These cells are regarded as the mother cells which can be differentiated into any other type of connective tissue cells.

White (collagenous) fibres : These are made up of a certain proteinic substance known as **collagen**. They form large wavy bundles, which branch and interconnect with each other, but the individual fibres do not branch. They transform into a gelatinous substance when boiled in water. They also dissolve in pepsin, and become markedly swollen on treatment with acetic acid.

Yellow (elastic) fibres : These exist in the form of single straight fibres which branch and interconnect with each other. They are formed of another variety of proteinic substance known as **elastin**. These fibres dissolve in trypsin, but they are neither affected by acetic acid nor by boiling water.

2 — Fibrous Connective Tissue

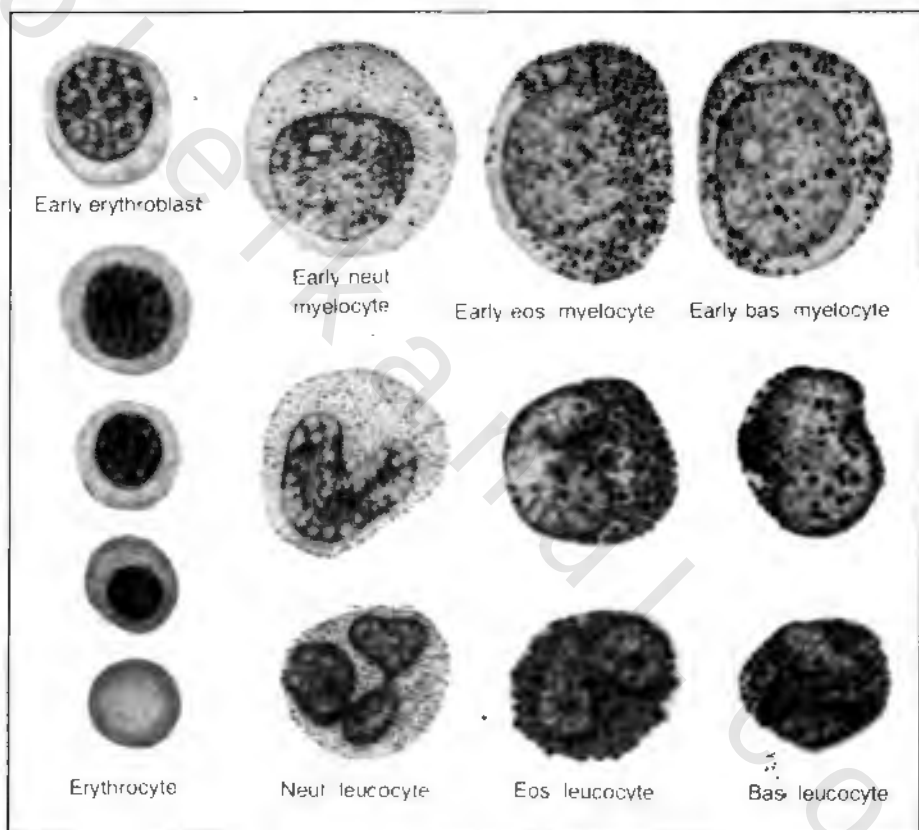
In this type of connective tissue, the white fibres predominate over the yellow or elastic fibres. The bundles of white fibres run parallel to each other. This type of connective tissue is found in the structures which act to pull adjacent parts of the body together, such as in the tendons which connect the muscles to the bones.

3 — Elastic Connective Tissue

In contrast with the preceding type, this tissue contains more elastic or yellow fibres than white fibres. This sort of connective tissue exists in organs which need some elasticity and strength, by which they can expand and then return to their normal condition, as the arteries and lungs, as well as the ligaments which serve to bind articulating bones together.

4 — Reticular Connective Tissue

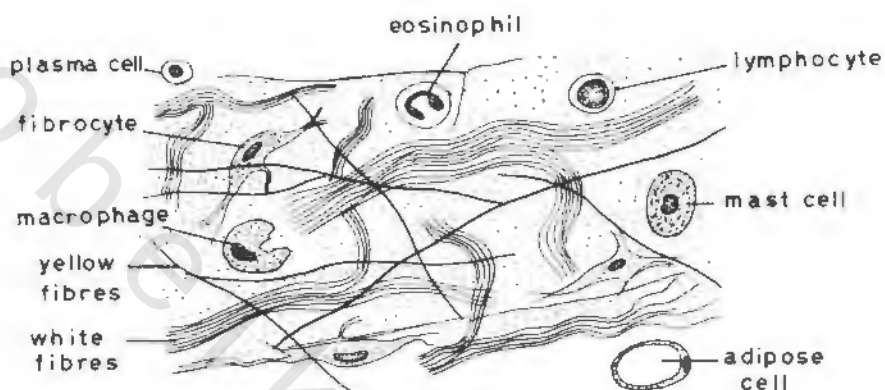
This type of connective tissue contains a few short bundles of white fibres, an extensive ground substance formed of lymph, and numerous lymphoid cells. Such cells are markedly branched, and the branches traverse each other forming a reticulum, e.g. the connective tissue in the spleen and bone marrow.



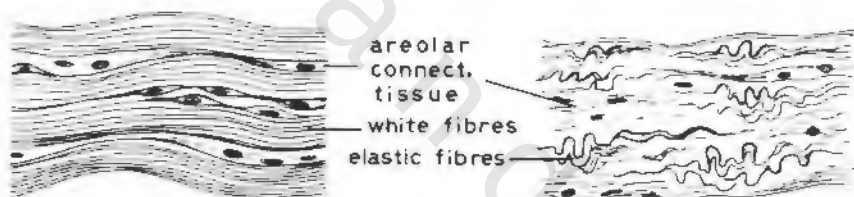
مراحل تكوين كريات الدم في الإنسان

Stages of blood cell formation in Man

CONNECTIVE TISSUES PROPER

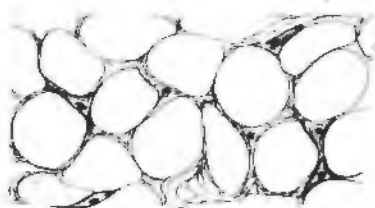


Areolar

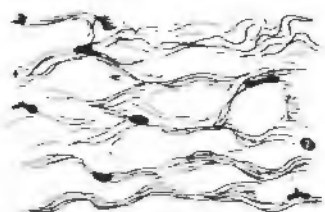


Fibrous

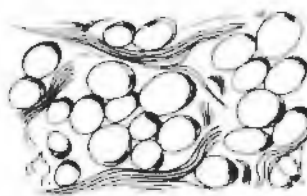
Elastic



Reticular



Mucous



Adipose

5 — Mucous Connective Tissue

This type of connective tissue contains few fibres; the ground substance consists of a gelatinous material. It exists mainly in embryonic organs and particularly in the umbilical cord.

6 — Adipose Connective Tissue

This type of connective tissue contains numerous large adipose cells which are densely packed together. These cells appear empty in microscopic preparations because their fat inclusions are dissolved by the alcohol and other fat solvents used in preparing the material for microscopic examination. This type of connective tissue forms the subcutaneous tissue found below the skin and other regions in which fat reserves accumulate. Such regions are usually known as fat depots.

B. SKELETAL TISSUES

These tissues form the internal skeleton which supports the body and to which the muscles are attached. Skeletal tissues include two main types : cartilage and bone.

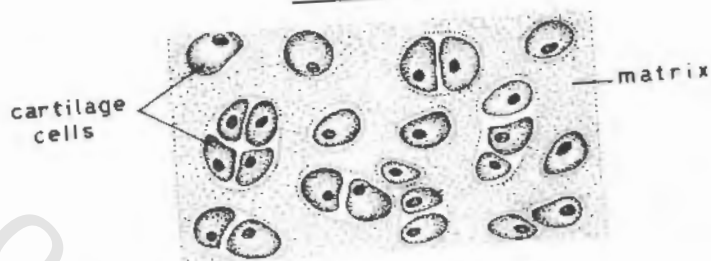
1 — CARTILAGE

Cartilage is a semi-solid translucent tissue which is softer than bone. The component cells of this tissue are called **cartilage cells** or **chondroblasts**. They are large and found within **capsules** containing a fluid substance. Each capsule contains one, two or four cartilage cells. The ground substance is secreted by these cells and consists of a substance known as **chondrin**. The whole cartilaginous tissue is surrounded by a thin membrane of areolar connective tissue, known as the **perichondrium**. This membrane is rich in blood vessels which carry blood and nourishment to the cartilage cells.

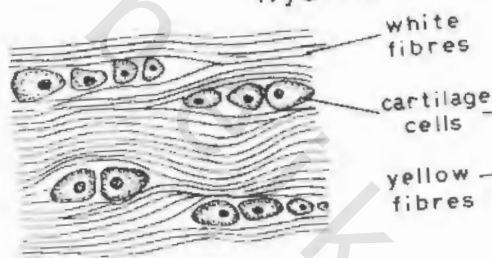
Several types of cartilage are found in the body. They include :

a) **Hyaline cartilage** : In this type, the ground substance is clear and does not contain any fibres. This type exists in the trachea, xiphoid cartil-

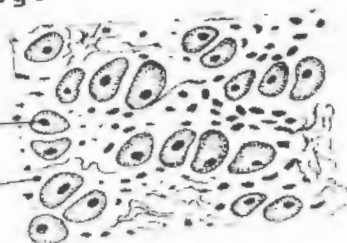
CARTILAGE



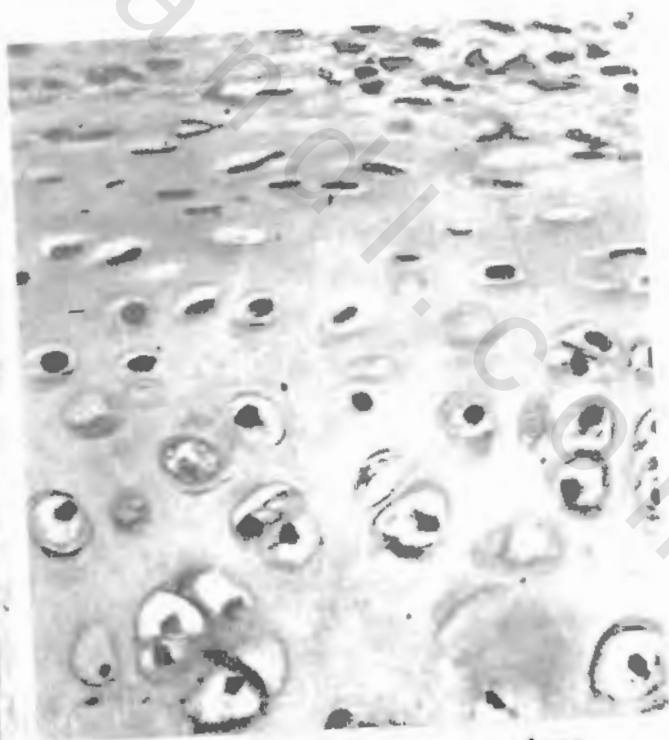
Hyaline cartilage



Fibro - cartilage

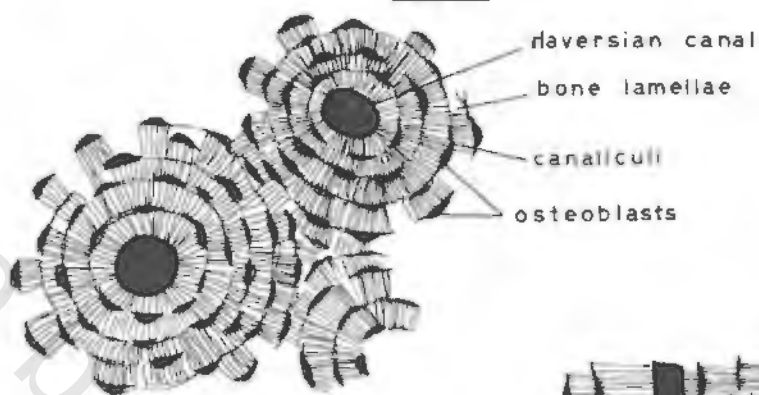


Elastic cartilage

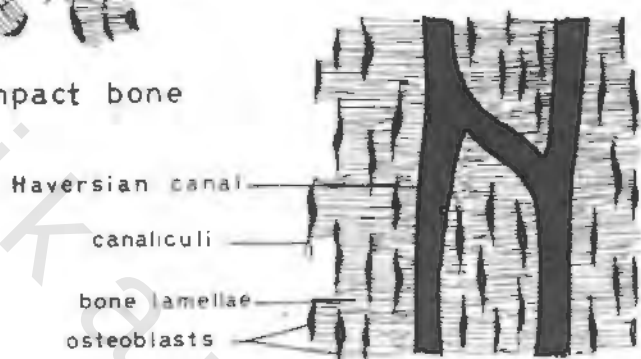


Transverse section of compact bone

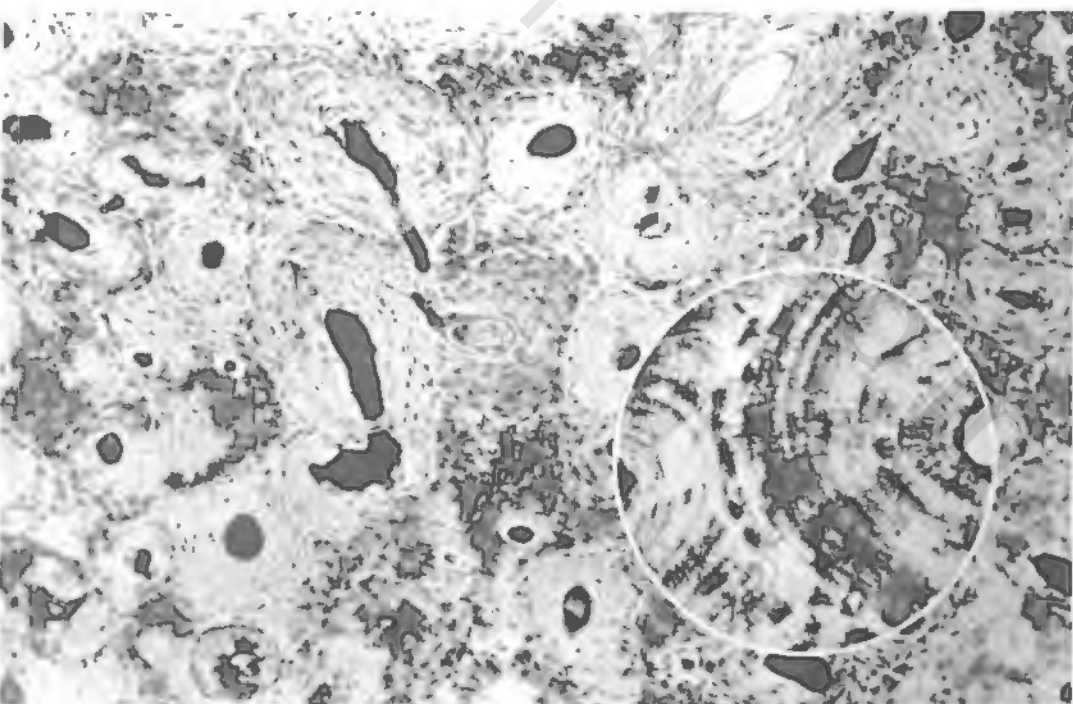
BONE



T.S. of compact bone



L.S. of compact bone



Transverse section of compact bone

age, and at the ends of long bones. It protects the long bones against the effects of friction. Hyaline cartilage forms the embryonic skeleton which becomes gradually replaced by the bony skeleton of the adult.

h) Fibro-cartilage : This type is characterized by the presence of bundles of white fibres in the ground substance and by the absence of a perichondrium. It exists mainly in the intervertebral discs.

c) Elastic cartilage : This tissue is elastic due to the presence of numerous elastic fibres in its ground substance. It exists in the ear pinna.

d) Calcified cartilage : In this cartilage, calcium salts are deposited in considerable amounts in the matrix, as in the xiphisternum of the toad.

2 — BONE

Bone is a sort of connective tissue which has a solid ground substance known as **ossein**. This substance consists of large amounts of calcium carbonate and calcium phosphate. These salts constitute 70-80 % of the tissue weight; the remaining portion consists of some organic substances. Structurally, bone is of two types : compact bone and spongy bone.

a) Compact bone appears in cross section under the microscope to consist of rounded structures known as the **Haversian systems**. Each Haversian system consists of a central **Haversian canal**, surrounded by thin concentric plates of bony material called the **bone lamellae**. In between these lamellae are arranged the bone-forming cells, or **osteoblasts**, within elliptical spaces known as the **lacunae**. The cells communicate with each other through numerous finely branched processes, which run within narrow spaces called the **canaliculi**. This arrangement helps in the transmission of nutrients from the Haversian canals, inside which blood capillaries run, to the osteoblasts. The Haversian canals are interconnected by transverse and oblique branches. In between neighbouring Haversian systems there are some bone lamellae and bone cells which are not arranged around Haversian canals and form what are known as the **non-Haversian systems**.

b) Spongy bone is not composed of regular bone lamellae, but consists of separate masses of bone tissue with wide spaces filled with bone marrow in between.

These two types can be clearly seen in a longitudinal section of one of the long bones, as the humerus or femur. Such a bone consists of a cylindrical shaft, called the **diaphysis**, carrying a swollen part at each end, known as the **epiphysis**, which usually has some protrusions to which the ligaments of the muscles are attached.

The **diaphysis** consists of compact bone and contains an inner cavity filled with bone marrow, and is lined by a thin vascular membrane called the **endosteum**. It is also covered externally by a similar thin membrane, the **periosteum**, of fibrous connective tissue richly supplied with blood capillaries that carry nourishment to the bone. The capillaries also penetrate the bony structure and run within Haversian canals. The periosteum serves for the attachment of different muscles.

The **epiphysis** consists of spongy bone surrounded by compact bone, and covered by a surface layer of hyaline cartilage. The covering cartilage facilitates the articulation of bones at the joints and protects their ends.

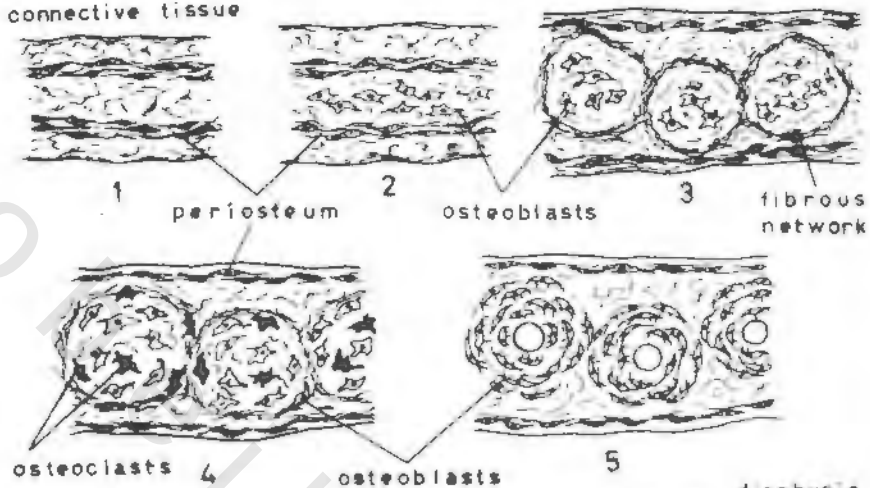
Between the epiphysis and the diaphysis there is a layer of hyaline cartilage, known as the **inter-cartilaginous disc**, which allows for increase in length of the bone in this region. The disc remains in human beings till the age of twenty years, and is then replaced gradually by compact bone, thus no further growth takes place.

Development of Bone

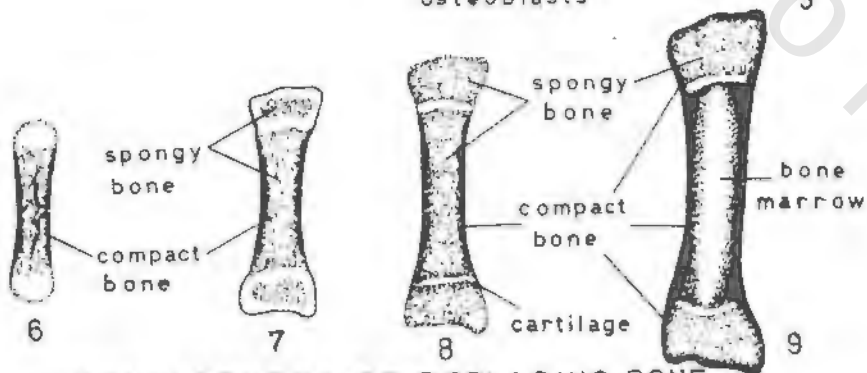
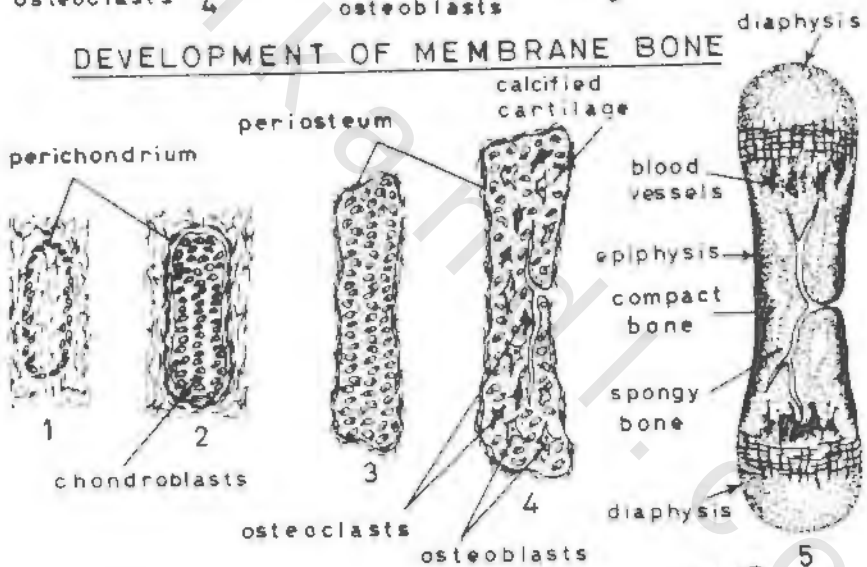
In the early embryonic stages of vertebrate animals, the skeleton is mainly formed of cartilage. This cartilaginous skeleton either persists throughout life, or becomes replaced by bones, as in higher vertebrates. However, there are certain bony parts which are developed in adult stages of higher vertebrates and are not represented in a cartilaginous form in the embryo. These parts are produced directly from specialized embryonic connective tissue cells. Hence, bone is classified into two categories according to its embryonic origin : cartilage bone and membrane bone.

a) **Membrane bones** are the bones which are not preceded by cartilage and are formed directly from mesenchyme (connective tissue) cells by a process known as **intramembranous ossification**, such as most of the bones of the skull. The process starts by the arrangement of mesenchyme cells in the dermis in the form of two parallel sheets separated by a narrow

connective tissue



DEVELOPMENT OF MEMBRANE BONE



DEVELOPMENT OF REPLACING BONE

space. Each sheet is called **periosteum**. The cells of each periosteum produce new bone-forming cells called **osteoblasts** in the space between the two sheets. These osteoblasts become surrounded by fibrous networks secreted by them. These fibres become later ossified by impregnation with hard mineral deposits. The osteoblasts become connected together by their protoplasmic processes which run within fine passages or **canaliculi** in the bony material. The bony material thus formed is known as **spongy bone**. This bone persists for a considerable time, then becomes invaded by certain bone-destroying cells, or **osteoclasts**, produced by some mesenchyme cells lying in certain cavities in the spongy bone. These osteoclasts act to resorb parts of the bony material so as to form passages for blood vessels, and gradually the bone undergoes reshaping and remodeling so as to form compact **Haversian systems**.

b) Cartilage or replacing bones are the bones which replace cartilage by a process called **endochondral ossification**, such as all long bones, the vertebrae, the ribs and some bones of the skull. As in case of membrane bones, replacing bones are produced mainly by mesenchyme cells of the connective tissue. These cells become so arranged as to form a continuous layer known as **perichondrium**. The perichondrial cells divide actively producing cartilage-forming cells, or **chondroblasts**. These cells increase progressively and become arranged in longitudinal rows parallel to the long axis of the future long bone. The cartilage so formed becomes later calcified by the deposition of mineral salts, thus most of the cartilage cells disintegrate and the perichondrium becomes transformed into a **periosteum**.

This calcified cartilage is then replaced by bone by a process similar to that of membrane bone. An embryonic connective tissue containing cartilage-destroying cells, or **osteoclasts**, invade the calcified cartilage through the periosteum and act to resorb gradually considerable parts of that cartilage. Consequently, narrow channels are formed for the passage of blood vessels, followed by mesenchyme cells which form specialized **bone-forming cells or osteoblasts**. These cells secrete the bony material in the form of long bars running parallel to the long axis of the future bone. Neighbouring bars are then connected by transverse bony parts. The cavities lying between these different bony structures are occupied by blood vessels as well as embryonic connective tissue forming the future bone marrow.

This process of ossification extends gradually from the central portion of the bone towards the periphery, and results in the formation of **spongy bone**. The future long bone now has a cylindrical shaft called **diaphysis**, and two swollen heads, each called **epiphysis**. Now, throughout the whole structure cartilage has been converted into spongy bone, except in certain narrow disc-like parts found between the diaphysis and each of the two epiphyses. These two discs remain cartilagenous to permit growth and elongation of the bone until a certain size is reached. They are then transformed into compact or dense bone and no further elongation of the bone occurs.

Compact bone becomes then deposited in the outer region of the shaft in the form of concentric **Haversian systems**. Each system has a central canal around which are concentrically deposited areas occupied by the cellular components of the bone and blood cells. The inner part of the shaft as well as its two ends contain spongy bone with irregular channels occupied by soft connective tissue that forms the future bone marrow.

Gradually the osteoclasts resorb the spongy bone in the core of the shaft and thus an internal cavity is produced and filled with the **bone marrow**.

C. VASCULAR TISSUES

These are fluid connective tissues. They include blood and lymph.

BLOOD

This is a sort of connective tissue in which the ground substance is a fluid material known as the **plasma**. It contains blood cells or blood corpuscles and certain minute spindle-shaped bodies known as blood platelets or thrombocytes. The amount of blood in man ranges from 5-6 litres, and this amount constitutes about 9% of the total body weight.

Blood Corpuscles

There are two main types of blood corpuscles :

1 — Red blood corpuscles or Erythrocytes

These cells are red in colour as they contain an iron pigment known as **haemoglobin**. Each red blood cell is bounded by a thin elastic membrane which facilitates the passage of these cells inside the narrow blood capillaries. The average number of these cells in man is 5 millions per cubic millimeter of blood, and about 4.5 millions per cubic millimeter of blood in the woman.

The red blood cells are nucleated in fishes, amphibians, reptiles, and birds, but not in mammals. The red blood cell of mammals contains a nucleus at the early stages of its development, but later, the nucleus undergoes gradual disintegration until it disappears completely in the fully developed cells. Owing to the absence of nuclei from the mammalian red blood cells, they live only for short periods (15 - 17 weeks), after which they pass to the spleen where they are broken down. The degeneration products include iron and certain pigments. Iron remains in the spleen, but the coloured substance passes to the liver which makes use of it in the manufacture of bile.

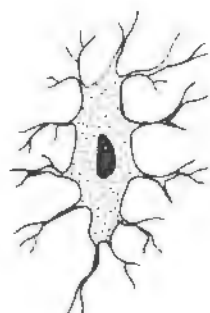
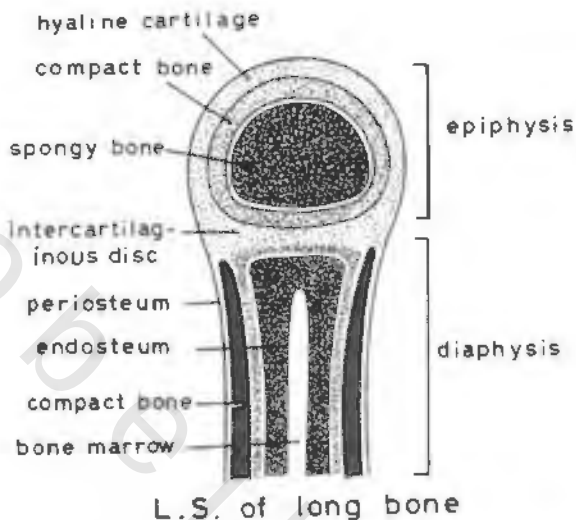
In mammalian embryos, the red blood cells are first formed in the liver then in the spleen. But, in late stages of pregnancy, the bone marrow starts to participate in this process and gradually becomes the only site for **haemopoiesis** in the individual. The newly formed red cells pass into the general blood circulation, continuously replacing the degenerated ones.

2 — White blood corpuscles or Leucocytes

These are fewer than the red blood corpuscles; each cubic millimeter of human blood contains about 7,000 white blood corpuscles. They differ from the erythrocytes in having nuclei throughout their life and in lacking haemoglobin. Some of the leucocytes can engulf bacteria and other foreign material which enter the body, in which case they are known as the **macrophages**. Leucocytes are divided into two main categories according to the presence or absence of granules in their cytoplasm. These are :

a) **Agranulocytes** : These are formed in the lymph glands. They do not possess cytoplasmic granules, and include the two following forms :

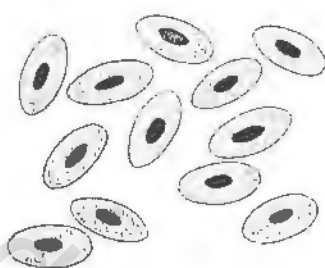
(i) **Macrocytes** : These are large cells, each containing a small horse-



Bone cell
(osteoblast)



non - nucleated

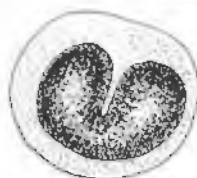


nucleated

ERYTHROCYTES



Blood
platelets



Monocyte



Lymphocytes



LEUCOCYTES

(Agranulocytes)



Eosinophil



Basophil



Neutrophil

(Granulocytes)

shoe-shaped nucleus surrounded by a wide cytoplasmic area.

(ii) **Lymphocytes** : These are small cells, each having a large nucleus surrounded by a narrow cytoplasmic region.

b) Granulocytes : These cells are produced in the bone marrow. They possess numerous cytoplasmic granules and are divided into three forms according to the affinity of their granules to different stains.

(i) **Acidophils or eosinophils** : In these granulocytes the granules take up acidic stains. Each cell contains a nucleus formed of two lobes connected together by a thread of chromatin.

(ii) **Basophils**: their granules are stainable with basic dyes. Each cell contains an S-shaped nucleus showing one or two constrictions along its length.

(iii) **Neutrophils**: Their granules stain with neutral dyes. Each cell contains a nucleus formed of 3-5 small lobes connected together by a chromatin thread. Hence, they are also known as **polymorphonuclear leucocytes**.

In a normal leucocytic count, each 100 leucocytes generally include : 70 neutrophils; 22 lymphocytes; 4 macrocytes; 3 eosinophils and 1 basophil. However, these numbers are subject to marked alterations under certain physiological and pathological conditions.

Blood plasma

This is a pale yellow fluid consisting of 90% water. The remaining 10% consists of some proteins such as fibrinogen, albumen and globulins. Besides, there are certain substances such as sodium bicarbonate and potassium bicarbonate which are responsible for the alkalinity of the blood. In the plasma, there always exist certain products of food digestion as glucose, amino acids and fatty acids. Besides, the plasma contains some hormones and waste products.

Blood platelets or Thrombocytes

These are minute spindle-shaped bodies formed from specialized cells known as the **megakaryocytes** found in the bone marrow. Their number averages 200,000 in each cubic millimeter of the human blood. When these platelets are exposed to air, they break liberating a substance known

as **thrombokinas**e or **thromboplastin** that plays an essential role in blood clotting.

Functions of the blood

1 — Blood transports the digested food stuffs from the alimentary tract to the different parts of the body.

2 — It performs an important respiratory function. The haemoglobin of the red blood cells combines with oxygen in the lungs forming an unstable compound known as **oxyhaemoglobin**. This substance dissociates in the body tissues where oxygen is released to the cells, and instead, carbon dioxide diffuses from the cells into the blood capillaries. This carbon dioxide is carried by the blood plasma in the form of carbonic acid which is dissociated in the respiratory organs, and carbon dioxide is thus expelled outside the body.

3 — Blood carries hormones from the endocrine glands to the body organs.

4 — Blood carries to the tissues the different salts necessary to keep the cells in a balanced physiological condition.

5 — Blood conveys the waste products from the different tissues to the excretory organs, such as the kidneys, which eliminate them outside the body.

6 — The leucocytes protect the body against certain diseases by engulfing the parasitic microorganisms and other foreign material which enter the body. Besides, they secrete certain substances which serve to neutralise the poisonous materials secreted by these foreign microorganisms.

7 — Blood keeps the temperature of human beings and warm-blooded animals at a constant level by carrying heat from active organs, such as the digestive organs, to the cold organs, such as the nervous system. In this way, blood helps to keep metabolic processes going on at a more or less constant level all the time, irrespective of the temperature fluctuations occurring in the surrounding medium.

Bone marrow

This tissue is strongly related to blood. Two kinds of bone marrow are found in the body : red and yellow. The red marrow is responsible for the formation of the blood corpuscles, whereas the yellow type is concerned with storage of lipoid material. In the embryonic stages, bone marrow is formed only of the red type, but after birth, this red marrow decreases gradually until it becomes restricted to the heads of the long bones, the ribs and the vertebrae. The yellow marrow is found in the cavities of the long bones.

The bone marrow is formed of reticular connective tissue containing adipose cells, phagocytes and certain other cells related to blood formation (haemopoiesis).

LYMPH

Lymph is the second category of vascular tissues. From the arterial capillaries, blood filters off a colourless fluid containing most of the constituents of the plasma except proteins. This process is called **ultra-filtration**, and the filtrate is called the **interstitial** or **tissue fluid**. It acts as a mediator between the blood and the tissue cells, carrying to them oxygen and nutrients and simultaneously collecting from them waste products and pathogenic microorganisms. Some of this tissue fluid, after being loaded with waste products, returns back to the blood capillaries by diffusion. But the greater portion of the fluid collects in a network of **lymph capillaries** and constitutes what is known as **lymph**. The lymph capillaries collect in larger **lymph vessels** or **lymphatics**, which are interrupted in their course by filtering **lymph nodes**. The lymph vessels unite together forming a number of large **lymph ducts** which return the lymph back to the venous circulation.

III. MUSCULAR TISSUES

These tissues form the muscles of the body. They are composed of simpler units called muscle cells or **muscle fibres** which are capable of contraction and relaxation. These cells differ from other body cells in the fact that most of their cytoplasm is modified into contractile threads, known as the **myofibrils**, running parallel to the long axis of the fibre. The remaining cytoplasm is known as the **sarcoplasm**.

Muscles are of three types, namely : unstriated muscles, striated muscles and cardiac muscles.

1 — Unstriated (Smooth) Muscles

These include the involuntary muscles found in the parts of the body whose movements are not controlled by the will of the individual, such as the alimentary canal and blood vessels. The unstriated muscle fibre is thin, elongate and is tapering at both ends. It contains a number of **myofibrils**, a small amount of cytoplasm, the **sarcoplasm**, containing a centrally located oval **nucleus**. Unstriated fibres differ in length in different parts of the body: those found in the walls of blood vessels are about 20μ in length, whereas those found in the intestine may reach 200μ and those found in the uterus of pregnant females are about 500μ in length.

Unstriated muscle fibres may be separate as in case of the skin, or may be arranged in a reticular manner as in the respiratory organs. In other organs such as the alimentary tract, the fibres form thick muscle layers, usually an outer longitudinal layer in which the fibres run parallel to the longitudinal axis of the tract and an inner circular layer in which the fibres run parallel to the circumference of the tract. The contraction of the longitudinal fibres causes the alimentary canal to shorten and thicken, whereas the contraction of the circular fibres causes the alimentary canal to elongate and become thinner. Such muscle contractions take place simultaneously, thus producing what is known as the peristaltic movement that helps to drive food along the digestive tract.

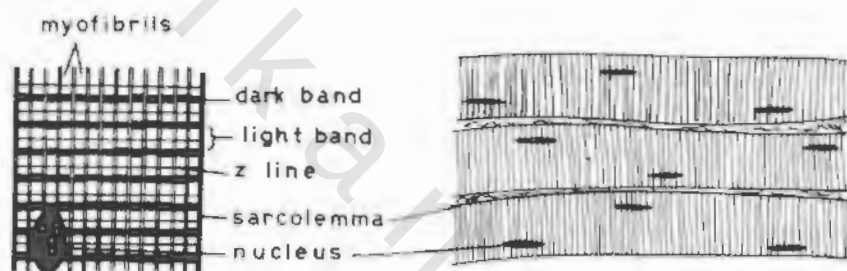
2 — Striated (Skeletal) Muscles

These are the muscles which are attached to the skeleton. They are voluntary because their movement is controlled by the will of the animal.

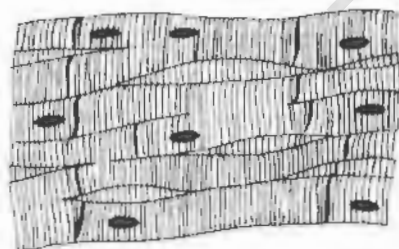
MUSCLES



Unstriated muscle fibres



Striated muscle fibres



Cardiac muscle fibres

They are responsible for the movement of limbs, head, jaws, etc. These muscles form the greater part of what is known as the flesh or meat.

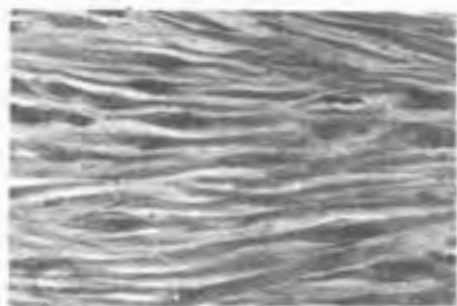
The striated muscle fibre is cylindrical; its diameter ranges from 0.01 to 0.1 mm and its length may reach 40 mm or more. Each fibre is bounded by a thin membrane, the **sarcolemma**, and contains a large number of **nuclei**, either peripherally located as in case of mammals, or scattered in the fibre as in amphibians. Such a structure containing many nuclei without cell partitions is called a **syncytium**.

The striated muscle fibre contains numerous **myofibrils**, each being formed of two types of substances which alternate regularly with each other along the length of the fibril. Thus, certain regions of the muscle fibre appear pale (I-bands) and the others dark (A-bands). Hence, a striated muscle fibre appears differentiated into alternating **dark** and **light bands**. The dark band is traversed by a faint line, known as the **Hansen's line of H-zone**, and the light band is traversed by a dark line known as the **Krause's membrane** or **Z-line**. The electron microscope has shown that the myofibrils are formed of thick and thin protein filaments built up of **myosin** and **actin** respectively, and that these filaments are arranged in a definite regular manner.

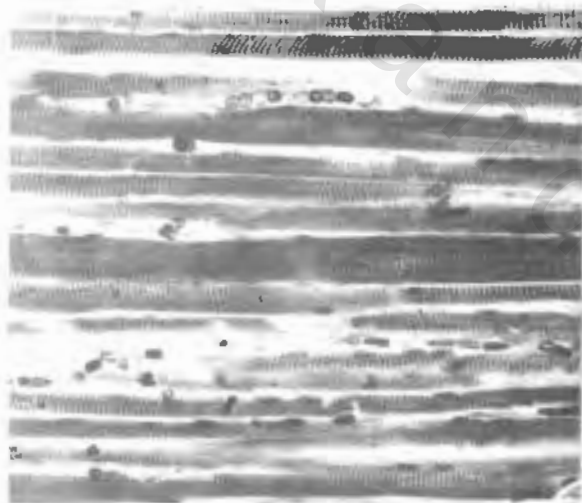
The striated muscle fibres are usually bound together by connective tissue into bundles; these bundles, in turn, are bound together by connective tissue to form the known body muscles. The connective tissue binding the bundles of muscle fibres is called **perimysium** and that enclosing the whole muscle is known as the **epimysium**. Inside each bundle, there is a third variety of connective tissue, known as the **endomysium**, extending inbetween the individual muscle fibres.

3 — Cardiac Muscles

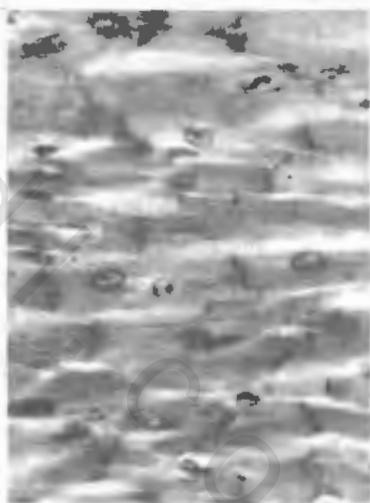
These muscles are found in the heart only. Their fibres are characterized by their rhythmic contractions which produce what is known as heart beats. The fibres appear in a longitudinal section branched and connected together, forming a network structure. They are bounded by thin sarcolemmal sheaths, and they are striated, though their striations are fainter than those of skeletal muscle fibres. They also possess numerous nuclei. These muscle fibres are traversed by certain dark lines, known as the **intercalated discs**.



**Longitudinal section
of unstriated muscle fibres**



Longitudinal section of striated muscle fibers



**Longitudinal section
of cardiac muscle fibers**

IV. NERVOUS TISSUES

These tissues are formed mainly of cells specialized to receive external and internal stimuli and to transmit them between different parts of the body. They are thus responsible for the coordination of the different activities of body organs.

Nervous tissues originate from the ectoderm, the cells of which become differentiated in one of two ways :

1 — Some ectodermal cells differentiate into embryonic nerve cells known as **neuroblasts**. These cells multiply actively and transform gradually into fully developed nerve cells, or **neurons**, which do not undergo further multiplication.

2 — Other ectodermal cells differentiate into another type of cells known as the **spongioblasts**. These cells continue their modification forming the **neuroglia cells** which serve to bind and protect the neurons.

Structure of the nerve cell

The fully developed **nerve cell** or **neuron** consists of two main parts : a cell-body or **cyton**, and a number of cytoplasmic processes extending from it. These processes include :

a) A number of small branched processes, known as the **dendrites**, which receive the stimuli and transmit the impulses to the nerve cell body.

b) A single long process known as the **axon** or **axis cylinder** which extends from the cell body and ends in a number of small branches known as the **terminal arborizations**. The axon acts to carry the nerve impulses from the nerve cell outwards. The axons of several neurons collect together to form **nerves**.

The cytons are located in certain nervous organs, such as the brain, spinal cord and nerve ganglia. From these organs, nerves extend out to the different body tissues and organs.

Nerve cells are usually arranged in a special manner by which the ends of the terminal arborizations of the axon of one cell lie very close to the dendrites of the following nerve cell; a physiological connection known as a **synapse** exists between them. This connection enables the passages of nerve impulses from the terminal arborizations of one cell to the dendrites of the following cell.

Types of nerve cells

Nerve cells are classified according to structure into the following types :

- 1 — **Unipolar nerve cells** : These are small, rounded or ovoid cells, each is provided with a single process which represents the axon. This type of nerve cells exists mainly in lower vertebrates.
- 2 — **Bipolar nerve cells** : The cell of this type carries two processes; one is a dendrite and the other is the axon. These cells are found in the embryonic stages of many vertebrates and in the retina of the adult vertebrate eye.
- 3 — **Multipolar nerve cells** : The cell body is usually polygonal and the cell has a single axon and several dendrites. These are the nerve cells commonly found in the bodies of adult vertebrates.

Cell body or Cyton

The cell bodies or cytons differ in size and shape, some of them are few microns in diameter while others may be hundreds of microns in diameter. They may be round, ovoid, spindle-shaped, star-shaped, etc. The cell body contains a centrally located spherical nucleus, with one or more nucleoli and a few chromatin particles. The nucleus is surrounded by the ground cytoplasm which contains the Golgi apparatus, mitochondria, lysosomes as well as other common cytoplasmic organoids and inclusions. Besides, there exist certain structures specific for the nerve cells only, such as the Nissl bodies and the neurofibrils. The nerve cell does not possess a centriole, since it has lost its ability for multiplication.

The **Nissl bodies** are small granular structures of different sizes found also in the dendrites, but not in the axons. They are rich in ribonucleic acid and have a strong affinity to basic stains.

The **neurofibrils** are fine thread-like structures which form a sort of a

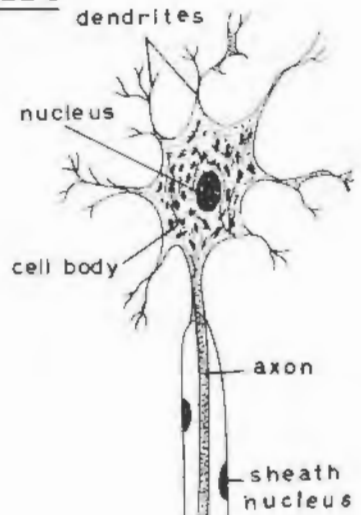
NERVE CELLS



Unipolar nerve cell



Bipolar nerve cell



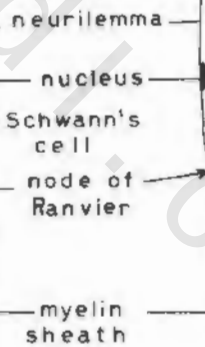
Nissl bodies



Neurofibrils



Medullated nerve fibre



terminal arborization

Multipolar nerve cell

network in the cell body. These fibrils may provide pathways for the nerve impulses within the nerve cells.

Nerve fibres

Each nerve fibre consists of an **axis cylinder** surrounded by a layer of lipoprotein material known as the **myelin** or **medullary sheath**. This layer is covered externally by a thin membrane, the **neurilemma**. The myelin sheath is interrupted at regular intervals forming what is known as the **nodes of Ranvier**. The distance between two successive nodes is known as the **internode**. Just below the neurilemma there is a very thin layer of cytoplasm which forms a tube containing a nucleus in each internode, the **Schwann's cell**. This cell is responsible for the secretion of the myelin sheath and the neurilemma. Nerve fibres of this sort are known as **medullated nerve fibres** and are found in the cranial and spinal nerves.

There is another type of nerve fibres which lack medullary sheaths and are thus known as **non-medullated nerve fibres**. These are found in the sympathetic nerves.

Nerves

A nerve consists of a large number of **nerve fibres** which are arranged in bundles known as the **funiculi**. The nerve is covered externally by connective tissue rich in blood capillaries and fat cells, the **epineurium**. This connective tissue binds the funiculi together. Each funiculus is also covered by a connective tissue sheath called the **perineurium**, and the nerve fibres within each funiculus are supported by connective tissue known as the **endoneurium**.

CHAPTER IV

SYSTEMATIC ZOOLOGY

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SYSTEMATIC ZOOLOGY

INTRODUCTION

'Systematic Zoology' or 'Animal Taxonomy' is the branch of Zoology concerned with the identification, description, nomenclature and classification of different kinds of animals.

At present, more than one million species of animals are known. They present an interesting diversity of structure, function, habits and mode of life. It is evident that some system is required for accurately naming and grouping such a large number of animals in order to facilitate their objective study and also to show the relationship between the various groups.

The Greek philosopher Aristotle (384 - 322 B.C.) was among the earliest scientists who attempted classifying living organisms. He suggested that animals could be classified according to the presence or absence of 'red blood' into two groups : **Enaima** and **Anaima**, with and without red blood respectively. It was also once suggested that animals may be classified according to the type of environment they live in as terrestrial, aquatic or aerial, or according to the type of food they use into flesh-eaters (carnivorous) and plant-eaters (herbivorous).

Gradually, however, emerged the idea of classifying animals according to the morphological similarities between them. This idea was formulated clearly in the 17th century by the English naturalist John Ray (1627-1705) whose system can be considered as the first scientific approach to animal classification. Moreover, he was the first to give a precise definition of the **species**, the basic unit for classification of living organisms. He defined the species as "*an assemblage or grouping of animals which are morphologically similar and which interbreed freely with one another, but they commonly do not inter-breed with other species, and if they do so, they produce infertile (sterile) hybrids*".

Later came the Swedish naturalist Linnaeus (1707-1778) who laid down the basis of the system of classification we use nowadays. He classified

living organisms according to the morphological and anatomical similarities between them. He also devised the system of "**Binomial nomenclature**" by which each type of organism is given a name composed of two words; the first is the name of the **genus**, and the second is the name of the **species**. Both are latin and are written underlined or typed in italics. The name of the genus starts with a capital letter and that of the species with a small letter. The scientific name of man, for example, is *Homo sapiens*, where *Homo* denotes the generic name while *sapiens* represents the specific name.

Nowadays, the classification of animals is not only based upon morphological and anatomical characteristics but also on biochemical, genetical, embryological and physiological features.

Species having many features in common are placed in the same genus. Similarly, related genera are grouped in a **family**, and families with certain common characteristics constitute an **order**, and orders in turn are grouped into **classes**. From these classes, the higher taxonomic groupings known as **phyla** are formed. Although the relationships between the different phyla may not be obvious, it is always possible to arrange them according to the degree of complexity of structure and function into larger groups known as subkingdoms or branches.

Thus, the **Animal Kingdom** is classified into three subkingdoms :

I. Subkingdom Protozoa : This subkingdom includes a single phylum, Phylum Protozoa, the members of which are referred to as unicellular animals (or acellular) since the body of each is formed of a single protoplasmic mass that performs all life activities.

II. Subkingdom Parazoa : This includes a single phylum, phylum Porifera, the members of which are simple multicellular animals commonly known as sponges. The body of the animal is formed of many cells which are not much differentiated and do not form proper tissues.

III. Subkingdom Metazoa : This includes the rest of the animal phyla. The body in these animals is composed of many cells which are well differentiated into distinct types and form definite tissues. Division of labour and cell specialization are remarkable in these phyla. The different phyla of the Metazoa show gradations from simple structural organization to complicated organ systems in the body.

SUBKINGDOM PROTOZOA

PHYLUM PROTOZOA

The phylum includes more than 50,000 species which are found in almost all habitats, wherever moisture is present

General characters

1 — The great majority are very small in size and can only be seen by the aid of the light microscope. Some of them are only 2 or 3 μ in length ($1\mu = 1/1000$ mm), but the majority are larger, reaching 250 μ in length. There are few species, however, which reach 16 mm in length and thus can be seen by the naked eye.

2 — Many species live as solitary individuals, while a few live in colonies.

3 — In the majority of cases, there is only one nucleus in the cytoplasm with distinct nucleoli often referred to as the endosomes. The cytoplasm is usually differentiated into outer clear ectoplasm and inner granular endoplasm. The cell is covered by a delicate plasma membrane or by a firm living pellicle. Some forms have non-living external envelopes of gelatinous, cellulose or calcareous substances.

4 — They move either by temporary protrusions of their cytoplasm known as pseudopodia, (sing. pseudopodium) by long whip-like filaments known as flagella (sing. flagellum) or by short hair-like filaments known as cilia (sing. cilium) and some have no locomotory organelles.

5 — Holozoic nutrition (animal-like) is the most common type of nutrition met with in this phylum. In this type, the animal feeds actively on other organisms (bacteria, algae, smaller protozoa, etc.) or on decaying organic matter. Some protozoa, by virtue of having chlorophyll-bearing organelles, exhibit a plant-like mode of nutrition known as holophytic nutrition. In this type, the organism synthesizes its own complex organic food material from carbon dioxide and water in the presence of sunlight, as plants generally do. Some protozoa were thought to adopt saprozoic nutrition

feeding by diffusion through their body surfaces on the simple organic and inorganic substances found in the surrounding medium. But electron microscopy has recently shown that most of these protozoa actually ingest droplets of the surrounding medium in tiny vacuoles at the surface, a process known as pinocytosis.

6 — Osmoregulatory organelles, in the form of contractile vacuoles, are characteristic of the great majority of the protozoa which live in fresh water.

7 — Aerobic respiration is the rule in many protozoa. Exchange of respiratory gases occurs by simple diffusion through the body surface. Some protozoa, however, are capable of anaerobic respiration which means respiration in the absence of suitable concentrations of free oxygen in the surrounding medium.

8 — Excretion of catabolic nitrogenous wastes (mostly in the form of ammonia) takes place also by diffusion through the body surface. There are no specialized excretory organelles for excretion.

9 — All protozoa can reproduce asexually, either by binary fission or by multiple fission. But, in addition, some protozoa can reproduce sexually by forming male and female gametes.

10 — Encystment is a common feature of the life cycle of many protozoa where the animal secretes a resistant protective cyst around itself to enable it to survive unfavourable environmental conditions and for dispersal.

Classification

Phylum Protozoa is divided into four subphyla on the basis of the locomotory organelles found in the various species :

I — **Subphylum Mastigophora**, includes protozoa which move by one or more flagella.

II — **Subphylum Sarcodina**, includes protozoa which move by pseudopodia.

III — **Subphylum Sporozoa**, includes protozoa which have no distinct locomotory organelles. They produce resistant spores towards the end of their life cycle, hence the name Sporozoa.

IV — **Subphylum Ciliophora**, includes protozoa which move by cilia.

1. SUBPHYLUM MASTIGOPHORA

Mastigophora includes those protozoa which move by one to several flagella. Many species live in fresh or marine waters, and some live as parasites. This class is of particular interest because its members combine the characters of plants and animals, and is therefore considered as the most primitive of the protozoan classes. It is divided into 2 classes according to the presence or absence of chromatophores :

a) **Class Phytomastigophorea** : includes plant-like free living flagellates which have chromatophores, e.g. *Euglena*.

b) **Class Zoomastigophorea** : these are animal-like flagellates with no chromatophores. The great majority of this group live as parasites in larger animals, e.g. *Trypanosoma*, and *Leishmania*.

1. *EUGLENA*

Habitat

Euglena is a free living flagellate which lives in freshwater ponds, particularly those which are rich in nitrogenous organic matter. The presence of large numbers of this flagellate, especially in laboratory cultures, gives the water a greenish tint.

Morphology

Euglena is a small, spindle-shaped organism, measuring less than 0.1 mm in length. The anterior end is blunt while the posterior end is pointed. The body is covered by a thin, firm but elastic covering known as the **pellicle**. The pellicle is marked by distinct spiral ridges or striations.

At the blunt anterior end of the body, there is a funnel-shaped depression

which starts with the mouth or **cytostome** and leads through a narrow gullet or **cytopharynx** into a spherical **reservoir**.

A long, whip-like **flagellum** extends outwards from the cytostome. It originates from a conspicuous granule known as the **basal granule** or **blepharoplast** found at the bottom of the reservoir. Another short flagellum extends in the reservoir, originating from a second blepharoplast. When a cross section of the flagellum is examined by the electron microscope, it appears to consist of 2 **central fibrils** encircled by 9 larger **double filaments**.

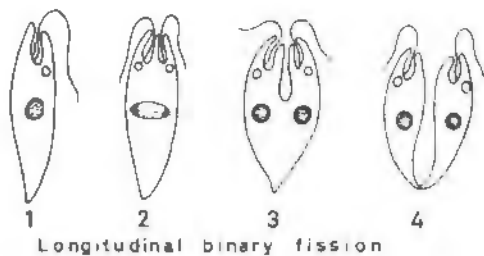
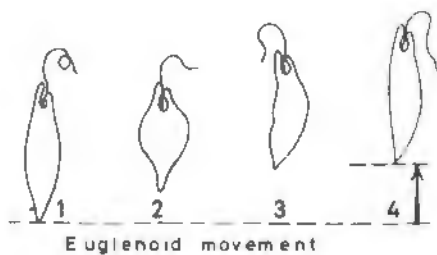
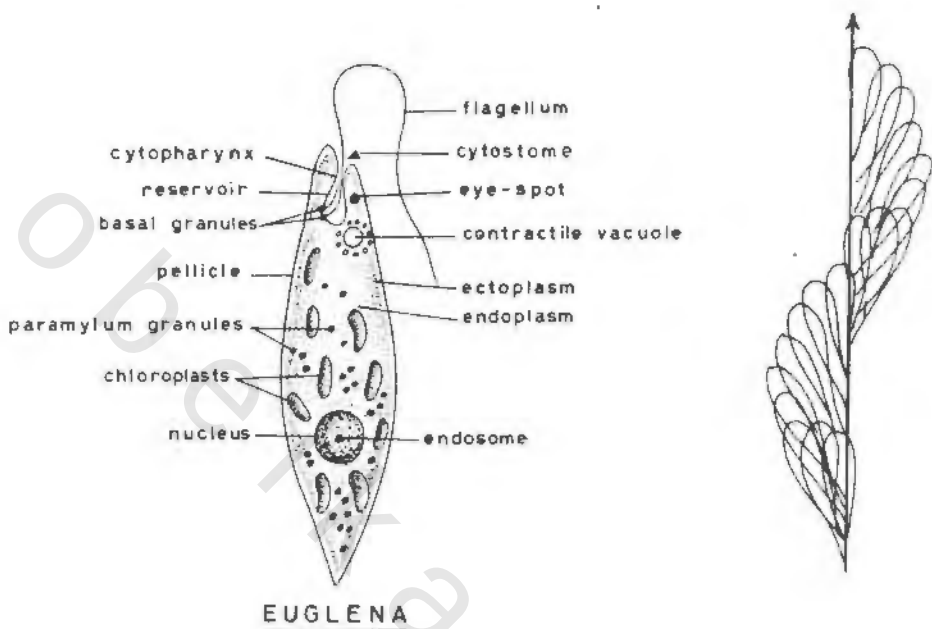
On one side of the gullet, there is a conspicuous red pigmented spot known as the **stigma** or **eye-spot**. Very close to the reservoir there is a **contractile vacuole system** which is formed of a large central vacuole surrounded by a number of smaller ones.

The cytoplasm is differentiated into an outer clear non-granular **ectoplasm** and an inner granular **endoplasm**. The **nucleus** is large, oval and usually lies nearer to the pointed end of the body. It encloses a distinct central **endosome**. A number of rod or disc-shaped green bodies are found suspended in the cytoplasm. These are the **chloroplasts** which are responsible for the green colouration of the animal. Suspended also in the cytoplasm are some living organelles, such as the mitochondria and Golgi apparatus, as well as ovoid **paramylum granules** formed of a carbohydrate allied to starch.

Locomotion

Euglena moves in its environment by two methods. The first is a slow worm-like movement known as the **euglenoid movement**. This type of movement is brought about by differential contractions and relaxations of the different parts of the body.

The second type of movement is faster and enables the animal to swim rapidly in water. It is carried out by the long flagellum and the mechanical principle involved in this type of movement is the same as that of the screw or propeller. The flagellum lashes obliquely backwards with waves passing along the flagellum from base to tip in a spiral manner, with an increase in velocity and amplitude. This results in rotation along the longitudinal axis and whirling about the axis of the general direction of locomotion. The animal then behaves as a rotating inclined plane and thus moves forward through the water.



As the animal moves forwards, it also rotates spirally around its longitudinal axis. Most probably, this is brought about by the generation of successive undulations along the flagellum during the effective stroke.

Nutrition

In the presence of sunlight, *Euglena* can synthesize carbohydrates from carbon dioxide and water by the aid of its chloroplasts. This method of nutrition is identical to the process of photosynthesis which occurs in plants and is referred to as **holophytic** or **autotrophic nutrition**.

In the absence of light, certain species of *Euglena* can absorb soluble food material from the surrounding environment through the body surface by **pinocytosis**. No food is taken in through the cytostome in *Euglena* and related flagellates.

Osmoregulation

Since the outer covering of *Euglena* is semi-permeable and the concentration of salts is higher in its cytoplasm than in the surrounding fresh water, water tends to flow continuously into its body by osmosis. This water should be expelled, otherwise the animal would gradually swell and eventually die. Water balance or osmoregulation in *Euglena* is carried out by the **contractile vacuole system**. Excess water collects as minute droplets in the small vacuoles which empty in the large central vacuole, and this bursts at regular intervals driving this water into the reservoir, from which it passes to the exterior through the cytostome.

Respiration and Excretion

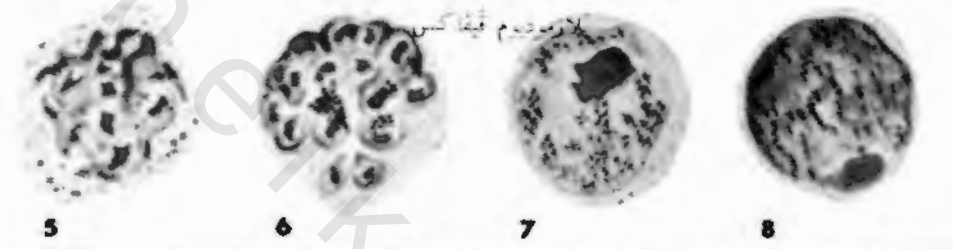
Euglena is aerobic and respire the oxygen dissolved in the surrounding water.

Exchange of oxygen and carbon dioxide takes place by **simple diffusion** through the body surface. Similarly, soluble excretory products of metabolism pass from the cytoplasm to the external environment by simple diffusion.

During daytime, respiration may be masked by the process of photosynthesis. Carbon dioxide resulting from respiration is utilized in photo-



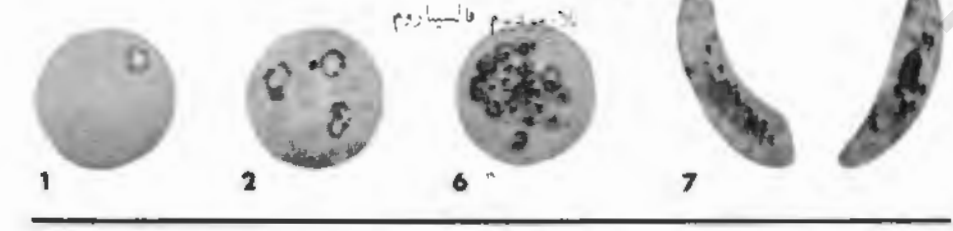
Plasmodium vivax



Plasmodium malariae



Plasmodium falciparum



Stages of Malaria

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synthesis, while the oxygen produced by the latter process is used in respiration.

Reproduction

Euglena reproduces only asexually by **longitudinal binary fission**. Immediately before this division starts, the animal stops moving and encloses itself in a thin envelope. The nucleus, then, divides by mitosis and the various organelles are duplicated. Eventually, the animal divides lengthwise, starting at the anterior end, into two daughter individuals.

When the prevailing conditions of the environment are unfavourable, the organism is capable of **encystment** by the secretion of a thick gelatinous **cyst** around itself. Quite frequently, *Euglena* reproduces by binary fission during encystment. In some instances, as many as 16 or 32 young euglenas may be formed in a single cyst.

Sensitivity

Chlorophyll-bearing euglenas are attracted to ordinary light. This is expectable particularly when we take into consideration the importance of light in the holophytic nutrition of the organism. It responds negatively to strong chemical solutions, twisting its body and changing its course.

Euglena : a plant or an animal ?

Some botanists believe that *Euglena* and related flagellates should be considered as plants rather than animals. This belief is apparently based on the fact that *Euglena* - as the great majority of plants - possess chloroplasts and exhibits holophytic nutrition.

However, most zoologists believe that these organisms should be classified as animals on the following grounds :

1 — The presence of a contractile vacuole system. Such a system is not known in the plant kingdom.

2 — None of the known plants move by an organelle comparable in structure to the flagellum.

3 — The plane of division in binary fission of *Euglena* and related flagellates is longitudinal while in plants it is transverse.

4 -- The presence of an eye-spot in many flagellates and its absence in all known plants.

2. *TRYPANOSOMA*

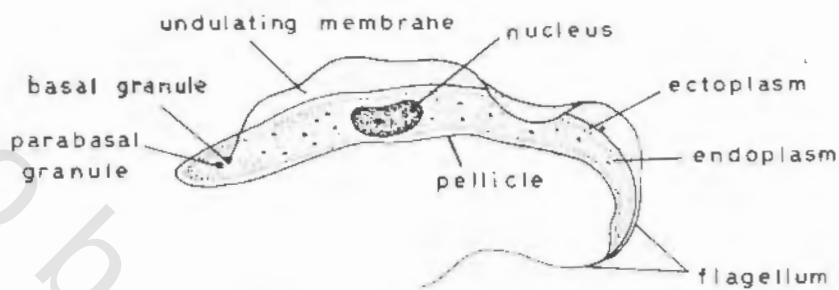
Trypanosomes live as parasites in the blood and some tissues of many warm-and cold-blooded vertebrates (**definitive or final host**). Several species are found in fishes, amphibians (e.g. frogs and toads), reptiles (e.g. snakes), birds and mammals, including man. But the life cycle usually involves another blood-sucking invertebrate host (**intermediate host**) which is frequently an insect (e.g. flies, fleas or bugs).

In their natural and wild hosts, these parasitic flagellates usually produce very little harm, i.e. they are non-pathogenic. However, in man and some of his domesticated animals, they produce dangerous diseases which are frequently fatal. Trypanosomes produce in man a disease known as **sleeping sickness** which in many parts of Africa ranks as the first problem in economic and social progress.

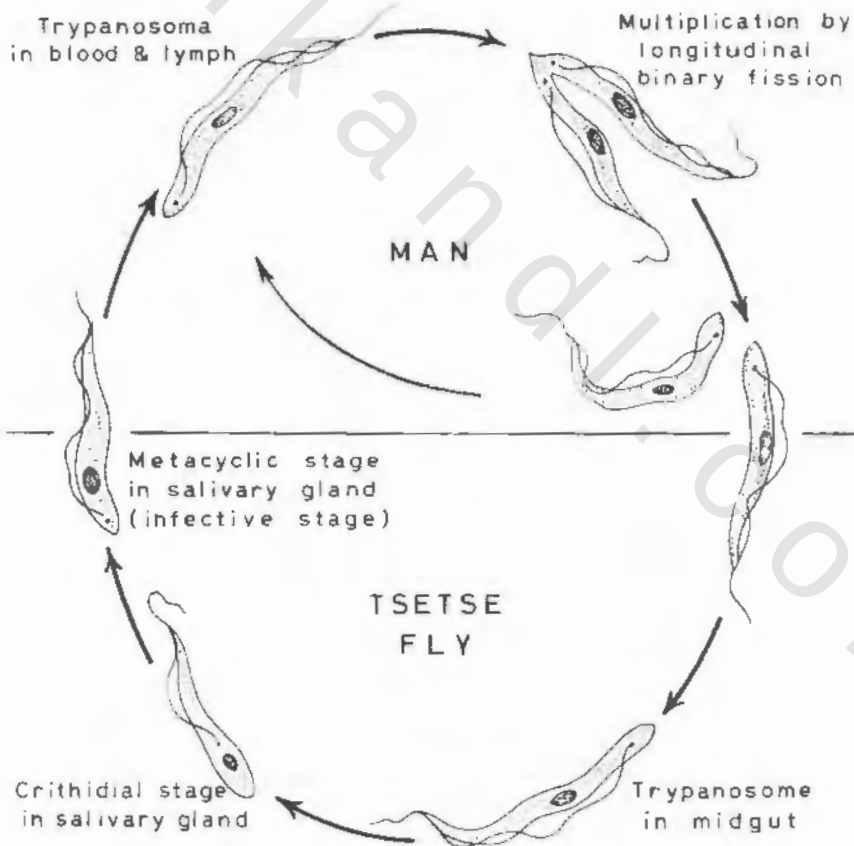
Common species of trypanosomes are : *Trypanosoma gambiense* and *Trypanosoma rhodesiense* which infect man in some parts of Africa, and *Trypanosoma lewisi* which is cosmopolitan and infects rats.

Morphology

A trypanosome has a fusiform body which is pointed at both ends. The shape of the body is maintained by the presence of a firm **pellicle** which is marked by longitudinal thickenings known as the myonemes. Within the cytoplasm, there is a large oval **nucleus** with a large central **endosome**. Arising from near the posterior end, there is a long **flagellum** which continues anteriorly alongside the whole length of the body. Throughout the greater part of its length, the flagellum is joined to the body by a thin **undulating membrane**, and it continues anteriorly in front of the body as a **free flagellum**. At the base of the flagellum, there is a distinct granule known as the **basal granule** or **blepharoplast**. Very close to the blepharoplast, there is a larger granule known as the **Kinetoplast** or **parabasal granule**.



TRYPANOSOMA



Life cycle of T. gambiense & T. rhodesiense

Ultrastructure

When examined with the electron microscope, the pellicle appears as a double membrane provided with a number of fine tubules to maintain the structure of the organism. These tubules appear in light microscopy as oblique striations. The nucleus is surrounded by a double envelope perforated by certain pores which allow the exchange of material between the nucleus and cytoplasm.

In some types of trypanosomes (**Trypanosome lewisi**) the only mitochondrion appears in the form of a long tube extending along the length of the organism. It possesses an inner fine membrane which gives certain internal ridges or cristae. In the other two varieties of trypanosomes, namely, **Trypanosome rhodesiense** and **Trypanosome gambiense** such ridges are not found, but instead there is a discoid structure elongated in the mitochondrion.

The cytoplasm also includes tubules of the endoplasmic reticulum, besides the ribosomes and Golgi bodies.

The flagellum starts from the basal granule in front of the kinetoplast. It contains a pair of central fibrils and 9 thick encircling double filaments.

Locomotion

Trypanosomes swim in the blood plasma of the host by the vibratile movements of the flagellum and the undulating membrane.

Nutrition

Formerly, it was believed that trypanosomes exhibit a saprozoic type of nutrition by absorbing (through simple diffusion) soluble organic material through their body surface. However, recent studies with the electron microscope have shown that this protozoon is capable of engulfing small droplets of blood plasma by a process known as **pinocytosis** (sipping).

Osmoregulation

No osmoregulatory mechanisms are required by trypanosomes and accordingly contractile vacuoles are absent. These parasites, as many others,

live in the blood plasma where an osmotic balance exists between the organism and the surrounding environment.

Respiration and Excretion

Exchange of oxygen and carbon dioxide between trypanosomes and their environment occurs by simple diffusion through the body surface. The poisonous soluble excretory products of metabolism are also eliminated by diffusion through the same body surface.

Reproduction

Trypanosomes reproduce only asexually throughout their entire life cycle by **longitudinal binary fission**. The belephroplast and parabasal granule divide, and this is followed by the nucleus. The body then splits lengthwise into two equal parts, starting from the anterior end. One part retains the original flagellum, while the other forms a new flagellum.

Trypanosoma gambiense
and *Trypanosoma rhodesiense*

These are the causative agents of **sleeping sickness** in certain parts of Tropical Africa. Basically, the two species produce a similar type of disease but infections due to *T. rhodesiense* are more serious, being quite frequently fatal.

Initially, the trypanosomes live and multiply in the blood of man. The early stages of the disease in man are characterized by irregular fever, skin rashes and enlarged lymph nodes. Unless treated, the parasite eventually reaches the nervous system causing brain damage and resulting in increasing weakness, coma and finally death.

These trypanosomes are transmitted by both sexes of biting **tsetse flies** of the genus **Glossina**. The same trypanosomes are non-pathogenic to many wild animals which act as reservoir hosts for these parasites.

When a tsetse fly bites an infected person, or animal, the trypanosomes are taken up along with the sucked blood into the midgut of the fly. There, they undergo a series of longitudinal binary fissions by which a large number of immature stages or forms are successively produced. After about 10-12 days the parasites invade the anterior part of the fly's gut and reach its salivary glands where they continue to multiply by binary fission producing a stage known as the **crithidial stage**. This has a narrow undulating membrane and its basal and parabasal granules lie in front of the nucleus.

Multiplication by binary fission continues for few more days when another stage appears known as the **metacyclic stage**. Its basal and parabasal granules lie behind the nucleus. This is the **infective stage**; all previous stages are incapable of infecting man. When the fly bites a person, the infective stage of the parasite passes into his blood along with the saliva of the fly. There it multiplies rapidly by longitudinal binary fission for about two weeks (a period known as the **incubation period**) before the symptoms of the disease start to appear on the patient.

No sexual reproduction occurs, and no cysts are produced in the life cycle of *Trypanosoma*.

Host-parasite relationships

Trypanosomes affect the human host in the following ways :

- 1 — When the parasites invade the tissues of the brain they produce a great damage to that organ.
- 2 — Trypanosomes are known to consume large amounts of glucose from the blood of the host.
- 3 — The excretory products of the metabolism of trypanosomes are toxic to the human host.

Trypanosoma lewisi

This is a common parasite of the black and brown rats in various parts of the world.

It is transmitted by the **rat flea**, which becomes infected by feeding on the blood of an infected rat. The trypanosomes included in the ingested blood undergo repeated binary divisions in the mid-gut of the flea. The produced organisms later migrate to the posterior part of the gut (hind-gut) where they undergo further binary divisions to form the infective stages which pass with the flea's faeces to the exterior. When the rat licks its fur, it gets infected as a result of the intake of the infective stages found in the faeces with which its body hair may be contaminated. When these infective forms of trypanosomes reach the intestine of the rat, they penetrate the wall of the gut and pass into a blood vessel, which carries them to the general blood circulation. The infected rat shows no signs of disease and the parasite is accordingly described as **non-pathogenic**.

3. LEISHMANIA

Parasites of the genus *Leishmania* live in the lymphoid macrophage cells of several vertebrates, including reptiles and mammals.

Ultrastructure

The fine structure of leishmania resembles that of trypanosomes. The pellicle appears as a double membrane supported by a number of oblique tubules. The nuclear membrane is also double and porous.

The single mitochondrion present appears as a fine tube extending horizontally in front of the nucleus then backwards representing an inverted L.

The kinetoplast appears as a distinct structure inside the horizontal part of the mitochondrion. Golgi apparatus is in the form of double lamellae lying between the arm of the mitochondrion containing the kinetoplast and the nucleus. Besides, the cytoplasm contains ribosomes and endoplasmic reticulum.

The flagellum is seen with its characteristic structure (a pair of central fibrils and 9 pairs of double filaments), and it originates from the basal granule embedded in the cytoplasm.

Three species of *Leishmania* infect man where they produce a disease known as **leishmaniasis**. The parasites are transmitted by species of blood-sucking **sandflies** of the genus *Phlebotomus*.

In the vertebrate host, the parasite is found in the leishmania stage, while in the insect, it changes into the leptomonad stage.

The **Leishmania stage** is a round form with a large central nucleus, above which lies a parabasal body, and a blepharoplast. From the latter arises a short flagellum which does not extend outside the body. Inside the host cell, the parasite multiplies by simple binary fission.

The **Leptomonad stage**, is spindle-shaped and has a free flagellum arising from a blepharoplast anterior to the large nucleus. In the insect's gut, the leptomonad individuals multiply by longitudinal binary fission, and migrate forwards to the pharynx and buccal cavity where they are ready to produce infection. During the insect's bite, they enter the host skin and change into leishmania forms.

Leishmania tropica is the common species infecting man in several parts of the world and causing **cutaneous leishmaniasis**, known as **oriental sore** or "Baghdad boil".

Leishmania donovani is another species, common in Sudan, southern Europe, India, South America and other countries, and is the causative agent of **visceral leishmaniasis** or **Kala-azar**. Dogs and certain rodents are known to act as natural reservoirs for human infections caused by *Leishmania*.

II. SUBPHYLUM SARCODINA

This class includes protozoa which use temporary protoplasmic projections known as **pseudopodia** for locomotion. Free-living members of this class are either freshwater or marine inhabitants. Certain species live in association with other organisms either as commensals or as parasites. *Amoeba*, *Entamoeba* and Foraminifera are common examples of this class.

1. AMOEBAS

This protozoan is usually found in freshwater ponds and ditches where decaying vegetable matter is abundant.

Morphology

The body is about 250μ in diameter. A living *Amoeba* appears under the microscope as an irregular, jelly-like mass which is constantly changing its shape due to the formation of temporary, finger-like projections of the cytoplasm known as the false feet or **pseudopodia** (sing. pseudopodium).

The body is covered by a thin living membrane known as the **plasma membrane** or **plasmalemma**. The cytoplasm is differentiated into an outer transparent layer of **ectoplasm** and an inner granular mass of **endoplasm**.

In the endoplasm there is an oval **nucleus** with a distinct **endosome**. A pulsating spherical **contractile vacuole** is also found. It enlarges gradually until it reaches a maximum size when it bursts, releasing its fluid contents to the outside. A new vacuole is then formed, and the same process is repeated at regular intervals. Two or more other vacuoles containing food material and known as the **food vacuoles** are also seen in the cytoplasm.

Besides the above mentioned organelles, some non-living materials, such as crystals of various salts and oil droplets, may occasionally be found in the endoplasm.

Locomotion

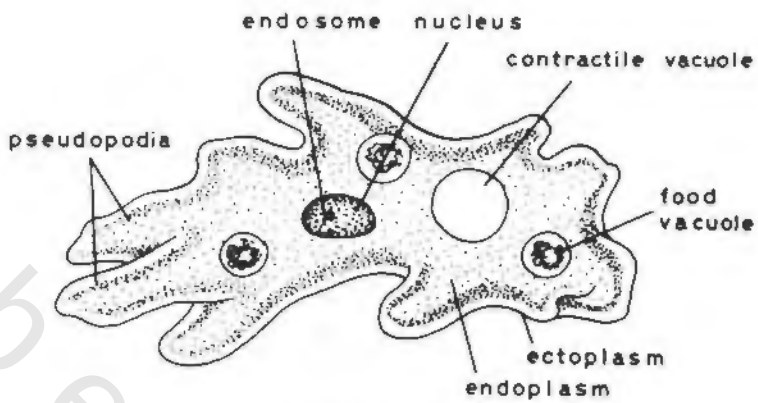
Amoeba moves and captures food by means of the pseudopodia which arise at any point on the body surface. This sort of irregular movement is very slow and is called **amoeboid movement**.

Several theories have been proposed to explain how this movement is affected. The actual mechanism is not yet well understood, but the theory which is widely accepted nowadays assumes that it is produced as a result of changes in the colloidal state of the cytoplasm from the **gel** to the **sol** conditions and vice versa. At the point where a pseudopodium is to be formed, the plasmagel softens, changing to plasmasol. As a result of this change, internal pressure causes the plasmasol from the endoplasm to flow out at this weak point forming a pseudopodium. As the plasmasol keeps flowing forwards, the cytoplasm at the sides of the pseudopodium changes again to plasmagel, thus building rigid sides to the pseudopodium, which keeps steadily elongating.

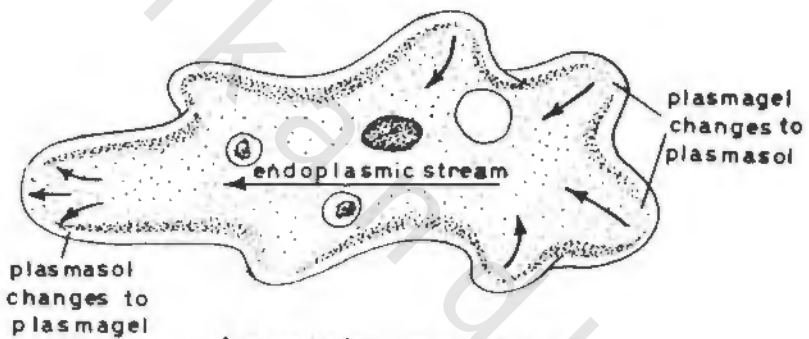
A similar process takes place at the other end of the body where the plasmagel changes to plasmasol, and this flows along with the rest of the plasmasol in the direction of the new pseudopodium. Several pseudopodia may be developing at one end at the same time.

Nutrition

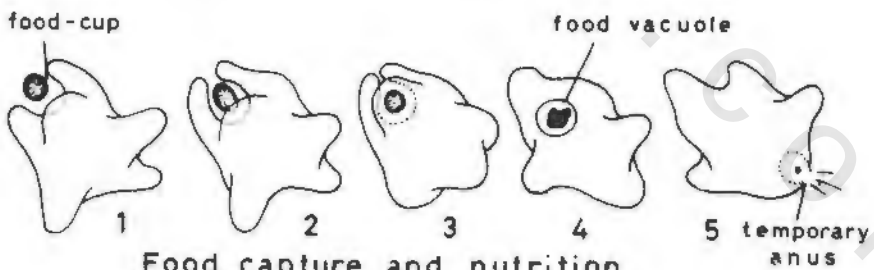
Amaeba is holozoic in nutrition. It feeds on minute organisms (mainly unicellular plants, but occasionally other smaller protozoa) which are found in its aquatic environment. When an *Amoeba* comes in contact with one of these organisms, it flows around it forming a cup-shaped pseudopodial structure which is called the **food-cup**. This cup gradually encloses the prey together with a drop of water and in this way a **food vacuole** is formed inside the cytoplasm. Digestion immediately starts under the effect of the digestive enzymes which are secreted into the food vacuoles. The contents of the vacuole are acidic at first but as digestion proceeds, they become alkaline. This indicates that at least two types of enzymes are involved in the process of digestion; one of them acts in acidic medium while the other in alkaline medium. At the end of digestion, the digested food materials are absorbed by diffusion into the cytoplasm. The remaining undigested materials are



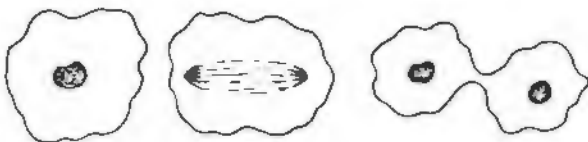
AMOEBA



Amoeboid movement



Food capture and nutrition



Binary fission

egested at any point on the surface, when the cytoplasm flows away from them.

It has recently been demonstrated that *Amoeba* can also obtain dissolved organic matter from the surrounding environment by **pinocytosis**.

Osmoregulation

This is carried out by the pulsating contractile vacuole which bursts at regular intervals expelling to the exterior the excess water which diffuses into the cytoplasm from the surrounding medium.

Respiration and Excretion

Exchange of respiratory gases between *Amoeba* and its environment takes place by simple diffusion. The products of nitrogenous metabolism diffuse in a similar way through the body surface to the outside.

Reproduction

If the food is abundant in the environment, *Amoeba* grows in size by addition of more substances to its living protoplasm. There is, however, a limit to this increase in the size and once this limit is reached, the animal starts reproduction.

Amoeba reproduces only asexually by **binary fission**. The nucleus divides mitotically into two parts which move away from each other. This is followed by the division of the cytoplasm into two parts, one around each nucleus. Eventually, two small amoebae are produced which feed and grow gradually in size then divide again. The process of division takes about 30 minutes.

Encystment

Under unfavourable conditions, such as the drying up of the water in the environment, *Amoeba* withdraws its pseudopodia, becomes spherical and forms a tough resistant **cyst** around itself. The nucleus of the organism divides repeatedly to form a large number of daughter nuclei which migrate towards the periphery. Each daughter nucleus becomes surrounded by a

portion of the cytoplasm and in this way a number of small amoebae are produced inside the cyst. When the conditions of the environment improve, the wall of the cyst ruptures and the small amoebae are free. These daughter amoebae immediately start feeding and growing until they reach the normal size of the parent *Amoeba*.

Sensitivity

Though *Amoeba* resembles all other free-living sarcodinians in the absence of differentiated nervous organelles or specialized sense organs, yet it can respond to external stimuli in a variety of ways.

Amoeba reacts negatively (moves away from the stimulus) when touched with a solid object at any point on the body; the affected part contracts and the animal moves away. However, if the animal is moving freely in the aquatic environment and one of its pseudopodia comes in contact with a substratum, the animal reacts positively by moving towards that pseudopodium. Contact with food results in the same reaction.

Amoeba is also sensitive to changes in the chemical composition and the temperature of the surrounding medium. It is believed that the positive reaction of the organism towards food is basically due to chemical stimuli.

2. ENTAMOEBA

Entamoeba is similar to *Amoeba* in many of its characteristics, but the former lives as an endoparasite in the large intestine of certain mammalian hosts. Three species of *Entamoeba* infect man : *E. histolytica*, *E. coli* and *E. gingivalis*. Several other species occur in other mammals, e.g. *E. muris* which is a parasite of rats and mice.

Entamoeba histolytica

This is an intestinal parasite of man which has a world-wide distribution. Three forms or stages are recognized in the life cycle of this parasite: an active feeding form known as the **trophozoite**, an **encysted form** and an excysted multinucleated organism known as the **metacyst**.

Morphology and Life cycle

The trophozoite is almost spherical, but at one end there is a cytoplasmic

projection to form a pseudopodium which is made up almost exclusively from the ectoplasm. The trophozoite has a single nucleus of a characteristic structure. It has a small central **endosome** (karyosome) surrounded by a clear area and the nuclear membrane is lined with a single layer of fine chromation granules. The space between the **endosome** and the membrane is free of chromation. The cytoplasm is differentiated into outer clear and thick ectoplasm and inner granular endoplasm. It contains food vacuoles, but no contractile vacuoles.

There are two types of trophozoites which can be differentiated according to their size and feeding habits. **Minute trophozoites** measuring $10-20\mu$ in diameter live in the lumen of the intestine feeding on bacteria and food debris. For some unknown reasons, these trophozoites invade the mucosa and the submucosa of the host's intestine, feeding on the cellular elements of these tissue layers, and on the red blood cells which appear inside their food vacuoles. In these richer environments they develop into **large trophozoites** measuring $20-40\mu$ in diameter. If these large trophozoites are passed back to the lumen and carried to the outside with the faeces, the trophozoites do not live long and do not transmit the infection which is transmitted only by the encysted stage.

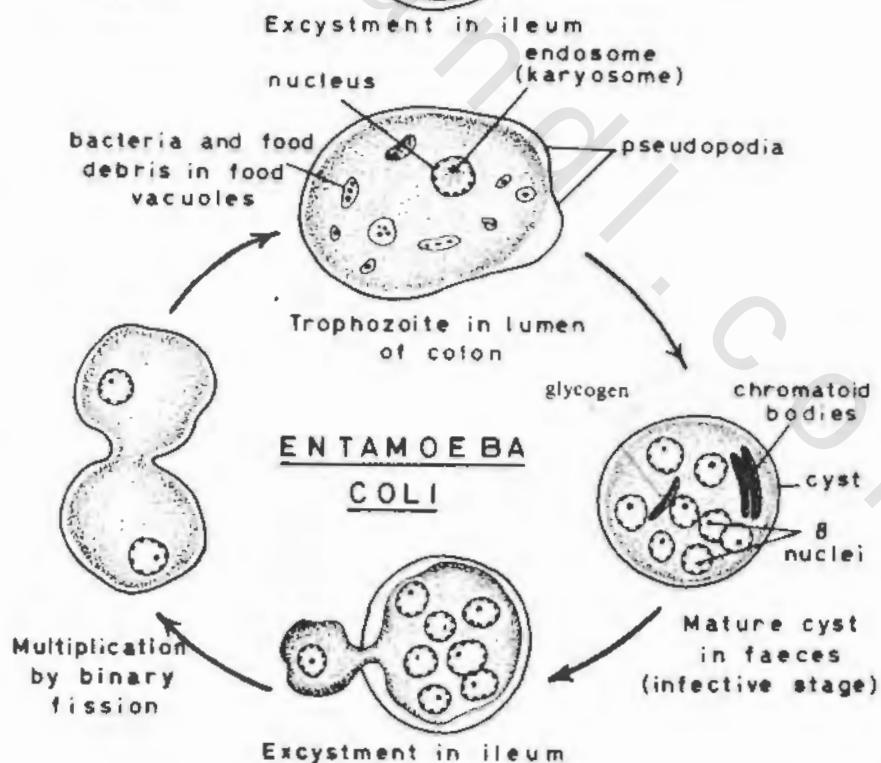
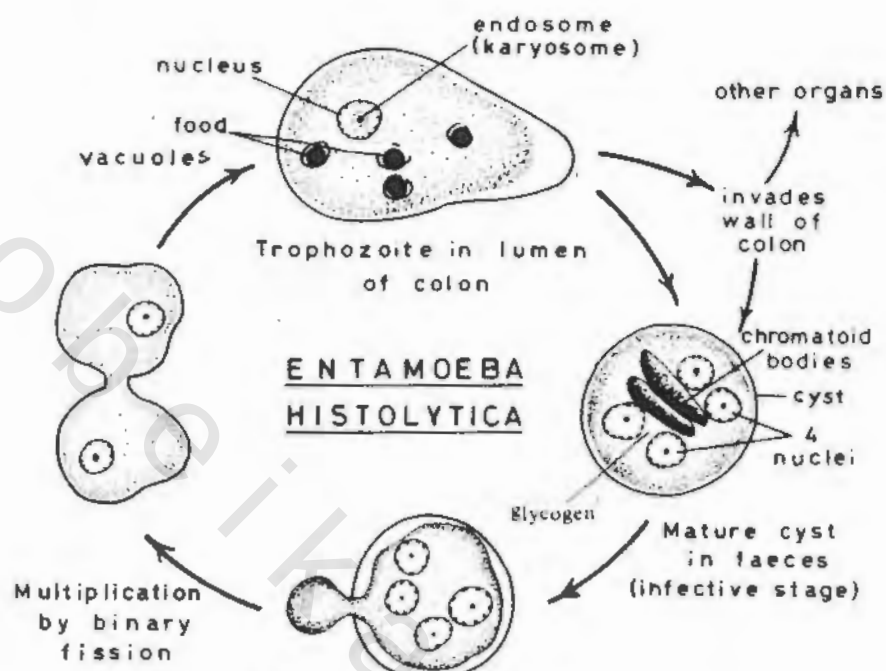
The trophozoites encyst only in the gut lumen. They round up and secrete a thin protective cyst; thus the **encysted** or **cyst stage** is produced. The nucleus divides twice by mitosis to produce 4 nuclei. The **mature cyst** measures about 12μ in diameter and includes, besides the 4 nuclei, 2 chromatoid bodies (protein reserve) and a diffuse mass of glycogen.

The mature cyst is the **infective stage** of this parasite. It is passed out with the faeces and can survive outside for some time.

A new host acquires the infection by the ingestion of the encysted stage in contaminated food or water. This stage passes without any changes in the stomach but it becomes excysted in the duodenum liberating a 4-nucleated individual. The 4 nuclei divide once more so that an 8-nucleated individual is formed, and this is followed by cytoplasmic divisions, thus 8 small uni-nucleated amoebae are produced. These reach the large intestine, feed actively on bacteria and debris until they grow to the normal size then start to multiply by binary fission.

Ultrastructure of the trophozoite

The trophozoite is surrounded by the double plasma membrane which is similar in structure to that of most animal cells. It is difficult to distinguish



in the electron micrographs between the ectoplasm and endoplasm for unknown reason. The nuclear membrane is double and has many pores. The chromatin material lies adjacent to the inner surface of the nuclear membrane being in the form of aggregates of electron dense masses invaded by small less dense masses. The nucleolus appears as an irregular dense mass. Besides, the nucleus contains a number of minute vesicles of unknown nature.

The cytoplasm also contains a number of **pinocytotic vesicles**, some of which contain bacteria and others contain starch material, but both inclusions do not exist together in any vesicle. It is thus concluded that each type is digested in special vesicles in which chemical and physical conditions are suitable.

Besides, the cytoplasm includes a number of ribosomes and aggregates of glycogen particles surrounded by a membrane, that exhibiting the appearance of glycogen vacuoles. The endoplasmic reticulum is not well developed. Also there is no evidence for the existence of Golgi apparatus in any of the entamoebae examined so far. Mitochondria have not been also observed which indicates that metabolism occurs in the trophozoite anaerobically. Only one type, namely *Entamoeba gingivalis* which lives in the gums of the teeth display clear mitochondria and hence metabolism takes place aerobically in it. The cytoplasm also contains a pair of **chrometoid bodies** which contain DNA that is also scattered in the trophozoite and appears crystalline in the cyst.

Host-parasite relationships

E. histolytica has long been regarded as an obligatory tissue parasite. Recent evidence, however, indicates that in the majority of cases, it lives as a harmless parasite in the gut lumen. Only under certain conditions it changes its feeding habits and produces pathological infections. Accordingly there are two types of infections in man:

a) **Harmless infections** : in these, the small trophozoites live in the lumen of the gut feeding on bacteria and faecal debris. In such cases, the organisms behave as commensals and the human host is not affected in any way.

b) **Pathological infections** : in some cases — due to certain unknown reasons — the usually balanced host-parasite relationships are disturbed

to the benefit of the parasite. The trophozoites attack the epithelial cells of the mucosa and digest them by some histolytic enzymes which they secrete. They gradually erode the surface of the mucosa and penetrate into the deeper tissues, after breaking through the muscularis mucosa and the submucosa. During this invasion they ingest partially digested tissue cells as well as blood corpuscles which come out from damaged blood capillaries. They grow in size and reproduce at a great speed by repeated binary fissions, causing ulcers in the submucosa and developing the disease known as **amoebic dysentery**. Some of the trophozoites may penetrate a small blood vessel and reach the blood stream, by which they are carried to certain organs such as the liver, lungs or brain where they produce certain ill effects in these locations.

Entamoeba coli

This species is commonly found in the large intestine of man. It never attacks the wall of the intestine and it always lives as a harmless commensal in the lumen of the gut. The life cycle and the mode of transmission are identical with those described for *E. histolytica*.

The trophozoites measure 20-30 μ in diameter. There are usually 2 pseudopodia formed almost exclusively from the ectoplasm. The nucleus differs from that of *E. histolytica* in having a larger endosome which is typically eccentric (not central) in position. The peripheral chromatin is formed from coarser and more irregular bodies, and the space between the karyosome and the nuclear membrane contains large chromatin granules.

The cysts of *E. coli* are larger than those of *E. histolytica*; they reach 17 μ in diameter. The mature or infective cyst contains 8 nuclei, and occasionally 16 nuclei, and two thin elongated chromatoid bodies.

3. THE FORAMINIFERA

The Foraminifera are amoeboid protozoa which are mostly marine. Some float near the surface while the majority live at great depths on the sea bottom. Many are just visible to the naked eye, but some species are several centimeters in diameter. These protozoa have played a major role in the geologic history of earth. They are extremely abundant in oceans and

their calcareous shells represent the major constituent of ocean bottom sediments. Some are drifted ashore where they form a considerable proportion among the sand grains of the sea shore.

Much of the limestone and chalk now present on earth was formed from deposits of foraminiferan shells. The Great Pyramids, for example, were carved from limestone deposits made of such shells. Fossil Foraminifera obtained at different depths while drilling in earth tell a great deal about the geologic structure of an area and help petroleum geologists to identify oil-bearing strata.

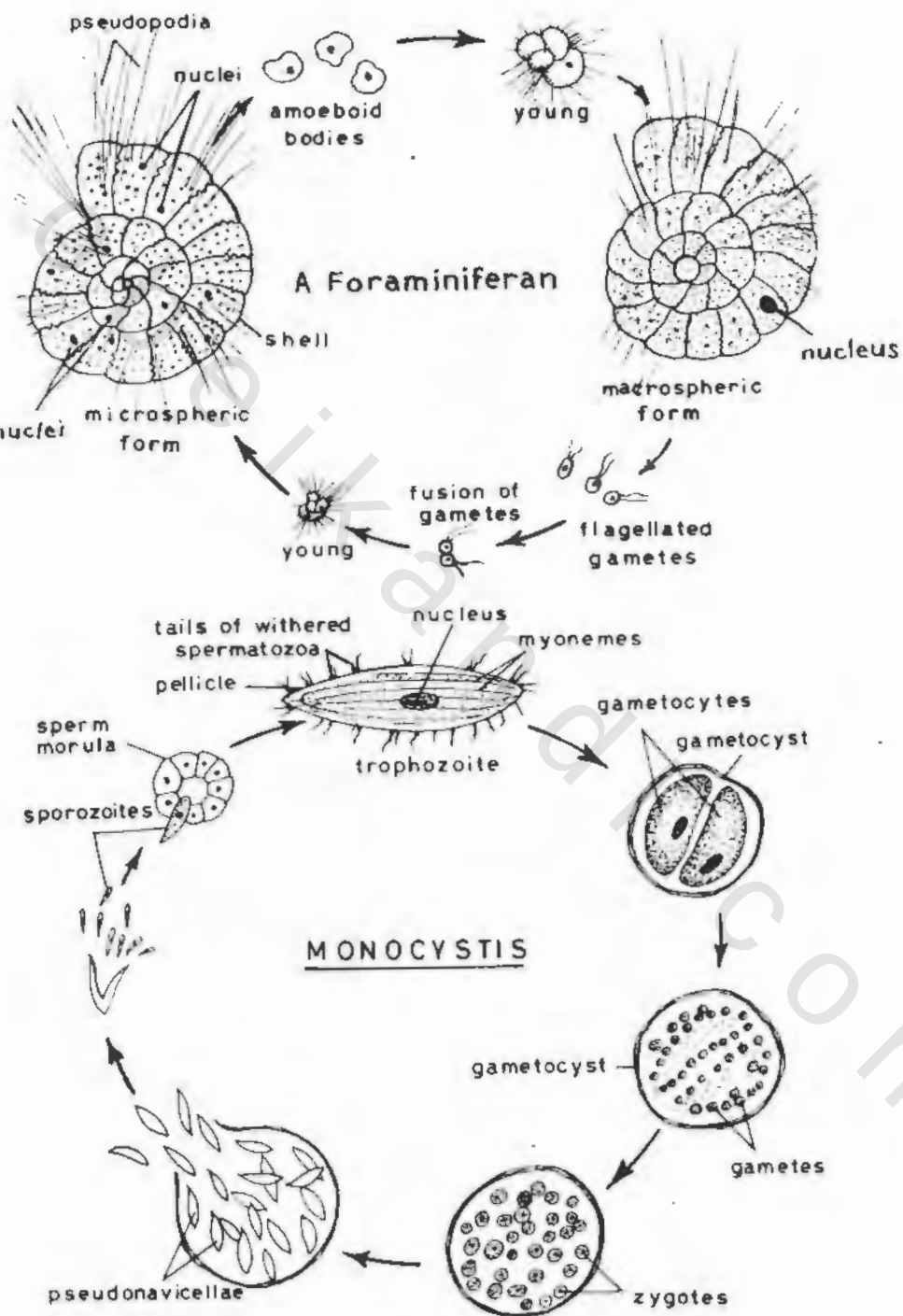
Morphology

A young foraminifer resembles *Amoeba* in structure, but it secretes a shell or test around itself, and marine forms lack contractile vacuoles. Few species live within a shell of one chamber, but the majority secrete many-chambered shells, usually of calcium carbonate. These forms begin life with a small spherical shell that has an opening at one end. As the animal increases in size, its protoplasm overflows out of the shell opening, spreads over the original shell and secretes a second shell. This process continues throughout life so that a many-chambered shell is formed, each chamber being larger than the preceding one. The new chambers may be added in a straight line, laid alternatively on both sides of the original central chamber or have each chamber almost enclosing the preceding chamber, or become arranged in a spiral manner.

All the shell chambers are occupied by the protoplasm and they communicate with each other by small openings so that the protoplasm is continuous throughout the organism. Each chamber is usually pierced by numerous minute pores through which project long fine reticulate pseudopodia.

Vegetative activities

The pseudopodia are used for creeping slowly on the sea bottom, but they act primarily as traps for capturing microorganisms on which these animals feed. They branch and anastomose forming pseudopodial networks outside the shell. Organisms which come in contact with such pseudopodia are attached to them then coated with a mucous film. The prey is thus paralysed and eventually enclosed in a food vacuole. The food is dige-



sted in the vacuole while outside the shell, and the products of digestion are then absorbed and passed to the interior.

All other life processes are performed as in *Amoeba* except reproduction which is much more complicated.

Reproduction

Most species of the Foraminifera are **dimorphic** with each species existing in two forms during the life cycle. These two forms usually differ in the size of the first or central chamber of their shells. One form, known as the **microspheric form** or **schizont**, has a small central shell chamber and reproduces asexually by multiple fission. The other, known as the **macro-spheric form** or **gamont**, has a large central shell chamber and reproduces sexually by the formation of gametes.

An example of this complex reproduction may be seen in *Elphidium* (= *Polystomella*) which is a dimorphic marine foraminifer with a calcareous perforated shell of many chambers of increasing size arranged in a flat coil. Its microspheric form has several small nuclei and reproduces asexually by multiple fission. The protoplasm flows outside to cover the shell and divides into a number of small amoeboid bodies each containing a single nucleus. Each of these bodies secretes a shell and develops into a macro-spheric individual.

When mature, the protoplasm of the macrospheric form divides producing a large number of **flagellated gametes** which swim about in sea water, leaving the empty shell behind. Each gamete unites with a similar gamete from another macrospheric individual to form a zygote which develops into a microspheric individual, thus completing the life cycle. This cycle illustrates the phenomenon known as "**alternation of generations**" as it involves an alternation of a sexual generation (the macrospheric form) with an asexual one (the microspheric form).

III. SUBPHYLUM SPOROZOA

The Sporozoa are all parasites which have no distinct locomotory organelles and reproduce by **spores**. Their life cycle is complex and usually involves asexual and sexual generations, and sometimes also two hosts.

Amoeba and *Euglena*, as we have seen, are free-living creatures which exist in an environment inhabited by many other organisms, some of which may be competing with these protozoa while others may prey upon them. Environmental conditions around them are also unstable.

The Sporozoa, however, are all parasites which live within the bodies of other organisms, i.e. in a totally different environment where competition with other organisms is minimal, food is abundant and conditions for existence are uniform. Thus they generally have a simple structure compared to free-living protozoa. They lack special locomotory, feeding and water-balancing organelles, the development of which seem unnecessary for their existence. But the comfortable conditions in which they live have one serious drawback. For continuation of the race, a sporozoan parasite must be transferred to a new host, i.e. must pass through the outside world where dangers, enemies and competition are found. To compensate for the high mortality occurring during this risky and dangerous journey, the number of offspring produced during reproduction is greatly increased so as to ensure that a sufficient number of individuals will survive and reach new hosts. *Plasmodium* and *Monocystis* are common examples of this subphylum.

1. MONOCYSTIS

Several species of *Monocystis* live as parasites in the seminal vesicles of earthworms. Within these vesicles there are collections of sperm mother cells, known as sperm morulae, which develop the spermatozoa. The parasite attacks these sperm morulae during the early stages of infection. Thus a minute nucleated body, the **trophozoite** or feeding stage, appears in the centre of the sperm morula. It feeds and grows at the expense of the proto-

plasm of the developing spermatozoa until their cytoplasm is fully consumed and nothing is left of them except their tails.

Morphology

The trophozoite has an elongated cigar-shaped body covered externally by a firm **pellicle** and is often surrounded by the tails of the dead spermatozoa of the earthworm. Its cytoplasm is differentiated into outer clear **ectoplasm** and inner granular **endoplasm**; contractile **myonemes** extend longitudinally in the ectoplasm. No other prominent organelles are seen.

Vegetative activities

The trophozoite has no special locomotory organelles. It is only capable of slow movements by contraction and relaxation of the myonemes, known as **gregarine movement**. It has no contractile vacuoles or food vacuoles, and feeds by absorbing the cytoplasm of the developing spermatozoa around it. Presumably it secretes digestive enzymes which act upon that cytoplasm before absorption. Reserve food material is stored as paramylum granules.

Respiration and excretion take place by simple diffusion through the pellicle. The surrounding fluid, inside the seminal vesicles, receives oxygen from the blood of the earthworm, and carbon dioxide and nitrogenous wastes are also carried away by that blood.

Reproduction and Life cycle

The trophozoite is haploid and most of the life cycle is passed in this phase (i.e. with half the number of chromosomes typical of the species). When fully grown, the trophozoite starts reproduction and is then termed a **gametocyte** or **gamont**. Two gametocytes come together, round up and secrete a common double-walled cyst around them known as the **gametocyst**. Within this cyst, each gametocyte undergoes multiple fission (by mitosis) producing a large number of **gametes** (usually 64). The resulting nuclei migrate to the periphery of the gametocyte where each is surrounded by some cytoplasm, thus forming a gamete. The gametes finally separate, leaving some **residual cytoplasm** in the centre. The two associated gametocytes usually produce the same number of gametes which, in some species, are identical in form and described as **isogametes**. In other species, the

gametes from the two associated gametocytes are different in form and known as **anisogametes**. The gametes then unite in pairs (a process of sexual fusion known as **syngamy**) forming diploid **zygotes** or **sporoblasts**. The whole process of formation of gametes and their union occurs within the gametocyst.

Each zygote or sporoblast surrounds itself with a resistant covering cyst known as the **sporocyst** or **pseudonavicella** (because of its boat-shaped appearance similar to that of the diatom, *Navicella*). Within each sporocyst, the sporoblast undergoes 3 successive divisions (the first of which is by meiosis) producing 8 fusiform haploid bodies known as the **sporozoites**. This process of asexual multiplication is called **sporogony**.

No further development takes place until the sporocysts are transferred to another worm. They may be either passed out through the vasa deferentia of the worm to the soil, or set free in the soil when the infected worm dies and its body decays, or when it is eaten by a bird in which case the sporocysts are passed unharmed to the soil in the faeces of the bird. Upon reaching the soil, by either of these methods, the sporocysts may be swallowed by other earthworms which consequently acquire the infection. The sporocysts rupture and the sporozoites are liberated in the intestine of the new host. They find their way to the seminal vesicles, attack the sperm morulae, feed, and grow as trophozoites, thus the life cycle is repeated.

2. PLASMODIUM

Four species of *Plasmodium* infect man and cause a disease which is commonly known as Malaria. These species are : *P. vivax*, *P. falciparum*, *P. malariae* and *P. ovale*. The first two species are responsible for about 90 % of all malaria cases in the whole world, but the greater killer of man is *P. falciparum*, and accordingly the form of the disease it produces is known as **malignant malaria**. Malaria is of tremendous medical and economic importance; several millions of people are infected each year. In 1942, an epidemic of the disease in Upper Egypt killed thousands of people in a few weeks. Human plasmodia require two types of hosts : an invertebrate, *viz.* female mosquitoes of the genus *Anopheles* where the parasites reach sexual maturity, and the human host where asexual multiplication takes place.

There are three phases of development in the life cycle of malaria parasites: fixed tissue, erythrocytic and invertebrate phases.

a) Fixed tissue phase

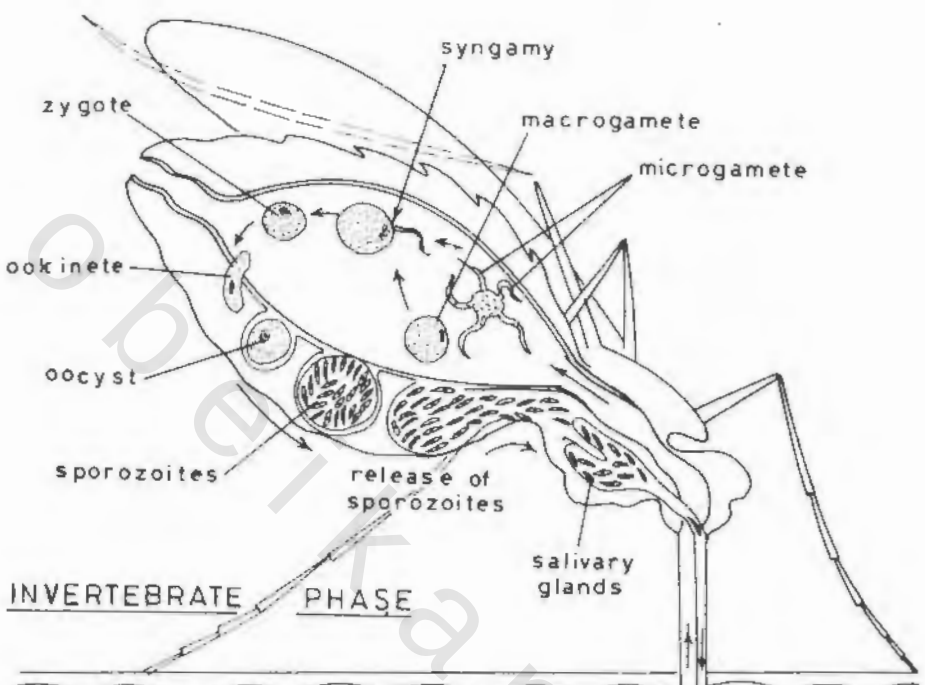
When an infected mosquito bites man, numerous sporozoites are injected together with the mosquito saliva directly into his blood stream. A **sporozoite** is a minute slender fusiform organism with one or more chromatin masses near its centre.

After injection, the sporozoites circulate in the blood for about half an hour then they leave the blood stream to enter fixed tissue cells of the liver and undergo an asexual schizogonic cycle before re-invading the blood stream.

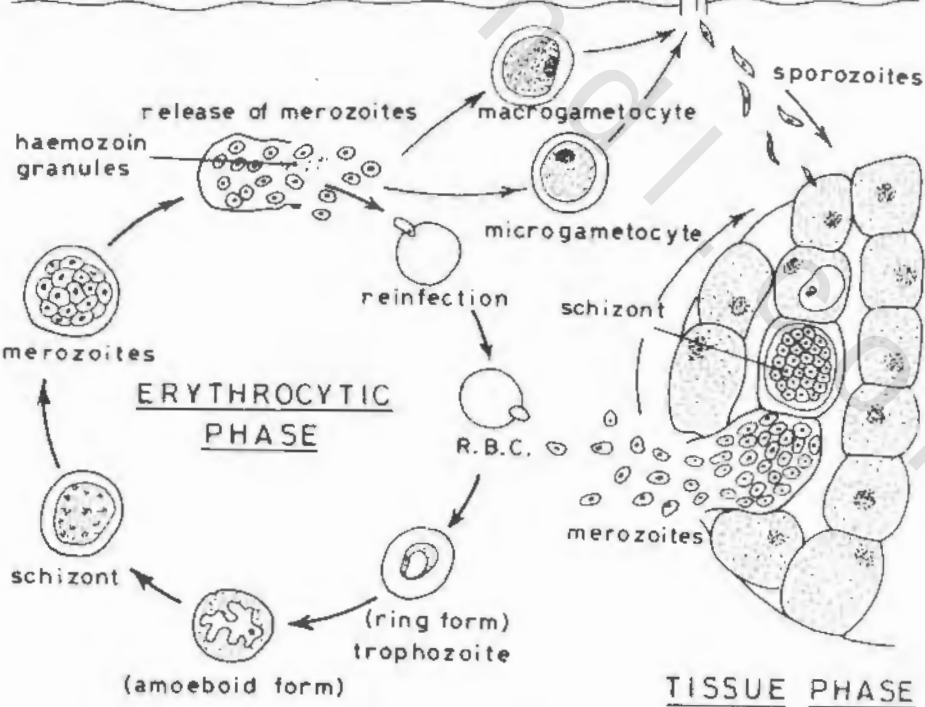
When the sporozoites enter the parenchyma cells of the liver, they round up and grow rapidly to form primary **exo-erythrocytic schizonts** which divide by **multiple fission** to give a large number of **merozoites**. During this asexual multiplication, the nucleus divides into a large number of nuclei, each of which becomes surrounded by a portion of the cytoplasm forming a merozoite. The schizont then ruptures and the released merozoites may re-invade more liver cells where a second schizogonic cycle takes place. In this second cycle, **pre-erythrocytic schizonts** are produced which when fully developed contain an enormous number of merozoites. The number of these merozoites varies according to the species of the parasite. While more than 40,000 merozoites are produced in *P. falciparum*, only 1,000 merozoites develop from schizonts of *P. vivax*. The produced merozoites then leave the infected liver cells and enter the blood stream where they start the following erythrocytic phase. The schizogonic cycle in the liver takes 8-9 days, a period known as the **incubation period**, during which the patient shows no symptoms of malaria.

b) Erythrocytic phase

When the merozoites invade the blood stream, each enters an erythrocyte in which it rounds up and forms a **trophozoite** that feeds and grows at the expense of the host cell. It acquires different forms during its growth. At first a vacuole appears inside it so that it assumes a **ring form**. It then forms pseudopodia and acquires an **amoeboid form**. It feeds on the



INVERTEBRATE PHASE



PLASMODIUM VIVAX

haemoglobin of the cell by phagocytosis and respire and excrete by simple diffusion. The haemoglobin is incompletely metabolized and a dark residue is left which is called the **malaria pigment** or **haemozoin granules**.

The trophozoite continues to grow, its amoeboid activity slows down, the vacuole disappears and it becomes ready for division, whence it is called **erythrocytic schizont**. The nucleus divides repeatedly by mitosis (schizogony). The number of the resulting nuclei differs according to species, being as few as 4 in some species and as many as 72 in others. **Merozoites** are thus formed as in the exo-erythrocytic cycle. Some **residual cytoplasm** with the haemozoin granules are left after the formation of the merozoites. The much damaged envelope of the red cell collapses and the merozoites escape into the blood stream, where they quickly invade new erythrocytes to start a new erythrocytic cycle.

The schizogonic cycle takes 48 hours in case of *P. vivax* and 72 hours in *P. malariae*, and the release of the merozoites at the end of each cycle takes place more or less at the same time in all infected erythrocytes. In case of *P. falciparum*, although the cycle takes 48 hours, yet the merozoites are not released at the same time.

After a number of erythrocytic schizogonic cycles the produced merozoites instead of becoming trophozoites which develop into schizonts, they are transformed into rounded compact bodies known as gametocytes. Two types of gametocytes are distinguishable : the female or **macrogametocyte** which has a small peripheral nucleus and a dense cytoplasm loaded with reserve food material, and the male or **microgametocyte** with a large eccentric nucleus and a clear cytoplasm. The mature gametocytes undergo no further development in the human blood. If the life history is to be continued, it is necessary for the gametocytes to pass into the body of an invertebrate host, which is the female anopheline mosquito. Unless this happens, the gametocytes ultimately degenerate and die.

c) Invertebrate phase

When a female mosquito sucks the blood of an infected host, the microgametocytes and macrogametocytes enter its alimentary canal. Any asexual stages which happen to be present in that blood are destroyed by the processes of digestion, while the gametocytes quickly shed their erythrocyte

envelopes and undergo maturation forming respective male and female gametes.

The male gametocyte form the mature gametes by a process called **exflagellation**. Its nucleus divides into two nuclei which undergo two further divisions to give rise to 8 nuclei that immediately migrate to the periphery of the organism. From eight points on the surface of the organism, long thin cytoplasmic projections are ejected and a nucleus travels down each. These projections lash around continuously and one by one break away from the parent body, thus 8 filamentous male or **microgametes** are produced. The whole process takes 5-20 minutes.

In the meantime, the macrogametocyte gives rise to a single female gamete or **macrogamete**. Its nucleus moves towards the surface where a small projection forms. A microgamete wriggles into this projection, thus the 2 gametes unite (a process of sexual fusion known as **syngamy**) and a **zygote** is formed. The zygote develops into a mobile elongated **ookinete** which penetrates the gut wall of the mosquito passing between the cells and developing into an **oocyst** below the epithelium. The oocyst matures in 10-20 days; the nucleus divides repeatedly into hundreds of small nuclear masses. This is followed by the divisions of the cytoplasm resulting in the formation of hundreds of thread-like **sporozoites** (a means of asexual reproduction known as **sporogony**). When mature, the oocyst bursts and the released sporozoites make their way to the salivary glands, where they stay until they are injected into a new human host during the act of biting in the next blood meal of the mosquito to initiate a new infection and repeat the life cycle. All stages in the life cycle, except the zygote and ookinete, are haploid.

The life cycle of *Plasmodium* illustrates the phenomenon known as **alternation of generations** as it involves the alternate succession of sexual generations (reproducing by gametes) and asexual generations (reproducing by schizogony or sporogony).

The erythrocytic phase in three species of *Plasmodium*

- 1-2 Trophozoite (ring stage); 3 trophozoite (amoeboid stage);
- 4-5 Schizont, 6 schizont divided into merozoites;
- 7 Microgametocyte; 8 macrogametocyte.

Host-parasite relationships

Various malaria parasites produce different ill effects on the human host. While the parasite occupies an intracellular position, little or no harm occurs, but on the rupture of schizonts, pigments, residual cytoplasm and fragments of erythrocyte envelopes are thrown into the blood stream, and one or more of these are responsible for the symptoms accompanying malaria. It has been recently suggested that the parasites also produce an enzyme known as **lecithinase** which damages the mitochondria and from this originates all or at least some of the later effects, including the inhibition of the respiratory processes of the erythrocytes.

Plasmodium falciparum exerts a more serious effect on the human host. The infected erythrocytes become clumped and accumulate in the capillaries of some internal organs, especially the brain. The circulation in these organs is disturbed and many cellular and tissue changes follow.

It is believed that in cases of human malaria, as much as 5 % of the total red cells in the circulation may be destroyed each day. Unless the human host compensates for this significant loss of red cells, anaemia eventually follows.

IV. SUBPHYLUM CILIOPHORA

This group includes protozoa which have **cilia** as locomotory organelles. There are two types of nuclei, a large nucleus known as the **macronucleus** and a small nucleus referred to as the **micronucleus**. Nutrition is holozoic. Reproduction may be asexual or sexual. There are free-living as well as parasitic representatives. As examples of this group, *Paramecium*, *Vorticella* and *Balantidium* are considered here.

1 — *PARAMECIUM*

This protozoon lives in freshwater ponds and streams that contain decaying vegetation. It has a slipper-shaped body measuring about 0.25 mm in length. It has a dorsal convex surface and a flat ventral surface. The anterior end is blunt, while the posterior end is pointed.

The body is limited by a firm pellicle and the cytoplasm is differentiated into an outer clear area, the **ectoplasm** and an inner granular **endoplasm**. The body is covered by an almost uniform layer of small hair-like locomotory processes known as the **cilia**.

On the flat surface of the animal there is a shallow groove, the **oral groove** which extends obliquely into the endoplasm to form a wide tube known as the **vestibule** that ends in a **cytostome**. The latter opens in a short narrow **cytopharynx** in which the cilia are arranged so close to each other as to form what looks like an **undulating membrane**. Just behind the cytopharynx there is a **temporary anus** or **cytoproct**.

As in other ciliates, there are two dissimilar nuclei which differ in size and appearance, a large kidney-shaped **macronucleus** and a small rounded **micronucleus**. The macronucleus appears to control the vegetative activities of the animal whereas the micronucleus is important for reproduction.

The cytoplasm includes a number of **food vacuoles** as well as two **contractile vacuole systems**; one is located at the anterior end and the other is

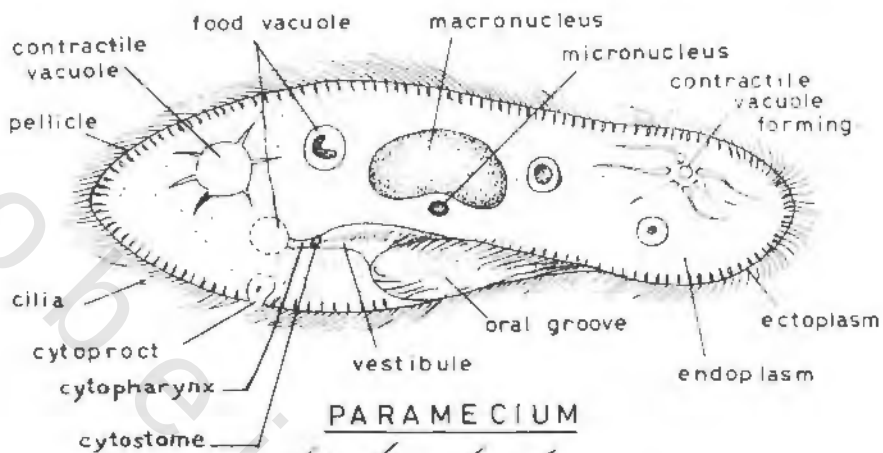
found near the posterior end of the body. Each contractile vacuole system is formed of a **central vacuole** into which leads a number of elongated pear-shaped **radiating canals**.

The ectoplasm contains some highly differentiated organelles. When *Paramecium* is treated with special staining techniques, the pellicle shows a large number of hexagonal depressions which are separated by ridges. From the centre of each of these depressions projects a cilium which originates from a basal granule known as the **kinetosome**. The kinetosomes of each longitudinal row of cilia are joined together by longitudinal fibrils known as **kinetodesmata**. The kinetosomes of each transverse row of cilia are also joined by similar fibrils.

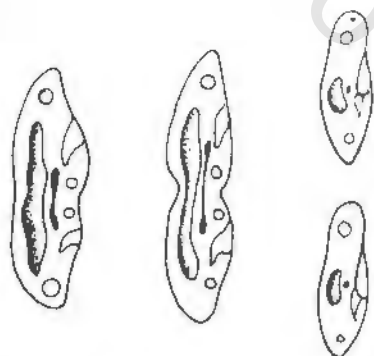
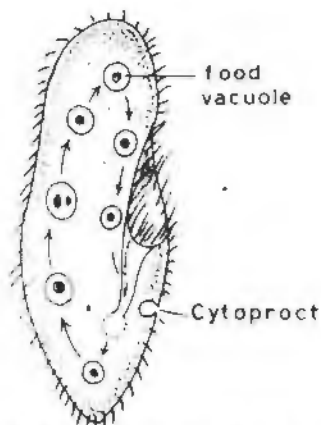
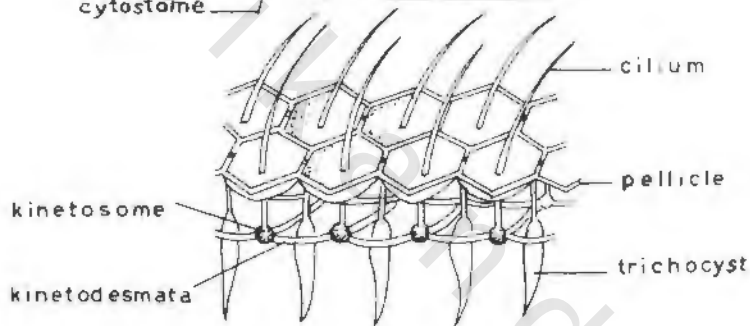
Alternating between the bases of the cilia there are spindle-shaped structures known as the **trichocysts** which open to the exterior by fine openings on the ridges between the hexagonal depressions. Upon irritation, these trichocysts are extruded to the exterior as long fine threads which act as defensive organelles. They may also act as means of attachment or anchorage of the animal to the substratum.

Locomotion

Paramecium swims rapidly in water by means of well-coordinated movements of numerous cilia found on the body of the animal. A cilium beats throughout its length and strikes the water so that the organism as whole tends to move in a direction opposite to that of the effective beat. Usually, a cilium on a single longitudinal row moves slightly in advance of the cilium behind it and slightly behind the one in front of it. Accordingly, the cilia on the same longitudinal row beat metachronously while those on the same transverse row are usually observed at the same phase of locomotion and thus are described as beating synchronously. The beating of cilia in this manner cannot be the only element in the locomotion of *Paramecium*, since the animal never moves in a straight line, but it follows an anti-clockwise (left) spiral path and at the same time it rotates along its longitudinal axis. There are three components which apparently lead to this characteristic type of locomotion:



PARAMECIUM



Food capture and nutrition → Transverse binary fission →

a) The backward beating of the cilia propels the animal forwards in the water.

b) The body rotates because the cilia are arranged in diagonal rows and thus beat obliquely to the right, causing the animal to roll over on its left side.

c) The spiral nature of the movement is caused by the cilia along the oral groove which beat more strongly than those on the rest of the body.

The ciliary beat can be reversed enabling the animal to swim backwards. Electron microscopy has shown that a cilium has the same structure as a flagellum (p. 204).

Nutrition

Paramecium is holozoic and feeds mainly on bacteria, although it may also feed on minute animals or unicellular plants.

If the animal happens to come in an area in which abundant food materials are present, the cilia of the oral groove become more active. The food is thus driven down the groove and the vestibule towards the cytostome and then down the cytopharynx and taken with a drop of water in a food vacuole into the endoplasm. If the food is abundant, several food vacuoles are formed and are then driven into the endoplasm: each, in turn, driving the preceding one ahead. The food vacuoles circulate throughout the endoplasm in a definite route (cyclosis) during which time digestive enzymes are poured into these vacuoles. The secretions in the early stages are acidic but later become alkaline. When fully digested the soluble food materials are absorbed and assimilated. The undigested particles eventually reach a point somewhere behind the cytostome, where the cytoproct or temporary anus is located. There, the vacuole bursts and they are thrown out.

Osmoregulation

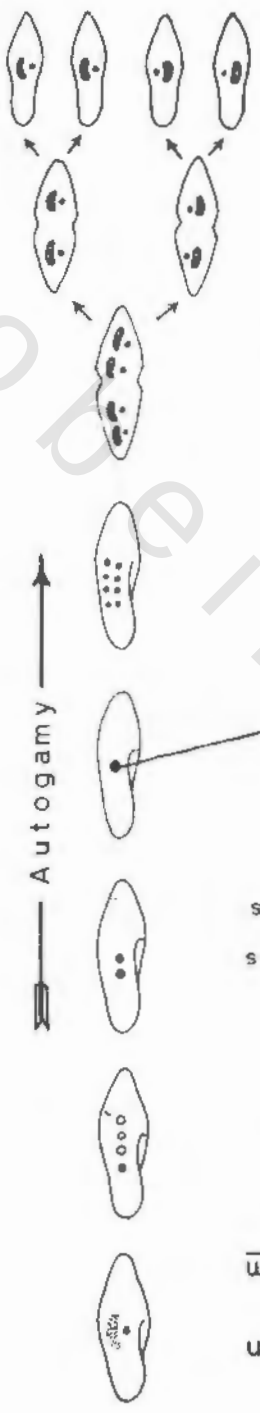
As in other protozoa inhabiting freshwater, osmoregulation is carried out by the two contractile vacuole systems. Excess water first accumulates in the radiating canals then passed into the central vacuole, from which it is discharged through a minute pore in the pellicle.

Respiration and Excretion

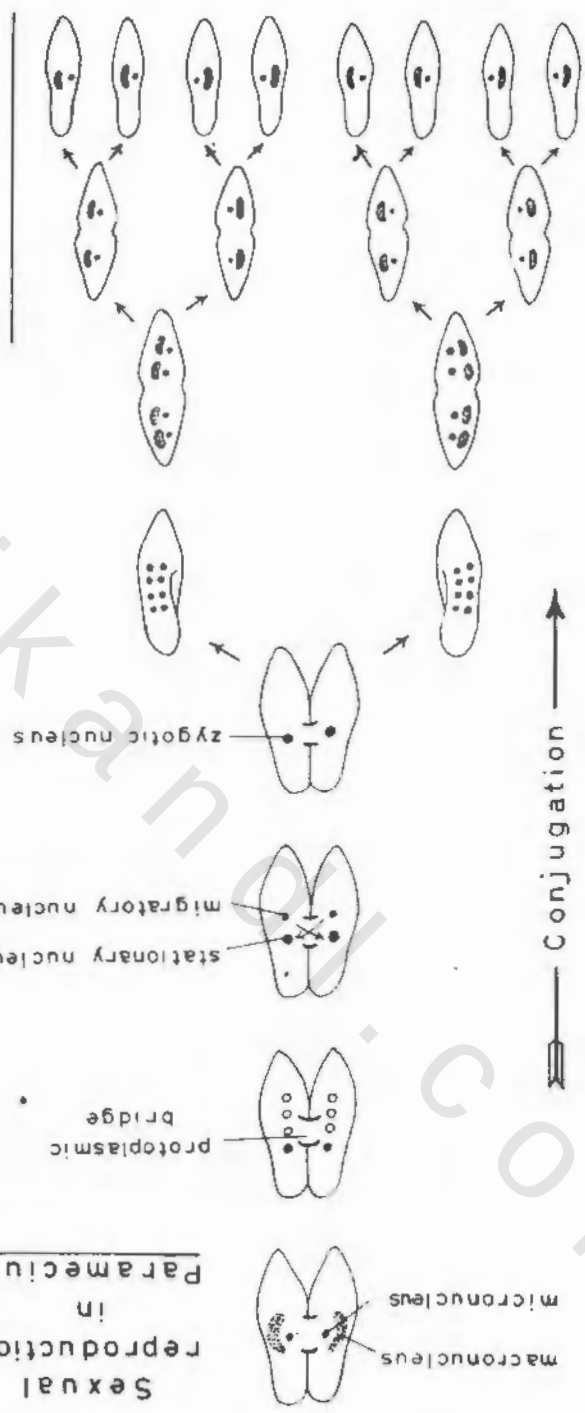
Exchange of oxygen and carbon dioxide takes place by simple diffusion through the body surface. Excretion of nitrogenous waste products takes place also by simple diffusion.

Sexual reproduction in Paramecium

Autogamy



Conjugation



zygotic nucleus
stationary nucleus
migratory nucleus
protoplasmic bridge

macronucleus
micronucleus

Reproduction

Paramecium reproduces both asexually (by transverse binary fission) and sexually (by conjugation and autogamy).

1 — Transverse binary fission

Unlike many other protozoa, binary fission in *Paramecium* takes place in a transverse plane. The micronucleus divides by **mitosis** into two micronuclei that move towards the opposite ends of the body, then the macronucleus divides transversely by **amitosis**. Other organelles such as the contractile vacuoles, oral groove, cytostome and cytopharynx become duplicated. Then a transverse furrow divides the cytoplasm into two almost equal parts. The resulting two daughter animals grow eventually to full size before another division is initiated.

Transverse binary fission is completed within about 2 hours and occurs one to four times per day. However, this process cannot proceed indefinitely as the daughter paramecia become progressively less viable, some abnormalities appear in them, and the rate of their division gradually slows down until it eventually stops, as if they become senescent. This is because the macronucleus is highly polyploid and when it divides by **amitosis**, its chromosomes become divided at random between the two daughter paramecia. Repeated division of this sort naturally causes some disturbance in the chromosome structure of the resulting macronuclei which results in a progressive decrease in the viability of the offspring. However, the animal resorts at intervals to a special type of sexual reproduction, known as conjugation, by which it regains its juvenescence, normal viability and power to reproduce by binary fission again. During that sexual process, the old macronuclei disintegrate and new ones with the original number of chromosomes are developed from the micronuclei, which are always diploid.

2 — Conjugation

This process includes the following steps :

a) Two individuals become sticky, adhere to one another by their oral surfaces and a protoplasmic bridge is formed between them. Each of these individuals is referred to as a **conjugant**.

b) The macronucleus in each conjugant breaks up into pieces and

ultimately degenerates. In the meantime the micronucleus divides twice by mitosis to form four nuclei, each with the normal diploid number of chromosomes. Of these four nuclei three degenerate and only one is left.

c) The remaining nucleus divides by a reduction division (meiosis) into two nuclei; a small **migratory (male) nucleus** and a larger **stationary (female) nucleus**. Each of these two nuclei is haploid, containing half the number of chromosomes found in the original nucleus.

d) The migratory nucleus in each conjugant becomes active, move into the other conjugant and fuses with the stationary nucleus therein. Thus, in each conjugant a **zygotic or fusion nucleus** is formed which contains the original diploid number of chromosomes. When this fusion is completed, the two pairing paramecia separate and they are now referred to as the **ex-conjugants**.

e) The zygotic nucleus in each ex-conjugant divides thrice forming eight nuclei each with the diploid number of chromosomes. Four of these nuclei enlarge and become polyploid, thus forming macronuclei, while the other four remain as diploid micronuclei. This is followed by two cytoplasmic divisions and accordingly four new daughter paramecia are produced from every ex-conjugant, each with one macronucleus and one micronucleus.

Worthy of notice is that the old macronuclei of the two conjugants disappear at the begining of conjugation and new ones are developed in the daughter individuals. Besides reorganizing the chromosomal structure of the macronuclei, conjugation involves the exchange of nuclear (hereditary) material between two individuals which result in the production of better offspring.

3 — Autogamy

This involves a similar process of nuclear re-organization as in conjugation, but occurs within one individual. It runs as follows:

a) In one *Paramecium* the macronucleus disintegrates while the micronucleus divides twice forming 4 nuclei.

b) Three of these nuclei disappear and the remaining one divides once more (by meiosis) into 2 haploid nuclei.

c) These two nuclei fuse together to form a zygotic or fusion nucleus.

d) The zygotic nucleus divides three successive times (by mitosis) forming 8 nuclei.

e) The cytoplasm then undergoes two repeated divisions producing 4 daughter paramecia, each with two nuclei. One of these nuclei forms a macronucleus and the other a micronucleus.

Autogamy is essentially similar to conjugation in that the macronucleus disintegrate at its begining and becomes replaced by a new one derived from the products of division of the micronucleus. But while conjugation allows for exchange of hereditary characters between two individuals, autogamy gives pure lines.

Sensitivity

Paramecium responds to different stimuli in much the same way like other free living protozoa described above. There is no specialized organs for sensation, although it is believed that the anterior end is more sensitive than the posterior one.

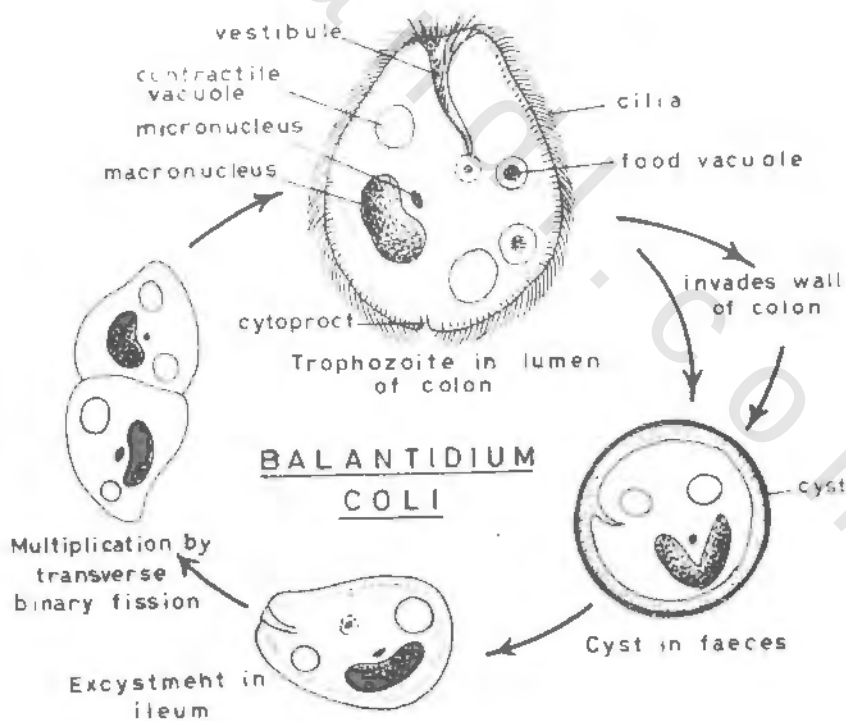
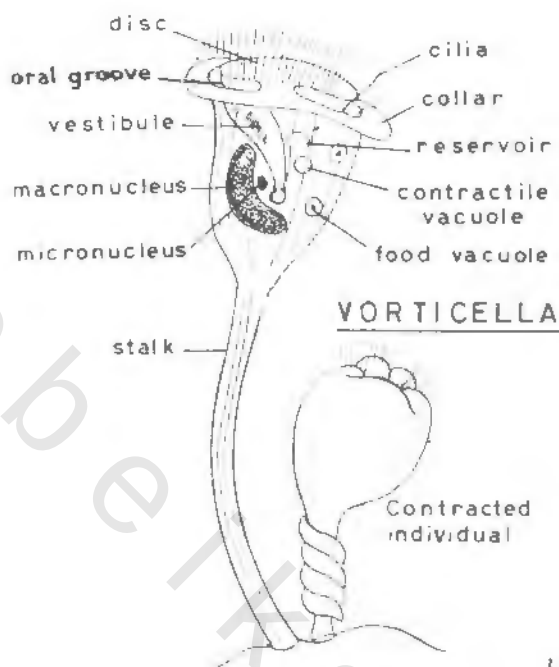
One of the most interesting reactions of *Paramecium* is the **avoiding reaction**. If the animal is met with an adverse stimulus, it reacts negatively by moving away from that stimulus. Then it moves forwards and if it happens to face the same stimulus it will repeat the negative reaction, and by repeated trial and error it avoids that adverse stimulus.

2 — VORTICELLA

Morphology

Vorticella is a bell-shaped ciliate which lives sedentary in freshwater, and attaches to waterweeds and stones by means of a long stalk. The bell has a thickened margin, called the **collar**, which bears a row of long cilia. A flattened **disc** surrounded by another row of cilia lies at the base of the bell, to the inside of the collar. The disc is separated from the collar by a deep groove, the **oral groove**, which leads on one side into a funnel-shaped **vestibule**. The latter passes deeply into the bell and ends in a small **cytostome**, followed by a narrow **cytopharynx**. Rows of adherant cilia project along one side of the vestibule to form an **undulating membrane**. A temporary anus or **cytoproct** also opens in the vestibule.

The body is covered by an elastic **pellicle**, the cytoplasm is differentiated into ectoplasm and endoplasm, but the stalk is devoid of endoplasm.



Contractile **myonemes** extend lengthwise in the ectoplasm of the bell and converge at its tip to join in a single thick myoneme that extends along the stalk. The endoplasm contains **food vacuoles** and a single **contractile vacuole** which discharges in a **reservoir** that opens in the vestibule. Two nuclei, a large horse shoe-shaped **macronucleus** and a tiny **micronucleus** close to it, are present in the endoplasm.

Vegetative activities

Although sedentary, *Vorticella* frequently swings in the water by rapid contractions and relaxations of the stalk. When the myoneme of the stalk contracts, the stalk becomes tightly coiled in a spring, thus rotating the bell and drawing it rapidly near to the substratum. It then relaxes jerking the bell again to the full length of the stalk.

Vorticella is holozoic and feeds largely on bacteria, other microorganisms and organic particles which are brought into the vestibule by the ciliary beat. They are then swept by the undulating membrane through the cytostome into the cytopharynx and taken inside food vacuoles in the endoplasm. After digestion is completed, undigestible remains are discharged through the temporary anus into the vestibule and passed to the exterior.

Osmoregulation, respiration and excretion take place in similar ways as in *Paramecium* and other free living protozoa in general.

Reproduction

Vorticella reproduces both asexually (by longitudinal binary fission) and sexually (by conjugation).

1 — Longitudinal binary fission

The two nuclei divide first, the other organelles become duplicated, and the bell divides lengthwise into two equal halves. One of these retains the original stalk, while the other separates and develops a posterior circle of cilia by which it swims away. It later develops a new stalk, attaches to a substratum and grows into a new individual.

2 — Conjugation

Unlike the case in *Paramecium*, conjugation takes place in *Vorticella* between two unequal individuals. It proceeds as follows :

a) Instead of dividing asexually by binary fission into two, *Vorticella* occasionally divides by multiple fission producing few small individuals called the **microconjugants** which, after a while, swim away leaving the dividing organism attached with its stalk and acting as a **macroconjugant**.

b) When a microconjugant comes in contact with a macroconjugant, or an individual of the normal size, it adheres to its bell and the protoplasm of the two communicates. The macronuclei disintegrate in the two conjugants while the micronuclei divide 2 or 3 successive times.

c) All the resulting nuclei in each conjugant disappear except one which divides again (by meiosis) into a **stationary nucleus** and a **migratory nucleus**.

d) The migratory nucleus of each conjugant fuses with the stationary nucleus of the other forming a **zygotic** or **fusion nucleus**.

e) The two conjugants do not separate thereafter as in *Paramecium*. The microconjugant degenerates, while the macroconjugant persists. The zygotic nucleus of the latter divides only once producing one micro- and one macronucleus. Thus the normal nuclear structure and viability of the organism are restored.

3 — BALANTIDIUM

Several species of this parasitic ciliate infect fishes, amphibians, pigs, sheep, monkeys and camels. *Balantidium coli* is the only species of ciliates which infects man. It has been reported from all parts of the world.

B. coli inhabits the large intestine of man and some other mammals, e.g. pigs, monkeys and dogs. The pig is the commonest and probably acts as the main reservoir host of this parasite; man acquires the infection from pigs. Although the parasite seems to be non-pathogenic to pigs, in man it may cause a disease known as **balantidiosis** or **balantidial dysentery**. Two stages are recognized in the life cycle, a trophozoite stage and an encysted stage.

Morphology, Nutrition and Life Cycle

The trophozoite has a relatively large and ovoid body measuring about 60-70 μ in length. The entire surface is covered with cilia arranged in longitudinal, slightly oblique rows.

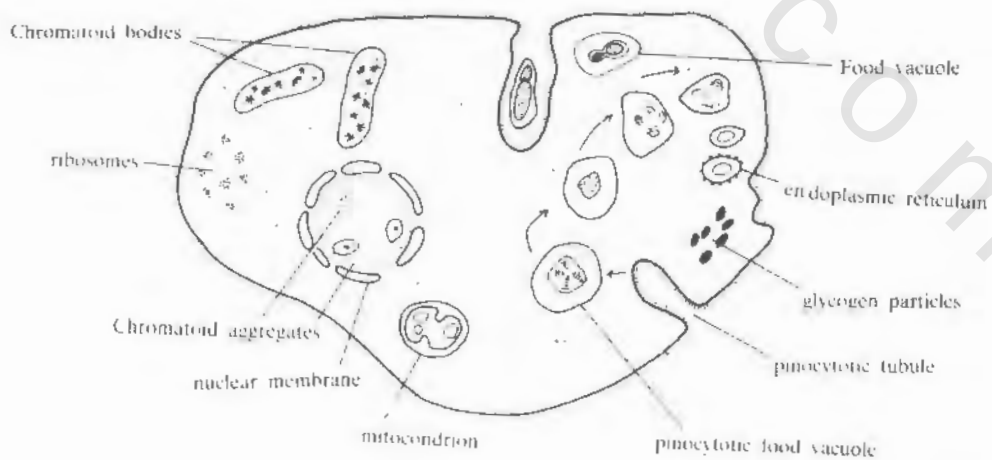
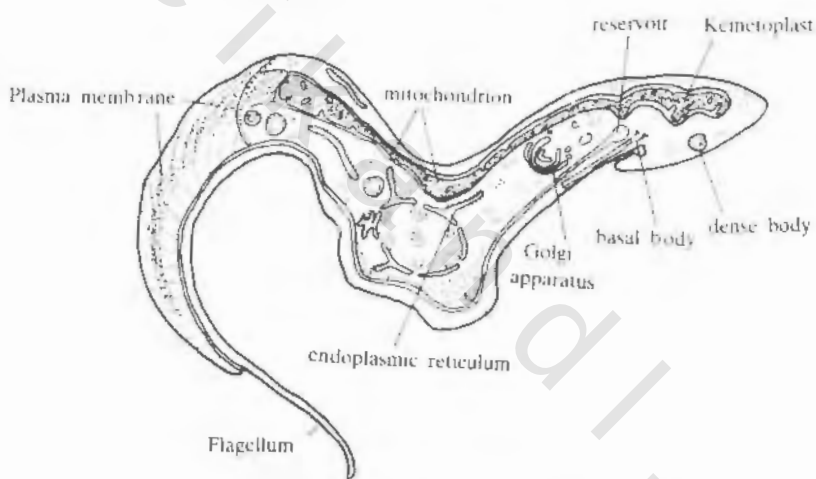
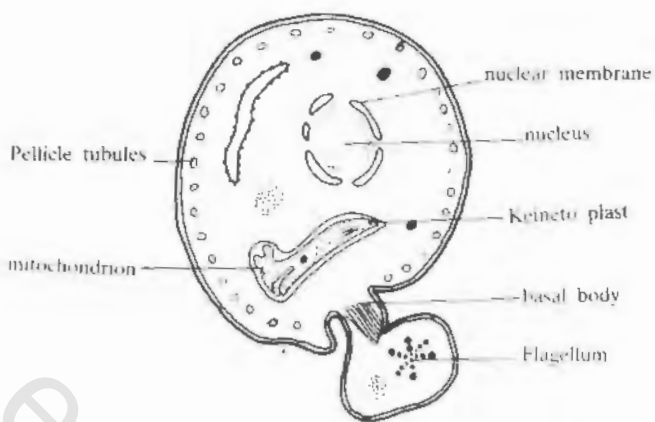
At the front end, there is a deep oral groove leading into a vestibule which is lined with longer cilia and ends in the cytostome. The animal has two contractile vacuoles, a macronucleus and a micronucleus.

The animal feeds by drawing a current of water down the vestibule, by means of cilia lining the latter. Any food particles carried in this current are ingested in small food vacuoles, which then circulate along a definite path through the parasite's body while their contents are being digested. Eventually, any undigested food materials are expelled through a permanent cytoproct which is found near the hind end of the organism.

B. coli reproduces asexually by transverse binary fission and sexually by conjugation as in *Paramecium*. The parasite encysts in the lumen of the host's intestine and the cyst is passed with the faeces to the exterior. No nuclear division occurs in the cyst which represents the infective stage. The cysts can survive outside the host for some time. A new host acquires the infection by swallowing food contaminated with the infective cysts. The trophozoites are liberated in the intestine after the disgestion of the cyst wall.

Host-parasite relationships

While in the lumen of the gut of man, very little harm results because the organism lives as a commensal. Quite frequently, however, the organism invades the intestinal wall, penetrating the mucosa and submucosa and producing ulcers and pathogenic bloody dysentery like those of *Entamoeba histolytica*. In pigs, the ciliate is not pathogenic because it is normally not invasive.



SUBKINGDOM PARAZOA

PHYLUM PORIFERA

Sponges are sessile and mostly marine animals which show little or no detectable movement. They are regarded as the most primitive multicellular animals and are placed in a separate subkingdom called the Parazoa, including one phylum, the Porifera.

General characters

1. They vary in form from thin flattened crusts, to vase-shaped, branched, globular or irregularly shaped bodies.
2. The body is perforated by numerous pores, canals or chambers through which water continuously flows, hence the name Porifera. Inside the body there is a single cavity lined by peculiar flagellated cells known as choanocytes.
3. The body cells are far less specialized and dependant upon each other than in the Metazoa. Although sponges have a few differentiated cells arranged in distinct layers, there is no coordination between the activities of similar cells and therefore they do not form proper tissues.
4. They have a skeleton of calcareous or siliceous spicules, or of organic spongin fibres.
5. They are holozoic and digestion is entirely intracellular.
6. They respire and excrete by simple diffusion.
7. They have no sensory or nerve cells, thus coordination of their activities is very limited and their responses to stimuli are local and very slow.
8. They reproduce asexually by budding, and have a remarkable power of regeneration. They also reproduce sexually by gametes, and have free-swimming larvae.

Structure

Sponges vary considerably as regards their body organization. Generally they exhibit 3 structural grades with increasing complexity, referred to as the ascon, sycon and leucon types.

A. ASCON TYPE

This is the simplest structural type of sponges in which the body is tube- or vase-shaped. The body wall surrounds a central cavity, known as the **paragastric cavity**, lined with **flagellated cells**. The wall is thin and perforated by many small openings or **ostia** which lead directly into the paragastric cavity. The latter cavity opens to the outside through a single large opening known as the **osculum**.

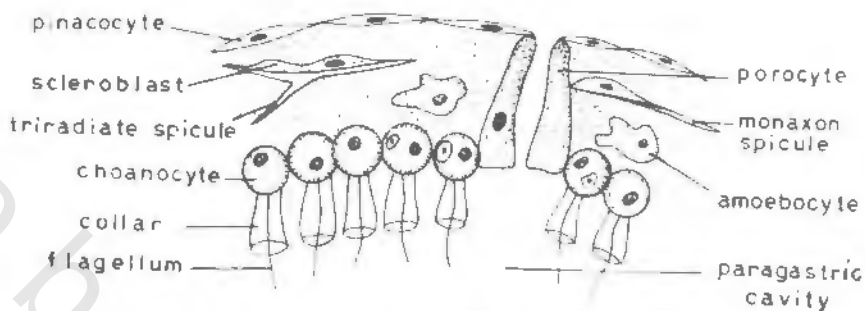
Sponges of this ascon type are all small and are not usually solitary but live in colonies of many individuals attached together at their bases. *Leucosolenia* illustrates well this simple type of sponge structure.

Leucosolenia

This is a sessile marine sponge which lives in colonies attached to seashore rocks. The colony consists of few upright tubes united at their bases by irregular horizontal branches. Each tube is a thin-walled sac enclosing a central cavity, the **paragaster** or **paragastric cavity**, and has one large opening known as the **osculum** at its free end. The wall of the tube is very thin and is perforated by numerous **ostia** or inhalant pores.

The **body wall** consists of two cellular layers : an outer dermal layer and an inner gastral layer :

1 — The **dermal layer** consists of an outer covering layer of thin flattened cells know as **pinacocytes**, and an inner **skeletogenous layer** of scattered cells embedded in a stiff non-living jelly substance. These cells are of three distinct types :



Body wall of a simple sponge of the ascon type

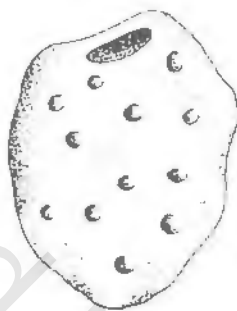
SPONGES



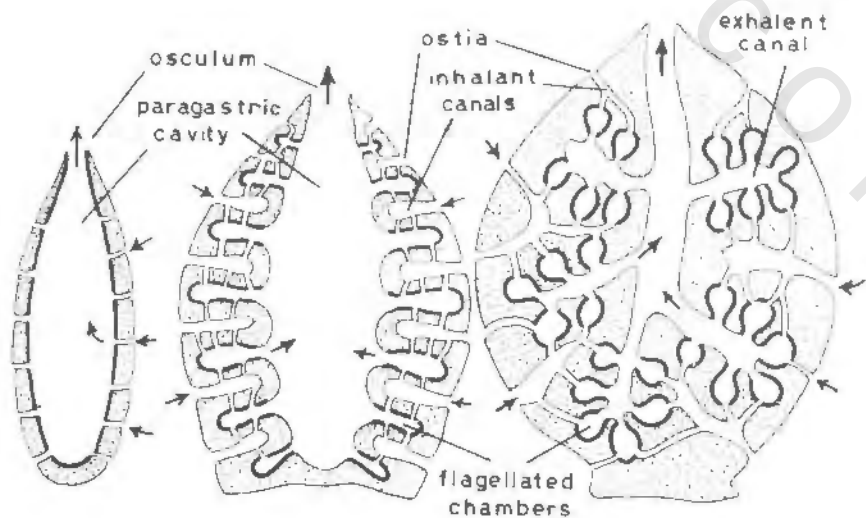
ASCON
TYPE



SYCON
TYPE



LEUCON
TYPE



a) The **scleroblasts** are the most numerous. They secrete crystalline **calcareous spicules** which form a supporting framework for the living cells of the sponge. These spicules are either monaxon or triaxon (triradiate). A monaxon spicule is secreted by a single scleroblast as an organic thread around which calcium carbonate is deposited. The scleroblast wanders off when the spicule is completed. A triaxon spicule is formed by the cooperation of 3 scleroblasts.

b) The **amoebocytes** are probably the least differentiated cell type in the sponge. They wander in an amoeboid fashion in the jelly transporting food and other material throughout the body of the sponge. They also give rise to the reproductive cells, and can develop into any of the other differentiated cell types.

c) The **porocytes** are tubular cells, each pierced by a narrow intracellular tube that opens to the exterior by an inhalant pore at one end and into the paragastric cavity at the other end.

2 — The **gastral layer** consists of peculiar flagellated cells known as the **choanocytes** arranged in a single layer lining the paragastric cavity. Each of these cells is rounded or oval and bears at its free end a long **flagellum** encircled at its base by a thin contractile membrane called the **collar**. They collect food particles and digest them. The continuous beating of the flagella causes the surrounding water to flow through the inhalant pores into the paragastric cavity, then to pass out through the osculum.

All sponges of the ascon type are small because this type of structure imposes serious limitations on size. As the sponge increases in size, the ratio of the surface available for the location of the choanocytes to the volume of the sponge becomes progressively smaller. A point is thus reached when that surface becomes insufficient to accommodate the number of choanocytes necessary to collect food and to create a water current strong enough to suffice the respiratory and excretory demands of the sponge.

B. SYCON TYPE

The problem of insufficient area available for the choanocytes has been overcome in one way during the evolution of sponges by simple folding of the layer of choanocytes. Thus, another higher grade of sponge structure

has been attained in which the body wall has been folded horizontally so as to form numerous finger-like outgrowths or evaginations of the paragastric cavity. These evaginations are lined with choanocytes and are known as the **flagellated chambers**. They open at their inner ends into the paragastric cavity through pores called **apopyles** and end blindly towards the outer surface of the sponge. These chambers leave in between them narrow spaces or channels known as the **inhalant canals** which are lined with pinacocytes. These canals open at the surface by **ostia** and end blindly inwards, but they communicate with the flagellated chambers through pores called **prosopyles**. The paragastric cavity is no longer lined with choanocytes, but with pinacocytes as the outer surface of the sponge. *Sycon* is a common example of this type.

Sycon (= *Scypha*)

This is a solitary marine sponge, which lives attached to rocks in shallow waters. It has a vase-shaped body with a single large osculum at the free end and numerous minute ostia on its outer surface. The body wall is relatively thick. It is folded in the above described manner, thus forming many horizontal flagellated chambers arranged radially around the paragastric cavity and leaving in between them narrower inhalant canals. The inhalant canals and the paragastric cavity are lined with pinacocytes as those covering the external surface of the sponge, while the flagellated chambers are lined with choanocytes. The jelly found in between these two layers of cells contains amoebocytes, scleroblasts and calcareous spicules as in *Leucosolenia*.

In *Sycon*, as in other sponges of the sycon type, water is continuously drawn through the ostia into the inhalant canals, passed through the prosopyles into the flagellated chambers, then through the apopyles into the paragastric cavity, and is finally driven to the outside through the osculum. This water current is created as usual by the flagella of the choanocytes.

C. LEUCON TYPE

The vast majority of sponges exhibit a still higher or a more complex grade of structure known as the leucon type. In this type the layer of choanocytes is highly folded so as to form innumerable small rounded evaginations or flagellated chambers. These are embedded in a considerably thick jelly matrix, while the paragastric cavity is greatly reduced. The minute ostia found on the outer surface lead into some large subdermal cavities, from which narrow branched inhalant canals extend to the flagellated chambers. Water leaves the latter chambers through narrow exhalant canals which become progressively larger as they join together and lead to the outside through one or more oscula.

This complexity of structure further increases the feeding and respiratory efficiency of the sponge. A sponge of the leucon type 10 cm in height and 1 cm in width may contain more than 2 million flagellated chambers and may pump more than 20 litres of water per day. The bath sponge is a common example of this type.

Euspongia

The Bath Sponge

Species of *Euspongia* are roughly spherical, cup-shaped or irregular in form. Their outer surface is pierced by minute ostia, in between which several larger oscula are found. They live on the sea bottom attached to rocks by a secretion of a horny substance chemically related to silk and known as spongin. The skeleton is made up of the same material, and of calcareous spicules. It consists of a complex network of branching and anastomosing elastic spongin fibres, which extends within the jelly and gives the animal its characteristic spongy texture.

Life processes in sponges in general

Water current

The life of sponges depends largely on the current of water that flows continuously through their bodies. This water current is produced by the beating of the choanocytes' flagella, which lack coordination and synchrony in their activity. The water current serves feeding, respiration, excretion and even reproduction. It brings in food, oxygen and foreign sperms to the sponge, and carries away different body wastes.

Nutrition

Sponges are holozoic, feeding on fine organic particles and small planktonic organisms (such as diatoms, protozoa, etc.) brought in their bodies by the water current. Such food particles adhere to the outer surfaces of the collars of the choanocytes. They are then passed down to the bases of the choanocytes where they become either ingested by these cells then passed to the amoebocytes to complete their digestion, or ingested directly by the amoebocytes. Digestion occurs intracellularly within food vacuoles which pass through acid and alkaline phases as in the protozoa. The amoebocytes distribute the digested products to other cell types and also act as storage centres for food reserves.

Respiration and Excretion

No cell in any sponge is far removed from the water which circulates throughout its body. Respiration is therefore carried out by simple diffusion. Exchange of respiratory gases takes place directly between the cells and the flowing water.

Excretion of nitrogenous wastes also takes place by diffusion, and excreted material (largely in the form of ammonia) is carried away by the outflowing water. The amoebocytes probably aid in excretion by transporting excretory products from deeper cells to surfaces exposed to the water current.

Sensitivity

Sponges seem to be very insensitive to the surrounding conditions. Their reactions to external stimuli are local and very slow. This is not strange since sponges have no special sensory cells to receive stimuli or nerve cells to transmit these stimuli. Thus, although any sponge cell is irritable and will react if directly stimulated, the animal cannot respond as a whole.

Reproduction

Reproduction occurs by asexual or sexual means :

1 — Asexual reproduction

a) Budding. Sponges commonly reproduce by developing external buds which grow to form new individuals. These buds either separate from the parent or remain attached to it, thus forming a colony of several individuals.

b) Gemmule formation. Some sponges, especially freshwater forms, develop internal buds called **gemmules** which enable them to survive unfavourable conditions such as cold or drought. Gemmules are developed from groups of amoebocytes rich in food reserves. These amoebocytes gather and become surrounded with a protective cyst strengthened with spicules. As the sponge dies and disintegrates during the unfavourable season, the gemmules are freed. They withstand freezing and drying until favourable conditions become available when the cells inside each gemmule escape through a thin spot of the cyst, aggregate in a small mass and grow into a new sponge.

2 — Regeneration

Sponges have a remarkable capacity to replace lost or injured parts of their bodies, a process known as regeneration. If a living sponge is broken into pieces, a complete individual may grow from each piece. Certain sponges when squeezed through fine-meshed silk so that their cells are separated from each other, these cells will come together again in an amoeboid fashion to form small masses which regenerate new sponges. This regenerative ability illustrates the relative undifferentiation of the sponge cells.

3—Sexual reproduction

Some sponges are **unisexual** i.e. with male and female individuals. However, most sponges are **bisexual (hermaphrodite)** with each individual producing sperms and ova, but at different times.

The sperms and ova are produced by the amoebocytes found in the jelly-matrix, there being no special reproductive organs. The ova remain in the jelly, while the sperms leave the sponge by means of the water current to enter another sponge in the same way. Upon reaching the flagellated chambers of the latter sponge, each sperm attaches to a choanocyte or to an amoebocyte which acts as a carrier transporting it to an ovum, thus fertilization takes place and a **zygote** is formed.

The zygote divides repeatedly (a process known as cleavage) forming a hollow ball of cells called the **amphiblastula**. Its upper pole consists of small flagellated cells, while the lower pole consists of large cells filled with granules of food reserves. This amphiblastula breaks out of the jelly and escapes with the outflowing water to live as a free-swimming larva for some time, thus dispersing the species. Meanwhile, its flagellated cells become invaginated or overgrown by the larger granular cells (a process known as gastrulation) so that a double-walled **gastrula** is formed.

The gastrula soon settles down on a rock, attaches to it and develops into a sponge. The flagellated cells acquire collars and develop into a layer of choanocytes, while the granular cells form pinacocytes, and both layers secrete the jelly in between them and produce amoebocytes and scleroblasts in it. The osculum, opens at the free end and porocytes form pores through the wall. A young sponge of the ascon type is thus formed which, by folding of the choanocyte layer, attains either the sycon or the leucon grade characteristic of the species.

SUBKINGDOM METAZOA

All multicellular animals, other than the Porifera, constitute the true **Metazoa**, or **Eumetazoa**. This separation between multicellular groups is largely based on the differentiation or specialization of cells to perform different functions. Division of labour and interdependency of cells characterize the true metazoan body, though the degree of body construction varies from one phylum to another. Cell specialization has led to the development of tissues, each tissue being formed of structurally similar cells performing similar functions. In lower phyla, tissue formation is primitive, while in higher groups, the tissues are more developed and organized into organs and organ systems.

Evolution of Metazoa

It is believed that all Metazoa must have evolved from unicellular (or acellular) Protozoa, through a common ancestor. Three theories were put forward to suggest the origin of metazoa.

1. **The syncytial theory** : suggests that the ancestral Metazoa evolved from a multinucleated ciliate, which gradually formed cell membranes around each nucleus and thus a multicellular form was obtained.

2. **The colonial theory** : suggests that the ancestral Metazoa evolved from colonial flagellates. This theory is widely accepted because of the tendency of certain phytoflagellates to live in colonies, the appearance of some cellular specialization in these colonial forms, and because of the common presence of flagella in metazoan animals.

3. **The polyphyletic theory** : suggests that some metazoan groups (as sponges and coelenterates) evolved from colonial flagellates, while other groups (as flat-worms) evolved from ciliates. The flat-worms then gave rise to all other phyla.

General characters of Metazoa

1 — The Metazoa differ from the Protozoa in attaining much larger sizes. As they became larger, their food requirements increased and therefore a specialized digestive cavity and digestive system have developed in them for collecting and digesting food. Their food is usually of such a large size that it cannot be taken inside food vacuoles as in the Protozoa.

Also with increasing size, the distance between the digestive organs and many parts of the body became too great to allow for the travel of digested material and respiratory gases by simple diffusion. Thus, a special transport system, called the blood vascular systems, has been developed in most Metazoa for internal transport of nourishment and respiratory gases.

2 — Some of the smallest Metazoa are aquatic and respire and excrete by simple diffusion. But the large majority of the Metazoa are of such a size that their surface area is proportionally small compared to their volume, and thereby insufficient for gas exchange and for the excretion of nitrogenous wastes. Therefore, various branching and laminated respiratory and excretory organs have developed in them.

3 — The Metazoa have developed a nervous system made up of specialized nerve cells that synapse with each other. Besides coordinating between the performance of the different cells and tissues of the body, this system serves the conduction of nerve impulses from the receptor cells, found on the outer surface, to the effector cells found in the deeper tissues.

4 — The Metazoa have developed various kinds of external and internal supporting structures to their bodies, or skeletal system, which enabled them to attain much larger sizes and to live in a wider variety of habitats.

5 — The Metazoa have also developed certain reproductive organs or gonads specialized for the production of sexual gametes, which are never produced within the cells as in the Protozoa.

6 — All Metazoa pass through similar steps during their early stages of embryonic development. Any metazoan animal passes onto 3 steps from the fertilized egg until it reaches the adult stage. These are cleavage, germ-layer formation and organ formation.

Cleavage : The fertilized egg divides repeatedly into 2, 4, 8, 16 ...

cells or blastomeres, until a solid mass of cells is formed which is referred to as the **morula**. The cells then arrange themselves into one layer around an internal cavity, known as the primary body cavity of **blastocoel**. This stage is called the **blastula**, and is common to all true Metazoa.

b) Germ-layer formation : In the following step, known as **gastrulation**, the blastula transforms into a 2-layered **gastrula** through invagination of part of the blastula wall. As a result, a new cavity communicating with the exterior and representing a primitive gut is formed: this cavity is called the **archenteron**, and the two layers are termed **ectoderm** and **endoderm**.

At this stage, some Eumetazoa end their development and differentiate their body form. The gastrula elongates and grows into adult. This is represented in one phylum, the Coelenterata, which are described as **diploblastic** because their body wall is formed of 2 layers of cells.

Other groups proceed development beyond the gastrula stage and develop a third layer, intermediate between the ectoderm and endoderm. This layer is called **mesoderm**, and such animals are thus described as **triploblastic**.

c) Organ formation or Organogeny : The cells of the 3 primary germ layers start differentiation to form tissues and organs. The degree of tissue and organ construction in the body varies from one group to another. In some triploblastic animals, the mesoderm forms a parenchymatous tissue that fills the whole internal space in the body, leaving no cavity. These are referred to as triploblastic acoelomate animals or **Acoelomata**. In others, a true body cavity appears in the mesoderm. This cavity is known as the **coelom**, and such animals are referred to as triploblastic coelomate animals or **Coelomata**.

Classification of Metazoa

According to the above description, the true metazoan phyla fall under two main divisions :

- I. **DIPLOBLASTICA**, where the body is built up of two layers, an outer ectoderm and inner endoderm. This division includes the phylum Coelenterata.
- II. **TRIPLOBLASTICA**, where a middle layer, or mesoderm, is formed in between the ectoderm and endoderm of the embryo. This division includes :

A. **Acoelomata**, with no internal body cavity, or coelom, in the mesoderm and includes the following major phyla :

1. Phylum Platyhelminthes.
2. Phylum Aschelminthes

B. **Coelomata**, with an extensive fluid-filled cavity in the mesoderm known as the coelom, and includes the following major phyla :

1. Phylum Annelida.
2. Phylum Arthropoda.
3. Phylum Mollusca.
4. Phylum Echinodermata.
5. Phylum Chordata.

THE DIPLOBLASTICA

PHYLUM COELENTERATA

The phylum Coelenterata is probably the least familiar to us, but those who visit the Red Sea can be really impressed with the marvelous display of different coelenterates living there in shallow water near the sea-shore, including delicate plant-like colonies of zoophytes, colourful sea anemones, massive reef-building corals, as well as the free-swimming jellyfishes.

General characters

1 — The Coelenterata are simple aquatic Metazoa which are mostly marine and sessile.

2 — They are radially symmetrical animals, i.e. if cut lengthwise in any plane passing by the centre, the body is divided into two symmetrical halves.

3 — Their body is made up of different types of cells arranged in two tissue layers, an outer ectoderm and an inner endoderm, separated by a structureless jelly-like mesogloea.

4 — They possess characteristic stinging cysts, known as the nematocysts, which are not found in any other phylum.

5 — There is a single cavity within their body the gastrovascular cavity or coelenteron. It is a digestive cavity (hence the name Coelenterata), and has a single opening to the outside, the mouth. Digestion is partly extracellular occurring in the gastrovascular cavity, and partly intracellular taking place within food vacuoles inside the endodermal cells.

6 — Respiration and excretion take place by simple diffusion through the surface of the ectoderm and endoderm.

7 — They possess a simple diffuse nervous tissue in the form of a nerve-net or concentrated rings.

8 — They reproduce asexually by budding, and sexually by gametes. Most coelenterates exhibit two different body forms or stages in the life cycle; a sessile *Hydra*-like “polyp or hydroid form”, and a free-swimming jellyfish-like “medusa or medusoid form”. The two forms may be well represented and alternate in the life cycle, one giving rise to the other in succession, or one of them may predominate.

9 — Some colonial forms secrete massive external calcareous skeletons.

Classification

The phylum Coelenterata is classified into 3 main classes :

A. Class Hydrozoa (*Hydra*-like animals).

This includes many plant-like zoophytes and small jellyfishes. The majority exhibit 2 body forms in the life cycle : a hydroid form (or polyp) and a medusoid one (or medusa).

The polyp or hydroid form is usually colonial, sessile and does not produce a calcareous skeleton. It has few simple tentacles, an oral cone, and a simple gastrovascular cavity not divided by internal partitions or mesenteries.

The medusa or medusoid form is small, bell-like, solitary and free-swimming. It has a velum, simple sense organs and the gonads develop from the ectoderm, e.g. *Hydra* and *Obelia*.

B. Class Scyphozoa (Cup-like animals).

This includes larger jellyfishes which exist mainly in the medusoid form; the hydroid stage is much reduced and may appear only as a small solitary polyp during the life cycle.

The medusa is large, saucer-shaped and has complex sense organs, digestive gastric filaments, gonads developed from the endoderm, and no velum, e.g. *Aurelia*.

C. Class Actinozoa (= Anthozoa).

This includes flower-like animals as sea anemones, corals and their relatives, which exist only in the hydroid form; the medusoid form is totally absent. Some live as solitary polyps while others are colonial and secrete massive calcareous skeletons.

The polyp differs from that of the Hydrozoa in having numerous tentacles, a flat oral disc and an invaginated stomodaeum. Its gastrovascular cavity is divided by internal mesenteries which bear digestive mesenteric filaments and endodermal gonads.

1 — Order **Alcyonaria** (or Octocorallia) : These are mostly colonial. The polyp has 8 pinnate tentacles, 8 unpaired mesenteries, and one ciliated groove or siphonoglyph running along the stomodaeum. The ectoderm in some forms secretes a skeleton of calcareous spicules embedded in the mesogloea, e.g. *Alcyonium*.

2 — Order **Zoantharia** (or Hexacorallia) : Some of these live as solitary polyps (sea anemones), while others form large colonies (stony corals). The polyp has simple tentacles and paired mesenteries, both arranged in multiples of 6, and two siphonoglyphs on the stomodaeum. The skeleton, when present, is external and is secreted by the ectoderm at the bases of the polyps.

A. CLASS HYDROZOA

1 — HYDRA

This is a simple coelenterate which lives attached to rocks and aquatic vegetation in freshwater ponds and streams. *It exists in the hydroid form only and develops no medusae.*

Morphology

Hydra has a small cylindrical body (2-20 mm in length) with a closed lower end known as the **basal disc** or "foot" by which it is attached to the substratum; the other end forms a small **oral cone** on the top of which the **mouth** is situated. Six to ten slender hollow **tentacles** arise from around the base of the oral cone. They are very mobile during life and capable of great extension and contraction. The body of the animal is also very flexible and can be extended into a long slender tube, bent in any direction, or contracted into a very short barrel. Either **buds** or rounded projections representing several **testes** or one **ovary**, are sometimes seen on the sides of the body.

There is a single cavity in the body which acts as a digestive and a circulatory cavity and is therefore referred to as the **enteron** or **gastrovascular cavity**. This cavity is extended inside the tentacles.

Cellular structure

The walls of the body and tentacles are built up of two layers of cells, a thin outer **ectoderm** and a thick inner **endoderm**. In between these two layers, there is a thin structureless jelly-like **mesogloea** secreted by these cells. Considerable differentiation is met with among the cells of both ectoderm and endoderm. The following cell types are recognized:

a) In the Ectoderm

1 — The **myo- or musculo-epithelial cells** are cone-shaped cells with broad outer ends which touch each other to form a continuous covering to the body (hence considered epithelial). They rest by their narrower inner ends on the mesogloea where each cell gives off two or more contractile processes or **muscle tails** (hence considered also muscular). These processes are oriented parallel to the long axis of the body and therefore act as longitudinal muscle fibres. When they contract equally on all sides, the body is shortened, and when they contract more on one side, the body is bent on the direction of greater contraction.

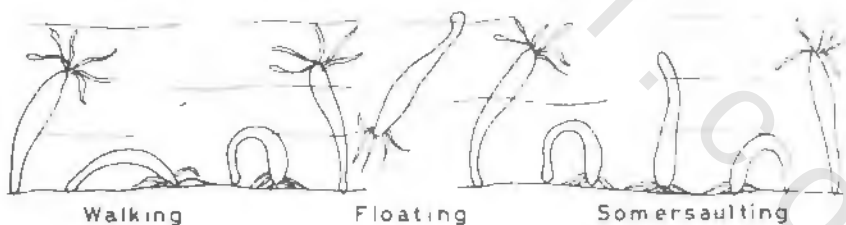
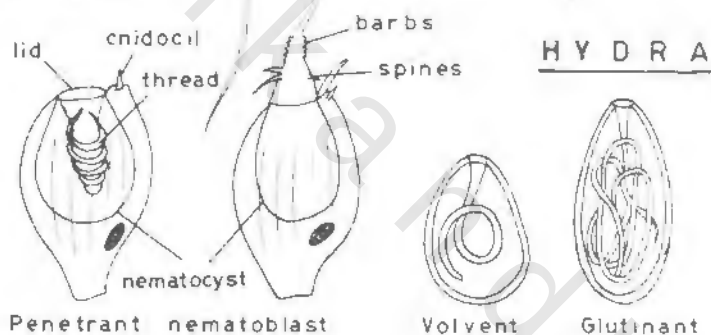
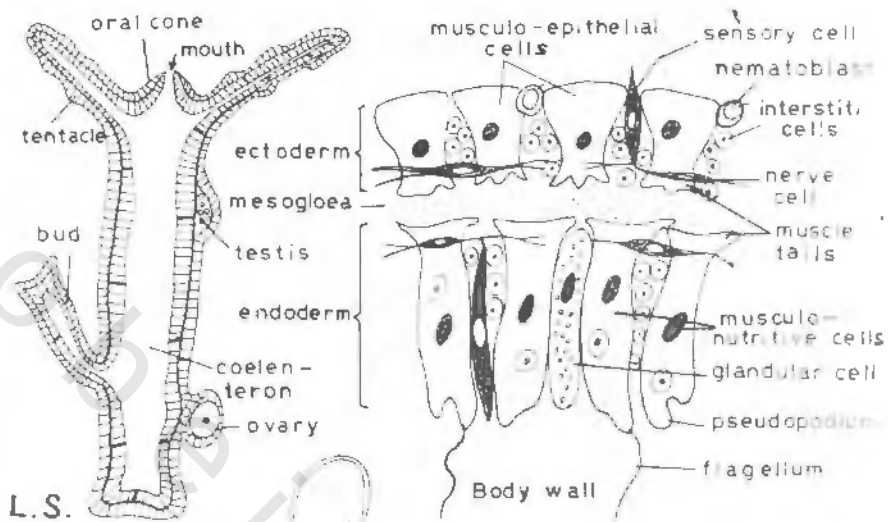
2 — The **interstitial cells**, are small rounded cells lying in the spaces between the musculo-epithelial cells. These are the least differentiated cells in *Hydra* and can differentiate into any of the other specialized cell types as needed. They serve repairing or regenerating any injured parts of the body, besides producing the sperms and ova in the breeding season.

3 — The **nematoblasts** (or **cnidoblasts**), are extremely specialized cells which lie in groups or batteries, particularly numerous on the tentacles. One end of the cell is exposed to the surface of the ectoderm and from it projects a short bristle known as the **cnidocil** or trigger. Inside the cell, there is a remarkable stinging cyst, called the **nematocyst**, which acts as an efficient organ for food capture, defence or attachment.

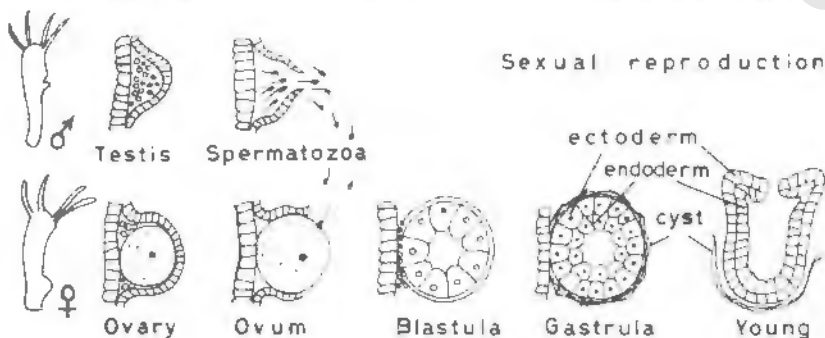
Four kinds of nematocysts are recognized in *Hydra* : the penetrants, the volvents, and the large and small glutinants.

Each **penetrant** or **stenotele nematocyst** consists of a pear-shaped capsule with a lid or **operculum**, and is filled with a highly hygroscopic fluid. The walls of the capsule have a number of refractile rods which are attached to contractile fibrils running to the base of the nematoblast. A long inverted capillary tube, the **thread**, is coiled inside the capsule. It is open at its narrow tip, and has a wide base that bears on its inner surface 3 pointed **spines** and 3 rows of minute **barbs**.

When this nematocyst is suitably stimulated by tactile and chemical stimuli from a prey or enemy, water rushes inside the capsule, which swells up, its lid is forced open, and water passes under pressure into the thread causing it to uncoil and, rapidly everts. Thus the thread is suddenly shot out



Sexual reproduction



of the capsule with such a force that it pierces the skin of the prey or enemy and injects in its tissues a protein poison which has a paralysing effect.

The **volvent** or **desmoneme nematocyst** is essentially similar to the penetrant, but is generally smaller and its thread is shorter, unarmed and coiled. When discharged it wraps around suitably sized bristles or other processes of the prey's body, thus grappling it.

The **large** or **streptoline glutinant** has a long adhesive thread, armed with minute thorns, which may coil when discharged.

The **small** or **stereoline glutinant** has a short, coiled unarmed sticky thread which remains uncoiled when discharged. Both types of glutinant nematocysts respond only to mechanical stimuli and are used in food collection as well as in locomotion.

The nematoblasts develop from interstitial cells in the middle third of the body. From there, young nematoblasts pass into the enteron where they are picked up by the endodermal cells in the tentacles or other parts of the body and passed to the ectoderm again. There, they become properly oriented near the external surface and the nematocysts become fully developed inside them. Once discharged, the threads cannot be retracted again. Thus used nematoblasts degenerate and are replaced by new ones.

4 — The **nerve cells**, lie between the bases of the ectodermal cells. Each nerve cell gives off a number of branching processes or nerve fibres which connect with those of neighbouring nerve cells to form a **nerve-net** that extends on the outer surface of the mesogloea, all around the body and tentacles.

5 — The **sensory cells**, are narrow columnar cells which have pointed ends projecting on the surface, and are connected at their other ends by a number of branched processes to the nerve-net.

6 — The **reproductive cells**, are developed in mature individuals by the proliferation of the interstitial cells. They form the gonads, either testes or ovaries.

7 — The **mucous cells**, are most numerous in the ectoderm of the basal disc. They produce a sticky mucous secretion by which *Hydra* attaches to the substratum. They are also found in the oral cone around the mouth opening where they secrete mucus to facilitate the entrance of large food particles.

b) In the Endoderm

1 — The **nutritive** or **musculo-nutritive cells** are tall columnar cells which have their bases projecting as muscle tails. These muscle tails are oriented circularly and therefore act as circular muscle fibres. When they contract, the body narrows and elongates. Some of these cells carry flagella, while others can produce pseudopodia, and both contain food vacuoles.

2 — The **glandular cells**, are granular cells with no muscle tails. They secrete the digestive enzymes inside the gastrovascular cavity.

Among the endodermal cells, are also some **interstitial cells**, **nerve cells** which form a second (but less developed) nerve-net on the inner surface of the mesogloea, sparse **sensory cells** and few **mucous cells** around the mouth, but no *nematoblasts*.

Locomotion

Hydra is essentially sessile and lives attached by a sticky secretion to the substratum. Occasionally, it moves from one place to another by one of the following means :

1 — **Gliding**. This is the simplest method by which the animal glides over the surface of the substratum with the help of the mucous secretion and the pseudopodia-like extensions of the ectodermal cells of the basal disc.

2 — **Walking**. This is the most common method of locomotion. The animal elongates its body, then bends over so as to bring the tentacles down and attaches them to the substratum through the help of the adhesive threads of the small glutinant *nematocysts*. The basal disc is then freed and moved near the tentacles or to a new site where it attaches. The tentacles are then freed, the body assumes an upright position, and the process is repeated.

3 — **Somersaulting**. The animal elongates, bends over, and attaches its tentacles to the substratum. It then frees its basal disc, swings it over the tentacles, attaches it to the substratum on the other side of the tentacles, then the tentacles are freed and the body assumes an upright position.

4 — **Floating**. Rarely *Hydra* frees its basal disc and drifts or floats at the surface using a gas-bubble entangled in the mucous secretion of its basal

disc. It is thus carried by the water currents to another place where it settles down again.

Nutrition

Hydra is mainly holozoic and carnivorous, feeding on minute crustaceans, insect larvae and similar small aquatic animals which come within reach of its tentacles, but it does not chase the prey. If such animal passes by *Hydra* and touches one of its tentacles, a large number of nematocysts are immediately shot at it. The prey is thus paralysed by the poisonous fluid injected into it through the penetrants' threads. At the same time it becomes held by the volvents' threads, and affixed by the large glutinants' threads. The tentacles then cooperate to bring the prey above the mouth, which opens widely to swallow it and pass it into the gastrovascular cavity.

The glandular cells of the endoderm soon become active and produce the digestive secretion which contains several enzymes. The prey is thus killed in the cavity, partly digested, and the digested material are absorbed by the endodermal cells. This is known as **extracellular digestion**, the method of digestion more commonly met with in higher animals.

As a result of this partial digestion, the body of the prey becomes softened and fragmented into smaller pieces. These are then taken into food vacuoles by the pseudopodia of the musculo-nutritive cells of the endoderm where the process of digestion is completed. The food vacuoles in these cells undergo the same acid and alkaline phases characteristic of the food vacuoles of the Protozoa. This is a primitive way of digestion known as **intracellular digestion** which is common among the Protozoa. Undigested remains are passed into the gastrovascular cavity then expelled through the mouth, which therefore also acts as an anus. Larger particles are driven out of the mouth by sudden contractions of the body.

The beating of the flagella of the endodermal cells and the contractions of the body and tentacles help to circulate the digested material throughout the gastrovascular cavity and the cavities of the tentacles. Therefore, the body cavity does not only serve digestion (thus called enteron) but also circulation (hence also called gastrovascular cavity). The soluble products of digestion, whether found in the enteron or inside the endodermal cells, are distributed by diffusion to all parts of the body.

Respiration and Excretion

Hydra possesses no special tissues for either respiration or excretion; both processes take place by diffusion as in the Protozoa. The small size of the body, the thinness of its wall, and the circulation of water inside the enteron make nearly all the cells freely exposed to the surrounding water. Thus oxygen diffuses easily from this water into the cells, and carbon dioxide and nitrogenous wastes diffuse out of them in the same manner. But, the mechanism of osmoregulation in *Hydra* is still unknown.

Sensitivity

Hydra possesses the simplest and most primitive type of nervous tissue known in the Metazoa. This is made up of the nerve cells which are connected together with their branched processes to form two **nerve-nets** extending all around the body and tentacles, on either surface of the mesogloea. These cells are non-polarized (i.e. their processes are not differentiated into axon and dendrites as in the nerve cells of higher Metazoa) and are not grouped into nerve centres or ganglia. Some of the branches of these cells are connected with the sensory cells, while others terminate in the muscle tails of the ectodermal and endodermal cells.

Stimuli received by the sensory cells are picked up by the nerve cells and transmitted through the nerve-nets to the muscle tails to contract. Since the nerve cells are non-polarized, nerve impulses are not conducted in definite pathways along the nerve-nets, but are transmitted in all directions to longer or shorter distances according to the strength of the stimulus. Of course this is not a very efficient nervous mechanism, but it is apparently enough for co-ordinating the limited activities of such a small sessile creature.

Hydra responds to touch and to chemical changes in the surrounding water. It avoids high temperatures and injurious chemical solutions, and moves towards lighted places where more food organisms are usually found.

The discharge of the nematocysts, however, is not controlled by the nervous tissue. They react according to stimuli affecting their cnidocils directly.

Reproduction

Hydra reproduces both asexually by budding and sexually by the formation of gametes. Besides, it has a great capacity for regeneration.

1 — Asexual reproduction by budding

Hydra reproduces in this way during the favourable seasons of the year. The bud develops as a simple evagination from the body wall, usually at the junction between its two lower thirds. This evagination elongates, then a crown of tentacles arises at its free end and the mouth opens in between the tentacles. In this way the bud gradually grows into a small *Hydra* which becomes constricted at its base, breaks free from the parent and floats at the surface for a while, then settles down.

2 — Regeneration

Hydra has a great ability to restore lost tentacles and to repair injured parts of its body through the proliferation of its undifferentiated interstitial cells. Even if the animal is cut into two or more pieces, each piece will grow into a complete individual, and if the body is turned inside out, the cells of the ectoderm and endoderm will migrate past each other until they assume their original positions again.

3 — Sexual reproduction

With the beginning of the unfavourable season, *Hydra* starts to develop gonads and reproduce sexually. Some species of *Hydra* are bisexual, developing both types of gonads on the same individual, although testes may form first and shed the spermatozoa before the ovaries become ripe. But most species are unisexual, with each individual producing either testes or ovaries throughout its life. The testes arise on the sides of the upper third of the body, while the ovary develops near the basal disc.

The testes and ovaries are developed by repeated division or proliferation of the interstitial cells, producing germ mother cells. In the testis, these cells produce a large number of spermatozoa which escape through a hole or fissure in the ectoderm and are thus carried by the water to fertilize the ova on other individuals. In the ovary, a number of germ mother cells is pro-

duced, but only one of them develops into a mature ovum at the expense of the other cells. This ovum becomes loaded with food reserves which will later nourish the developing embryo. The ovum breaks through the ectoderm and becomes thus exposed to the surrounding water.

After fertilization, the zygote undergoes cleavage or repeated division, ultimately forming a small hollow **blastula**, with a thin wall of a single layer of cells, and a small central cavity known as the **blastocoel**.

The embryo then undergoes a process known as gastrulation in which its cells continue to divide, migrate inwards, then arrange in a second inner layer, so that the wall becomes two-layered and the embryo is then referred to as the **gastrula**. The outer layer is the ectoderm, the inner one is the endoderm, and the central cavity is called the **archenteron**.

The ectoderm then secretes a protective **cyst** around the embryo, which separates from the mother, falls to the bottom of the pond and remains as such until environmental conditions become favourable again when a small two-layered embryo escapes from the cyst. It gradually elongates, attaches at one end and develops tentacles and a mouth at the other end. The cells of the ectoderm and endoderm start to differentiate and the embryo is thus transformed into a young *Hydra*. There is no free larval stage in this life cycle. *Hydra* is therefore said to have **direct embryonic development**.

2 — *O B E L I A*

This is a marine coelenterate which is dimorphic, exhibiting both a hydroid form and a medusoid form in its life cycle. In the hydroid form, the animal exists as a delicate plant-like sessile colony, of many small *Hydra*-like polyps, found attached to rocks and sea-weeds near the sea shore. The medusoid form is solitary and free-swimming.

Morphology and Cellular structure

1. The colony

The colony of *Obelia* consists of a branched creeping root-like horizontal portion known as the **hydrorhiza**, which extends over the surface of the substratum, and one or more upright stems, each called a **hydrocaulus**. Short branches arise alternately on both sides of the hydrocaulus, each ending in

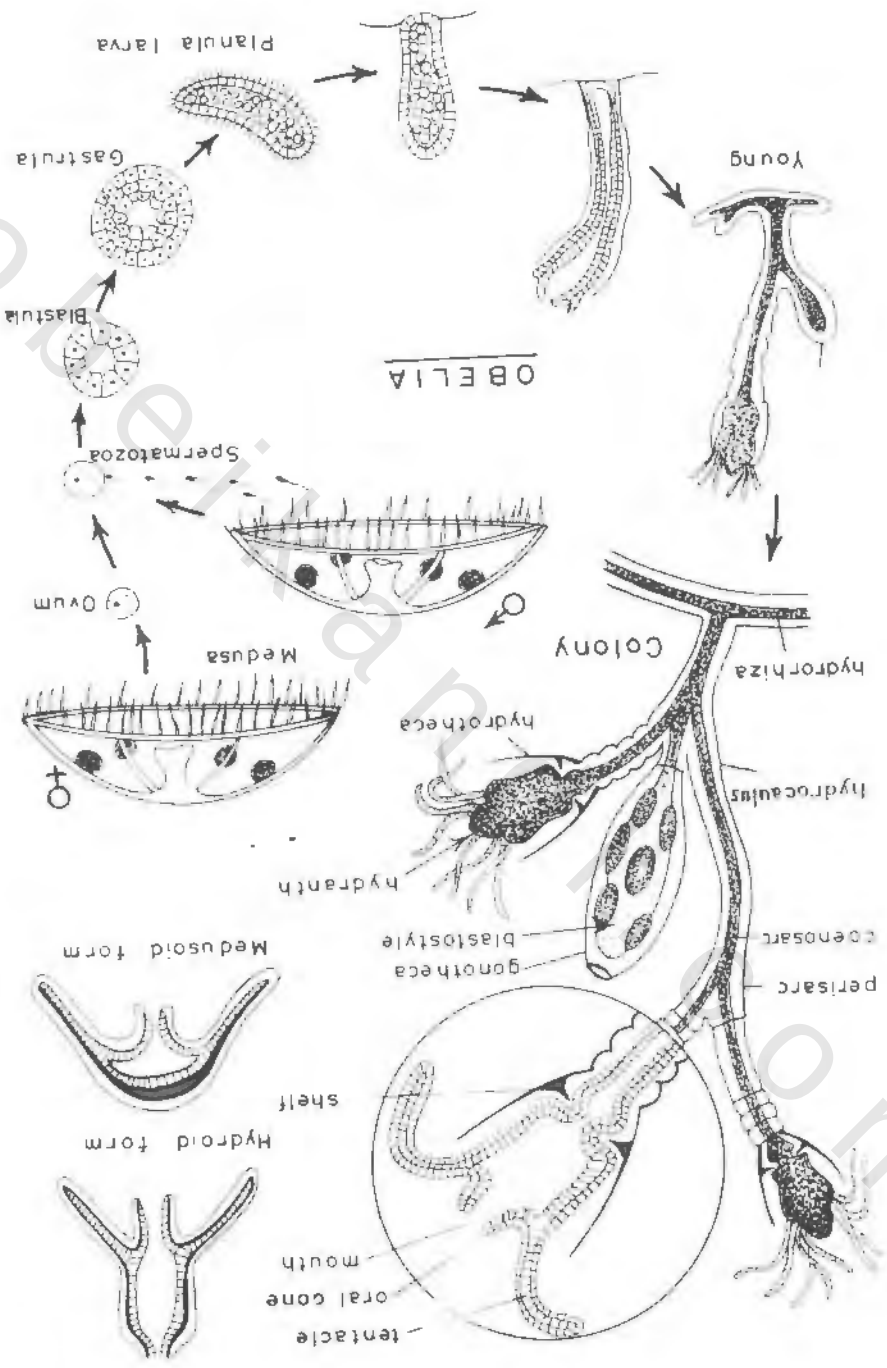
a small individual or polyp. The polyps are of 2 kinds : the majority are *Hydra*-like, have mouth and tentacles by which they collect food and are called the feeding polyps or **hydranths**. Others have no mouth or tentacles, serve for asexual reproduction and are called the reproductive polyps or **blastostyles**. The hydrorhiza, stems and polyps are all hollow and form a continuous soft mass known as the **coenosarc**. This living coenosarc consists of ectoderm, mesogloea and endoderm, surrounding a common **gastrovascular cavity**. The ectoderm and endoderm are composed of the same cell types found in *Hydra* (p 176). However, the ectoderm secretes a thin transparent non-living cuticular sheath, known as the **perisarc**, which covers the whole colony and holds the polyps and stems erect. It acts as a protective exoskeleton, extends also around the polyps, and is annulated at intervals to allow for bending.

a) The **hydranth** : Each hydranth is a little individual closely similar in form and structure to *Hydra*. It has an oral cone with a mouth on top and a whorl of tentacles arising around its base. The tentacles, however, are more numerous (about 24) than in *Hydra* and are solid, i.e. they do not enclose extensions of the gastrovascular cavity, but have a solid central core of endoderm.

The hydranth is covered by a cup-like extension of the perisarc, known as the **hydrotheca**, with an inner circular **shelf** projecting at its base. When attacked, the hydranth contracts its tentacles and pulls itself down in the hydrotheca seeking protection.

The hydranths feed the colony in a similar way as in *Hydra*. They capture small organisms by means of their tentacles which are richly supplied with nematoblasts. The paralysed prey is passed through the mouth into the gastrovascular cavity of the hydranth where digestion starts. Partly digested food is then circulated through the whole colony by the beating of the flagella of the endodermal cells. The food is thus distributed to all parts of the colony and digestion is completed within food vacuoles in the endodermal cells. The basal shelf of the hydrotheca narrows the opening between the hydranth and its stalk, thus preventing the passage of large food particles into the latter.

b) The **blastostyle** : This is a modified polyp which usually develops in the angles where hydranths arise. It is an elongated hollow body which has no mouth or tentacles, and is enclosed in an elongated vase-shaped



extension of the perisarc known as the **gonotheca**. The wall and gastrovascular cavity of the blastostyle are continuous with those of the rest of the colony, and through the latter cavity the blastostyle receives its share of the food captured by the hydranths.

The blastostyle functions mainly in asexual reproduction by producing special buds called the **medusae**. When fully developed, the medusae separate one by one, escape from the terminal opening of the gonotheca and swim freely in the water, away from the parent colony.

All parts of the colony respire and excrete by simple diffusion and have a double diffuse **nerve-net** as in *Hydra*.

2. The medusa

This is a small bell-like body with an upper convex surface called the **exumbrella**, and lower concave one known as the **subumbrella**. A short hollow tube, the **manubrium**, hangs down from the centre of the subumbrella and bears the **mouth** opening at its tip. The mouth leads into the gastrovascular cavity which consists of a small **gastric cavity** in the centre of the medusa, and 4 narrow **radial canals** radiating out from it to join a **circular canal** running along the edge of the medusa.

A narrow circular ridge called the **velum** projects inwards from the free margin of the medusa, and 16 short solid **tentacles**, armoured with nematoblasts, hang down from the latter margin. Below the bases of 8 of the tentacles are 8 small balancing organs known as the **statocysts**. Each is a small fluid-filled sac lined with ectoderm, and has a protoplasmic sensory process and a minute particle of calcium carbonate or **statolith** hanging from the roof inside it.

Four ovoid **gonads** hang down from the subumbrella below the 4 radial canals. The reproductive cells in these gonads are derived from the ectoderm. *Obelia* is unisexual; each medusa carries gonads of one sex only (either testes or ovaries), and all medusae produced by a single colony have the same sex.

The whole outer surface of the medusa is covered by a layer of ectoderm. The endoderm lines the gastric cavity and the different canals, and further extends as a solid sheet in the areas found between these canals. The mesogloea fills the space between the ectoderm and endoderm, and is much thicker than in the polyps.

The muscular and nervous tissues are more developed in the medusa than in the polyps, a character which seems to be correlated with the greater activity of such a free-swimming creature. The muscle tails of its musculo-epithelial cells are more developed. Some of them even have separate nuclei and constitute distinct muscle fibres. In addition to the usual double nerve-net, the medusa has also 2 marginal **nerve rings** which act as controlling centres. Moreover, the medusa has specialized sense organs — the statocysts — which are lacking in the polyps.

The medusa floats at the water surface with the manubrium down, and swims actively by alternate contractions and relaxations of its body in much the same way as an umbrella is opened and closed. These swimming movements are coordinated and the horizontal position is maintained with the help of the statocysts. When the medusa becomes inclined to the horizontal plane while swimming, the statoliths press against the sensory processes in certain statocysts and this will stimulate the medusa to contract in a special manner in order to restore the equilibrium.

The medusa captures small organisms by means of its tentacles and force them into the mouth. Extracellular digestion starts in the gastric cavity, and small partly-digested food particles circulate in the radial and circular canals where they become ingested by the endodermal cells, and digestion is thus completed intracellularly within food vacuoles.

The medusa respire and excretes by simple diffusion. The water current circulating in its gastrovascular cavity aids in these processes.

Comparison between the structure of the polyp and the medusa

The polyp and medusa of *Obelia* are homologous structures. Although they may be quite different in general appearance, a careful consideration will show that the medusa can easily be derived from the polyp. If the polyp is progressively flattened until it becomes disc-like, its lumen becomes reduced to a narrow dorso-ventrally compressed cavity. If this cavity becomes further obliterated, except along 4 narrow radial tubes and a circular one at the edge, the medusa form is attained.

Reproduction and Life cycle

The colony of *Obelia*, as mentioned above, represents the asexual stage in the life cycle. No gonads are developed on any of its polyps as in *Hydra*; it reproduces only asexually by budding. The colony increases in size and adds new stems, hydranths and blastostyles by simple budding. The blastostyles also produce the medusae by budding.

It is the medusa which represents the sexual stage. It develops gonads which, when ripe, burst liberating the sperms or ova in the water where fertilization and subsequent development take place. The zygote undergoes cleavage and gastrulation, developing into a solid ciliated **planula larva**. This larva has an outer covering of ciliated ectoderm and an inner mass of endoderm. It swims freely for a while with the help of its cilia, develops a cavity within its endoderm, then settles down on a rock. It fixes itself at one end and develops tentacles and a mouth at the other end. A small polyp is thus formed which by repeated budding gives rise to a new colony with several hydranths and blastostyles.

This life cycle may be considered to illustrate an example of the phenomenon known as "**alternation of generations**" which means that the organism exists in two stages or generations which alternate regularly in the life cycle; one generation reproduces by sexual means to give the second generation, and this by asexual methods gives rise to the first generation again and so on.

However, alternation of generation in case of *Obelia* differs from that occurring in plants. Among green plants, the term "alternation of generations" means precisely that a haploid generation (sexual generation or gametophyte) producing gametes alternates with a diploid generation (asexual generation or sporophyte) producing spores. But in *Obelia*, both the hydroid and medusoid generations are diploid, the haploid phase is represented only by the gametes. For this reason, many biologists prefer not to consider the case in *Obelia* as an example of alternation of generations. They also prefer not to look upon the medusa as a distinct sexual stage or generation, but as another form of modified polyps which produces gametes and leads a free-swimming life for the purpose of dispersing these gametes away from the parent colony. Accordingly, the life cycle of *Obelia* illustrates nothing but the phenomenon known as **polymorphism** (many forms), with the animal

showing 3 types of individuals : hydranths specialized for feeding, blastostyles serving asexual reproduction by budding, and medusae serving sexual reproduction and dispersal of the species.

B. CLASS SCYPHOZOA

AURELIA

This is one of the commonest coastal jellyfishes which is often seen drifting along the surface waters, swimming slowly by rhythmic contractions of its body, or stranded on sandy beaches. The medusoid form predominates in the life cycle.

Morphology

The medusa of *Aurelia* has the form of a thick gelatinous glassy bluish disc which has a slightly convex exumbrellar side and measures 10 - 25 cm in diameter. The edge of the disc is fringed by numerous short hollow **tentacles** which are set closely together, being interrupted by 8 notches where 8 special sense organs known as the **tentaculocysts** are found.

A square mouth is carried on a very short manubrium which hangs from the centre of the subumbrella. The 4 corners of the mouth are prolonged into 4 long tapering **oral lobes** or **arms** which are deeply grooved on their lower sides and heavily armoured with nematoblasts. The mouth leads into the gastrovascular cavity which consists of a wide **gastric cavity** in the centre of the disc, 16 **radial canals** (8 branched and 8 unbranched), and a marginal **circular canal** with which the hollow tentacles are connected. All this gastrovascular cavity is lined with endoderm. The flagella of the endodermal cells create a steady water current in this canal system which brings a constant supply of food and oxygen and removes away wastes from all parts of the medusa.

The central gastric cavity is produced into 4 symmetrical **gastric pouches**. From each pouch, 2 unbranched canals, called the **adradial canals**, run outwards to the circular canal at the periphery of the disc, and from the latter

canal 4 branched **interradial canals** and 4 other branched **perradial canals** lead inwards to the gastric pouches.

Four red or purple horse-shoe-shaped **gonads** (either testes or ovaries) are conspicuous in the adult medusa. They develop from the endoderm and project on the floor of the gastric pouches. Four groups of solid tentacle-like **gastric filaments** of digestive function also project in the cavity of the gastric pouches to the inside of the gonads. Each filament is a short endodermal tube with a central core of mesogloea and carries numerous nematoblasts.

Cellular structure

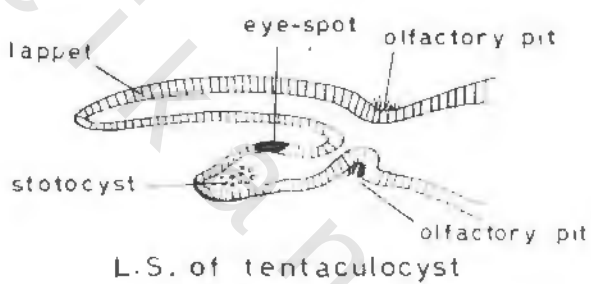
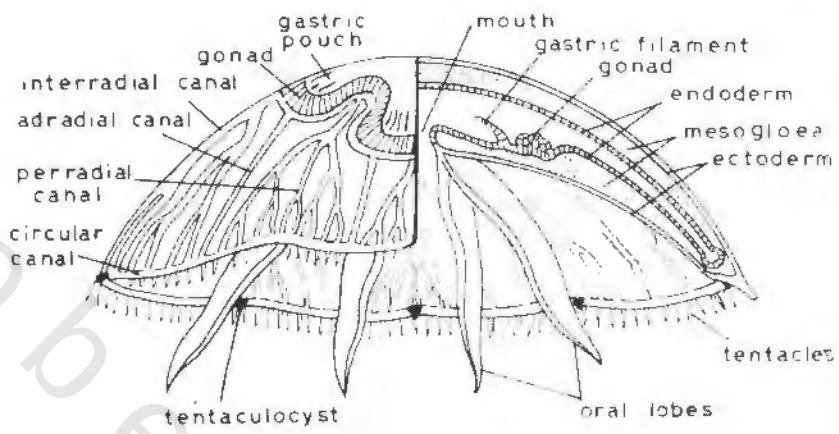
The tissue layers and types of cells found in this medusa are basically similar to those described in *Hydra* and *Obelia*. A layer of ectoderm covers the whole of the ex- and subumbrellar surfaces, and a layer of endoderm lines the gastrovascular cavity. The mesogloea in between is very thick and is not quite structureless as in *Hydra* but contains various amoeboid cells and fibres derived from the endoderm.

Locomotion

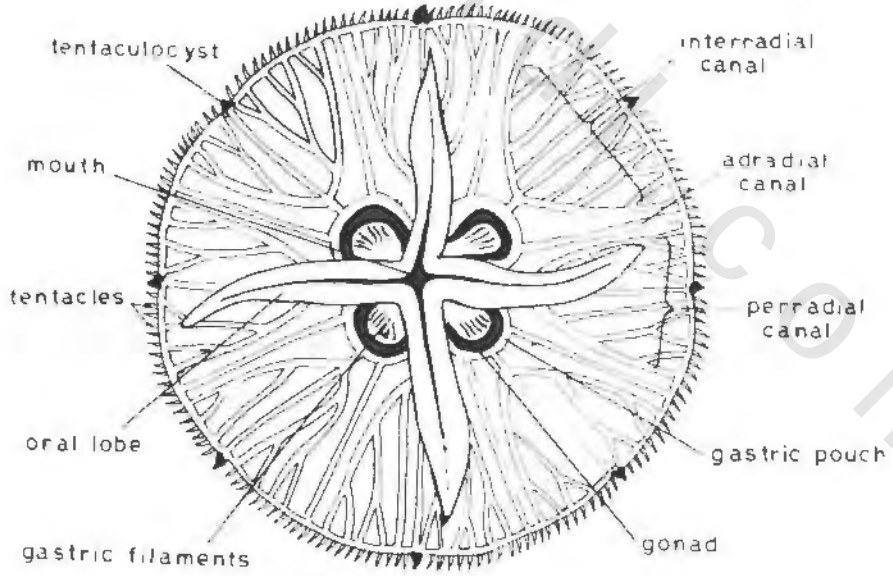
The medusa of *Aurelia* swims by successive contractions of its disc and may also drift along without muscular contraction. The swimming movements are affected by well developed radially and circularly arranged muscle fibres which extend below the ectoderm of the subumbrella.

Nutrition

Aurelia feeds on small crustaceans and other organisms which are paralysed and entangled by the nematocysts on the oral arms, then swept along the grooves of these arms and passed through the mouth into the gastric pouches. The nematocysts on the gastric filaments further paralyse the prey if it was still alive. Digestion is extracellular and intracellular. It starts in the gastric pouches, and partly digested food is then circulated in the canal system and is taken inside food vacuoles in the endodermal cells where digestion is completed.



L.S. of tentaculocyst



AURELIA

Respiration and Excretion

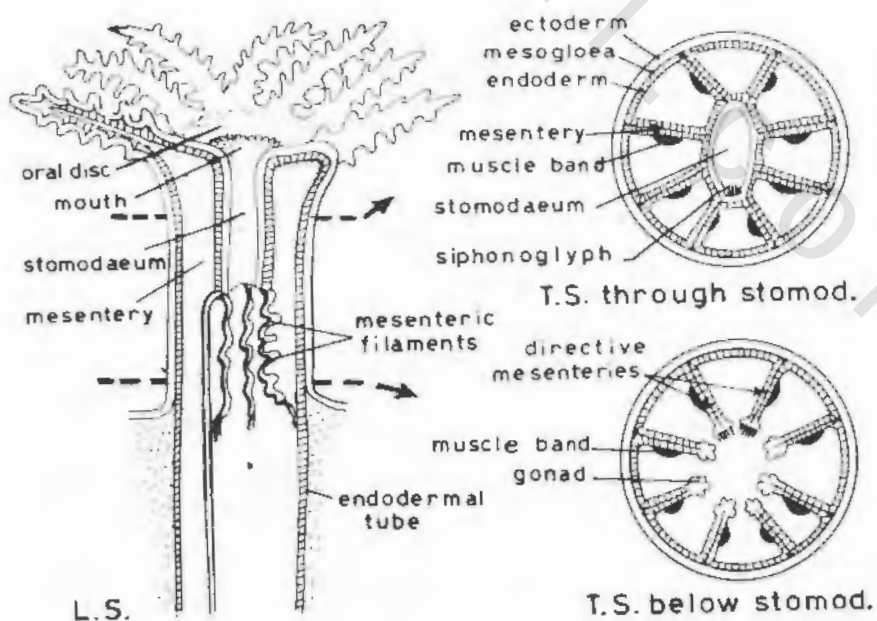
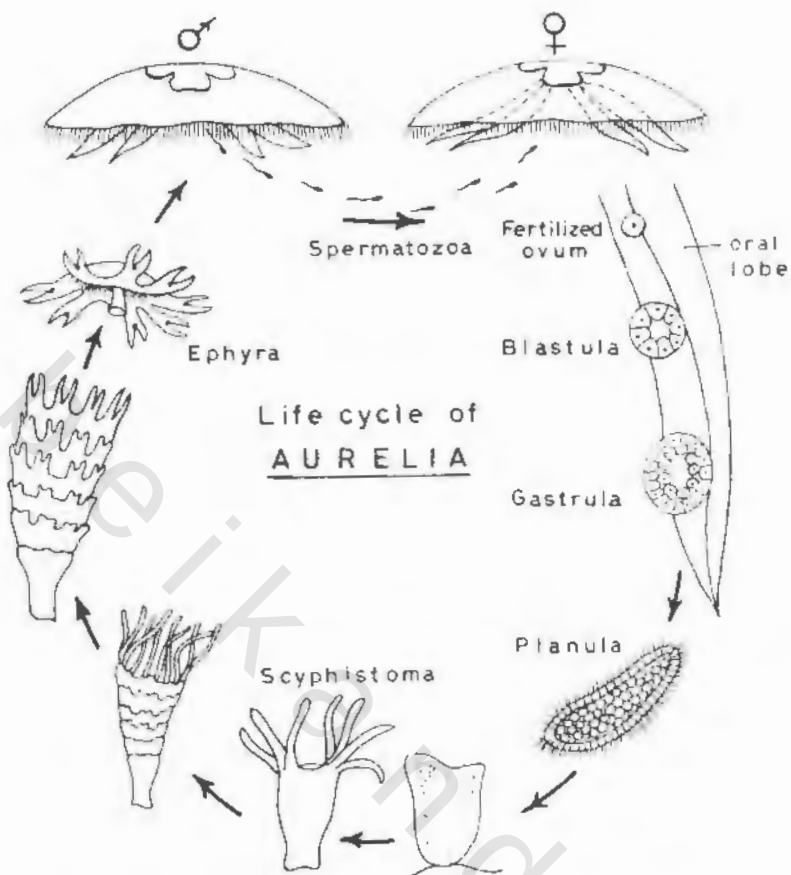
Respiration and excretion both take place by simple diffusion. The water current flowing continuously within the gastrovascular cavity brings in oxygen and carries away carbon dioxide and nitrogenous waste products.

Sensitivity

The medusa has a diffuse nerve-net, extending below the ectoderm of the subumbrella, which coordinates its various activities. It has also specialized sensory organs, the **tentaculocysts**, which serve a triple sensory function. Each tentaculocyst consists of a hollow modified tentacle enclosing a **statocyst** with few calcareous particles which stimulate the medusa to maintain equilibrium and control its swimming movements. A **pigmented eye-spot** sensitive to light lies on the upper surface of the tentaculocyst, and 2 **olfactory pits** are found on its upper and lower sides. These pits are lined with sensory cells which are sensitive to chemical changes in the surrounding water.

Reproduction and Life cycle

Sexes are separate; the medusa is either male or female. Sperms are shed into the gastric cavity and pass out through the mouth. In female medusae, the eggs are also shed into the gastric cavity but are fertilized there by sperms entering with the water current. The zygote passes out of the mouth and lodges in the grooves of the oral arms where it continues to develop forming a ciliated **planula larva**. The planula swims freely for a while then settles down on a rock and develops into a small polyp called the **scyphistoma**. The scyphistoma feeds and lives as such for several months, meanwhile it undergoes a series of horizontal fissions; a peculiar process known as **strobilization**. By this process, the scyphistoma becomes cut transversely into a series of little immature medusae situated one on top of the other like a pile of dishes. Each of these immature medusae has the form of a small 8-rayed star and is called an **ephyra**. It has a short manubrium, a central gastric cavity provided with gastric filaments, and its umbrella is divided into 8 bifid arms, each ending in a tentaculocyst. The ephyrae detach one by one from the scyphistoma, swim away and each develops gradually into an adult medusa.



ALCYONIUM

If the life cycle of *Obelia* is considered to exhibit alternation of generations, then that of *Aurelia* may also be regarded as illustrating the same phenomenon, the sexual generation being represented by the medusa and the asexual generation by the scyphistoma.

C. CLASS ACTINOZOA

1 — Order ALCYONARIA

ALCYONIUM

Alcyonium, the dead man's fingers, is a marine colonial coelenterate found permanently fixed to rocks and shells in colder seas.

Morphology

The colony of *Alcyonium* consists of a lobed fleshy mass, called the **coenenchyme**, from which project the individual polyps, and inside which the polyps retract for protection when attacked. The part of each polyp which projects on the surface of the coenenchyme does not represent all the polyp. The polyps actually penetrate very deep into the substance of the coenenchyme.

The polyp has a flat **oral disc** at its free end instead of an oral cone. Eight hollow pinnate tentacles, each provided with 2 rows of small hollow **pinnules** and armoured with nematoblasts, arise around the oral disc. A slit-like mouth lies in the centre of the oral disc. It does not lead directly into the gastrovascular cavity as in *Hydra*, but into a short invaginated tube, the **gullet** or **stomodaeum**, which passes down in the interior of the polyp. This tube is lined, with ectoderm and has a ciliated groove, called the **siphonoglyph**, running along one side of it (commonly regarded as the ventral side). The cilia lining the siphonoglyph create a continuous respiratory water current that passes through the mouth downwards into the gastrovascular cavity.

The stomodaeum does not hang freely in the gastrovascular cavity, but is connected with the body wall by 8 vertical and radially arranged partitions.

or **mesenteries**, which alternate with the bases of the 8 tentacles. These mesenteries divide the gastrovascular cavity around the stomodaeum into 8 **inter-mesenteric chambers**. Each of these mesenteries is composed of two layers of endoderm separated by a thin supportive sheet of mesogloea. In addition to ordinary muscle tails, a band of spindle-shaped nucleated muscle fibres, which constitute a **refractor muscle**, runs longitudinally below the endodermal layer on one side of each mesentery; the ventral side which faces the siphonoglyph.

Below the level of the stomodaeum, the inner edges of the mesenteries are free and enlarged to form thick convoluted cords known as the **mesenteric filaments**. All mesenteries and mesenteric filaments stop short near the base of the exposed part of the polyp, except the 2 dorsal mesenteries (lying on the opposite side of the siphonoglyph) which are much longer and extend along the whole length of the polyp. These 2 mesenteries are called the **directive mesenteries**. Their mesenteric filaments are heavily flagellated and the flagella serve to direct the water current upwards, toward the mouth. The remaining 6 mesenteric filaments are rich in glandular cells and nematoblasts which serve for killing and digesting food. Gonads develop on these 6 filaments also in the breeding season.

Cellular structure

The arrangement of the cellular layers and the types of cells are generally the same as in members of the two preceding classes. An ectodermal layer covers the whole outer surface of the colony and the exposed parts of the polyps. The endoderm lines the gastrovascular cavity of each polyp. It actually forms a long tube which penetrates deeply into the coenenchyme below the exposed part of each polyp. The endodermal tubes of neighbouring polyps are inter-connected by narrow endodermal connections from which new polyps bud off, so that the colony increases in size.

All the space between the outer ectoderm and the inner network of endodermal tubes is occupied by thick gelatinous mesogloea which contains a skeleton of numerous minute irregularly-shaped **calcareous spicules**. Although embedded in the mesogloea, these spicules are actually secreted by wandering cells from the ectoderm.

Nutrition

Alcyonium feeds on small organisms which are as usual paralysed by the nematocysts and carried by the tentacles to the mouth. They are passed down the stomodaeum to the gastrovascular cavity where digestion starts through the help of the digestive enzymes secreted by the glandular cells of the mesenteric filaments. Digestion is then completed intracellularly within food vacuoles in the endodermal cells lining the gastrovascular cavity. Undigested remains are expelled out of the mouth.

Respiration and Excretion

The cilia in the siphonoglyph beat downwards drawing a current of water into the gastrovascular cavity, while the cilia found on the directive mesenteries beat upwards driving this water out again. This steady water current brings in oxygen and carries away carbon dioxide and other wastes.

Reproduction and Life cycle

Sexes are separate; the whole colony is of one sex. The gonads are endodermal and develop on the mesenteric filaments. The sperms and ova are shed into the water where fertilization takes place. The zygote develops into a ciliated planula larva which, after swimming for a while, settles down. It grows into a small polyp which, by asexual budding gives rise to a new colony. Thus, the cycle does not include a medusoid stage, or show alternation of generations.

2 — Order ZOANTHARIA

a) SEA ANEMONES

These are flower-like, brilliantly coloured marine coelenterates which exist as large solitary polyps attached to rocks and seaweeds near the sea shore. They form no calcareous skeletons.

Morphology

A sea anemone is a relatively short stout cylindrical body which has a muscular adhesive basal disc by which it attaches to the substratum, and a rounded flat oral disc at the other end. An elongated slit, the mouth, is found in the centre of the oral disc, surrounded by many short hollow tentacles which are arranged in concentric whorls; each containing 6 or multiples of 6.

From the mouth, a wide flattened stomodaeum hangs down into the gastrovascular cavity. The stomodaeum is lined with ciliated ectoderm and is marked along two opposite sides with 2 ciliated siphonoglyphs. The cilia of one siphonoglyph draw water into the gastrovascular cavity, while those of the other siphonoglyph drive water out of the mouth.

Extending radially between the body wall and the stomodaeum are 6 pairs of complete vertical **primary mesenteries**. In between these mesenteries is another set of 6 paired but incomplete **secondary mesenteries** extending only part of the distance between the body wall and the stomodaeum. Arising in between the latter mesenteries and the primary ones are 12 pairs of still narrower **tertiary mesenteries**. All these mesenteries are built up as in *Alcyonium*, each of two layers of endoderm supported by a thin sheet of mesogloea inbetween. The primary mesenteries divide the gastrovascular cavity into 6 inter-mesenteric chambers which communicate freely with each other below the stomodaeum, but in the region of the stomodaeum they communicate only through one or 2 ostia in each mesentery.

The free edges of all the mesenteries, below the level of the stomodaeum, form thickened convoluted cords or **mesenteric filaments** which appear trilobed in transverse sections. The middle lobe is rich in glandular cells and nematocysts, while the two lateral lobes are heavily ciliated for water circulation.

A band of muscle fibres or retractor muscles extends along one side of each mesentery below the endodermal layer as in *Alcyonium*, but the arrangement of these retractor muscles is different here. The 2 pairs of mesenteries which are connected to the stomodaeum opposite to the two siphonoglyphs have the muscles on each pair facing away from one another. These mesenteries are recognized as the **directive mesenteries**. On all the remaining

primary, secondary and tertiary mesenteries the muscles face one another in each pair. Gonads develop from the endoderm on all the mesenteries except the directive ones. Each gonad appears as a swollen folded band inbetween the mesenteric filament and the retractor muscle.

Cellular structure

The outer surface of the polyp is covered with ectoderm which is ciliated on the tentacles, oral disc and the lining of the stomodaeum. The endoderm lines the whole of the gastrovascular cavity. In between the two layers is a thick mesogloea which contains wandering cells and muscle fibres derived from both ectoderm and endoderm. Circularly arranged muscle fibres extend below the ectoderm of the body wall and serve to elongate the polyp. Other longitudinal muscle bands which extend below the endoderm of the mesenteries serve as retractor muscles, pulling the oral disc and tentacles completely inside upon irritation. The polyp has also a well developed nerve-net extending below the ectoderm.

Locomotion

Although sessile, the sea anemone can shift its position by gliding very slowly over the substratum with the help of some creeping movements of its basal disc.

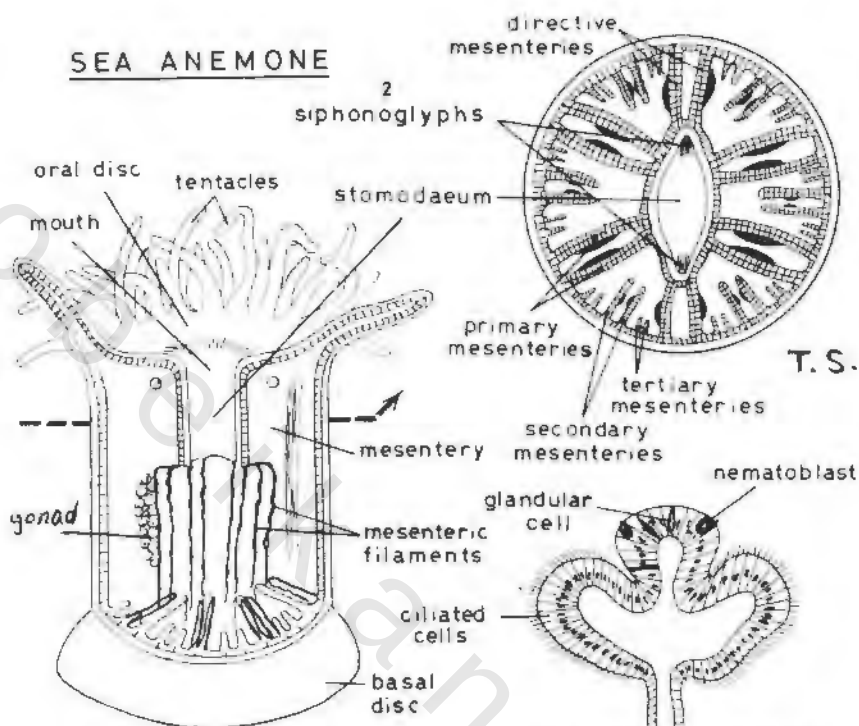
Nutrition

Sea anemones feed on molluscs, crustaceans and other small animals including fish. The prey is partly paralysed before ingestion by the nematocysts on the tentacles, and the process is completed after swallowing by the nematocysts carried on the mesenteric filements. Digestion then proceeds as in *Alcyonium* (p. 284).

Respiration and Excretion

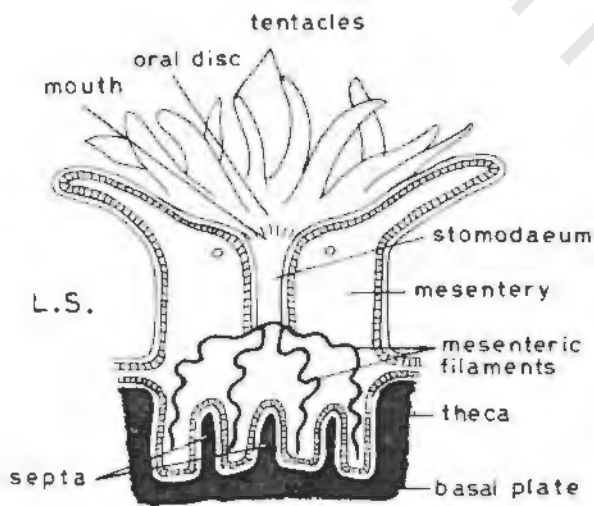
The water current created by the cilia of the 2 siphonoglyphs serves respiration and excretion as in *Alcyonium*.

SEA ANEMONE



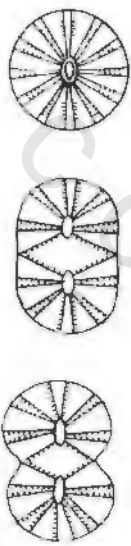
L.S.

Mesenteric filament
T.S.



L.S.

STONY CORAL



Budding

Reproduction and Life cycle

Sexes are separate. Sperms and eggs are usually expelled through the mouth and fertilization takes place in the water. The zygote develops into a ciliated planula larva which settles down and grows into a single sea anemone.

Asexual reproduction by longitudinal fission also frequently occurs.

b) STONY CORALS

These are mostly colonial marine coelenterates which flourish in tropical and subtropical seas. They secrete massive calcareous exoskeletons which form coral reefs and islands. Few forms are solitary.

A colonial coral consists of a large number of small delicate anemone-like polyps which grow over the stony exoskeleton they secrete. Each polyp is basically similar in form and structure to a sea anemone polyp, but has poorly developed musculature and a much thinner mesogloea.

The ectoderm of the basal disc of each polyp secretes a stony cup of calcium carbonate below it, i.e. between the polyp and the substratum. This cup consists of a circular **basal plate** with a raised wall around the edge known as the **theca**. To the inside of this wall, a series of radially arranged vertical plates or **septa** are then secreted underneath the inter-segmental spaces of the polyp. Some of these septa meet in the centre in a vertical rod, the **columnella**.

Secretion continues as long as the polyp lives. Thus the theca and septa continue to grow, carrying the polyp higher and higher and adding to the mass or thickness of the skeleton. A thin sheet of living tissue extends between the polyps. This tissue also adds to the skeleton by filling the spaces between neighbouring cups with secretion.

The endodermal cells of many corals and of several other coelenterates harbour unicellular symbiotic algae (zooxanthellae and zoochlorellae). The coral use the oxygen released by these algae as a result of photosynthesis, and the algae take up carbon dioxide and some other metabolic products of the coral.

Reproduction

Stony corals are either unisexual or bisexual. Sperms are shed into the water, but fertilization takes place usually within the gastrovascular cavity of the mother, and the planula larva develops there. It becomes later expelled through the mouth, swims for a while in the water then settles down and grows into a polyp, that gives a new colony by budding.

Budding results in huge colonies of thousands or millions of polyps. Buds arise as swellings at the base of the polyp. Each bud develops into a new polyp which secretes its own skeleton and gives new buds in turn.

Another method by which some colonial corals reproduce asexually and increase in size is by **longitudinal fission** of the polyps. The polyp develops a new mouth surrounded by whorls of new tentacles on its oral disc, the disc elongates, then a constriction appears between the 2 mouths and proceeds downwards, dividing the polyp into two.

THE TRIPLOBLASTICA

THE ACOELOMATA

1. PHYLUM PLATYHELMINTHES

(Flat-worms)

The Platyhelminthes or flat-worms are the lowest triploblastic animals, and the first to develop distinct organs and organ systems, i.e. to exhibit the organ system level of organization. This phylum includes a group of free-living aquatic forms (Turbellaria), and two other groups of very important parasites, the flukes (Trematoda) and the tapeworms (Cestoda).

General Characters

1 — They are free-living or parasitic, triploblastic acoelomate animals, i.e. they possess no coelom; the spaces between the internal organs are filled by loose parenchyma cells of mesodermal origin.

2 — They have soft dorso-ventrally flattened and bilaterally symmetrical bodies, i.e. only one median or sagittal section can divide the body into two symmetrical halves.

3 — The body muscles are fairly well developed, and share in the formation of the body wall.

4 — The digestive system, when present, is simple with only a mouth opening, but no anus.

5 — The excretory system is essentially formed of basic units, known as flame cells or solenocytes, connected together by minute excretory ducts, leading to the exterior by one or more excretory pores.

6 — They have no respiratory or circulatory systems.

7 — In addition to a diffuse nerve-net, they have a centralized nervous system with a pair of cerebral ganglia lying in the anterior region of the body, and connected to one to three pairs of longitudinal nerve cords with

occasional transverse commissures.

8 — The majority are hermaphrodite, with complicated reproductive systems including internal mesodermal gonads, genital ducts, occasionally, accessory genital glands, and copulatory organs.

Classification

Phylum Platyhelminthes is divided into three classes :

A. Class Turbellaria

This class includes free-living flat-worms which live in fresh or marine waters, and sometimes on land. The body is covered by a layer of ciliated epithelium, devoid of any cuticular structures. They possess a digestive system, and have no suckers or any other adhesive organs. They exhibit direct development, involving no asexual stages.

B. Class Trematoda

These are parasitic unsegmented flat-worms. The body is covered by a thick non-ciliated layer known as the tegument. They have a digestive system and adhesive organs in the form of suckers by which they cling to the tissues of their hosts. This class includes two distinct orders :

1 — Order **Monogenea** (Monogenetic trematodes) : This order includes external (or very rarely internal) parasites which use one host and have simple direct life cycles and direct development.

2 — Order **Digenea** (Digenetic trematodes) : This order includes internal parasites or endoparasitic flat-worms with complicated indirect life cycles, i.e. the transmission of the parasite from one host species (usually a vertebrate animal) to another requires a second host (usually an invertebrate animal) which is called the intermediate host.

C. Class Cestoda

This includes endoparasitic segmented flat-worms. The adult stages of these parasites are mainly found in the alimentary canal of their hosts. They have no digestive system or mouth and the body is covered by a thick tegument. They have adhesive organs in the form of suckers, grooves, or hooks for attachment to the host tissues.

A. CLASS TURBELLARIA

PLANARIA

Planaria is a free-living freshwater turbellarian commonly found creeping on the bottom mud of ponds and streams or clinging to the underside of submerged plants and stones.

Morphology

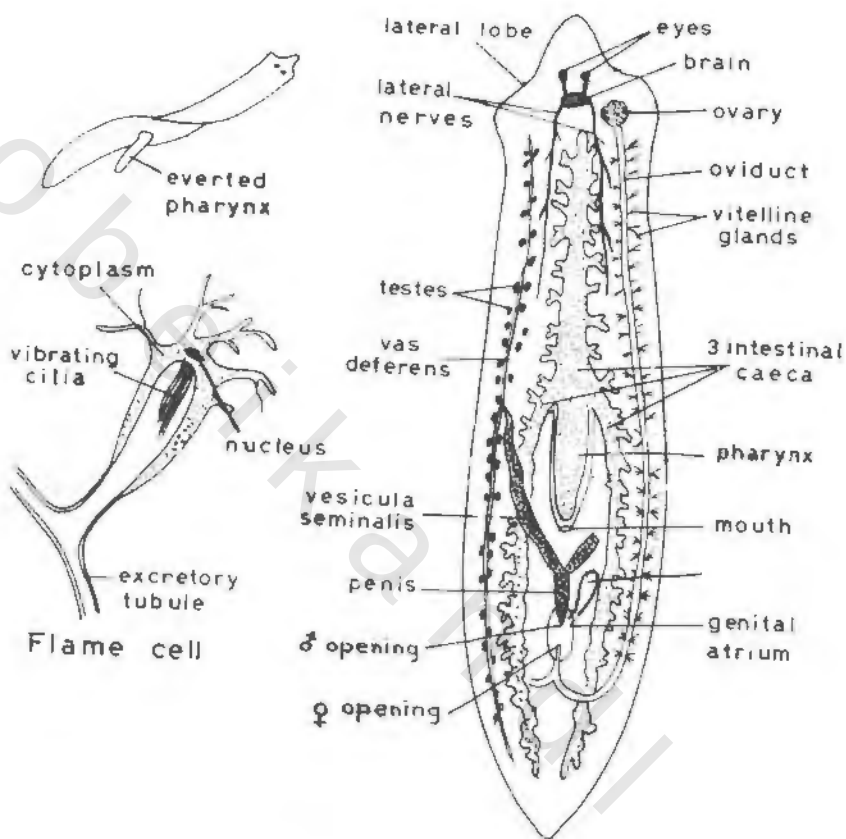
Planaria has a small, elongated, thin, flattened body with a broader anterior end and a somewhat pointed posterior one. Two small **lateral lobes** project near its anterior end, and two small black eyes are found on the dorsal surface. The **mouth** opening is not terminal, but lies on the mid-ventral surface in the posterior half of the body. A **common genital opening** lies close behind the mouth.

Histological structure

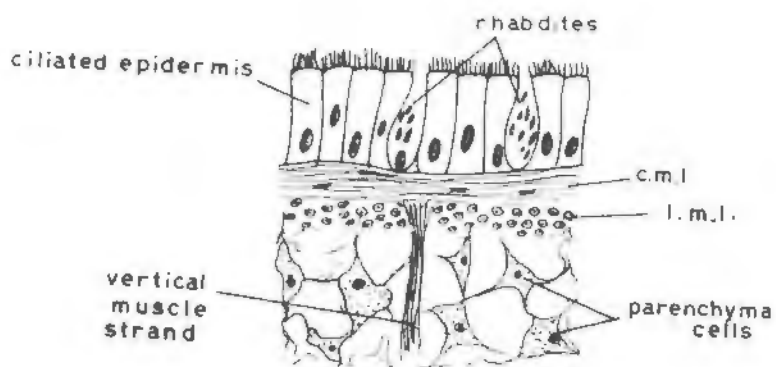
The body is covered externally by a single layer of ciliated epithelial cells, the **epidermis**, which rests on a very thin basement membrane and contains numerous gland cells and sensory cells. Some cells of the epidermis contain minute rod-shaped bodies known as **rhabdites** which, when discharged in the water, swell rapidly forming a sticky mucous film on the body surface. This sticky substance probably serves in adhesion, in entangling and capturing live prey, and in protection against enemies.

Underneath the epidermis are two layers of well developed **muscle fibres**, an outer circular muscle layer and an inner longitudinal one. In addition, there are thin strands of vertical muscle fibres running between the dorsal and ventral sides of the body. All these muscle fibres are separate nucleated cells; they are not mere contractile extensions of the epidermal cells as in *Hydra*.

The whole space found between the outer covering epidermis (ectoderm) and the inner epithelium of the gut (endoderm) is filled with a peculiar loose



PLANARIA



Body wall of Planaria

tissue of irregularly-shaped amoeboid cells and wide intercellular spaces. This tissue is derived from the mesoderm and is called the **mesenchyme** or **parenchyma**. It forms a packing around the internal organs and thus functions as a supportive connective tissue. Its cells also serve for storage of glycogen and fats, and its wide spaces contain a fluid that apparently plays the role of blood in higher animals by aiding in the transport of soluble substances and gases from one part of the body to another.

Locomotion

Planaria does not swim freely in water but glides slowly on the bottom mud and submerged objects with the help of the cilia found on its ventral surface, aided by a mucous secretion from the epidermal gland cells.

The worm occasionally crawls more actively by setting regular waves of muscular contractions in its body, passing from in front backwards.

Digestive system and nutrition

The **mouth** leads into a thick-walled muscular **pharynx** which lies within an invaginated sac of the ventral body wall called the **pharynx pouch** or **sheath**. It leads anteriorly into the intestine which is divided up into 3 main branches or **intestinal caeca** or **crura**, one passing medially forwards and the other two running backwards on either side of the body. The 3 caeca end blindly and give off numerous side branches or diverticula by which the digestive lining of the intestine is greatly increased in area. The intestine thus encloses a wide gastrovascular cavity which is lined with phagocytic endodermal cells (producing pseudopodia and engulfing food particles in an amoeboid fashion) and enzyme-secreting glandular cells. There is no anus; the mouth serves both ingestion and egestion.

Planaria is carnivorous, feeding on small live organisms and on dead bodies of larger animals. The prey is entangled in its mucous secretions, then the pharynx pouch is everted and the pharynx is protruded outside the mouth opening and applied to the prey. Juices and bits of the prey's body are thus sucked in by the strong pumping movements of the pharynx. Digestion is mostly intracellular, occurring within food vacuoles of the endodermal cells lining the intestine, and products of digestion are passed by diffusion through the parenchyma to other tissues.

Respiration

The worm has no respiratory organs. Gaseous exchange takes place by simple diffusion through the whole body surface as in coelenterates. Oxygen further diffuses through the parenchyma to all body tissues, and carbon dioxide diffuses out in the same manner.

Excretion and Osmoregulation

In the Platyhelminthes we see for the first time an organ system specialized for excretion. This excretory system consists of a large number of branched excretory tubules which ramify throughout the parenchyma and collect in 2 longitudinal **excretory canals**, that run longitudinally one on each side of the body and open to the exterior on the dorsal surface by several pairs of minute **excretory pores**.

The smallest terminal tubules end in **flame cells** or **solenocytes** (hollow cells). Each is a nucleated cell which has a number of branched processes and encloses a central cavity within its cytoplasm. A tuft of cilia hangs down in that cavity and shows a characteristic flickering movement like that of a candle-flame. These flame cells collect nitrogenous wastes and excess water from the parenchyma and drive them, with the help of their cilia, down the excretory tubules to the exterior.

The primary function of this flame cell system seems to be osmoregulation rather than excretion. This is because considerable amounts of the nitrogenous wastes are still excreted by diffusion through the body surface, and the flame cell system is relatively reduced in marine turbellarians.

Nervous system

The Platyhelminthes are also the first to have a centralized nervous system. In addition to a diffuse **nerve-net** extending just below the epidermis, *Planaria* possesses another plexus of nerve cells and fibres extending in the parenchyma below the muscle layers. Some of the latter nerve cells aggregate in the anterior region of the body to form 2 **cerebral ganglia** (or **brain**), as well as along certain longitudinal tracts forming 2 **lateral nerves** which give off fine lateral branches and are connected to each other by cross strands like the rungs of a ladder.

The cerebral ganglia and nerve cords constitute a **central nervous system** which provides more coordination in behaviour and more rapid responses to stimuli than is possible with the non-centralized nerve-net of coelenterates.

External stimuli of various kinds are received by numerous **sensory cells** which lie in the epidermis covering the entire body surface, each with its tip projecting on the surface. These sensory cells are especially more concentrated along the lateral edges of the body and in the anterior region. Thus, the 2 anterior lateral lobes are rich in cells sensitive to touch, water currents, food and chemical changes in the water. Each of the 2 eyes consists of a cup of pigmented cells enclosing many sensory cells sensitive to light, and other light perceiving cells are also scattered on the body surface. *Planaria* avoids strong light and therefore hides during daytime under stones and plant leaves.

Reproductive system and Reproduction

Planaria is monoecious or hermaphrodite and has a complicated reproductive system. The testes and ovaries are internal and are developed from the mesoderm. Sperms and ova, instead of being shed directly to the exterior as in coelenterates, are conveyed to the outside along special canals or **gonoducts**. The reproductive system also includes special chambers for storage of the reproductive cells and for fertilization of the ova, certain yolk producing glands, and special devices for transferring sperms to other individuals.

The **male genital system** consists of numerous paired testes in the form of small follicles, scattered in the parenchyma on either side of the body. A delicate **vas efferens** collects sperms from each testis, and all the vasa efferentia on each side lead into a single **vas deferens** that runs longitudinally and dilates posteriorly to form a **vesicula seminalis**. The 2 seminal vesicles of both sides join in a small protrusible **cirrus** or **penis** which projects in a median chamber, the **genital atrium**.

The **female genital system** consists of 2 small rounded ovaries located close behind the eyes. A long **oviduct** leads from each ovary and runs longitudinally backwards along one side of the body. Numerous small follicular yolk or **vitelline glands**, scattered in the parenchyma on either side of the body, lead into each oviduct by minute **vitelline ducts**. The 2 oviducts unite posteriorly into a short common median oviduct which opens into the genital

atrium. A median stalked sac, the **copulatory bursa**, also opens in the genital atrium and serves to store the sperms received from another individual during copulation.

1 — Asexual reproduction

Planaria reproduces asexually by transverse binary fission. It attaches by its posterior end firmly to the substratum while the anterior part of the body swings so strongly that the body becomes cut transversely into two, usually behind the pharynx. Each half then regenerates a new worm.

2 — Regeneration

The worm has a great ability to regenerate lost or injured parts of its body. Quite small pieces of the body can regenerate whole worms. If starved for several weeks, certain tissues and organs in the body become absorbed and utilized for food. The worm thus diminishes gradually in size, but the lost organs are restored and the worm grows to its initial size upon feeding normally again.

3 — Sexual reproduction

In spite of having male and female systems, self fertilization rarely occurs. Instead, **cross fertilization** takes place between two worms which bring their posterior ventral surfaces opposite to one another, and the cirrus of each becomes inserted into the genital atrium of the other, depositing the sperms in its copulatory bursa. The two worms then separate and the sperms in each travel later from the copulatory bursa along the oviducts to the ovaries. The ova are fertilized as they come down from the ovaries along the oviducts. Each egg is then surrounded by some yolk cells as it passes backwards along the oviduct, then receives an outer protective shell in the genital atrium. Sometimes few eggs surrounded with many yolk cells are all enclosed in a common egg capsule. The eggs are deposited on submerged objects in the water and hatch after sometime in minute young planarians similar to the parent. Thus *Planaria* is said to have **direct development**, with no free larval stages appearing in the life cycle.

B. CLASS TREMATODA

ORDER DIGenea

(Digenetic trematodes)

Digenetic trematodes constitute a major group of flat-worms which are commonly found in hosts belonging to almost every class of vertebrate animals, including fishes, amphibians, reptiles, birds and mammals.

These trematodes have received a widespread medical and veterinary attention because many species - in their adult stages - are known to be the causative agents of some diseases of man and his domestic animals.

The adult flukes (worms) may be found in various tissues and cavities of the vertebrate body. While the majority of them may be located in the digestive tract of their hosts, several others reside in the bile passages, in the lungs, or in the circulatory system of the host. According to their location in the body of the host, digenetic trematodes are described as hepatic, blood, intestinal or pulmonary flukes.

In the present text the morphology and the biology of the following trematodes are considered :

- | | |
|-----------------------|-------------------------|
| 1 — Liver flukes | <i>e.g. Fasciola</i> |
| 2 — Blood flukes | <i>e.g. Schistosoma</i> |
| 3 — Intestinal flukes | <i>e.g. Heterophyes</i> |

1 — Liver Flukes

Fasciola

The liver flukes were probably the first trematodes to be seen by helminthologists. They are quite prevalent particularly in sheep-raising areas. Although they are primarily parasites of sheep, cattle and other herbivorous mammals, yet human infections are not uncommon.

There are two common species of liver flukes: *Fasciola hepatica* and *Fasciola gigantica*, which are fairly similar, yet they can be distinguished by certain morphological and anatomical characteristics. In many parts of Africa and Asia *F. gigantica* is more common, while *F. hepatica* is more common in Europe and Australia. In A.R. Egypt *F. gigantica* is a very common parasite of sheep, goats and cattle. The fluke is most prevalent in the northern parts of the Nile Delta where it causes serious losses in cattle and sheep. The loss in animals infected with the liver flukes is not only due to the destruction of infected livers in abattoirs, but also to the reduction in the productivity of the diseased animals. The disease weakens the animals, thus devaluating them as a source of meat, reduces their production of milk, decreases their working and breeding activities, and may lead, in severe cases, to serious fatalities in the farm livestock.

Fasciola gigantica

Morphology

The adult fluke which inhabits the bile passages of the liver is relatively large measuring 25 - 75 mm in length and 10 - 15 mm in breadth. It has a leaf-like body which is more or less flattened along the margins than along the median line. At the anterior end of the worm there is a distinct conical projection known as the **head cone**, while the posterior end is broadly rounded. Behind the head cone, the body widens gradually to form the 'shoulders'. The **mouth** opening lies at the anterior end, surrounded by a large muscular organ known as the **oral sucker**. A short distance behind the oral sucker, there is another larger and strong muscular adhesive organ known as the **ventral sucker** lying along the median line on the ventral surface. In between the oral and ventral suckers and along the median line, lies the **genital atrium**, while a single **excretory pore** is located at the posterior end of the fluke.

Histological structure

The body wall of trematodes in general, and *Fasciola* in particular, was extensively studied only recently. In classical textbooks, the body of *Fasciola* is described as being covered externally by a non-living protective layer,

the cuticle. However, recent studies, specially those in which the electron microscope was used, have improved to a great extent our knowledge of the structure and function of this body covering. It is now widely accepted that the body of *Fasciola*, and probably of most other digenetic trematodes, lacks an outer cuticle. Instead, it has an external living covering, called the **tegument**, which is essentially a cytoplasmic extension of flask-shaped **tegument-forming cells** lying deep among the parenchyma cells. This layer is provided with a large number of small sharp **spinules**. The surface of the tegument is covered by a membrane which also covers the spinules, which are accordingly inter-cellular organelles. The surface configuration of the membrane may show primary and secondary invaginations. **Pinocytotic vesicles** may be present in the tegument. The deep part of the tegument is rich in mitochondria which appear arranged in rows perpendicular to the surface. They are very small, being only $0.3 - 0.4\mu$ in width. The tegument lies on a basement membrane, below which there are circular and longitudinal muscle layers. In addition, there are some vertical muscle strands. All the space found between the body wall and internal organs is filled with **parenchyma**.

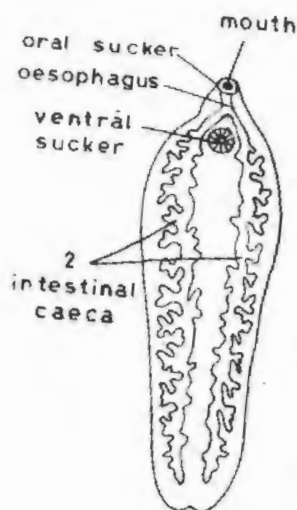
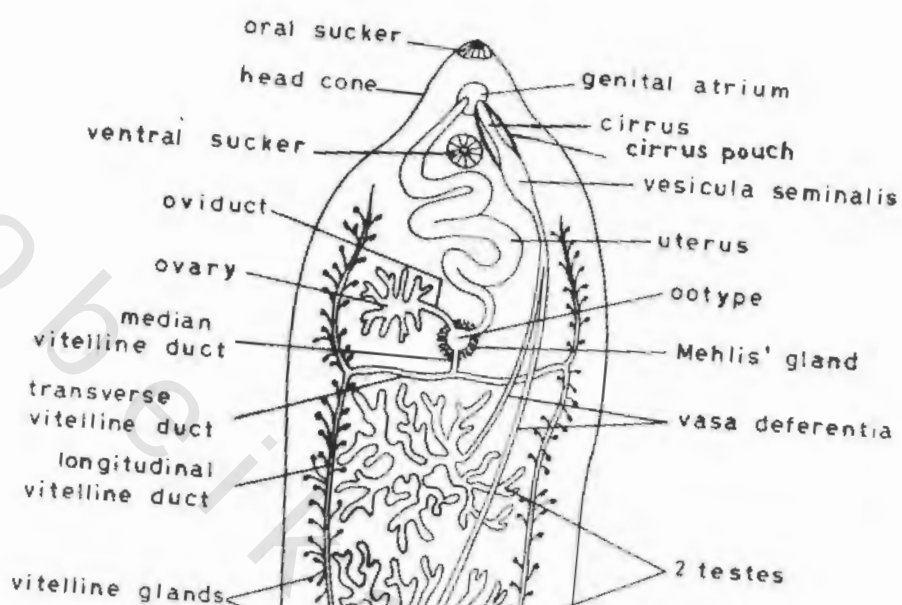
Muscular system and Locomotion

Well differentiated muscle cells in the form of longitudinally, circularly, and vertically arranged fibres occur in *Fasciola*. However, the adult liver flukes usually exhibit little locomotion because of the limited space within which they live, i. e. in the bile ducts of the host. Migrating young flukes are more active at the early stages of their development.

Digestive system and Nutrition

The **mouth** leads into a flask-shaped muscular **pharynx** which opens into a relatively short **oesophagus**. The oesophagus bifurcates to form two wider **intestinal caeca** or **crura** which run posteriorly on both sides of the body, and end blindly very close to the posterior end of the worm. Both crura give off extensive lateral as well as medial diverticula; some of which may subdivide once or twice to form numerous smaller branches.

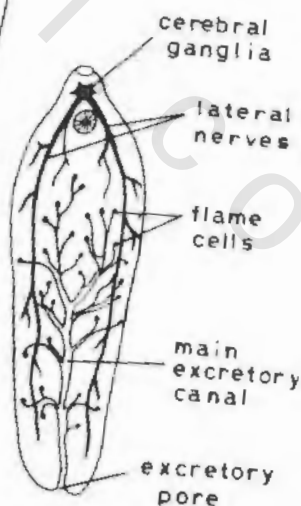
The inner walls of the intestinal caeca are lined with epithelial cells which may undergo both secretory and absorptive cycles. In this way, a particular epithelial cell may be secretory (secreting digestive enzymes) in one phase and absorptive (absorbing digested food materials) in another phase.



Digestive system

Reproductive system

FASCIOLA



Excretory & Nervous systems

It has been always assumed that liver flukes feed on bile and blood of the host, but this assumption was not verified except recently. It is now widely accepted that these flukes feed on certain elements of the liver tissues and on the blood (corpuscles + plasma). Liver cells and blood may be ingested by the worm through the mouth opening and in this way they reach the intestinal crura where they are digested, absorbed and distributed to other parts of the body through the parenchyma cells. Moreover, simple sugars and proteins may be utilized from the blood plasma of the host. These substances are taken in the form of small droplets by pinocytosis through the tegument of the worm.

Respiration

There are no special respiratory organs in the liver flukes and the parasite respire anaerobically. Like many other parasites, it can release energy from oxygen-bearing food substances by complicated chemical reactions involving some specific enzymes.

Excretory system and Excretion

In the liver flukes, as in all other flat-worms, there is a specialized system for the removal of dissolved nitrogenous waste materials and excess water from the body of the worm. This system consists of a fine network of excretory tubules or canals which extend in the parenchyma and end in excretory units known as **flame cells** or **solenocytes** (hollow cells) which have branched protoplasmic extensions ramifying in the parenchyma, and a hollow cytoplasm with a large, distinctly oval nucleus. The cytoplasmic cavity is continuous with the lumen of an excretory tubule. A bunch of long, flickering cilia hang down in that cavity and move in a way comparable to that of a candleflame, hence the name "flame cells" is acquired. The excretory products of metabolism together with any excess water pass through the protoplasmic processes of the flame cells and eventually collect in the lumen of these cells. The flickering movements of the cilia then push these waste materials into the excretory tubules which open in larger **excretory canals**. The excretory canals coming from both sides of the body continue into a **main excretory canal** which opens to the exterior by the **excretory pore**.

Nervous system

The liver fluke has a more advanced nervous system if compared with any coelenterate. There is an aggregation of nerve cells around the oesophagus to form 2 **cerebral ganglia** from which arise a number of nerve cords to different parts of the body. The longest of these are two **lateral nerves** which run posteriorly. Specialized sense organs are absent, a feature correlated with the parasitic life of these flukes.

Reproductive System and Reproduction

As in most other trematodes, this system is a hermaphroditic one which occupies a good deal of the body of the worm.

The male reproductive system consists of two branched **testes** which lie one in front of the other in the middle third of the body. The spermatozoa are carried by two **vasa deferentia**, which unite to form a **common vas deferens**. The first part of this canal is wide and forms the **vesicula seminalis** in which the spermatozoa are stored, while the distal part narrows gradually till it terminates in a protrusible structure known as the **cirrus** or **penis**, that is encircled by a membranous pouch known as the **cirrus pouch** and opens in **genital atrium** by the male genital pore.

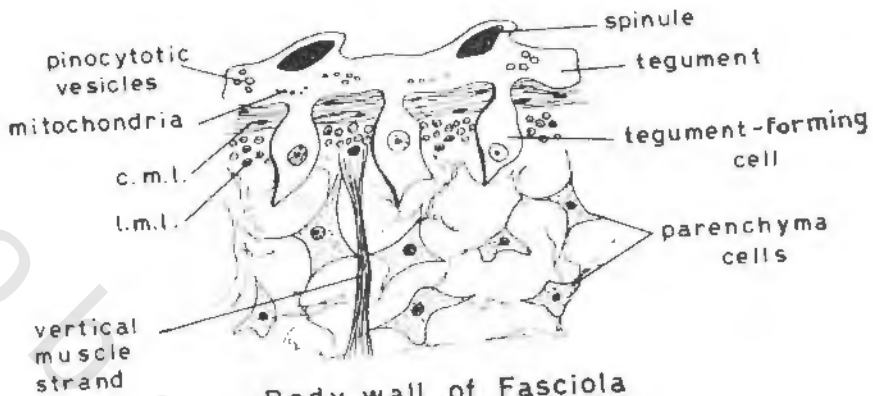
The female reproductive system includes a single branched **ovary** which lies in front of the testes; to the right of the median line. An **oviduct** runs medially from the ovary to open into the **ootype** which is surrounded by cells of the **Mehlis' gland**. There are two other ducts which lead into the ootype : the median vitelline duct and Laurer's canal. **The median vitelline duct** is a short canal which arises from the union of two similar, transverse canals, the **transverse vitelline ducts**. Each of these transverse ducts originates from two **longitudinal vitelline ducts** which run on one side of the body and carry the secretions of the **vitellaria** or **vitelline glands**. The vitellaria are relatively large yolk cells scattered on both sides of the body. **Laurer's canal** is a short duct extending dorsally to open separately on the dorsal surface of the body. Extending from the ootype, there is also a short coiled tube known as the **uterus** which opens by the female genital pore in the genital atrium, very close to the male genital opening. The proximal part of the uterus is sometimes called the **receptaculum seminis**.

Although **cross fertilization** is the rule, self fertilization may also take place when few worms are present in the liver. In self fertilization, the cirrus is inserted into the female genital pore and in this way the injected sperms travel down the uterus until they reach the ootype where fertilization occurs. In cross fertilization, it is believed that the mechanism may be similar; the sperms of worm are injected into the female genital pore of another worm. Some parasitologists believe that this route may be inefficient and suggest that the cirrus of one fluke may be inserted into the opening of the Laurer's canal of another fluke. The injected spermatozoa pass down Laurer's canal until they reach the ootype where fertilization occurs.

Egg cells are released periodically from the ovary and passed along the oviduct until they reach the ootype where fertilization occurs. The vitelline cells produced by the vitellaria travel along the vitelline ducts to meet the fertilized egg, also in the ootype. The fertilized egg is then surrounded by a number of vitelline cells and all are enveloped by an egg-shell and, then passed into the uterus. The exact mechanism by which the shell is formed is still not clear. Older suggestions that the Mehlis' gland-which is often misnamed the shell gland-is involved in shell formation have never been proved. It is now assumed that the Mehlis' gland may be secreting a hormone which plays a part in the synchronization of the reproductive processes.

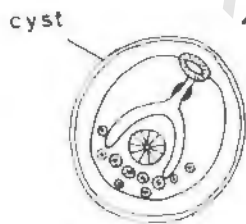
Life cycle

The eggs leave the body of the adult worms through the female genital pore. It is believed that under normal conditions each fluke is capable of maintaining regular egg production of about 3,000 eggs per day, and this may continue for about 8-11 years. The eggs travel with the bile secretions of the host to reach its small intestine, then along the large intestine to leave the host's body together with the faeces (dung). The egg is large, oval or hen's egg-shaped, and has a thin **egg-shell** with a flat **operculum**. It measures about 0.15×0.08 mm. When the eggs are released to the exterior, they do not contain a fully formed embryo. If the external environment provides sufficient moisture and warmth, a fully developed embryo, known as the miracidium, is formed inside the egg in about two weeks. The eggs then hatch, mostly during daytime. The operculum opens, and a ciliated, free-living miracidium is liberated.



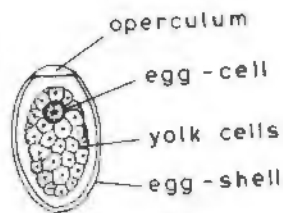
Body wall of *Fasciola*

Adult fluke
in bile ducts



Encysted metacercaria

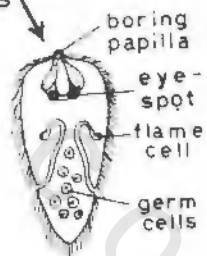
Life cycle
of *Fasciola*



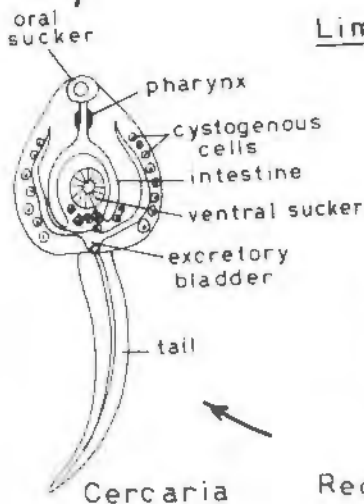
Egg in
faeces



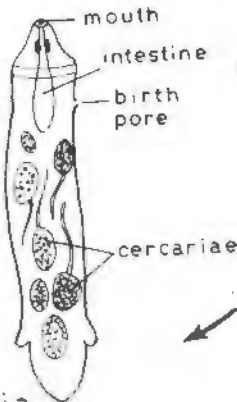
Limnaea shell



Miracidium



Cercaria



Redia



Sporocyst

The **miracidium** has an elongated conical body whose anterior end is broader than the posterior end and the surface is covered with numerous cilia by which the miracidium swims actively in water. At the broader end, there is a small conical **boring papilla** on which open an **apical gland** and two pairs of penetration glands. There is also a pair of darkly pigmented **eye-spots** near the anterior end. Moreover, there is a pair of **flame cells**, each of which leads into an excretory ductule, and a mass of **germ cells**.

The life span of the miracidium in the aquatic environment is relatively short, being about 24 hours. During this period the miracidium swims actively searching for a snail of a particular species to use it as an **intermediate host** where subsequent larval development proceeds. In A.R. Egypt the intermediate host of *F. gigantica* is the snail *Limnaea caillaudi*. Once the miracidium comes in contact with the exposed soft tissues of the snail, the secretions of the apical gland help to attach the miracidia to the tissues of the snail. The secretions of the penetration glands digest these tissues and the beating cilia then help to propel the body of the miracidium into the deeper tissues of the snail. It usually takes the miracidium about 15 minutes to complete the different processes involved in the penetration of the tissues of the snail host. Once the miracidium is found inside the tissues of the snail, it loses its ciliary covering, changing into the next larval stage known as the **sporocyst**.

After few days the sporocysts leave the original site of penetration and migrate towards the digestive gland of the snail. Inside the sporocysts, there are masses of germ cells which divide parthenogenically to give the next larval stage which is called the redia. In each sporocyst up to 8 rediae are produced.

The **redia** has an elongated, cylindrical body with two stumps projecting from the side, near its anterior end. It possesses a primitive gut consisting of a mouth at the anterior end, a muscular pharynx and a short sac-like intestine. Very close to the posterior end of the redia, there are two lateral projections known as the lappets. Inside the body of the redia there are clusters of germ cells which may divide parthenogenically to form a second generation of rediae known as **daughter rediae**, that leave the body of the mother redia through a lateral pore situated anteriorly, the **birth pore**.

The germ cells included in either the mother or daughter radiae divide, also parthenogenically, to form the next larval stage known as the cercaria.

The **cercaria** of *F. gigantica* has a disc-shaped body and a long simple tail. The surface of the body is beset with numerous distinct spines. At the anterior end of the body there is a mouth opening which is surrounded by an oral sucker. The mouth leads into a muscular pharynx followed by a blind intestine. It has also a large ventral sucker, rudiments of the genital organs, cystogenous cells and flame cells opening into excretory ductules, and an excretory reservoir that opens by an excretory pore.

Once fully formed, the cercariae leave the body of the redia through the birth pore and push their way out of the snail's tissues to reach the surrounding water. Emergence of the cercariae from infected snails usually starts 5-6 weeks after the penetration of the miracidium. A single miracidium can give, under favourable conditions, a total of about 600 cercariae.

Once the cercariae are shed in water, they cannot develop any further. They encyst on leaves of aquatic plants or other floating objects. When the cercariae come in contact with any of these objects, they lose their tails and their cystogenous glands secrete a chitinous cyst which surrounds the body. The encysted cercaria is known as the metacercaria.

The **metacercaria** is the infective stage of the liver fluke; it is rounded measuring about 0.2 mm in diameter. Under favourable conditions, it remains viable for several months. Grazing animals acquire the infection by eating grass or aquatic vegetation infested with the metacercaria. In the duodenum of the **final host** (cattle, sheep, goats, etc.), the metacercariae lose their protective cysts under the action of digestive enzymes, and the released young flukes immediately penetrate the wall of the intestine and reach the body or peritoneal cavity of the host in a few hours. They crawl over the peritoneal membranes of the internal organs until they reach the liver capsule which they penetrate. They continue their migration into the liver tissues until they reach the bile passages, where they finally reside and become mature in about 10 weeks.

The life cycle of *Fasciola* illustrates the phenomenon of alternation of generations. It includes four asexual generations (miracidia, sporocysts, radiae and cercariae) alternating with a sexual stage (the adult worm).

Host-parasite relationships

a) Effect of the parasite on the intermediate host :

As mentioned before, a single miracidium can give several hundreds of larval stages inside the tissues of the snail host. Such a large number of parasites greatly affect the viability of the snail through their immense nutritional requirements. Therefore, heavily infected snails have a shorter life span if compared with healthy snails. The reproduction capacity of infected snails also decreases.

b) Effect of the parasite on the definitive host :

The liver fluke affects the definitive hosts in a number of ways :

i. During the migration of the young flukes from the intestine to the liver, they produce haemorrhages in the intestinal wall and the liver capsule.

ii. The presence of the flukes and their eggs in the liver usually induces a series of tissue reactions. These eventually lead to the development of fibrous tissues which gradually replace the liver cells.

iii. Mechanically, the flukes if present in large numbers will block the bile passages, resulting in jaundice and certain disturbances in the digestive processes in the intestine of the host.

iv. The infected animals usually become anaemic due to the toxic excretory substances produced by the flukes through their effect on the haemopoietic organs.

2 — Blood Flukes

SCHISTOSOMA

This is a group of trematodes that inhabit the blood stream of certain vertebrate hosts (birds and mammals). They are unique amongst digenetic trematodes in being dioecious, i.e. sexes are separate. They are called schistosomes or split bodies because of the groove found on the ventral surface of the male, in which the female is held during copulation and egg-laying.

When Man becomes infected with schistosomes, an important disease

develops which is known as **schistosomiasis** or **bilharziasis**. Schistosomiasis is a very old disease and recent reports of the World Health Organization (W.H.O.) estimated the number of infected individuals to be about 200 millions in many tropical and subtropical countries in Africa, Asia and South America .

The disease is highly endemic in Egypt; it is estimated that some 16-20 millions are infected, and in some villages in the northern parts of the country more than 70 % of the population are reported to be suffering from the disease. Schistosomiasis is thus ranked as public health enemy number one in our country. Recent reports of the W.H.O. estimate our loss due to that disease at more than 200 million pounds per year .

Three species of schistosomes are the causative agents of the disease in Man : *Schistosoma haematobium*, *S. mansoni* and *S. japonicum*. *S. haematobium* in man produces a certain type of the disease known as vesical or urinary schistosomiasis, whereas *S. mansoni* and *S. japonicum* produce another type known as intestinal schistosomiasis. The type of the disease produced by any of these species usually depends, amongst other factors, on the location of the worms in the host. Thus, *S. haematobium* is usually located in the pelvic vesical venous plexus and its eggs are passed out in urine. Adults of *S. mansoni* and *S. japonicum* are usually found in the mesenteric veins and the eggs are voided in the faeces (stools) of the host.

S. japonicum occurs only in some countries of South East Asia, whereas *S. mansoni* and *S. haematobium* are more widespread; they are reported from Africa, Western Asia and South America. In A.R. Egypt, both *S. mansoni* and *S. haematobium* are present, *S. mansoni* is present mainly in The Nile Delta and in some governates of Upper Egypt, while *S. haematobium* is known on both sides of the valley, from Aswan to the Mediterranean.

Schistosoma haematobium &*Schistosoma mansoni***Morphology**

The male worm is short and cylindrical; measuring 6-12 mm in length. The sides of the body are ventrally infolded to form the **gynaecophoric canal** in which the female is carried during copulation and egg-laying. The body of the male is covered with numerous tubercles which carry hair-like sensory papillae.

The female worm is generally longer than the male. It measures 12-18 mm and has a narrow, cylindrical body which is not tuberculated.

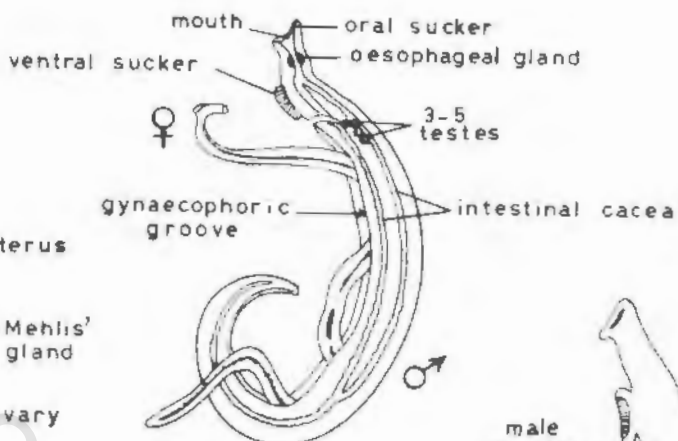
At the anterior part of the body of both male and female worms there are two suckers; an **oral sucker** which encircles the mouth opening, followed a short distance posteriorly by a larger **ventral sucker**. It is important to note that the suckers are usually more developed in the males than in females.

There are three distinct openings on the body of the worm (either a male or a female) : the **mouth** opening found at the anterior end, the **genital opening** which is found immediately posterior to the ventral sucker, and the **excretory pore** which is located at the posterior extremity of the body.

Digestive System and Nutrition

The **mouth** leads directly into an **oesophagus**, i.e. there is no pharynx. The oesophagus is surrounded by a number of glandular cells which collectively form the **oesophageal gland**. Immediately in front of the ventral sucker, the oesophagus bifurcates to form two **intestinal caeca** or **crura** which run posteriorly, on both sides of the worm, then unite to form a single **intestinal caecum** that passes posteriorly to end blindly very close to the posterior end of the body. The level at which the two intestinal crura unite varies according to the species of the worm. In *S. mansoni* the two intestinal crura unite at the end of the anterior third of the body, while in *S. haematobium* such a union occurs more posteriorly, at the end of the middle third.

Schistosomes are haematophagous worms, i.e. they feed on the blood

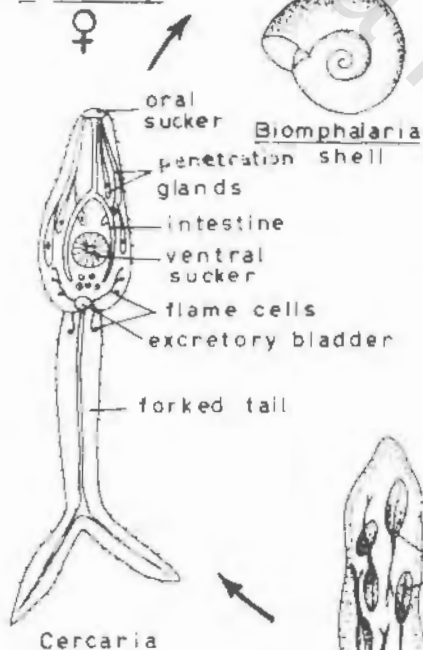


S. haematobium

S. mansoni

SCHISTOSOMA

S. mansoni



Biomphalaria

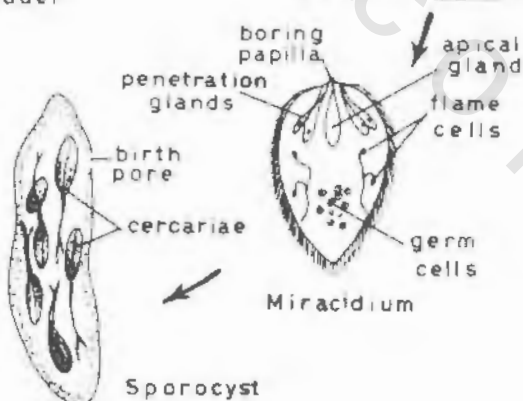


Bulinus
shell



Egg

S. mansoni *S. haematob.*



of the host. Portal blood, rich in amino acids and monosaccharides, is ingested by the worms through the mouth opening, then passed into the intestine where it is digested and absorbed by mechanisms similar to those described for *Fasciola*. It is known that blood haemoglobin is not completely digested by the worms and thus a dark brown pigment known as **bilharzia pigment** is produced in the intestine of the worm. This pigment is periodically extruded from the body through the mouth opening into the circulating blood of the host.

Apart from active ingestion of blood through the mouth of the worm, it is now believed that schistosomes utilize simple proteins and sugars from the blood plasma, which they obtain by pinocytosis through the body tegument.

Respiration

Like the liver flukes, schistosomes have no specialized system for respiration. Although they live in the blood where the oxygen tension is relatively high, respiration appears to be largely anaerobic. However, during the early stages of the flukes' development in the final host, when the worms migrate through the lungs, their dependence on aerobic respiration is greater; in this case gaseous exchange probably occurs through the body surface of the young fluke.

Excretory, Nervous and Muscular systems

The functional anatomy of these systems does not show unusual features when compared with the corresponding systems in *Fasciola*.

Reproductive system and Reproduction

The reproductive system of the male includes a number of testes which are located posterior to the ventral sucker. The number of testes varies in different species of schistosomes, being 6-9 in *S. mansoni* and 3-5 in *S. haematobium*. The spermatozoa from the testes pass into vasa efferentia which unite in a **vas deferens** that opens in the **vesicula seminalis**. The vesicula seminalis is a pear-shaped membranous sac which leads directly to the exterior by the male genital pore, i.e. there is no cirrus.

The genital system of the female is more complicated than that of the

male. There is an elongated, pear-shaped **ovary** which is located immediately anterior to the place of union of the two intestinal crura. Thus, in *S. mansoni* the ovary is found at the end of the anterior third of the body, while in *S. haematobium* it is located at the posterior end of the middle third of the body. From the ovary arises the **oviduct** which runs anteriorly to open into the **ootype** that is surrounded by the **Mehlis' gland**. Also opening into the ootype is the **median vitelline duct** formed by the union of two vitelline ducts which carry yolk from the **vitellaria**. The vitellaria are in the form of large vitelline cells which are distributed on both sides of the common intestinal caecum. Another thin-walled, membranous canal known as the **uterus**, originates from the ootype and passes anteriorly to open by the female genital pore. The uterus of *S. mansoni* is short and usually contains a single egg, while that of *S. haematobium* is much longer and includes numerous eggs. In schistosomes, Laurer's canal is absent.

When the male and female worms become mature, copulation usually takes place; each male carries a female partner in its gynaecophoric canal. The spermatozoa produced by the testes pass into the vesicula seminalis and then through the male genital pore to reach the gynaecophoric canal and from this canal they migrate to enter the female system through the female genital pore. The migrating sperms then travel down the uterus until they reach the ootype where fertilization occurs. The egg cells produced by the ovary of the female pass along the oviduct to reach the ootype, and in this location they are fertilized. The yolk cells produced by the vitellaria also reach the ootype via the median vitelline duct. The fertilized egg is then surrounded by a number of yolk cells and all become enveloped by a chitinous egg-shell. The fully formed egg then passes into the uterus and leaves the body through the female genital pore.

Life cycle

Egg-laying of *S. haematobium* usually occurs in the small venules of the vesical plexus found in the wall of the urinary bladder whereas that of *S. mansoni* occurs in the small branches of the mesenteric veins. The female, while held in the gynaecophoric canal of the male, extends its anterior end far into the smaller venules and deposits the eggs, one at a time. Each time an egg is laid, the worm withdraws a short distance and lays another egg immediately behind the first. The eggs then make their way through the vessels and the mucosa of the urinary bladder

(in *S. haematobium*) or the intestine (in *S. mansoni*) and finally into the lumen of these organs along with the urine or stools respectively. It is estimated that a female *S. haematobium* lays 100 eggs/day whereas the corresponding figure for *S. mansoni* is about 200 eggs/day.

When the eggs leave the human body in the stools or the urine, they contain a fully formed larval stage, the miracidium. The eggs of *S. haematobium* have a distinct **terminal spine** whereas those of *S. mansoni* have a **lateral spine**. The eggs hatch only when they reach fresh water. The hatching of eggs in water is, however, controlled by a number of factors, mainly temperature and light. Eggs usually hatch at an optimum temperature of about 26° C and in the presence of light. Once the hatching process is completed, the miracidium leaves the egg-shell and swims freely in water searching for the intermediate snail host where subsequent larval development occurs.

The **miracidium** of schistosomes is similar to that of liver fluke, except that it is somewhat smaller and lacks the eye-spots. The miracidia have a short life span in water (24-36 hours) and if they do not find the proper snail host during that period they become motionless and eventually die.

The intermediate hosts of human schistosomes in Egypt are the fresh-water non-operculated snails *Bulinus truncatus* and *Biomphalaria alexandria* for *S. haematobium* and *S. mansoni* respectively. *B. truncatus* has a globose, sinistral (left-handed) shell which is higher than wide, whereas *B. alexandrina* has a discoid dextral (right-handed) shell.

The miracidia swim about in water until they find, probably by chemotaxis, the snail host which they penetrate. The mechanisms involved in the process of penetration of the schistosome miracidia into the soft parts of the snail host are essentially similar to those described above for the liver flukes. After penetration, the miracidia lose their cilia and the **sporocyst** stage is thus produced. The germ cells inside the sporocyst divide parthenogenically to form another generation of sporocysts known as the **daughter sporocysts**. The daughter sporocysts make their way into the body cavity and then to the digestive gland of the snail. The germ cells included in the daughter sporocysts undergo repeated divisions to give eventually

the next larval stage, the cercariae. The cercariae leave the sporocysts and then the tissues of the snail to reach the surrounding water in which they live for some time until they find the final host which they penetrate to complete the life cycle. It is now believed that a single miracidium can give over 100,000 cercariae after its penetration and multiplication in the snail's tissues. The time taken by a miracidium to reach the cercaria stage is generally controlled by the temperature under which the snail lives, at about 26° C the period is 3-4 weeks.

The cercaria of human schistosomes has a characteristic pear-shaped body and a long forked tail; the body and the tail are covered with minute spines. It has an oral sucker and a larger ventral sucker. The mouth opening leads into a capillary oesophagus which bifurcates to form two, blind intestinal crura. The excretory system consists of four pairs of flame cells, collecting tubules and a posterior excretory bladder. One more pair of flame cells is found in the tail, the tubules of which open at the tips of the tail furca. There are five pairs of cephalic (penetration) glands which empty their secretions through ducts opening along the edge of the oral sucker. Immediately posterior to the ventral sucker there is a mass of genital cells which represent the primordia of the genital organs.

Once the cercariae are shed into the water, they start moving up and down in the surface layer until they find the human host. It is not yet certain how a cercaria can find the final host, but it is assumed that it does so by thermal attraction or thermotaxis. The cercariae have a short life span, and if they do not find the final host within about 36-48 hours, they die.

Human infection is brought about by bathing or wading into infective water. Once the cercariae locate the soft skin of the human host, they attach themselves to the epidermis, hydrolyse the horny and Malpighian layers by the action of the proteolytic enzymes secreted by their penetration glands, and then penetrate deeply into the dermis. The process of penetration usually takes about 10-15 minutes. While the body of the cercaria penetrates deeply in the skin of the host, the tail is left outside, and the young trematode is then called the *schistosomula*. The schistosomulae enter the lymphatic or peripheral blood vessels along which they are carried to the heart, and from the right chambers of the heart to the lungs. The migration of the schistosomulae from the peripheral circulation to the lungs usually takes 4-5 days.

Few days later, most of the migrating young flukes are found in the blood vessels of the liver where active growth takes place. For sometime it was believed that worms might reach the liver from the lungs through the following route : lungs - pulmonary vein - heart - aorta - hepatic artery - liver. However, recent evidence suggests that the route of migration from the lungs to the blood vessels of the liver may not necessarily be in the blood circulation: some schistosomulae may migrate through the tissues of the lung to the pleural cavity and pierce the diaphragm to reach the liver where they enter the blood vessels of the portal system. The developing flukes eventually reach sexual maturity in 4-5 weeks and then leave the liver after coupling (mating) occurs. The coupled worms, aided by their suckers, travel against the blood stream until they reach the mesenteric veins or the veins of the vesical plexus, depending upon the species. The period between successful cercarial penetration and the appearance of eggs in urine or stools is 40-60 days.

Host-parasite relationships

a) Effect of schistosomes on the intermediate host :

Like the intermediate hosts of other digenetic trematodes, the snail hosts of schistosomes suffer to a great extent from the developing larvae of the parasite. In *Fasciola*, a single miracidium gives about 600 cercariae in the snail tissues, but in schistosomes the corresponding figure is about 100,000 cercariae. The development of such a tremendous number of larval stages in a single snail certainly affects the biology of this host. Besides affecting feeding and reproduction, the life span of the infected snails is greatly reduced.

b) Effect of schistosomes on the final host :

The direct ill effects of schistosomiasis upon the human host are usually underestimated, owing to the fact that it is a chronic disease which runs a long and insidious course.

The type and the degree of the pathological changes associated with the disease depend - amongst other factors - on the stage and severity of the infection and on the species of the parasite.

Different pathological changes are associated with various stages of the disease in man. The following stages are now recognized :

i) **Stage of invasion and maturation** : which includes the penetration of the cerariae through the skin, migration of the schistosomulae to the liver, and their subsequent maturation.

ii) **Stage of established infection** (acute stage) : which starts with intense egg-laying accompanied by a corresponding egg discharge.

These two stages are characterized by the formation of certain tissue reactions towards the metabolites of the developing worms (mainly the bilharzia pigment) and also by the appearance of focal haemorrhages in the sites through which the eggs pass when they cross the mucosa to reach the lumen of the affected organs.

iii) **Chronic stage** (stage of irreversible changes) : which starts by the formation of fibrous tissue around the eggs, either those which are directly laid by the worms in the urinogenital or intestinal organs, or those which are passively carried by the blood stream to other organs, such as liver, lungs, . . etc. Although *S. haematobium* and *S. mansoni* produce fairly similar pathological changes in the early stages of the infection, yet the changes produced are different in the chronic stage of the disease. In old *S. mansoni* infections the principal lesions occur in the intestine, liver, spleen and lungs, while in *S. haematobium* infections the lesions are mainly restricted to the urinary bladder, ureters, kidneys and genital organs.

3 — Intestinal Flukes

HETEROPHYES

The great majority of Trematoda inhabit the intestine of their hosts, yet there are only few flukes that can be considered as primarily parasitic of the human intestine. A few species are commonly found in man in some localities, but these are primarily parasitic in other animals; man is only an occasional host for such trematodes. An example of such intestinal trematodes which is found in A.R. Egypt is *Heterophyes heterophyes*. This species is also known from certain countries in South East Asia.

Heterophyes heterophyes

This trematode is primarily a parasite of the intestine in cats, dogs, foxes and other fish-eating mammals. Human infections in the northern parts of the Nile Delta are not uncommon, particularly amongst fishermen around Manzallah and Bourollos Lakes. The parasite is usually found in large numbers between the villi of the intestine.

Morphology

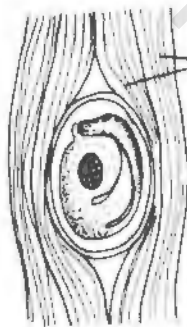
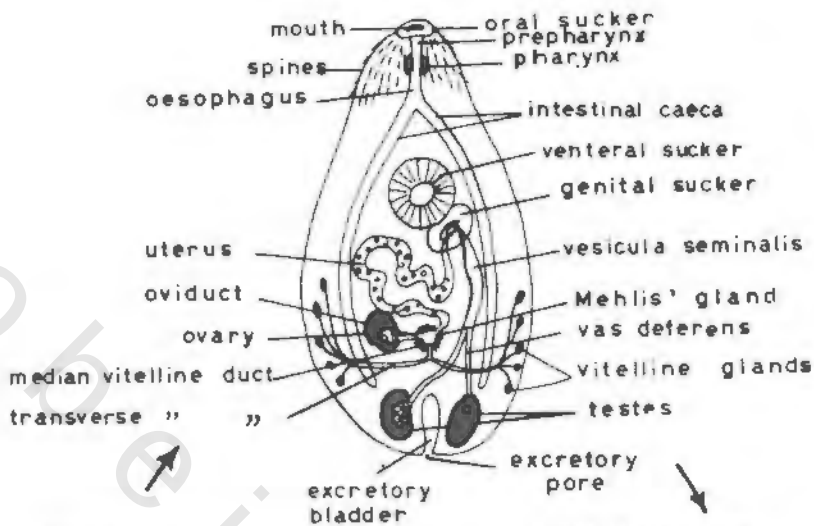
The adult fluke is a minute pyriform worm, broadly rounded posteriorly and somewhat narrower anteriorly. It measures 1-1.7 mm in length and 0.3-0.4 mm in breadth. The body is covered with numerous minute **spines** which are set close together. The **oral sucker** is very small, while the **ventral sucker** is considerably large. There is a third sucker, the **genital sucker** (**gonotyl**), which lies close behind the ventral sucker. The digestive system includes a **mouth**, **prepharynx**, **pharynx**, **oesophagus** and two **intestinal caeca** which end blindly at the posterior end of the worm. The male genital system includes two posteriorly located oval testes, vasa deferentia and a seminal vesicle which lacks an enveloping cirrus pouch or a cirrus. The female genital system includes a single ovary which is located in front of the testes, an oviduct, Laurer's canal, ootype, Mehlis' gland, vitellaria and uterus. The eggs are flask-shaped, small (0.030 x 0.015 mm) and have a conspicuous conical operculum.

Life cycle

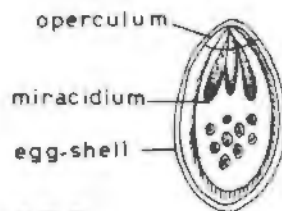
When the egg passes out with the stools, it contains a fully formed asymmetrical miracidium. The eggs usually settle on the bottom of the lake until they are ingested by the proper snail intermediate host.

The intermediate host of *Heterophyes heterophyes* in A.R. Egypt is the operculated snail *Pirenella conica* which is usually found crawling on the bottom of the brackish water of the northern lakes.

Hatching of eggs occurs in the alimentary canal of the snail host and the liberated miracidium penetrates the deeper tissues of the snail transforming into the sporocyst stage.

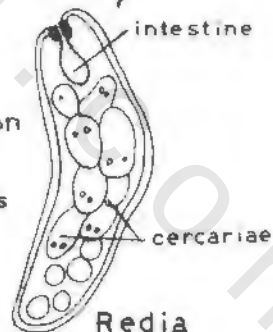


Encysted metacercaria

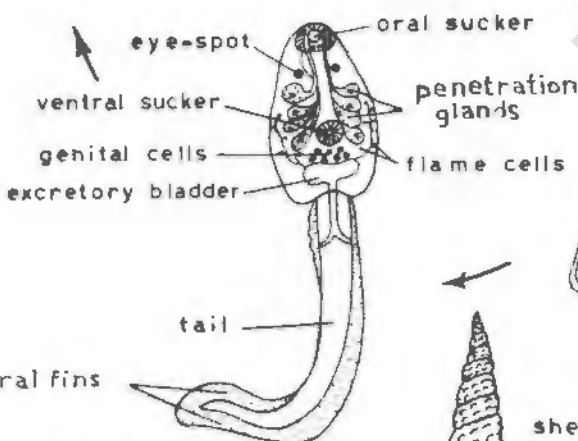


Egg

Sporocyst



Redia



Cercaria



shell of *Pirenella*

HETEROPHYES

Like *Fasciola*, two generations of rediae are produced followed by the cercariae. The cercaria has a pair of eye-spots on the body and a number of minute spines around the mouth, the tail is simple with lateral fins.

The cercariae leave the body of the snail and immediately they start searching for a second intermediate host which they penetrate, and encyst in its superficial muscles to form the metacercariae. The bony fishes *Mugil cephalus* (Bouri), *Tilapia* (Bulti) and *Gambusia* act as the second intermediate hosts. The metacercaria gradually increases in size and becomes infective about two weeks from encystment.

Man acquires the infection by eating poorly-cooked or salted infested fish. In the small intestine the metacercariae excyst and develop rapidly within 7-10 days, to reach the adult stage.

Host-parasite relationships

The presence of *Heterophyes* worms in the mucosal crypts of the small intestine usually produces superficial irritation, accompanied by excessive mucous secretions. When the worms penetrate deeply into the mucous lining of the intestine, their small eggs pass into the mesenteric venules and lymphatics from which they may be carried to some organs as the heart, brain, spinal cord, etc. The presence of the eggs in these organs usually stimulates strong tissue reactions which lead to the development of certain important pathological conditions that may be fatal in severe cases.

C. CLASS CESTODA

(Cestodes or Tapeworms)

Adult cestodes or tapeworms commonly occur in a wide range of vertebrate hosts including fishes, amphibians, reptiles, birds and mammals. Unlike trematodes, their presence in the body of the final host is restricted to the alimentary canal.

A cestode is usually differentiated into the following 3 parts : (a) The **scolex** or the head which is found at the anterior end and carries the organs by which the body is attached to the mucosa of the intestine. (b) The **neck** which is immediately found behind the scolex. This is the region of growth from which all the distal portions of the worm are derived. (c) The **strobila** which consists of a series of segments or proglottids, beginning with the immature proglottids (segments which have only the rudiments of the genital organs), then the **mature proglottids** which contain the fully developed sex organs, and the distal most **gravid proglottids** which are reservoirs of eggs. Each of the mature segments contains one (or rarely two) complete sets of hermaphrodite genital organs, i.e. each of these segments has fully formed male and female genital systems.

Man and many domestic animals are frequently infected with a variety of tapeworms and that is the reason for the medical and veterinary importance of this group. Some species of cestodes infecting man are small, not exceeding few millimetres in length, others are very long and voluminous, measuring 10 metres or more. The number of segments forming the strobila may be as few as five in some species, while certain other species may include about 4,000 proglottids.

TAENIA

Taenia saginata and *Taenia solium*

T. saginata, which is commonly named the beef tapeworm, is a cosmopolitan parasite among beef-eating people. The pork tapeworm, *Taenia solium*, occurs wherever raw or inadequately cooked pork is consumed. Cattle and pigs are the intermediate hosts of *T. saginata* and *T. solium* respectively. These tapeworms are generally found in the middle third of the intestine. In the majority of human cases, only one worm is present in the intestine of the host; very rarely more than one worm may be present.

Morphology

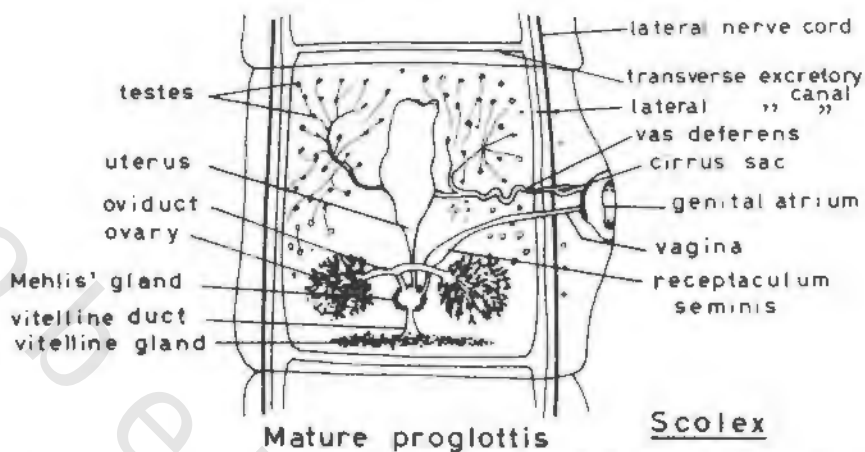
The average length of *T. saginata* is about 5-7 metres, while that of *T. solium* is about 3-5 metres. However, there are records of specimens of *T. saginata* reaching 25 meters or more. The number of proglottids in *T. saginata* and *T. solium* is 1000-2000 and 600-900 respectively.

The **scolex** of *T. saginata* is provided with four **suckers**. The scolex of *T. solium*, besides having the four suckers, has a **rostellum** on which there is a double circle of alternating large and small **hooklets**, numbering 22-32.

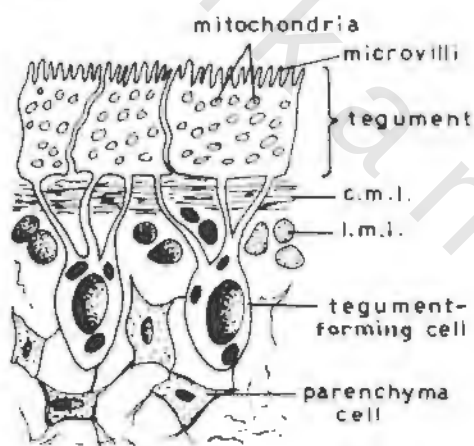
Immediately behind the neck region, which measures 5-10 mm, there is a region of immature proglottids. Gradually, the more distal of these increase in breadth and length and the mature proglottids usually measure about 15 — 12 mm in length. Still more distally, the mature segments are transformed into more elongated, narrower gravid proglottids due to the development of the large, voluminous and branched uterus which occupies most of the segment. Due to the presence of such a large uterus, other genital organs disappear. In the gravid segment of *T. saginata* the uterus has 15-20 (usually 18) main lateral branches, whereas that of *T. solium* has 7-13 (usually 9) branches.

Structure of the body wall

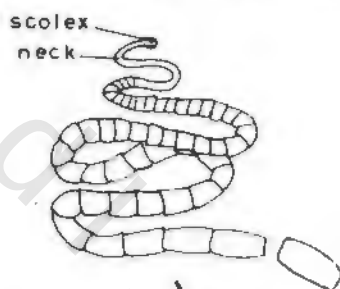
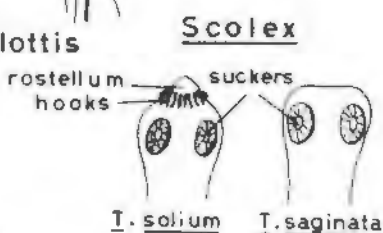
Like *Fasciola* and other trematodes, the body of *Taenia* is covered by a cytoplasmic syncytial layer known as the **tegument**, which is formed as a



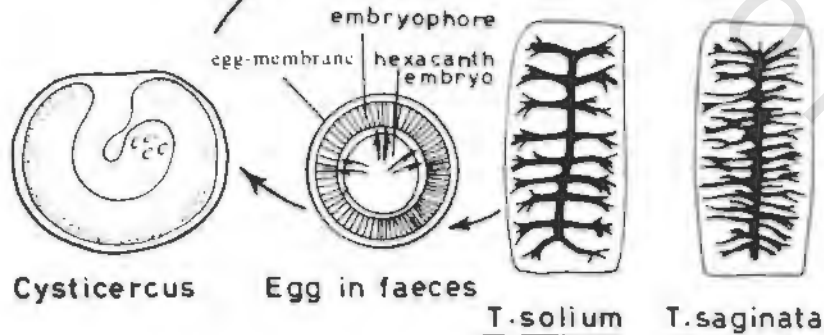
TAENIA



Body wall



Gravid proglottis



distal protoplasmic extension of **tegument-forming cells** which are located between the parenchyma cells. With light microscopy, the free surface of the tegument appears as a fringe of fine, hair-like processes. At the electron microscope level these are revealed as a series of spine-like processes called **microvilli**, **tegumental projections** or **microtriches**. The tegument and the tegument cells include numerous intracellular organelles such as **mitochondria** and **Golgi apparatus**. There are also intracellular secretions which probably act as anti-enzymes to neutralize the effects of the digestive enzymes present in the intestine of the host. The tegument rests on a distinct basement membrane, below which there are circularly and longitudinally arranged muscle fibres.

Muscular System

The musculature of the body of *Taenia* is generally well developed. In sectioned worms, the muscles usually appear in the form of circularly and longitudinally arranged fibres. The musculature of the suckers is also well developed to keep the worm strongly attached to the intestinal wall.

Nutrition

Cestodes in general, lack an alimentary canal, yet they obtain the required food materials by pinocytosis through the tegument from the digested food materials found in the intestine of the host.

Respiration

This appears to be largely anaerobic. Some physiologists now believe that certain parts of the intestinal mucosa have relatively high oxygen tension to allow aerobic respiration to take place. If this is the case, the external surface of a tapeworm strobila may be in a region of sufficiently high tension to permit aerobic metabolism.

Excretory system and Excretion

Inbetween the parenchyma cells, there are numerous flame cells which lead into excretory ductules opening into the main excretory ducts. At the anterior part of the worm, there are 2 pairs of main excretory ducts; one

pair on each side of the strobila, one dorsal and one ventral. However, at the distal part of the body there are only two **lateral excretory canals**. These two lateral excretory canals are joined together at the posterior end of each proglottid by a **transverse excretory canal**. At the posterior end of the last proglottid in the strobila, there are two **excretory pores** through which the lateral excretory canals open.

The end products of metabolism are excreted by the same mechanism described above for trematodes. Also, it is assumed that the flame cells may act as osmoregulators.

Nervous system

It consists of a mass of **cerebral ganglia** which is located in the scolex; from these ganglia arises a number of small nerve fibres which extend to the suckers and a pair of **lateral nerve cords** which pass posteriorly, very close to the margins of the strobila. Nerves extend from this system to the muscles, skin and internal organs. Very little is known about the physiology of the nervous system in these tapeworms.

The Reproductive system and Reproduction

This system differentiates progressively from the anterior to the posterior ends of the strobila and a mature proglottid possesses complete reproductive systems of both sexes. **The male organs** consist of numerous small spherical **testes**, about 500 in number, scattered within the parenchyma. A slender tubule, the **vas efferens** comes out from each testis, the vasa efferentia join together to form a convoluted tube, the **vas deferens**. The vas deferens then dilates to form the **vesicula seminalis** and ends by a muscular **cirrus** which is enclosed in a **cirrus pouch**. The cirrus opens by the **male genital opening** in the **genital atrium** which is located in the middle of the lateral margin of the proglottid.

The female organs include a single **ovary** which is located at the distal part of the proglottid. The ovary is composed of two symmetrical lobes and from each lobe arises a short duct which leads into the median **oviduct**. The oviduct passes backwards before opening into the **ootype**, which is surrounded by the cells of the **Mehlis' gland**. There is a compact **vitelline gland** whose secretions are carried through the **vitelline duct** which opens into the

ootype. Two other canals arise from the ootype : the **uterus** which extends anteriorly to form a blind thin-walled sac that acts as a reservoir for the eggs produced in the ootype, and the **vagina** which extends anteriorly, then laterally to open by the **female genital pore** in the genital atrium, immediately posterior to the male opening. The proximal part of the vagina may be slightly swollen to form the **receptaculum seminis**.

Self fertilization by the insertion of the cirrus into the vagina of the same proglottid may take place. Copulation between two different proglottids of the same strobila may also occur by the same mechanism described above. The impregnated sperms travel down the vagina to reach the ootype. The egg cells which develop in the ovary, pass down the oviduct to reach the ootype where fertilization occurs. The fertilized eggs receive yolk cells from the vitelline gland and all these structures are then enveloped by a thick shell known as the **embryophore**. The eggs then leave the ootype and pass into the uterus, which becomes gradually filled up and develops lateral branches in order to accommodate more eggs.

Life cycle

The fully developed worm usually sheds 3-10 of its gravid proglottids per day, and each of these proglottids contains about 100,000 eggs in its voluminous, branched uterus. The detached proglottids pass with the stools of man and extrude their eggs while crawling on moist earth, or the eggs break out when the proglottids disintegrate.

The **eggs** are spherical and have a thin transparent outer envelope and a thick lamellated shell known as the embryophore. Within this shell there is an **oncosphere (hexacanth embryo)** which has six delicate lancet-shaped hooklets. The eggs are small, measuring 0.03-0.04 mm in diameter.

When the eggs are ingested by cattle (the intermediate hosts of *T. saginata*) or pigs (the intermediate hosts of *T. solium*), the embryophore is digested by the action of the digestive enzymes in the stomach and duodenum of the host and the oncosphere is thus liberated in the intestinal lumen. Histolytic secretions released by the oncosphere assist it to bore its way through the mucosa until it reaches a blood vessel from which it is carried into the general circulation. The oncosphere is thus carried to a skeletal or a cardiac muscle

where it loses its hooks and develops within 60-70 days into a **bladder worm** or **cysticercus**. The cysticercus has a small head, like that of the adult worm invaginated into a fluid-filled bladder. Cysticerci occur frequently in the muscles of the heart, diaphragm, shoulder, tongue, etc. They become infective within 7-10 weeks and remain viable for 4-9 months. Man becomes infected through eating under-cooked meat infected with these cysticerci. The wall of the cysticercus is digested in the stomach, and the liberated larva passes to the duodenum where the scolex is evaginated and the bladder disintegrates. The larva then migrates to the middle third of the intestine, the scolex gets hold of the intestinal wall and starts to develop into the adult worm within 3-6 months.

Host-parasite relationships

The presence of the cysticerci in the muscles of the intermediate host usually produces little reaction except when they occur in large numbers in some vital organs as the heart and diaphragm. It is interesting to note that the eggs of *T. solium* when ingested by man can develop into cysticerci, i.e. in such cases man acts as intermediate host. When the cysticerci are present in the skeletal muscles of man, they do little damage, but in sites such as the nervous system, sense organs or heart, substantial damage may result.

The adult fluke affects the human host in many ways :

a) The worm is voluminous; its size sometimes reaches 1000 ml (1 litre); such a worm certainly occupies most of the lumen of the human intestine. Accordingly, the intestine may be partly obstructed and the digestive and absorptive processes become consequently disturbed.

b) The worms have tremendous food requirements which they satisfy by absorbing large amounts of the digested food found in the intestine and in this way they deprive the host from his own food. In undernourished individuals this usually leads to weakness and loss of weight.

c) The worms excrete poisonous metabolites which may be absorbed in the blood and cause certain systemic complications.

Modifications correlated with parasitic life in trematodes and cestodes

Although *Fasciola*, *Schistosoma* and other trematodes retain the general plan of organization of the Platyhelminthes, they show several modifications in structure and life history which are correlated with their parasitic habits, or by which they adapt themselves to live as internal parasites. Thus, while their free-living relatives, the Turbellaria, have ciliated epidermis and well developed sense organs, and produce a limited number of eggs which develop directly, these trematodes and cestodes exhibit the following modifications :

- 1 — Their bodies are not covered with ciliated epidermis.
- 2 — They almost lack sense organs.
- 3 — They possess suckers for attachment to their hosts.
- 4 — They possess an elaborate reproductive system, produce enormous numbers of eggs, and have a very complicated indirect development involving several asexual larval stages.

The trematodes and cestodes, like most other internal parasites, face a major problem in their life, that is how to get their offspring safely established inside a new host. The path from one final host to another is very hazardous and beset with many chances of failure such as :

- a) The chance that many eggs may not meet suitable conditions for hatching or development.
- b) The chance that many larval stages may not reach the proper kind of intermediate host during their short life.
- c) The chance that many cercariae metacercariae or bladder worms may not reach the proper final host.

Only animals capable of producing enormous numbers of eggs can survive these hazards. In this way they compensate for the enormous loss they face during their transmission from one host animal to another.

II. PHYLUM ASCHELMINTHES

(Nematodes)

This phylum is one of the largest phyla of the Animal Kingdom. The majority of nematodes are free-living forms universally present in enormous numbers in all types of environments or habitats, including the sea bottom, bottoms of all kinds of freshwater bodies, and the surface layer of all kinds of soils. There are also many parasitic forms which attack all kinds of plants and animals. As parasites of animals, many of them are found in the alimentary canal, liver, kidneys, lungs, blood, lymph, etc. The numerous species which infect crop plants, domestic animals and man make of this phylum one of man's worst enemies.

Despite their great abundance and wide distribution, nematodes are amongst the least conspicuous animals because the free-living forms and plant parasites are mostly less than 1 mm in length and many are microscopic. Animal parasites although large, they are all endoparasites hidden of sight.

General Characters

1 — This phylum includes elongate, cylindrical, non-segmented animals which exhibit bilateral symmetry.

2 — They have a complete digestive tract with a mouth and an anus.

3 — The body is covered with a thick layer of finely ridged or smooth cuticle.

4 — The musculature is well developed, but entirely consisting of longitudinal fibres.

5 — There is no true coelomic cavity, but there is a cavity often referred to as the pseudocoel which is formed by the junction of the large vacuoles of special cells that occupy the space between the intestine and the body wall.

6 — The excretory system consists fundamentally of few (usually two)

cells or renettes which are drawn into two longitudinal tubules that end blindly at their posterior ends, while anteriorly they have a transverse ventral connection with a single mid-ventral opening close behind the mouth.

7— The nervous system is composed of a circum-oesophageal nerve ring from which arise six short anterior trunks and six long posterior trunks.

8— With few exceptions they are dioecious, i.e. sexes are separate, their genital organs are usually filamentous (thread-like) and they produce eggs with tough resistant coverings.

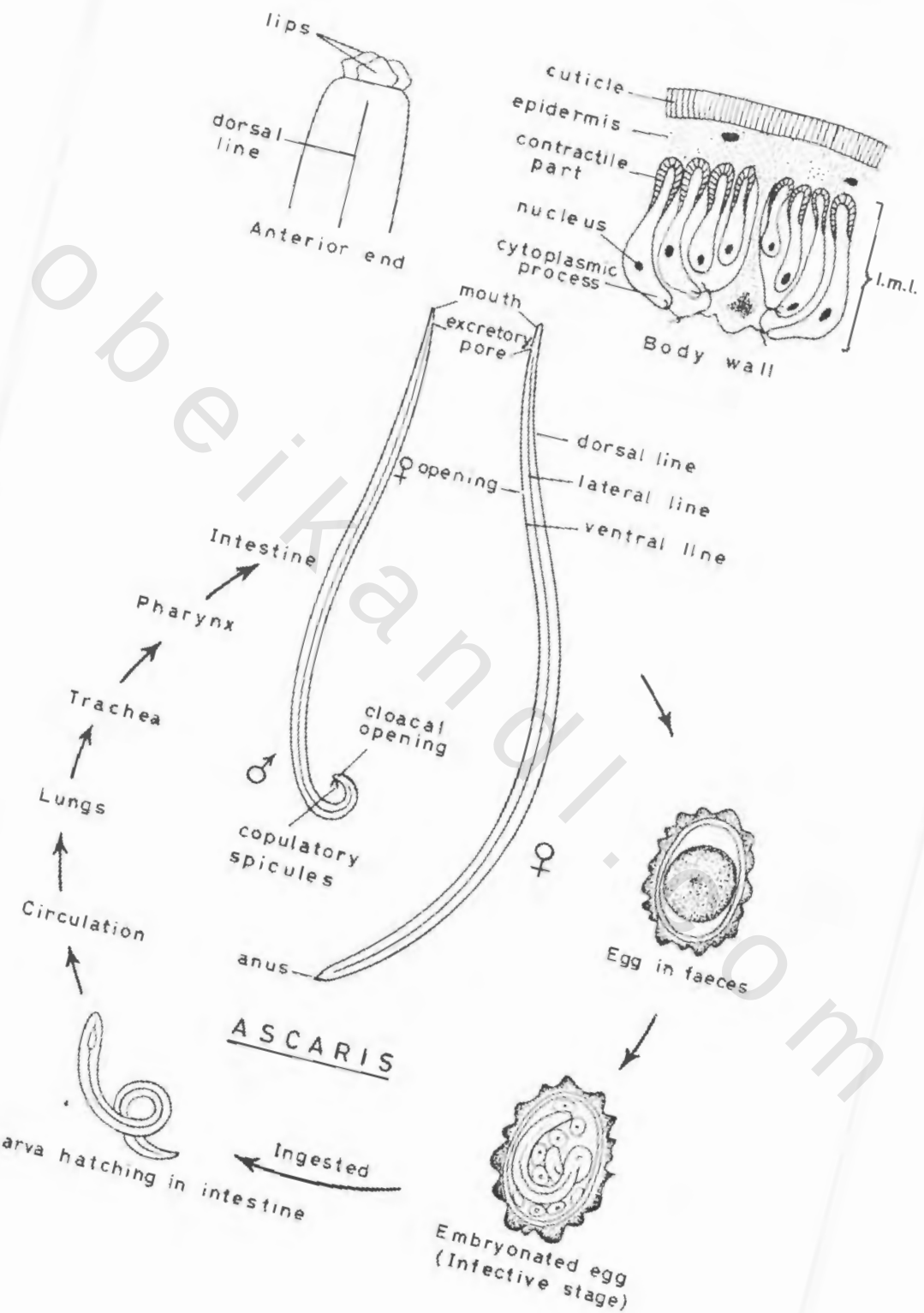
9— The life cycle is direct, and rarely indirect as in *Filariae*.

1— *Ascaris lumbricoides*

A. lumbricoides is commonly named the large intestinal round worm of man. It is usually found in the lumen of the intestinal tract of man in all parts of the world except in the cold, dry climates. Although the highest frequency occurs in tropical areas, yet this infection is also common in many temperate regions of the world. It is one of the important intestinal parasites of man in A.R. Egypt.

Morphology

Females (20-35 cm) are longer than the **males** (15-30 cm); the latter are also distinguished by a curved posterior end bearing a slit-like **cloacal opening** from which protrudes a pair of **copulatory spicules**. The position of the excretory canals is marked by two broad brownish **lateral lines**, while the position of the main nerve cords is similarly marked by whitish **dorsal** and **ventral lines**. The **mouth opening** lies at the anterior end of the worm, and the **excretory pore** is located on the ventral surface about 2 mm behind the anterior tip. In the female, the **genital opening** is situated ventrally at the end of the first third of the body and the **anus** is located very close to the posterior extremity of the worm. In the male, there is a subterminal **cloacal opening**.



Muscular system

The musculature consists exclusively of longitudinal fibres; circular muscles are completely lacking. Since the lateral cords divide the muscles into dorsal and ventral regions, *Ascaris* and most other nematodes move by dorso-ventral and not by lateral bending movements.

Structure of the body wall

Ascaris appears circular in cross section. The body wall is covered by a layer of epidermis, which secretes an outer layer, the **cuticle**, and is followed by a muscular layer. Unlike that of insects, the cuticle of *Ascaris* is not chitinous.

The **epidermis** consists essentially of a thin syncytial layer which bulges inwards to form four longitudinal ridges (cords) : a dorsal and ventral ridges and two lateral ridges. The dorsal and ventral ridges enclose the dorsal and ventral nerve cords respectively, while the two lateral ridges enclose the two excretory canals.

The muscle layer is built up exclusively of **longitudinal muscle fibres**. These are arranged into four quadrants, each quadrant including about 150 muscle cells. Each muscle cell is differentiated into a fibrillar or contractile outer portion and an inner cytoplasmic portion. The cytoplasmic portion includes the nucleus and is drawn out into cytoplasmic processes which are directed towards either the dorsal or ventral lines.

Between the body wall and the internal organs is a wide perivisceral cavity called the **pseudocoelom** or **pseudocoel**. This cavity is formed by the union of large vacuoles included in 2-5 very large **parenchyma cells**. The pseudocoel contains a fluid which has a relatively high hydrostatic pressure.

Digestive system and Nutrition

The **mouth** is surrounded by three cuticular **lips**; one of them is dorsal while the other two are ventro-lateral. The alimentary canal is a simple straight tube which is differentiated into the following 3 parts :

a) The **stomodaeum**, includes a short buccal cavity followed by a long muscular oesophagus. Both structures are lined with a cuticular layer which

is continuous with the cuticle on the surface of the body wall.

b) The **mid-gut or intestine**, a straight and long tube which does not show distinct differentiation into regions. Epithelial cells which line the intestine have brush borders.

c) The **proctodaeum**, a flattened tube which, like the stomodaeum, is lined with a cuticular layer that is continuous with the cuticle of the body wall. In the female worm, this tube opens to the exterior by the anal opening, while in the male it joins the genital duct into the cloaca which opens by the cloacal opening.

Adult *Ascaris* feeds on semi-digested food and debris which are found in the intestine of the host. The following enzymes have been demonstrated in the gut of *Ascaris* : amylase, maltase, protease, peptidase, lipase and esterase. This indicates that extracellular digestion of the ingested food material occurs in the gut of the worm. The digested food is then absorbed by the intestinal cells from which it passes by diffusion into the perivisceral fluid, to the different parts of the body.

Respiration

Since *Ascaris* worms live in the lumen of the intestine, they have access to little oxygen and accordingly they respire anaerobically. However, these worms can utilize oxygen if it is offered to them *in vitro*, i.e. they are facultative rather than obligate anaerobes.

Excretory system

This is formed from a single **renette** that is drawn out into an H-shaped system of tubules which open by a mid-ventral excretory pore close behind the mouth. There are no flame cells or other current-producing mechanisms, the excretory products and excess water are forced through the excretory pore by the hydrostatic pressure exerted by the perivisceral fluid on the excretory canals of the moving worms.

Nervous system

This consists of a **ganglionic nerve ring** which is found around the oesophagus. From this ring arises six nerve cords, the largest and longest of

which are two, **dorsal** and a **ventral nerve cord** running along the dorsal and ventral lines respectively. These two cords are interconnected at intervals by a number of transverse connectives.

There are certain **sensory papillae** which are arranged on the lips as well as at the posterior end of the worm.

Reproductive system and Reproduction

In the male, there is a single thread-like and coiled **testis**. It leads to a **vas deferens** which is thicker than the testis, and then to a wider tube, the **vesicula seminalis**. This ends in a short narrow muscular tube, the **ejaculatory duct**, which joins the proctodaeum into the **cloaca**. Dorsal to the proctodaeum there is a pair of muscular sacs containing setae which can be protruded out through the cloaca during copulation. The setae are known as the **copulatory spicules**, while the sacs are called the **penial sacs**. The anterior end of the testis is glandular and is believed to be the part which produces the spermatozoa.

In the female, there are two **ovaries** which are thread-like convoluted tubules, one of them is situated anteriorly while the other is situated posteriorly. Each ovary leads into an **oviduct** which passes into a wider tube, the **uterus***. The two uteri join together to form a thin tubular **vagina** which opens at the end of the anterior third of the body on the ventral surface. Each ovary is made up of a continuous sac consisting of an epithelial layer and a **germinal rachis**. The germinal rachis contains maturing cells.

During copulation, the male meets the female worm in such a way that the cloacal opening of the male faces the vaginal opening of the female, this being aided by the copulatory spicules of the male worm. The spermatozoa travel down the vagina to reach the lower parts of the uteri where fertilization of the ova occurs. The produced zygote is then enveloped with a **vitelline membrane** (sometimes called the fertilization membrane), a **chitinous shell**, and an external protein coat known as the **mammillated coat**. The vitelline membrane and the chitinous shell are both secreted by the zygote, whereas the mammillated layer is secreted by certain gland cells in the wall of the uterus.

* In *Neoscaris vitulorum* which is commonly dissected during the practical classes, there is a spherical structure, the *receptaculum seminis*, between the oviduct and the uterus.

Life cycle

The eggs passed in the faeces of the human host include an uncleaved zygote. The eggs are broadly ovoid, measuring $0.06-0.08 \times 0.04-0.05$ mm. A single female worm usually produces about 200,000 eggs/day on the average.

Further development of the passed eggs is largely dependent on the availability of oxygen, moisture and the temperature in the outer environment. In a very cold and dry atmosphere, it is believed that the eggs may remain inactive, but alive, for six years. At a temperature of $22-35^{\circ}\text{C}$ and in the presence of sufficient oxygen and a certain degree of humidity, the zygote develops within 9-13 days into a coiled **rhabditiform larva**. After another week, the rhabditiform larva undergoes the first moult to form the **second-stage rhabditiform larva** while still within the original egg envelopes, and this is the **infective stage** of the parasite.

Man acquires the infection by ingesting eggs containing the second-stage rhabditiform larva. In his intestine, the egg envelopes are digested and the larvae are released. The released larvae burrow into the intestinal mucosa, penetrate a blood vessel and are then carried to the liver via the hepatic portal vein. There, they may remain for a few days, but they continue travelling to the heart, and thence via the pulmonary arteries to the lungs. Within the lungs the larvae moult twice, break out of the capillaries into the alveoli, and are finally driven by the cilia lining the bronchi and trachea to the pharynx, eventually reaching the small intestine. There, they undergo their final moult and become mature, some 8-9 weeks after the initial ingestion of the eggs.

It is important to note that the tissue-migrating larvae of *Ascaris* ingest sufficient amounts of blood to satisfy their nutritional requirements up to the fourth moult. It is significant that the most rapid growth phase does not take place until the intestine, with its abundant supply of food materials, is reached.

Host-parasite relationships

a) **Effect of migrating larvae on the host** : The migrating tissue stages of *Ascaris* produce little effects when they pass from the intestine to the liver

and then to the heart. The presence of the larvae in the lungs, usually initiate certain tissue reactions there. When the larvae break out the pulmonary capillaries to reach the alveoli, they cause minute haemorrhages, and these in heavy infections may allow for secondary infections of the lungs with certain pathogenic bacteria.

b) Effect of the adult worms on the host : In light infections, there may be no apparent pathological changes. However, in heavy infections, which frequently occur in children, the nutritional demands and the space requirements of the parasite may lead to serious problems.

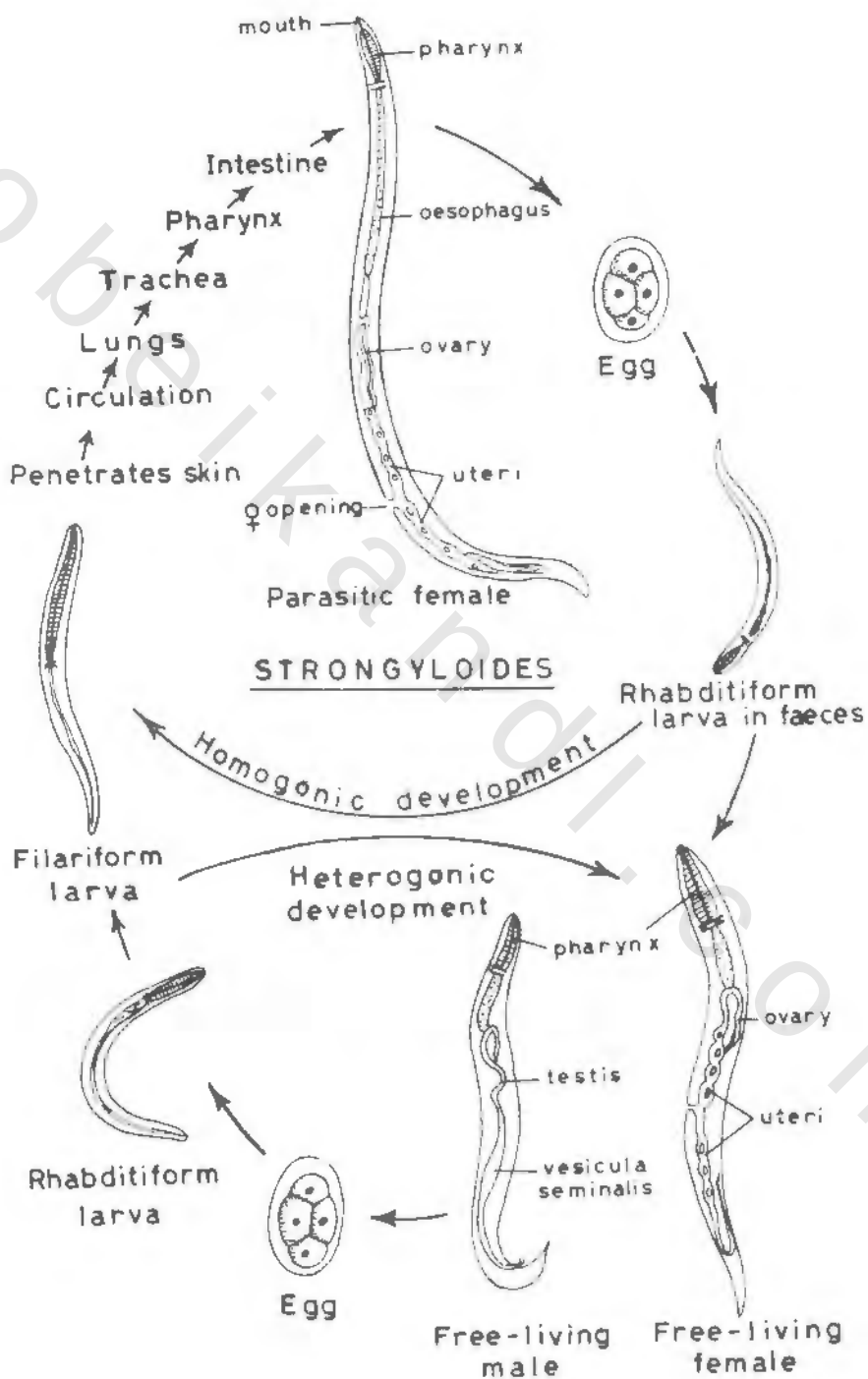
Ascaris-infected school children are usually shorter and have less memory and thinking capacity than the uninfected ones. This is partly attributed to the fact that the worms secrete certain substances which inactivate trypsin, thus the host's food proteins are left undigested in the lumen of the host's intestine.

Under certain conditions, the numerous worms found in heavy infections may be entangled together in masses which completely block the intestine of the host and this may be fatal unless such masses are surgically removed. When the worms are present in large numbers, they may pass anteriorly to invade the bile or pancreatic ducts, thus obstructing these passages.

The excretory products of the worms are known to be toxic to man. When such substances pass into the general circulation they may produce certain pathogenic manifestations.

2 — *Strongyloides stercoralis*

S. stercoralis is an intestinal parasite of man in many tropical and subtropical countries throughout the world. The worms belonging to the genus *Strongyloides* are unique amongst other nematodes because they have alternating generations of free-living and parasitic adults which undergo heterogonic and homogonic developments respectively. There is a free-living generation consisting of males and females, and a parasitic generation of parthenogenetic females which have a distinctly different appearance.



Morphology and General anatomy

The **parasitic female**, which is found in the anterior part of the intestine, is slender and measures up to 2.2 mm in length and 0.03-0.07 mm in breadth. The **mouth** leads into a relatively long **oesophagus** which extends $1/3-2/5$ of the body length. This opens into a flattened **intestine** which leads into a short **rectum**. The **anus** is located a short distance from the pointed posterior end. Although the genital system is similar to that of *Ascaris*, yet the **ovaries** are located more posteriorly and the **female genital pore** is situated at the end of the second third of the body.

The free-living adults are **sexually dimorphic**, the males being smaller than the females. The **free-living male** is about 0.7 mm long, with a rounded anterior end and a pointed caudal extremity, curved conspicuously to the ventral side. The alimentary canal is similar to that of the parasitic female but the oesophagus is much shorter. There is a single **testis**, **vesicula seminalis**, **ejaculatory duct** and **copulatory spicules**.

The **free-living female** is fairly similar to the parasitic female but it is much shorter, measuring about 0.9-1.0 mm in length. The oesophagus is also short and the female genital pore is located near the middle of the body.

Life cycle

The parasitic female produces parthenogenically thin-shelled transparent eggs which are either passed in the host's faeces or hatch within the intestinal lumen. In the latter case, the larvae are passed in the faeces, often growing to twice or three times their hatching size by the time they reach the outside. The larvae are of the **rhabditiform type**.

The fate of the larvae passed in the faeces is determined to a great extent by the amount of food available in the environment. When favourable nutrients and humidity prevail, indirect (heterogonic) development occurs, whereas lack of food and dryness favours direct (homogonic) development.

In **heterogonic development**, the rhabditiform larvae rapidly grow and show sexual differentiation, and within 30 hours they develop into free-living sexually mature male and female worms. After copulation, eggs are released and hatch to give the rhabditiform larvae. These larvae develop into free-

living males and females and this cycle is continually repeated as long as the conditions remain favourable. When the conditions become less favourable, the rhabditiform larvae moult and develop into filariform larvae instead. The filariform larvae are long and have a very long oesophagus; these larvae are infective to man.

In **homogonic development**, the rhabditiform larvae hatching in the faeces undergo direct development into the filariform larvae without attaining sexual maturity.

Human infections are acquired by skin penetration or oral ingestion of the filariform larvae. The larvae penetrate the skin and are carried by the venous circulation to the heart then to the lungs and up the bronchi and trachea to the pharynx. There, they are swallowed and passed into the intestine where they invade the mucous epithelium, moult twice, and develop into the parasitic females that reproduce parthenogenically in about two weeks.

Host-parasite relationships

In very light infections there may be no measurable pathogenic effects, but very heavy infections are sometimes fatal.

The migrating larvae induce certain types of tissue reactions in the skin, liver and lungs. The adults burrowing in the intestinal mucosa may cause inflammation and erosion of the mucous layers.

3 — *Ankylostoma duodenale*

(The Hook-worm)

This is another nematode parasite of man which is much more dangerous than *Ascaris*. Adult hookworms live in enormous numbers in the small intestine of man (particularly in the jejunum and duodenum) attached by their buccal capsules to the mucosa of the intestine which they bite to suck plentiful blood for nutrition.

Two species of hook-worms infect man and have a wide distribution in tropical and subtropical areas where warm weather, humidity and poor sanitation favour their existence. These are *Ankylostoma duodenale* and *Necator americanus*. The former is the species which is prevalent in the A.R.

Egypt. **Ankylostomiasis** is a serious endemic disease which is very common in this country and ranks next to schistosomiasis as regards the injury and economic loss it causes to man.

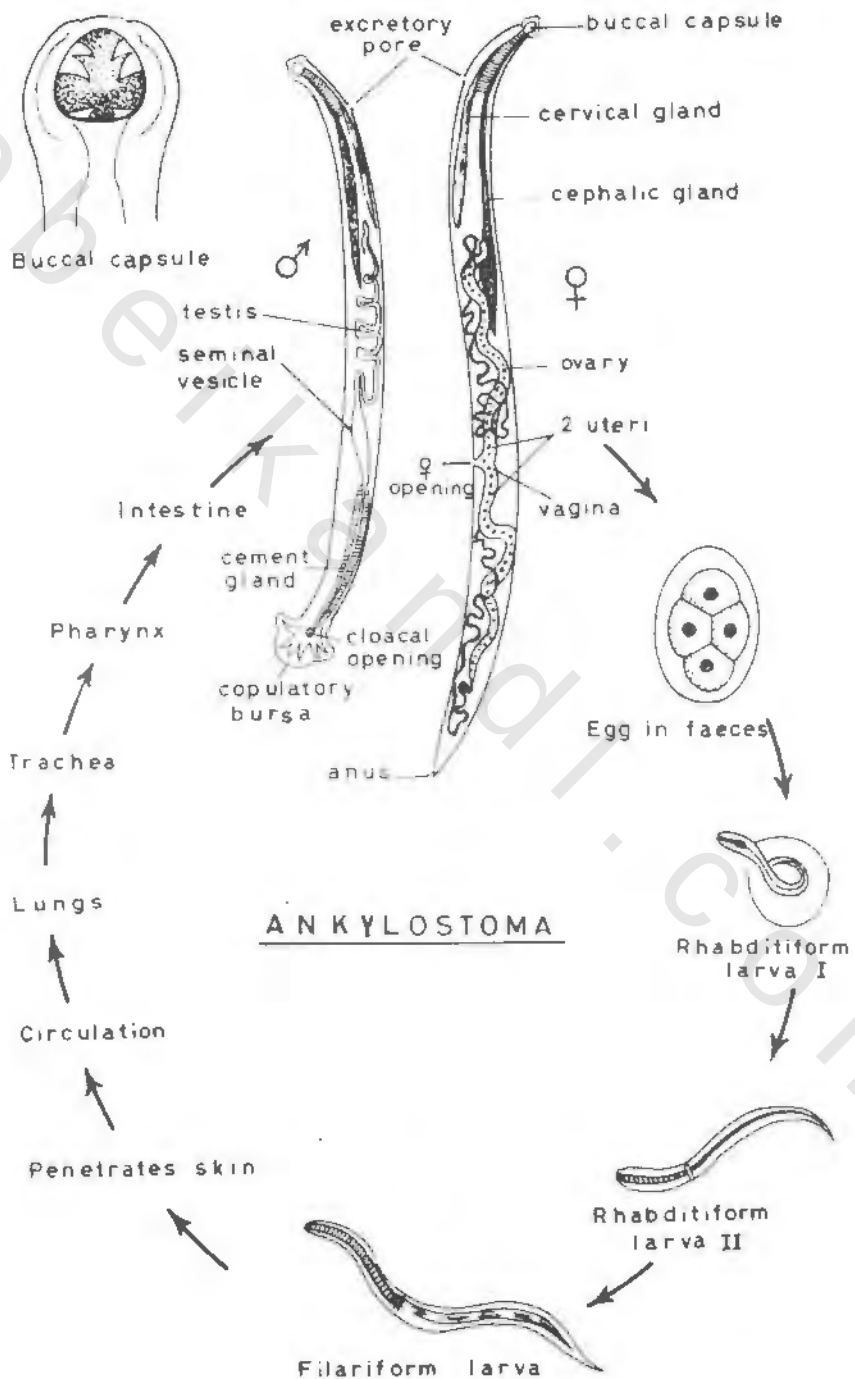
Morphology

The adult worms have small greyish cylindrical bodies. The female is longer (1 - 1.4 cm in length) and has a pointed posterior end, while the male (0.8 - 1.1 cm in length) has its posterior end expanded and modified into a **copulatory bursa**. The anterior end which bears the **mouth** is slightly bent dorsally in both sexes, and the single **excretory pore** lies on the ventral surface a short distance behind the mouth. The **genital opening in the female** lies on the ventral surface at the beginning of the posterior third of the body, and the **anus** opens on the same side near the posterior end. But in the male, the genital system and the gut open together by a common **cloacal opening** on the ventral surface of the copulatory bursa.

Digestive system and Nutrition

The **mouth** is turned towards the dorsal surface, and leads into an open, cup-like buccal cavity which is lined with cuticle, thus forming a **buccal capsule**. This capsule is armed with 2 pairs of **ventral teeth** and one pair of smaller **dorsal teeth**. Two more saw-like teeth project from the floor of the buccal capsule. The capsule is followed by a long muscular **oesophagus**, both forming the stomodaeum. This is followed by a simple tubular **intestine**, then a short proctodaeum or **rectum**. Connected with the digestive system are 2 large **cephalic glands** which extend along the anterior third of the body and open in the buccal capsule. Their secretion prevents coagulation of the host's blood.

Hook-worms hold on to the mucosa of the intestine with their buccal capsule and cut bits of the mucosa with their teeth causing haemorrhage. They feed on the blood and bits of the mucosa which they suck by their muscular oesophagus. The worm pumps in much more blood than what it apparently digests, and shifts its position from time to time. The wound continues to bleed for a short time after the worm leaves it.



Excretory and Nervous systems

Ankylostoma has an H-shaped excretory cell or **renette** with a canal system similar to that of *Ascaris*, in addition to 2 **cervical glands** of excretory function which connect with the transverse canal. The nervous system is essentially similar to that of *Ascaris*.

Reproductive system

The male has a single tubular coiled **testis** which leads by a narrow **vas deferens** into a dilated spindle-shaped **vesicula seminalis**. This is followed by a long **ejaculatory duct**, which is surrounded by a large **cement gland** and opens into the rectum, both leading to the outside by the **cloacal opening**. Two long **copulatory spicules** lie in pouches dorsal to the ejaculatory duct. The posterior end of the male is expanded into a **copulatory bursa** which curves about the genital opening of the female during copulation. It has 3 lobes supported by fleshy rays.

The female has 2 coiled **ovaries** which lead by narrow **oviducts** into 2 dilated and coiled **uteri**. These join in a very short **vagina** which opens to the exterior by the genital opening.

Life cycle

The female produces 25-35 thousand eggs daily. The egg is oval, has a thin transparent egg-shell and is in an early stage of cleavage, or in the **4-blastomere stage**, by the time it passes out with the faeces. If it reaches the soil, it continues to develop rapidly under suitable conditions of moisture and hatches within 48 hours. A very active **rhabditiform larva** (0.2-0.3 mm long) emerges from the egg and feeds voraciously on bacteria and other matter in the faeces. It thus grows then moults on the 3rd day, transforming into a **second-stage rhabditiform larva** (0.5-0.6 mm long). This larva moves away from the faeces into the soil where it goes on feeding on organic matter in the soil until the 5th day when it stops feeding and moults for the second time, thus transforming into another larval stage called the **filariform larva** which is the **infective stage**. But this time, the larva keeps its old skin as a protective sheath. The ensheathed filariform larva remains quiet for a while, then becomes active again and moves up towards the soil surface. It does

not feed and can remain as such for several weeks moving about on moist soil particles. Temperatures of 18-24°C, moist atmosphere without much rain, shade and loose broken up soil all constitute optimum conditions for this larval development of *Ancylostoma*. All these conditions prevail in the agricultural areas of our country.

Infection of human beings normally takes place by penetration of the filariform larvae through the soft skin of the foot and in between the toes as a result of walking barefooted on contaminated soil. The habit of defecating around houses and in fields and later on playing and walking in the same localities exposes children as well as adults to infection and re-infection. The larva penetrates the skin within few minutes, leaving its sheath behind. It reaches a lymph or blood vessel and is thus carried with the blood circulation to the heart then to the lungs, and breaks into the alveoli. It is then passed along the trachea to the pharynx, swallowed and finally reaches the intestine. It moults for the 3rd time in the intestine then attaches to the mucosa, grows rapidly to the length of 3-5 mm, moults for the 4th time and grows to maturity. Eggs start to appear in the faeces in about 3-6 weeks after infection, and the adult worms live for about 5 years.

Host-parasite relationships

When the filariform larvae penetrate the skin of the human host, certain tissue reactions occur at the sites of penetration. Sometimes, bacterial contamination also occurs at the places of entry of these larvae.

Focal haemorrhages also occur when the larvae pass into the air sacs of the lungs and in massive infections this may lead to serious complications.

When the hook-worms reach the small intestine of man, they become attached to the villi with their buccal capsules. The tips of the villi become eroded, a haemorrhage is produced and the worms start to suck the flowing blood. It has been recently demonstrated that each worm is capable of removing 0.67 ml of blood per day. In light infections, this blood loss can be compensated by new supplies from blood-producing organs. However, in heavy infections, severe blood loss may lead to anaemia. Heavy infections in children may cause considerable retardation in their physical and mental growth, as well as an increase in their susceptibility to other diseases.

THE COELOMATA

The Coelom

It is to be recalled that the cleavage of the zygote in the Metazoa results in the formation of a hollow blastula which is bounded by a single layer of cells, and encloses a central cavity known as the blastocoel or primary body cavity.

By either cell-proliferation or by invagination of one side, the blastula transforms into a 2-layered gastrula. This has two germ layers in its wall, the ectoderm and the endoderm, and has a new central cavity known as the archenteron. During this process of gastrulation, the blastocoel (which is now represented by the space found between the ectoderm and endoderm) becomes more or less obliterated. This is the space which will become later on invaded by the third germ layer or mesoderm.

The mesoderm arises in several ways :

1 — In the Acoelomata, it arises by cell-proliferation from the ectoderm and endoderm, and the resulting mesoderm cells fill the whole of the blastocoel.

2 — In the Coelomata, the mesoderm arises either : (a) as lateral out-pocketings or pouches from the archenteron, which later separate from the endodermal tube and form closed mesodermal pouches. The cavity in these pouches is the coelom or secondary body cavity, or (b) as solid masses of cells which arise from the endoderm and later develop a cavity inside them, the coelom. In both cases, the mesoderm cells provide an epithelial lining, called the coelomic epithelium or peritoneum to the coelomic cavity.

The appearance of the coelom had a great effect on the evolution of the internal organization of the coelomate body. Some organ systems have become well differentiated and modified than in acoelomate groups :

1 — **The digestive system**, has become freed from the body wall, except at both ends, i.e. mouth and anus, and has attained increased surface by coiling rather than by lateral branching. The alimentary canal is divided

into specialized parts adapted to perform specific digestive and absorptive functions.

2 — **The muscular system**, originating from the mesoderm, is well developed and distinguished into the musculature of the body wall which serves for locomotion, and the visceral muscles. Efficiency of the muscular system is apparent in animals which develop exo- or endoskeleton to which the muscles can attach.

3 — **The circulatory system** or "blood vascular system" is specialized in transport of food materials, oxygen, carbon dioxide and waste products to and from the various tissues in the body. Blood passes in vessels and in definite routes, and contains blood cells and special oxygen-carrying elements. A specialized portion of these vessels acts as contractile heart or forms heart-like structures. Special organs of respiration are related to the blood system. These may be external structures, such as the skin or external gills, or internal structures such as internal gills, tracheae, lung books or lungs.

4 — **The excretory system** : Paired excretory organs in the form of nephridial tubules or "nephridia" usually develop in each segment of the body. The inner ends of these tubules open into the coelom and have a direct connection to the coelomic fluid, usually by means of ciliated funnels or "nephrostomes". These collect waste products and pass them into the tubules. The other ends of the tubules open to the outside through excretory pores or "nephridiopores". The excretory organs vary in structure and complexity in the various coelomate groups. In higher vertebrates, for example, they form compact organs or "kidneys" which collect waste nitrogenous substances directly from the blood.

5 — **The reproductive system** : Sex organs, primarily appearing as paired mesodermal masses, connect with the exterior through special coelomoducts which carry their products to the outside. In higher coelomates sex organs become much reduced in number and more restricted in position to certain regions of the body, being usually one pair with special genital ducts and external openings.

6 — **The nervous system and sense organs :** During embryonic development of coelomate animals, paired nerve ganglia appear in each segment. In the invertebrates, these ganglia lie ventrally and connect together to form a long chain, or ventral nerve cord. Ganglia in the anterior segments fuse together to form a cerebral mass or "brain" situated dorsal to the fore-gut in the head region. Paired nerves arise from the ganglia. Sense organs are well developed and more advanced in coelomate than in acoelomate animals.

I. PHYLUM ANNELIDA

The Annelida, segmented or ring worms, comprise a large phylum of mostly free-living animals which inhabit the sea, freshwater and moist soil, and few forms live as ectoparasites. The Annelida include such familiar forms as the earthworms and leeches, as well as many less known marine bristle worms.

General characters

- 1 — They are triploblastic coelomate animals.
- 2 — The body exhibits a bilateral symmetry and is divided into a linear series of segments (somites or metamerer); inter-segmental grooves separate these metamerer externally, while they are separated internally by inter-segmental septa.
- 3 — The body is covered by a moist non-chitinous cuticle overlying a columnar epithelium containing unicellular gland cells and sensory cells.
- 4 — There are few to many chitinous appendages per segment.
- 5 — The body cavity between the alimentary canal and the body wall is a true coelom.
- 6 — There is a complete digestive tract which starts with the mouth and ends with the anus.
- 7 — Respiration generally occurs by diffusion through the epidermis, but in some aquatic forms respiratory organs in the form of gills may be present.
- 8 — The excretory system consists of a pair of nephridia in each body segment.
- 9 — There is a closed circulatory system composed of longitudinal blood vessels with lateral branches in each segment, the blood plasma usually containing dissolved haemoglobin and free amoebocytes.
- 10 — Musculature is generally well developed, being formed of circularly and longitudinally arranged muscle fibres in the body wall and in the wall of the alimentary canal.

11 — The nervous system consists of a pair of cerebral ganglia, connected to a mid-ventral double nerve cord, with a ganglion and pairs of lateral nerves in each segment.

12 — The sexes are usually separate, but sometimes both male and female organs occur together in the same individual.

Classification

The phylum is divided into 3 classes :

A. Class Oligochaeta

This includes the earthworms, which inhabit damp soil as well as some freshwater forms. They have numerous body segments, each carrying few chaetae, but no parapodia or gills. The head is not well defined and has no tentacles. Sexes are united (monoecious). The reproductive system is complicated and includes few permanent gonads (1 or 2 pairs) and special gonoducts. Eggs are laid in cocoons secreted by a glandular clitellum and development is direct without a free larval stage, e.g. *Allolobophora*.

B. Class Polychaeta

This includes the bristle worms and tube worms which are marine annelids found chiefly along the sea coast. They have many body segments with lateral fleshy parapodia carrying numerous long chaetae. They have gills and a better differentiated head with eyes, tentacles and sensory palps. Sexes are usually separate (dioecious) and there is no clitellum. The reproductive system is simple and the gonads are numerous, metamerically repeated and not permanent. Fertilization is external and development is indirect through a free-swimming trochophore larva. Some species also reproduce asexually by budding.

The Polychaeta display different modes of existence which have led to various modifications in their structure. They are generally grouped under 2 categories :

1 — **The Errantia** are free-moving predatory forms some of which are free-swimming, others crawl among rocks and shore animals and plants, or burrow in the bottom sand, and many construct tubes in which they live, e.g. *Nereis*.

2 — **The Sedentaria** are sedentary forms which live permanently inside tubes or burrows, emerge by their heads only from their tubes or burrows and feed on detritus and plankton.

C. Class Hirudinea

This includes the leeches which are either freshwater, marine or terrestrial, free-living or ectoparasitic. They have neither parapodia nor chaetae. Their body is pigmented, more or less flattened and composed of a fixed number of segments (relatively few) subdivided externally into secondary annuli. They have a reduced head with no tentacles, and possess terminal suckers for attachment and locomotion. The coelom is reduced and obliterated by connective tissue. The sexes are separate, and the reproductive system is complicated and includes numerous testes, a single pair of ovaries and copulatory organs. Development is direct within a cocoon, e.g. *Hirudo*.

A. CLASS OLIGOCHAETA

Allolobophora caliginosa

(The Earthworm)

Earthworms are terrestrial annelids which live in the damp soil of fields and gardens, inside burrows which they excavate in the soil. They are nocturnal, staying inside their burrows during the daytime and coming to the surface at night to breed and to feed on plant leaves and decaying organic matter found on the soil surface. They are not harmful, but rather beneficial to man. By their continuous burrowing into the soil they make innumerable channels into it, which help aerating the soil, allow water to penetrate more easily through it, loosen the soil particles thus allowing for more growth of plant roots, and improve drainage. This burrowing also continuously brings up fresh soil from below to the surface. At the same time the soil is divided up into fine particles and enriched by various organic secretions of the worms as it is passed into their alimentary canals. This increases the organic content of the surface layer of the soil, thus adds to the fertility of the land.

Morphology

Allolobophora caliginosa has a long cylindrical body which is more tapering anteriorly. The dorsal surface is dark reddish-brown in colour while the ventral surface has a paler colour and is somewhat flattened posteriorly. The body is divided into a large number of annular segments separated by distinct transverse **intersegmental grooves**. However, a thick, glandular, saddle-shaped band, known as the **clitellum**, covers the dorsal and lateral sides of segments 26-34 where segmentation is partly obscured. The lower edges of this clitellum are thickened in segments 31-33 forming two **puberty ridges**. Four pairs of minute chitinous bristles, known as the **chaetae** or **setae**, project on the ventral and lateral sides of each segment, except the first segment and the last one. They are embedded in small **chaetigerous sacs** within the body wall. They are moved by special chaetigerous muscles and serve a locomotory function.

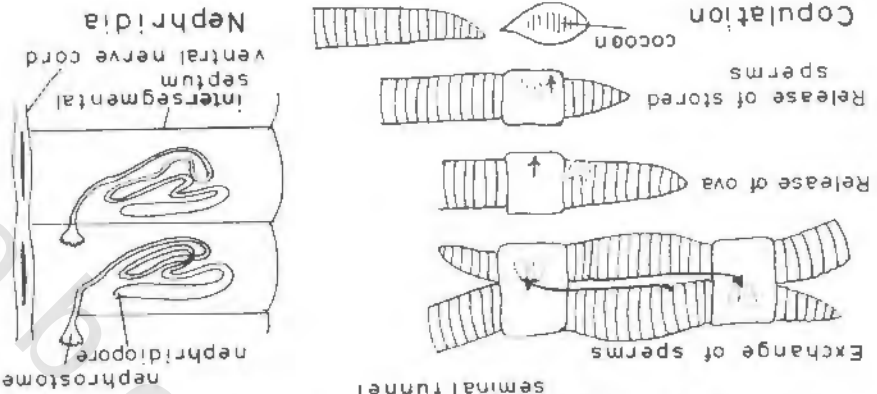
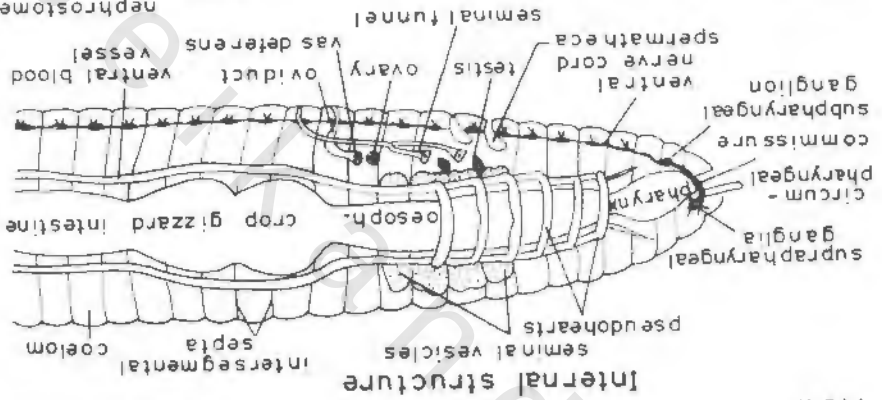
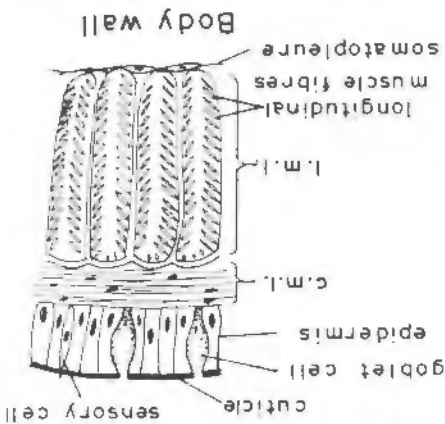
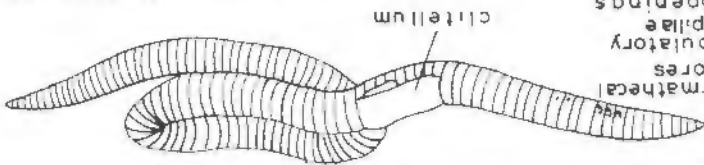
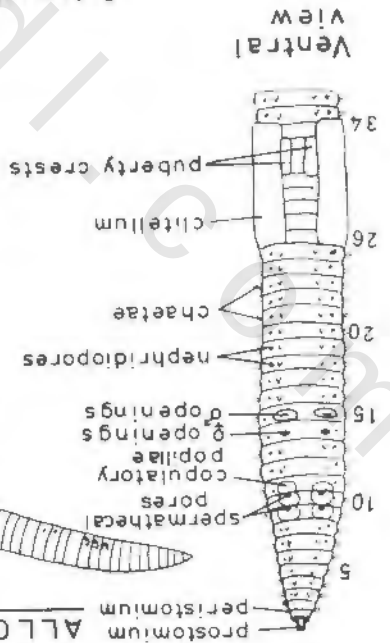
The first segment in the body is perforated by the **mouth opening** and is known as the **peristomium**. A small club-shaped **prostomium** (which is not considered a true segment) projects above and in front of the mouth, and serves as an upper lip. The **anus** opens on the last segment. Each segment, except the first three segments and the last one, is perforated on the ventral side by a pair of minute excretory openings known as the **nephridiopores**. In addition there is a series of single median **dorsal pores** which open in the intersegmental grooves starting from the groove between segments 8/9 till the posterior end.

The external openings of the reproductive organs include two **female genital openings** which lie ventro-laterally on segment 14, two **male genital openings** on the ventro-lateral sides of segment 15, and two pairs of **spermathecal pores** which lie in the intersegmental grooves between segments 9/10 and 10/11. The latter pores are surrounded by three pairs of glandular areas or **copulatory papillae** on the ventral surface of segments 9, 10 and 11.

Histological structure.

The **body wall** is covered by a thin layer of **cuticle** secreted by the underlying epidermis. The **epidermis** is formed of a single layer of columnar epithelium which contains mucus-secreting or goblet cells and sensory cells. Below

ALLOLOBOPHORA



the epidermis, there is a continuous **circular muscle layer**, followed by a thick **longitudinal muscle layer** which is divided up into 7 bands. The muscle fibres in the latter layer are arranged in bundles, separated by thin connective tissue sheets. Each sheet, together with the muscle fibres found on both sides of it, presents a feather-like appearance.

The body cavity : The earthworm has a wide fluid-filled **coelomic body cavity** which occupies the space between the body wall and the gut. This cavity is completely surrounded by the coelomic epithelium or peritoneum. The outer part of this epithelium, which lines the body wall, is formed of flattened cells and is known as the **somatic layer** or **parietal peritoneum**. The inner part surrounds the gut and is known as the **splanchnic layer** or **visceral peritoneum**. The cells of this epithelium are club-shaped, modified to perform some excretory function, and are called the **yellow** or **chloragogenous cells**.

The coelomic cavity is filled with a colourless coelomic fluid in which amoeboid **coelomic corpuscles** float freely. This cavity is connected with the exterior through the dorsal pores, the nephridia and the genital ducts. However, the coelomic cavity is not continuous throughout the body, but divided into a linear series of ring-like chambers, one in each segment, separated by transverse **intersegmental septa**.

The mesoderm arises in the Annelida as paired lateral pouches or evaginations from the wall of the archenteron (the endoderm). These pouches then separate from the endoderm, become closed and enlarge greatly so as to form a double series of coelomic sacs surrounding the gut, a right and a left sac in each segment. The outer walls of these sacs become applied to the body wall, while their inner walls become applied to the gut. The latter walls meet in the middle line above and below the gut forming double sheets of coelomic epithelium referred to as the **dorsal** and **ventral mesenteries**. These mesenteries disappear in the adult worm so that the right and left coelomic sacs of each segment connect with each other forming a continuous ring cavity. Meanwhile, the anterior and posterior walls of successive coelomic sacs meet forming the intersegmental septa that are perforated by minute pores through which the coelomic fluid passes from the coelomic cavity of one segment to the other.

The important advantages of having a coelom are :

1 — It separates between the gut and the body wall, thus permits free

movement and muscular contraction of the gut independently of the body movements. The gut could consequently be differentiated into a series of compartments, each specialized to perform a different function.

2 — The coelom is fully turgid with the coelomic fluid, thus maintains the shape of the body and gives a strong support to it. This support is necessary for the muscles to work properly and to produce movement. At the same time the turgid coelom helps to reduce the effect of external mechanical shocks on the internal organs, in much the same way as the air-filled inner tubes of automobile tires protect the passengers from shocks and jerks while running on a rough road.

3 — The coelom also serves important excretory and reproductive functions. The excretory products and reproductive gametes accumulate in the coelomic cavity then become passed to the exterior through the nephridia and gonoducts.

4 — The coelom also plays a role similar to that of a circulatory system because the coelomic fluid is filled with coelomic corpuscles and many dissolved substances and these pass freely from one segment to another.

Digestive system and Nutrition

The alimentary canal is complete, and is differentiated into a number of organs, each specialized to perform a certain function. The mouth leads into a thin-walled **buccal cavity** (extending within segments 1 and 2), followed by a thick-walled muscular **pharynx** (segments 3-5). This is provided with pharyngeal glands and is connected to the body wall by numerous radial muscle strands. A narrow **oesophagus** (segments 6-14) leads from the pharynx and opens posteriorly into a thin-walled **crop** (segments 15-16), followed by a thick-walled muscular **gizzard** (segments 17-19) which serves to grind the food, aided by very small stones. A long tubular **intestine** passes from the gizzard to the posterior end of the body, and opens by the anus on the last segment. It is lined with a partially ciliated columnar epithelium, which is secretory and absorptive and contains numerous goblet cells. The intestine also appears U-shaped in transverse section because its dorsal wall is invaginated so as to form a **typhlosole** which increases the digestive and absorptive surface of the organ. To the outside of the lining epithelium of the intestine, there is a thin circular muscle layer followed by another thin longitudinal muscle layer.

The earthworm feeds mainly at night on all kinds of decaying organic matter and plant leaves found on the soil surface. Sometimes it also pulls bits of vegetation into its burrow to feed on them. In addition, the earthworm often swallows the earth while burrowing into the soil. It does not swallow the earth only to make its burrow, but it also feeds on the different organic material contained in that earth, such as plant seeds, eggs and larvae of many animals, and decaying plant and animal matter.

The muscles of the wall of the alimentary canal produce successive waves of contractions which push the food along the gut. This food becomes moistened and softened while passed down the pharynx, oesophagus and crop, and is therefore easily broken up by the crushing action of the muscular gizzard. It is then passed into the intestine where extracellular digestion as well as absorption of the soluble digested material take place. This material is then passed into the blood stream to be distributed throughout the body. The indigestible remains and soil particles are egested and piled around the mouths of the burrows forming what is known as "worm casts".

Respiration

The earthworm is aerobic. It has no special respiratory system, and respire atmospheric oxygen by simple diffusion through the skin. The body wall is richly supplied with blood capillaries, and the body surface is kept moist by the mucous secretion of the epidermal goblet cells and by the coelomic fluid which escapes through the dorsal pores. Thus oxygen, in solution, diffuses through the epidermis and the thin walls of the blood capillaries. It combines with the haemoglobin dissolved in the blood plasma forming oxyhaemoglobin, and is thus carried to various parts of the body. The oxyhaemoglobin gives up this oxygen again in the tissues wherever the oxygen tension is low. Carbon dioxide passes from the tissues to the outside in a similar manner.

Excretory system and Excretion

The excretory system consists of a large series of segmentally arranged excretory tubes called the **nephridia**. A pair of these nephridia lies on the floor of each segment, except the first three segments and the last one. Each nephridium consists essentially of a ciliated coiled tube which is open at

both ends. It opens in the coelomic cavity at one end by a ciliated funnel known as the **nephrostome**, and opens to the outside at the other end by a **nephridiopore** on the ventral surface of the body. However, each nephridium actually extends in two segments. The nephrostome projects in the coelomic cavity of the segment found in front of the segment which contains the main coiled body of the nephridium and the nephridiopore.

The nephridia do not represent all the excretory organs of the earthworm. The coelomic epithelium surrounding the gut also plays a role in excretion. Its cells are modified into large club-shaped **yellow** or **chloragogenous cells**. These cells filter the nitrogenous wastes from the blood and pass them as ammonia and urea into the coelomic fluid, which is continually driven by the cilia of the nephrostomes into the nephridia. There, useful salts and some water become re-absorbed from this fluid, while the rest is passed to the exterior through the nephridiopores. Occasionally the yellow cells also detach, while loaded with excretory matter, and fall into the coelomic fluid where they become engulfed by the phagocytic coelomic corpuscles. The latter corpuscles then escape with their load through the dorsal pores and the nephridia, or penetrate in an amoeboid fashion through the body wall and degenerate within the wall leaving a pigment deposit.

Blood vascular system

In the Annelida we encounter for the first time a genuine blood vascular system. This system consists of a number of longitudinally running tubular vessels which connect by circularly running branches in each segment. The most important of these blood vessels are : a median contractile **dorsal blood vessel** which extends above the alimentary canal throughout the whole length of the body, and another median non-contractile **ventral blood vessel** runs below the alimentary canal. These two vessels are directly connected with each other by 6 pairs of transverse contractile vessels running on both sides of the oesophagus in segments 6 - 11 and are called the **pseudohearts**.

The blood flows from in front backwards along the ventral blood vessel, which is the main distributing vessel. This vessel gives off lateral branches in each segment to the body wall, alimentary canal, nephridia, etc. Blood capillaries from these branches connect with other capillaries which convey the blood to the dorsal blood vessel. The latter vessel contracts rhythmically propelling the blood from behind forwards until it reaches the contractile

pseudohearts which pump it downwards into the ventral blood vessel again. In this way, blood keeps circulating inside vessels and capillaries and the blood system is therefore described as a **closed circulatory system**.

The blood of the earthworm consists of red fluid plasma with few colourless amoebocytes. It contains haemoglobin dissolved in the plasma and not confined to special blood cells.

Nervous system

This consists of a **nerve ring** around the pharynx carrying 2 dorsal cerebral or **suprapharyngeal ganglia**, 2 **circumpharyngeal commissures** and 2 **subpharyngeal ganglia**. From the latter ganglia, a double **ventral nerve cord** extends backwards below the alimentary canal till the posterior end of the body. This cord bears a double **nerve ganglion** in each segment from which 3 pairs of **nerves** arise to innervate the different organs in the segment. The sense organs are simple and consist mainly of sensory cells which are scattered in the epidermis. Some of these cells occur singly and are sensitive to light, while others occur in small groups, have minute projections on the surface and are sensitive to tactile and chemical stimuli.

Reproductive system and Reproduction

The earthworm is hermaphrodite. The gonads are developed from the coelomic epithelium as in all other coelomates. The gametes are shed into the coelomic cavity, from which they are passed to the exterior by special coelomoducts which function as gonoducts.

The male genital system consists of two pairs of small lobed **testes** located in segments 10 and 11. Immature sperm cells separate from the testes and complete their development inside four pairs of large **seminal vesicles** located in segments 9-12. From these vesicles, the fully formed spermatozoa pass to the exterior during copulation by way of two pairs of ciliated **seminal funnels**, which lie in segments 10 and 11 behind the testes. Each of these funnels leads backwards into a narrow **vas efferens**. The two vasa efferentia of each side unite into a single **vas deferens**, and the two vasa deferentia of both sides open to the exterior by two slit-like male genital openings on the ventral surface of segment 15.

The female genital system consists of two small carrot-shaped **ovaries**

which lie in segment 13. The oocytes are shed into the coelomic cavity and then carried to the outside by two ciliated **ovarian funnels** which lie behind the ovaries in the same segment. Each ovarian funnel leads into a dilated **ovisac** inside which the ova complete their development, then pass to the exterior through a short **oviduct**. The two oviducts open to the outside by two female genital openings on the ventral surface of segment 14.

Two pairs of small spherical sacs, the **spermathecae** lie in segments 10 and 11. These are accessory reproductive organs which serve to store the spermatozoa received from another worm during copulation. They do not open internally, but open to the outside by two pairs of minute spermathecal pores on the ventral surface, in the intersegmental grooves between segments 9/10 and 10/11. These spermathecal pores are surrounded by three pairs of glandular copulatory papillae which also serve a reproductive function.

The earthworm reproduces sexually throughout most of the year, and although it has a hermaphrodite system, yet **cross fertilization** always occurs. The worms emerge from their burrows at night to copulate. Copulation involves the mutual exchange of spermatozoa between two worms, which then separate and later on form cocoons in which fertilization of the eggs and development of the embryos take place. The two worms appose the ventral surfaces of their anterior parts and cling to each other by their chaetae, with their heads pointing in opposite directions and the clitellum of each worm lying opposite to the region of the spermathecal pores of the other worm. Much mucus is then secreted by the epidermis so that the anterior part of each worm becomes enveloped in a mucous tube. The spermatozoa are then squeezed out of the male genital openings of each of the two worms and are carried backwards along temporary longitudinal seminal grooves to the region of the clitellum, where they become forced into the spermathecae of the other worm. The two worms then separate.

When the eggs are ripe, the clitellum of each worm secretes a mucous tube around itself, the **cocoon**, and fills it with albumen secretion from its glands. This cocoon is then forced to glide forwards by muscular contraction of the body behind it. As the cocoon passes over the female genital openings, few eggs are discharged into it, then as it passes further forwards over the spermathecal pores, it receives some of the spermatozoa which are stored in the spermathecae. Finally the worm slips out of the cocoon, closes it at both ends, and leaves it in the soil.

Fertilization occurs inside the cocoon, and the zygotes develop into young worms which later on escape from the cocoon, i.e. there is no free larval stage. Each worm continues to secrete new cocoons and repeat the same process until all spermatozoa stored in its spermatheca are used up.

B. CLASS POLYCHAETA

Nereis

(The Sandworm)

Species of the genus *Nereis* are of the commonest bristle worms found between tide marks along the sea coast, swimming by gentle undulations of their bodies or crawling under stones and among seaweeds. Although capable of swimming, the worm spends most of its time burrowing into the bottom sand and occasionally leaves its burrow to construct a new one.

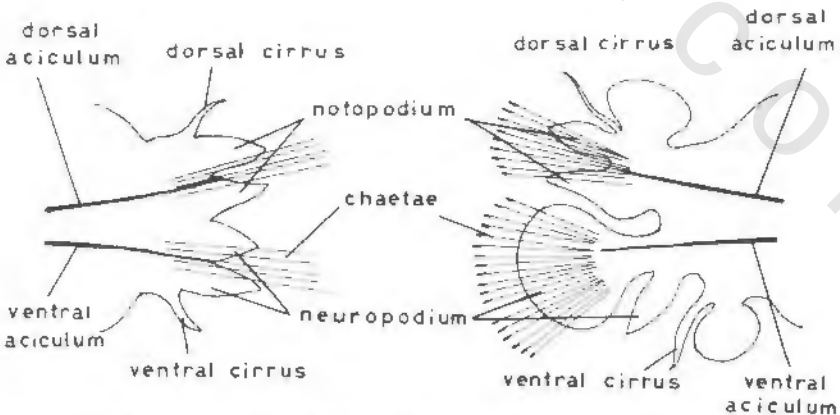
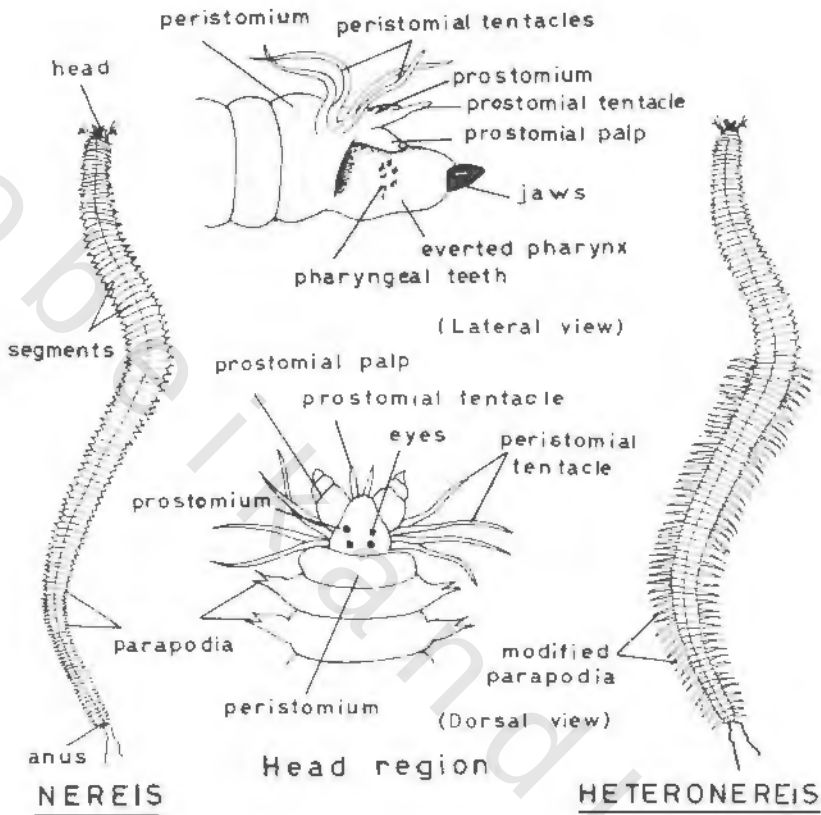
Nereis, and the Polychaeta in general, are among the least modified annelids. Therefore, they are better representatives of the phylum Annelida than the Oligochaeta which are more specialized and modified for terrestrial life.

Morphology

Nereis has an elongated, almost cylindrical body with a somewhat tapering posterior end. The most noticeable feature of this worm, as of the earthworm, is the division of its body into a large number of identical ring-like segments, separated by **intersegmental grooves**. *Nereis*, however, exhibits more obvious cephalization than the earthworm, i.e. its prostomium and peristomium form a more distinct "head" provided with special sensory organs of sight, touch and taste.

The **prostomium** is a small triangular lobe which overhangs the mouth. It bears 4 large black **eyes** on its dorsal surface, a pair of short **prostomial tentacles** (tactile in function) in front, and a pair of longer and much thicker **prostomial palps** (probably gustatory) behind. The **peristomium** surrounds the **mouth** opening and consists of the first two fused body segments. It carries 4 pairs of long slender **peristomial tentacles**.

All the rest of the body segments, except the last or anal segment, are alike and each bears a pair of lateral flattened appendages known as the **parapodia**. The parapodium consists of 2 parts : a dorsal bilobed **notopodium**



Parapodium of Nereis

Parapodium of Heteronereis

and a ventral bilobed **neuropodium**, both supported by 2 long stiff internal chetae known as the **dorsal aciculum** and **ventral aciculum**. The notopodium bears a sensory **dorsal cirrus** (tactile) and a bunch of long chaetae lodged in a chaetigerous sac. The neuropodium likewise bears a **ventral cirrus** and another bunch of chaetae. The parapodia serve as limbs and also as gills since they increase the body surface available for respiration.

The **anus** opens on the last segment which lacks parapodia. Instead, it carries 2 pairs of long ventral **anal cirri**. A pair of **nephridiopores** lie on each segment, below the bases of the neuropodia.

Histological structure

The body wall of *Nereis* has the same general arrangement as in the earthworm. It is covered by an **epidermis** that contains glandular and sensory cells, and secretes a thin **cuticle**. Beneath the epidermis is a thin **circular muscle layer**, followed by a thick **longitudinal muscle layer** divided into 4 bands. In addition, 2 pairs of **oblique muscles** are found in each segment, extending between the ventral body wall and the two parapodia which they move.

Within the body wall is a wide, fluid-filled **coelomic cavity** lined by peritoneum or coelomic epithelium, and divided by transverse intersegmental septa in between the segments as in the earthworm.

Locomotion

Nereis burrows in the bottom sand, crawls among stones and seaweeds and occasionally swims freely in the water with the help of the parapodia and the chaetae. The parapodia serve as limbs by moving back and forth like paddles. The action of the parapodia is aided by alternating muscular contractions taking place on either side of the body.

Digestive system

The worm is carnivorous, feeding on other small worms, crustaceans, etc. The **mouth** opens into a wide **buccal cavity** which leads into a muscular **pharynx**. These two chambers are lined with cuticle which is especially thickened in certain places to form numerous small **teeth** in the buccal region,

and 2 large serrated **jaws** in the pharynx. Both regions can be everted, or turned inside out, and extended outside the mouth during feeding. The prey is thus grasped by the jaws and drawn inwards as the pharynx becomes retracted by muscles. The teeth aid in pulling in the food during the withdrawal of the pharynx.

The pharynx is followed by a narrow **oesophagus**, then a long **intestine** which has no typhlosole and ends in the **anus** on the last segment.

Respiration

Respiration takes place by diffusion through the whole body surface as in the earthworm. *Nereis*, however, is more active and therefore requires a more extensive respiratory surface. The area available for gaseous interchanges is enormously increased in *Nereis* by the thin flattened parapodia which are richly vascularized, or provided with numerous blood capillaries, therefore acting as gills.

Excretory system

This system consists as in the earthworm of segmentally arranged **nephridia**, one pair per segment, except the peristomium and the anal segment. Each nephridium opens internally into the coelom by a ciliated nephrostome, and leads to the exterior at the other end by a nephridiopore located below the base of a neuropodium.

Blood vascular system

This system includes a contractile **dorsal blood vessel** and a **ventral blood vessel** which run medially above and below the alimentary canal. The two vessels are connected with each other by pairs of segmentally arranged contractile transverse vessels which run within the intersegmental septa, on either side of the alimentary canal. The transverse vessels give off lateral branches to the intestine, parapodia and body wall in each segment. The blood is red and contains haemoglobin dissolved in the plasma.

Nervous system

The nervous system is also essentially similar to that of the earthworm, but the sense organs are better developed in *Nereis* and include the eyes.

the tentacles and cirri which are sensitive to touch, and the palps which are probably organs of taste.

Reproductive system

Unlike the case in the earthworm, sexes are separate in *Nereis* and the reproductive system is far more simpler. The gonads are numerous and are developed at a certain season of the year from the coelomic epithelium in most of the segments. The reproductive cells (either sperms or ova) bud off from the coelomic epithelium and mature in the coelomic cavity. There are no gonoducts to convey them to the exterior.

At the breeding time, when the worms mature, they leave their burrows in the bottom sand and swim actively near the surface. The males are attracted to the females and both swarm in large numbers at the surface. The segments containing the gonads rupture shedding the eggs and sperms into the water where fertilization takes place.

Heteroneries

In some species of *Nereis* there is no difference in appearance between immature and sexually mature individuals. In other species, however, distinct changes in body form take place so that distinct phases are recognized. The sexually mature phase is so different from the immature ordinary *Nereis* phase that it was once placed in a different genus called *Heteronereis*, but this is now recognized as merely a sexual phase of *Nereis*.

The *Heteronereis* phase exhibits various modifications especially in its posterior segments which contain the gonads. Two distinct regions become therefore recognized in its body : an anterior region, called the *atoke*, with ordinary unaltered segments, and a posterior one, called the *epitoke* with modified appendages. In the latter region, the parapodia become larger, more flattened and develop additional foliaceous outgrowths, and the chaetae become replaced by much longer, oar-shaped ones inserted fan-wise on the parapodium. Thus, the swimming ability of the worm is much increased. The eyes become also much enlarged. *Heteronereis* leaves its burrow and swims actively at the surface.

Development

Development is indirect. A characteristic free-swimming larva, called the **trochophore larva**, hatches from the egg and metamorphoses gradually into an adult. The trochophore has a **preoral ciliated band** by which it swims in the water and drives food particles into the mouth, an apical sense organ carrying a tuft of apical cilia at its upper pole, a complete gut with mouth and anus, a larval nephridium, some mesoderm cells, and encloses a wide blastocoel.

The lower or postoral half of the trochophore gradually elongates then becomes divided into a series of segments which develop bristles. The ciliated bands of the larva disappear and the young worm settles to the bottom and continues to grow, adding new segments at its posterior end throughout its life.

C. CLASS HIRUDINEA

Hirudo medicinalis

(The Medical Leech)

This is a common freshwater annelid which lives in ponds and streams feeding on the blood of vertebrates like fish, frogs, etc. Man has long made use of this worm by letting it suck the blood of some patients, hence the name "medical leech". It is regarded as an ectoparasite.

The leech has a dorso-ventrally flattened body which is capable of considerable elongation and contraction. The body has a greenish brown colour, with a darker dorsal surface pigmented with yellowish longitudinal stripes and black spots. It bears no chaetae or parapodia. At each end of the body there is a cup-shaped sucker. The **anterior sucker** is perforated by the mouth, while the much larger **posterior sucker** is unperforated.

The external segmentation of the body does not correspond to the true internal segments. The body consists of a fixed number of **segments** (only 33), but is divided externally into a much larger number of **annuli**. Every 5 annuli correspond to one internal segment, except at the anterior and posterior

ends of the body where the number of annuli per segment is less.

The first 5 segments carry 5 pairs of small pigmented **eyes** on the dorsal side; the rest of the segments carry each a row of minute **segmental papillae** of sensory function. Seventeen pairs of **nephridiopores** open on the ventral side of segments 7-23, and the **anus** opens mid-dorsally just in front of the posterior sucker. The genital openings are single and median. The **male genital opening** lies on the mid-ventral side of segment 11, and the **female genital opening** on segment 12.

Histological structure

The **epidermis** is covered with thin **cuticle** which is shed periodically and renewed. It is followed by a **circular muscle layer**, a **longitudinal muscle layer** and numerous diagonal and dorsoventral muscle strands. The coelomic cavity, unlike that of the earthworm or *Nereis* is greatly obliterated or reduced, by the latter muscle strands and by connective tissue, to a system of **coelomic sinuses** which are filled with blood and replace entirely the circulatory system. Close around the gut and the blood sinuses there is a peculiar spongy pigmented tissue known as the **botryoidal tissue** which is probably of excretory function, acting like the chloragogenous cells of the earthworm.

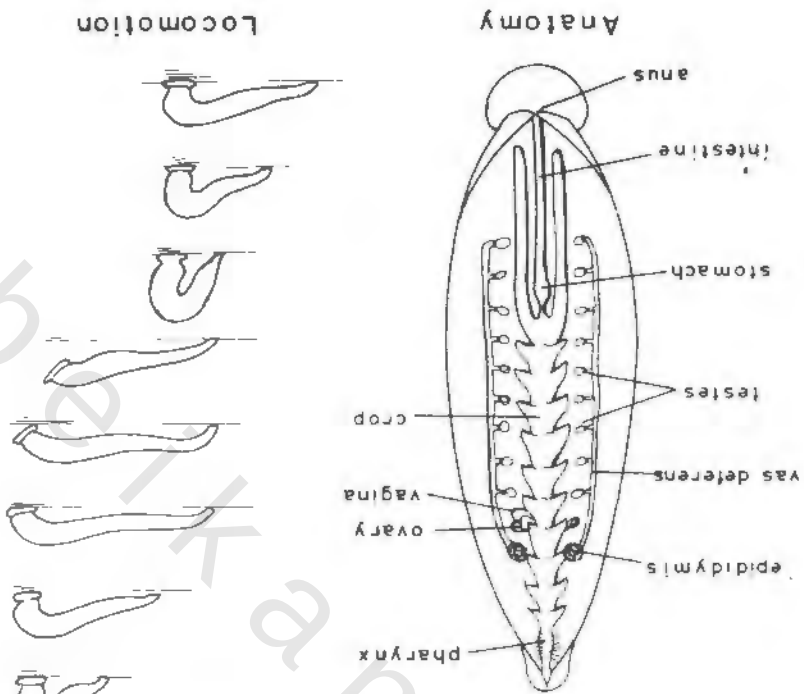
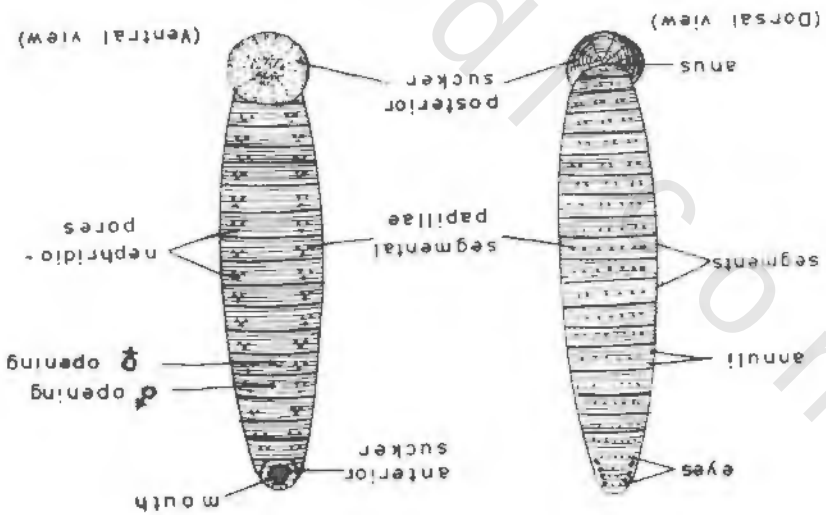
Locomotion

The leech either swims freely in the water by vertical undulations of its body, or walks and loops using its suckers in much the same way as *Hydra* does.

Digestive system and Nutrition

The alimentary canal shows various modifications correlated with the blood sucking habits of this animal. The buccal region, surrounding the **mouth**, encloses 3 serrated chitinous **jaws**, one dorsal and 2 ventro-laterals. It is followed by a highly muscular suctorial **pharynx**, then a voluminous **crop** which extends along 11 segments and consists of 11 thin-walled wide chambers, each provided with a pair of lateral pockets or diverticula. The crop is followed by a small digestive **stomach**, then a narrow **intestine** which opens to the exterior by the **anus**.

HIRUDO



In sucking blood, the leech attaches to the body of its host by the posterior sucker, applies its anterior sucker to the host's skin, makes a triradiate wound in it with the jaws, and sucks the host's blood by its muscular pharynx. Numerous unicellular salivary glands open close to the mouth. They secrete **hirudin**, a substance which prevents the coagulation of blood while the leech is feeding. After filling its crop with the victim's blood, the leech drops off, seeks shelter and digests slowly that blood over a period of several weeks.

Respiration and Excretion

Respiration takes place by diffusion through the skin. Excretion is mainly carried out by 17 pairs of **nephridia** which open to the exterior through 17 pairs of nephridiopores on segments 7-23.

Blood vascular system

Hirudo does not have a closed blood system as that of the earthworm and *Nereis*. Its blood does not circulate in true blood vessels formed independently of the coelom, but in coelomic spaces or sinuses. The most important of these sinuses are four longitudinal ones which connect with each other on both sides of the body : one dorsal, one ventral and 2 laterals. The dorsal and ventral blood sinuses lack muscular walls, but the two laterals have muscular walls and are therefore referred to as the lateral blood vessels. The blood contains haemoglobin dissolved in the plasma.

Nervous system

This system consists, as in other annelids, of an **anterior nerve ring** bearing a pair of **cerebral ganglia** and a double **ventral nerve cord** with a **ganglion** in each body segment.

Reproductive system

The leech is hermaphrodite and has a complicated reproductive system. It has 9 pairs of small **testes** lying in segments 12-21. The testes of each side lead by **vasa efferentia** into a long **vas deferens** which passes forwards and leads into a **vesicula seminalis**, followed by an **ejaculatory duct**. The 2 ejacula-

tory ducts open through the **penis** mid-ventrally on segment 11.

The female system consists of 2 **ovaries** and 2 **oviducts** which join in a single **albumen gland** and a **vagina**. The latter opens to the exterior mid-ventrally on segment 12.

Mutual copulation and cross fertilization occur. The eggs are laid in cocoons on stream banks outside the water and develop directly, hatching in young leeches which resemble the parents.

II. PHYLUM ARTHROPODA

Arthropoda is the largest phylum in the animal kingdom. About three-fourths of the species belong to this group. It is a very successful group that has invaded all environments. They are adapted for life on land, in soil, in fresh, brackish or salty water, and in air. Moreover, arthropods have a wide range of feeding habits; they feed on solid food materials or juices, or on vertebrate blood. Many of them are free-living, and others live as parasites on plants and other animals, or as predators. Most arthropods play an important role in the general economy of man, his crops, and his livestock. They may be beneficial to man, e.g. honey bees, silk worms, edible crustaceans; or harmful, causing annoyance; or acting as vectors of several diseases, e.g. mosquitoes, lice, bed-bugs, fleas, ticks and mites, or formidable and poisonous, e.g. spiders, scorpions and myriapods.

General characters

1 — Arthropods like annelids, have bilaterally symmetrical, triploblastic, coelomate and metamerically segmented bodies. However, their bodies are divided into a smaller number of segments which are not all alike but differ in form and structure. They are also usually grouped into three main regions recognized as the head, thorax and abdomen.

2 — They have paired jointed appendages which are specialised in many ways, thus adapted to perform various functions. The name Arthropoda means "jointed legs" and refers to the kind of limbs these animals possess.

3 — The body segments and limbs are covered with a thick, hard, chitinous cuticle which provides protection and support to the soft tissues and serves for the attachment of muscles. Therefore it is considered an exoskeleton. This cuticle is secreted by the epidermis in the form of a series of hard skeletal plates or sclerites, separated by areas of thin flexible cuticle which act as joints permitting movement of the body segments and limbs.

4 — The coelom is greatly reduced in adult arthropods, being represented only by the cavities of the gonads and some excretory organs. The body

cavity is therefore not a coelom, but a haemocoel, filled with blood and forms part of the circulatory system.

5 — They possess an open blood vascular system which consists mainly of the haemocoelic body cavity. Blood circulation in this cavity is maintained by the pulsations of a dorsally situated tubular heart.

6 — Their alimentary canal is simple and basically similar to that of annelids, but the mouth is not terminal, i.e. does not open on the first body segment.

7 — Aquatic arthropods respire by gills and through the body surface, but most terrestrial forms respire by a system of branching air tubes known as the tracheae, or by lung books.

8 — They have no nephridia or cilia. Excretion is carried out by coxal glands and/or Malpighian tubules.

9 — They have a well developed muscular system composed of a series of separate striated muscles which do not form part of the body wall as in annelids. These muscles insert on the inner surface of the exoskeleton and move the various parts of the body and limbs in a similar way as in the vertebrates.

10 — Their nervous system is built up on the same plan as annelids, but is relatively more concentrated. The nerve ganglia are fewer in number and some of them fuse together. The sense organs are highly developed and include simple or compound eyes, sensory setae, auditory organs and statocysts.

11 — Sexes are separate, and the young usually hatch from the eggs in an immature stage that undergoes a gradual change, called metamorphosis, to become adult.

Classification

Phylum Arthropoda is classified into a number of classes, the most important of which are the following :

A. Class Crustacea

This includes most aquatic forms which breathe by means of gills or modified appendages. A few land forms are present. Typically, the crusta-

cean body is divided into three regions : a head, usually composed of fused segments, and carrying 2 pairs of antennae, and modified appendages acting as mouth parts; a thorax, carrying a number of specialised appendages; and an abdomen, formed of a number of segments each carrying a pair of appendages. Commonly known examples of the Crustacea are the prawns and crabs.

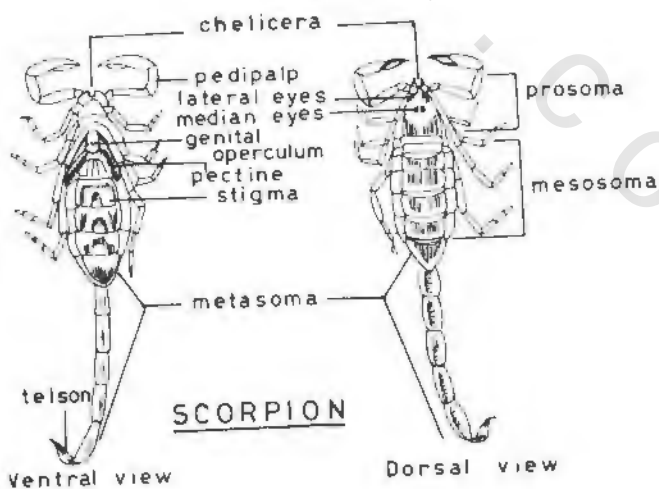
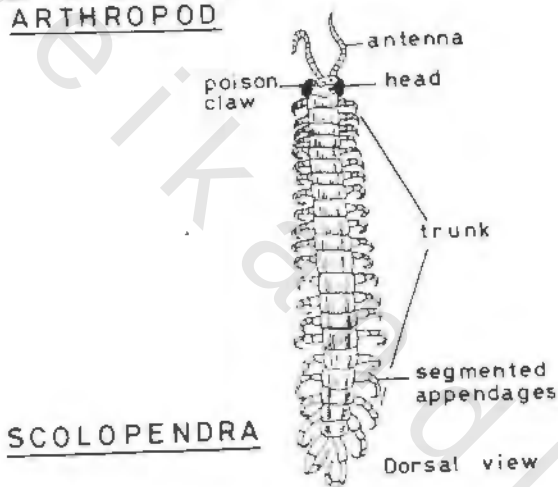
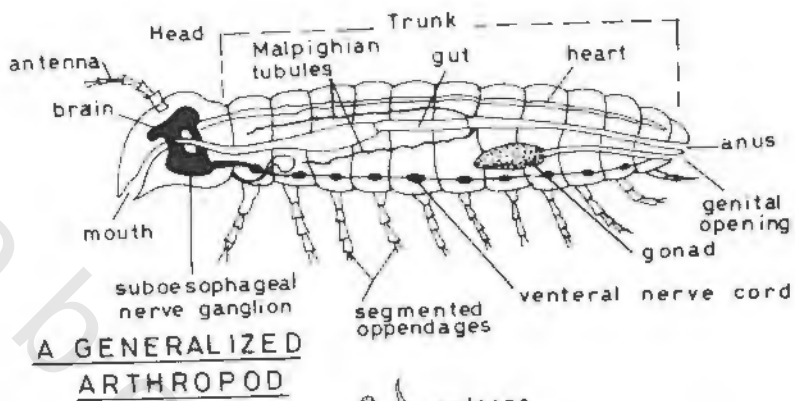
B. Class Myriapoda

This includes terrestrial arthropods which respire by means of tracheae. The body is multisegmented, and distinguished into a head carrying one pair of antennae and mouth parts, and a trunk composed of several segments each carrying one pair of appendages, as in centipedes (e.g. *Scolopendra*) or 2 pairs of appendages as in millipedes (e.g. *Julus*).

Scolopendra is a poisonous myriapod which lives in tropical countries and feed, usually at night, on insects and worms. The body is dorsoventrally flattened, and composed of head and trunk formed of 22 segments, each, except the last segment, carrying a pair of jointed appendages. The appendages of the first trunk segment, which contribute to the mouth parts, are modified into poison claws containing poison glands. The bite of these animals is fatal to the prey and dangerous to man.

C. Class Insecta (Hexapoda)

This class includes tracheate arthropods which possess 3 pairs of legs, hence the name Hexapoda. The body of an insect is divided into head, thorax and abdomen. The head is composed of 6 fused segments and carries one pair of antennae, a pair of compound eyes (each formed of a number of simple ommatidia), and mouth parts which modify in various ways according to the feeding habits of the insect. The thorax is composed of 3 segments, each carrying a pair of walking legs. In winged insects, called Pterygota, there are usually 2 pairs of wings arising on the second and third thoracic segments respectively. The second pair of wings may be modified or absent. Some insects are wingless, hence, they are called Apterygotes. The abdomen is composed of varying number of segments not exceeding eleven, and usually carries no locomotory appendages. During development, many insects metamorphose or pass onto several stages until they



become adults. Metamorphosis may be incomplete or complete as represented in the various insect orders.

D. Class Arachnida

This group of arthropods includes some aquatic and numerous terrestrial forms which respire by means of gills (aquatic), or by tracheae and lung books (land forms). Exceptionally, this class exhibits certain morphological characteristics by which it differs from all other classes of arthropods. Arachnids are called **Chelicerata** since the first pair of appendages is in the form of claw-like pincers or chelicerae, while all other classes are known as **Mandibulata**, as they possess mandibles as functional mouth parts. Furthermore, arachnids possess no antennae, which characterise all other arthropods. The arachnid body is divided into an anterior region or prosoma carrying 6 pairs of appendages, viz. chelicerae, pedipalps and 4 pairs of walking legs. This prosoma does not correspond to the proper head region of other arthropods. The other region of the body is called opisthosoma and is usually segmented and sometimes distinguished into mesosoma and metasoma. The opisthosoma bears no appendages and is not homologous to the proper abdomen of arthropods. Arachnida includes scorpions (order Scorpionida), spiders (order Araneida), ticks and mites (order Acarina), as well as several other examples belonging to other orders.

In the present text the morphology and biology of only some medically important arthropods, which are known to be poisonous to man or to act as vectors or transmitters of several human disease pathogens, are considered.

CLASS INSECTA (HEXAPODA)

This class includes numerous orders which are classified according to their mode of development or metamorphosis from the egg to the adult, and also to their possession of wings and the mode of wing formation.

Some orders possess no wings at any stage of development, i.e. they are wingless, and therefore called **Apterygota**. They also have a simple or direct mode of development, during which they pass through a number of very similar stages, or "**instars**", until they reach the adult stage. Thus they do not exhibit any remarkable changes in the life cycle and are therefore also called

Ametabola, i.e. showing no or very slight degree of metamorphosis. These insects are generally primitive. Springtails and silverfishes are common examples of apterygote, ametabolous insects.

The other insect orders possess wings, i.e. **Pterygota**, and pass during their development through a number of immature instars which show remarkable morphological changes until they reach the mature adult stage. Because they undergo metamorphosis, they are called **Metabola**. The degree of metamorphosis varies considerably in this group. Some of these winged insects have young stages, usually called **nymphs**, which resemble adults, except for the absence of a genital aperture. They possess similar type of mouth parts, eyes, and body form as the adults. These insects are said to undergo incomplete metamorphosis and are therefore called **Hemimetabola** or **Heterometabola**. In this group, the wings develop externally and are visible throughout most of the nymphal stages. Thus they are also called **Exopterygota**. Cockroaches (order Dictyoptera), locusts, grasshoppers, and crickets (order Orthoptera), bed-bugs (order Heteroptera), and lice (order Anoplura) are common examples of exopterygote, hemimetabolous insects.

Other winged insects show a remarkable degree of metamorphosis. The egg hatches into a stage which differs completely from the adult. This stage is called **larva**. The larva metamorphoses into **pupa** then adult. This is known as complete metamorphosis, and these insects are called **Holometabola**. The wings develop internally and are not visible in any stage of development, except when they are outfolded in the emerging adult. They are therefore also called **Endopterygota**. Beetles (order Coleoptera), ants, wasps and bees (order Hymenoptera), butterflies and moths (order Lepidoptera), houseflies and mosquitoes (order Diptera) and fleas (order Aphaniptera) are examples of endopterygote, holometabolous insects.

Several insects are important from the medical point of view, since they suck blood and therefore act as vectors and transmitters of many pathogens to man. Common examples of such insects are bed-bugs, lice, fleas and mosquitoes.

1—The bed-bug

Cimex lectularius

(Order Heteroptera)

Bed-bugs are temporary, obligatory ectoparasites which bite man and feed on his blood by means of their piercing and sucking mouth parts. They hide in dark cracks and crevices in the walls, in bed mattresses and in furniture and attack their host at night.

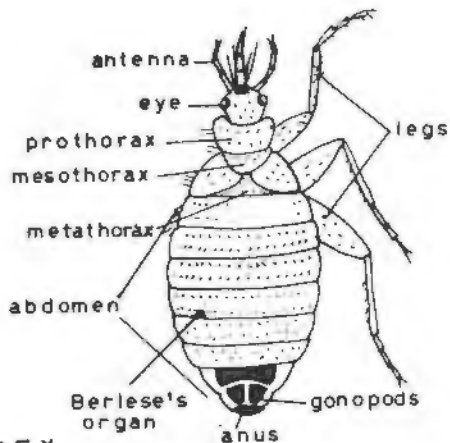
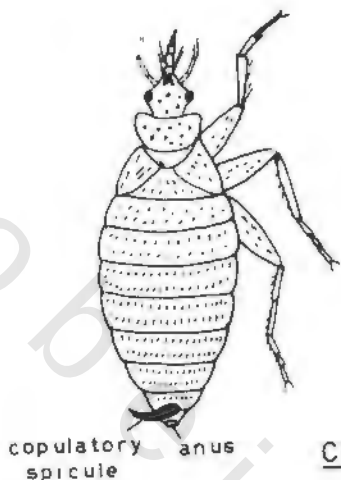
Morphology

The body is broad, dorso-ventrally flattened and covered with small bristles. Wings are absent, except for a pair of small bristly pads which represent rudiments of the first pair of wings on the mesothorax. The head carries two prominent **compound eyes** projecting aside, a pair of long 4-segmented **antennae**, and the mouth parts or proboscis, forming a **rostrum** which is usually bent backward underneath the body. The **mouth parts** are of the **piercing and sucking type**, and consist of a **labrum** as a small dorsal flap, a pair of **mandibles**, a pair of **maxillae** and a **labium**. Both mandibles and maxillae are long needle-like stylets used for piercing the host skin; each maxillary stylet has 2 grooves on its inner surface, and when the stylets are applied together the grooves form two tubes. The dorsal tube communicates with the pharynx and acts as a **suction tube**, while the ventral tube is connected with the salivary duct and acts as an **ejection tube** through which saliva is discharged. There is no maxillary palp. The labium is a long 4-segmented process which possesses a median, dorsal groove in which the stylets are enclosed when not in use. Labial palps are absent.

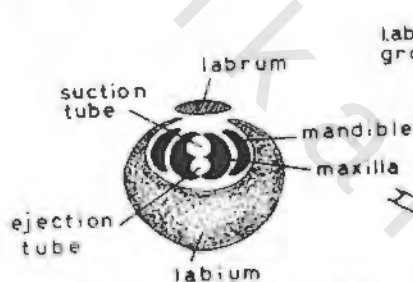
The thorax is 3-segmented, the mesothorax carries the rudiments of the fore-wings or **hemi-elytra**, and each segment carries one pair of segmented **legs**, each terminating with a 3-segmented **tarsus** and a pair of **claws**.

The abdomen is composed of 10 segments, the first and the second fuse together, while the last or tenth segment is reduced and carries the anus.

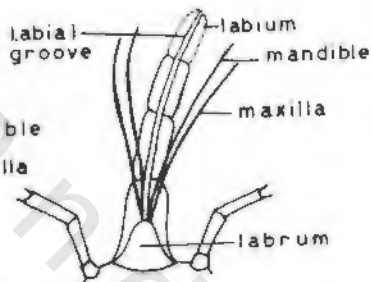
In the female, the posterior end is rounded, and the **genital opening**, lying ventrally at the posterior end, is a vertical slit surrounded by paired, sclerotized plates or **gonopods**. The **opening of Berlese's organ** lies on the right



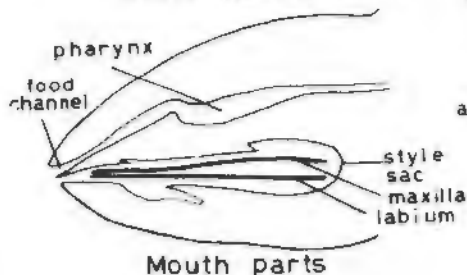
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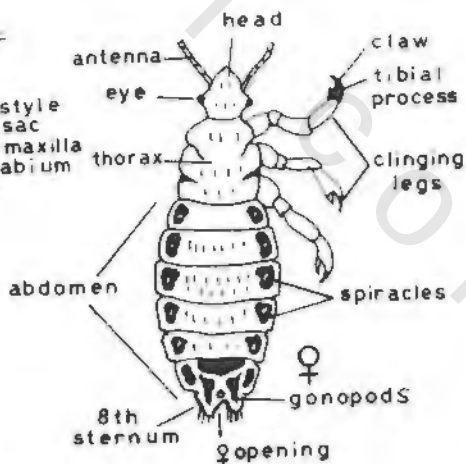
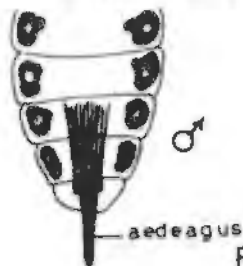
T.S. of mouth parts



Mouth parts



Mouth parts



PEDICULUS

side of the sternum of the fifth segment. Through this opening, sperms received during copulation pass into the oviducts.

In the male, the posterior end of the abdomen is narrow and the ninth segment carries a conspicuous **copulatory spicule**.

Life cycle

The female lays eggs 3-4 times a year: each time about 50 eggs are laid. Eggs are operculated and the shell contains numerous, very minute spines. They hatch into nymphs within 5-10 days. Nymphs resemble adults, except for the absence of genital openings. After four moultings, nymphs reach the adult stage.

Disease relationships

Normally, bed-bugs are not known to transmit any disease to man. But they may act as mechanical vectors of certain disease. Bed-bugs can experimentally transmit relapsing fever spirochaetes, trypanosomes and certain viruses from one individual to another.

Other species of blood-sucking bugs, such as the winged bugs, *Rhodnius* and *Triatoma*, known as kissing bugs and common in South America, act as main vectors of Chagas' disease of man caused by certain species of *Trypanosoma*.

2 — The human louse

Pediculus humanus

(Order Anoplura)

Human lice are cosmopolitan, blood-sucking ectoparasites of man that feed on his blood and consequently act as biological vectors of several human diseases caused by various pathogens. Two varieties of human lice infest man; the body louse or *Pediculus humanus corporis* and the head louse or *P. h. capitis*. Another type of human lice, *Phthirus pubis* or "the pubic louse", infests mainly pubic and peri-anal regions of man, and occasionally the axilla, eye-lashes and other hairy regions of the body.

Morphology

The body of *Pediculus humanus* is dorso-ventrally flattened and divided into head, thorax and abdomen.

The head carries **reduced eyes**, 5 - segmented **antennae** and **piercing and sucking mouth parts** which are normally retracted inside, and only protrude during feeding. The mouth parts are represented by two needle-like **stylets** lying one above the other in a **stylet sac**, ventral to the pharynx. Originally during development, the stylets are paired, but later, the halves fuse together. The **dorsal stylet** represents the fused maxillae, and the **ventral stylet** represents the labium. Running in between the 2 stylets is a long **hypopharynx** which contains the salivary duct. The mandibles are greatly reduced, and a rudimentary pharynx is modified into a sucking tube whereas the stylets form the piercing organ.

The 3 thoracic segments are distinctly separated. Wings are absent, and the walking legs are specialised for clinging.

The abdomen is 8-segmented, the first segment represents the fusion of 2 embryonic segments, the last segment is reduced. In the female, the abdomen end is cleft; an inverted V-shaped cleft of the eighth segment which carries the genital aperture. Two ventral **gonopods**, enclosing the aperture, secrete a cement substance which helps in adhering eggs to the hairs or clothes of the host. In the male, the abdomen end is narrow and carries a **penis** or **aedeagus** which protrudes beyond the posterior end.

Life cycle

Human lice permanently live on the host. The female lays about 200-300 eggs during the life span; about 12 eggs are laid every day. Eggs are operculated, and fix firmly to hairs or clothes material. They hatch after about one week into **nymphs** which resemble adults in morphology, but are smaller, paler, and sexually immature. Nymphs are blood suckers, and moult three times before reaching adulthood.

Disease relationships

Both head and body lice are biological vectors of the following human diseases :

- 1 — Epidemic typhus caused by *Rickettsia prowazeki*.
- 2 — Trench fever caused by *Rickettsia quintana*.
- 3 — Relapsing fever caused by the spirochaete, *Borrelia recurrentis*.

3 — The human flea

Pulex irritans

(Order Aphaniptera)

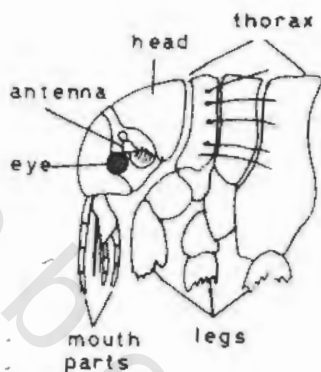
Fleas are wingless holometabolous insects, which in the adult stage feed on the blood of vertebrate hosts, thus acting as vectors of several diseases. Several species infest mammals, e.g. *Pulex irritans*, the human flea; *Xenopsylla cheopis*, the rat flea; *Ctenocephalus canis*, the dog flea; and others.

Morphology

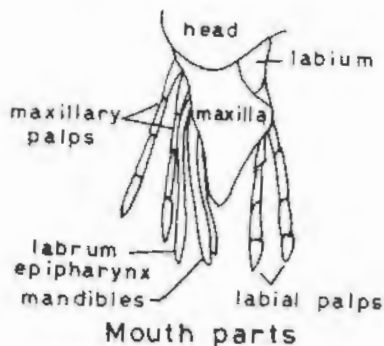
The body is bilaterally compressed. The head is broadly attached to the thorax, and carries a pair of **simple eyes** which may be absent in some species, a pair of short stout **antennae**, and mouth parts. The antenna consists of three segments, the **scape**, the **pedicel** and the **flagellum**, and lies in a groove behind the eye. The mouth parts are modified into the **piercing and sucking type**. These consist of a **labrum-epipharynx**, two **mandibles**, a pair of **maxillae** reduced into triangular blades and possessing long 4-segmented **maxillary palps**, and an oblong **labium**, which is reduced and carries 5-segmented **labial palps**. The labrum-epipharynx is grooved and forms together with the mandibles a **suction tube** or food channel, through which extends a short **hypopharynx**.

The thorax is 3-segmented. Wings are absent and legs are long and adapted for jumping.

The abdomen is 10-segmented. On the ninth segment, there is a dorsal sensory plate called **pygidium**. The posterior end of the abdomen is rounded in the female, and directed upwards in the male. Moreover, the male is characterised by the presence of a long, coiled spring-like **aedeagus**, and by the modification of the terminal abdominal segments into finger-like **claspers**,



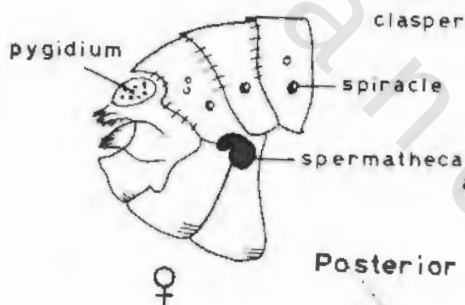
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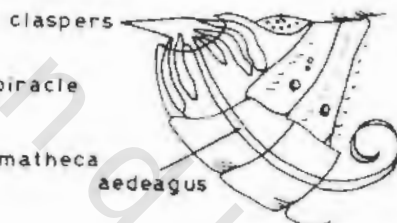
Mouth parts



T.S. of mouth parts



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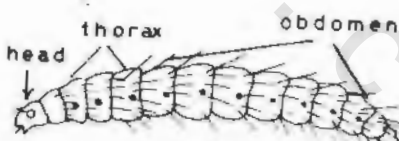


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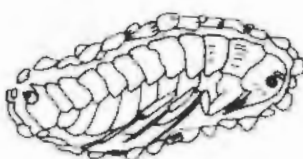
Posterior end



Egg



Larva



Pupa inside cocoon



Cocoon

Life cycle

while the female is distinguished by the presence of a comma-shaped, chitinized **spermatheca**. The morphology of the aedeagus and spermatheca is important in the differentiation between species.

Life cycle

A female flea lays about 300-500 eggs during its life, about 3-10 eggs per day. Eggs hatch into worm-like **larvae**. The body of the larva is composed of a head, 3-segmented thorax and 10-segmented abdomen. All segments are provided with bristles directed towards the posterior end.

The larva feeds on solid matter, and moults twice before it spins a silky cocoon where it pupates, i.e. transforms into the **pupa** stage. The pupa metamorphoses into adult, which leaves the cocoon in 1-2 weeks.

Disease relationships

Fleas are the main vectors of two important diseases transmitted to man.

1 — **Plague**. This is a bacterial disease caused by *Pasteurella pestis*, and is primarily a disease of rats. When the rat flea, *Xenopsylla cheopis*, feeds on an infected rat, the plague bacteria multiply in the proventriculus of the gut, and block the lumen. When infected fleas feed on man, these bacteria are regurgitated, i.e. go back with injected blood, through the oesophagus to the mouth parts, then into the skin; thus man acquires infection. Faeces of infected fleas are contaminated with the pathogens, and can cause infection to the host when introduced into wounds or skin abrasions. Transmission of plague bacteria from man to man is carried by the human flea *Pulex irritans*.

2 — **Endemic or murine typhus**. This is a rickettsial disease, closely related to louse-borne typhus. The causative agent is *Rickettsia mooseri* (= *R. typhi*). The rickettsia multiplies in the gut epithelium of the flea, invades the gut lumen, and passes out with faeces. Contaminated faeces enter the host skin through wounds or abrasions while the flea is feeding.

In addition to the above mentioned diseases, fleas are intermediate hosts and vectors of certain cestode parasites of man, e.g. *Hymenolepis nana*.

4 — Mosquitoes

Culex, Anopheles and Aedes

(Order Diptera)

Mosquitoes are endopterygote, holometabolous insects which have a cosmopolitan distribution. Adult female mosquitoes feed on vertebrate blood e.g. birds, and mammals including man, and their mouth parts are well adapted for piercing and sucking. Therefore, they are capable of transmitting several disease agents to their hosts.

The adult mosquito body is slender and delicate, and is divided into head, thorax and abdomen.

The head is subglobular and carries two large **compound eyes**, two long multi-segmented hairy **antennae**, and mouth parts. The mouth parts consist of a **labium epipharynx**, 2 thread-like **mandibles**, 2 needle-like **maxillae**, each with a 3-segmented **maxillary palp**, and a **labium** ending with 2 sensitive **labella**. A long **hypopharynx**, pierced by the salivary duct, forms with the labrum epipharynx a food channel. The labium is grooved so as to enclose the rest of the mouth parts.

The mouth parts of the female mosquito are modified for piercing and sucking. Thus, the blade-like mandibles and hypopharynx and the serrated maxillae cut and pierce the skin of the wound. The labrum epipharynx, mandibles and maxillae form a sort of a tube which enters the skin. Saliva is secreted into the wound preventing coagulation of the blood, which is then passed through the food channels, into the alimentary canal by the pumping action of the muscular pharynx.

In male mosquitoes, the mouth parts are not adapted for piercing. The mandibles are absent and the maxillae are much reduced. Males feed on plant juices, and so are not concerned with transmission of diseases to vertebrates.

The mosquito thorax is 3-segmented; the second segment or mesothorax, is the largest and carries a pair of scaly membranous **wings**, while the third segment or metathorax carries a pair of rudimentary wings modified into

halters or **balancers**. Each of the thoracic segments carries a pair of long segmented walking legs covered with scales.

The long, slender abdomen is composed of 10 segments; the last segments carry external genitalia which in males are diagnostic in species differentiation. Both thoracic and abdominal segments are covered by scales.

Life cycle

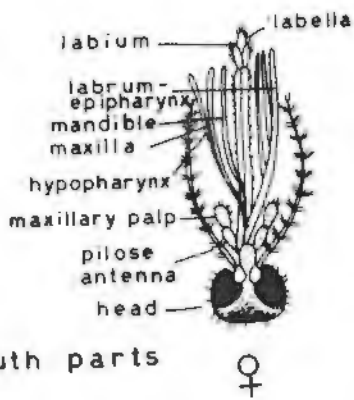
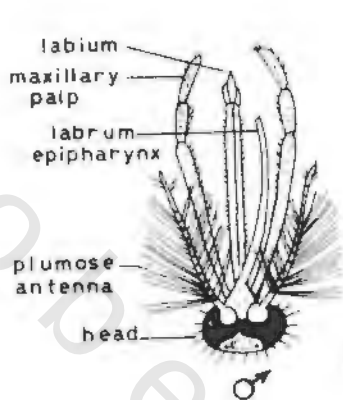
Fertilized female mosquitoes lay eggs after each blood meal. Eggs are laid either singly or in patches, in water or moistened habitats. The egg shape and arrangement in the patch are characteristic of each mosquito genus.

The egg hatches into an aquatic **larva**, which has distinct head, thorax and abdomen. The head carries a pair of eyes, a pair of short antennae, a pair of feeding brushes and mouth parts adapted for biting or chewing food. The thorax is composed of 3 fused segments and the abdomen is formed of nine segments. In *Culex* and *Aedes* the eighth segment carries a long **respiratory siphon** with two apical **spiracles** and lateral rows of spines (comb or pecten), while in *Anopheles*, the siphon is absent and the eighth segment carries two spiracles on its dorsal side, and two chitinated plates and a row of spines or pecten on the lateral sides. In all mosquito larvae, the last abdominal segment, the anal segment, carries **anal gills** and tufts of brush hairs. The larva moults after several instars, usually four, into a pupa.

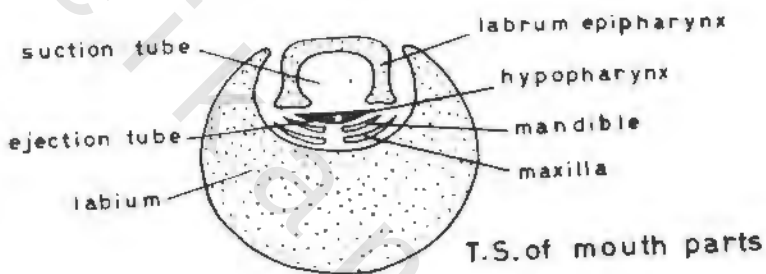
The **pupa** is comma-shaped, with anterior cephalothorax (fused head and thoracic regions), and a strongly curved, nine-segmented abdomen. The cephalothorax contains the head and thorax structures of the future adult, and carries a pair of **respiratory tubes**, which are trumpets in culicine mosquitoes and funnel-shaped in anophelines. These tubes lead into tracheal tubes. The eighth abdominal segment in the pupae of all types of mosquitoes carries a pair of membranous **paddles** which help in swimming and act as respiratory gills. The pupa moults into the adult mosquito.

Disease relationships

Mosquitoes are well known vectors of several diseases transmitted to man and animals during feeding. Female *Anopheles* mosquitoes are vectors of human malaria, caused by certain species of *Plasmodium*. Other *Plasmodium* species are transmitted by anophelines to monkeys and rodents.



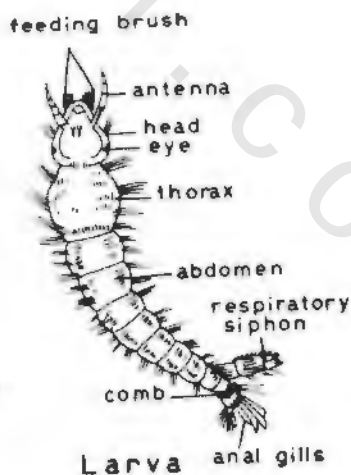
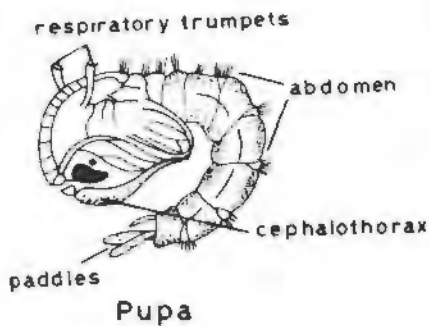
Mouth parts



CULEX



Cluster of eggs



Culex, *Aedes*, and rarely *Anopheles*, also transmit bird malaria, e.g. *Plasmodium gallinaceum* to chicken.

The females of certain *Culex* species, e.g. *C. fatigans* and *C. pipiens*, are vectors of human elephantiasis caused by filarial nematodes of the genus *Wuchereria*. *W. bancrofti* is the common filaria causing the disease in Egypt and is transmitted by *Culex pipiens*.

Several mosquitoes are vectors of human diseases caused by viruses. *Aedes aegypti* transmits yellow fever and dengue fever viruses to man. Several encephalitis viruses are also transmitted by mosquitoes to man and animals, particularly horses.

CLASS ARACHNIDA

1 — The scorpion

BUTHUS

Scorpions are nocturnal animals, which hide in crevices and under stones during daytime and become active and search for food at night. They inhabit tropical and subtropical regions of the world. Like other arachnids, scorpions are cannibals, i.e. eat each other, and feed on insects, spiders and small animals.

Morphology

The body of the scorpion is divided into 3 regions; prosoma, mesosoma and metasoma. The **prosoma** is composed in the adult of six segments which are fused together, thus showing no segmentation. Dorsally, the prosoma is covered by a hard **carapace** which carries a pair of **median eyes** at the centre and five pairs of **lateral eyes**. All eyes are of the simple type. Ventrally, the prosoma carries six pair of appendages. The first pair is the **chelicerae** which are preoral in position. The chelicera is 3-segmented, the two distal segments form a toothed **chela** or pincer, by means of which food is crushed. The second pair of appendages is the **pedipalps**. Each pedipalp is composed of six segments, the distal two of which form a powerful, toothed chela used for capturing the prey and acting as efficient offensive weapon. The other four pairs of appendages are **walking legs**. Each leg is formed of seven segments: coxa, trochanter, femur, patella, tibia, metatarsus and tarsus. The tarsus ends with curved claws.

The **mesosoma** is composed of six segments. Each is covered by hard exoskeletal plates, a dorsal **tergum**, and a ventral **sternum** connected laterally by **pleural membranes**. The first mesosomal segment carries on its ventral side the genital opening which is covered by a **genital operculum** (a modified appendage) and is, therefore, termed genital segment. The second segment carries a pair of comb-like appendages known as **pectines**. The function of these structures is said to be tactile, olfactory or possibly too, sexual. The rest of the mesosomal segments carry four pairs of slit-like openings, or **stigmata**, on the lateral sides of the sternal plates. These stigmata are respiratory openings, each leading into a respiratory chamber containing leaf-like cuticular foldings and known as a **lung book**.

The **metasoma** is formed of six segments which carry no appendages. The dorsal and ventral exoskeletal plates of each segment fuse together so that the segment is more or less cylindrical in shape. The last segment of the metasoma bears the **telson**, a bulb-like sting which contains a pair of poison glands and which is produced into a sharp curved spine.

Life cycle

Males are generally smaller and thinner than females. As in other arachnids, copulation is preceded by a period of courtship. Females usually devour males after copulation. Scorpions are viviparous, i.e. they give birth to young. The fertilized eggs are kept inside separate diverticula of the tubular ovary. Embryos develop in these diverticula and obtain their nourishment, by absorption, from the mother haemolymph through the thin walls of the diverticula. Youngs are then born, and the mother scorpion carries them on its back for maternal care. Youngs are similar to adults and when they grow old enough they leave the mother and lead an independent free life. Scorpions feed on sucking the juices of the crushed preys. The powerful chelicerae and the muscular pumping pharynx help in the feeding mechanism.

Scorpion venom

The ducts of the poison glands unite together to open close to the tip of the sting spine by means of a minute pore. When the scorpion strikes its victim by the metasoma or "tail", the sting spine pierces the skin and the

venom is forced into the wound. The venom is a clear fluid containing haemorrhagic, haemolytic neurotoxins and adenosine triphosphatase. It is quickly fatal to invertebrates and is sometimes fatal to man. However, an antitoxin or antivenom neutralises the injected venom and is able to effect a cure within a few hours.

ORDER ACARINA

Ticks and Mites

Acarina is a highly specialised group of Arachnida which has almost lost body segmentation and which shows complete fusion of the prosoma and opisthosoma into one single piece. The chelicerae and pedipalps form the functional mouth parts which are usually adapted for piercing and sucking. The other 4 pairs of appendages function as walking legs. However, the number of legs may be reduced to 2 only, as in some minute mites.

1 — Ticks

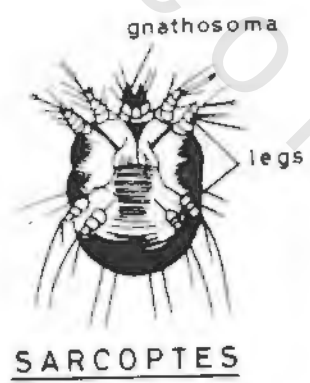
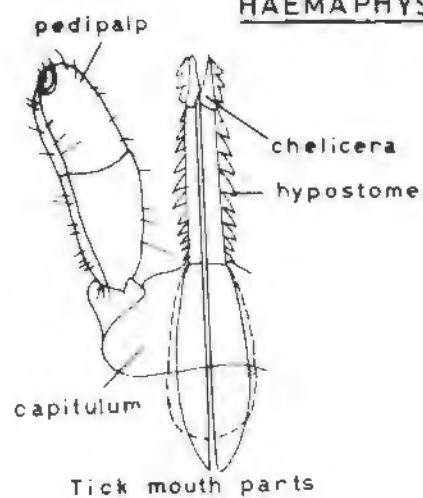
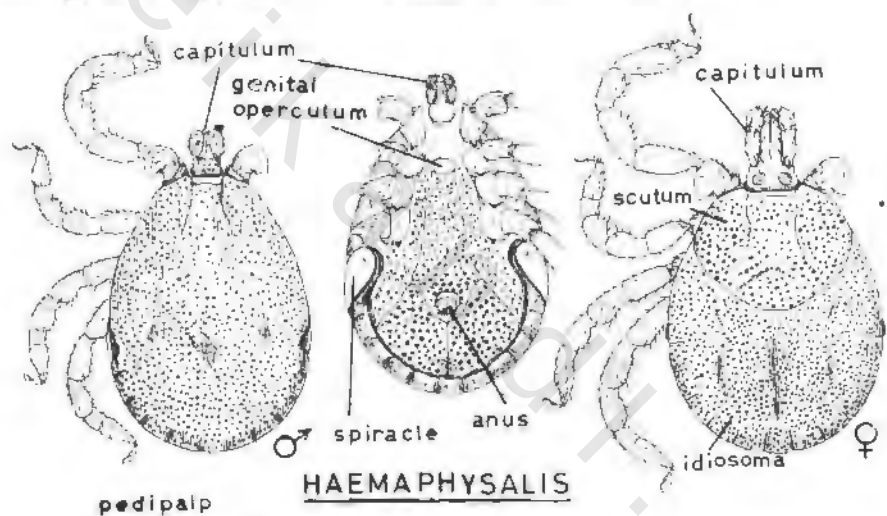
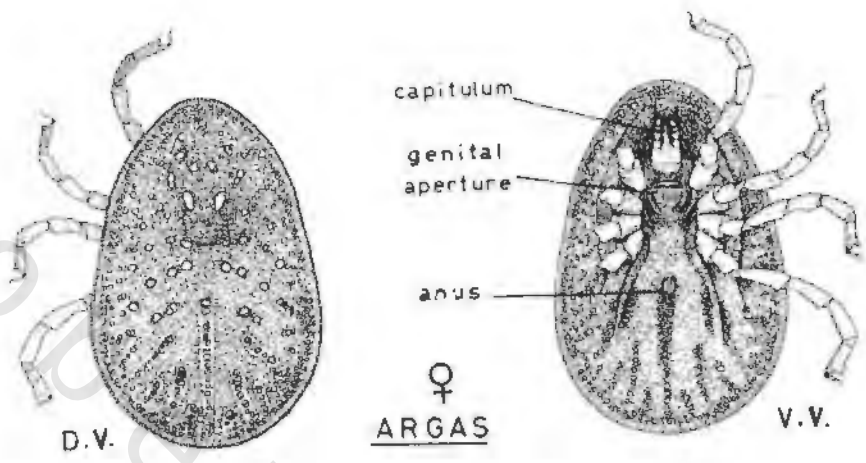
ARGAS and IXODES

Ticks are ectoparasites which feed exclusively on blood of vertebrates, such as amphibians, reptiles, birds and mammals including man. In many cases, they act as vectors of several diseases transmitted to their hosts. Ticks are characterised by the following :

1 — The body is not segmented, but can be distinguished into 2 divisions : the gnathosoma or capitulum and the idiosoma.

The **capitulum** is formed of a pair of blade-like **chelicerae** and a pair of short 4-segmented **pedipalps** fused together at the base. The ventral side of the capitulum is projected to form a median, toothed **hypostome** which anchors in the host skin during feeding. The capitulum is movable on the rest of the body. The **idiosoma** forms the rest of the body and carries the **walking legs** on its ventral side.

2 — Sexes are separate, and males are generally smaller than females.



The genital aperture lies on the ventral surface, between the coxae of the first and second pairs of walking legs.

3 — They respire by means of trachea. A pair of spiracles lie behind the coxae of the last pair of legs.

4 — The integument is leathery, and sometimes covered by a hard chitinized plate or **scutum**.

5 — They are oviporous. After copulation, the female lays eggs which hatch into **larvae** with 3 pairs of walking legs. Some ticks lay eggs without mating. These eggs develop by parthenogenesis, i.e. without being fertilized by sperms. Following a blood meal, the larvae metamorphose into **nymphs** with 4 pairs of legs and resemble adults, except for the absence of genital openings. Nymphs moult into adults after taking another blood meal.

6 — Some ticks possess one pair of **simple eyes**, located on the dorsal surface or lateral sides of the body.

Ticks are divided into 2 groups or families : soft ticks as *Argas* (Family **Argasidae**) and hard ticks as *Ixodes* (Family **Ixodidae**). Ticks of both groups differ from each other in the following :

a) The integument in soft ticks is leathery, and provided with small chitinized discs and mammillae, while in hard ticks it is provided with a hard skeletal plate or scutum on its dorsal side. The scutum covers the whole dorsal side in male hard ticks, whereas in females, nymphs and larvae, it covers only the anterior region of the dorsal integument.

b) The capitulum in soft ticks lies ventrally at the anterior region of the body, while in hard ticks it lies antero-dorsally. In larvae of both argasid and ixodid ticks, the capitulum extends antero-dorsally.

c) Several nymphal stages exist in soft ticks, while in hard ticks, there is only one nymphal stage.

d) Soft ticks are quick feeders; they attach to the host, suck blood and engorge in a very short time. Nymphs and adults feed frequently, while hard ticks are slow-and long-feeding ticks. They remain attached to the host for several days and feed only once. After feeding, the adult female lays a large mass of eggs and dies. Adult soft ticks, on the other hand, lay eggs after each blood meal.



Scanning electron micrograph of the head and mouth parts of a mosquito.



*Scanning electron micrograph of the capitulum of a hard tick.
(courtesy of Dr. I-Wu / Wang)*

e) Male and female argasid ticks are usually equal or subequal in size, while males of hard ticks are much smaller than females.

Medical and economic importance of ticks

1 — Ticks are important vectors of several diseases transmitted to man and his domestic animals during their bite. Several disease pathogens, e.g. protozoa, bacteria, rickettsiae and viruses are well adapted to live and multiply in the tissues of argasid and ixodid tick species. Some argasid ticks, e.g. *Ornithodoros*, transmit the relapsing fever spirochaetes to man. Similarly *Argas* ticks transmit spirochaetes to fowls. Several ixodid ticks, e.g. *Derma-centor*, *Boophilus* and *Rhipicephalus*, transmit spotted fever, rickettsiae, and encephalitis viruses (i.e. viruses which affect the nervous system) to man and animals. Among animal diseases, ticks are known to transmit several pathogenic protozoa, e.g. piroplasms.

2 — Tick bite may cause inflammation and damage to the host tissues. The tick salivary secretion, which passes into the wound during the bite, may cause tick paralysis to the host.

2 — Mites

Mites are minute acarines which may live freely in the soil and water; as ectoparasites on man, animals and plants; or as endoparasites, such as those which infest internal organs as tracheae, lungs, or facial pores in skin of man and animals.

Plant mites are serious pests affecting economic crops of the country. Ectoparasitic mites on animals may feed on skin secretions, feathers of birds, or may invade the surface tissues to form tunnels in the skin where they live and lay eggs, as the itch mite, *Sarcoptes scabiei*. Some mites form colonies in the skin and feed on hair follicles and sebaceous gland secretions. Other mites are blood suckers, thus having the opportunity of disease transmission to their hosts. Several species of mites are endoparasites, living in respiratory organs of insects, animals and man, and forming lung nodules.

BIOLOGICAL ASSOCIATIONS

Most animal species lead their own, independent life in various habitats. Other individuals live in association with organisms of the same or different species. Interaction between two individuals in such association is said to be homospecific, if they belong to the same species, or heterospecific, if they belong to different species.

Homospecific association is usually common among individuals forming united communities, as herds of cattle or flocks of sheep; or forming well-organized societies with a considerable division of labour, such as ants, bees or wasps.

Heterospecific association, on the other hand, is generally more complicated, and includes several types of associations ranging from a harmless, almost beneficial association to a harmful, or even fatal, type of association. Several terms are used to define this type of association according to the various degrees of relationships found among associated individuals, and the degree of their dependance on one another.

Phoresis is a term applied to an association merely for shelter, support or transportation from one place to another.

Commensalism defines a harmless association between two individuals, one of which gains benefit, but its metabolic requirements are not dependant on the other partner. Several protozoa, e.g. *Entamoeba coli* in the large intestine of man, are commensals.

Mutualism is a term used to define a more deeper and intimate type of beneficial association, where the two partners are metabolically dependant on each other. Benefit is exchanged between the two partners during their period of association. Intestinal flagellates living in the gut lumen of white ants (Termites) or in certain cockroaches are well known examples of mutual association. The insect is entirely dependant on the flagellate for the break down of wood cellulose, the main food of the insect. The flagellate secretes cellulase enzymes for wood digestion, and the insect gains the final product of such digestion. In turn, the flagellates depend on the insect for their

nutrient requirements and provision of the physical environment in which they live. The association between intestinal ciliates and ruminants is also mutualistic.

Parasitism shows a variable degree of metabolic dependance on the host. The parasite may be almost harmless or extremely harmful. Zooparasites of lower animals, such as the trypanosomes, intestinal sporozoa and filarial nematodes of cold-blooded vertebrates, are harmless to their host. But some of these harmless parasites in one host may become highly pathogenic in other host species.

The parasite may be metabolically dependant on the host for developmental stimulation, nutritional requirements, digestive enzymes and for control of its maturation. These biochemical and physiological aspects of dependance do not, in fact, involve the degree of harmlessness or harmfulness due to the parasitic association.

Symbiosis is a term that has long been used in two distinct ways. In a broad sense, it means "living together", thus indicating a variety of associations that include both commensalism and parasitism. In a more restricted sense, it denotes a particular type of association, implying mutual benefit and mutual interdependence. However, the term symbiosis or endosymbiosis is still applied to the very intimate and mutual association between certain microorganisms as bacteria and rickettsiae and a variety of hosts, particularly among arthropods.

III. PHYLUM CHORDATA

Phylum Chordata is the last phylum in the animal kingdom. This phylum follows, in sequence, phylum Echinodermata which is regarded as the last and most advanced group of invertebrates. Phylum Chordata includes the most complicated animal types; one of its subdivisions (subphylum Vertebrata) constitutes the group to which man belongs.

General characters

The following are the most important characters of the chordates by which they differ from all invertebrate groups :

1 — **The presence of a notochord** : All chordates possess a long flexible, rod-like supporting structure known as the notochord. The name of the whole phylum is derived from this feature. The notochord is not found in any group of invertebrates. In a cross section, the notochord appears formed of an inner tissue composed of vacuolated cells enveloped by a layer of fibrous tissue.

The notochord either persists throughout the whole life, or may only appear in the embryonic stages and then becomes gradually replaced by the vertebral column. The latter case is found in higher chordates, namely, the vertebrates.

2 — **A dorsal nerve cord** : In chordates, there is a tubular nerve cord which runs dorsal to the notochord. This is contrary to the case in the invertebrates in which the nerve cord extends along the ventral side of the body. Also, the nerve cord in the invertebrates is solid, whereas it is hollow in the chordates. The internal cavity of the nerve cord is known as the central canal. The anterior part of the nerve cord becomes enlarged to form the brain.

3 — **Pharyngeal pouches and gill-slits** : Chordates possess a number of paired gill pouches in the pharyngeal region. These pouches open externally by narrow openings known as the gill-slits. Such slits either remain through-

out the whole life of the animal, in which case they are used for respiration as in fishes, or may only appear in the early embryonic stages, then become closed gradually during subsequent embryonic development, and lungs develop instead for respiration.

4 — **Direction of blood flow in the dorsal and ventral blood vessels :** The blood flows backwards in the dorsal blood vessel and forwards in the ventral blood vessel. This is contrary to what occurs in the invertebrates.

5 — **Tail region :** The tail region is the part of the body lying posterior to the anal opening, and contains the end portion of the notochord as well as the posterior part of the dorsal blood vessel. No such post-anal structure is found in the invertebrates. The tail either remains throughout life, or may develop only in the embryonic stages. In the latter case, the tail region disappears gradually before birth as in man, or before the adult stage is reached, as in frogs and guinea-pigs.

These characters are represented either in the adult or at earlier stages of development.

Classification

Phylum Chordata is classified into the following subphyla :

A. **Subphylum HEMICHORDATA**, in which the notochord is only found in the anterior portion of the body.

B. **Subphylum UROCHORDATA**, having the notochord in the posterior portion of the body.

C. **Subphylum CEPHALOCHORDATA**, in which the notochord extends along the whole length of the animal.

D. **Subphylum VERTEBRATA**, in which the notochord appears only in the early developmental stages, then becomes gradually replaced by the vertebral column in the adult.

A. SUBPHYLUM HEMICHORDATA

This group includes worm-like chordates, the body of which is distinguished into the following parts :

- a) The **proboscis**, which is an anterior egg-shaped part.
- b) The **collar**, which is a small cup-shaped portion lying posterior to the proboscis. It contains the mouth opening as well as a primitive brain followed by the spinal cord.
- c) The **trunk**, which forms the largest part of the animal. The anterior part of the trunk region carries a number of paired gill-slits.

An example of this group is *Balanoglossus*.

B. SUBPHYLUM UROCHORDATA

This subphylum includes a group of small marine animals, which have tadpole-like larvae. The adult urochordates are known as tunicates because they are covered externally by a gelatinous membrane known as the **tunic**. An example of this group is *Ascidia* which is commonly known as the sea squirt.

ASCIDIA

Morphology

The body of the animal is sac-like. The basal part of the animal is attached to different substrata in the sea water. The body is covered by a leathery gelatinous **tunic** secreted by the external layer of the body wall, namely, the **mantle**. The tunic contains a considerable amount of cellulose, a substance which is rarely found in animals.

The free end of the body has 2 openings or siphons : one is the **oral open-**

ing, or **incurrent siphon**, which serves for the entrance of water carrying with it oxygen and food particles, and the other opening is known as the **atrial opening**, or **excurrent siphon**, through which water is expelled violently outside (as a squirt), carrying the gametes and excretory products.

Internal anatomy

The oral opening leads to the **pharynx** which is a wide barrel-shaped structure containing a number of **gill-slits** that do not open externally, but lead to an internal cavity known as the **atrium**. The atrium opens to the exterior by the atrial opening or **atriopore**.

The pharynx is followed by a short narrow **oesophagus** which leads into the **stomach** from which extends the **intestine**, that opens into the atrium by the **anus**.

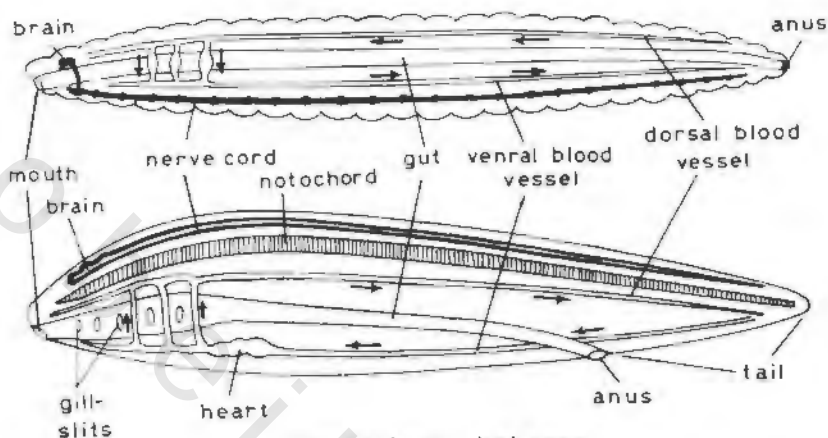
The animal is hermaphrodite, it has one **gonad**, part of which is a testis and the other part is an ovary. A **genital duct** leads from the gonad and opens into the atrium.

Larva

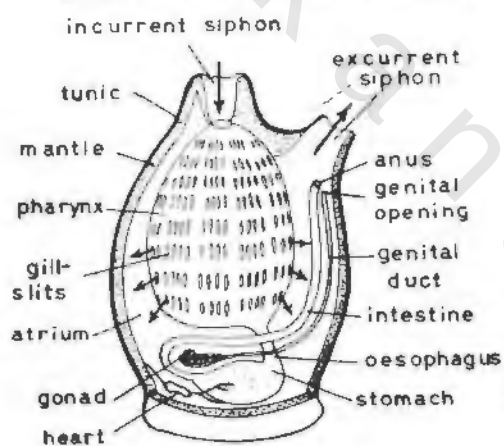
The larva of *Ascidia* resembles that of Amphibia, the tadpole. It is free-living and has a distinct notochord and a neural tube. The larva undergoes gradual metamorphosis during which it loses its tail with its chordate structures and develops gradually into an adult animal.

C. SUBPHYLUM CEPHALOCHORDATA

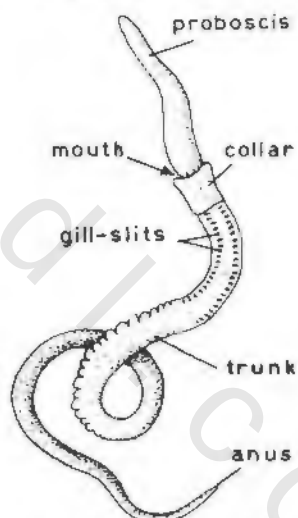
This subphylum includes small fish-like animals which display clearly the characteristic features of chordates. They are marine animals which occur in shallow waters. A typical example of this group is *Amphioxus*.



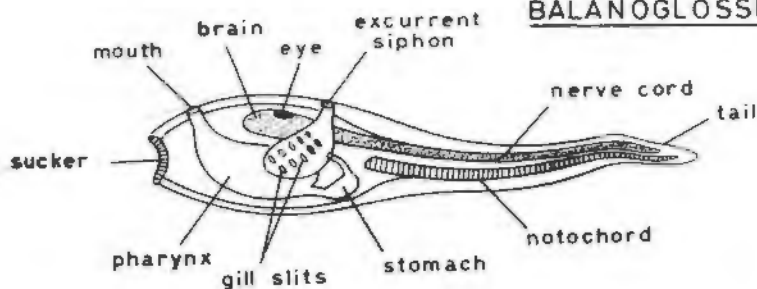
Comparison between
an invertebrate (earthworm) and a chordate (fish)



ASCIDIA



BALANOGLOSSUS



Larva of Ascidia

AMPHIOXUS

Habitat

Amphioxus lives along the sea coast where it lies in certain burrows in the sand with its anterior end protruding outside. It occasionally leaves these burrows at night and swims freely in water by rapid lateral bending movements and during rest it lies on one side.

Morphology

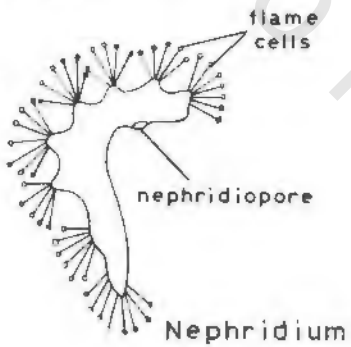
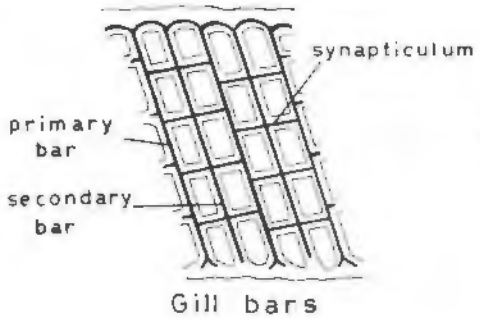
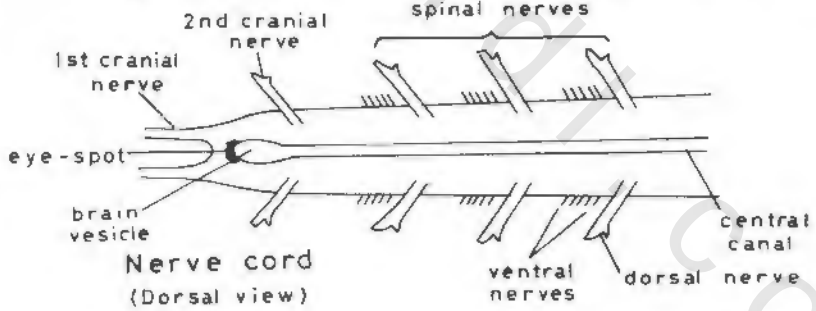
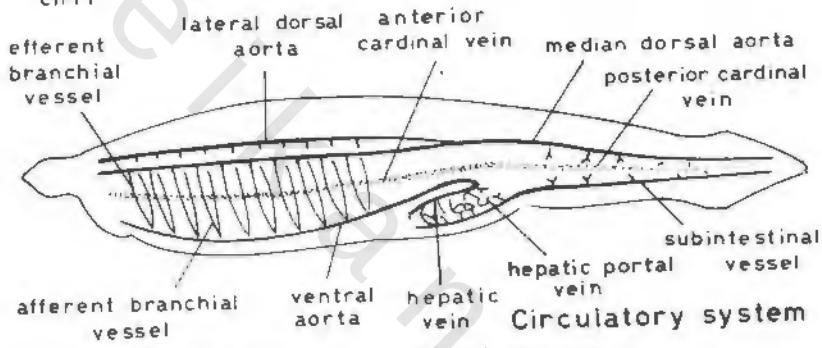
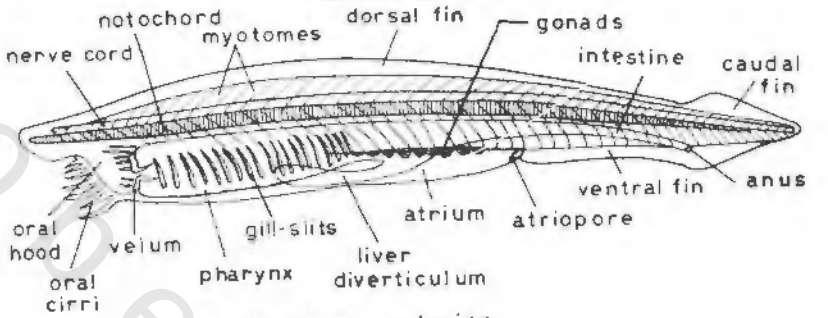
The animal is small, its length ranges from 5 to 7 cm. The body is bilaterally compressed, thus having a leaf-like appearance. It has anterior and posterior pointed ends. Its skin is rather transparent and accordingly, many of its internal organs are clearly seen from outside. *Amphioxus* has 3 median fins on its body : a **dorsal fin** running along the median dorsal region of the body, a **caudal fin** formed as a continuation of the dorsal fin around the tail region of the animal, and a **ventral fin** extending from the anterior end of the caudal fin, along the ventral side of the body, till the end of the posterior third of the animal. Besides, there is a pair of long fin-like folds of the skin, known as the **metapleural folds**, running along the ventro-lateral regions of the anterior two thirds of the body.

On the ventral surface of the anterior end of the animal there is an **oral hood**, the edges of which carry numerous **oral cirri**. The oral hood encloses a cavity known as the **vestibule**.

Body wall

The body wall is limited externally by the **epidermis**, which consists of a single layer of columnar cells with mucus-secreting cells inbetween. The epidermis is covered by a thin layer of **cuticle**. Below the epidermis, there is a **dermis** formed of a narrow layer of connective tissue. The musculature of the body wall consists of small V-shaped* muscle segments, or **myotomes** which are **segmentally** arranged. The apices of the myotomes are directed

AMPHIOXUS



anteriorly. They are separated from each other by thin strands of connective tissue, known as the **myosepta**. The myosepta on one side of the animal lie opposite to the myotomes of the other side. This mode of arrangement is responsible for the lateral bending movements of the animal observed during swimming.

Skeleton

The skeleton consists mainly of the **notochord** which is a long rod-like structure extending along the dorsal side of the body between the two pointed ends of the animal. It consists of large vacuolated cells containing a fluid material which provides a certain degree of turgidity to the body.

Besides the notochord, there are other skeletal parts, such as the **fin rays** which are formed of connective tissue and supports the fins. Also, the oral hood, oral cirri and gills are all supported by certain skeletal structures.

Digestive system and Feeding mechanism

The **oral hood** encloses a wide **vestibule** bordered posteriorly by a vertical partition known as the **velum**. The **mouth** proper is found at the centre of the velum. It is surrounded by a dozen of long processes, known as the **velar tentacles**, carried on the posterior surface of the velum. These tentacles prevent large food particles from reaching the distal parts of the alimentary canal.

The mouth leads to a wide **pharynx** which is perforated laterally by a large number of **gill (branchial) slits**. These are separated from each other by **gill-bars**, supported by delicate skeletal rods and containing small blood vessels. The gill-slits open externally into the **atrium**, that leads to the outside by the **atriopore**.

Along the dorsal side of the pharynx, there is a groove, known as the **epipharyngeal groove**, lined with a ciliated epithelium. A similar groove, which is the **endostyle** or **hypopharyngeal groove**, is found on the ventral side of the pharynx. It is lined with ciliated epithelial cells and mucus-secreting cells. The two grooves are connected together anteriorly by two strands of ciliated epithelial cells forming the **peripharyngeal bands**.

The pharynx leads into a narrow **oesophagus** which opens into a slightly

wider **stomach** that has an anterior pouch-like extension known as the **liver diverticulum**. The stomach leads into a tubular **intestine**, which runs posteriorly and opens to the exterior by the **anus**.

Water carrying food particles enter the animal through the oral hood by the help of the movement of the cilia found on the oral cirri. This water then passes through the mouth into the pharynx. Food particles become entangled by the mucous secretions in the ventral wall of the pharynx. The cilia of the endostyle beat forwards driving these food particles to the peripharyngeal bands which, in turn, direct them to the epipharyngeal groove. Cilia lining the latter groove further drive the food to the oesophagus, stomach and intestine where digestion and absorption take place. This method of nutrition is known as the **ciliary mode of feeding**.

Respiratory system and Respiration

The pharyngeal region is perforated by about 180 oblique gill slits which lead externally to the atrium. These slits are separated from each other by the septa, known as the gill-bars, which are parts of the body wall containing small blood vessels and covered by cilia.

Respiration takes place by the entrance of water which passes through the mouth opening to the pharynx, then through the gill slits to the atrium by the help of the cilia lining the gill-slits. During this process, exchange of gases takes place between water and the blood vessels in the gill-bars. Oxygen leaves water and diffuses into the blood, and on the other hand, carbon dioxide leaves the blood and diffuses into the water, which is then expelled through the atriopore.

Circulatory system

The circulatory system of *Amphioxus* consists of a ventral blood vessel extending along the lower side of the body. The posterior part of this blood vessel is known as the **subintestinal blood vessel**, and the anterior part lying in the region of the pharynx is the **ventral aorta**.

There is no heart in *Amphioxus*; blood is driven anteriorly along the aorta by the contraction of the aortic wall. It is then driven from the aorta along a series of paired arteries supplying the gills and extending inside the

gill-bars. These arteries are termed the **afferent branchial vessels**. Another set of blood vessels; the **efferent branchial vessels**, leave the gills carrying oxygenated blood. The efferent branchial vessels of each side open in a dorso-lateral blood vessel, the **lateral dorsal aorta**. The two lateral dorsal aortae unite together at the posterior end of the pharynx forming a **median dorsal aorta**, which runs backwards along the dorsal side of the body above the intestine. A small number of fine blood vessels extend from the median dorsal aorta to the oesophagus, stomach and intestine. Another set of minute blood vessels leave the intestine and pour into the subintestinal blood vessel. The subintestinal blood vessel extends anteriorly into the liver diverticulum, to form the **hepatic portal vein**. In the liver it splits into a tuft of capillaries which unite again forming a small **hepatic vein** that connects with the **ventral aorta**.

Blood is colourless in *Amphioxus* and contains a few white blood cells.

Excretory system

This consists of about 100 pairs of small bodies, the **nephridia**, arranged metamerically along the dorsal sides of the pharynx. The nephridium is a tubular body formed of two limbs nearly perpendicular to each other. A large number of ciliated **flame cells** are attached to each nephridium. The cells attract the body fluids to the nephridium, which opens into the atrium by the **nephridiopore**.

Nervous system and Sense organs

A long tubular dorsal **nerve cord** extends along the dorsal side of the animal. The nerve cord has a **central canal**. It is slightly enlarged at the anterior part of the body to form the **brain vesicle**, while the rest of the nerve cord is identified as the **spinal cord**.

Two pairs of **cranial nerves** extend laterally from the brain to innervate the head region. Also, paired **spinal nerves** arise on both sides of the spinal cord. These include two types : **dorsal nerves** which extend to the body wall and perform a sensory function, and **ventral nerves** which pass to the body muscles to perform a motor function.

At the anterior end of the brain vesicle there is an **eye-spot** formed of a mass of pigmented cells. Also, there is a number of **primitive eyes** on the

ventral side of the anterior part of the spinal cord. Each eye consists of a sensory cell, sensitive to light, and a pigmented cup-shaped structure. An **olfactory pit** is also found on the left side of the anterior part of the body.

Reproductive system

Sexes are separate in *Amphioxus*. There are 26 pairs of small **testes** or **ovaries** which are seen bulging into the atrium in the pharyngeal region. During the breeding season, the gonads rupture, and sperms and ova are thus liberated. They pass into the atrium, and leave the body together with the water current through the atriopore. Fertilization is external and takes place outside the animal in water, and a zygote is formed, which develops gradually into an adult *Amphioxus*.

D. SUBPHYLUM VERTEBRATA

Subphylum Vertebrata constitutes the group of animals to which man belongs. This subphylum is regarded as the most important and advanced group of chordates. It includes about 20,000 different species of chordates.

General characters

1 — **Vertebral column** : Vertebrates have a segmented backbone or vertebral column, from which the name of the subphylum is derived. They possess an axial notochord during the early stages of their life but, as development proceeds, the notochord becomes invested by cartilage or bone which is divided into segmental units, the vertebrae.

The vertebral column first appears as a linear series of four metamerically arranged skeletal masses of mesenchyme cells; two groups of these masses, known as the **basidorsals**, lie on the dorsolateral sides of the notochord, and the other two, or **basiventrals**, lie on the ventro-lateral sides of the notochord.

These mesenchyme cells become transformed gradually into cartilage. In the trunk region of the animal, the two basidorsals extend upwards until they meet together forming a **neural arch**, with a mid-dorsal **neural spine**. The

cavity enclosed by the neural arch is the **neural canal** which serves as a tunnel for the spinal cord. The two basiventrals extend laterally in the trunk region forming two **transverse processes**.

In the tail region, the two basiventrals extend ventrally until they meet together, thus forming a **haemal arch** which surrounds the caudal artery and caudal vein. The haemal arch carries a median **haemal spine**.

In the mean time, the skeletal cells invade the notochord, which becomes gradually transformed into segmental bony bodies, the **centra** of the vertebrae.

2 — **Cranium** : The Vertebrata are also known as the Craniata, owing to the presence of a cranium, or brain case, which encloses the brain. The following skeletal structures may develop in close association with the cranium : Olfactory capsules, optic capsules, auditory capsules, jaws, and hyoid apparatus.

3 — **Body regions** : The body is bilaterally symmetrical. It comprises a head, neck and trunk, in addition to a tail in some species.

4 — **Appendages** : There are generally two pairs of appendages which support the body and serve a locomotory function. These include two **thoracic appendages**, represented by the pectoral fins in fishes, the wings in birds, or the fore-limbs in mammals; and two **pelvic appendages**, represented by the pelvic fins in fishes and the hind-limbs in amphibians, reptiles, birds and mammals.

5 — **Integument** : The skin or integument is formed of an outer epidermis of stratified epithelium and an inner dermis of connective tissue. The skin may contain glands as in amphibians; or develop scales as in fishes and reptiles; feathers as in birds, or hairs as in mammals.

6 — **Coelom** : Vertebrates have a coelomic cavity distinguished into a **pericardial cavity** enclosing the heart, and a **perivisceral cavity** containing the visceral organs. In mammals, the perivisceral cavity is further differentiated into a **pleural cavity** enclosing the lungs, and an **abdominal cavity** containing mainly the digestive organs.

7 — **Digestive system** : The alimentary canal is a more or less convoluted tube which lies ventral to the vertebral column. It begins with the **mouth** opening which leads to the buccal cavity. In the more primitive verte-

brates, the digestive tract together with the urinary and genital ducts end in a common structure, the **cloaca**, which opens to the exterior by the **cloacal aperture**. But in higher vertebrates, the digestive tract has a separate opening, the **anus**.

Two digestive glands, the liver and pancreas, are found in vertebrates. They convey their secretions through certain ducts into the alimentary canal.

8 — **Respiratory system** : Respiration takes place in aquatic vertebrates by **gills**, whereas **lungs** are used for this purpose in terrestrial forms. In early embryonic life the lungs develop as outgrowths from the alimentary canal.

9 — **Circulatory system** : Vertebrates have a **closed circulatory system** in which blood flows into a closed system of arteries and veins. This system includes a well developed muscular **heart** lying ventral to the anterior part of the alimentary canal. The heart is formed of 2-5 chambers. The blood contains both **white and red blood corpuscles**. The latter contain **haemoglobin**, which serves as a respiratory pigment.

10 — **Excretory system** : This consists of two kidneys, which act to drain the waste materials from the blood and eliminate them outside the body in the form of urine. In most vertebrates the urine is carried via certain ducts into a urinary bladder which serves to store urine until it is extruded periodically outside the body.

11 — **Reproductive system** : Usually, sexes are separate in the vertebrates. The animal has a pair of **gonads** (either testes or ovaries) in which the sexual cells (sperms or ova) are produced.

12 — **Nervous system** : In the vertebrates, there is a central nervous system which is formed of the **brain** and the **spinal cord**. The brain is usually differentiated into certain regions which have different functional activities. Besides, there is a peripheral nervous system formed of ten to twelve pairs of **cranial nerves** arise from the brain and a number of paired **spinal nerves** arising from the spinal cord.

Moreover, there is a **sympathetic or autonomic nervous system** which regulates the involuntary activities of the vertebrate animal.

Well developed **sensory organs** are found in the vertebrates, including those for smell, sight, hearing, etc.

13 — **Endocrine organs** : Vertebrate animals have an endocrine system

formed of a number of ductless glands, such as the thyroid, pituitary, adrenal, etc. These glands produce certain secretions, known as hormones, which are poured directly into the blood stream and act to control various metabolic activities of the body.

Classification

Subphylum Vertebrata is classified according to the presence or absence of the upper and lower jaws into two major divisions, the **Gnathostomata** and **Agnathostomata**, respectively.

Agnathostomata includes a single class known as class Cyclostomata.

Gnathostomata includes six main classes viz. Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves and Mammalia.

Some systems of classification include Amphibia, Reptilia, Aves and Mammalia into one major group, **Tetrapoda**, since members of these classes have four limbs. Tetrapoda, in turn, is subdivided according to the presence or absence of the amnion (one of the embryonic membranes) into **Amniota** which includes Reptilia, Aves and Mammalia; and **Anamniota** or **Anamnia** which includes Amphibia. Amniota and Anamniota include animals with and without an amnion respectively.

THE AGNATHOSTOMATA

CLASS CYCLOSTOMATA

The Cyclostomata (cycklos = circular; stome = mouth) are animals having a rounded mouth without jaws. They include eel-like animals, which live as external parasites on fishes and other animals in salty and fresh waters. Cyclostomes represent the most primitive group of vertebrates. An example of this group is the lamprey, *Petromyzon*.

PETROMYZON

Petromyzon is an external parasite of certain freshwater fishes in Europe.

Morphology

The body is long, cylindrical and eel-like. It is differentiated into a **head**, **trunk** and **tail**. The head and trunk are cylindrical while the tail is laterally compressed. Unlike fishes, there are no paired fins, but only two separate median **dorsal fins** and a **caudal fin**.

The **mouth** opens on the ventral side of the anterior part of the head region, a single **olfactory opening** lies on the dorsal side, and seven pairs of **gill-slits**, are found on both sides of the head. The **urinogenital aperture** is carried on a small ventral papilla, the **urinogenital papilla**; and the **anus** opens on the ventral surface at the posterior end of the trunk, immediately anterior to the urinogenital opening.

The true mouth is found at the bottom of a suctorial **buccal funnel**. The edges of the buccal funnel are provided with numerous papillae, while its inner walls are beset with distinct rows of **horny teeth**. A tongue protrudes inside the buccal funnel. It carries horny conical teeth which help in rasping the flesh of the prey and is thus described as the **rasping tongue**.

An eye is found on either side of the head region. There are no eyelids, but each eye is covered by a transparent layer of skin. The skin of *Petromyzon* is soft and slimy. It contains many unicellular glands and lacks protective scales of any kind.

The body muscles are in the form of Σ - shaped myotomes, with myosepta inbetween. In the trunk region, muscles are distinguished into dorsal and ventral groups, but such distinction is not observed in the tail region.

Digestive system

The mouth opening leads into a short **pharynx**, followed by an **oesophagus** that opens into a tubular **intestine**, which is provided with a **spiral valve**. The

intestine opens to the exterior by the anus.

There is a compact **liver**, but with no bile duct in the adult. It is not certain that a **pancreas** is present in *Petromyzon*.

Circulatory system

It includes a heart, a number of veins and arteries as well as numerous lymphatic sinuses.

The heart is enclosed in a **pericardium**, and consists of three chambers : **sinus venosus**, **auricle** and **ventricle**.

A **ventral aorta** extends anteriorly from the ventricle. Eight pairs of **afferent branches** are given off from the ventral aorta to the gill filaments. The blood is then collected via similar sets of **efferent branches** into a median **dorsal aorta**.

A **venous system** collects blood from the different parts of the body and includes a **hepatic portal system** connected to the liver, but no renal portal system.

Skeletal system

There is a simple cartilaginous **cranium** which encloses the brain. A single **olfactory capsule**, which protects the olfactory organs, and two **auditory capsules**, which surround the auditory organs, are connected with the cranium.

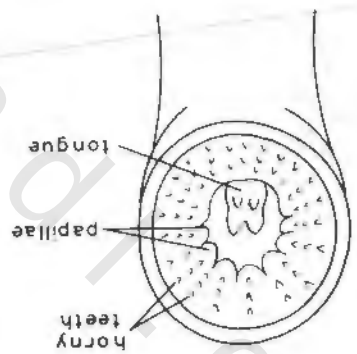
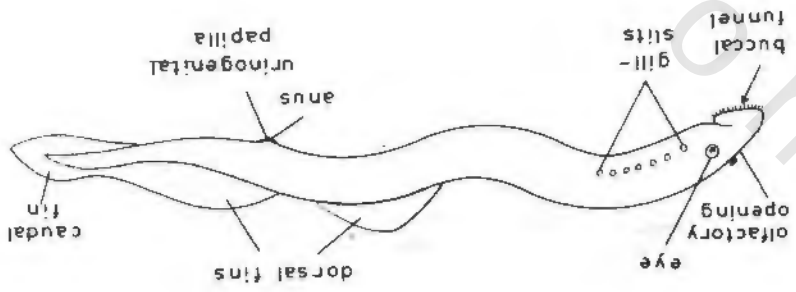
A **notochord** persists throughout the whole life of the animal. It has the form of a gelatinous rod ensheathed with a layer of connective tissue.

The branchial region is supported by a cartilaginous **branchial basket**. The median fins are also supported by cartilaginous **fin rays**.

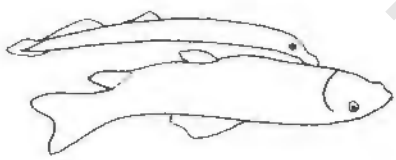
Excretory system

There are two mesonephric **kidneys** which lie dorsally in the body cavity. A tubular **ureter** extends from each kidney. The two ureters pass into a **urinogenital sinus** which opens to the exterior by the **urinogenital opening** found on the **urinogenital papilla**.

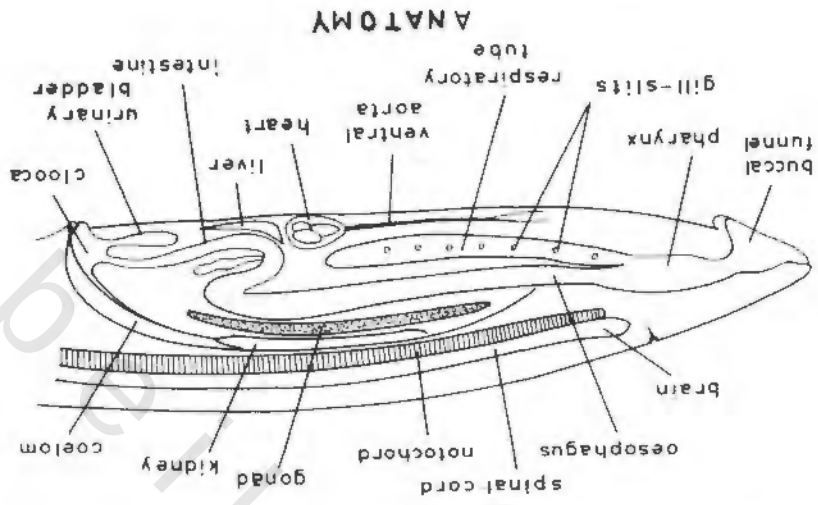
PETROMYZON



Feeding on a fish



Buccal funnel



ANATOMY

Reproductive system and Reproduction

Sexes are separate, and the gonad (either testis or ovary) is single. Eggs or sperms do not pass along genital ducts but are discharged into the abdominal cavity, then they pass through **genital pores** into the urinogenital sinus.

Breeding takes place in early summer. The male and female attach by their buccal funnels. Eggs and sperms are discharged into the water, where fertilization takes place. It is estimated that a single female is capable of producing about 60,000 eggs. After fertilization, the eggs hatch in a month giving rise to small larvae known as the **ammocoetes larvae** which grow gradually to reach maturity in about two years. Ammocoetes larvae are somewhat different from the adults, but they show certain similarities to primitive cephalochordates.

Nervous system

The brain is more complicated than that of *Amphioxus*. Ten pairs of **cranial nerves** arise from the brain.

The spinal cord is in the form of a flattened tube which extends throughout the whole length of the body above the notochord. Paired dorsal and ventral **spinal nerves** are given off from the spinal cord.

THE GNATHOSTOMATA

CLASS CHONDRICHTHYES

(Cartilaginous fishes)

This class includes sharks, rays and skates, which are exclusively marine vertebrates.

General characters

- 1 — The skeleton is cartilaginous.
- 2 — Paired fins in the form of pectoral and pelvic fins are present.

3 — The skin is covered with certain scales, known as the placoid scales, and includes many mucus-secreting glands.

4 — The mouth is ventral and is provided with strong teeth. There are two ventral nostrils which may be joined to the mouth by naso-buccal grooves, and upper and lower jaws are present. The intestine is provided with a spiral valve.

5 — There are 5-7 pairs of gill-slits which are not covered with an operculum.

6 — The heart is four-chambered, with a sinus venosus, an auricle, a ventricle and a conus arteriosus.

7 — Sexes are separate and gonads are paired. Genital ducts open into a cloaca, and fertilization is internal.

An example of this group is the dogfish.

The Dogfish

Scyliorhinus canicula

Morphology

The body is spindle-shaped, consisting of a dorso-ventrally compressed head, followed by the trunk, and then the tail.

There are two paired **pectoral fins** on both sides of the anterior end of the trunk region, two **pelvic fins** on both sides of the posterior part of the trunk, two median **dorsal fins** one behind the other, a **ventral fin** on the ventral side of the body, and a **caudal fin** surrounding the tail.

The **mouth** is a transverse crescent-shaped slit on the ventral surface of the head. On either side and slightly anterior to the mouth there is a **nostril** which is connected with the mouth by a **naso-buccal groove**. The **cloacal opening** lies inbetween the 2 pelvic fins. In the male, there is a pair of elongated **claspers** on each side of the cloacal opening.

There is an **eye** on either side of the head, guarded by two **eyelids**. Posterior to each eye there is a small aperture known as the **spiracle**, followed posteriorly by five narrow vertical **gill-slits**. The spiracle is considered a non-functioning gill-slit.

The **skin** is grey-coloured, covered with scaly structures known as the **placoid scales**. A placoid scale consists of a broad calcified **basal plate** embedded in the dermis, and a pointed **spine** directed posteriorly. The spine is formed of an inner **dentine** covered with a hard layer of **enamel**. Each scale has an inner cavity, known as the **pulp cavity**. This cavity contains a mass of connective tissue richly supplied with blood capillaries which pass into the spine. The placoid scales on the jaws are modified into **teeth** which are used for holding and tearing the prey.

A **lateral line** runs along each side of the body. It contains minute sensory organs which may be concerned with the detection of the changes of pressure waves in water.

The skeleton

This is cartilaginous, and includes two main parts : axial skeleton and appendicular skeleton.

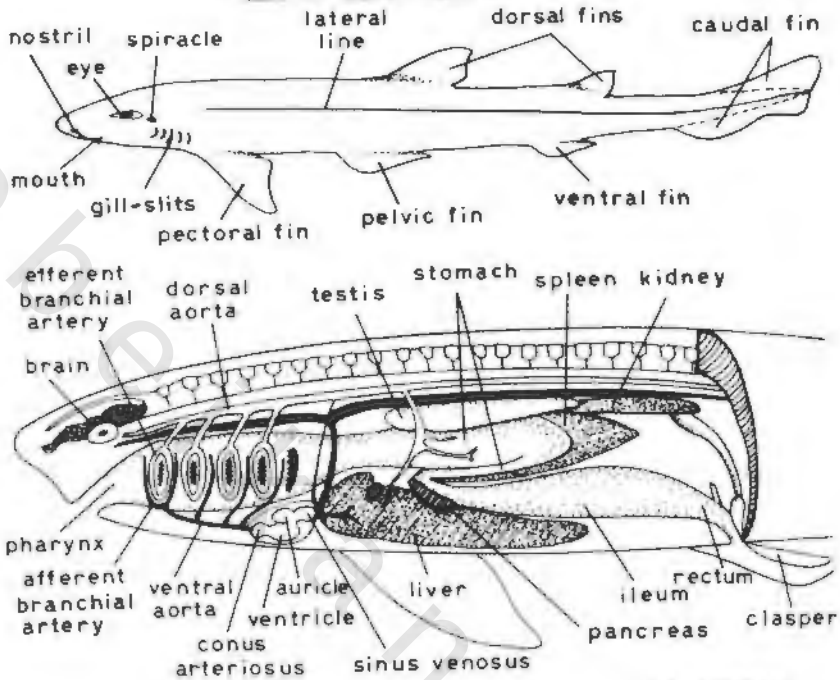
The **axial skeleton** consists of the skull and vertebral column. The **skull** includes the **chondrocranium** or brain case, two large anterior **nasal capsules**, two posterior **auditory capsules**, and the **visceral skeleton** made up of the **jaws** and the **branchial arches** which support the gill region. The **vertebral column** is built up of **amphicoelous vertebrae** (with biconcave centra). The **appendicular skeleton** consists of the cartilages of the fins and those which support the pectoral and pelvic girdles.

Digestive system

The mouth leads to a large **pharynx**, into which open the spiracle and gill slits. The pharynx leads into a short wide **oesophagus** which opens into a U-shaped **stomach**. The proximal limb of the stomach is rather wide and is known as the **cardiac portion**, but the distal limb is narrow, tubular and is known as the **pyloric portion**. Posteriorly, the stomach is provided with a circular sphincter muscle, the **pyloric valve**.

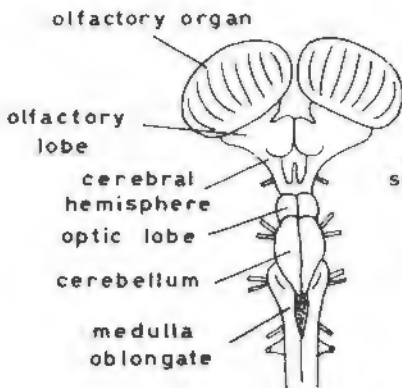
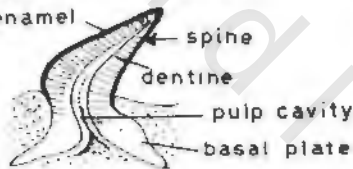
The stomach is followed by the **intestine** which is differentiated into a small **duodenum**, large **ileum** and short **rectum**. The ileum contains a spiral fold of mucous membrane known as the **spiral valve**. At the junction between the ileum and rectum, there is a small **rectal gland**. The rectum terminates in the **cloaca**, which opens to the exterior by the **cloacal opening**.

SCYLORHINUS

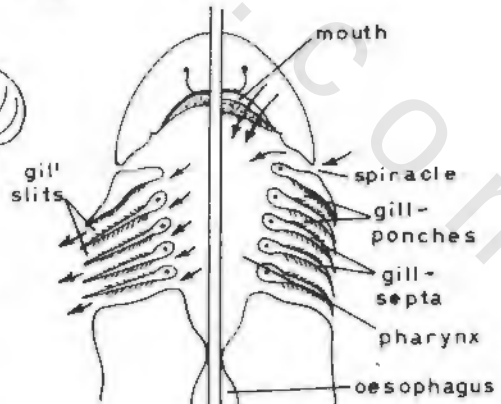


ANATOMY

Placoid scale



Brain



Expiration

Inspiration

The **liver** is a large bilobed structure which occupies most of the body cavity and is formed of two elongated lobes. A small **gall bladder** is embedded in the anterior part of the left lobe. A **bile duct** arises from the gall bladder, then passes posteriorly to open into the dorsal side of the duodenum.

The **pancreas** has two lobes; an elongated dorsal lobe which lies between the pyloric stomach and the ileum, and a small ventral lobe lying close to the duodenum. A **pancreatic duct** carries the secretions of the pancreas to the proximal part of the ileum.

The **spleen** is a dark red flattened structure which is closely connected to the pyloric limb of the stomach.

Circulatory system

The **heart** consists of four chambers : **sinus venosus**, **auricle**, **ventricle** and **conus arteriosus**.

A **ventral aorta** extends anteriorly from the conus arteriosus carrying blood to the gills through five pairs of **afferent branchial arteries**. After being oxygenated in the capillaries of the gills, the blood is conveyed by the **efferent branchial arteries** to the **dorsal aorta** which extends posteriorly to supply the different parts of the body with oxygenated blood.

De-oxygenated blood is collected from the different parts of the body by certain **veins** which pour into the sinus venosus of the heart. A **hepatic portal system** that transports the blood from the digestive canal, pancreas and spleen to the liver, and a **renal portal system**, which conveys blood from the posterior parts of the body into the kidneys, are found in the dogfish.

Respiratory system

Gills are the organs of respiration in the dogfish. The mouth is opened and the floor of the pharynx is lowered so that water is taken into the pharyngeal cavity. The mouth is then closed and the floor of the pharynx is raised, thus forcing the contained water into the gill pouches and driving it out through the gill-slits. Exchange of gases thus takes place between water and the blood in the fine tributaries of the afferent branchial arteries.

Urinogenital system

The urinary and genital systems are closely associated in the dogfish.

In the female, there is a single **ovary** which is situated slightly to the right of the median line. The ovary is attached to the dorsal body wall by the **mesovarium**. There are two **oviducts** which unite anteriorly with each other and open into the body cavity by the **ostium tubae**. The oviduct is swollen at its proximal part forming the **shell gland** which secretes the egg-cases surrounding the eggs. The distal part of the oviduct is also swollen to form the **uterus**. The two oviducts unite posteriorly before opening into the cloaca by a single aperture, which lies immediately behind that of the rectum. The **kidneys** are two dark red flattened bodies, from which extend two **mesonephric ducts**. These open into **urinary sinuses** that unite together before opening into the cloaca.

In the male, there are two elongated **testes**, each of which is attached to the dorsal body wall by the **mesorchium**. Fine **vasa efferentia** lead from each testis to the corresponding kidney where they form a long convoluted tube, the **vas deferens**. The two vasa deferentia dilate posteriorly to form the **vesiculae seminalis** which open into the urinogenital sinus. There are two **sperm sacs** which lie ventral to the seminal vesicles. The two sacs unite posteriorly to form the **urinogenital sinus**, which opens through a **urinogenital papilla** into the **cloaca**, just behind the rectal opening.

Fertilization is internal; the fertilized egg grows in the uterus where it becomes enclosed by a sac of horny material. The sac has two long coiled threads. These sacs pass outside the female into the surrounding water; they contain an embryo at a certain stage of the embryonic development. The threads of the egg sacs become attached to aquatic plants, and when the embryo completes its development, the young leaves the sac and swims freely in water.

Nervous system and Sense organs

The brain is more developed than in *Petromyzon*. It has two large **olfactory lobes**, two **cerebral hemispheres**, a pair of **optic lobes**, and a **cerebellum** which extends backwards over the **medulla oblongata**. There are ten pairs of **cranial nerves**.

The **spinal cord** is a flattened tube with a narrow central canal. Paired **spinal nerves** arise from the spinal cord to innervate the different parts of the body.

Sense organs include two large **olfactory sacs**, two **ears** each with three semicircular canals, and two well developed **eyes**. Certain sensory structures are also included in the lateral lines extending on both sides of the body.

CLASS OSTEICHTHYES

(Bony fishes)

This class includes a wide variety of bony fishes which inhabit all sorts of waters, fresh, brackish or salty.

General characters

- 1 — The skeleton is mainly formed of bone in the adults.
- 2 — Paired and median fins are usually present.
- 3 — The skin is provided with many mucous glands and is usually covered with bony scales which may be of the ganoid, cycloid or ctenoid types.
- 4 — The mouth is usually terminal and provided with teeth. The jaws are well developed. No spiral valve is found in the intestine.
- 5 — There are four gills which are included in a common gill chamber on each side of the pharynx. Gills on each side are covered with a bony operculum.
- 6 — The heart is usually three-chambered, with a sinus venosus, an auricle and a ventricle.
- 7 — Sexes are separate and gonads are paired. Fertilization is usually external.
- 8 — There are ten pairs of cranial nerves.

An example of this group is the Nile Bolti, *Tilapia nilotica*.

The Nile Bolti

Tilapia nilotica

Morphology

The body is bilaterally compressed, and is clearly distinguished into a head, a trunk and a tail.

The **skin** is covered with rounded scales, known as the **cycloid scales**, which have certain concentric rings indicating the age of the fish. The scales are arranged in successive rows; the hind part of a scale overlaps the front part of the following scale. In some other fishes, the posterior edges of the scales may be serrated. Such scales are known as the **ctenoid scales**.

The fish has a pair of **pectoral fins**, a pair of **pelvic fins**, a single **dorsal fin** running along the dorsal edge, an **anal fin** at the posterior part of the ventral surface, and a **caudal fin** around the tail region.

The **mouth** is a narrow slit found at the anterior end of the head, surrounded by upper and lower jaws carrying small sharp teeth. The mouth leads into a buccal cavity which can be opened and closed during respiration by two membranous oral valves. Two minute **nostrils** open at the anterior end of the head above the mouth, and 4 pairs of **gills** are found on either side of the pharynx. They are enclosed in a gill chamber on each side, that is covered by a flattened bony plate, the **operculum**. The **anus** lies on the ventral side of the body, at the beginning of the posterior third. A common **urinogenital aperture** is found in the male, behind the anus, but in the female there are two separate openings : a **genital opening** found behind the anus followed posteriorly by a **urinary opening**.

Two large rounded **eyes** lie on both sides of the head. They are not provided with eyelids. There is a pair of **lateral lines** which extend on each side of the body and contain certain sensory cells.

Digestive system

The mouth leads into the buccal cavity which opens into the pharynx. Since there is no clear separation between the buccal and pharyngeal cavities,

both form the **buccopharyngeal cavity**. This leads into a short **oesophagus**, followed by the **stomach** which is differentiated into **cardiac** and **pyloric portions**. The cardiac portion extends into a blind sac or **caecum**, while the pyloric portion opens into the **intestine**, which is a long coiled tube leading to the exterior by the **anus**.

The **liver** or **hepatopancreas** is bilobed; the left lobe is larger than the right. There is a membranous **gall bladder** from which extends a **bile duct** that opens into the anterior part of the intestine.

The pancreas is not found as a compact structure, but exists in the form of minute acini in the liver and mesenteries. A **pancreatic duct** collects from these acini and opens into the intestine, very close to the opening of the bile duct.

The **spleen** is a dark red organ which lies between the stomach and the left lobe of the liver.

Circulatory system

The **heart** is enclosed in a **pericardium**. It consists of three chambers : a **sinus venosus**, an **auricle** and a **ventricle**.

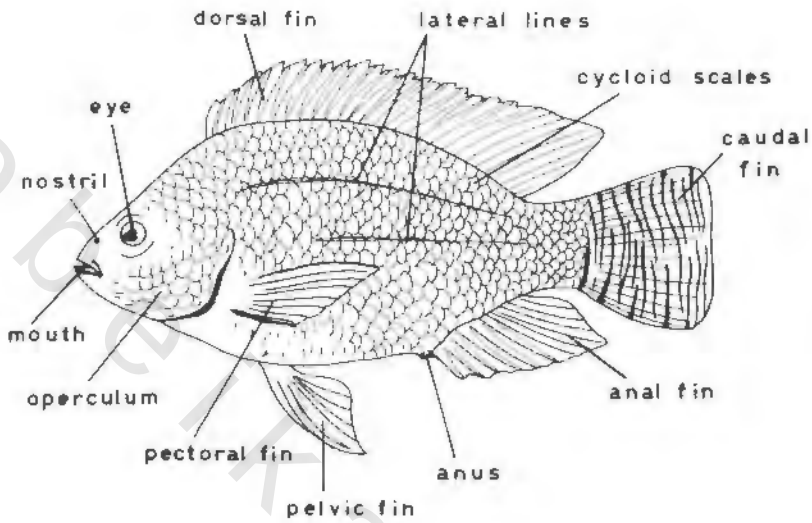
A **ventral aorta** extends from the ventricle to supply the gills with blood. At the beginning of the ventral aorta, there is a swollen non-contractile portion known as the **bulbus arteriosus**. The ventral aorta gives off four pairs of **afferent branchial arteries** which pass to the gills. Four **efferent branchial arteries** collect blood from the gills on each side and open into a **lateral dorsal aorta**. The two lateral dorsal aorta unite to form a loop, the **circulus cephalicus**, from which a **dorsal aorta** passes backwards to supply different parts of the body.

De-oxygenated blood is returned to the heart through 2 large **Cuvierian ducts** and 2 **hepatic veins**, all of which open into the sinus venosus.

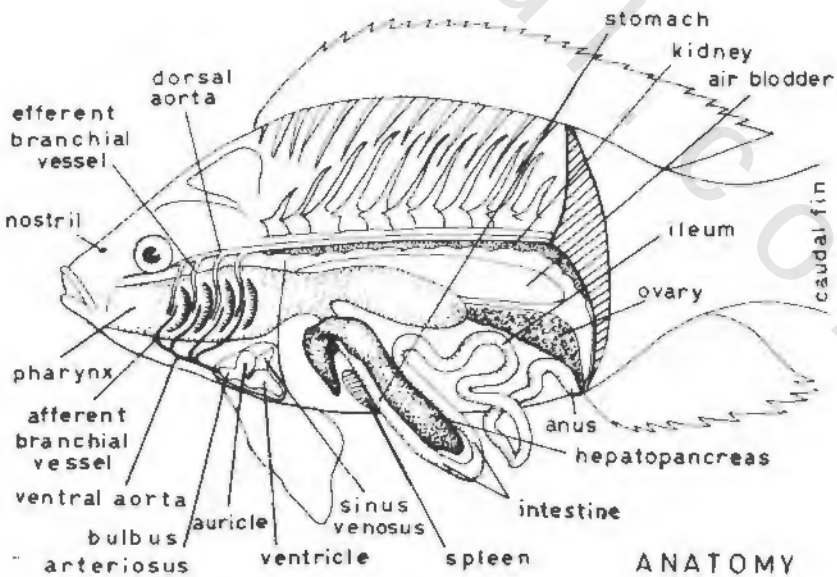
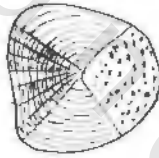
Respiratory system

The respiratory organs are the four pairs of **gills** found on both sides of the pharynx. During inspiration, the oral valves are opened, the buccopharyngeal cavity is dilated and the opercula are closed; water thus enters the cavity through the mouth. In expiration, the oral valves become closed

TILAPIA



Cycloid scale



ANATOMY

and the buccopharyngeal cavity contracts, forcing the contained water to pass over the gills and then to the outside through the openings of the opercula. During the passage of the water over the gills, exchange of gases takes place.

Swim (air) bladder

A bony fish usually has an elongated organ known as the **swim** or **air bladder**. In *Tilapia*, the bladder is in the form of an elongated membranous sac which extends along the dorsal side of the body cavity below the vertebral column. It is regarded as a hydrostatic organ which acts to regulate the specific gravity of the fish.

Urinogenital system

The urinary system consists of two elongated **kidneys** which extend very close to the vertebral column. A short **mesonephric duct** extends from the posterior end of each kidney, and the two ducts unite together forming a **common mesonephric duct**, that becomes dilated to form a small membranous **urinary bladder**. The common mesonephric duct opens to the exterior by a urinogenital aperture in the male, and by a urinary aperture in the female.

The male has a pair of elongated **testes** from which arise two **vasa deferentia** that unite to form a **common vas deferens**. This opens together with the common mesonephric duct through the urinogenital aperture.

The female has two **ovaries** from which arise two **oviducts** that unite to form a **common oviduct**, opening to the exterior through the female genital aperture. The female lays a large number of eggs, which are fertilized outside the body, i.e. fertilization is external.

Nervous system and Sense organs

The **brain** has two small **olfactory lobes**, two large **optic lobes** and a **cerebellum** which passes over the **medulla oblongata**. There are 10 pairs of cranial nerves similar to those of the dogfish. The **spinal cord** is a long flat tube which has a central canal. Pairs of lateral spinal nerves are given to the various parts of the body.

Sense organs include the olfactory sacs, taste buds and eyes. The lateral lines include special sensory cells that can apparently detect slight changes in pressure or current movements.

THE TETRAPODA

Tetrapods are four-footed vertebrates (Gk. tetras = four; podus = foot). This group includes the remaining four classes of vertebrates, viz. Amphibia, Reptilia, Aves and Mammalia. Although members of these classes exhibit a wide range of morphological and anatomical differences, yet they all agree in having two pairs of limbs which have a skeleton based upon a common plan, known as the pentadactyl limb skeleton. Their pectoral and pelvic girdles are also built up on the same generalized plan.

The Pentadactyle limb

The fore- and hindlimbs of tetrapods are differentiated externally into regions or parts which are movable on one another. The forelimb is differentiated into **upper arm, fore-arm, wrist and hand**. The **hindlimb** is also composed of the **thigh, shank, ankle and foot**.

The skeleton of the fore-limb includes the following bones :

- 1 — **Humerus**, a long bone found in the upper arm.
- 2 — **Radius and ulna**, shorter bones which support the fore-arm.
- 3 — **Carpals**, nine bones found in the wrist or carpus. They are arranged in three rows.
 - a) A proximal row, formed of three bones : **radiale** near the end of the radius, **ulnare** near the end of the ulna, and **intermedium** inbetween.
 - b) A median row, formed of a single bone, the **centrale**.
 - c) A distal row, consisting of five small **distal carpals**.
- 4 — **Metacarpals**, five slender bones found in the palm of the the hand or manus.
- 5 — **Phalanges**, form the skeleton of the fingers or digits. Their number is represented by the **digital formula** which indicates the number of phalanges in each finger. Typically, the digital formula for the digits of the hand is 2 : 3 : 3 : 3 : 3, starting with the first finger, the **thumb**.

The skeleton of the hindlimb includes bones which have precisely the same arrangement as those described in the forelimb, but are differently named. They are :

1 — **Femur**, found in the thigh.

2 — **Tibia** and **fibula**, lie in the shank.

3 — **Tarsals**, nine bones found in the ankle and are arranged in three rows :

a) A proximal row, formed of three bones : **tibiale** adjacent to the tibia, **fibulare** adjacent to the fibula, and **intermedium** inbetween.

b) A median row, formed of a single **centrale**.

c) A distal row, consisting of five small **distal tarsals**.

4 — **Metatarsals**, five slender bones found in the foot.

5 — **Phalanges**, in the fingers of the foot. Their number is also represented by the digital formula 2 : 3 : 3 : 3 : 3, starting with the first finger, the **hallux**.

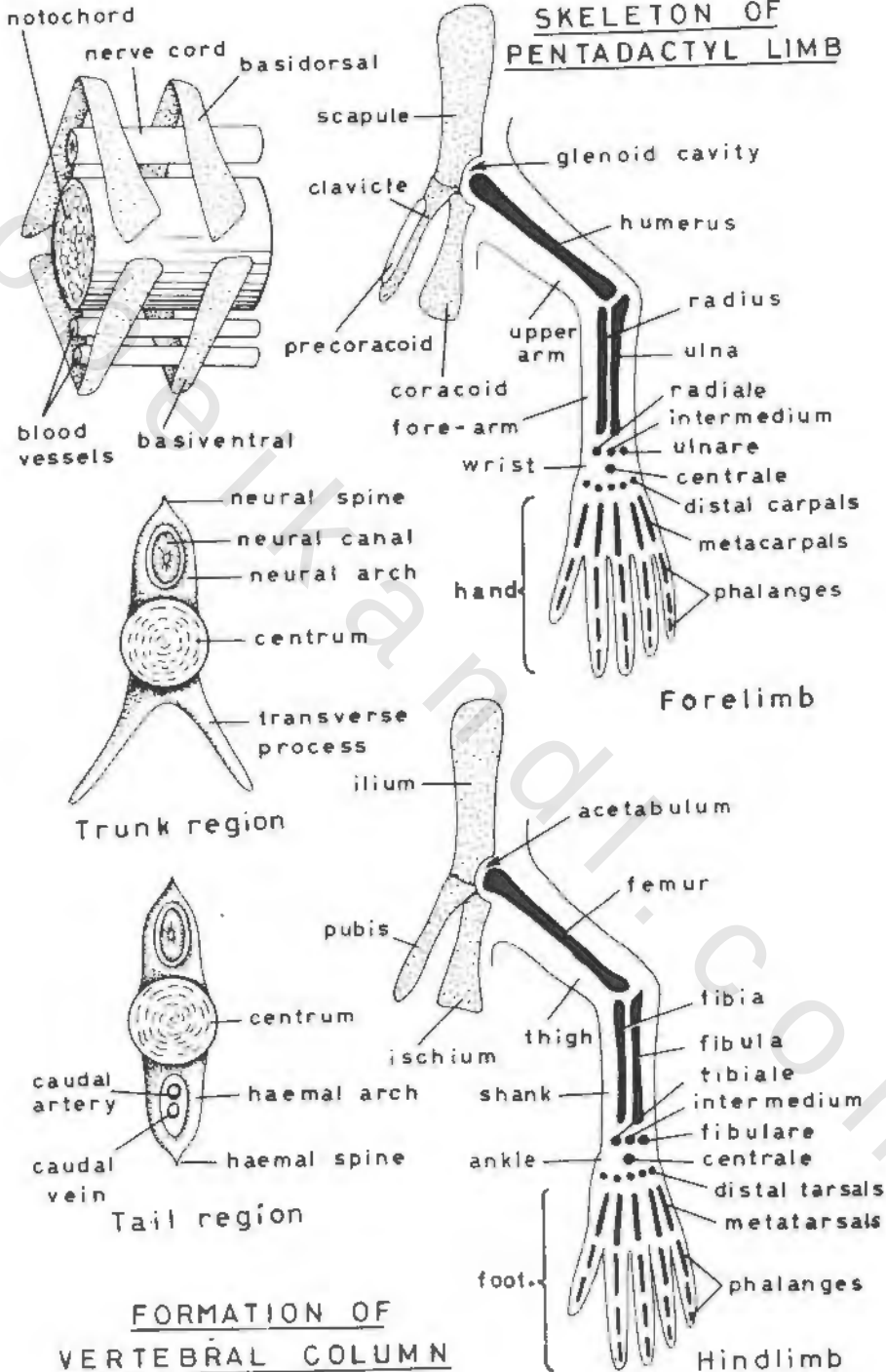
Girdles

There are two girdles, the pectoral girdle which is found in the pectoral region, and the pelvic girdle which is found in the posterior trunk region. The pectoral girdle serves to attach and articulate the forelimbs with the pectoral region of the animal, while the pelvic girdle serves to the support of the animal as well as for the attachment and articulation of the hind-limbs with the vertebral column.

The **pectoral girdle** is formed of two similar halves, each of which includes three bones : a dorsal **scapula**, and two ventral bones, namely an anterior **precoracoid** and a posterior **coracoid**. At the region where the precoracoid and coracoid bones meet there is a **glenoid cavity** which acts as a socket for the articulation of the head of the humerus.

The **pelvic girdle** is also formed of two halves, each of which includes three bones : a dorsal **ilium** and two ventral bones; an anterior **pubis** and a posterior **ischium**. A cavity known as the **acetabulum** is found at the point where the pubis and ischium meet; it acts as a socket for the articulation of the head of the femur.

SKELETON OF PENTADACTYL LIMB



FORMATION OF VERTEBRAL COLUMN

A. ANAMNIOTA

CLASS AMPHIBIA

Amphibians are vertebrates that lead a double mode of life (Amphi = double; -bios = life). They constitute a group of about 2,500 species of animals that spend their lives between land and water. Most of them start their life as fish-like individuals, the tadpoles, which breathe by gills and swim with a caudal fin. They gradually lose the gills and tail, and develop into lung-breathing, four-footed animals which leap from water to land. However, most of them return occasionally to water. Hence, their body organs are adapted for both aquatic and terrestrial modes of life.

General characters

1 — They are cold-blooded animals in which the body temperature varies according to the surrounding medium.

2 — They hibernate during winter, i.e. stop most of their activities, hide, and remain stationary between stones in pools and on river banks till the beginning of the next spring. During hibernation, pulmonary respiration stops, and breathing takes place by the skin. No food is taken by the hibernating animals, and they depend mainly on the food materials stored in their bodies. The body temperature decreases, almost reaching that of the surrounding medium, but they do not frost otherwise they die.

3 — The body is covered by a coloured skin which can be easily matched with the surrounding habitat.

4 — There are two nostrils, two eyes with movable eyelids and two ears.

5 — Respiration takes place by gills in the early developmental (larval) stages. But gills disappear gradually and become replaced by lungs, which are the principal organs of respiration in the adult stages.

6 — The coelom is distinguished into two main regions : pericardial cavity and peritoneal (abdominal) cavity.

7 — The heart consists of 5 chambers : a sinus venosus, 2 auricles, a ventricle and a truncus arteriosus. There is a hepatic portal system and a renal portal system.

8 — The kidneys are of the mesonephric type.

9 — They have ten pairs of cranial nerves.

10 — Fertilization is external in some species and internal in others.

An example of this group is the common Egyptian toad, *Bufo regularis*.

B. AMNIOTA

The Amniota include the remaining 3 classes of vertebrates : Reptilia, Aves and Mammalia.

General characters

1 — The embryo has an embryonic membrane known as the amnion.

2 — There is a neck (cervical) region following the head, and is supported by certain vertebrae, the cervical vertebrae.

3 — The buccal cavity is divided into an upper air passage, and a lower food passage.

4 — The thoracic region is protected by ribs.

5 — The heart consists of 2 auricles and a ventricle, which is a single chamber in some types, but is divided into two chambers in others.

6 — The respiratory system includes a larynx and trachea.

7 — The kidney is of the type known as the metanephros, which is the most advanced type of kidneys.

8 — There are twelve pairs of cranial nerves.

CLASS REPTILIA

This class includes lizards, snakes, turtles, tortoises, chamaeleons and crocodiles. These are generally known as creeping animals. The name of the class refers to the mode of their locomotion (reptum = creep).

General characters

- 1 — The body is covered with horny scales which prevent the loss of water. In some kinds, there are bony plates. The skin, in most species, is dry and does not contain any glands.
- 2 — There are two pairs of limbs, each with five fingers ending in horny claws.
- 3 — Respiration is always by lungs.
- 4 — The ventricle is incompletely divided, except in crocodiles where it is completely divided into two separate chambers. There are two aortic arches.
- 5 — The red blood cells are oval and nucleated.
- 6 — There is a single occipital condyle at the posterior portion of the skull.
- 7 — Fertilization is internal and the eggs are markedly rich in yolk.
- 8 — They are poikilothermic (cold-blooded) i.e. the body temperature varies with that of the environment.

CLASS AVES

General characters

- 1 — Their body is covered with feathers.
- 2 — The head is produced anteriorly into a beak, having various shapes in the different species.

3 — The skin possesses a single gland, the oil gland, which is located at the base of the tail.

4 — The fore-limbs are modified into wings.

5 — The skull has a single occipital condyle.

6 — Most of the vertebrae, particularly those of the trunk region, are fused together. Several other bones are also fused; a modification which helps in flight.

7 — The digestive canal includes a wide sac-like structure, the crop, for the temporary storage of food. There is also a thick-walled muscular gizzard for grinding hard food materials.

8 — The heart consists of 4 chambers : 2 auricles and 2 ventricles.

9 — There is only one aortic arch which is the right one; the left aortic arch is lacking.

10 — Red blood cells are oval and nucleated.

11 — There are air sacs connected with the lungs.

12 — Birds possess a lower larynx, called the syrinx, at the basal region of the trachea.

13 — There is no urinary bladder, and excretory materials are semi-solid.

14 — The females possess a single ovary, which is the left one, and there is also one oviduct, the left oviduct. Fertilization is internal. The eggs are large in size, rich in yolk and are protected by hard calcareous shells.

15 — They are homiothermic (warm-blooded), i.e. the body temperature does not vary with that of the environment.

CLASS MAMMALIA

The name of this class is derived from the fact that animals belonging to it feed their young by milk produced by mammary glands. Mammalia is the highest group in the Animal Kingdom. It includes about 15,000 species. Examples are : sheep, cattle, monkeys, bats and man.

General characters

1 — The body is distinguished into : a head, neck, thorax and trunk. A tail may be present in some forms.

2 — The skin is covered with hair and possesses sweat glands, sebaceous glands, scent glands and mammary glands.

3 — They possess 4 limbs; the foot has usually 5 toes modified for walking, running, climbing, burrowing, swimming or flying. They have horny claws, toes, nails or hoofs.

4 — They are warm-blooded; i.e. their body temperature is kept constant.

5 — The jaws are provided with similar or dissimilar teeth which are arranged into a definite manner that are represented by a dental formula.

6 — A muscular diaphragm separates the thoracic cavity from the abdominal cavity.

7 — The heart is 4-chambered, and only the left aortic arch is present. Red blood cells are non-nucleated.

8 — The skull has 2 occipital condyles.

9 — There is a urinary bladder, and urine is fluid.

10 — The testes are found in an external sac, the scrotum, lying outside the abdominal cavity.

11 — There is an external ear (pinna).

12 — Fertilization is internal and the embryo develops inside the uterus till birth. Embryonic membranes (amnion, chorion and allantois) and placenta are present.

An example of this group is the rabbit *Oryctolagus cuniculus*.

VERTEBRATE ANATOMY

CHAPTER V

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VERTEBRATE ANATOMY

THE EGYPTIAN TOAD

BUFO REGULARIS

INTRODUCTION

Frogs and toads are more commonly used as classical representatives of the vertebrates and convenient specimens for laboratory studies. This is attributed to the fact that they are easily obtained and bred and are relatively inexpensive. Their size is convenient, and they are easy to study. The arrangement of their internal organs is very similar to that of land vertebrates and a knowledge of their structure and function helps in understanding vertebrate anatomy and physiology and gives a good idea of the organization of the more complex groups, such as mammals.

Frogs and toads belong to **Amphibia**, a class of vertebrates. Amphibians (amphi = double; bios = life) are characterized by their ability to live both on land and in water. They start their life in water as aquatic forms, then transform gradually into terrestrial animals when adult. Adult amphibians, although mostly terrestrial, yet they cannot live away from water because they lay their eggs in water and hibernate in moist places.

HABITAT

Bufo regularis lives on land, in or close to ponds, pools, streams, marshes, and other moist places. When resting on land, the front portion of the body is raised on its short forelegs. The least noise causes the animal to leap rapidly towards nearby water where it swims and dives. The animal jumps and swims easily by the help of its powerful hindlegs. The presence of the slimy skin, a web, which is a fold of skin between the toes of the hindlegs, the short trunk, and the absence of a neck are all important adaptations for aquatic life. Frogs

and toads also float on water with all legs extended, and only the eyes and nostrils lie above water.

Frogs and toads are usually difficult to be seen because their colour blends highly with the surrounding medium. When the animal is placed on a light background, its colour becomes pale, and on a background of dark material, its colour becomes much darker. This change is slow and helps to protect the frog against its enemies. The principal enemies are snakes, turtles, herons and man.

Frogs and toads are cold-blooded animals; the temperature of their bodies varies according to that of the surrounding medium. It increases in summer, and decreases in winter.

They feed chiefly on flying insects which are caught by a quick movement of their protrusible sticky moist tongues.

They spend the winter time hibernating in certain burrows made in the mud of moist places. Inside these burrows, toads remain dormant until the following spring. The hibernating animals feed on the food materials stored in their bodies. Breathing takes place mainly by the skin. The heart beat is very slow and the body temperature is markedly lower than normal. In general, all physiological activities are highly reduced during hibernation.

During the breeding season, toads usually croak with a characteristic voice. They also croak at other times of the year, especially in the evening in damp atmospheres.

The jelly-coated eggs of toads are laid down in water where they are fertilized and develop into fish-like larvae known as **tadpoles** which feed and grow in water. They transform gradually into young toads which jump off the water onto neighbouring land.

EXTERNAL FEATURES

The body of the toad is divided into a **head** and a **trunk**; the neck region is lacking, and there is no tail in the adult. The whole body is covered by smooth slimy skin mottled with dark green patches and containing a large number of small protrusions known as the skin warts. The dorsal and lateral sides are dark in colour, but the ventral surface is pale. The "throat" or **subgular area** of the male is much darker than that of the female. This is due

to the presence of the dark vocal sacs in males only.

The **head** is flat and triangular with an anterior pointed end where a wide **mouth opening** is located. The eyes usually bulge upon the head but when the animal is irritated, they are rapidly drawn into the orbits and covered with the **eyelids**. The upper eyelid consists of an immovable thick fold of skin, but the lower eyelid is thin, translucent, and can move upward over the eyeball. Posterior to each eye, there is a rounded flat membrane known as the **ear-drum** or **tympanic membrane** which acts to receive sound vibrations. Behind each ear-drum is an elevated oval region of the skin indicating the presence of a **parotoid gland** formed of an aggregate of poison glands. When it is squeezed, a milky white viscid substance exudes. A pair of **nostrils** or **external nares** are situated on the dorsal side of the tip of the snout above the mouth. They serve for the entrance and exit of air.

The **trunk** carries two pairs of appendages or limbs. Each of the anterior appendages, or **forelimbs**, includes the following parts : an upper arm (the **brachium**) a lower fore-arm (**antebrachium**), and the hand (**manus**). The hand consists of a wrist (**carpus**), a palm (**metacarpus**), and the fingers (**digits**). There are 4 digits on each hand; the first digit, the thumb, is lacking. Two small **horny pads** are also found on the ventral surface of the hand.

The **hindlimbs** are much longer and more powerful than the forelimbs. Each limb consists of the thigh (**femur**), the lower leg, known as the shank (**crus**) and the foot, (**pes**). The distal end of the femur forms the **knee** while the distal end of the shank forms the **heel**. The foot consists of the ankle (**tarsus**), the sole (**metatarsus**) and the toes (**digits**). The foot has 5 well developed toes connected by a membranous web for swimming. A small rudimentary toe known as the **pre-hallux** is also carried on the foot.

At the posterior end of the trunk is situated the **cloacal opening**, a small aperture through which undigested food wastes, excretory substances (urine) and genital cells (eggs and sperms) are discharged.

Toads have no tail; hence they are placed in the order of Amphibia known as **Anura**, which means animals without tails.

SKIN AND COLOURATION

The skin or integument of the toad is smooth, thin and loosely attached to the body. It is always moist as the toad relies upon it for respiratory exchanges.

Histologically the skin of the toad, like that of all vertebrates, consists of two layers : an outer epidermis and an inner dermis.

The **epidermis** is much thinner than the dermis and is formed of stratified squamous epithelium. The basal layer in this epithelium is known as the **Malpighian or germinative layer**. It is formed of columnar cells which proliferate actively by mitosis, thus producing successive layers of cells that are pushed outward and become gradually flattened. They accumulate some horny material, and eventually die, forming a dead outer layer known as the **horny layer**. This layer is shed off about once a month during the active season, and is replaced by the active division of the cells of the germinative layer.

The **dermis** consists of fibrous connective tissue containing blood vessels, nerves and simple sense organs. It is differentiated into two regions : a) **Spongy layer** or stratum spongiosum, lying below the epidermis and formed of loose connective tissue, rich in alveolar glands, blood capillaries and nerve endings. The outer zone of this layer contains a large number of branched **pigment cells**. b) **Compact layer**, or stratum corneum, lies below the spongy layer. The fibres in this region are more regularly arranged and are more tightly packed than those of the spongy layer. They also contain a few smooth muscle fibres. Some of the connective tissue fibres in this layer run perpendicular to the surface, forming distinct **vertical strands**.

Skin glands : The skin of the toad contains many simple alveolar glands. These glands usually have muscle fibres at their bases for forcing out the secretions. Skin glands of the toad are of two types :

a) **Mucous glands**, are relatively small and surrounded by a simple epithelium of short columnar cells. These glands secrete a slimy mucus that is discharged over the surface of the body. This secretion helps in respiration,

by keeping the surface moist, and also protects the toad against dryness and excessive water loss.

b) **Poison glands**, are relatively few, except in the region of the parotoid glands where they are exceptionally numerous. Poison glands are larger in size than the mucous glands, and their wall is formed of a syncytium. These glands produce a thick whitish alkaloidal secretion which is very irritating to toads' enemies, and thus helps in protection against such enemies. This fluid is seen to be poured out when the toad is roughly handled or chloroformed.

Colour change

The skin colour of the toad is due to the presence of certain pigment granules in the epidermis and in the pigment cells or chromatophores found in the dermis. Three types of **chromatophores** are found :

1 — **Lipophores** : scattered in the uppermost part of the dermis. They are rounded and contain yellow to reddish lipoidal pigments.

2 — **Guanophores** : lying beneath the lipophores. They contain certain refractive granules of guanine crystals.

3 — **Melanophores** : found still deeper in the dermis. They have long, thin, branched processes, and possess brown to blackish melanin pigments.

The familiar colour of toads results collectively from the pigments which act to absorb some light rays and reflect others. The yellow light is reflected back through the epidermis by the lipophores and the blue light is reflected back by the guanophores. The light rays are absorbed by the melanophores. No green pigments are found in the skin, but the greenish colour observed is due to the reflection of the blue and yellow lights together.

The colour of the toad's skin is susceptible to marked changes under the effects of certain internal and external factors. Darkening of the skin results from the spreading out of the pigment granules in the chromatophores and their processes. On the other hand, when these pigments are concentrated in certain regions of the chromatophores (usually in the centre), the skin becomes pale. These colour changes are controlled by certain external and internal factors: low temperature produces darkening, whereas under high temperature, dry atmosphere or intense light, the colour becomes pale.

Some of these changes are induced through the eyes, as experimentally blinded toads do not show any change in the colour of their skin under any condition. The pituitary gland was found to play an essential role in the colour changes of toads. A hormonal secretion of this gland, known as **intermedin**, effects the spreading and concentration of pigment granules in the chromatophores. In hypophysectomized toads, the skin remains always pale, and injection of intermedin causes darkening.

Functions of the skin

The skin of the toad serves mainly the following purposes :

1 — **Protection** : The skin protects the internal body organs, particularly the muscles underneath. It also protects the toad against the invasion of many disease-producing germs, and against the attack of many carnivorous animals, mainly by the toxic secretions of its poison glands. Also, the mucous secretions make the skin slippery and this enables the toad to escape the grasp of its enemies. Besides, the ability of the skin to change its colour to match with the surrounding medium provides a sort of camouflage which enables the toad to escape its enemies.

2 — **Respiration** : The skin acts as a respiratory surface for gas exchanges by the help of the watery mucous secretion covering its surface. The large number of blood capillaries scattered in the skin play a principal role in this process. The toad depends exclusively on skin respiration while in water.

3 — **Sensation** : The skin of the toad performs a sensory function by the help of the nerve endings and sensory cells scattered in the dermis.

4 — **Water balancing** : The skin acts to maintain water balance in the animal's body since water can diffuse to a certain extent through it.

ORGAN SYSTEMS

MUSCULAR SYSTEM

Muscles of the toad are of the same three main types found in other vertebrates. These are :

1 — **Involuntary or smooth muscles** are found in the walls of many visceral organs as the digestive and respiratory ones. They are known as involuntary because they are not under the conscious will.

2 — **Cardiac muscles** are found only in the wall of the heart, hence they are also known as heart-muscles. They are capable of performing the involuntary rhythmic contractions of the heart, known as heart beat.

3 — **Voluntary muscles** are so called because they are under the control of the will. They are also known as the superficial or skeletal muscles since they are situated directly under the skin, and are primarily attached to the bony parts of the skeleton. Voluntary muscles are formed of bundles of muscle fibres, each being invested by a layer of fibrous tissue, and the whole muscle is covered with a tough membranous sheath known as the **fascia**. These muscles are usually attached to the bones by certain fibrous **tendons** which are continuations of the connective tissue layers extending between the muscle bundles, and are fastened to a vascular membrane known as the **periosteum** covering the outer surfaces of the bony parts.

Each voluntary muscle is usually differentiated into 3 parts : a central part, known as the **belly**, one end known as the **origin**, and the other end known as the **insertion**. The movements of any part of the body depend on the places of origin and insertion of its muscles, and on the nature of articulation of its bones with one another and with other parts of the body. The muscle origin is usually attached to a relatively immovable bone, while the insertion is fixed to a bone which moves when the muscle contracts. A muscle may have two or three origins. In the first case, it is known as a **biceps**, and in the second, as a **triceps**. Insertions, on the other hand, are frequently made through the fibrous tissue of a tendon. The tendon itself attaches to a certain projection of the bone.

Functions of muscles

Muscles perform three major functions : movement, maintenance of posture and heat production.

1 — **Movement** : Voluntary muscles produce motion as a result of their contractions which act to draw the ends of the muscle towards the central part, the muscle belly. Different types of muscle action are known in toads. Generally, muscles are arranged in an antagonistic manner that acts to produce opposite effects. One set of muscles is responsible for moving a part of the body in one direction, whereas movement in the opposite direction is produced by an antagonistic set found on the opposite side of the same part. For example, a muscle acts to bend a certain part, and another antagonistic muscle acts to straighten the same part.

The most familiar muscle movements are : flexion and extension, elevation and depression, adduction and abduction, constriction and dilation, as well as rotation. Each muscle is described according to the type of movement it produces as follows :

A. *a)* **Flexor muscle** : Bends one part upon another, e.g. the **biceps** which bends the fore arm to bring it against the upper arm.

b) **Extensor muscle** : Straightens or extends a part of the body, e.g. the **triceps** which extends the fore-arm.

B. *a)* **Adductor muscle** : Draws a part towards the axis of the body, e.g. the **latissimus dorsi** muscle which adducts the upper arm.

b) **Abductor muscle** : Draws a part away from the axis of the body, e.g. the **deltoid** muscle abducts the upper arm.

C. *a)* **Depressor muscle** : Lowers a part of the body, e.g. the **depressor mandibularis** moves the lower jaw down to open the mouth.

b) **Levator muscle** : Elevates or raises a part of the body, e.g. the **masseter** muscle raises the lower jaw to close the mouth.

D. *a)* **Constrictor muscle** : Constricts or closes an organ, e.g. the **circular muscles** of the iris.

b) **Dilator muscle** : Causes dilation of the an organ, e.g. the **radial muscles** of the iris.

E. **Rotator muscle** : Rotates one part on another. The antagonistic rotator

masseter
(levator)

depressor mandibularis
(depressor)

deltoid
(abductor)

triceps
(extensor)

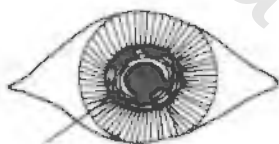
pyriformis
(rotator)

latissimus dorsi
(adductor)

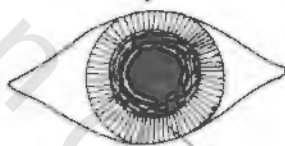
biceps
(flexor)

gastrocnemius
(flexor)

tibialis
anticus
(extensor)



circular muscles of iris
(constrictor)



radial muscles of iris
(dilator)

triceps
(extensor)

deltoid
(abductor)

biceps
(flexor)

latissimus dorsi
(adductor)

MUSCLE ACTIONS

muscle causes the rotation in the opposite direction, e.g. the **piriformis muscle** raises and rotates the femur.

2 — **Maintenance of posture** : Posture is generally maintained by controlled muscle action. Standing upright, sitting down or maintaining any other position are only allowed by controlled action of several sets of voluntary muscles. In cases of extreme fatigue or unconsciousness, when muscles fail to contract, the body collapses in a heap.

3 — **Heat production** : Heat energy is produced during certain reactions which take place within the muscles. The most important of these reactions is the breakdown of a component of the muscle tissue known as **adenosine triphosphate (ATP)**, which is considered as the trigger of muscle contraction. The phosphate radical in that compound is attached through what is termed an **energy-rich phosphate bond**. When such a bond is broken, adenosine triphosphate is converted into adenosine diphosphate (ADP) and a large amount of energy (11,500 cal/gm mol) is released :



Another component of muscles with a similar energy-rich phosphate bond is **creatine phosphoric acid (CP)**. It is converted on hydrolysis into creatine and inorganic phosphate, and a large amount of energy is released :



A third source of heat energy is the oxidation of certain metabolic products, such as lactic acid and pyruvic acid, found in the muscles through series of enzymatic reactions known as glycolysis and through the tricarboxylic acid cycle. The energy resulting from these reactions is utilized in the contraction of the muscle, in rebuilding ATP and CP and in providing necessary warmth to the body.

SKELETAL SYSTEM

The skeleton forms a supporting structure for the whole body, protects the internal organs, particularly the principal parts of the central nervous system, and serves for the attachment of muscles which produce movement and locomotion.

In the early tadpoles, the skeleton is made up entirely of cartilage. Later, many skeletal parts are transformed into hard bones, although cartilage persists on the ends of the limb bones and some other parts of the skeleton.

The skeletal system is divided into two main parts : Axial and appendicular skeleton.

I. AXIAL SKELETON

The axial skeleton of the toad consists mainly of :

A. Skull.

B. Vertebral column.

A. Skull

The skull of the toad is dorso-ventrally flattened, triangular and bluntly pointed anteriorly. It consists of a number of bones which are completely fused with each other, with the exception of the lower jaw which can move downward and upward to open and close the mouth. The skull is built up of the following parts :

- | | |
|-------------------|--------------------|
| 1. Cranium | 3. Jaws |
| 2. Sense capsules | 4. Hyoid apparatus |

1 — Cranium (brain case)

This is a narrow box which contains and protects the brain. The roof of the cranium is formed of two large bones known as the **frontals**, and its floor consists of an inverted T-shaped bone, the **parasphenoid**. The posterior part of the cranium is formed of two small **exoccipitals**, each bearing a rounded posterior projection, known as the **occipital condyle**, which articulates with a certain depression in the first vertebra. A large opening, the **foramen magnum**, is located posteriorly between the 2 occipital condyles. The brain connects through this opening with the spinal cord. Part of the **sphenethmoid** contributes in the formation of the anterior part of the cranium.

2 — Sense capsules

a) **Olfactory capsules** : These are found in the anterior part of the skull, being covered dorsally by the two **nasals**. Anterior to the nasals there are

two small bones, the **septomaxillae**. The two **vomers** and a part of the sphenethmoid form the floor of the olfactory capsules. The two capsules are separated from each other by a partition known as the **mesthoid**.

b) Optic capsules : There are no special bones forming capsules for the eyes. The 2 eyes are lodged within 2 large **orbits** found on both sides of the cranium. Each orbit is bordered internally by the bones of the cranium and externally by the bones of the upper jaw.

c) Auditory capsules : The auditory capsules surround the ears. Each consists mainly of a **prootic** bone, which is found lateral and posterior to the frontal bone.

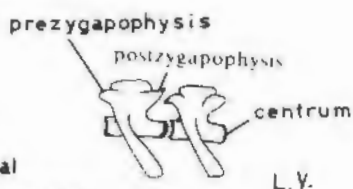
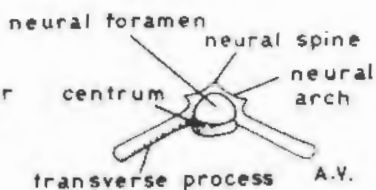
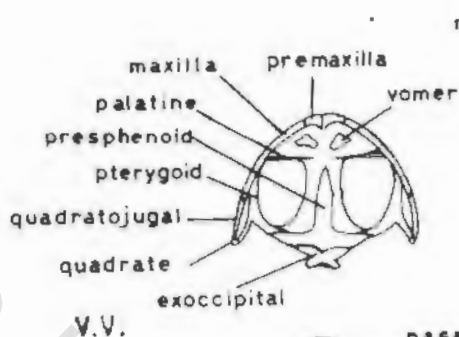
3 — Jaws

a) Upper jaw : The upper jaw of the toad consists of three pairs of bones which are fused to the cranium. Each half includes an anterior **premaxilla**, followed by the **maxilla** and the **quadratojugal**. Other bones entering in the formation of the upper jaw are the **palatine**, which is a transverse bone extending from the sphenethmoid to the outer edge of the skull, and an inverted Y-shaped bone known as the **pterygoid**. The anterior part of the pterygoid connects with the palatine; one posterior branch connects with the prootic and the other branch connects with the **quadrate**, which is a small cartilaginous bone found at the posterior end of the upper jaw. The **squamosal** is a hammer-shaped bone bordering the orbit posteriorly. It attaches at one end to the quadrate and at the other end to the prootic.

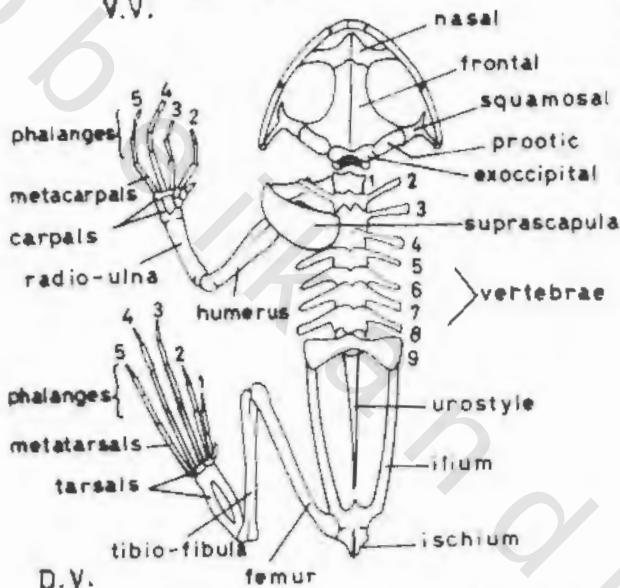
b) Lower jaw : This is formed of an anterior **mentomeckelian**, followed by the **dentary** and the **angulosplenial**.

4 — Hyoid apparatus

A large proportion of this apparatus is formed of cartilage. It is a flattened structure found on the floor of the lower jaw. It serves mainly to support the mouth and tongue, and for the attachment of the tongue muscles. The hyoid apparatus consists of a central main part known as the **body**, from which extend two anterior processes or **anterior cornua**, two lateral **alary processes**, two **posterolateral processes** and the **posterior cornua** which embrace the laryngotracheal chamber.

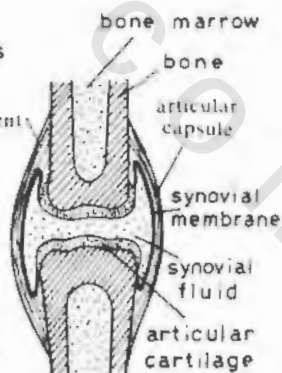
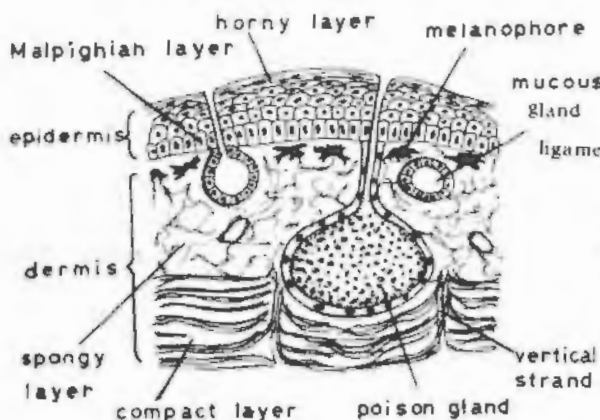


Normal vertebra



Urostyle

SKELETON OF THE TOAD



Hinge joint

B. Vertebral Column

The vertebral column of the toad is short and hardly flexible. It consists of 9 **vertebrae**, ending in a slender bone known as the **urostyle**, which represents a number of fused vertebrae. All the vertebrae are generally built up on the same plan.

1 — **Normal vertebrae** : The vertebrae from 2-8 are all alike and are known as the normal vertebrae. Each consists of a thick ventral **centrum** which is concave in front and convex behind, and the vertebra is thus described as a **procoelous vertebra**. Arching above the centrum is a **neural arch**, which carries a median short spine known as the **neural spine**. The cavity between the centrum and the neural arch is the **neural foramen**, through which passes the spinal cord. A **transverse process** extends laterally from each side of the vertebra and serves for muscle attachment. On either side of the neural arch there are certain processes used for the movement of the vertebrae on each other. These include two anterior **prezygapophyses** directed upwards, and two posterior **postzygapophyses** directed downwards. The two smooth surfaces of the postzygapophyses of one vertebra move on the smooth surfaces of the prezygapophyses of the next vertebra behind. This mode of articulation allows for some flexibility in the movement of the vertebral column. A small aperture, the **intervertebral foramen**, is found on either side of the vertebra and serves for the passage of a spinal nerve from the spinal cord.

2 — **First vertebra**; also known as the **atlas** in Amniota, differs from the normal vertebrae in the following:

- * It has no transverse processes,
- * its centrum is small,
- * the prezygapophyses are absent, and
- * the anterior surface of the vertebra possesses two concave **condylar facets** into which the two occipital condyles of the skull fit. This arrangement allows for the articulation of the skull with the vertebral column.

3 — **Last vertebra**; ninth or sacral vertebra, is characterized by having :

- * Two broad transverse processes.

- * no postzygapophyses,
- * two posterior protrusions which fit into two small concavities in the anterior part of the urostyle

4 — **Urostyle** : This is a long thin bone forming the posterior part of the vertebral column, and within which extends the end portion of the spinal cord, known as the **filum terminale**. On each side of the anterior part of the urostyle, there is a minute opening for the passage of the last spinal nerve.

II. APPENDICULAR SKELETON

This comprises the girdles, shoulder or pectoral girdle and hip or pelvic girdle, and the bones of the fore-and hindlimbs.

A. Pectoral Girdle

This girdle supports the forelimbs, serves for the attachment of the muscles which move those limbs, and protects the organs lying within the anterior portion of the trunk. The pectoral girdle is an incomplete ring attached to the vertebral column by certain muscles. On either side of the girdle there is a broad dorsal cartilaginous **suprascapula**, a narrow lateral **scapula**, a slender **clavicle** and a relatively broad **coracoid**. The clavicle is found anterior to the coracoid, the two bones being separated by a space known as the **coracoid foramen**. The inner part of the scapula has a small projection known as the **acromion process**. The clavicle and coracoid of each side meet two small median bones known as the **epicoracoids**. These are attached posteriorly to a median ventral bone, which is the **sternum** or breastbone. The sternum consists of a bony part known as the **xiphisternum**, and a posterior broad cartilaginous part, the **xiphoid cartilage**.

At the place of contact of the scapula, clavicle, and coracoid, there is a depression known as the **glenoid cavity** or **fossa** in which fits the head of the bone of the upper arm.

B. Bones of the Forelimb

The skeleton of the forelimb consists of the following bones :

- 1 — **Humerus** : This supports the upper arm. It consists of a long **shaft**,

a swollen **head**, which fits in the glenoid cavity, and a posterior swollen part known as the **trochlea**. On the inner side of the shaft, there is a projection known as the **deltoid ridge** which serves for the attachment of certain fore-limb muscles.

2 — **Radio-ulna** : This is found in the fore-arm, and consists of an inner **radius** and an outer **ulna**, both fused with each other. The ulna is projected upwards forming a process known as the **olecranon process**.

3 — **Carpals** : These are found in the wrist. They include six small bones arranged in two rows, three in each row.

4 — **Metacarpals** : These are four slender bones supporting the palm.

5 — **Phalanges** : The phalanges are thin bones supporting the digits. Their number differs in the different digits, and is expressed by what is known as the **digital formula**, which is in this case 2 : 2 : 3 : 4. The first 2 phalanges lie in the first finger found near the body.

C. Pelvic Girdle

The pelvic girdle supports the hindlimbs. It is a U-shaped framework of bones which are connected to the vertebrae by certain muscles. The girdle consists of three bones on each side : a long **ilium** which articulates with the transverse process of the ninth vertebra, a posterior **ischium** lying dorsally, and a **pubis** lying ventrally. The two pubic bones fuse together in a median ventral line known as the **symphysis pubis**. A socket is found at the region of contact between the three bones of the pelvic girdle. This is known as the **acetabulum** and serves for the articulation of the head of the long bone of the thigh.

D. Bones of the Hindlimb

The bones of the hindlimb include the following :

1 — **Femur** : This supports the thigh, and consists of a **head** which fits in the acetabulum, a long **shaft**, and the **condyles** at the other end.

2 — **Tibio-fibula** : This is found in the shank and consists of a **tibia** lying to the inside, and a **fibula** lying to the outside. The two bones are fused together.

3 — **Tarsals** : These consist of four bones supporting the ankle. They

are arranged in two rows : a proximal row of two elongated bones known as the **astragalus** (lying to the inside) and **calcaneum** (lying to the outside), and a distal row of small bones.

4 — **Metatarsals** : These include five elongate slender bones and a sixth small one. The last one belongs to the prehallux.

5 — **Phalanges** : These are found in the toes. They are expressed by the digital formula $2 : 2 : 3 : 4 : 3$, arranged from inside outwards.

Joints

A joint is identified as the place of articulation between two neighbouring bones. There are two main categories of body joints :

1 — Fixed joints

These are found in places where bones meet and only a slight or no movement takes place between them, as for example the joints found between the bones of the skull. The edges of joined bones are not smooth, but are more or less serrated in these joints. Such joints allow for growth of the joined bones, and may also allow certain movements as in skulls of embryos at birth time.

2 — Movable joints

These include the following types :

a) **Gliding joints** : which allow for a gliding movement, e.g. the joints found between the carpals.

b) **Hinge joints** : at which movement takes place in one direction only, e.g. the elbow joint, where the humerus and radio-ulna meet each other. Another example is the knee joint.

c) **Ball and socket joints** : in which one bone ends in a rounded part which fits in a cavity in the neighbouring bone, e.g. the joint between the head of the humerus and the glenoid cavity in the pectoral girdle, and also the joint between the head of the femur and the acetabulum in the pelvic girdle.

d) **Pivotal joints** : these permit a rotating movement in one plane, e.g. the joint between the first and second vertebrae which allows turning the head from side to side.

Joint structure

The surface of the bone in a movable joint is covered by a cartilaginous layer known as the **articular cartilage**, which protects the bones against friction with one another. The two articulating bones are attached together by certain **ligaments** formed of fibrous connective tissue which extend across the joint and form what is known as the **articular capsule**. The cavity surrounded by this capsule is known as the **synovial cavity**. This cavity is lined with a thin **synovial membrane** and contains the **synovial fluid** that also helps in preventing bone friction and facilitates the articulation of bones on each other.

Functions of the skeletal system

- 1 — Bones support the soft tissues of the body.
- 2 — Certain bones protect delicate tissue structures, such as the brain which is protected inside the cranium.
- 3 — Bones may be regarded as **calcium stores** on which the body can rely in certain conditions of calcium deficiency.
- 4 — Bones enclose the red bone marrow which is an important blood-forming tissue.
- 5 — Bones form levers that can be moved by contraction and relaxation of adjoining muscles.

BODY CAVITY

The body cavity, or **coelom**, encloses different internal organs and contains a fluid, known as the **coelomic fluid**, which facilitates the movement of the body organs in relation to each other. This cavity is differentiated into two parts : the **pericardial cavity** containing the heart, and the **abdominal cavity** enclosing other body organs. The coelom is surrounded externally by a thin epithelial membrane lying close to the muscle coat of body and known as the **parietal peritoneum**, and is lined internally by another similar **visceral peritoneum**, which invests some visceral organs as the stomach, intestine, liver, etc. The two peritoneal membranes run close to each other in certain parts of the body forming thin double membranes which are the **mesenteries**. These act to bind different body organs together and to the dorsal wall of the body. The mesenteries are richly supplied with blood vessels and nerves.

DIGESTIVE SYSTEM

The digestive system is responsible for providing the energy requirements of the body. It does so by ingesting and digesting foodstuffs, thus converting them into soluble products that are finally absorbed and passed into the blood and lymph to be distributed to the different body tissues.

This system consists of two main parts :

- I. The alimentary canal, which is concerned with mechanical digestion.
- II The digestive glands, which are responsible for chemical digestion.

I. ALIMENTARY CANAL

The alimentary canal is essentially a tube in which the different regions are modified in various ways to perform different functions. It begins with the **mouth**, which is guarded by two semicircular jaws, and opens into a large **buccal cavity** which is followed by the pharynx. The two cavities are confluent with each other and form together a wide **buccopharyngeal cavity**. This cavity is lined with a mucous membrane which secretes a slimy mucus that facilitates food swallowing. The **tongue** of the toad is loose, flexible and muscular. It is always covered by a sticky mucous secretion. Unlike most other animals, the tongue of toads is attached by its front end to the lower jaw, just behind the point of fusion of the two halves of that jaw. If an insect comes near a toad, the tongue is quickly protruded, and its free posterior end adheres to it, then draws the prey into the mouth cavity. The whole process takes only a fraction of a second. Swallowing of food is made possible by the raising of the floor of the mouth and the depression of the eyeballs inwards.

The **buccopharyngeal cavity** leads to the **oesophagus** which is a narrow elastic tube capable of considerable distension for swallowing large insects. The muscular wall of this flexible tube transports foodstuffs to the stomach by peristalsis (muscular contractions of the wall of the oesophagus), helped by the mucous secretion of the **buccopharyngeal cavity** and **oesophagus**.

The **stomach** is a large pear-shaped sac capable of great dilation, thus

accommodating large quantities of food. It lies on the left side of the body, partially obscured by the liver. The first part of the stomach is relatively wider and is known as the **cardiac portion**; the other narrower region is known as the **pyloric portion**. The first part is guarded by a valve, the **cardiac sphincter**, which controls the entrance of food into the stomach. At the posterior end of the stomach there is another valve known as the **pyloric sphincter**, which regulates the passage of food into the intestine. The wall of the stomach is folded and glandular. It is capable of performing partial digestion, but it mainly acts as a storage organ.

The stomach leads into the small intestine. The first part of the intestine is the **duodenum**. It is a short tube which loops sharply forward and runs parallel to the stomach, both forming a U-shaped structure.

The remainder of the small intestine, or **ileum**, is a long, narrow coiled tube which is supported by several mesenteries. The inner surface of the ileum is highly folded to form villi which provide a large surface area for food absorption.

The ileum leads posteriorly into the large intestine, or **rectum**, which is a small dilated tube leading directly into the **cloaca**.

The **cloaca** is a muscular chamber which also receives the ends of the urinary and genital ducts, and opens by the cloacal aperture to the outside.

II. DIGESTIVE GLANDS

The glands of digestion in the toad include :

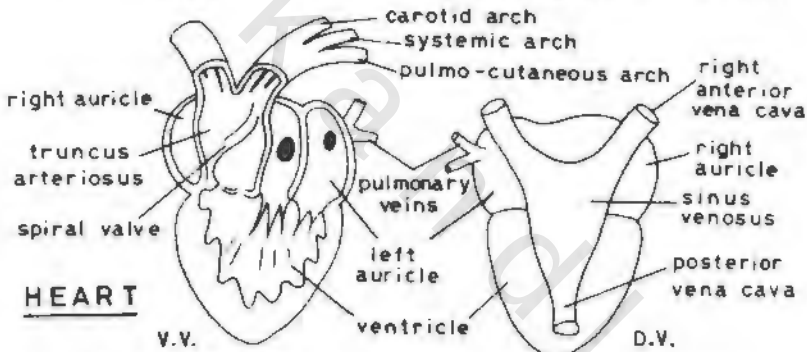
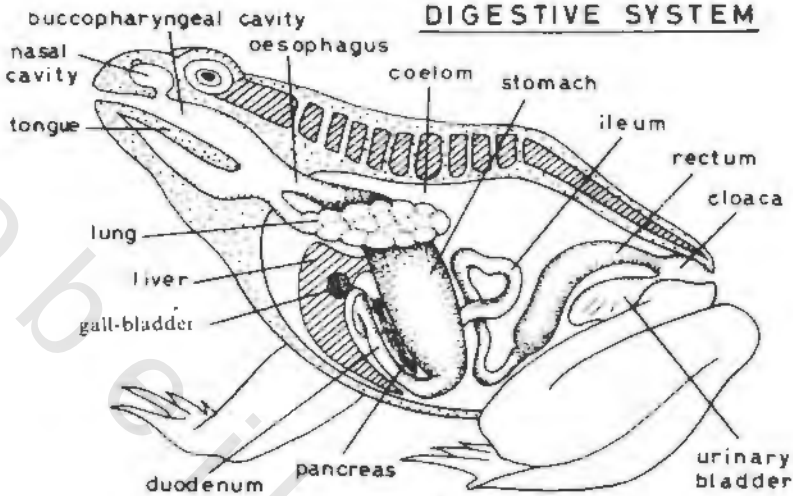
A. Gastric glands

These are simple branched tubular glands found in the walls of the stomach and secrete the gastric juice.

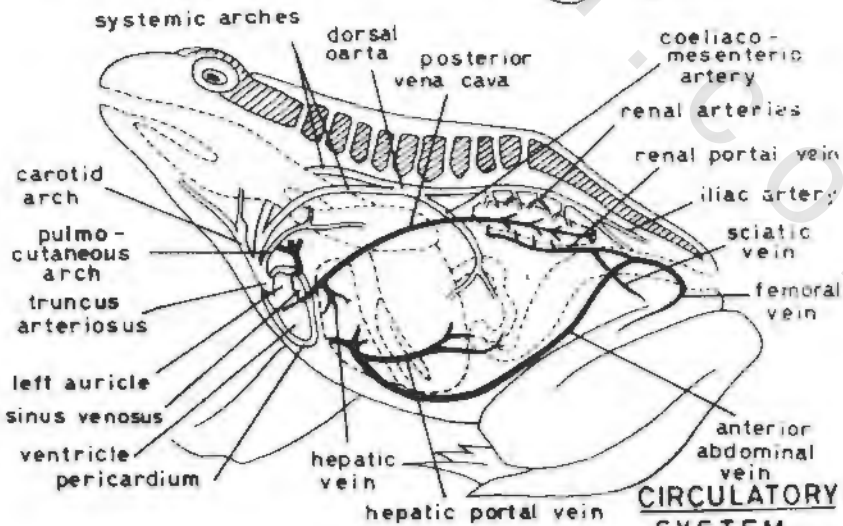
B. Liver

This is a reddish organ attached to the body wall anteriorly, and divided into two lobes connected together by a flattened portion known as the **isthmus**. The liver secretes bile which is stored in a spherical greenish sac, the **gall-bladder**, that lies between the two lobes. It receives bile from each lobe by a small **cystic duct**. Bile is carried away from the gall-bladder through the **bile duct**, which runs down along the pancreas.

DIGESTIVE SYSTEM



HEART



CIRCULATORY SYSTEM

C. Pancreas

The pancreas is a pale yellowish body lying between the stomach and duodenum and is surrounded by delicate mesenteries. It gives a number of fine **pancreatic ducts** which open in the bile duct. A small **hepato-pancreatic duct** leaves the pancreas carrying the bile and pancreatic juice, and opens in the first part of the duodenum.

D. Intestinal glands

These are tubular glands found in the wall of the intestine and secrete the intestinal juice.

Histology of the digestive organs

The wall of the alimentary canal is formed of a number of tissues which are nearly the same throughout its length. These are usually arranged in the following layers :

Serosa : A layer of visceral peritoneum investing the alimentary canal, and is formed of simple squamous epithelium.

Muscle layers : Two layers of unstriated muscle fibres are found below the serosa; an outer longitudinal muscle layer in which the muscle fibres run longitudinally, and an inner circular muscle layer in which the fibres are circularly arranged at right angles to the preceding fibres. These two muscle layers produce certain rhythmic waves of contractions, known as peristalsis, which help in driving food down the alimentary canal.

Submucosa : This consists of a highly vascular areolar connective tissue.

Mucosa or mucous membrane: It is a folded structure formed mainly of columnar cells and enclosing the digestive tubular glands. Each gland is formed of a central cavity surrounded by cuboidal epithelium.

In the oesophagus, in particular, the columnar epithelium is partially ciliated and contains certain mucus-secreting cells known as the **goblet cells**.

Histology of the liver and pancreas

The liver of the toad appears under the microscope to be built up of a very large number of more or less rounded structures known as the **hepatic**

acini. Each acinus has an internal narrow cavity, the **bile canalicule**, that is surrounded by a number of pear-shaped pigmented **hepatic cells** which secrete the bile juice. The bile canalicules of the different acini join to form the **bile ductules**, which ultimately form the **bile duct**. These ductules are lined by cuboidal epithelium. **Bile pigments** and **blood sinusoids** are found inbetween the hepatic acini.

The **pancreas** consists of two main parts :

The **exocrine part** is formed of a large number of **pancreatic acini**, each being built up of large darkly-stained conical cells and enclosing a small inner lumen. These cells secrete the pancreatic juice. A number of **pancreatic ductules** are found inbetween the acini, each having a wider cavity and a wall of a single layer of cuboidal epithelium.

The **endocrine part** consists of isolated clusters of cells, the **islets of Langerhans**, markedly rich in blood vessels. These cells secrete certain hormones which diffuse directly into the blood vessels.

Functions of the digestive system

1 — The digestive system performs **mechanical digestion** which takes place by chewing, mastication and trituration in the buccal cavity, as well as by grinding and mixing of food material in the rest of the alimentary canal.

2 — The system also performs **chemical digestion** through the help of hydrolytic enzymes which aid in splitting large molecules of food into smaller ones in preparation for absorption.

3 — **Absorption** of digested food takes place mainly in the small intestine which is structurally suited for this purpose by the possession of villi.

4 — Undigested remains are passed to the outside by **egestion** or **defaecation** through the cloacal or anal opening.

5 — The digestive system contributes to the **regulation of the body water content** as well as to the **excretion of salts of heavy metals**.

6 — The system is also considered an important line of defense. Food substances which might be harmful if allowed to pass into the body tissues are evacuated by regurgitation and/or by diarrhea.

RESPIRATORY SYSTEM

Adult toads possess **lungs**, while the larval stages possess **gills**. The **pulmonary organs** in adult toads include the larynx and the lungs.

The **larynx** (or **laryngotracheal chamber**) is a pear-shaped structure lying between the two posterior cornua of the hyoid apparatus. It is supported by 3 cartilaginous pieces : two lateral **arytenoids**, enclosing between them a longitudinal slit, which is the **glottis**; and a third piece of cartilage, known as the **cricoid**, surrounding and supporting the basal region of the larynx. Two small **pulmonary processes** extend from the cricoid to support the bases of the lungs. The glottis is opened and closed by certain muscles attached to the arytenoids.

Inside the larynx there are two elastic bands, the **vocal cords**, to each of which is attached a **cartilaginous ball**. These balls are more prominent in males than in females.

The **lungs** are two spongy elastic sacs lined by a highly folded epithelial layer containing mucus-secreting cells. The folds of this epithelium are known as the **trabeculae**. The chambers between these trabeculae are known as the **alveoli**. Each trabecula is richly supplied with blood capillaries and has some unstriated muscle fibres. The epithelium covering the free ends of the trabeculae is ciliated.

Respiration

Respiration takes place in adult toads by the lungs (pulmonary respiration), the lining of the buccopharyngeal cavity (oral respiration) and the skin (cutaneous respiration). Tadpoles rely on the gills (gill respiration) instead of the lungs.

a) Pulmonary respiration : This begins with the inhalation of air which takes place as a result of the opening of the nostrils and lowering of the floor of the buccal cavity. The nostrils are then closed and the floor of the buccal cavity is raised, thus air is forced through the glottis in to the lungs where exchange of gases takes place. When the abdominal muscles contract, air

is forced back from the lungs into the buccal cavity. The glottis is then closed, the floor of the buccal cavity is raised, and the nostrils are opened so that air is expired.

b) Oral respiration : Exchange of gases takes place also in the buccal cavity. This cavity is lined by a thin mucous membrane richly supplied with blood capillaries. During oral respiration, both the mouth and glottis remain closed while the nostrils rhythmically open and close and the floor of the buccal cavity is simultaneously raised and lowered. If the mouth is left open for sometime, the toad is asphyxiated.

c) Cutaneous respiration : This is the mode of respiration on which the toad completely relies when it is found in water. Exchange of gases takes place between oxygen dissolved in the water and the blood in the capillaries scattered in the skin.

d) Gill Respiration : In early tadpoles, respiration takes place by certain thin-walled, finger-like outgrowths of the skin known as the **external gills** which are richly supplied with blood vessels. These external gills later disappear, and another set of **internal gills**, similar to those of fishes, are formed. The latter function as respiratory organs for sometime, then become gradually replaced by the lungs.

Voice

During the passage of air inside the larynx, the two vocal cords vibrate, and as a result of friction between the two cartilaginous balls, sound is produced. Some of the expired air inflates the vocal sacs, which are paired evaginations from the wall of the pharynx. These sacs serve for resonating the sound, thus considerably increasing the volume of the sound; hence the voice known as croaking is heard. Croaking is more often heard during the breeding season, when males call for the females.

Functions of the respiratory system

1 — The respiratory system furnishes a passageway for atmospheric air to pass from outside to the body cells.

2 — The thin walls of the alveoli of the lungs serve as a respiratory surface at which exchange of gases takes place between atmospheric air and the body fluids.

3 — Air is filtered from impurities, moistened, warmed and chemically tested by means of the organs of smell found at the beginning of the respiratory system.

4 — The larynx aids in producing voice.

5 — The respiratory system participates in the regulation of the body temperature, body water content and the PH of the blood.

CIRCULATORY SYSTEM

The circulatory system of the toad consists of the **blood system**, which includes the heart and blood vessels, and the **lymphatic system**.

I. BLOOD SYSTEM

Heart

The heart of the toad is a pear-shaped muscular pump enclosed in a thin-membranous sac known as the **pericardium** which is filled with fluid that protects the heart against friction with other organs. The heart consists of 5 chambers : a sinus venosus, 2 auricles, a ventricle, and a truncus arteriosus.

The **sinus venosus** is a thin-walled triangular chamber lying on the dorsal side of the heart. It opens by a small opening, the **sinu-auricular opening**, into the right auricle. This opening is guarded by the **sinu-auricular valve** formed of two thin flaps that allow the flow of blood from the sinus venosus to the auricle only, and not in the reverse direction.

The **two auricles** are separated from each other by a vertical partition known as the **inter-auricular septum**. The right auricle is larger than the left one. The left auricle receives the common pulmonary vein carrying blood from the lungs. The 2 auricles open together into the right side of the ventricle by the **auriculo-ventricular opening**. This opening is guarded by an **auriculo-ventricular valve** of 4 flaps which allow blood to flow from the auricles into the ventricle, and prevent its backflow into the auricles.

The **ventricle** is a conical thick-walled chamber. Its inner wall is raised into certain muscular thickenings known as the **columnae carneae**, to which are attached a number of elastic cords known as the **chordae tendineae**. The other ends of these cords are attached to the flaps of the auriculo-ventricular

valve. They prevent these flaps from being reflected back into the auricles during the contraction of the ventricle. The flaps only float on the surface and close the auriculo-ventricular opening.

The **truncus arteriosus** is a muscular tubular chamber lying on the ventral surface of the heart. Its opening in the right side of the ventricle is guarded by 3 **semilunar valves** which allow the passage of blood in one direction only, from the ventricle to the truncus arteriosus. A flat twisted **spiral valve** is found within the truncus arteriosus.

Blood vessels

These are of two main types, arteries and veins.

Arteries : are markedly elastic and thick-walled. They appear pale pink in dissected toads. They have thick muscle coats, and are lined internally by an endothelial layer of squamous epithelium. Arteries carry blood from the heart to the body tissues.

Veins : are dark red and thin-walled. They contain less muscles and connective tissue than arteries; hence blood pressure in veins is lower than in arteries. Veins are also lined by an endothelium. They collect blood from the tissues and carry it to the heart.

The arteries divide into smaller branches known as **arterioles**, which divide in turn into a large number of **arterial capillaries** extending to the tissues cells of the body. There, food and oxygen diffuse out through the walls of these capillaries to the cells. In the same regions, another set of capillaries, known as the **venous capillaries**, are seen in continuation with the arterial capillaries. The venous capillaries unite into small veins known as **venules**, which, in turn, collect into large veins that ultimately pour into the heart.

However, some veins pass into certain body organs before they empty into the heart. These are the **portal veins**. Two of such veins are found in the toad :

1 — The **hepatic portal vein** brings blood with digested food material from the alimentary canal and enters the liver where it is broken into a large number of venous capillaries. In the liver, some food substances are filtered off the blood or stored, before blood is collected by another set of venous

capillaries. These unite together forming the hepatic veins, which convey blood to the heart.

2 — The **renal portal vein** runs along the outer border of the kidney. It branches inside the kidney into a large number of capillaries, which unite again into another set of capillaries that ultimately form the renal veins.

The different vessels constitute together the venous system while the arteries form the arterial system.

A. Venous System

This system comprises the following main blood vessels :

- Three large veins or *venae cavae*; two anterior ones (right and left) and a posterior one.
- Portal veins.
- Pulmonary veins.

Anterior *venae cavae*

Each anterior vena cava collects blood from the corresponding anterior part of the body and is formed by the three following veins :

1 — **External jugular vein** : formed by two main tributaries :

- a) **lingual vein** from the tongue and floor of the mouth,
- b) **faciomandibular vein** from the lower jaw.

2 — **Innominate vein** : results from the union of 2 tributaries :

- a) **internal jugular vein** from the brain,
- b) **subscapular vein** from the shoulder.

3 — **Subclavian vein** : formed by 2 tributaries :

- a) **brachial vein** brings blood from the forelimb,
- b) **musculocutaneous vein** formed of smaller branches from the skin and muscles.

Posterior *vena cava*

This vein returns blood from the posterior portion of the body and is

formed of 4-5 pairs or **renal veins** coming out from the kidneys. This vein pierces the liver, and on passing outside it, receives 2 small stout **hepatic veins**, then it pours into the posterior end of the sinus venosus.

Portal veins

Blood is brought from the hindlimb by a **femoral vein** which divides into two branches; a small outer **external iliac vein** and an inner **pelvic vein**. The external iliac vein receives a small branch, the **sciatic vein**, from the hind region of body, and both together form the **renal portal vein**. The two pelvic veins of the 2 sides unite together forming the **anterior abdominal vein** which proceeds forward to the posterior border of the isthmus where it joins the **hepatic portal vein**, then gives three small branches to the liver. A small **vesical vein** brings blood from the urinary bladder and pours into the first part of the anterior abdominal vein.

Pulmonary veins

Two **pulmonary veins** collect oxygenated blood from the two lungs. They unite together and open by a single opening into the left auricle.

Blood circulation inside toad's heart

Venous blood passes from the anterior and posterior venae cavae into the sinus venosus which contracts forcing it into the right auricle. In the meantime, oxygenated blood from the lung passes into the left auricle through the pulmonary veins. Both auricles then contract simultaneously pushing the contained blood into the ventricle, which contracts in turn passing it into the truncus arteriosus.

It was formerly believed that when the ventricle contracts, the spiral valve found in the truncus arteriosus deflects non-oxygenated blood from the right side into the pulmocutaneous arch, and oxygenated blood from the left side into the carotid arch. Recent studies using special dyes and radio-active isotopes have indicated that the blood included in both the right and left sides of the ventricle is mixed. It is thus assumed that mixed blood is pumped to all parts of the body. This seems reasonable if one remembers that a good proportion of the blood reaching the right auricle through the musculocutaneous vein is oxygenated in the skin. Therefore, the difference

in the oxygen content of the blood in the left and right auricles is not as great as might be expected.

B. Arterial System

From the truncus arteriosus, two main branches arise, each of, which divides into 3 large arteries or arches which are :

1 — **The carotid arch** : divides into 2 arteries :

- a) **lingual artery** supplies the tongue,
- b) **internal carotid artery** carries blood to the brain. There is a swelling at its base known as the **carotid labyrinth**, containing a spongy structure.

2 — **The systemic arch** : curves around the oesophagus and joins the systemic arch of the other side forming the dorsal aorta. Each systemic arch gives the following arteries :

- a) **occipitovertebral artery** to the head and vertebral column,
- b) **subclavian artery** to the forelimb,
- c) **oesophageal artery** is given only by the left systemic arch and supplies the oesophagus,
- d) **coeliacomesenteric artery** is also single and is given at the point of union of the two systemic arches. It supplies different organs in the digestive system.

The dorsal aorta runs medially backward between the 2 kidneys where it gives a number of **urinogenital arteries** to the kidneys and reproductive organs. At its end, the dorsal aorta divides into two **iliac arteries** extending to the hindlimbs.

3 — **The pulmocutaneous arch** : divides into 2 arteries :

- a) **pulmonary artery** to the lung,
- b) **cutaneous artery** to the skin.

II. LYMPHATIC SYSTEM

As a result of heart contractions and the pumping of blood into the blood vessels, a colourless fluid exudes or becomes filtered out through the thin walls of the blood capillaries, thus bathing the cells of the different body tissues. This filtrate is known as the **interstitial** or **tissue fluid**. It consists of a part of the blood plasma that contains oxygen, digested food materials, and leucocytes, but no erythrocytes. Oxygen and food diffuse into the body cells. On the other hand, carbon dioxide and other waste materials diffuse from the cells into this tissue fluid. After this exchange of materials takes place, the fluid ultimately reaches the blood circulation, hence, it acts as a mediator between blood and the body tissues (see p. 103).

The tissue fluid returns back to the blood circulation by two ways :

1 — Some of it diffuses back into the blood capillaries, to be conveyed to the heart by the veins.

2 — The greatest proportion of the fluid collects in large spaces, known as **lymph spaces**, found in the body especially under the skin. This is **lymph** which is returned back to the heart by four small pumping organs known as **lymph hearts**, two anterior ones located between the transverse processes of the third and fourth vertebrae, and two posterior ones on both sides of the urostyle. The pulsation of the anterior lymph hearts drive lymph into the internal jugular veins, and the posterior ones discharge lymph into the iliac veins.

A large lymph space is also found surrounding the kidneys and is known as the **cisterna magna**. Lymph is driven from this sac into the kidneys through ciliated funnel-shaped structures, the **nephrostomes**, found on the ventral surface of the kidneys. Inside the kidney, lymph diffuses into the renal veins, thus reaching the blood circulation.

Lymph nodes

Along the course of lymph vessels, there are certain swollen portions known as lymph nodes. They appear in the adult stages in the form of roun-

ded or oval bodies containing a large number of lymphocytes supported by reticular connective tissue.

Lymph nodes perform 2 principal functions :

a) **Defense** : by filtering out microorganisms and other injurious particles from the lymph and engulfing them by phagocytosis.

b) **Haemopoiesis** : by forming lymphocytes.

Spleen

This is considered as a lymphatic gland. It is more or less similar to lymph nodes, and contains venous blood spaces that serve as a blood reservoir, besides numerous areas of lymphatic tissue.

The spleen performs the following functions :

1 — **Defense** : The spleen's reticulo-endothelial cells, like all such cells, carry on phagocytosis and therefore play a role in defending the body against microorganisms and other foreign material.

2 — **Haemopoiesis** : Lymphocytes and monocytes are formed in the spleen. Before birth, red blood cells are also formed in the spleen, but after birth the spleen is said to form red cells only in extreme cases of haemolytic anaemia.

3 — **Blood storage** : The pulp of the spleen and its venous sinuses store considerable amounts of blood.

4 — **Destruction of red blood cells** : The reticulo-endothelial cells of the spleen also phagocytose fragments of old or worn out red blood cells.

URINOGENITAL SYSTEM

The urinary (excretory) and genital systems of the toad are closely associated with each other; hence they form together the "urinogenital system". The urinary organs are mainly concerned with the elimination of nitrogenous waste products from the blood and discharging them to the exterior. They also act to maintain the proper water and salt balance of the blood. On the other hand, the genital (reproductive) organs produce the germ cells, namely the sperms in males and the eggs in females.

1. MALE URINOGENITAL SYSTEM

The system comprises the following organs :

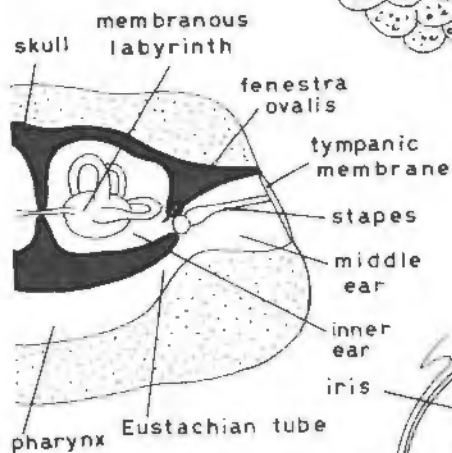
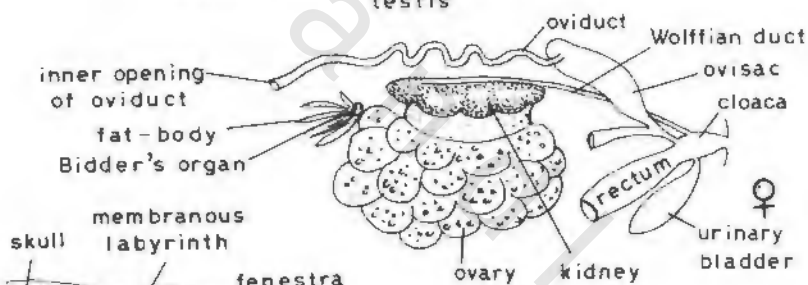
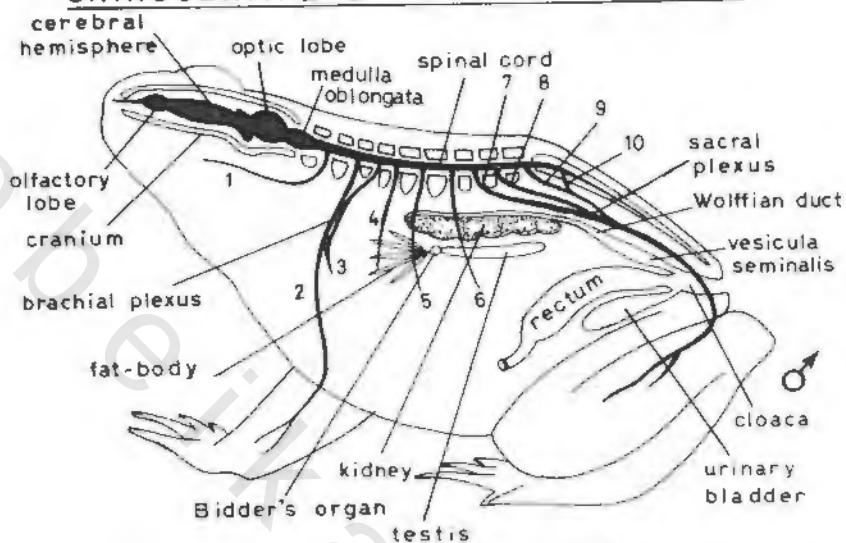
The kidneys : The kidney of the toad is an elongated reddish body situated in the dorsal side of the body and enclosed in a large lymphatic sac, the *cisterna magna*. The outer edge of the kidney is simple, but the inner border is lobulated. On the ventral surface of the kidney is situated an endocrine gland, the **adrenal gland**, which consists of irregularly-shaped yellowish patches.

Along the outer surface of the kidney, there is a narrow thin transparent duct, the **ureter** or **Wolffian duct**, which runs backward to open on the dorsal side of the cloaca. The two ducts open very close to each other in the cloaca. At its posterior end, the Wolffian duct swells forming a small sac, the **vesicula seminalis**, in which sperms are stored for some time.

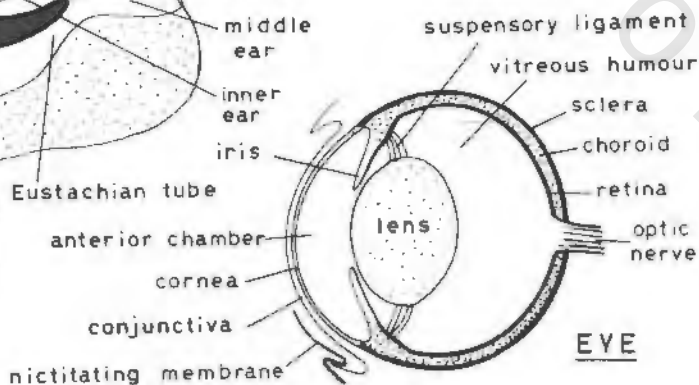
The urinary bladder: This is a large thin-walled sac formed of two lobes and opens by a small opening on the ventral surface of the cloaca. The urinary bladder stores urine temporarily before it is eliminated, and also some water may be reabsorbed in it.

The testis : The male toad possesses a pair of reproductive organs, the testes. Each testis is an elongated pale yellow organ which extends along the inner side of the kidney, being attached to it by a thin membrane known as the **mesorchium**. This membrane is traversed by 5-7 small narrow tubules,

URINOGENITAL & NERVOUS SYSTEMS



EAR



EYE

the **vasa efferentia**, which convey the sperms from the testis to the kidney, where they reach the Wolffian duct.

The fat bodies : Two large fat bodies in the form of creamy finger-like structures are found in the male toad attached to the anterior end of the testis. These bodies represent stores of fatty material which is used during hibernation and also during the mating period, which may indicate that they play some role in the development of gametes.

Bidder's organs : These are two small dark red bodies found at the regions of attachment of the fat bodies with the testes. Each represents a vestigial female gonad. If the testes are removed, Bidder's organs grow into ovaries.

II. FEMALE URINOGENITAL SYSTEM

This system includes the following organs :

The kidneys : are the same as those described in the male; but the Wolffian ducts are not swollen at their posterior ends.

The Ovaries : the ovary of the toad is a large blackish body formed of numerous small lobules in which eggs are developed. Each ovary is attached to the corresponding kidney by a thin membrane known as the **mesovarium**. The ovary is enlarged during the breeding season, and becomes highly reduced in size after egg laying and appears as a pale yellowish orange body.

The fat bodies : these are similar to those found in the male. They are attached to the anterior borders of the ovaries.

Bidder's organs : these are found between the fat bodies and the ovaries.

The oviducts : these are two long coiled tubules situated one on each side of the body. Each duct has a ciliated funnel-like opening, known as the internal opening of the oviduct, by which it opens in the anterior portion of the body cavity, near the base of the corresponding lung. Each oviduct is swollen at its end forming a wide **ovisac** in which the eggs are stored for a certain period before they are passed outside the body. The two oviducts unite posteriorly and open by a single opening on the dorsal side of the cloaca.

The oviduct is lined by a glandular epithelium which secretes certain gelatinous substances around the eggs during their passage along the duct.

Blood supply of the kidneys

Each kidney of the toad is provided by the following blood vessels:

- 1 — Renal arteries are given from the dorsal aorta to the kidneys.
- 2 — The renal portal vein extends along the outer border of the kidney gives off small branches into the substance of the kidney.
- 3 — Renal veins originate from the kidney; those coming out from the right and left kidneys unite together forming the posterior vena cava.

Histological structure of the kidney

Each kidney is formed of a large number of coiled tubules known as the **nephrons** or **uriniferous tubules** (about 2,000 nephrons are found in the toad's kidney). These open in certain ducts running transversely in the kidney, and known as the **collecting tubules**, which in turn open in the Wolffian duct.

The nephrons : Each nephron starts by a cup-shaped structure, known as **Bowman's capsule**. This capsule is lined by a layer of squamous epithelial cells and encloses a tuft of blood capillaries known as the **glomerulus**. The Bowman's capsule together with the glomerulus form what is known as the **Malpighian corpuscle**. The uriniferous tubule is lined by squamous epithelium at its proximal end, then it transforms gradually into ciliated cuboidal epithelium. The movements of the cilia serve to drive the fluids along the nephron. This latter epithelium is also gradually replaced by large columnar or conical cells in the distal portion. In this region, the duct appears in cross section in the form of a narrow cavity surrounded by a number of large granular cells.

The collecting tubules: These extend transversely in the kidney. Each tubule is seen in cross section to have a wide cavity and a wall formed of a single layer of cuboidal epithelium.

Blood circulation inside the kidney

As the renal artery enters the kidney, it gives off a number of small branches known as the **afferent arteries**. Each artery extends to a Bowman's

capsule where it is broken down into a tuft of blood capillaries, which unite again forming another blood vessel, **the efferent artery**, that leaves the Bowman's capsule. The different blood capillaries enclosed within Bowman's capsule form the glomerulus. The efferent arteries extend to the wall of another uriniferous tubule where it gives a large number of minute branches nourishing the wall of the tubule. The wall of the uriniferous tubule also receives a number of blood capillaries from the renal portal vein. Hence, Bowman's capsule receives blood from the renal artery only, whereas the wall of the uriniferous tubule receives blood from the renal portal vein and the efferent artery originating in the Bowman's capsule.

The blood capillaries in the wall of the uriniferous tubule collect together forming small vessels which combine to form the renal veins. These pass outside the kidney and unite with renal veins from the other kidney, forming the posterior vena cava.

Functions of the excretory system

1 — Elimination of products of catabolism, such as urea, uric acid, CO_2 , volatile substances, salts of heavy metals, etc., in order to keep the internal environment in a properly balanced condition.

2 — The system takes part in the regulation of the body water content and the osmotic pressure of the blood.

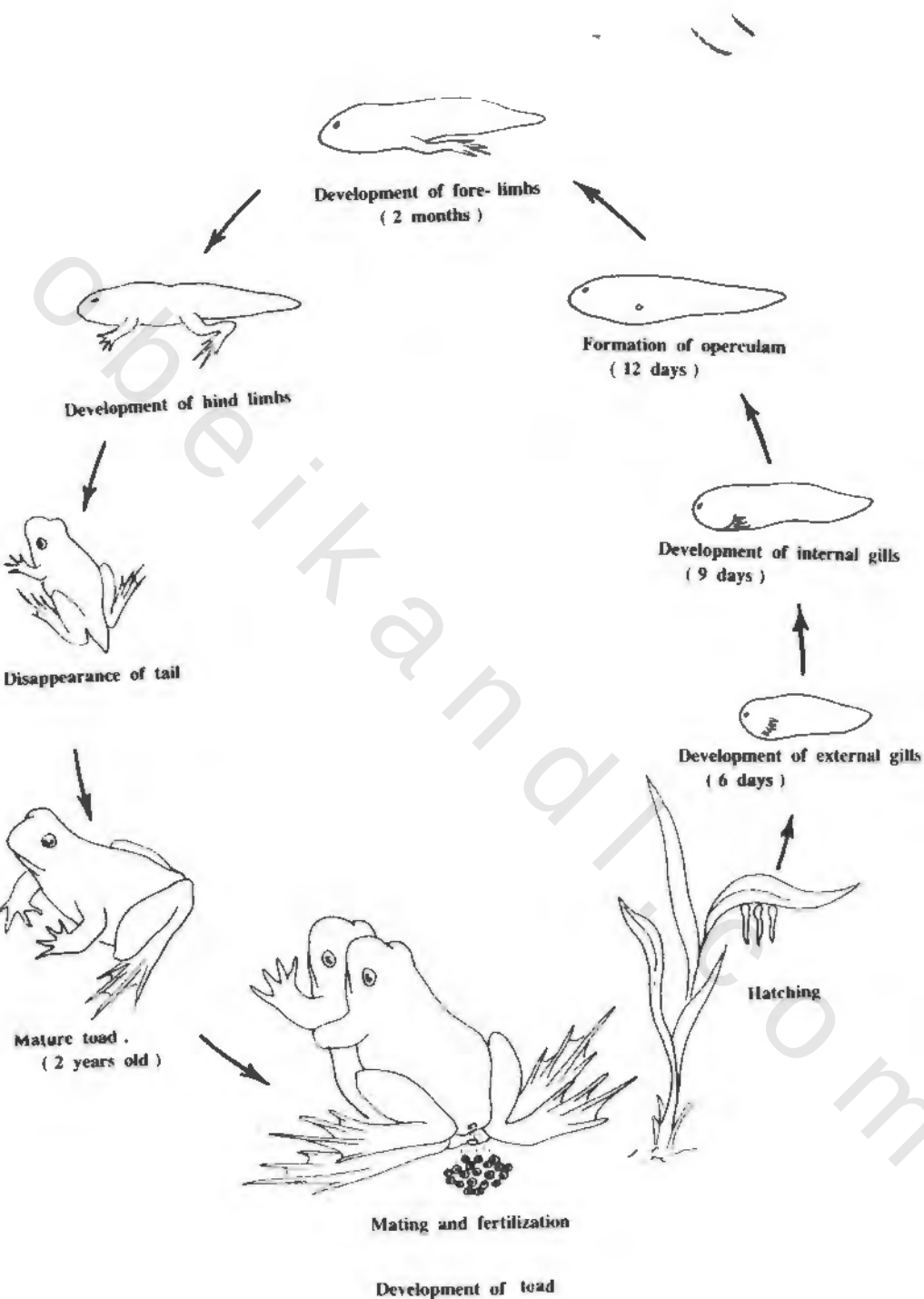
3 — It keeps the pH of the blood at a constantly safe level through controlled elimination of acidic and basic radicals.

4 — It participates in maintaining the arterial blood pressure at a suitably high level.

Reproduction

At the beginning of spring, sperms and eggs are developed in the testes and ovaries under the effects of certain hormones secreted by the pituitary gland. Sperms pass down the Wolffian duct where they are stored in the seminal vesicles before mating.

The ovaries are highly enlarged during the breeding season. They inflate the alimentary canal, thus the female ceases feeding during this season. Thousands of eggs are released from the ovaries into the coelomic cavity as a result of contractions of small bands of muscle fibres scattered in the ovaries. Eggs are directed toward the internal openings of the oviducts by the help of the cilia lining these openings, and are driven along the oviducts



where albumen and gelatinous coats are secreted around them. These materials serve to nourish and protect the eggs during their development. Eggs, covered by their gelatinous coats, pass into the ovisacs where they are kept for a certain period before they are laid in water.

Reproduction in case of the toad takes place in spring, shortly after the animals have emerged from hibernation. Males and females gather in ponds; the croaking of the male serves to attract females to its site. The male grasps the female during mating. This is facilitated by nuptial pads developed on the metacarpal region of the first digits of the male's forelimbs. The mating pair remains in this position for some days, while the eggs accumulated in the ovisacs are being shed into the water.

No internal fertilization takes place, but during mating, the male pours the sperms on the eggs during their passage outside the body. As the eggs are laid, their gelatinous coats absorb water and swell up; thus the eggs adhere together forming long ribbons known as **toad spawns**. The egg is rounded in shape, being about 1 mm. in diameter. Its black colour is due to the presence of black pigment in the jelly capsule surrounding it.

The fertilized eggs hatch after 1-2 days. The free swimming larvae or **tadpoles** wriggle out of the jelly capsules. The tadpole has nasal cavities and a number of small finger-like processes, which are known as the **external gills**. The mouth and cloacal openings soon appear. Tadpoles also have certain **oral suckers** to attach themselves to aquatic plants on which they feed. At this stage, the tadpole has a long coiled intestine.

Later, the external gills become covered by a growth of a skin fold known as the **operculum**. Then, gill slits similar to those of fishes are developed. At the same time, the external gills are lost and internal gills are produced within the gill slits. Then the hindlimbs develop at the posterior part of the trunk and later the forelimbs break out, through the opercular region, the left one being first. The tail shortens and gradually disappears, the gills are reabsorbed, and the **lungs** are developed.

Tadpoles undergo gradual changes in their different body organs, a process known as **metamorphosis**. This process lasts for about 20-30 days after which small toads similar in form to the adult are produced.

NERVOUS SYSTEM

The nervous system acts mainly to coordinate the working of the different parts of the animal and integrate the activities of its organs so that it can respond in a proper manner to the different external and internal stimuli. In this respect, certain receptor organs, namely the sense organs, act to detect the different changes in the environment. The impulses set in these organs are conveyed by the nervous system to special effector organs, such as the glands or muscles, which respond in an appropriate manner to these impulses. Certain substances, such as acetylcholine, secreted by the cells of the nervous system, play an essential role in the transmission of impulses.

Nerve impulses have a certain velocity, which ranges from 30-40 metres per second in the toad, (in man they range from $\frac{1}{2}$ - 140 metres per second).

The nervous system of the toad includes the following parts :

- I. Central (cerebro-spinal) nervous system : consists of the brain and the spinal cord.
- II. Peripheral nervous system : formed of the cranial and spinal nerves.
- III. Sympathetic (autonomic) nervous system : includes the sympathetic ganglia and sympathetic nerves.

I. CENTRAL NERVOUS SYSTEM

A. Brain

The brain lies within the brain case, or cranium, which is a part of the skull. It is surrounded by two membranes : (a) An outer thick membrane, the **dura mater**, which is closely adherent to the internal surface of the cranium and is formed of two epithelial layers enclosing a fluid known as the cerebrospinal fluid. (b) An inner membrane, known as the **pia mater** and is found close to the outer surface of the brain.

The brain of the toad consists of the main following parts :

a. **Forebrain**, which consists of :

1 — Two small **olfactory lobes** : from which extend two olfactory nerves to the nasal chambers. These lobes serve the sense of smell.

2 — Two **cerebral hemispheres** : are large bodies that lie behind the olfactory lobes. These hemispheres are the centres of memory, intelligence, consciousness, and voluntary control in higher animals.

3 — **Diencephalon (between-brain)** is found between the two posterior ends of the cerebral hemispheres. It carries dorsally a small body known as the **pineal body**. The diencephalon is related to vision and balance. On the ventral surface of this region of the brain, the 2 optic nerves are seen crossing each other; the nerve originating in the right side is directed toward the left eye, and the other originates in the left side which passes to the right eye. This crossing structure forms the **optic chiasma**. Posterior to the optic chiasma there is a median outgrowth from the diencephalon, known as the **infundibulum**, that lies in contact with the **pituitary gland** which is an endocrine gland.

b. **Midbrain**, which is formed of two **optic lobes** that are rounded and found behind the diencephalon. These represent the mid-brain (mesencephalon), whereas the first three parts constitute the fore-brain (prosencephalon). The optic lobes are related to certain reflexes in the spinal cord and act as centres of vision.

c. **Hindbrain** which comprises :

1 — **Cerebellum** : is a narrow transverse part of the brain found posterior to the optic lobes. The cerebellum is the centre of coordination in higher animals. It coordinates muscular activities. In the toad, it acts to control equilibrium.

2 — **Medulla oblongata** : is the posteriormost part of the brain. This medulla joins the spinal cord posteriorly. It controls most of the body activities of the toad. If the brain is removed, but the medulla is left, the toad can swim, jump, swallow food, breathe, react to pain and perform many other vital activities. But if the medulla is removed, the animal soon dies.

The brain is supplied by a number of arteries and veins. Besides, there

are two networks of blood vessels; one on the dorsal surface of the diencephalon known as the **anterior choroid plexus**, and another posterior one, the **posterior choroid plexus**, located on the dorsal side of the medulla oblongata.

The brain regions are not solid, but contain some internal cavities known as the **ventricles**. Those found in the cerebral hemispheres are termed the **first** and the **second ventricles**. They connect with a **third ventricle** in the diencephalon. The **fourth ventricle** is found in the medulla oblongata, being connected to the third ventricle by a small vertical duct known as **aqueduct of Sylvius**. On the other hand, the fourth ventricle is continuous with the central canal in the spinal cord. The two optic lobes also contain two ventricles known as the **optocoels**. These different cavities are filled with the cerebro-spinal fluid which serves to nourish the central nervous system.

B. Spinal cord

The spinal cord is a long tube which is in direct continuation with the hind part of the brain. It extends along the neural canal of the vertebral column. It tapers at its posterior end forming the **filum terminale**, which is lodged within a narrow canal in the urostyle.

The spinal cord, like the brain, is also surrounded and protected by the pia mater, lying close to its outer surface, and the dura mater which lines the neural cavities.

The substance of the spinal cord is distinguished into 2 portions :

1 — The inner portion is known as the **grey matter** (owing to its colour in the living condition). It contains the bodies of the nerve cells or **neurons**, surrounded and supported by the nervous connective tissue known as the **neuroglia**. This part is H-shaped, with two **dorsal horns** and two **ventral horns**. The ends of the ventral horns are broad, and lie away from the periphery of the spinal cord. On the other hand, the two dorsal horns are pointed and their ends lie near the periphery of the cord. The part between the 2 dorsal horns is known as the **dorsal commissure** and that lying between the ventral horns is the **ventral commissure**.

In the centre, there is the **central canal** lined by ciliated cubical epithelium; the movement of the cilia acts to move the cerebro-spinal fluid.

2 — The outer portion of the spinal cord is the **white matter**. It consists

of a large number of **nerve fibres** surrounded by neuroglia tissue.

In the median upper part of the spinal cord, the white matter dips inside forming a narrow groove known as the **dorsal fissure**. Ventrally, there is a similar groove, which is the **ventral fissure**.

II. PERIPHERAL NERVOUS SYSTEM

This includes the paired cranial and spinal nerves.

A. Cranial Nerves

The toad has 10 pairs of cranial nerves which arise from the brain and pass through certain foramina in the skull to innervate different parts of the body. The nerves on each side are :

I. **Olfactory nerve** : is a sensory nerve which carries sensation from the olfactory epithelium, lining the olfactory organs to the olfactory lobes and the cerebral hemispheres.

II. **Optic nerve** : extends from the retina of the eye to the floor of the diencephalon. The 2 optic nerves cross each other forming the optic chiasma, and they end in the optic lobes.

III. **Oculomotor nerve** : is a motor nerve extending from the midbrain carrying motor impulses to 4 of the eye muscles which move the eye-ball; and also gives certain motor fibres which move the lens.

IV. **Trochlear nerve** : is also a motor nerve which extends from the mid-brain to a fifth eye muscle.

V. **Trigeminal nerve** : extends from the lateral part of the medulla oblongata. It divides into 3 branches :

- a) **Ophthalmic nerve** carries sensory impulses from the skin covering the anterior part of the head and passes through the orbit.
- b) **Maxillary nerve** carries motor impulses to the upper jaw.
- c) **Mandibular nerve** carries motor impulses to the jaw muscles.

VI. **Abducens nerve** : originates from the ventral side of the medulla to a sixth eye muscle.

VII. **Facial nerve** : extends from the lateral side of the medulla oblongata and divides into two branches :

- a) **Palatine branch** innervating the roof of the buccal cavity.
- b) **Hyomandibular branch** to the hyoid apparatus and lower jaw.

VIII. **Auditory nerve** : a sensory nerve extending from the lateral side of the medulla oblongata to the middle ear.

IX. **Glossopharyngeal nerve** : also originates from the lateral side of the medulla oblongata and innervates the tongue and pharynx.

X. **Vagus nerve** : extends from the side of the medulla oblongata to the larynx, oesophagus, stomach, intestine, heart and lungs.

Besides, an eleventh nerve has recently been described, which is given the name "**terminal nerve**". It extends from the forebrain to the lining of the nostrils.

B. Spinal Nerves

Ten pairs of spinal nerves are found in the toad. These nerves pass through certain foramina between successive vertebrae, each known as an intervertebral foramen. Each spinal nerve arises by 2 roots : (a) a **dorsal root** from the dorsal horn of the grey matter, and (b) a **ventral root** from the ventral horn of the grey matter.

The dorsal root contains sensory fibres, and the ventral one contains motor fibres. The dorsal root has an enlargement, known as the **dorsal root ganglion**, containing a large number of nerve cells.

The two roots unite together forming the spinal nerve, which thus contains both sensory and motor nerve fibres. After leaving the intervertebral foramen, each spinal nerve runs for some distance, then divides into 2 branches : (a) a **sensory branch**, which ends in the sensory organs and cells, and (b) a **motor branch** connected with the muscle fibres or body glands.

The following spinal nerves are found on each side of the spinal cord :

1 — **Hypoglossal nerve**: to the muscles of the tongue. It passes out between the 1st and 2nd vertebrae.

2 — **Brachial nerve** : passes between the 2nd and 3rd vertebrae. This nerve joins with the third spinal nerve which passes out between the 3rd and

4th vertebrae; the two nerves together form the **brachial plexus** which innervates the shoulder and forelimb.

3 — The fourth, fifth and sixth spinal nerves are known as the **abdominal nerves**. They innervate the body wall.

4 — The seventh, eighth and ninth spinal nerves form the **sacral plexus** which extends to the hindlimb.

5 — The **coccygeal nerve** or tenth nerve, passes from the spinal cord through a small side opening in the urostyle. It extends to the cloaca and urinary bladder, and unites at its end with the sacral plexus, forming a bundle of nerves known as the **cauda equina**.

III. SYMPATHETIC NERVOUS SYSTEM

This system consists of two slender nerve strands running on either side of the vertebral column. Each strand bears a series of ganglia, known as the **sympathetic ganglia**; one lying near each of the first 8 spinal nerves and the ninth is common to both the ninth and tenth spinal nerves.

Each sympathetic ganglion is connected to the corresponding spinal nerve by a short branch known as the **ramus communicans**. These ganglia send nerves to the alimentary canal, circulatory system and glandular organs.

The sympathetic nervous system regulates and controls the body activities which are not voluntary such as heart beating, respiration, peristaltic movement of the intestine and secretion of certain glands.

SENSE ORGANS

There are generally five types of sense organs which are responsible for receiving different external stimuli that are then transmitted to the central nervous system to react to them properly. These organs include :

A. Tactile organs

These are responsible for the sense of touch. They consist mainly of the

sensory cells scattered in the skin. They receive different stimuli such as heat, cold, etc, and transmit them along their axons to the central nervous system that reacts to them.

B. Taste organs

Taste includes the sensation of acidity, alkalinity, salinity, bitterness, etc. This sensation is carried out mainly by certain cells found in the tongue and are usually grouped into masses of cells known as the **taste buds**.

C. Organs of smell

Sensation of smell is received by certain sensory cells scattered in the olfactory epithelium lining the nasal capsules. Nerve fibres extend from these cells along the olfactory nerve to the brain. .

D. Eyes

The eye is the organ of vision. The eye-ball is lodged in a **certain** cavity in the skull known as the orbit, being moved in different **directions** by six eye muscles. The eye consists mainly of the following parts :

1 — **Conjunctiva** : a transparent layer covering and protecting the eyeball; it also serves as a lining for the upper and lower eyelids.

2 — **Cornea** : this layer consists of two parts; an anterior transparent part found in front of the eye, and a posterior part which **consists of white** fibrous tissue together with fibro-cartilage. This posterior **part is known** as the **sclera**.

3 — **Choroid** : is a highly vascular membrane lying inner to the cornea, and contains besides the blood capillaries a large number of **black-pigmented** cells. The front part of the choroid forms a partition or **diaphragm** known as the **iris**, which is perforated by a central opening, **the eye-pupil**. The iris contains small bands of unstriated muscle fibres; an **inner layer** arranged concentrically, and an outer layer arranged radially. **These muscles** act to control the amount of light rays entering the eye-pupil. **The iris also** contains certain pigment cells which give the eye its **characteristic colour**.

4 — **Lens** : this is a spheroidal gelatinous body lying behind the iris. Two sets of fibrous bands extend from the upper and lower ends of the lens

and are known as the **suspensory ligaments**. Each ligament is attached at its other end to a swollen portion of the choroid known as the **ciliary body**.

5 — **Retina** : this is the innermost layer of the eye, containing the sensory cells which are responsible for the reception of light rays. The axons of these cells extend to the optic nerve, which transmits the sensation of vision to the brain.

The part of the eye lying in front of the lens is known as the anterior chamber. It contains a fluid material, which is the **aqueous humour**. The region behind the lens is the posterior chamber which is filled with a gelatinous substance known as the **vitreous humour**. The posterior part of the eye lying at the insertion of the optic nerve is termed the **blind spot**.

Vision

The eye is usually capable of detecting near and far objects through a certain ability known as **accommodation**. This is usually carried out by certain changes produced in the curvature of the lens. An inverted picture is formed in the eye; this is transmitted to the brain where it is identified as an upright one.

E. Ears

Ears are responsible for the sense of hearing. The ear in the toad consists of two main parts : middle ear and inner ear; the outer ear (pinna) is lacking in the Amphibia.

1 — **The inner ear** : includes the main organs of hearing, known as the **membranous labyrinth**, found in the auditory capsule. This part is filled with lymph, the **endolymph**, and is surrounded by the **perilymph**. The membranous labyrinth consists of two regions :

a) The first consists of an upper part known as the **utricle**, and a lower part known as the **sacculus**. The sacculus has an outgrowth known as the **lagena** which differs in structure in the different groups of vertebrates (in mammals it is named the cochlea).

A small narrow duct, which is the **endolymphatic duct**, extends from the sacculus. It contains small crystals of calcium carbonate, the **otoliths**, which are also found in the utricle, sacculus and lagena.

b) The second part of the membranous labyrinth is formed of three **semicircular canals** lying at right angles to each other and are attached to the utricle. At the end of each canal, there is a swollen part, the **ampulla**, which contains certain sensory cells that receive sound vibrations and transmit them to the auditory nerve.

At the surface of the inner ear there is an oval window, the **fenestra ovalis**, which contains a small piece of cartilage.

2 — **The middle ear** : this part is covered externally by the ear-drum or tympanic membrane. A slender bony rod, the **stapes**, extends along this part of the ear. The outer end of the stapes is in contact with the ear-drum, and its inner end fits into the fenestra ovalis. The cavity of the middle ear is connected with the pharynx by the **Eustachian tube** which serves mainly to balance the pressure on the inner side of the ear-drum.

Hearing and body equilibrium

In hearing, sound vibrations fall on the tympanic membrane which is thus vibrated; the vibrations are transmitted along the stapes to the fenestra ovalis. The perilymph is consequently vibrated, followed by vibrations set up in the endolymph. These vibrations are then transmitted to a specific group of sensory cells within the inner ear which are stimulated and initiate impulses in the auditory nerve. These stimuli are finally perceived as sound.

Other cells in the inner ear stimulated by the motion of the endolymph in the semicircular canals as a result of the vibrations in the otoliths. These vibrations are caused by changes in the position of the body. Hence, this part of the ear also acts to maintain proper balance of the animal.

Functions of the nervous system

A. Central nervous system :

- 1 — Coordination of voluntary movements.
- 2 — Reception and translation of sensation by sense organs.
- 3 — Allowance of reflex activities.

B. Sympathetic nervous system :

- 1 — Increasing the scope of vision by widening the eye pupil and palpal fissure.

- 2 — Rising the arterial blood pressure.
- 3 — Increasing the muscle tone, thus causing erection of hairs.
- 4 — Increasing the secretion of adrenaline from the medulla of the suprarenal gland, thus elevating the blood sugar level.
- 5 — Inhibiting the secretion of the digestive glands.
- 6 — Inhibiting the action of the smooth muscles in the walls of the stomach, small and large intestine.

C. Parasympathetic nervous system :

- 1 — Constriction of the eye pupil in accomodation for near vision.
- 2 — Decreasing the rate of heart beat and the oxygen consumption of the cardiac muscles.
- 3 — Increasing the secretion of the digestive glands.
- 4 — Causing contraction of the urinary bladder and relaxation of the internal uritheral sphincter.
- 5 — Causing relaxation of the internal rectal sphincter.
- 6 — Increasing the contraction of the smooth muscles in the walls of the alimentary canal.

ENDOCRINE GLANDS

The toad, as the other vertebrates, possesses a number of ductless glands known as endocrine glands (e.g. thyroid, adrenal, pituitary, etc.) which secrete certain chemical substances known as **hormones**. The hormones diffuse directly into the blood stream which carries them to different body organs where they play a major role in the regulation and control of the activities of these organs.

The well known endocrine glands in the toad are the thyroid, parathyroids, adrenal, islets of langerhans and pituitary glands *.

Thyroid gland

The thyroid gland of the toad consists of two small reddish bodies lying very close to the junction of the lingual and internal carotid arteries. The thyroid gland secretes the hormone thyroxine which has a marked effect on the metabolic activities of the toad, particularly during the period of metamorphosis. If these glands are removed from the tadpoles, they fail to complete their metamorphosis into adult toads. On the other hand, if tadpoles are supplied with thyroid extracts, they metamorphose rapidly into toads.

Parathyroid glands

These glands start their appearance as distinct bodies for the first time in Amphibia. They are formed of two pairs of small bodies lying very close to the external jugular vein. They consist of numerous strands of cells that show clear regions of degeneration during the winter time, then they regenerate during spring. Their functions are almost the same as those of mammals.

* The physiology of these glands is discussed fully in the Vertebrate Physiology Section

Islets of Langerhans

They consist of branched cords of cells scattered amongst the pancreatic acini. They secrete the hormone insulin which is concerned with carbohydrate metabolism. Removal of the pancreas from toads resulted in diabetes mellitus, accompanied with increase in the amount of urine and glucosuria.

Adrenal gland

This gland is found in the form of irregular yellowish patches on the ventral surface of the kidneys. They consist of three main types of cells which are homologous to those of mammals. They secrete the hormone adrenaline as well as the adrenal cortical hormones.

Pituitary gland

This gland develops in the early embryo by the union of a solid rod-like ectodermal ingrowth together with a sac-like diverticulum of the diencephalon, the **infundibulum**. It consists of two main parts : **adenohypophysis** and **neurohypophysis**. The adenohypophysis includes the **pars distalis**, **pars intermedium** and **pars tubularis**.

THE RABBIT

ORYCTOLAGUS CUNICULUS

The rabbit is a member of class **Mammalia** which include the most advanced vertebrates. It is so much like man in structure and function that a study of the structure and function of its internal organs serves as a good introduction to the study of the human body.

EXTERNAL FEATURES

The body is covered with soft hair or fur, and is divided into head, neck, trunk and tail. The trunk carries 2 pairs of pentadactyl limbs.

The **head** is rather rounded or oblong. The **mouth** is found at its anterior end or **snout** and is bounded by thin fleshy upper and lower **lips**; the upper lip has a longitudinal median cleft. Two small oblique openings, the **external nares** or **nostrils** lie above the mouth and extend to the cleft of the upper lip. The **eyes** lie on both sides of the head. Each eye is protected by 3 eyelids, **upper** and **lower eyelids** with few eyelashes, and a small third one known as the **nictitating membrane** attached to the anterior angle of the eye and serves for cleaning the cornea of the eye. Stiff long sensitive hairs, the **vibrissae**, extend around the eyes and on the snout. Two long freely movable external ears, or **pinnae**, are found on the dorsolateral sides of the head.

The **trunk** includes the **thorax** and **abdomen** and carries four limbs. The thorax is enclosed by the ribs and the sternum. Four to five pairs of **teats** or **nipples** are found on the ventral surface of the thorax and abdomen in the adult female. At the tips of these teats open the ducts of the mammary glands. The **anus** is situated at the base of the tail.

A **urinogenital opening** lies just in front of the anus. In the male, it is found at the end of a short muscular organ, the **penis**, on both sides of which lie the **scrotal sacs** containing the testes. In the female, the urinogenital opening is

a slit-like aperture, the **vulva**, which contains a short rod-like structure known as **clitoris** which is homologous to the penis of males.

Two hairless areas known as **inguinal depressions** are found on both sides of the anus. In these depressions open the ducts of the **perineal glands** which produce a certain secretion responsible for the peculiar smell of the rabbit.

The **limbs** are mainly used for locomotion and also for supporting the body of the animal. They are built up on the same plan of the **pentadactyl** type as those of other vertebrates.

The **forelimb** is much shorter than the hindlimb. It comprises the upper arm (**brachium**), forearm (**antebrachium**) and hand (**manus**). The hand is distinguished into a wrist (**carpus**), palm (**metacarpus**), and 5 fingers (**digits**), each ending with a long and curved **claw**. Between the upper arm and the trunk there is a depression known as the **axillary fossa**.

The **hindlimb** comprises 3 main divisions : the thigh (**femur**), shank (**crus**), and foot (**pes**). The foot is distinguished into the ankle (**tarsus**), instep (**metatarsus**), and 4 toes (**digits**) provided with curved **claws**.

The **tail** is short, upwardly directed and covered with a tuft of fur.

THE SKIN

The skin consists of the 2 main layers characteristic of the vertebrate skin, namely an outer thin **epidermis** and an inner thick **dermis**. The dermis is followed by a loose connective tissue layer known as **hypodermis** or **subcutaneous layer**.

The **epidermis** : develops from the embryonic ectoderm and consists of stratified squamous epithelium, devoid of blood vessels, but is nourished by the blood capillaries lying in the dermis.

The **dermis** : is derived from the embryonic mesoderm. It is formed of an outer layer of loose connective tissue, known as the **papillary layer**, and an inner thicker and denser layer, namely the **reticular layer**, and is penetrated by small blood vessels and nerves.

The **hypodermis** : is composed of loose connective tissue rich in fat cells, and contains blood vessels and nerves.

Hairs

The possession of hairs is one of the characteristic features of mammals. The hair is an epidermal structure embedded in a pit-like invagination called the **hair follicle**. The hair follicle is pierced by the **hair papilla** formed of some connective tissue fibres enclosing blood capillaries and nerve endings. The slender main part of the hair, known as the **hair shaft**, projects above the surface of the skin. The rest of the hair embedded in the skin is the **hair root**. The hair itself is composed of three layers: the **medulla** in the centre, the **cortex** next to medulla containing pigment granules, and the outer **cuticle** composed of cornified horny scales.

A **sebaceous gland** opens in the hair follicle from the side, and a band of smooth muscle fibres, known as the **erector muscle**, inserts on the side of the hair follicle and causes the hair to assume an erect position during cold or fear.

Skin glands

Mammals possess a large variety of glands which include the following :

Sweat glands : are simple coiled tubular glands distributed all over the body except on the margins of lips and claws. They secrete a fluid, chiefly composed of water, containing a small amount of solutes, particularly sodium chloride. Sweat glands serve mainly to regulate the body temperature.

Sebaceous glands : are simple branched alveolar glands which open into the hair follicles. They secrete a greasy substance which keeps the skin and hair glossy and soft.

Mammary glands : exist in all mammals, but their function is limited almost entirely to the females after birth of young.

Lacrymal or tear glands : produce a secretion which keeps the surface of the eye moist and clean.

Perineal or scent glands : secrete a substance which gives the rabbit its characteristic odour, by means of which the animal can distinguish its own kind.

Functions of the skin

1 — It protects the underlying tissues against the effects of external environmental factors.

2 — It contains sensory receptors which respond to changes in the environment.

3 — The sweat glands in the skin serve mainly to regulate the body temperature.

4 — The skin may be coloured to protect the animal by a camouflage pattern.

5 — Claws, as skin derivatives, are important for defence of the body and for catching preys. They are also used in climbing.

ORGAN SYSTEMS

MUSCULAR SYSTEM

(See p. 437)

SKELETAL SYSTEM

The skeletal system of the rabbit is divided into : the **exoskeleton** which is formed of epidermal derivatives of the skin, such as claws, hairs, etc., and the **endoskeleton** which comprises the internal skeleton of the body. The endoskeleton includes two main divisions : Axial skeleton and Appendicular skeleton.

I. AXIAL SKELETON

The axial skeleton consists of :

A. Skull

C. Ribs

B. Vertebral column

D. Sternum

A. Skull

The skull of the rabbit is formed of the following parts :

- | | |
|--------------------|---------------------|
| 1 — Cranium | 3 — Jaws |
| 2 — Sense capsules | 4 — Hyoid apparatus |

1 — Cranium (brain case)

The cranium is formed of bones arranged mainly in a series of 3 bony rings including :

a) The **occipital ring** lies at the posterior end and is made up of 4 bones :

- **basioccipital**, forms the floor,
- 2 **exoccipitals**, make the sides, and
- **supraoccipital**, forms the roof.

Between the occipital bones lies the **foramen magnum**, which is guarded by two lateral **occipital condyles**.

b) The **parietal ring** is in the middle and consists of :

- **basisphenoid**, forms the floor,
- 2 **alisphenoids**, make the sides, and
- 2 **parietals**, form the roof and are separated from the hind bones by a small **interparietal**.

c) The **frontal ring** is anterior and is composed of :

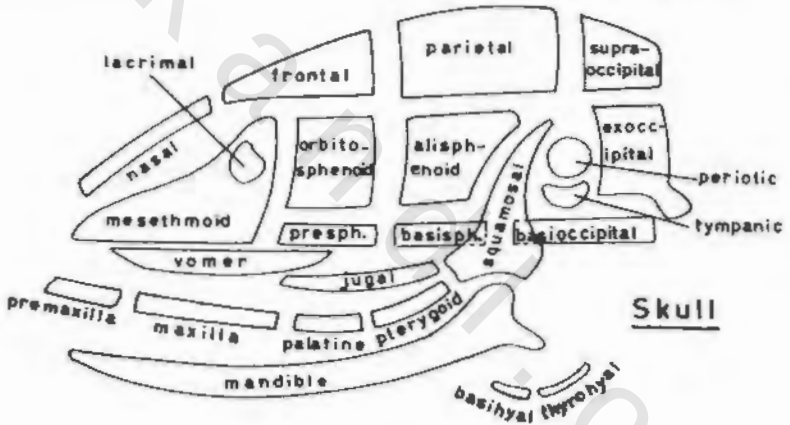
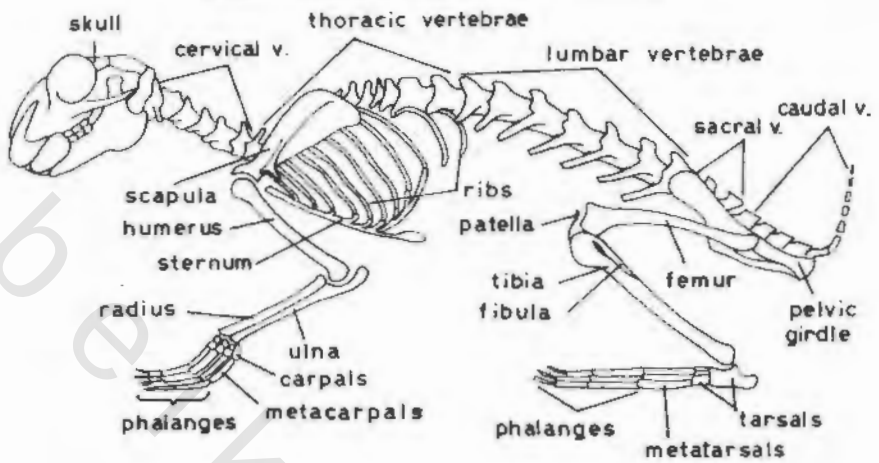
- **presphenoid**, forms the floor,
- 2 **orbitosphenoids**, make the sides.
- 2 **frontals**, form the roof and complete the side walls, each bears a **supraorbital process**.

The space between the exoccipital and alisphenoid on each side is filled by the cranial portion of the **squamosal**.

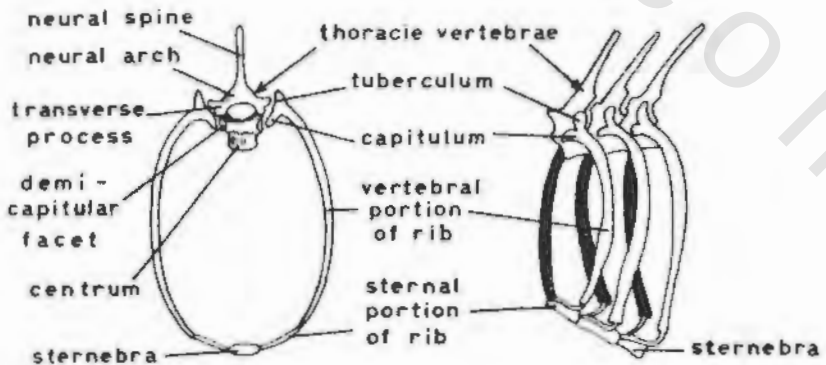
Extending between the squamosal and the maxilla of each side, there is a bony arch known as the **zygomatic arch**, the anterior part of which forms the lower margin of the orbit. Some of the powerful jaw muscles lie between the posterior part of the arch and the cranium.

The front of the cranial cavity is closed by the **ethmoid**.

SKELETON OF RABBIT



Skull



Thoracic vertebrae and ribs

2 — Sense capsules

a) The auditory capsules : are completely embedded in the wall of the cranium. Each consists of a single perforated bone, the **periotic**. Near the periotic, but lying outside the cranium, is the flask-shaped **tympanic bulla** which encloses the **tympanic cavity**; the neck of this bulla forms the **external auditory meatus**. The auditory ossicles lie within the tympanic cavity.

b) The olfactory capsule : encloses the respiratory channel, which is roofed by 2 flat bones known as the **nasals**. The cavity of the capsule is divided into right and left halves by the partly cartilaginous **mesethmoid**, the anterior end of which forms the **internasal septum**. The mesethmoid rests on a V-shaped **vomer** bone. The outer sides and the floor of the nasal cavities are formed by the **palatines**, **maxillae** and **premaxillae**. The greater part of each cavity is occupied by thin, much folded **turbinal bones** which project from the walls into the cavity.

c) The optic capsules : There are no special bones forming these capsules. The eye is lodged in a wide orbital cavity limited dorsally by the **supraorbital ridge** of the frontal, and ventrally by the **zygomatic arch**.

3 — Jaws

a) The upper jaw : is formed of bones fused to the cranium. These bones are the **pterygoids**, **palatines** (on the roof of the mouth), the **premaxillae** (each having 2 processes, a nasal process which passes backwards beside the nasal bone, and a palatine process), and the **maxillae** (from which arise the zygomatic and palatine processes).

b) The lower jaw or mandible : is formed of a single bone called **dentary**. It consists of 2 lateral halves or rami united anteriorly at the **symphysis mentis** and diverging posteriorly. Each ramus is formed of a **horizontal portion** which bears the teeth, and a vertical or **ascending portion** with a dorsal **coronoid process**, a **condyle** for articulation with the squamosal, and a ventral **angular process**.

4 — Hyoid apparatus

This is derived from the embryonic visceral arches and functions as a support for the tongue. It includes a median hyoid bone or **basihyal**, and a pair of long backwardly directed cornua or **thyro-hyals**.

B. Vertebral Column

The vertebral column consists of a chain of separate units, the **vertebrae**. These vertebrae are distinguished into 5 types; **cervical**, **thoracic**, **lumbar**, **sacral** and **caudal**. Despite the difference between these types of vertebrae, certain features are common to all and make it possible to describe a typical vertebra.

Typically, the vertebra consists of :

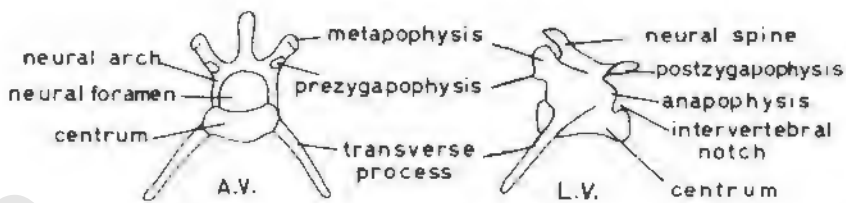
- A body, or **centrum**, with a dorsal **neural arch** forming a ring around the spinal cord.
- **Neural foramen**, the opening through which the spinal cord extends.
- **Neural spine**, is a dorsal median process in the neural arch.
- **Transverse processes** extend laterally on both sides of the vertebra and serve for muscle attachment.

— **Zygapophyses**, are 4 small processes situated on both sides of the arch and serve for the articulation of the vertebrae. The two found in front are called **prezygapophyses** and have flat surfaces facing upwards, while those behind are called the **postzygapophyses** and have flat surfaces facing downwards to rest on the surfaces of the prezygapophyses of the next vertebra. This mode of articulation allows some flexibility in movement of the vertebral column.

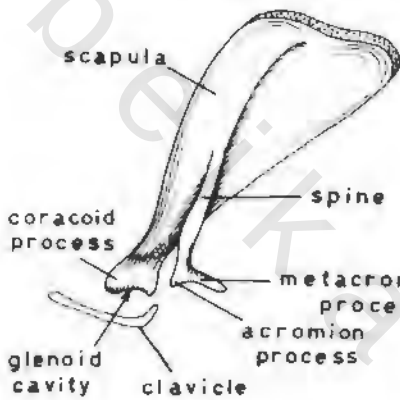
1 — **Cervical vertebrae** : these are 7 in number.

The first cervical or **atlas** articulates with the skull. It is characterized by :

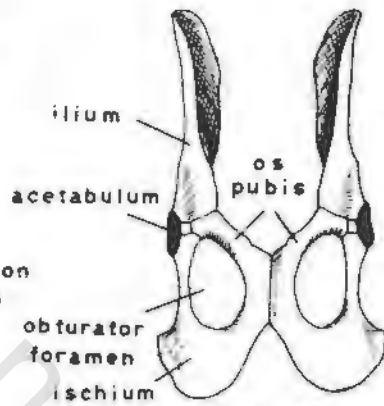
- Very reduced centrum, which was detached during development and later fused with that of the second cervical vertebra to form an odontoid process.
- Large neural foramen divided by a **transverse ligament** into a



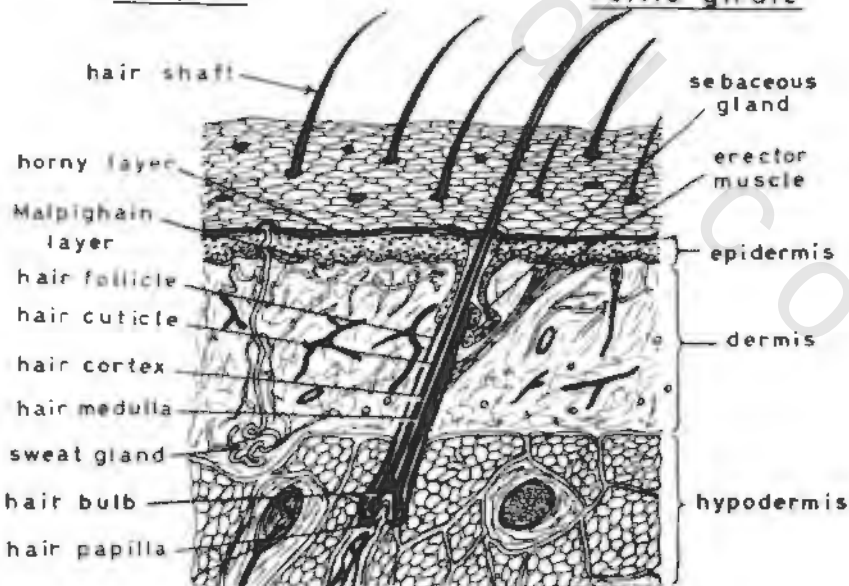
Lumbar vertebra



Scapula



Pelvic girdle



V.S. of skin

large dorsal part for the spinal cord and a small ventral part for the odontoid process of the second cervical vertebra.

— Broad and flat transverse processes.

— 2 anterior concave **condylar facets** for articulation with the occipital condyles of the skull.

— 2 posterior concave facets for articulation with the centrum of the second cervical vertebra.

The **second cervical** or **axis** is mainly characterized by the presence of the **odontoid process** and absence of prezygapophyses.

Normal cervical vertebrae are 5 in number. They are short and broad and have the following characters :

— 2 Transverse processes pierced by two **vertebrarterial foramina** for the passage of the two vertebral arteries.

— Pre- and postzygapophyses.

2 — **Thoracic vertebrae** : these are 12-13 in number, and are associated with the ribs. They are characterized by :

— Elongated spines; in the first 9 vertebrae, the spine is directed backward, in the 10th thoracic it is nearly vertical, while in the last 2 or 3 vertebrae, it is directed anteriorly. The spines serve for attachment of the ligaments of the neck.

— They have certain facets for articulation with the ribs, namely the **tubercular** and **capitular facets**.

3 — **Lumbar vertebrae** : these are 7 large vertebrae, characterized by :

— Long transverse processes which are directed forward and outward.

— Accessory processes, as **metapophyses**, are situated in front over the prezygapophyses, and **anapophyses** project backward below the postzygapophyses.

4 — **Sacral vertebrae** : include 3-4 vertebrae fused into a single piece known as the **sacrum**. This fusion provides a firm basis for attachment of the pelvic girdle of the hindlimb.

The first sacral is the largest and is characterized by :

- Broad wing-shaped transverse process rigidly articulated with the ilium of the pelvic girdle.
- A pair of metapophyses.
- The anterior surface of the centrum is broader than the posterior surface.

The other sacral vertebrae decrease successively in size

5 — **Caudal vertebrae** : these are 15-16 small bodies lying in the tail region. At the end of the tail, the neural arch, zygapophyses, etc., become progressively reduced until the terminal ones consist only of rounded cylindrical centra.

C. Ribs

The ribs, are 12-13 in number, and form a bony cage surrounding the thorax. They articulate dorsally with the thoracic vertebrae and ventrally with the sternum. Each rib, therefore, has a dorsal **vertebral portion** and a ventral **sternal portion**. The vertebral portion has 2 broad heads : the dorsal head, or **tuberculum**, articulates with the transverse process, and the ventral head, or **capitulum**, articulates with two successive centra.

The first 7 ribs are directly attached to the sternum and are therefore called **true ribs**, while the sternal portions of the eighth and ninth ribs are fused with those of the seventh rib and are commonly called **false ribs**. The last three ribs do not reach the sternum and are termed the **floating ribs**.

D. Sternum

The sternum is a median ventral rod-like structure lying in the thoracic region. It is composed of 7 pieces called **sternebrae**. The last sternebra ends by a thin round plate of cartilage termed **xiphoid cartilage**. The sternum serves for attachment of ligaments and muscles.

II. APPENDICULAR SKELETON

The appendicular skeleton consists of the pectoral and pelvic girdles and the bones of the limbs.

A. Pectoral girdle

The pectoral girdle comprises 2 pairs of bones, the scapulae (shoulder blades) and the clavicles (collar blades). It is attached to the axial skeleton by ligaments and muscles.

1 — **The scapula** : is a triangular blade, at the ventral end of which there is a depression called the **glenoid fossa** serving for the articulation with the humerus. On the outer surface of the blade there is a ridge, the **spine**, which has two projections, the **acromion** and **metacromion processes**. These provide insertions for the muscles moving the shoulder. The **coracoid** bone, present in lower tetrapods, is represented in mammals by a small **coracoid process** overhanging the glenoid cavity.

2 — **The clavicle** is a small, slender curved bone suspended by ligaments to the acromion process and sternum.

B. Bones of the Forelimb

The limb is formed of several regions built on the pentadactyl plan. Its bones are :

1 — **Humerus** : supporting the upper arm. It consists of a **shaft** (**diaphysis**) with an **epiphysis** at each end. The **head** lies at the proximal end and articulates with the glenoid fossa, while the **trochlea** is found at the distal end and articulates with the radius and ulna.

On the front surface of the head, there is the **bicipital groove** which receives the tendon of the biceps muscle. On the outer side of the groove there is a prominent ridge, the **deltoid ridge**, used for the attachment of certain muscles.

2 — **Radius and ulna** : these are the bones of the forearm. Both are long, slender and somewhat curved. Although still separated, they are so tightly

bound together. The ulna is the larger bone and has a prominent **olecranon process** or elbow at the proximal end, forming a notch called the **greater sigmoid cavity** for articulation with the humerus.

3 — **Carpals** (bones of the wrist) : are 9 bones arranged in 3 rows : A proximal row of 3 pieces named from the medial line to the lateral line, **radiale**, **intermedium** and **ulnare**, a middle row of one bone called **centrale**, and a distal row made of 4 pieces. The fourth and fifth carpals are fused together. The ninth carpal is a small bone found on the posterior surface of the carpus and articulates with the ulna and ulnare.

4 — **Metacarpals** (bones of the hand) : are 5 long bones.

5 — **Digits** (or fingers) : are 5 in number and have the typical number of phalanges which are expressed by the following digital formula 2 : 3 : 3 : 3 : 3.

C. Pelvic girdle

The pelvic girdle is directly articulated to the vertebral column and is composed of 2 halves, called innominate bones, joined ventrally to form the symphysis pubis. Each **innominate** is formed of 3 bones, namely : **ilium**, **ischium** and **pubis**. The ilium is long and flattened and is fused at its inner surface to the transverse process of the first sacral vertebra. The ischium is separated from the pubis by a large foramen called **obturator foramen** with muscles attached all around its margin and provides a cavity for their transverse swelling when they contract.

The 3 bones share in the formation of a cup-shaped depression called **acetabulum** which receives the head of the femur.

D. Bones of the Hindlimb

1 — **Femur** (or thigh bone) : this is a long, strong and slightly curved bone. Its proximal end bears a large rounded **head** which articulates with the acetabulum. At the distal end of the femur there are two **condyles** for articulation with the tibia, and are partially separated by an **intercondylar notch**.

2 — **Tibia** and **fibula** : these are the bones that support the shank. The tibia is a thick and strong bone which articulates with the femur. The fibula

is a slender bone which takes no part in that articulation.

3 — **Tarsals** (bones of ankle) : are 6 bones arranged in 3 rows. The proximal row consists of 2 bones called the **astragalus** (tibiale and intermedium fused together) for articulation with the tibia, and **calcaneum** (fibulare) for articulation with the fibula. The middle row has a single bone called the **centrale**, and the distal row is composed of 3 tarsals.

4 — **Metatarsals** : consists of 4 long bones.

5 — **Digits** (or toes) : have the digital formula 0 : 3 : 3 : 3 : 3.

Joints : See p. 447.

Functions of the skeletal system : See p. 448 .

BODY CAVITY

The body cavity, or **coelom**, is divided in the mammalian body into **thoracic** and **abdominal cavities** which are separated by the **diaphragm**.

The thoracic cavity contains the heart which is enclosed in the **pericardial cavity**, the lungs which are surrounded by the **pleural cavities**, and the posterior part of the oesophagus.

The abdominal cavity contains all the visceral organs.

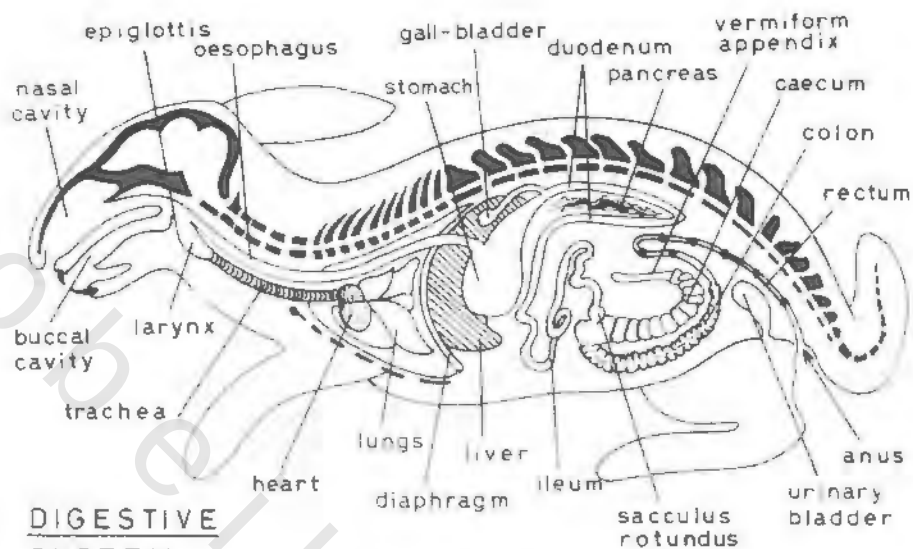
DIGESTIVE SYSTEM

The digestive system comprises the alimentary canal and the associated digestive glands.

I. ALIMENTARY CANAL

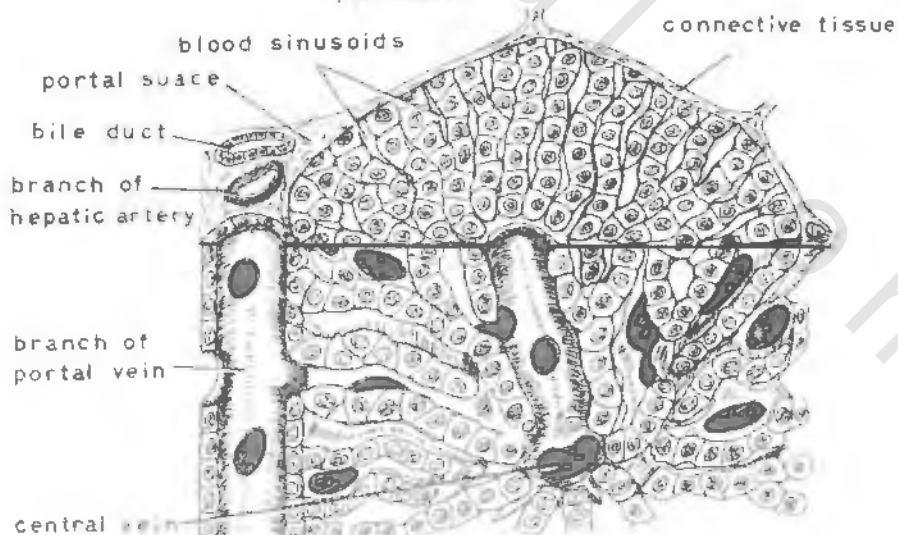
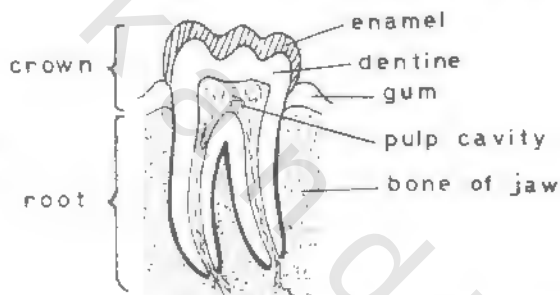
The alimentary canal begins with the **mouth** which leads to the buccal cavity containing the teeth and the tongue.

Teeth : In most mammals, there are 2 sets of teeth. The first set, known as the deciduous or **milk teeth**, appears in the early stages of development



DIGESTIVE SYSTEM

Section of tooth



Three dimensional section of a hepatic lobule

and is later replaced by the **permanent teeth** that persist throughout the life of the animal.

As in other mammals, the teeth of the rabbit are not alike, i.e. **heterodont**, and include the **incisors**, **premolars** and **molars**. In the rabbit, the canines are absent and their place is represented by a space called **diastema**. The teeth are represented by a **dental formula** which indicates the number of teeth of upper and lower jaws on one side. The dental formula for the rabbit is $2 \times i. \frac{2}{1}, c. \frac{0}{0}, p. \frac{3}{2}, m. \frac{3}{3} = 28$ (where i. = incisors, c. = canines, p. = premolars, m. = molars). The formula may be simply written as follows : $\frac{2033}{1023} \times 2 = 28$.

Tooth structure : Each tooth is lodged in a **socket** in the gums, and is fixed to it by cement. The part embedded in the gums is called **root**, and that protruding outside the socket is known as the **crown**. The bulk of the tooth is made up of **dentine** substance penetrated with minute canals in which nerve endings and blood capillaries extend from the **pulp cavity** inside the tooth. The dentine is covered by a layer of **enamel**.

The mouth cavity is separated from the nasal or air passage by a horizontal partition composed of **hard** and **soft palate**. The hard palate is formed as an elongation of the premaxilla, maxilla and palatine bones. These bones are covered by a mucous membrane. The soft palate forms the posterior part of the roof of the mouth cavity and ends behind in a free soft flap.

Pharynx : The buccal cavity leads to the pharyngeal region which is common to both the digestive and respiratory systems. Its upper portion is called the nasopharynx, at the centre of which open the Eustachian tubes.

The **glottis** is a slit-like opening located on the floor of the pharynx and leads to the larynx. Overhanging the glottis is a movable leaf-like cartilaginous flap called the **epiglottis** which closes the glottis during food passage.

Oesophagus : This is a long narrow tube passing through the neck into the thoracic cavity, then piercing the diaphragm to open into the cardiac portion of the stomach.

Stomach : The stomach is an ovoid sac lying transversely in the abdomen just behind the liver. It is differentiated into a large **cardiac portion** to the left side, and a narrower **pyloric** portion, ending with the **pyloric**

sphincter which regulates the passage of food materials from the stomach to the small intestine.

Small intestine : This is a narrow elongated coiled tube. Its first part the **duodenum**, forms a U-shaped loop, in the mesentery of which lies the **pancreas**. The duodenum is followed by the **jejunum** which leads to a long coiled **ileum**. Along the whole length of the small intestine there are slightly thickened oval lymphatic nodules known as **Peyer's patches**. The small intestine ends in a whitish rounded swelling called the **sacculus rotundus** which contains the **ileo-caecal valve**.

Large intestine : From the sacculus rotundus extend 2 tubes. The first is the **caecum** which is thin-walled and marked by certain spiral constrictions showing the line of attachment of an internal spiral valve. The caecum terminates in a narrow blind **vermiform appendix**. The second tube is the large intestine, the first part of which is the **colon**. The walls of the colon are sacculated to increase its area. The colon leads to a smooth **rectum**, which ends in the **anus**.

II. DIGESTIVE GLANDS

The digestive glands associated with the alimentary canal are the salivary glands, the pancreas and the liver.

The Salivary glands: are 4 pairs, namely, the **parotid** (below the external ear), the **submandibular** (behind the lower jaw), the **infraorbital** (below the eye-ball) and the **sublingual** (at the floor of the mouth below the tongue). These glands open by ducts into the buccal cavity and secrete saliva.

The pancreas : is a diffused gland found in the mesentery lying between the two limbs of the loop of the duodenum; its single **pancreatic duct** opens into the distal limb of the duodenum.

The liver : is a large gland attached to the diaphragm by a fold of the peritoneum. It is made up of 5 lobes, right central, left central, left lateral, caudate, and a small Spigelian lobe. The **gall-bladder** lies in a depression in the right central lobe of the liver. The **common bile duct**, formed by the union of the **cystic duct** from the gall-bladder and the **hepatic ducts** from the various parts of the liver, runs to open into the duodenum near the pylorus.

Functions of digestive system : (see p. 365).

CIRCULATORY SYSTEM

The circulatory system of the rabbit consists of the **blood system**, including the heart and blood vessels, and the **lymphatic system**.

I. BLOOD SYSTEM

Heart

The heart lies in the pericardial cavity which is bounded externally by the **pericardium**. The lower border of the heart, forming a blunt point known as the **apex**, lies on the diaphragm and is slightly directed towards the left side. The pericardium is distinguished into 2 parts :

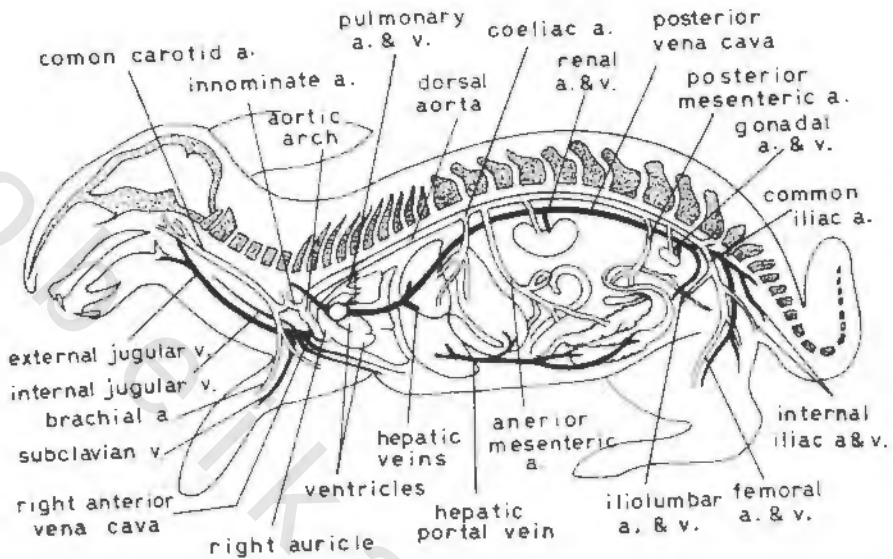
a) **Serous pericardium**, which is a double layer surrounding the heart. The inner layer, adhering to the heart surface is known as the **visceral layer** or **epicardium**, while the outer layer is known as the **parietal layer**. The narrow space between the 2 layers contains a small amount of pericardial fluid.

b) **Fibrous pericardium**, which forms a sac surrounding the serous pericardium, and provides protection for the heart against friction.

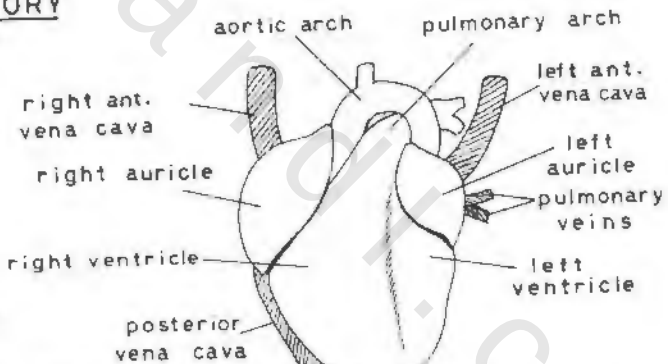
The heart of the rabbit consists of four chambers, 2 **auricles** and 2 **ventricles**. The right auricle is larger than the left, but its walls are thinner. The inter-auricular septum which separates the two auricles bears an oval depression, the **fossa ovalis**. It marks the location of the **foramen ovale**, which is an opening between the two auricles normally present before birth.

The **ventricles** are considerably larger and thicker-walled than the auricles. Also, the left ventricle has thicker walls than the right, and includes the apex. It pumps blood through all the body vessels except those passing to the lungs, whereas the right ventricle sends blood only to the lungs.

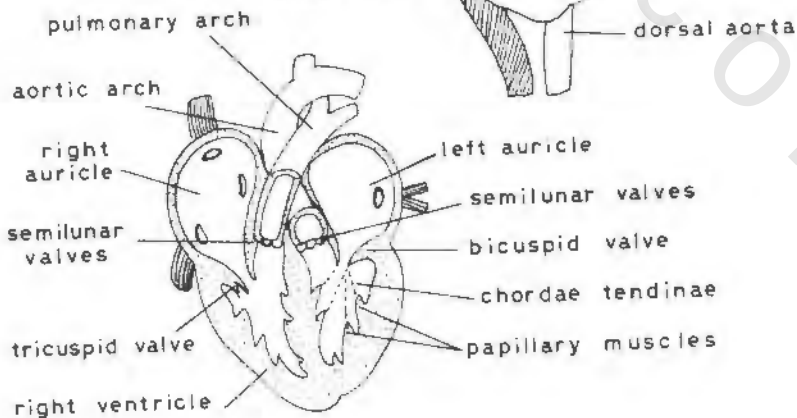
The walls of the ventricles possess numerous muscular ridges, or **columnae carneae**, from which the **papillary muscles** arise. These muscles are connected to the valves guarding the openings between the auricles and ventricles by slender fibres or cords called **chordae tendineae**.



CIRCULATORY SYSTEM



HEART



Heart valves : These are mechanical devices that permit the flow of blood in one direction only. These valves include :

a) Bicuspid valve : formed of 2 flaps and situated between the left auricle and left ventricle.

b) Tricuspid valve : consists of 3 flaps guarding the opening between the right auricle and right ventricle.

c) Semilunar valves : are two valves, one situated inside the base of the pulmonary artery, and the other at the base of the aorta. These valves are half-moon-shaped flaps, which close the opening when filled with blood

Blood vessels

There are 2 main types of blood vessels, arteries and veins.

Arteries : are vessels through which the blood flows from the heart to the organs. They have comparatively thick walls made up of three coats :

a) The outer coat, or tunica adventitia, is composed of connective tissue which prevents the artery from being much stretched when filled with blood.

b) The middle coat, or tunica media, is formed of smooth muscle fibres and elastic connective tissue. The contraction of the muscle fibres regulates the amount of blood sent to each organ, while the elastic tissue keeps a continuous pressure on the blood to flow through the capillaries at the intervals between successive heart pulses.

c) The inner coat, or tunica intima, is made up of elastic connective tissue and is lined with a layer of squamous **endothelial cells**.

Inside the organs, the arteries divide into small branches, or **arterioles**, which further divide into finer **arterial capillaries**.

Veins : are vessels through which blood flows from the organs to the heart. Like arteries they have walls composed of three coats, but these coats are thin and contain fewer elastic and muscle fibres. Unlike the arteries, the veins, especially the medium-sized ones, possess valves which prevent any backward flow of the blood. The smallest veins are called **venules**, into which blood collects from fine **venous capillaries**.

Veins which pass from the organs directly to the heart are called **proper veins**, while those which originate from one organ and end into another

organ are known as **portal veins**, such as the hepatic portal vein arising from the alimentary canal and ending into the liver.

Capillaries : are minute thin-walled vessels which consist of a single layer of endothelial cells. The wall of the capillaries is continuous with the endothelial lining of the arteries or veins. The lumens of the capillaries vary in diameter (average 7.5μ), while the length of a capillary does not exceed 0.3 mm. There are several hundred capillaries per square millimetre of tissue of any organ. Exchange of nutrient material, oxygen and carbon dioxide takes place between the blood and the tissue through the capillary walls. Part of the blood plasma passes also from the blood into the tissues in the form of **lymph**.

A. Venous System

Blood is collected from the different parts of the body by large veins : 2 anterior venae cavae (right and left), and a posterior vena cava.

Right and left anterior venae cavae

Each anterior vena cava is formed of the following tributaries :

- 1 — **Internal jugular vein** : arises in the brain, and runs in the neck.
- 2 — **External jugular vein** : is formed by the union of the anterior and posterior facial veins, and drains blood from head and face.
- 3 — **Subclavian vein** : receives blood from the forelimb.
- 4 — **Internal mammary vein** : extends from the lateral borders of the sternum.
- 5 — **Anterior intercostal vein** : drains blood from the anterior 4 or 5 intercostal spaces.
- 6 — **Azygos vein** : is a single vein, joining the right anterior vena cava only. It drains blood from the posterior 7-8 intercostal spaces of both sides.

Posterior vena cava

This vein collects blood from the posterior part of the body. It receives the following veins :

- 1 — **Phrenic veins** : 2 small veins from the diaphragm.
- 2 — **Hepatic veins** : 3-4 veins draining the blood from the liver.
- 3 — **Renal veins** : 2 veins collecting blood from the kidneys.
- 4- **Spermatic or ovarian veins**: 2 veins from the gonads (testes or ovaries).
- 5 — **Iliolumbar veins** : 2 veins from posterior abdominal region.
- 6 — **External iliac veins** : 2 large veins from the hindlimbs. The external iliac veins are continuations of the **femoral veins** coming from the thighs, each receives a **vesical vein** from the urinary bladder.
- 7 — **Internal iliac veins** : 2 veins from the back of the thighs.

Hepatic portal vein

This receives tributaries from the intestine and rectum (**duodenal, anterior and posterior mesenteric veins**) and from the stomach and spleen (**lienogastric vein**).

Pulmonary veins

These are small veins which carry blood from the lungs and open into the left auricle.

Coronary veins

These arise from the walls of the heart as numerous small veins which join together to form 2 main trunks, the right and left **coronary veins**. These in turn unite to enter the coronary sinus which opens into the right auricle. In addition, several **cardiac veins** open independently into the right auricle. Few veins may also enter the ventricle.

Blood circulation inside the mammalian heart

The anterior and posterior venae cavae bring blood to the right auricle from the anterior and posterior parts of the body. The blood then passes into the right ventricle. It is prevented from going back into the right auricle by the tricuspid valve. From the right ventricle, blood goes to the pulmonary arch, which divides into right and left pulmonary arteries to the lungs. After being oxygenated in the lungs, blood is carried back by the pulmonary veins

to the left auricle. It is then passed to the left ventricle from which it is carried along the aortic arch to all parts of the body. The opening between the left auricle and left ventricle is guarded by the bicuspid valve. Semilunar valves at the bases of both the pulmonary and aortic arches prevent the blood in these vessels from returning back to the ventricles.

On the surface of the heart itself there is a complex series of vessels called **coronary arteries and veins**. The coronary arteries arise from the aorta just in front of the semilunar valves. They supply the walls of the heart itself with blood. The coronary veins collect this blood from the walls of the heart and empty it into the right auricle, through a common opening.

B. Arterial System

Two major arteries originate from the heart, namely the pulmonary and the aortic arches.

Pulmonary arch

This originates from the right ventricle and divides immediately into **right and left pulmonary arteries**, supplying the right and left lungs respectively.

Aortic arch or Systemic aorta

This arises from the left ventricle, and curves to the left side. Starting from the base of the arch, the following vessels are given off :

1 — **Coronary arteries** : are small arteries arising at the base of the aorta and ramifying throughout the walls and septa of the heart.

2 — **Innominate artery** : arises from the top of the aortic arch and gives rise to the **left and right common carotid arteries** to the head. Each divides at the base of the head into **external and internal carotid arteries**.

Close to the origin of the right common carotid artery, arises the **right subclavian artery** to the right forelimb. The **left subclavian** that supplies the left forelimb arises from the aortic arch itself. Each subclavian artery gives rise to a **vertebral artery** (to the cervical vertebrae) and an **internal mammary artery** (to the thoracic wall).

3 — **Intercostal arteries** : are about 9 arteries supplying the thoracic wall.

4 — **Coeliac artery** : gives off 2 branches, a **hepatic artery** to the liver and a **lienogastric artery** to the stomach and spleen.

5 — **Anterior mesenteric artery** : to the intestine.

6 — **Renal arteries** : to the kidneys.

7 — **Spermatic or ovarian arteries** : to the gonads.

8 — **Posterior mesenteric artery** : to the rectum.

9 — **Common iliac arteries** : arise as bifurcation of the aorta; one branch to each thigh. Each gives off :

a) **iliolumbar artery** to the body wall,

b) **internal iliac artery** to the pelvic region, and

c) **vesical artery** to the urinary bladder.

10 — **Femoral arteries** : are continuations of the common iliac extending into the hindlimbs.

II. LYMPHATIC SYSTEM

In mammals, the lymph from all over the body is collected into fine **lymph capillaries** which open into large then larger **lymphatics**. All these lymphatics eventually open into two main collecting ducts or vessels. From most of the body and the whole of the intestine, the lymph passes to the **thoracic duct** which opens into the left subclavian vein at the point where it joins the left external jugular vein. On the other hand the lymph from the right upper half of the body enters the right subclavian vein at almost the same position, and is called the **right lymphatic duct**.

Lymphatics are similar to veins in structure, but their walls are thinner and contain more valves. These valves make the lymph flows in one direction out of the organ, but never into the organ. Small lymphatics in the villi of the intestine are called **lacteals**.

Lymph nodes : These are small round or elongated masses of lymph tissue found at various regions along the lymph vessels. Each lymph node receives certain lymphatic vessels, the afferent lymphatics, and gives rise to other lymphatics, the efferent lymphatics. The lymph node is bound by a connective tissue capsule which gives off trabeculae or partitions to the interior.

The nodes are arranged in groups in certain areas, e.g. submaxillary (in the floor of the mouth), superficial cervical gland (in the neck), axillary nodes (in the axilla), etc.

RESPIRATORY SYSTEM

The organs composing the respiratory system of the rabbit include the nasal passages, pharynx, larynx, trachea, bronchi, and lungs.

A. Nasal passages and pharynx

The **external nares** lead to the **nasal passages** which are situated above the hard palate, being surrounded by the anterior bones of the face. A nasal septum divides the nasal cavity into right and left halves. The nasal passages

are lined by mucous membranes containing blood vessels and nerve endings. Glands in this mucous membrane secrete mucus which moistens the walls of the nasal cavity. The mucous membrane of the upper part of the nasal cavity contains sensory (olfactory) cells which constitute the organ of smell.

The nasal passages serve as pathways for air going to and from the lungs; they warm, moisten and filter air from impurities. Besides, they serve as organs of smell, since olfactory receptors are located in their lining mucosa.

The **pharynx** is common to both the digestive and respiratory systems; its upper portion is known as the **nasopharynx**. During food swallowing, the soft palate is pushed against the roof of the pharynx, temporarily blocking the opening between the nasopharynx and pharynx.

The **glottis** is located on the floor of the pharynx. It is a longitudinal slit which marks the opening leading to the larynx.

B. Larynx

This is a box-like structure lying on the ventral side of the body at the base of the head. The larynx is supported by cartilages chiefly derived from the visceral skeleton. These are the **thyroid cartilage**, the largest of all pieces, a pair of **arytenoid cartilages**, the **cricoid cartilage** and the **epiglottis**. The latter guards the glottis which leads to the larynx. During swallowing, the epiglottis covers the entrance of the larynx and keeps food out of the respiratory tract.

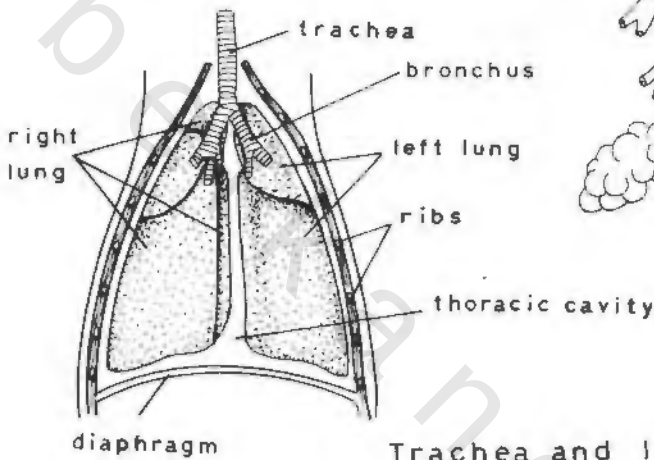
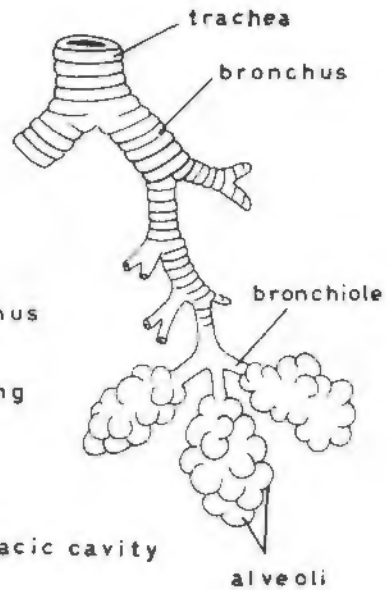
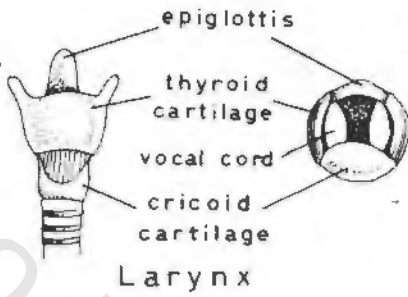
On either side of the base of the epiglottis there is a fold of mucous membrane. The two folds form the **false vocal cords** which are followed at a short distance by another pair of membranous folds, the **true vocal cords**.

C. Trachea and bronchi

The trachea is a long tube extending from the larynx posteriorly to the lungs. Its wall is supported by incomplete cartilaginous rings whose ends are dorsally connected by connective tissue and muscle bands, thus providing a place for accommodation of the ventral surface of the oesophagus.

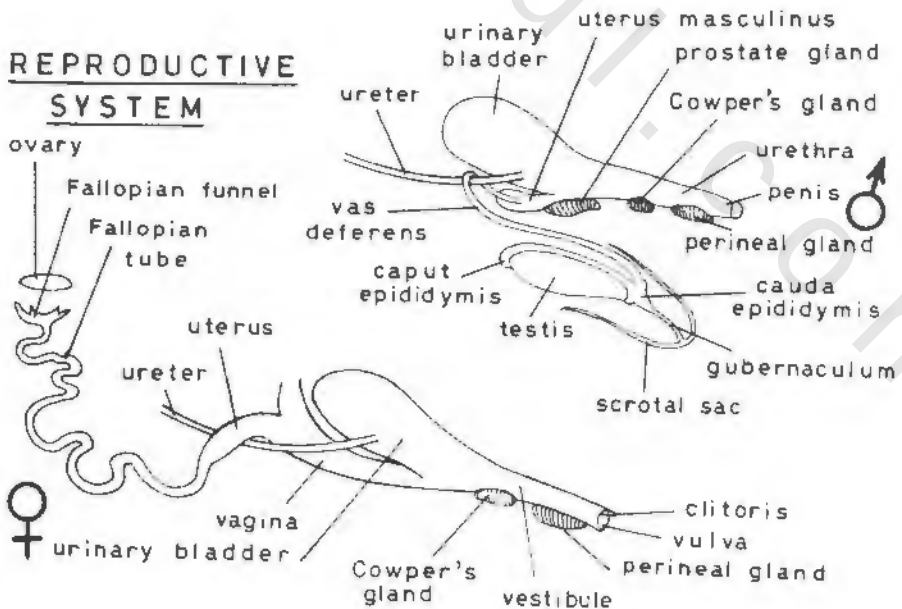
The trachea performs a simple but vital function. It furnishes part of the open passage through which air can reach the lungs from the outside. Obstruction of this airway for even a few minutes causes death by asphyxiation.

RESPIRATORY ORGANS



Trachea and lungs

REPRODUCTIVE SYSTEM



The trachea divides at its lower end into 2 **primary bronchi** which enter the lungs where they divide into smaller bronchi called **secondary bronchi**. These continue to divide and redivide forming fine **bronchioles**, which lead into small sacs, the **alveoli**, lined with blood capillaries.

Like the trachea, the bronchi are supported by cartilaginous rings which prevent their walls from collapsing. The alveoli are enveloped by dense networks of capillaries. Alveoli provide spaces where gases can diffuse between air and blood.

D. Lungs

The lungs are divided into several lobes. The right lung has 4 lobes and the left one has 2. The lungs are situated in the pleural cavities, each being enclosed by 2 peritoneal layers. The layer surrounding the lung is known as the visceral pleura.

The lungs provide a place where gas exchange between blood and air takes place. Because of the branching of the airways into millions of thin-walled alveoli enveloped by networks of capillaries, large amounts of oxygen are quickly loaded into blood and large amounts of carbon dioxide are quickly expelled from the latter.

Respiration

In **inspiration**, the muscles of the diaphragm contract so that the organ flattens out. The intercostal muscles similarly contract moving the ribs forwards. The thorathic cavity is thus widened and the lungs are expanded so that the pressure inside them is lowered. Air is drawn into them through the air passages as a consequence.

In **expiration**, the relaxation of the diaphragm muscles causes the return of the ribs and diaphragm to their normal position. The volume of the thoracic cavity decreases and the lungs are thus compressed, their internal pressure rises, expelling air through the air passages. However, these respiratory movements never empty the lungs completely; there is always some residual air left in them.

Functions of the respiratory system (see p. 368)

EXCRETORY SYSTEM

Excretion is the process of the removal of metabolic waste products from the body mainly through the kidneys. However, some wastes are disposed through the skin and lungs, others are discharged from the liver in the bile, and some are egested from the intestine as faeces.

Kidneys

The principle excretory organs of the rabbit are the **kidneys**. These are a pair of bean-shaped bodies situated on the dorsal wall of the abdominal cavity, the right one being somewhat anterior to the left. On the inner side of each kidney, there is a notch called the **hilus** from which a **ureter** arises. Internally, the kidney is differentiated into two regions, an outer **cortex** and an inner **medulla**. The medulla is produced internally into conical projections, the **pyramids**.

The kidney of the rabbit is composed of a large number of renal tubules or **nephrons**. Each nephron begins in the cortex by a cup-shaped, thin, double-walled **Bowman's capsule**. An **afferent arteriole** enters Bowman's capsule and branches inside it into a network of blood capillaries, the **glomerulus**. It then leaves the capsule as a relatively narrower **efferent arteriole**. Blood pressure is increased in the glomerulus and filtration occurs in Bowman's capsule. The Bowman's capsule together with the glomerulus constitute a **Malpighian corpuscle**.

The remaining part of the renal tubule is distinguished into three regions:

- a) **Proximal convoluted tubule.**
- b) Descending and ascending limbs of **Henle's loop**.
- c) **Distal convoluted tubule.**
- d) The distal convoluted tubules lead into wider and straight tubules called the **collecting tubules**.

The Malpighian corpuscle, and proximal and distal convoluted tubules are located in the cortex, while the loops of Henle and the collecting tubules are found in the medulla of the kidney. The medulla is radially striated due

to the straight arrangement of the tubules in it. The tubules open on the surface of the pyramid, which opens into the **pelvis** of the kidney. The **pelvis** is the dilated commencement of the ureter which emerges out of the kidney at the hilus, and runs backward along the dorsal wall of the abdomen to open into the **urinary bladder**.

Functions of the excretory system (see p. 468).

REPRODUCTIVE SYSTEM

A. Male reproductive organs

The **testes** develop close to the kidneys during the early stages of development, on the inner surface of the dorsal wall of the abdominal cavity. Later, at maturity, they descend into the **scrotal sacs** on both sides of the penis. The cavity of each sac communicates with that of the abdomen by an **inguinal canal**. Each testis still retains connection with its original position by a **spermatic cord** which consists of some connective tissue, an artery and a vein.

A mass of convoluted tubules, the **epididymis**, is closely attached to each testis in the scrotal sac. The anterior end of the epididymis is called the **caput epididymis**, and its posterior end is enlarged into the **cauda epididymis**. The latter is connected with the scrotal sac by a short elastic cord called the **gubernaculum**, and forms the proximal part of the **vas deferens**. The vas deferens then comes out of the inguinal canal, enters the abdominal cavity, runs forward, curves over the ureter, and passes backwards again to open into a small median sac known as the **uterus masculinus**, situated on the dorsal side of the neck of the urinary bladder. The uterus masculinus and the neck of the urinary bladder are continued backward as the **urinogenital canal** or **urethra**, which passes through the penis and opens out at its tip.

A number of glands are associated with the male reproductive system. These are the **prostate gland**, a pair of **Cowper's glands** and **perineal glands**.

The sperms from the testis, along with the secretion of the prostate gland, Cowper's glands, uterus masculinus and epididymis form the semen. The secretions of these glands nourish the sperms and neutralize the acidity of the urethra as it is harmful to the spermatozoa.

Female reproductive organs

Two **ovaries** are attached to the dorsal wall of the abdomen behind the kidneys. The two **oviducts** are very narrow and slightly convoluted. Each opens into the abdominal cavity by a funnel-shaped opening called the **Fallopian funnel**, found just behind the corresponding ovary. The Fallopian tube extends backwards and enlarges into a muscular **uterus**. The two uteri lead into a median tube, the **vagina** which, together with the urinary bladder, form the urinogenital canal or the **vestibule**. This opens to outside by a slit-like **vulva**. The vulva is bounded by 2 prominent folds known as the **labia majora**. On the ventral wall of the vulva lies a small rod-like **clitoris** which is homologous to the penis of the male.

A pair of **Bartholin's glands** open into the dorsal wall of the vestibule; their secretion lubricates the vagina. They correspond to Cowper's glands. **Perineal glands** are also found.

A female rabbit receives the male for copulation only during oestrus. The domesticated rabbits may copulate at any time of the year, but wild rabbits copulate in spring and summer.

The ripe ova are discharged by the burst of the Graafian follicles into the Fallopian funnels. This process of ovulation takes place after copulation. The spermatozoa move upwards from the vagina to the Fallopian tube where fertilization of the ova takes place.

The fertilized ovum immediately begins cleavage then travels down the oviduct until it reaches the uterus, where a special connection called **placenta** is established between the developing embryo, or foetus, and the wall of the uterus. The mother supplies nourishment and respiration to the foetus through the placenta. The period of gestation in the rabbit is one month.

NERVOUS SYSTEM

The nervous system together with the endocrine system are responsible for the regulation and coordination of the physiological activities of the animal.

The nervous system includes the following divisions :

- I. **Central nervous system (C.N.S.)** which comprises :
 - A. Brain
 - B. Spinal cord
- II. **Peripheral nervous system** which consists of the nerves extending from the central nervous system and include :
 - A. Cranial nerves
 - B. Spinal nerves.
- III. **Autonomic nervous system**

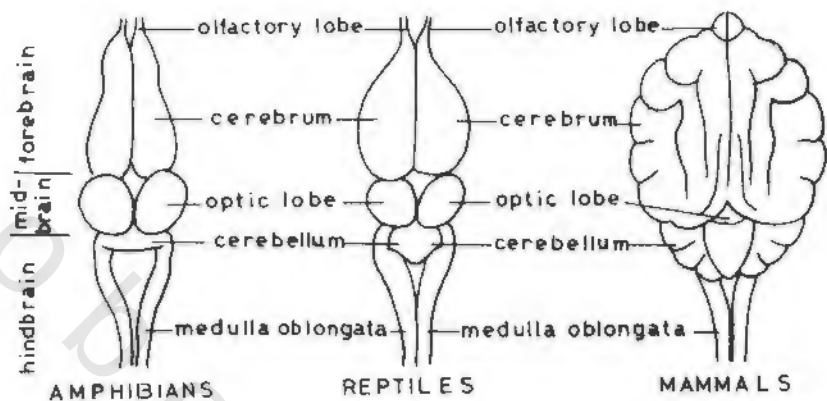
I. CENTRAL NERVOUS SYSTEM

A. Brain

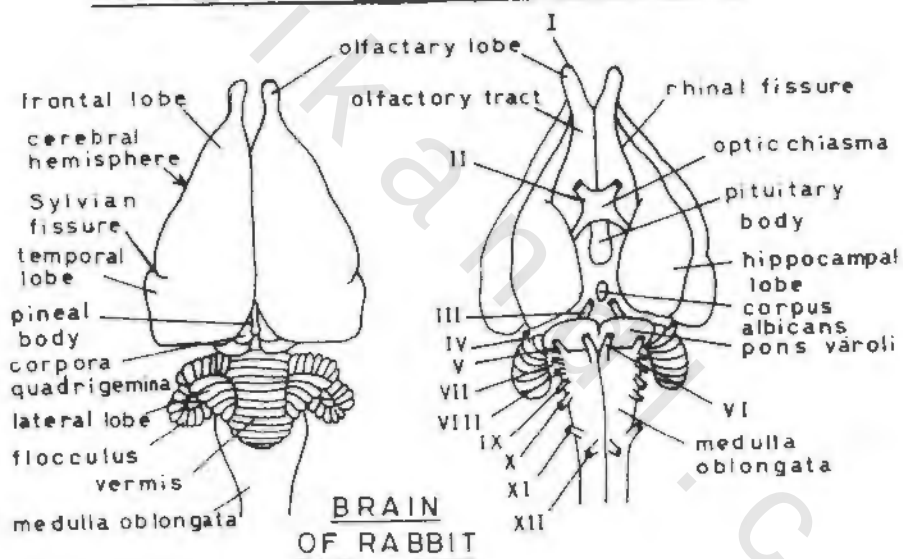
The brain lies within the cranium (brain case). It is covered by 3 distinct membranes :

- a) **Dura mater** : formed of strong white fibrous tissue adhering to the cranium.
- b) **Arachnoid membrane** : a delicate layer of connective tissue.
- c) **Pia mater** : a transparent layer adhering to the brain and containing blood vessels.

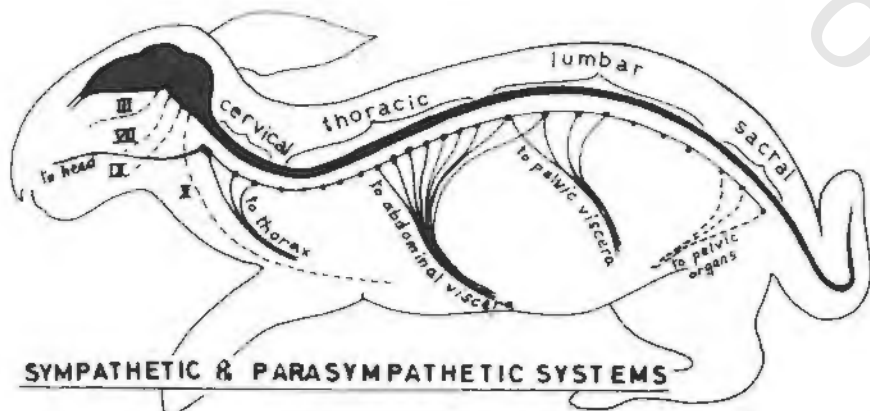
The brain arises as an anterior vesicle of the embryonic neural canal. During subsequent development, this vesicle becomes differentiated into 3 parts : the fore-brain, the mid-brain and the hind-brain. Later on, these parts differentiate into the following :



Evolution of the vertebrate brain



BRAIN OF RABBIT



SYMPATHETIC & PARASYMPATHETIC SYSTEMS

1 — Fore-brain (prosencephalon)

This is differentiated into :

- a) Telencephalon (cerebrum)
- b) Diencephalon (thalamencephalon).

The **telencephalon** is further differentiated into 2 relatively small **olfactory lobes** concerned with the sense of smell, and 2 large **cerebral hemispheres** (sometimes called cerebrum). The cerebral hemispheres form the greater portion of the rabbit's brain and overlie most of the olfactory lobes. They are divided by a deep median cleft known as the **median fissure**. The surfaces of the cerebral hemispheres are smooth while in higher mammals, the surfaces of the corresponding hemispheres possess numerous folds (**gyri**) with grooves (**sulci**) between them. Laterally, each hemisphere is divided by the **Sylvian fissure** into an anterior **frontal lobe** and a lateral **temporal lobe**. On the ventral surface of each cerebral hemisphere, there is a longitudinal fissure called the **rhinal fissure** which marks the **olfactory tract** from the **hippocampal lobe**. The **cerebrum** is mainly regarded as the organ of thinking memory and speech in higher mammals.

The **diencephalon**, or thalamencephalon, is a narrow region covered by the cerebral hemispheres. The thin roof is provided with vascular folds called the **anterior choroid plexus**. The stalk of the pineal body arises from the dorsal surface of the diencephalon. The lateral walls of the diencephalon are thickened to form the **thalami** which are adjusting centres for nerve tracts connecting the cerebral hemispheres with the more posterior part of the brain.

The ventral portion of the diencephalon, which is the only part visible externally, is called the **hypothalamus** which acts mainly to regulate metabolism, body temperature and sleep as well as emotional sensation.

The **optic chiasma** (the crossing of optic nerve fibres) is located at the anterior end of the hypothalamus. Posterior to the chiasma there is the **tuber cinereum** which is ventrally attached to the **infundibulum** by a narrow stalk. A portion of the infundibulum forms part of the **pituitary body** which is an important endocrine gland.

2 — Mid-brain (mesencephalon)

This is almost completely covered by the cerebral hemispheres. It is formed of 4 rounded elevations called **corpora quadrigemina** or **colliculi**. Certain auditory reflex centres lie in the posterior lobes of the corpora quadrigemina, while visual centres lie in the anterior lobes. Ventrally, there are 2 large bands of fibres called the **crura cerebri** which connect the cerebral hemispheres with the hind-brain.

3 — Hind-brain (rhombencephalon)

This is differentiated into :

a) Cerebellum : which is well developed and projects forwards to meet the posterior margin of the cerebral hemispheres. It is divided into 5 regions : a median **vermis**, 2 **lateral lobes** and 2 **flocculi**. It acts mainly to coordinate muscular movements and maintain the balance of the body.

b) Medulla oblongata : which is much thickened and joins the spinal cord posteriorly. The **posterior choroid plexus** is found in its roof and is formed of vascular folds.

It contains certain vital centres, e.g. cardiac activities and respiration centres.

c) Pons Varolii : is a thickened portion composed of fibrous tracts extending across the medulla and connecting the two sides of the cerebellum.

Ventricles of the brain

The brain is not solid, but contains 4 internal cavities known as ventricles. Two **lateral ventricles** (or first and second) are located one in each cerebral hemisphere, and communicate with one another by the **foramen of Monro**. These ventricles join a **third ventricle** in the diencephalon. The **fourth ventricle** is found in the medulla oblongata. All these ventricles are filled with the cerebro-spinal fluid which provides nourishment for the tissues of the nervous system.

B. Spinal Cord

The spinal cord is located in the vertebral or neural canal. It extends from the medulla oblongata and passes through the foramen magnum to the posterior end of the vertebral column as a long white cylindrical tube which is slightly thickened in the brachial and lumbar regions. The posterior end of the spinal cord is cone-shaped and called **conus terminalis**. The spinal cord encloses a **central canal** filled with cerebro-spinal fluid, and is continuous with the brain ventricles.

Like the brain, the spinal cord is surrounded by the dura mater, arachnoid membrane and the pia mater. The spinal cord is made up of two kinds of nervous tissue.

a) **White matter** : This is the outer portion of the spinal cord. It consists of a large number of **nerve fibres** surrounded and supported by a nervous connective tissue known as the **neuroglia**.

Along the median line of the upper and lower surfaces of the white matter, there are the **dorsal** and **ventral fissures** which divide it rather incompletely.

b) **Grey matter** : This is the inner portion of the spinal cord. It consists of the bodies of the nerve cells or **neurons** supported by **neuroglia**. In a transverse section, the grey matter has an H-shape, with two **dorsal horns** and two **ventral horns**. The ends of the two dorsal horns are pointed and lie near the periphery of the cord, while the ends of the two ventral horns are broad and lie away from the periphery.

In the median part of the grey matter, the **central canal** is located, lined by ciliated cubical epithelium. The spinal cord is mainly concerned with the conduction of nerve impulses and reflex activities.

II. PERIPHERAL NERVOUS SYSTEM

This system includes the cranial and spinal nerves.

A. Cranial nerves

As in all mammals, there are twelve pairs of cranial nerves which arise from the brain and pass through minute foramina in the skull to innervate different parts of the body; some of these nerves are purely sensory, some purely motor, and others are mixed. The cranial nerves on each side are :

I. Olfactory nerve : originates from the olfactory organ and is connected with the olfactory lobe. It is a sensory nerve.

II. Optic nerve : extends from the retina of the eye to the floor of the diencephalon. The two optic nerves meet to form the optic chiasma, in which some of the fibres of each nerve cross to the opposite side and continue in the optic tract of that side. They end in the anterior colliculi of the mid-brain. This is a sensory nerve.

III. Oculomotor nerve : arises from the ventral surface of the mid-brain and supplies four of the eye muscles. It is a motor nerve.

IV. Trochlear nerve : extends from the mid-brain to the fifth eye muscle. It is a motor nerve.

V. Trigeminal nerve : is a mixed nerve which arises from the pons Varolii, and has three branches :

a) **Ophthalmic nerve** : carries sensory impulses from the skin of the anterior part of the head, upper eyelid, conjunctiva and eyeball.

b) **Maxillary nerve** : carries sensory impulses from the upper teeth, skin of upper lip, lower eyelid and nose.

c) **Mandibular nerve** : innervates the lower teeth, skin of lower lip, tongue and all masticatory muscles. It is a mixed nerve.

VI. Abducens nerve : arises from the medulla oblongata and innervates the sixth muscle of the eye. It is a motor nerve.

VII. Facial nerve : extends from the medulla oblongata near the pons

Varolii, close to the fifth nerve, and gives motor branches to the superficial muscles of the face and to the submaxillary and sublingual glands. It also gives sensory fibres to the taste buds of the tongue. This nerve is mixed.

VIII. Auditory nerve : arises from the medulla oblongata and innervates the inner ear. It is a sensory nerve.

IX. Glossopharyngeal nerve : extends as a mixed nerve from the medulla oblongata. The motor fibres innervate the muscles of the pharynx, while the sensory fibres innervate the mucous membrane of the pharynx and the base of the tongue and parotid glands.

X. Vagus nerve : is a mixed nerve containing motor, sensory and parasympathetic fibres. It arises from the medulla oblongata and innervates several organs, e.g. pharynx, larynx, thyroid gland, oesophagus, trachea, bronchi, lungs, heart, stomach, liver, pancreas, spleen, the small intestine, and the greater part of the large intestine.

XI. Spinal accessory nerve : extends from the medulla oblongata and the upper part of the spinal cord. It innervates certain pharyngeal, laryngeal, and cervical muscles. It is a motor nerve.

XII. Hypoglossal nerve : arises from the medulla oblongata and supplies all the muscles of the tongue. It is a motor nerve.

B. Spinal Nerves

There are usually 37-38 pairs including; 8 cervical, 12-13 thoracic, 7 lumbar, 4 sacral, and 6 caudal spinal nerves.

Each spinal nerve arises by a **dorsal** and a **ventral root** connected with the horns of the grey matter of the spinal cord. These roots unite within the neural canal to form a spinal nerve which passes out through an intervertebral foramen in the vertebral column. The dorsal root bears a **dorsal root ganglion** containing cell bodies of the sensory neurons. It contains only sensory fibres, while the ventral root contains motor fibres whose cell bodies are located within the spinal cord.

The first spinal nerve emerges out between the skull and the first vertebra, and the other spinal nerves extend out through the intervertebral foramina. The spinal nerves supply the skin and the muscles of the body.

III. AUTONOMIC NERVOUS SYSTEM

This system controls many internal functions that are not under the voluntary regulation such as the rate of heart beat, the secretion of digestive juices, muscular movements in the stomach and intestine, and other functions.

The autonomic nerves are subdivided into two main divisions : **sympathetic nerves** which originate in the thoracic and lumbar regions, and the **parasympathetic nerves** which arise in the cranial and sacral regions.

Many organs are supplied by both sympathetic and parasympathetic nerves, and in this case the nerves are antagonistic to each other. This is well illustrated in the case of the heart, where the parasympathetic fibres in the vagus nerve are inhibitory and the sympathetic fibres are augmentory.

The parasympathetic system continues as a pair of nerve cords which extend from the cranial nerves VII, IX and X to the hinder part of the body. In the neck region it passes close to the vagus and runs alongside the carotid artery. It bears anterior and posterior cervical ganglia. In the thorax it runs just beneath the heads of the ribs, while in the abdomen it runs close to the centra of the vertebra. It bears ganglia, each is connected with the corresponding spinal nerve by a connecting branch called **ramus communicans**.

SENSE ORGANS

The sense organs are specialized receptors developed for the detection of specific environmental changes. Some of these receptors are confined to regions close to the body surface and are called **cutaneous receptors** while others have some form of a capsule around them (smell and hearing). Some of these organs are sensitive to chemical changes and hence are known as **chemoreceptors** (smell and taste).

A. Cutaneous sense organs

The skin is richly supplied with nerve endings which receive stimuli for touch, pressure, cold, heat and pain. At the base of the hairs, especially in

the vibrissae, there are tactile receptors which are extremely sensitive to slight movements.

B. Organs of taste

These are represented by the **taste buds** located in the taste papillae of the tongue. A taste bud is oval in shape and formed of a group of narrow columnar sensory cells, surrounded by supporting cells. The sensory cells bear cilia at their free ends, and their basal parts are connected to the nerve ends of the VII, IX and X cranial nerves. Taste buds sensitive to sweet and acidic substances are located at the tip of the tongue, and those for bitter taste are found in the hinder part. The taste buds are stimulated only by substances in solution.

C. Organs of smell

These organs are situated in the olfactory capsules. They are composed of special columnar sensory cells located in the moist olfactory mucous membrane lining the nasal passages. The free end of each columnar cell bears a single sensory hair, while the base is connected to a nerve fibre of the olfactory nerve. Substances must be in solution to be smelled.

D. Organs of vision

The eye-ball is more or less spherical and well protected by the incomplete bony orbit in which it lies. The eye is guarded by the upper and lower eyelids which are extensions of the skin. These eyelids are provided with eyelashes which prevent the entrance of dust particles into the eyes. A nictitating membrane is found at the anterior margin of the orbit. Several tear glands are associated with the eye : **extraorbital, lacrymal, infraorbital** and **Harderian glands**. Their secretion keeps the surface of the eye moist and washes away dust that may settle on it. The eye-ball is moved by 6 eye muscles.

The wall of the eye is formed of three coats, an outer coat or **tunica fibrosa**, a middle coat **tunica vasculosa**, and an inner sensitive **retina**.

1 — **Tunica fibrosa** : This consists of 2 parts :

a) An anterior **cornea** which is a transparent membrane supplied with sensory nerve endings; but has no blood vessels. The cornea is covered by

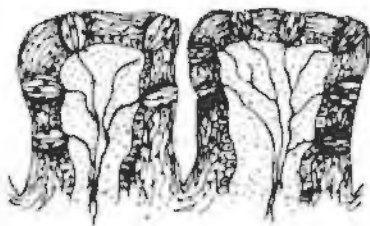
SENSE ORGANS



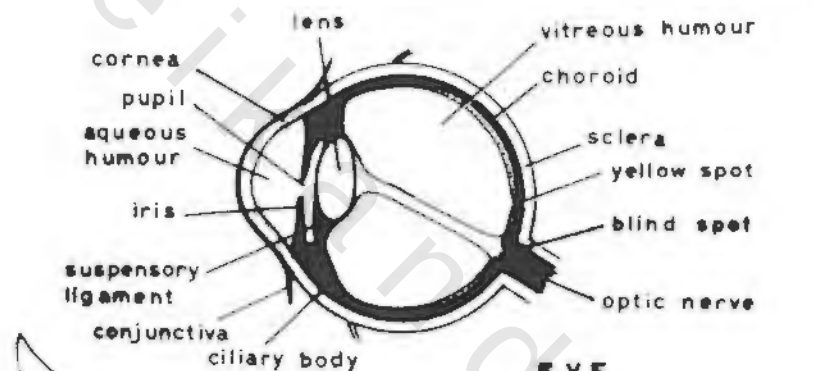
TACTILE CORPUSCLE



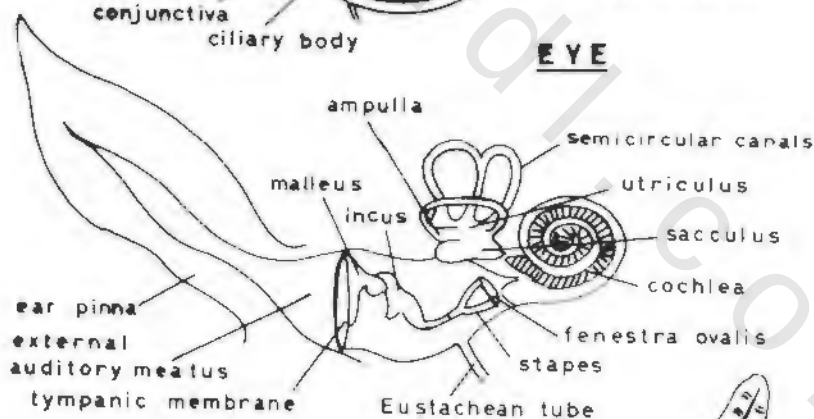
SENSORY RECEPTORS



TASTE BUDS
(in tongue)

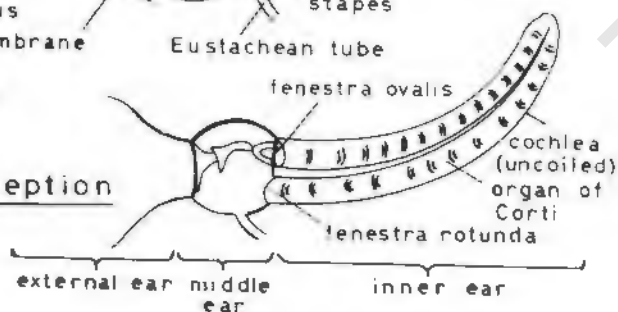


EYE



EAR

Sound perception



the **conjunctiva**; a transparent layer which also lines the upper and lower eyelids.

b) A posterior **sclera** which is white, opaque and contains few blood vessels.

2 — **Tunica vasculosa** : This coat consists of 3 parts :

a) The **iris** which is a coloured circular plate with an opening in the centre called the **pupil**. Inside the iris there are circular and radial smooth muscles for constricting and dilating the pupil, thus controlling the amount of light which passes into the eye.

The space between the cornea and the iris is called the **aqueous chamber**, and is filled with a clear watery fluid, the **aqueous humour**.

b) The **ciliary body** in the middle part which contains smooth muscle fibres concerned with changing the curvature of the lens to enable it to form images at varying distances. The **lens** is situated behind the iris and is connected with the ciliary body by **suspensory ligaments**.

c) The **choroid** is the posterior part of the middle coat. It contains blood vessels and a large amount of pigments.

3 — The **retina** is the innermost coat, it is incomplete as it has no anterior portion, and ends at the border of the ciliary body. The **retina** consists mainly of nervous tissue and contains **rods** and **cones** which are photosensitive cells. The cones are associated with diurnal vision and the rods with nocturnal vision. The rods contain a substance known as the **visual purple** or **rhodopsin** formed of a protein and vitamin A. The disturbance in the formation of visual purple leads to night blindness.

E. Organs of hearing

The ear of the rabbit consists of three parts: the external ear, the middle ear, and the internal ear.

1 — **External ear** : is formed of the **ear pinna** and the narrow **auditory canal** which opens to the outside by the **external auditory meatus** and ends inside by the **tympanic membrane**. The ear pinna is provided with muscles which can move it in all directions to receive sound waves.

2 — **Middle ear** : is situated inside the tympanic bulla, it is lined with mucous membrane and filled with air. It opens on the inner side into the

internal ear by two apertures, the **fenestra ovalis** and the **fenestra rotunda**. It communicates with the pharynx through the **Eustachian tube** to balance the pressure on both sides of the tympanic membrane. The cavity of the middle ear is traversed by three auditory ossicles called **malleus** (hammer), **incus** (anvil) and **stapes** (stirrup). The malleus is attached to the inner surface of the tympanic membrane and on the other side to the incus which articulates with the stapes. This fits into the fenestra ovalis which leads into the internal ear. These auditory ossicles transmit sound vibrations from the tympanic membrane to the internal ear through the fenestra ovalis.

3 — **Inner ear** : lies in the periotic bone and consists of the **membranous labyrinth** surrounded by a space filled with perilymph. The membranous labyrinth is filled with endolymph and is differentiated into an upper chamber known as **utricle**, and a lower chamber called the **sacculus**. The two chambers are connected by a small **sacculo-utricular canal**.

Into the utricle open three **semicircular canals** arranged so that each lies in one of the planes of scope, i.e. there are two vertical canals at right angles to each other and a horizontal canal. One of the ends of each semicircular canal is dilated into an **ampulla**. The utricle, semi-circular canals and ampullae are concerned with the equilibrium of the body. Any change in the direction of the head will produce movement in the fluid of the semicircular canals and stimulates the receptors in the ampullae.

The **sacculus** is connected to a spirally coiled tube called the **cochlea**. The cavity of the cochlea contains perilymph and is divided by a special bony plate into two parts communicating with each other only at the apex of the cochlea. The cochlea contains the **organ of Corti** which is the principal organ of hearing and performs a sound-perceiving function. It consists of fibrils which are stretched like the strings of a musical instrument. The fibrils are of various lengths. The vibrations in the organ of Corti give rise to excitation in the endings of the auditory nerve which is then transmitted to the temporal lobe of the brain.

Functions of the nervous system : (see p. 501)

ENDOCRINE GLANDS

(See p. 503)

CHAPTER VI

VERTEBRATE PHYSIOLOGY

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VERTEBRATE PHYSIOLOGY

INTRODUCTION

Physiology is the science that deals with the way or ways in which the organism as a whole, its different systems, organs or tissues perform their functions.

Physiology is closely associated with a number of other sciences such as chemistry and physics. Physiology is also linked with all branches of medicine; it always finds its widest field of application in medical sciences.

The functions performed by a living organism can be discussed under the following items : Locomotion, nutrition, circulation, respiration, excretion, reproduction, and coordination which is carried out by both the nervous and endocrine systems.

LOCOMOTION

The movements of a part of the vertebrate body depend on the origin and insertion of its muscles and on the nature of articulation of its bones with each other and with other parts of the body.

Muscles are usually arranged in opposite groups to perform **antagonistic actions** to one another. They are classified according to the type of movement they produce into : flexor or extensor, adductor or abductor, depressor or dilator, or rotator muscles (p. 438).

The histology of unstriated, striated and cardiac muscles is described on page 190.

Muscle contraction

There are two kinds of muscle contractions :

a) Isometric contraction : In which the length of the muscle remains the same, but the pressure or tension within the muscle increases. This mode of muscle contraction takes place when the muscle fails to lift a certain weight. No external work is done because the weight is greater than what the muscle can move. Thus the length of the muscle remains the same, but the tension inside it increases.

b) Isotonic contraction : In which there is a change in length, but the pressure or tension within the muscle remains the same. This type of contraction takes place when the muscle succeeds to lift a weight.

Mechanism of muscle contraction

Many theories have been proposed to explain the mechanism of muscle contraction, but none of them is completely acceptable.

A striking feature of the skeletal muscle fibre is that it consists of alternating light and dark bands. The light band is also known as the isotropic or **I-band** because it is transparent and permits light. The dark band, on the other hand, does not permit light and is termed the anisotropic or **A-band**. The I-band is crossed at its middle by a dark **Z-line**, while the A-band is crossed by a light **H-zone**. The area between every two Z-lines is known as a **sarcomere**.

The two main protein constituents of skeletal muscle fibres are the proteins **actin** and **myosin**. Neither actin nor myosin alone is capable of contraction, but when both are mixed together they form the complex substance **actomyosin** which contracts in the presence of potassium, calcium, sodium and magnesium ions and ATP.

When the muscle fibre contracts the I-bands become shorter, while the length of the A-bands remains constant. This phenomenon was noticed by Huxley and inspired him, few years ago, to advance his famous **sliding filament hypothesis** for explaining the mechanism of muscle contraction. According to this theory, the sarcomere is built up of two types of filaments :

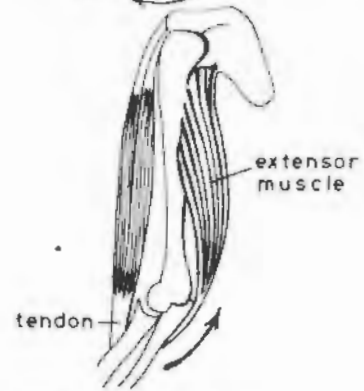
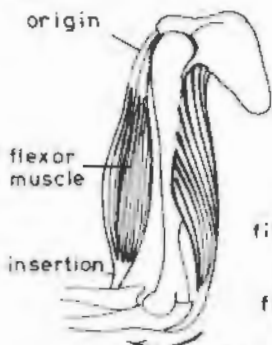
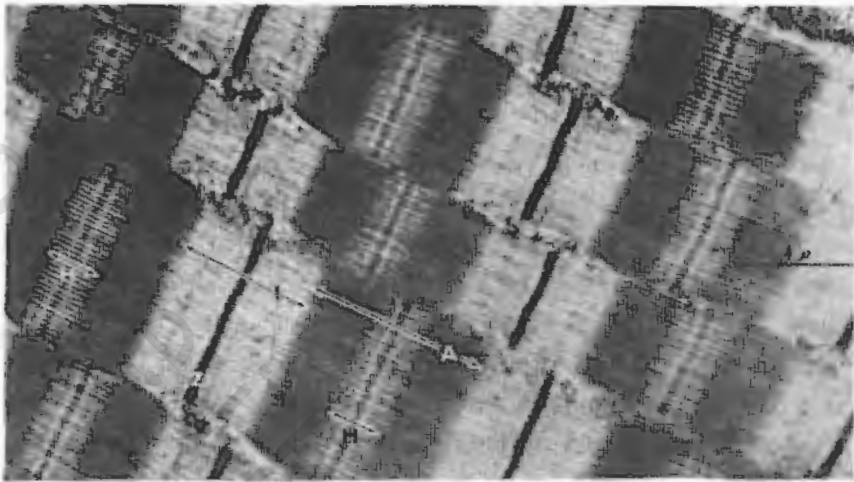
a) Thin filaments of actin found in the I-band and extend also into the A-band, but do not meet in the middle part of that band. They leave a narrow H-zone in between their ends.

b) Thick filaments of myosin found only in the A-band.

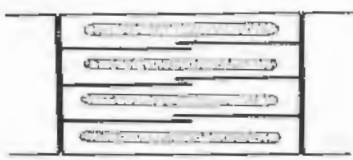
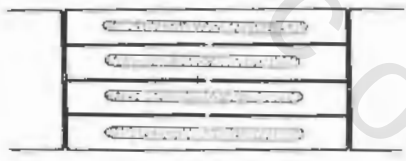
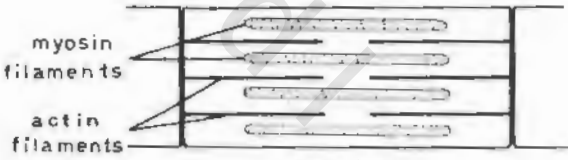
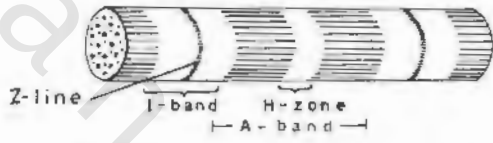
During muscle contraction, the sarcomere shortens as the length of the I-band is decreased, but the length of the A-band remains the same. The actin filaments from both sides slide towards each other till they meet in the H-zone, which thus disappears in contracting muscle fibres. If the contraction is great, the actin filaments may further overlap, causing the H-zone to appear dark. This shows that although the muscle fibre shortens during contraction, the length of the filaments does not change as they slide past each other.

Muscle fibres generally follow the **all or none law** when they contract. This means that they either contract with all the force possible or they do not contract at all.

Electron micrograph of striated muscle fibres



Muscle action



Muscle contraction

NUTRITION

All substances taken into the body and used to build up protoplasm and to produce energy are considered foods. All foods are derived from green plants which are able to manufacture their organic food material from inorganic sources taken from the surrounding media (**autotrophic nutrition**). Animals depend on plants for their food which they get either directly by feeding on plants or indirectly by feeding on animals which had obtained their food by eating plants (**heterotrophic nutrition**). Animals which feed entirely on plants are called **herbivorous**, those which feed on other animals are called **carnivorous**, and those which feed on plant as well as animal matter are called **omnivorous animals**.

The principal components of foods are carbohydrates, lipids, proteins, water, inorganic salts and vitamins.

A **balanced diet** is a mixture of foods containing all substances essential for the development, growth and maintenance of the individual.

The food taken in by animals is used in :

- 1 — Building up new protoplasm, particularly during periods of growth.
- 2 — Replacing the protoplasm which is worn out during life.
- 3 — Supplying energy required for various activities.
- 4 — Regulating life processes.

I. CARBOHYDRATES

These are naturally occurring substances composed of carbon, hydrogen and oxygen, in which the ratio of hydrogen to oxygen is the same as in water.

Carbohydrates are classified into 3 main groups :

A. Monosaccharides

These are the simplest sugars, each being composed of a single sugar unit. They are classified into different types according to the number of carbon atoms they contain, e.g. **pentoses** ($C_5H_{10}O_5$), as ribose; and **hexoses** ($C_6H_{12}O_6$), as glucose, fructose, galactose, etc.

The most important of this group is glucose which is found in blood and other tissues. Fructose occurs in the seminal fluid. Galactose is a constituent of the disaccharide lactose (milk sugar). Ribose and deoxyribose are essential for the formation of nucleic acids and nuclei of animal and plant tissues.

B. Disaccharides ($C_{12}H_{22}O_{11}$)

A disaccharide is composed of 2 molecules of monosaccharides, chemically combined with the loss of one molecule of water, e.g. sucrose (cane sugar), maltose (malt sugar) and lactose (milk sugar). The bond found between the 2 monosaccharide molecules is called a **glucoside linkage**.

C. Polysaccharides ($C_6H_{10}O_5$)_n

A polysaccharide is formed of many molecules of monosaccharides chemically combined, with the loss of one molecule of water at each linkage e.g. starch, glycogen (animal starch), dextrans, cellulose and chitin.

Biological significance of carbohydrates

Carbohydrates form about 50-60% of the human diet and about 0.6% of the human body weight. Within the animal body, carbohydrates are stored chiefly in the liver and muscles as polysaccharide glycogen, which is a straight or branched molecule of many glucose units. Glucose may readily be changed into glycogen for storage within the liver or muscles. This is a reversible reaction which takes place in the liver only, so that glycogen may be changed back to glucose when the body needs it.

Within the animal body, carbohydrates may be used in any of the following processes:

1 — They may be circulated as blood sugars to be distributed to different parts of the body.

- 2 — They may be oxidized for energy (yields 4.2 calories / gm).
- 3 — They may be converted to glycogen and stored in the liver or muscles.
- 4 — They may be transformed into fats and deposited in adipose tissues.

II. LIPIDS

Lipids include the fats, oils and waxes. They are composed of carbon, hydrogen and oxygen, but the proportion of oxygen to hydrogen is less than in carbohydrates.

A lipid simply consists of a fatty acid plus an alcohol; the linkage between the two is called an **ester linkage**.

Lipids are classified according to the degree of complexity of their molecules into :

A. Simple lipids

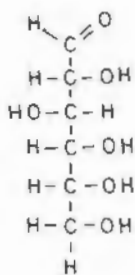
These are esters of fatty acids with different alcohols. They include :

- a) Fats and oils (esters of fatty acids with glycerol).
- b) Waxes (esters of fatty acids with long aliphatic or aromatic alcohols).

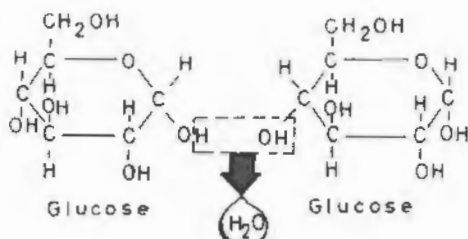
B. Compound lipids

These are esters of fatty acids with alcohols; in addition they contain other groups, e.g. :

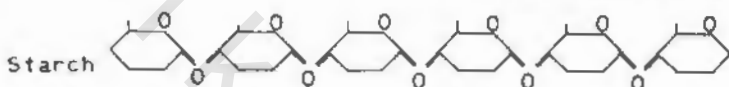
- a) Phospholipids, containing a phosphorus group, such as lecithin, cephalin and sphingomyelin
- b) Glycolipids (cerebrosides), containing a sugar group, such as keraseine and nervone.
- c) Aminolipids (lipoproteins), containing an amino group, such as thromboplastin.



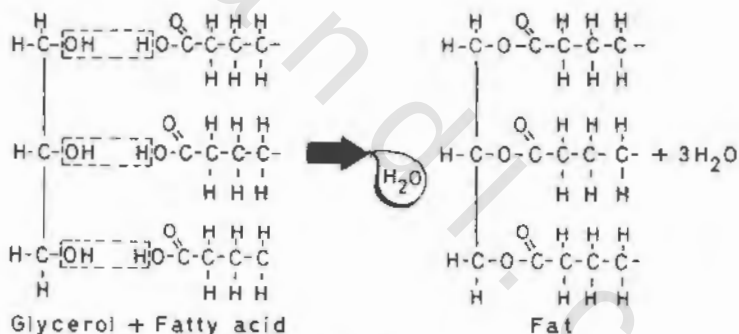
Glucose
(a monosaccharide)



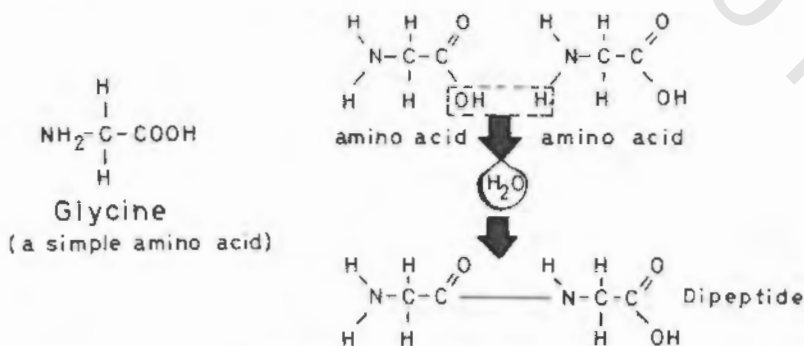
Maltose (a disaccharide)



Synthesis of a polysaccharide



Synthesis of a fat



Synthesis of a dipeptide

C. Derived lipids

These result from hydrolysis of simple and compound lipids, e.g. glycerol, cholesterol, fat-soluble vitamins, and carotene.

Biological significance of lipids

1 — Lipids are the most common storage materials. All cells store some fat, especially those found in adipose connective tissues under the skin, around the heart and kidneys, and along the membranes supporting the intestine. The liver is an important fat depot. It is also capable of manufacturing fats from excess carbohydrates and amino acids.

2 — Lipids are important sources for energy in the body (9.3 calories / gm).

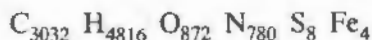
3 — Subcutaneous fats provide an insulating layer that protects the animal from heat loss in cold weather.

4 — Animal fats are the most important sources of some vitamins, such as vitamins A and D. Fats also dissolve certain vitamins, as vitamins A, D, E, K, and thus serve in their absorption.

5 — Lipids enter in the formation of some hormones and several cellular and tissue substances.

III. PROTEINS

Proteins contain nitrogen in addition to carbon, hydrogen and oxygen. Sometimes they may contain sulphur, phosphorus, magnesium, copper, iron and several other elements. A protein molecule is composed of simple units called amino acids. Hundreds or thousands of such amino acid molecules are required to form a single protein molecule, such as that of haemoglobin which has the approximate formula :



An **amino acid** is a simple organic acid with a carboxyl group (COOH) and one or more amino groups (NH_2).

When two amino acids combine, losing one molecule of water, they form a **dipeptide**. The linkage thus formed between the two amino acids is called a **peptide linkage**.

Proteins are classified into :

A. Simple proteins

These are composed of amino acids only, e.g. albumin, globulin, elastin and collagen.

B. Conjugated proteins

These contain amino acid units conjugated with nonprotein groups called **prosthetic groups**. They include :

- a) Phosphoproteins, containing phosphorus groups, such as caseinogen of milk.
- b) Glycoproteins, containing sugar groups, such as heparin.
- c) Chromoproteins, or coloured proteins, such as haemoglobin.
- d) Lipoproteins, containing lipids, such as the lecithoprotein of egg yolk.
- e) Nucleoproteins, associated with animal and plant nucleic acids.

C. Derived proteins

These are derived from the hydrolysis of proteins, e.g. peptones, proteoses, metaproteins and peptides.

Biological significance of proteins

1 — Proteins provide the body with the essential amino acids which cannot be synthesized in the body.

2 — They provide the body with the amino acids necessary to build up new tissues during periods of growth or pregnancy and to provide the milk proteins during lactation.

3 — They enter in the formation of many cellular structures such as cell membranes, mitochondria, chromosomes, etc.

4—Proteins are important in the synthesis of enzymes and some hormones (e.g. hormones of the adenohypophysis, thyroxine and adrenaline). It also combines with vitamin A to form the visual purple.

5—Plasma proteins take part in the regulation of body water.

6—Proteins are also important in the formation of antibodies and in blood coagulation.

7—Proteins constitute a considerable proportion of the haemoglobin and muscle proteins (actin and myosin).

8—Proteins enter in the formation of mucous secretions which facilitate the passage of food and protect the lining of the digestive tract against the effect of various enzymes.

9—Proteins share also in the formation of exoskeletal structures, such as hairs and nails.

10—Proteins may be converted to fats and other compounds, which may be oxidised to provide energy, after the removal of their amino groups (a process known as deamination.)

IV. VITAMINS

Vitamins, also termed "accessory food factors", are special organic compounds which are needed in extremely small quantities in the diet of animals for their well-being and normal functioning. They are not confined to any particular class of organic substances as they may be organic acids, amines, amino acids, esters, etc.

Vitamins regulate the metabolic processes in the cells by acting as co-enzymes. Some vitamins are concerned with the oxidative processes, while others are concerned with the maintenance of the structure of epithelial tissues, cartilage, collagenous tissues and bone.

Animals have to depend on natural sources of vitamins, such as from plants and microorganisms, which can synthesize these substances, because animals are unable to do so. However, not all vitamins are present in our food. Some have to be prepared inside our body, not by the body itself but by certain microorganisms living in the large intestine, e.g. vitamin K₂. Also a vitamin may be taken in the diet in the form of its precursor, or "provitamin". This provitamin is later changed inside the body into the active vitamin, e.g. carotenes are provitamin A.

Some vitamins are characterized by their species specificity i.e. they may serve as vitamins for one species and not as vitamins for another species, e.g. vitamin C is necessary in the diet of man, monkeys, guinea pigs, etc., but dogs, rats and other species are able to synthesize this vitamin.

The condition induced by the absence of a single vitamin from the diet is called **avitaminosis**. If the deficiency is multiple the term **polyavitaminosis** is applied.

Vitamins are named after the letters of the Alphabet or according to the diseases caused by their deficiency. Vitamins are also usually classified into two major groups based on their solubility properties :

Fat-soluble vitamins : which are present in fats of natural food and are soluble in fat-solvents, e.g. vitamins A, D, E, and K.

Water-soluble vitamins : e.g. vitamins C and B complex.

Vitamin A

This is a fat-soluble yellow substance found chiefly in fats and oils especially those of fish livers, egg yolk and in green and yellow vegetables and fruits (carrots, tomatoes, lettuce, apricots, etc.).

Its main functions are :

1 — It is the precursor to visual purple necessary for good vision in dim light.

2 — It prevents dryness of mucous membranes, such as those of the cornea, nose and throat .

3 — It ensures proper growth of nervous tissues, enamel of teeth and bones.

The deficiency of vitamin A causes night blindness, nervous disorders and dryness and roughness of the cornea (a disease known as xerophthalmia) and hence this vitamin is also called antixerophthalmic.

Vitamins of the B complex

These are 12 vitamins designaed as B₁, B₂, etc. All are water-soluble. The most important of this group are :

Vitamin B₁

This vitamin exists mainly in meat, egg yolk, liver and spinach. It is concerned with carbohydrate metabolism.

A deficiency of this vitamin causes beri-beri disease in man and polyneuritis in birds, hence this vitamin is also called antiberi-beri or antineuritic. These diseases are caused by the accumulation of pyruvic acid in the body cells, which results in muscle weakness, decreased digestive secretion, weak peristaltic movements of the alimentary canal and loss of appetite. Beri-beri is prevalent among people who feed mainly on polished rice.

Vitamin B₂

Rich sources of this vitamin are yeast, milk, liver, eggs, heart, leafy vegetables and some fruits as banana and oranges.

It is important for cellular respiration as it acts as a carrier of oxygen. It is also essential for growth.

Its deficiency mainly affects the ectodermal layers, thus causing dermatitis in the face, hands and feet; redness of the tongue; and inflammation in the alimentary canal.

Vitamin B₆

This vitamin is found mainly in meat, liver, grains, yeast, etc. It is important for tissue respiration and amino acid metabolism. Its lack causes nervous disorders and muscular weakness.

Vitamin B₇

This is found in the kidney and liver tissues and in yeast. It enters in the formation of many co-enzymes necessary for cell functions. It is known as the pellagra-preventing factor, as its deficiency causes pellagra shown by roughened skin on the hand, arms, feet, face and neck; diarrhea; nervous disturbances and mental disorders. This disease prevails in maize-eating people because maize does not contain the amino acid tryptophan which is essential for the formation of vitamin B₇.

Vitamin B₁₂

Rich sources of this vitamin are meat, fish, yeast, liver, lactobacilli and *Streptomyces*. It is essential for growth and enters in the formation of red blood cells. Its lack causes pernicious anaemia (hence it is also called pernicious anaemia-preventing factor) and slows growth in young individuals.

Vitamin C

This is a water-soluble vitamin found mainly in citrus fruits, tomatoes, cabbage and some animal organs as the adrenal glands, liver and kidneys.

Most animals can synthesize vitamin C except man and few other animals. It plays a role in some oxidation processes in the body. It is also essential for the healing of injuries, and for the formation of new cells and antibodies. Its deficiency results in scurvy (a disease characterized by bleeding in different places especially under the skin and gums; teeth become loose and fragile) and brittleness of the newly formed bones. Its lack also leads to retardation in the development of fibrous tissues and intercellular material.

Vitamin D

This is a group of fat-soluble vitamins, D₁ to D₅. The most important are D₂ and D₃. Both are produced by the action of sunlight or ultra-violet rays upon certain sterols found under the skin. Sources of these two vitamins are cod liver oil, yolk, milk, liver. Both vitamins facilitate absorption of calcium and phosphorus from the intestine and regulate their levels in the body.

Deficiency of these vitamins causes rickets which is a disturbance in the formation of bones due to a decrease in the Ca and P content in the cartilaginous ends of bones, hence they are also called antirachitic.

Vitamin E

This is a fat-soluble vitamin found in germinating wheat and in green plants as lettuce.

The absence of this vitamin causes reduction in fertility in experimental animals. In females, abortion may occur as a result of this vitamin deficiency, and in males, degeneration of the germinal epithelium occurs (therefore, it

is also called antisterilitic). Vitamin E is necessary for a honey bee to be a queen.

Vitamin K

A fat-soluble vitamin found in green vegetables as spinach, cabbage, soyabean, tomatoes, egg yolk and liver. It is necessary for the formation of prothrombin in the liver cells. Its lack results in haemorrhage due to reduced coagulability of the blood, thus it is also called antihaemorrhagic.

V. INORGANIC SALTS

The mineral constituents of the human body amount to 4.3-4.4 %, particularly found in the skeleton. Many salts are present as ions in the cytoplasm and in extracellular fluids. Their presence is essential for cell function and for operation of the nervous and muscular tissues. Mineral salts are taken in the diet and the deficiency of certain salts sometimes causes disease. As examples :

1 — Lack of **iodine** results in a disease called simple goitre because iodine is required for the synthesis of the hormone thyroxine of the thyroid gland.

2 — Deficiency of traces of **fluorine** in water causes dental caries.

3 — **Iron** is an important element used by the body in the formation of haemoglobin of the blood and in the formation of certain enzymes as cytochromes.

4 — **Calcium** is essential in blood clotting and milk formation, and is an important factor in the excitability of nervous tissues.

5 — **Phosphorus** and **calcium** are necessary for normal bone development.

6 — **Potassium** deficiency in man is associated with weakness and muscular paralysis, while in other mammals, hypertrophy of the heart and kidneys has been noted.

VI. WATER

Water, though partially produced by metabolic processes, must be regarded as a kind of food. Without water, the cell and consequently the whole organism is unable to function since many of the vital processes, such as digestion, respiration, secretion, excretion, etc., must take place in a watery medium. Water also has a great capacity for absorbing heat with a slight change in its temperature; thus it protects the protoplasm against sudden thermal changes.

Animals can withstand hunger for several days, but if water is withheld, death occurs in a short period after the body loses 10-20 % of its water. This water loss leads to a thickening of the blood and stoppage of its circulation. However, if water is available, but no food, life may continue for several weeks, inspite of the loss of all body fats and as much as 50 % of the tissue proteins.

DIGESTION AND DIGESTIVE ENZYMES

Digestion is the means whereby the various items of the diet are broken down into simpler and soluble molecules so that they can be absorbed and assimilated by the animal. The breaking down of such large molecules is done by **hydrolysis**, a process in which water is inserted at the junctions of the initial molecules of the organic food material, thus breaking down their molecules into smaller units. Digestion is carried out by the aid of **digestive** or **hydrolytic enzymes**, which are defined as organic thermolabile colloidal protein substances produced by the living organisms. They act as catalysts accelerating the rate of the reaction without being used up or appearing as one of the reaction products. Digestive or hydrolytic enzymes are classified into :

1 — **Carbohydrases** or **glucosidases** : affect the glucoside linkage of carbohydrates, e.g. amylase.

2 — **Lipases** or **Esterases** : hydrolyse fats into glycerol and fatty acids, e.g. pancreatic lipase.

3 — **Proteolytic enzymes or peptidases** : act on proteins, e.g. pepsin and trypsin.

Factors affecting enzyme action in general

1 — **Specificity of enzymes** : Enzymes are specific in their reaction. Those which act upon carbohydrates are not capable of affecting proteins or fats. It is said that the enzyme must fit its substrate as a key fits its lock, e.g. salivary amylase catalyses the hydrolysis of carbohydrates formed of alpha-glucoside units, such as starch, dextrin and glycogen, but not beta-glucoside units, as cellulose.

2 — **Temperature** : Every enzyme has a temperature, called the optimum temperature, at which its activity is at a maximum. Most enzymes have optimum temperatures ranging between 40-50°C above which destruction of the enzymes takes place.

3 — **Hydrogen ion concentration (pH)** : Enzymes are sensitive to changes in pH and most of them function within a limited pH range. Some enzymes act in acidic media such as pepsin, while others work in alkaline media as trypsin.

4 — **Surface area of the substrate** : Rapid digestion depends to a great extent on good admixture of enzymes and substrate. The presence of fat in emulsified form increases the velocity of its digestion.

5 — **Activators** : Certain ions or substances increase the activity of enzymes, e.g. amylase is activated by halogen ions.

6 — **Inhibitors** : Some substances depress, or even stop, the enzymatic action, e.g. trichloroacetic acid and salts of mercury, lead and silver.

7 — **Kinases** : Some enzymes are secreted in an inactive form (zymogens) and need other substances, known as kinases, to change them into the active form, e.g. enterokinase changes the inactive trypsinogen into active trypsin.

8 — **Co-enzymes** : Some enzymes require the presence of an active group, known as co-enzyme, attached to their molecules, e.g. some members of the vitamin B complex act as co-enzymes.

BUCCAL DIGESTION

Digestion starts in the buccal cavity under the effect of secretions of the salivary glands. These glands are present only in mammals. The **saliva** is a mixed secretion of the salivary glands as well as of small glandules scattered in the mucosa of the mouth. It is a colourless, turbid and viscid slightly alkaline fluid. It consists mainly of water and contains about 0.5% solid material formed of organic and inorganic substances. The organic substances (60%) include mucin, albumin, urea and salivary amylase. The inorganic substances are chiefly chlorides, phosphates and bicarbonates of sodium, potassium and calcium.

The secretion of the saliva is mainly controlled by the autonomic nervous system. This secretion is affected by psychic stimuli brought about by sight, smell, mastication of food, or even by thinking of food.

Functions of the saliva :

- 1 — Saliva moistens and lubricates the food to be easily swallowed.
- 2 — It has some cleaning action on the mouth and teeth.
- 3 — It dissolves solid food stuffs due to its high water content and thus subserves the sense of taste.
- 4 — Certain substances, such as mercury, lead and iodine salts, are excreted from the body through the saliva.
- 5 — It plays a role in regulating the water balance of the body.
- 6 — Bicarbonates, phosphates and proteins in the saliva have an important buffering action, protecting the mouth against acids and alkalies.
- 7 — It contains the enzyme **lysozyme** which has an antibacterial effect, thus destroying some microorganisms entering the mouth.
- 8 — It also contains the enzyme **amylase** which digests carbohydrates composed of alpha-glucose. The digestion of starch by this enzyme proceeds as follows:

Starch → amyloextrins → erythroextrins → achroextrins → dextrins → maltose.

Digestion by the salivary amylase starts in the buccal cavity, but con-

tinues for a longer period in the stomach (20 minutes). The acidity of the stomach is not so high as to stop the activity of the enzyme.

GASTRIC DIGESTION

When food reaches the stomach, the gastric juice is secreted in response of nervous as well as hormonal stimulation. The nervous stimulation is initiated by the taste, smell or sight of food, or even by thinking of food. Upon contact of food with the pyloric mucosa, that mucosa releases a hormone called **gastrin** which is passed into the blood stream, circulates with the blood and when it returns to the wall of the stomach it stimulates the gastric cells to produce their secretions.

Gastric Juice

The gastric secretion is a watery solution containing HCl, pepsin and lipase; suckling mammals have rennin instead of pepsin.

A — Hydrochloric acid

HCl serves the following functions :

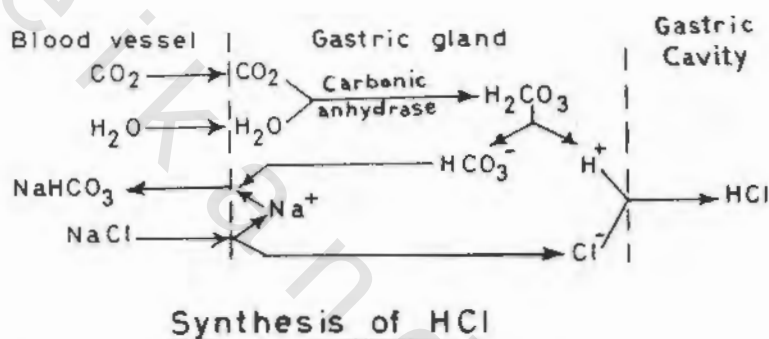
- 1 — It kills the majority of the bacteria taken in with the food, thus preventing putrefaction in the stomach.
- 2 — It converts the inactive pepsinogen into active pepsin and provides a favourable medium for its action.
- 3 — It causes partial hydrolysis of some sugars.
- 4 — It changes proteins into acid metaproteins, a preparatory step necessary for protein digestion.
- 5 — It produces curling of milk in the stomach which helps to keep it exposed for a longer period to the action of pepsin
- 6 — It regulates the evacuation of the stomach by stimulating the pyloric sphincter to relax.
- 7 — When HCl leaves the stomach to the duodenum, it stimulates the mucosa of the latter to release the hormone **secretin**.

HCl is secreted by the gastric gland cells of the mucosa of the stomach in the following manner :

CO_2 combines with water to form carbonic acid (H_2CO_3), which beco-

mes ionized into bicarbonate (HCO_3^-) and hydrogen (H^+) ions. These ions combine with the sodium (Na^+) and chlorine (Cl^-) ions which diffuse from the blood into the gastric cells; the hydrogen ions combine with the chlorine ions to form HCl which is released by the gastric cells into the lumen of the stomach, while the sodium ions combine with the bicarbonate ions to form sodium bicarbonate (NaHCO_3) that diffuses back into the blood stream.

The lack of chloride from food for long periods decreases and even stops the secretion of HCl . Also breathing air rich in CO_2 increases the HCl secretion.



B – Pepsin

This enzyme is first secreted in an inactive form called **pepsinogen**, which is converted by the HCl into the active enzyme pepsin. This enzyme is a proteolytic enzyme which works in an acid medium; its optimum pH is between 1-2. It accelerates the breakdown of proteins into free amino acids. But, during the short period of gastric digestion in the stomach, it usually breaks down proteins only partially into polypeptides (proteoses and peptones).

C – Rennin

This is a proteolytic enzyme which is unique to mammals. It is first secreted in an inactive form known as **prorennin** which is converted by HCl into the active rennin. Rennin changes the protein caseinogen of milk into insoluble calcium caseinate, in presence of calcium ions. Its optimum pH

range is 5-6; thus it acts only in the stomach of young mammals because the medium is far more acidic in older mammals (pH 1-2).

D — Gastric lipase

This is a weak lipolytic enzyme of optimum pH of 5-6, and like rennin, it acts in the stomach of youngs. It hydrolyses emulsified fats into glycerol and fatty acids.

During gastric digestion, the pyloric sphincter muscle remains closed, but as the food becomes progressively more acidic, the sphincter relaxes from time to time to allow some of the semi-fluid contents of the stomach, the **chyme**, to pass into the duodenum.

INTESTINAL DIGESTION

Digestion in the intestine is achieved by the aid of the bile, pancreatic juice, and intestinal juice. These secretions are stimulated by the nervous system and by certain hormones which are liberated from the duodenal mucosa. These hormones are :

1 — **Enterogastrone** : Is secreted by the cells of the duodenal mucosa when food, especially fats, enters the duodenum. When this hormone reaches the stomach, it inhibits the secretion of the gastric glands.

2 — **Pancreozymin** : Stimulates the pancreas to secrete the pancreatic enzymes.

3 — **Secretin** : Stimulates the secretion of bile and the alkaline fluid of the pancreas.

4 — **Cholecystokinin** : Is produced by the action of the dietary fat, and causes the discharge of bile from the gall-bladder.

5 — **Duorokrinin and Enterokrinin** : Are secreted as a response to presence of the acidic chyme and stimulate the secretion of the succus entericus or intestinal juice by the intestinal glands.

Bile

This is an alkaline viscous fluid, which is secreted by the liver cells and passed down along the bile canalicules to the gall-bladder, where bile is stored and concentrated.

Bile consists of **bile pigments** and **bile salts**. The pigments are breakdown products of the blood haemoglobin. They are **biliverdin** (green) and **bilirubin** (red). The bile salts are **glycocholate** and **taurocholate** of sodium and potassium. These reduce the surface tension of fluids, thus serving in emulsifying fats. Bile therefore aids in the absorption of fats and fat-soluble vitamins, and prevents the action of putrefactive bacteria in the intestine. Moreover, bile stimulates the peristaltic movements of the gut. A certain amount of bicarbonates is released with the bile giving it a pH of 8.

Pancreatic juice

This is a watery alkaline secretion (98.5 % water) containing inorganic ions (mainly sodium bicarbonate) and organic substances, including the following enzymes :

A – Pancreatic amylase

Hydrolysis of sugars which starts in the buccal cavity is completed by this enzyme which breaks down starch into maltose as follows :

Higher dextrins → erythrodextrins → achrodextrins → dextrins → maltose.

B – Trypsin and Chymotrypsin

These are secreted in the inactive forms **trypsinogen** and **chymotrypsinogen** respectively. Trypsinogen is activated by the enterokinase of the duodenum, while chymotrypsinogen is activated by trypsin. Both are proteolytic enzymes which act in alkaline medium, hydrolysing partially digested proteins (coming from the stomach) and whole protein molecules (not hydrolysed by pepsin) into di- and polypeptides.

C – Carboxypeptidase

This catalyses the transformation of proteoses and peptones (polypeptides) into dipeptides.

D – Pancreatic lipase

This is an esterase or fat-splitting enzyme which hydrolyses the ester linkage between glycerol and fatty acids. It is activated by the bile salts, and its optimum pH is around 7.

Intestinal juice

This is a watery (98.5 % water) and slightly alkaline fluid. It contains the following enzymes which work at an optimum pH of 8.3 .

A – Disaccharidases

These hydrolyse disaccharides into monosaccharides, thus ending the process of digestion of carbohydrates. They include : a) **Maltase**, which splits maltose (malt sugar) into 2 molecules of glucose; b) **Sucrase**, which acts on sucrose (cane sugar) converting it into glucose and fructose; and c) **Lactase**, which converts lactose (milk sugar) into glucose and galactose.

B – Erepsin

This is a complex of proteolytic enzymes including **carboxypeptidase**, **aminopeptidase** and **dipeptidase**, which hydrolyse polypeptides and dipeptides of different structures into free amino acids, thus bringing digestion of proteins to an end.

C – Intestinal lipase

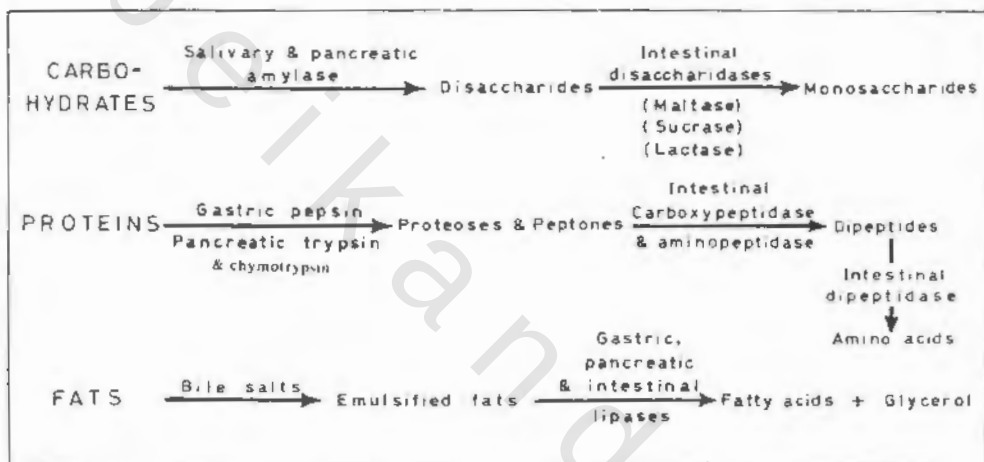
This is an esterase which hydrolyses fats into glycerol and fatty acids. The action of this enzyme represents the last step in fat digestion.

DIGESTION IN LARGE INTESTINE

In carnivorous animals, the large intestine is short and relatively less important in digestion than in herbivorous animals where it is long and plays a vital role in digestion of cellulose by the rich bacterial flora found in its lumen. Bacteria are capable of breaking down cellulose into its simple components which are easily absorbed by the large intestine. Also, bacteria are

able to synthesize amino acids from carbohydrates and nonprotein nitrogen and to incorporate them in their own protoplasm.

At the end of the journey of food along the alimentary canal, **faeces**, which consists of a semi-solid mass containing unmacerrated plant tissue, pieces of cellulose and other undigested food remains together with small amounts of water, is **egested** or passed out of the body at intervals through the anal opening.



Digestion of carbohydrates, proteins and fats

ABSORPTION

Absorption is the passage of digested food, water, salts and vitamins through the intestinal mucosa into the blood or lymph. No absorption takes place in the mouth except for some drugs, e.g. morphine and steroid hormones. Absorption takes place mainly in the small intestine. The mucosal lining of the small intestine is greatly increased by the numerous inner foldings or **villi**, which are finger-like processes; covered with columnar epithelium. Each villus is traversed by a **lacteal vessel** and a number of **venous** and **arterial blood capillaries**.

Absorption is not entirely a physical process which can be explained on the basis of the physical laws of diffusion, filtration and osmosis alone, but

is also an active process in which the selectivity of the cell membrane plays a major role. This property controls the passage of materials at different rates according to the cellular needs and activities.

Carbohydrates, or monosaccharides in general, are absorbed after a process of phosphorylation in which the hexose is linked up with a phosphate group by the aid of the coenzyme **adenosine triphosphate** (ATP) to form glucose 6-phosphate. The latter diffuses across the mucosal cells, where dephosphorylation takes place by the enzyme **phosphatase**, thus glucose is liberated and passed into the blood stream.

Proteins, in the form of amino acids, are actively absorbed by the mucosal cells of the small intestine and passed into the blood stream. However, some proteins are absorbed as dipeptides, which become then hydrolysed into amino acids in the mucosal cells.

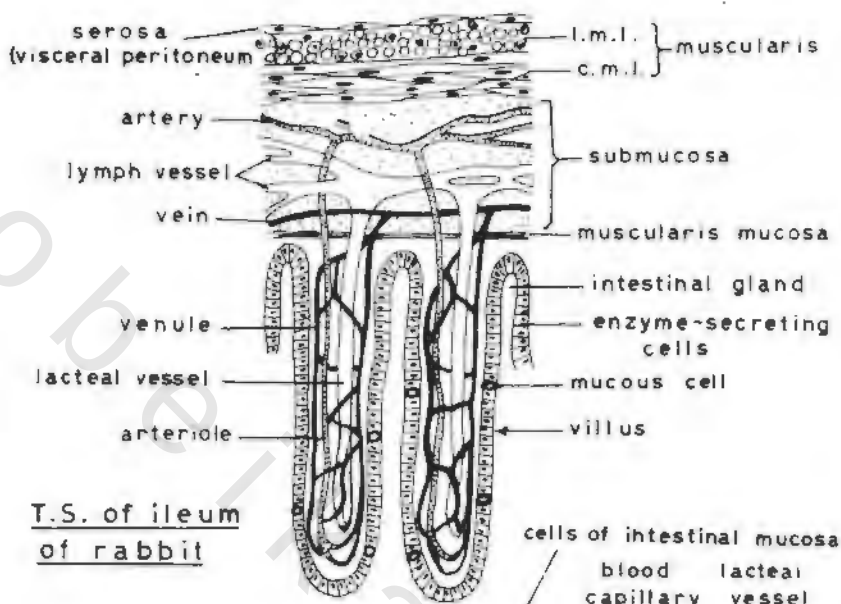
Fats are absorbed in different forms. Some digested fats or lipids, in the form of fatty acids and glycerol, are absorbed directly by the mucosal cells and passed as such into the blood capillaries. In other cases fatty acids and glycerol recombine in the mucosal cells to form some neutral fats, which then diffuse into the lacteal vessel or lymphatic capillaries. In addition, some neutral fats may be absorbed by the mucosa in a very finely emulsified form, without being previously digested into fatty acids and glycerol.

Water and mineral salts are also actively absorbed by the mucosal lining. However, some substances, such as magnesium sulphate, are not easily absorbed in spite of the small sizes of their molecules.

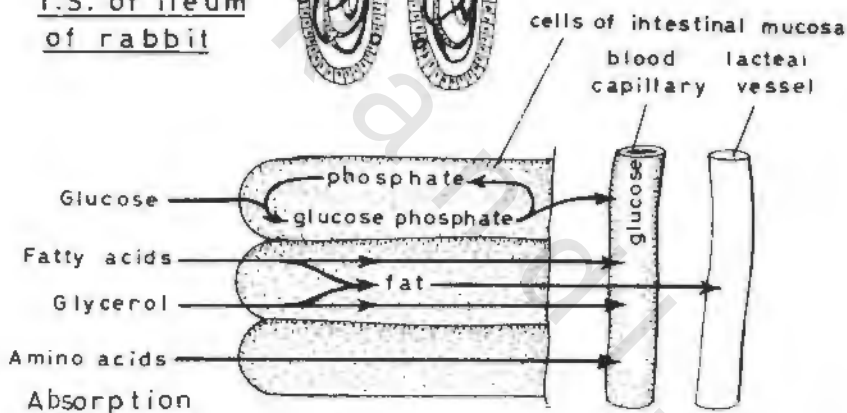
Following absorption, food is carried via the hepatic portal vein to the liver, before it is passed into the general blood circulation.

METABOLISM

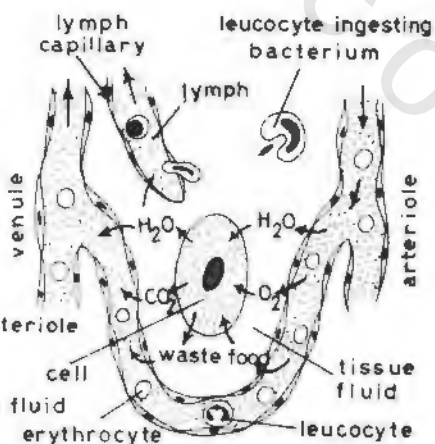
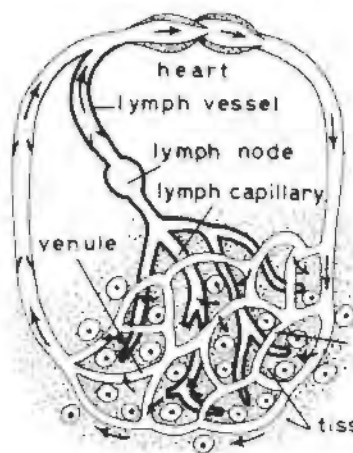
Metabolism comprises all the chemical changes which take place in the absorbed food within the body cells, including the building up of various materials (**anabolism**) and the breaking down of materials for the release of energy (**catabolism**).



T.S. of ileum of rabbit



Absorption



Carbohydrate Metabolism

Carbohydrates are mainly utilised to provide energy needed for other metabolic processes. They are absorbed as glucose, fructose or galactose; the latter two are converted into glucose in the liver. Carbohydrates are stored mainly in the liver and to a smaller extent in the body muscles in the form of glycogen. The blood glucose level is kept almost constant under normal conditions (80 - 100 mg/100ml). This level is regulated through uptake and release of glucose by the liver and extrahepatic tissues to or from the blood stream. This depends upon the level of the blood glucose as well as the level of some hormones such as **Insulin** from beta-cells and **glucagon** from alpha-cells of the islets of Langerhans of the pancreas, adrenaline from the adrenal gland and the adenohipophysial hormones from the pituitary gland.

The metabolic routes of the carbohydrate metabolism can be summarised as follows:

1 — Glycogenesis: This is the synthesis of glycogen from glucose.

2 — Glycogenolysis: This is the breakdown of glycogen to produce glucose in the liver and pyruvate and lactate in the muscles.

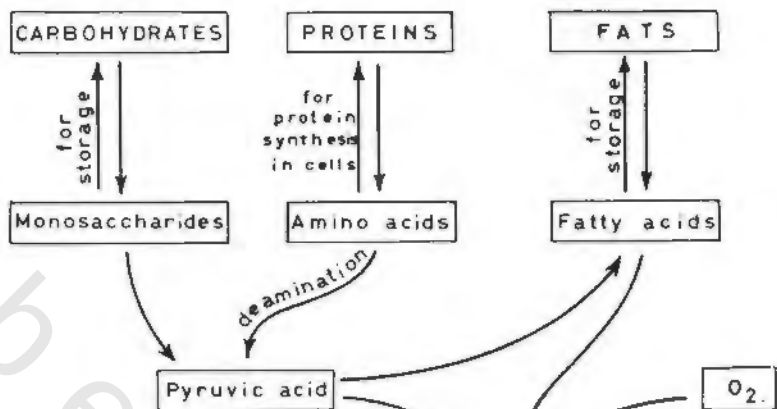
3 — Glycolysis: In this route glucose or glycogen are oxidised to glucose 6- phosphate then to pyruvate or lactate. Pyruvate is then transferred into acetyl- A or active acetate.

4- Citric Acid Cycle: (Kerb's Cycle or Tricarboxylic Acid Cycle): This is the final common pathway of the oxidation of carbohydrates, lipids and proteins through which Acetyl coenzyme-A is oxidised to CO_2 and H_2O with the liberation of energy.

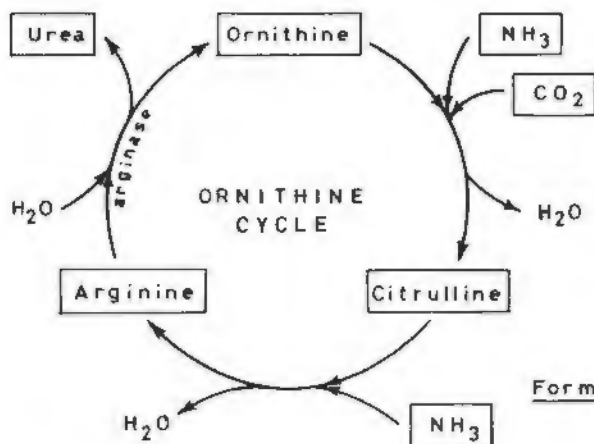
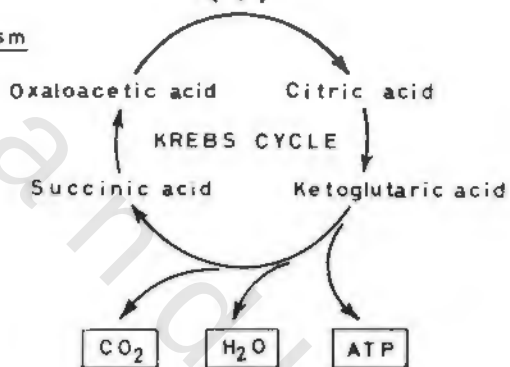
5 — Gluconeogenesis: This is the formation of glucose or glycogen from non-carbohydrate sources, such as amino acids, lactate and glycerol.

Lipid Metabolism

Lipids absorbed in the form of fatty acids and glycerol are either stored in the form of triglycerides (neutral fats) in adipose connective tissues or oxidised to yield energy. Lipids constitute a richer source of energy if compared to carbohydrates. The oxidation



Pathways in metabolism of carbohydrates, proteins & fats



Formation of urea

of 1gm of fats yields 9.3 Calories whereas the same amount of carbohydrates yields 4.2 Calories.

Triglycerides stored in connective tissues must be hydrolysed to fatty acids and glycerol before further catabolism can proceed. Thus, these glycerides are continuously undergoing both hydrolysis and re-esterification.

Free fatty acids released into the blood plasma are taken by most tissues, including both the liver and muscles and oxidised by beta-oxidation to form Acetyl coenzyme-A which enters the Citric acid Cycle for final oxidation into CO_2 and H_2O , with the liberation of energy.

The liver produce small amounts of acetoacetate and beta-hydroxybutyrate and acetone. Liver tissues cannot utilise these ketone bodies which pass to the blood stream. The normal level of these ketone bodies does not exceed 1mg/ 100ml. Amount less than 1mg/24 hours are normally lost through urine and the rest are taken by the extrahepatic tissues and activated into Acetoacetyl coenzyme-A which is split into Acetyl coenzyme-A that enters the Citric acid Cycle for final oxidation.

Under certain metabolic conditions associated with high rate of fatty acid oxidation, the level of the ketone bodies increase significantly in the blood. (a condition known as **Ketonemia**) and urine (**Ketonuria**). The extrahepatic tissues cannot utilise these considerable amount of ketone bodies producing a condition known as **Ketosis**.

Glycerol which is normally absorbed with fatty acids can be transferred into the liver (but not the muscle tissues) into glucose or glycogen using the enzyme **glycerokinase** which is found in the liver and not the muscles.

Protein and Amino Acid Metabolism

Proteins are primarily tissue-building foods while both carbohydrates and fats are energy-supplying foods. Proteins are absorbed in the form of amino acids which undergo certain anabolic and catabolic processes in the tissues of the animal body.

Amino acids are involved in the anabolism or synthesis of blood and tissue proteins, proteins of hormones, enzymes and antibodies.

In anabolism, large numbers of amino acids unite together by peptide bonds to form polypeptides and proteins. On the other hand, excess amino acids undergo one or more of the following processes:

1— Transamination: This is a reversible reaction which involves the transfer of the amino group (NH_2) from an amino acid to a keto acid produced during carbohydrate metabolism. Thus, an amino acid is produced from a keto acid and in this way some amino acids can be synthesised inside the animal body. Such amino acids are often referred to as **non-essential amino acids**. On the other hand, certain amino acids cannot be synthesised in the animal body and accordingly they must be taken ready made in the animal diet. These amino acids are called **essential amino acids**.

2— Deamination: This process involves the removal of the amino group (NH_2) from the amino acid producing a molecule of ammonia and a ketoacid.

3— Some amino acids produce ketoacids similar to those produced during lipid catabolism and these are called **ketogenic amino acids**. Some other amino acids produce ketoacids similar to those produced during carbohydrate catabolism and these are called **glycogenic amino acids**. Some other amino acids are both ketogenic and glycogenic, since they produce ketoacids similar to those produced during the catabolism of both lipids and carbohydrates. The resulting ketoacids may be oxidised through the Citric acid Cycle or transferred into glucose or fat.

The ammonia produced after deamination is a toxic substance which is removed from the animal body by one of the following mechanisms:

- a. Excretion in the form of ammonium salts in the urine.
- b. It combines with CO_2 to form urea. This reaction takes place in the liver and the produced urea is excreted by the kidneys in the urine.

Functions of the liver

1 — The liver participates in carbohydrate metabolism by synthesizing and storing glycogen.

2 — It also controls the amount of glucose passing into the blood stream by breaking down glycogen into glucose (glycogenolysis), or by changing glucose into glycogen (glycogenesis).

3 — It also plays an important role in protein anabolism by synthesizing some essential proteins, such as fibrinogen, prothrombin and other plasma proteins, and in protein catabolism including urea formation.

4 — It also participates in fat metabolism by oxidizing fatty acids, and transforming some carbohydrates into fats and fat soluble vitamins.

5 — It secretes bile which participates in the digestion and absorption of fats and fat-soluble vitamins.

6 — It is an important site of detoxication. Some toxic substances, such as indole, are formed in the large intestine through the putrefaction of proteins. These substances are transformed in the liver into nontoxic substances which are eliminated from the body in the urine.

7 — It stores the iron resulting from the breakdown of exhausted red blood cells in the form of ferritin.

8 — It acts as a haemopoietic organ (blood forming) in embryonic stages.

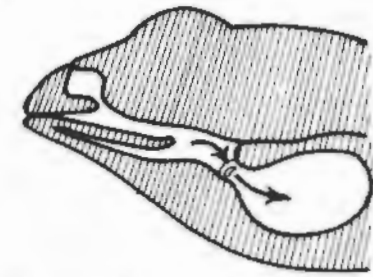
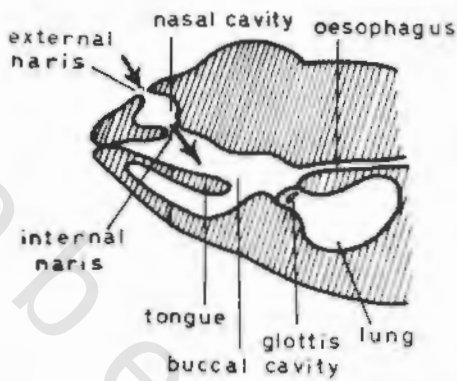
RESPIRATION

Oxygen is needed for the oxidation of food stuffs and the release of energy, and therefore must be provided to all parts of the body. Carbon dioxide, a waste product resulting from the oxidation of foods, must be eliminated from the organism. This important function of gaseous exchange between the body and the surrounding environment is carried out by the respiratory system.

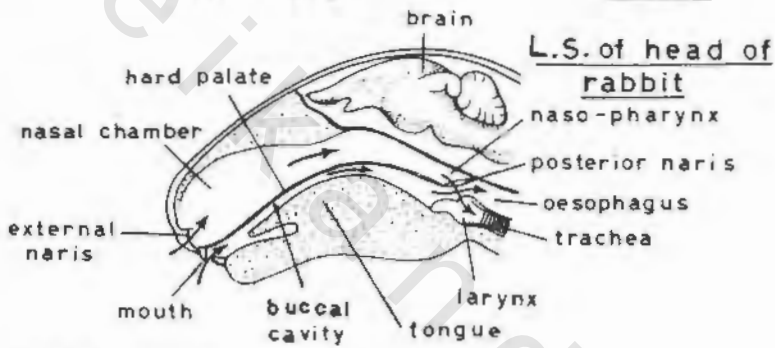
In higher animals, the cells of different tissues are not in direct contact with atmospheric oxygen, therefore the process of respiration necessitates the presence of the following :

1 — An **oxygen supply** from atmospheric air or oxygen dissolved in water.

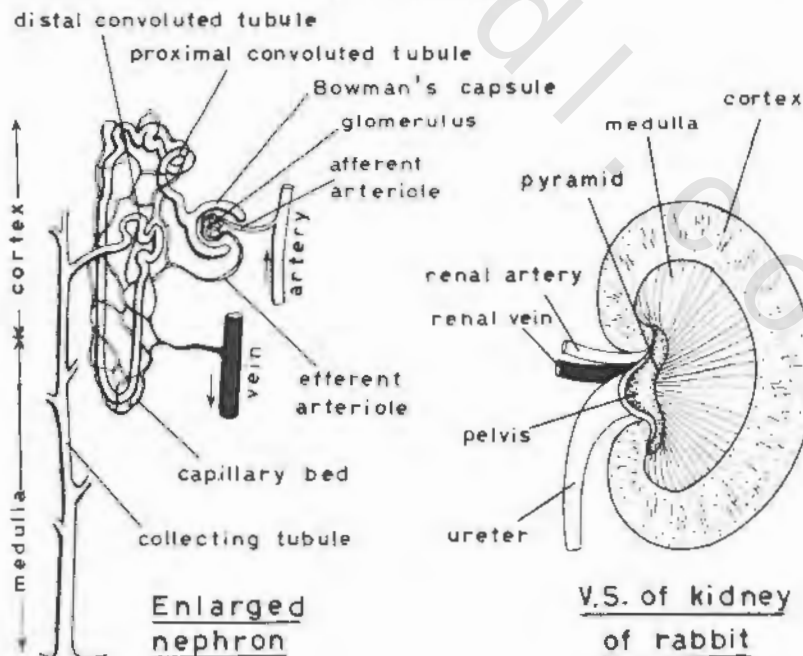
2 — A **respiratory surface** on which exchange of gases occurs.



Respiratory movements
in toad



L.S. of head of
rabbit



Enlarged
nephron

V.S. of kidney
of rabbit

3 — A **respiratory pigment**, as haemoglobin, which is a compound protein formed of a protein part (globin) and a nonprotein part (haem). At the respiratory surface, haemoglobin unites with oxygen forming **oxyhaemoglobin** which is an unstable compound that is transported by the blood from the respiratory organs to the body tissues where it dissociates to release oxygen.

4 — A **transporting medium** as blood and lymph, for the transportation of gases to and from the tissues. In addition to the transport of oxygen, carbon dioxide from the tissues combines with sodium and potassium in the blood plasma forming sodium and potassium bicarbonates, which are transported to the respiratory organs where CO_2 is discharged to the outside. Moreover, a small amount of CO_2 combines with haemoglobin and is thus carried to the lungs where it is liberated.

Gaseous exchange occurs according to the laws of diffusion, i.e. the gas passes through membranes from one medium where it has a higher partial pressure to another in which the same gas has a lower partial pressure.

In higher animals, respiration takes place on 3 steps :

a) **External respiration**, in which exchange of oxygen and carbon dioxide takes place between air or water and the blood.

b) **Internal respiration**, in which exchange of gases takes place between the blood and the tissues.

c) **Cellular respiration**, which occurs within the cells and involves the oxidation of food stuffs to liberate energy through a complicated series of chemical reactions that take place with the aid of some respiratory enzymes present in the cell protoplasm, such as the **cytochromes** and **dehydrogenases**.

Control of Respiration

Respiration is controlled and respiratory movements are co-ordinated by a nerve centre located in the medulla oblongata, on the floor of the 4th ventricle. This centre is differentiated into **inspiratory** and **expiratory centres**. A third centre, called the **pneumotaxic centre**, found in the upper part of the pons Varolii, controls the activity of those two centres lying below it so as to maintain normal respiratory movements. It stimulates the expiratory centre during inspiration, thus ensuring rhythmic alternation of inspiration and expiration. This centre is also responsible for

changing the depth and rate of the respiratory movements according to the requirements of the organism.

External environmental factors, such as the composition and pressure of atmospheric air, the prevailing temperature, the physical activities of the organism, etc. influence the intensity of metabolism and consequently the absorption of O_2 and elimination of CO_2 . The volume of pulmonary ventilation is changed as a result, and respiration is automatically regulated by that centre on the feedback principle, i.e. if CO_2 accumulates in the blood, more inspiration is stimulated.

Respiratory Quotient (R.Q.)

R.Q. is the ratio of the amount of CO_2 expired to the amount of O_2 absorbed from the inspired air. This ratio depends on the kind of food being oxidized. It is 1.0 in case of carbohydrates, 0.79 for proteins, and 0.71 for fats.

When the proportions of the food stuffs being burnt in the body are known, it is possible to determine the respiratory quotient of the individual. If the total oxygen utilized by the individual is also measured, it is possible to calculate his caloric output since it is known that each litre of oxygen consumed is equivalent to 4.686-5.047 Calories, depending on the R.Q. of the person.

Basal metabolic rate (B.M.R.)

This is the rate at which oxygen (and accordingly the energy produced) is used when the animal is at complete physical and mental rest.

B.M.R. values vary according to sex (being higher in males than in females), age (youths have higher values than adults), race, weight, environmental temperatures, etc. During disease, the B.M.R. may become abnormally low or high, e.g. diminished thyroid secretion results in decreased B.M.R., while excessive thyroid secretion results in high B.M.R. values.

CIRCULATION

The circulatory system includes the **heart** and an extensive network of tubular **blood** and **lymphatic vessels** through which blood and lymph respectively circulate.

BLOOD

Blood is composed of plasma, erythrocytes, leucocytes and platelets (page 184).

The functions of the blood are summarized on page 188.

HEART

The heart is the central pumping organ in the circulatory system of the vertebrate body. It consists of a number of chambers with muscular walls (for the structure of the heart in the toad see page 457 and for that of rabbit see page 499).

Heart beat

The work of the heart consists of rhythmic contractions and relaxations of the muscle fibres of the walls of the auricles and ventricles. The contraction of the heart is known as **systole**, and its relaxation is known as **diastole**. Normally the systole and diastole occur alternatively in a regular pattern and constitute the **cardiac cycle**, i.e. the complete sequence of events during one complete heart beat.

During each cardiac cycle two chief sounds can be heard by the aid of a **stethoscope** in man. The first, called **systolic sound**, is due to the contraction of the ventricular muscles and the closure of the auriculo-ventricular valves. The second sound, called **diastolic sound**, is due to the closure of the semilunar valves during the ventricular diastole.

Two theories were put forward to explain the mechanism of heart contractions :

1 — **The myogenic theory**, attributes these contractions to muscular activity only.

2 — **The neurogenic theory**, regards these contractions as being due to nervous effect, i.e. an effect exerted by certain nerve ganglia scattered in the wall of the heart.

However, it is now believed that the heart beats in vertebrate animals are myogenic in nature, for the following reasons :

a) When the nerve ganglia are removed from the heart, it still rhythmically contracts.

b) The heart of a frog removed from its body continues to contract rhythmically for some time.

c) Isolated cardiac muscles cultured outside the body show rhythmic contractions.

d) The heart of birds begins to contract on the second day of incubation, before the appearance of the nerve cells.

However, the nerves connected to the heart play an important role in the regulation of heart beats, e.g. the vagus nerve inhibits heart beating, while the sympathetic nerve accelerates it. Some hormones, as adrenaline, also affect heart beating.

In the toad, the sinus venosus is the **originator** or **pace-maker** of the heart beat. In mammals, the rhythm originates in a special region of the right auricle known as the **sinu-auricular node**. When the pace-maker is stimulated, a wave of contraction spreads out to every part of the heart by a special conduction system called the **Purkinje system**. This system consists of bundles of modified heart muscle specialized for impulse conduction. During contraction, the heart muscles obey the "All or None Law", i.e. if the heart muscle contracts, it does so to its maximum. The **refractory period**, or period of noncontractility, is relatively long. This prevents overworking of the heart muscles.

Circulation in the blood vessels

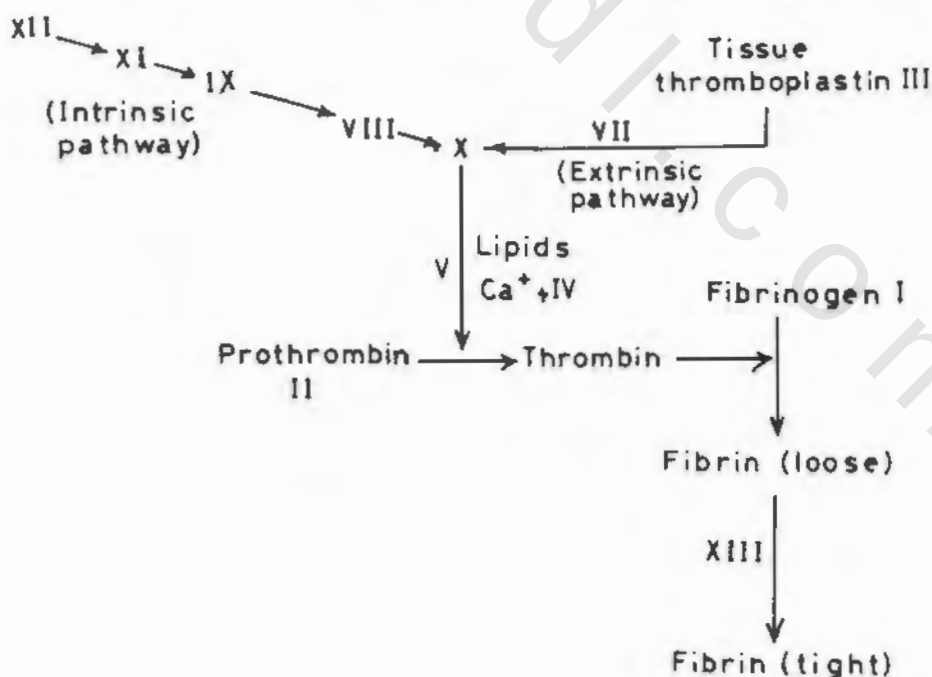
The movement of the blood through the blood vessels is due to the rhythmic beats of the heart. During contraction, the heart drives the blood under pressure into the arteries. The blood pressure is highest at the beginning of the circuit then drops gradually, reaching its lowest level at the end of the circuit, e.g. in man, the blood pressure in the aorta is 150 mm Hg, in median arteries it is about 120 mm Hg, in arterioles it is 40 mm Hg., and in capillaries it is 20 mm Hg. In veins it is still lower. This difference in blood pressure between the different parts of the vascular system is the direct cause of circulation. The blood moves from the point of higher pressure to the point

of lower pressure. The contraction of muscle fibres in the walls of arteries helps in propelling the blood into the arteries and capillaries.

Besides the work of the heart, two factors promote the return of venous blood to the heart; respiration and skeletal muscle contractions. In the process of breathing, the thoracic cavity widens and consequently the pressure inside it decreases than that in the abdominal cavity. Therefore, blood moves from the abdominal veins towards the thoracic ones. This movement is also aided by the contraction of muscles because these compress the veins and drive the blood they contain in the direction of the heart. The venous blood is prevented from flowing back by valves which open only in the direction of the blood flow. The presence of the valves is particularly important in the veins of the lower limbs of man where blood has to flow upwards.

Blood Clotting

This is a vital process which prevents the loss of blood as it escapes from the blood vessels when a wound or cut occurs. The fundamental reaction in the clotting of blood is the conversion of the soluble plasma protein **fibrinogen** into the nonsoluble **fibrin**. This conversion is catalysed by **thrombin** (an enzyme synthesized in the liver) and it involves a complex series of reactions in which several



factors known as **blood clotting factors** are involved. The blood clotting factors are usually indicated by certain English names or a series of **Roman Numbers (I, II, III, IV, and XIII)**.

The mechanism of blood clotting can be summarised as follows:

The **thrombin** that catalyses the conversion of fibrinogen to **fibrin** is formed from its inactive precursor **prothrombin** under the influence of the active Factor X. Factor V, lipids and calcium ions (Factor IV). The active Factor X is activated from its inactive precursor through two main pathways:

a- **Intrinsic Pathway:** This involves the interaction of activated Factors XII, XI, IX and VIII and is initiated when blood is exposed to the collagen fibres underlying the endothelium of the broken blood vessels.

b- **Extrinsic Pathway:** This involves tissue **thromboplastin** which is a protein-lipid complex released from damaged blood vessels, platelets and other tissues as well as Factor VII.

Fibrin is first formed in a loose form, then under the influence of Factor XII it changes into tight dense aggregates.

Anticoagulants

There are several ways by which blood can be prevented from clotting, as by :

1 — Collecting blood in containers coated with a thin layer of paraffin wax or paraffin oil to avoid injury of the blood platelets.

2 — Cooling blood rapidly to 0 °C.

3 — Addition of oxalates, citrates or fluorides to rob the blood from the calcium ions necessary for clotting.

4 — Heparin, which is a polysaccharide produced by the liver and other organs, acts as a powerful anticoagulant by preventing the change of prothrombin into thrombin. The presence of heparin in the blood prevents blood clotting inside the normal healthy blood vessels. Only when a wound occurs and sufficient blood platelets are broken that the effect of heparin is overcome and blood clots.

Immunity

Immunity can be defined as the ability of a living organism to resist invasion by harmful microorganisms or other foreign material.

Blood plays an essential role in immunity. Certain types of leucocytes in the blood and in other tissues can ingest and destroy microorganisms and foreign material. Moreover, the blood plasma contains **antibodies** which are formed by certain body cells against any foreign proteins or other materials associated with proteins. Any such protein materials that stimulate the tissues of the body to form antibodies are called **antigens**.

Some antibodies precipitate the foreign proteins and are thus called **precipitins**. Others cause microorganisms or red blood corpuscles to clump together and are called **agglutinins**, and some neutralize toxins and are thus termed **antitoxins**.

Immunity may be natural or acquired. An animal that resists invasion by certain microorganisms for the first time, i.e. without being previously in contact with it, is considered to have **natural or innate immunity**. But, immunity resulting from a previous exposure to microorganisms is called **acquired immunity**. Children recovering from infections with the measles virus and remaining capable of resisting a second infection with that particular virus are described as having acquired immunity to measles.

Acquired immunity may be natural or artificial. The above example of immunity developing after measles infection in children is **natural acquired immunity**, whereas immunity developing in a child after vaccination with diphtheria or typhoid vaccines is described as **artificial acquired immunity**.

Haemorrhage and Blood transfusion

Continuous haemorrhage may lead to death of the individual. If the amount of blood lost is less than 30%, the body can restore the lost blood during few weeks without any external aid. This is explained by the fact that the bone marrow becomes much activated in such cases, and produces much more blood cells than normal. At the same time, the tissues of the body supply that blood with the water necessary for the production of the plasma, and the kidneys excrete much more concentrated urine to save some water for that blood too.

If the amount of blood lost from the body exceeds 30% of the total amount, blood transfusion must be carried out to the individual after his blood group has been identified.

Blood groups

Before blood transfusion is carried out, the blood of the recipient must be first examined and its type identified, otherwise this process may have serious consequences. Certain substances are found in the blood, two of which are found in the red blood corpuscles and are known as the **antigens**, and two others exist in the plasma and are known as the **antibodies**. Antigens are denoted by the two capital letters **A** and **B**, and the antibodies are denoted by the small letters **a** and **b**. The blood of any human being belongs to one or another of the following four main blood groups. These are:

Group A : contains the antigen A, and the antibody b.

Group B : contains the antigen B, and the antibody a.

Group AB : contains the antigens A and B, but no antibodies.

Group O : does not contain antigens, but contains the antibodies a and b, as shown in the following table :

Blood group	Antigens in red cell	Antibodies in serum
A	A	b
B	B	a
AB	A and B	None
O	None	a and b

When blood containing the antigen A is mixed with or transferred to blood containing the antibody a, a process known as **blood agglutination** takes place. The blood corpuscles adhere together, then break down, and the kidneys are unable to get rid of them. Blood agglutination also takes place when blood containing the antigen B is mixed with or transferred to blood containing the antibody b.

On the other hand, no agglutination occurs when blood containing the antigen A is mixed with blood containing the antibody b, or with blood containing no antibodies such as that of group AB. Similarly, no agglutination happens when blood from group B is mixed with blood which is also of group B, or of group AB, where the former contains the antibody a, and the latter contains no antibodies. The following table summarises the results expected from mixing blood of one group with that of the other groups :

Donor	Receipient			
	A	B	AB	O
	Antibody (b)	(a)	(o)	(ab)
A	—	+	—	+
B	+	—	—	+
AB	+	+	—	+
O	—	—	—	—

+ agglutination.

— No agglutination

It is clear that blood from group O can be transferred safely to any individual with blood of the same group (O), or of any other group. Accordingly, group O is known as the **universal donor**. Also, a person belonging to group AB can receive blood from the same group (AB) or any other group. Thus, group AB is known as the **universal recipient**.

Worthy of notice is that although agglutination occurs when blood containing antigens A or B is transferred to blood containing the antibodies a or b respectively, the reverse does not usually produce agglutination. In other words, blood from a donor containing antibodies a or b does not produce agglutination when transferred to a recipient with blood containing antigens A or B respectively. This is because the amount of blood transferred is small compared to that found in the recipient's body, and since it becomes further diluted in the recipient's body, no effect is produced.

It has been recently discovered that some individuals have a distinct variant of A- antigen called A_2 to distinguish it from A-proper which is better named A_1 . Therefore, six ABO groups are now known instead of the usual four groups known before. These groups include: A_1 , A_2 , B, $A_1 B$, $A_2 B$ and O.

Rhesus (Rh) factor

It was noticed that agglutination may take place during blood transfusion in spite of the fact that the blood groups of the discovered recipient have been identified and considered. This was discovered to be due to the presence of a certain antigen which was observed for the first time in monkeys of the genus *Rhesus* and has been referred to as **Rhesus** or **Rh factor**. Blood

containing this antigen or factor is denoted by Rh^+ , whereas that lacking this factor is denoted by Rh^- . When blood from an Rh^+ person is transfused to an Rh^- one, this will induce the blood of the recipient to produce certain antibodies called **anti-RH agglutinins**. This is not dangerous when it happens for the first time because the antibodies produced are relatively few. But with a second transfusion of Rh^+ blood to the same recipient, blood agglutination occurs as a result of the interaction between the RH agglutinogens and the anti-RH agglutinins.

LYMPH

The lymph (p. 101) is the medium across which continuous exchange of materials between the blood and the tissue cells is maintained. Lymph is produced mainly as a result of the filtration of the tissue fluid through the capillary walls. The lymph draining from the blood capillaries of different organs and tissues varies in composition, e.g. lymph draining from the liver contains more proteins than that from the limbs.

Circulation of lymph

Circulation of lymph in the body is maintained by :

- 1 — The rhythmical contractions of the walls of certain lymphatic vessels.
- 2 — Some lower vertebrates, e.g. toads, have lymph hearts which act as pumps causing the movement of lymph.
- 3 — The decrease in pressure within the chest and the increase in the volume of the thoracic cavity during inspiration lead to the dilation of the thoracic lymphatic ducts and the flow of lymph into them.
- 4 — Movement of the limbs during work or walk.

The presence of valves in the lymphatics makes the lymph flow in one direction.

EXCRETION

Excretion is the process by which waste products of metabolism are removed from the body. This term is not generally applied to the voiding of material which enters the body and passes out unchanged: thus the nitrogen which leaves the lungs and the undigested cellulose expelled in the faeces

are not regarded as excretory products. Some wastes are disposed through the skin and the lungs; others are discharged from the liver in the bile, and some are expelled from the intestine with the faeces. However, the principal excretory organs in vertebrates are the kidneys (for their structure see pages 467 and 510) which eliminate water, nitrogenous substance and inorganic substances, all collectively known as urine.

Urine formation

Urine formation is accomplished by 3 processes, namely glomerular filtration, tubular reabsorption and tubular secretion.

Glomerular filtration : Ultrafiltration (filtration under blood pressure) takes place from the blood in the glomeruli out into the Bowman's capsules. Water and solutes are filtered off the glomeruli faster than the ordinary capillaries because of two structural features :

- a) The glomeruli have more pores than other capillaries.
- b) The efferent arteriole leaving the glomerulus is smaller in diameter than the afferent arteriole, thus offering higher resistance to the blood flowing out of the glomeruli than out of other capillaries. Consequently there is a higher blood pressure in the glomeruli.

Tubular reabsorption: During the passage of the blood filtrate, which is called primary urine, through the uriniferous tubule, a process of selective re-absorption occurs. Thus about 90-99% of water, all useful substances such as glucose, and various amounts of salts are returned to the blood against the concentration gradient by an active process which uses large quantities of energy. The loop of Henle found in the kidneys of birds and mammals only plays an important physiological role in this process.

Tubular secretion: During the passage of the primary urine along the kidney tubules, certain substances, such as ammonia and some drugs, are secreted by the cells of these tubules and added to the urine.

The components of the primary urine may be differentiated into two types:

- a) **Threshold substances**, which, under normal conditions, are reabsorbed completely from the urine by the kidney tubules. These are useful substances

which pass out with the excreted urine only when their concentration rises above a certain level in the blood (threshold value). Examples are glucose and amino acids.

b) Non-threshold substances, are useless substances or are waste products which are passed out even when present in low amounts in the blood. Such substances are not re-absorbed at all in the tubules, e.g. urea, creatinine and sulphates.

The amount of urine secreted is regulated chiefly by the **antidiuretic hormone (ADH)** of the pituitary gland and also by **aldosterone** of the adrenal cortex, through controlling the amount of water re-absorbed by the distal tubule cells.

The formed urine passes continuously through the ureter to the urinary bladder where it is stored temporarily. The involuntary muscles of the bladder's wall contract when it is full, driving the urine out, a process known as **micturition**.

Nitrogenous excretion

The principal source of the excreted nitrogen is the protein of food. It results mainly from deamination of amino acids. This nitrogen may be excreted in the form of ammonia, urea or uric acid.

Animals are classified according to the type of nitrogenous excretory substance they produce into :

a) Ammonotelic animals, in which ammonia is the main excretory product, e.g. most lower aquatic animals, freshwater fishes and marine teleosts.

b) Ureotelic animals, which excrete mainly urea in their urine, e.g. elasmobranchs, amphibians and mammals.

c) Uricotelic animals, in which uric acid is the main excretory product, e.g. lizards, snakes and birds.

REPRODUCTION

Reproduction is the process by which living organisms maintain their kind. In the vertebrates in general, the gonads arise as paired pouches from the coelomic epithelium and project in the coelomic body cavity. The testes either remain permanently inside the body cavity, as in case of bats, or lie outside that cavity, in a special sac known as the scrotum, as in man. In some animals, as in many rodents, the testes remain in the body cavity most of the year and move out into the scrotum only during the breeding season.

In early embryos, each gonad appears formed of an outer **cortical layer** and an inner **medulla**. The former corresponds to a female gland and the latter to a male gland. The gonads of the two sexes are thus identical at the beginning and have equal potentialities for both sexes.

The sex chromosomes, which are already inherited in the genotype of the individual, then induce the secretion of certain hormones which initiate the development of either the male or the female sexuality, i.e. direct the development of the originally undifferentiated gonads to one sex and inhibit the development of the other sex.

Sexual cycles

Most animals produce gametes during certain **breeding seasons**, the duration of which varies considerably. It may be one day or one night, as in some marine annelids, or may extend for one season, as in most fishes, birds and some mammals (in spring) as well as in the deer and sheep (in autumn). Some animals, however, may have 2 or more breeding seasons per year, as the dog (in spring and in autumn). For others, such as the monkeys, apes, man and domesticated cattle, the breeding season extends throughout the whole year.

Males usually produce sperms continuously throughout the breeding season or seasons and often also, but to a lesser extent, in between those seasons. But females do not produce eggs continuously. Therefore, the sexual rhythm is often more marked in the females. Most females produce a single batch of eggs during the breeding season. This is true also for many mammals, in which the period of egg production and maturation is called

the **oestrous cycle**. It is the period of maximum breeding activity, when the female is most attractive to the male and most receptive to it. The oestrous cycle in mammals ensures optimum conditions for implantation of the fertilized ovum in the uterus.

Some animals are **monoestrous**, such as the silver fish, having a single cycle per year extending for about 5 days during late winter. If the produced eggs are not fertilized during these days, the animal remains infertile till the following breeding season.

Other animals, such as the horse and sheep, are **seasonal polyoestrous**, i.e. they undergo several oestrous cycles during the breeding season, thus producing successive batches of eggs during that season. However, as soon as one batch is fertilized, the production of the succeeding batches is stopped throughout the rest of the breeding season.

Gestation or pregnancy is defined as the period of growth of the embryo in the uterus of the mother. It differs in the different animals; being longer in larger animals, e.g. in the elephant it is 21-22 months, horse : 11 months, sheep : 5 months, dog : 63 days, cat : 56 days and rabbit : 32 days.

Parturition is the process of birth and is mainly brought about by the rhythmic contractions of the smooth muscles of the uterus.

Oestrous cycle in man

With the onset of puberty, ovulation occurs periodically in human beings. In women the sex cycle lasts from 25-28 days and is divided into 4 periods :

1 — **Pro-oestrous or pre-ovulation period** : In this period the woman is prepared for pregnancy. The uterus becomes enlarged filled with blood and its mucous membrane thickens. These changes are caused by increased secretion of the follicle stimulating hormone (F.S.H.).

2 — **Oestrous or ovulation period** : The Graafian follicle ruptures and the discharged ovum moves along the Fallopian tube into the uterus. Fertilization with the sperms may occur during its passage in the tube and in this case the cycle is interrupted and pregnancy sets in. If the ovum is not fertilized, the third period begins.

3 — **Post-oestrous or post-ovulation period** : The unfertilized ovum, having reached the uterus, remains there for several days before it disin-

tigrates. Under the influence of the hormone progesterone, the secretion of gonadotrophic hormones decreases. The decrease in the luteinizing hormone (L.H.) leads to the atrophy of the corpus luteum and to tonic contractions of the uterus with the result of discharge of its mucous lining together with some blood. This is called **menstruation**; it lasts for about 5 days. Menstruation occurs only in human beings and higher primates, not in other animals.

4 — **Di-oestrous or period of rest** : During this period (10 days), a new Graafian follicle is in the process of development. It reaches maturity about 14 to 15 days after the beginning of the last menstrual period.

The reproductive period of human females ends in middle age, a time known as **menopause**.

NERVOUS COORDINATION

Nervous conduction and coordination is brought about by the nervous system, the basic functional and anatomical units of which are the neurons.

A **neuron** is composed of the cell body or **cyton**, **dendrites** and an **axon** which terminates in a number of **terminal arborizations** (page 106). The dendrites carry the nerve impulses to the cell body while the axon conducts the impulses from the cell body outwards. With respect to the direction of impulses, axons (or fibres) are classified into two groups : **afferent axons** (fibres) which carry the nerve impulses from the receptor organs (ear, eye, etc.) to the central nervous system, and **efferent axons** (fibres) which carry impulses from the central nervous system to various organs or tissues inducing them to produce the appropriate reactions.

Transmission of nerve impulses

A nerve impulse involves a sequence of electrochemical changes propagated along a nerve fibre. The conduction of impulses along neural pathways include : 1) transmission along nerve fibres, and 2) transmission across synaptic areas.

1) **Transmission along nerve fibres** : Many theories were put forward to explain the way of transmission of impulses along nerve fibres; the most accepted theory is the **membrane theory**. This theory suggests that transmission occurs as a result of a wave of electrical depolarization that passes along the covering membrane of the nerve fibre.

In the resting, non stimulated nerve fibre, the surface membrane is electrically positive along its outer surface and negative along its inner side. The electric charges are carried by inorganic ions (Na, K, Cl) attached to the two sides of the membrane. In this form the membrane is said to be electrically polarized. This polarization of the membrane is due to its semipermeability, i.e. at rest, it prevents the positive and negative ions from passing through it to neutralize each other.

When the nerve fibre is stimulated at any point, the semipermeability of

its membrane is lost at that point. In other words, the membrane becomes depolarized at the point where the fibre is stimulated. It becomes permeable to the positive and negative ions which pass through it to neutralize each other.

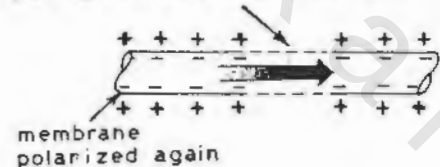
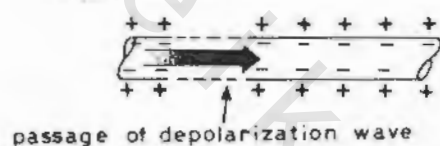
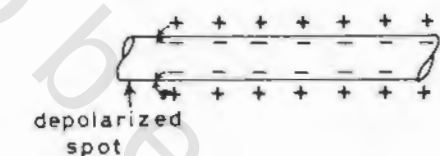
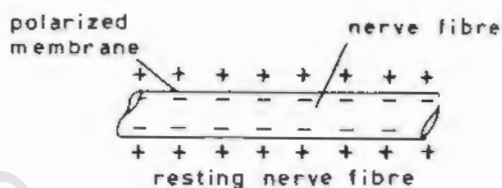
Ions on an adjacent, not yet activated area, jump through this depolarized point to neutralize each other. Therefore, a new depolarised and permeable area is created next to the first one, and ions from a third adjacent point jump through it, and so on the ionic shift continues along the length of the nerve fibre. After the impulse has passed a certain spot, semipermeability and polarization of the membrane is restored at that spot. This explains what is meant by the passage of the nerve impulse as a wave of depolarization in the membrane of the nerve fibre.

All the nerve impulses are essentially the same, but they differ in the action they produce according to where the fibre terminates. If it ends in a muscle, the contraction of a muscle is produced; if it ends in a certain region of the cerebral cortex, the sensation of sight is experienced; or in other region of the cerebral cortex, the sensation of hearing is experienced. If it ends in contact with dendrites of another neuron at a synapse, an impulse is initiated in that neuron of the same chain.

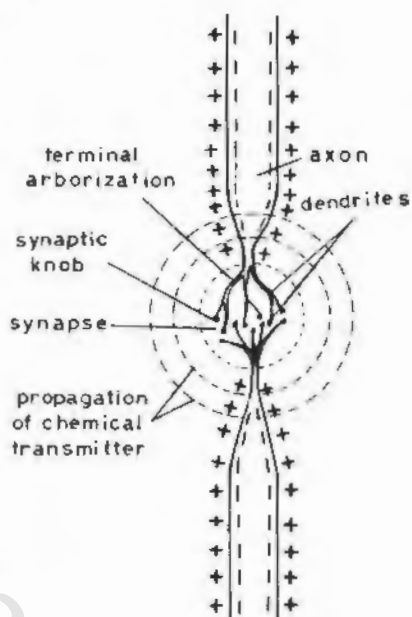
2 — Transmission across synapses

Anatomically, a **synapse** is described as the site at which the terminal arborizations of a nerve cell axon (considered presynaptic in position) lies very close to the dendrites of a neighbouring neuron (considered postsynaptic in position). However, physiologically the synapse is defined as a functional connection between neurons accomplished through contact or near contact of their adjacent membranes. A **synaptic vesicle** or **cleft** is formed between the presynaptic membrane and the postsynaptic membrane, among which the transmission of nerve impulses takes place.

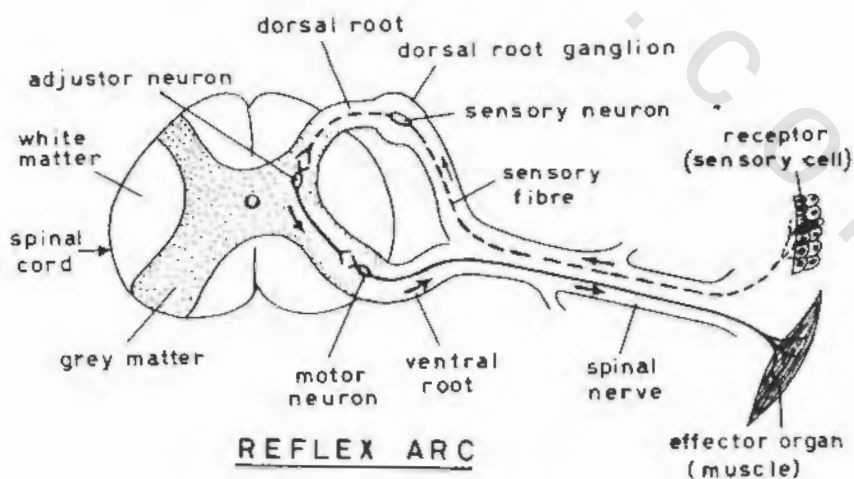
In a few examples of the invertebrates, transmission of nerve impulses across a synapse may be electrical, but in the majority of animals, especially among the vertebrates, transmission occurs by a diffusible chemical substance. This is confirmed by recent electron microscope studies of synapses, where the synaptic knobs or clefts were shown to contain numerous vesicles.



Transmission of impulses along nerve fibres



Transmission of impulses across synapses



These **synaptic vesicles** apparently contain the chemical transmitter which is secreted when the impulse reaches the synaptic knob. This chemical then diffuses to the dendrite terminals of the adjacent neuron where it initiates a new impulse. The impulse passes at the synapse in one direction only, from the axon of one neuron to the dendrites of the next neuron, i.e. the synapse acts as a one way valve. On the other hand, impulses are conducted in both directions in the neurons.

Two transmitter substances or local hormones known to play a role in synaptic transmission are :

a) **Sympathin** which is similar to noradrenaline in chemical structure and biological effect. This is secreted by the axon terminals of the post-ganglionic fibres of the sympathetic system and it may be destroyed by an oxidation reaction.

b) **Acetylcholine** is secreted by pre-ganglionic fibres of the sympathetic nervous system and all the parasympathetic and possibly also the nerve fibres of the central nervous system. The enzyme choline esterase is present at the synapse to split acetylcholine into acetic acid and choline fractions to inhibit the action of acetylcholine, thus destroying the chemical transmitter.

Reflex arc

A reflex is a response to a stimulus that would cause an impulse to pass to the central nervous system, from which it is reflected back to the effective organ which produces that response.

The simplest example of nerve action which is not controlled by the will is the reflex arc, e.g. when a bright light shines suddenly in the eye, the eye pupil unconsciously contracts. Also a blow on the tendon of the quadriceps femoris (below the patella) causes the contraction of this muscle and the jerking of the leg upwards.

A reflex arc involves the following elements :

1 — A **receptor**, usually a sensory cell, to receive the stimulus.

2 — **Afferent** or **sensory fibre**, which runs along the sensory branch of the spinal nerve then along the main trunk of the nerve and its dorsal root. It transmits the impulse from the receptor to the sensory cell found in the dorsal root ganglion. This fibre represents the dendrite of the sensory neuron.

3 — **Sensory neuron**, which receives the stimulus and transmits it along its axon, that passes into the dorsal horn of the spinal cord and ends with fine branches, the terminal arborization.

4 — **Adjustor neuron**, which is found in the grey matter between the dorsal and ventral horns of the spinal cord. It has short dendrites in the dorsal part of the spinal cord, and a small axon in the ventral region. It translates the sensory impulse into motor effects.

5 — **Motor or effector neuron**, which is located in the ventral horn of the spinal cord. It bears small dendrites at the upper side and a long axon, known as the **effluent** or **motor fibre**, which passes along the ventral root, then through the spinal nerve and along the motor branch of that nerve to the effector organ.

6 — An **effector**, which may be a muscle or gland.

A **reflex action** takes place in the following manner : The stimulus, received by the receptor, is passed along the afferent or sensory fibre which transmits the sensory impulse to the sensory neuron. This carries the sensory impulse to the adjustor neuron which translates it into a motor impulse, that is transmitted along the motor fibre to the effector. The latter organ responds in an appropriate manner to the stimulus.

Reflexes are often studied in the laboratory on the so-called spinal toads. In such toads, the brain is either removed or destroyed, but other parts of the body including the spinal cord and its nerves are left intact. If the skin is stimulated (by pinching, application of acid, etc.) the toad responds with a movement of its legs. If the sensory cutaneous nerves or the motor nerves innervating the muscles of the legs are transected, there is no reflex in response to stimulation of the skin. The reflexes are also lost if the nerves are left intact, but the spinal cord (reflex centre) is destroyed.

CHEMICAL COORDINATION

(ENDOCRINE GLANDS)

Chemical coordination of various bodily activities is provided by an endocrine system consisting of several ductless glands whose secretions, the **hormones**, are carried directly by the blood stream to other organs or tissues. Their secretion is controlled by a complex of chemical and nervous factors. Increase (hyperactivity) or decrease (hypoactivity) in the normal activity of the endocrine glands lead to various disturbances in the metabolism of the organism.

Chemical nature and properties of hormones

Hormones are organic catalysts which resemble enzymes in the following respects:

- 1— They are required in small amounts.
- 2— They are not used during their catalytic action.

However, they differ from enzymes in the following respects:

- 1— They are produced in organs other than those on which they act.
- 2— They pass into the blood stream before being used.
- 3— They are not always proteins. They might be proteins, polypeptides, amino acid derivatives or steroids.

Hormones may either stimulate or inhibit a function, but generally they do not initiate a process, e.g. oxidative processes still go on in the absence of thyroid hormones, but not at the normal rate.

Hormones, with few exceptions, are not species specific. Extracts of sheep's thyroid, for example, can accelerate the development and metamorphosis of tadpoles.

The action of a hormone on a target organ is regulated by four factors:

- 1— The rate of the hormone synthesis and release from the endocrine gland.

- 2— The appropriate transport system in the plasma.
- 3— Specific hormone-receptors in the cell membranes of target organs or tissues.
- 4— Ultimate degradation of the hormone by the liver or the kidneys.

It is important to note that variations in any of these factors can result in rapid changes in the amount or activity of a hormone at a given tissue site.

Hormones affect several life processes, such as growth, development, reproduction, utilization of energy and cell permeability through affecting metabolism in two general ways:

- 1— Hormones induce or stimulate the synthesis of specific enzymes that catalyse specific metabolic pathways.
- 2— They are involved in the transport of certain substances, such as monosaccharides, amino acids and nucleotides, across the cell membranes and accordingly affect their rate of metabolism.

THYROID GLAND

The thyroid gland in mammals is situated in front of trachea, just below the level of the thyroid cartilage of the larynx. The gland consists of two lobes joined together by an isthmus. In toads, this gland is found as a diffused mass on the pulmocutaneous arch.

Histologically, the thyroid gland consists of a great number of glandular follicles or acini, each lined by a single layer of cubical epithelium. The lumen of these follicles is filled with a semi-fluid colloid called **thyroglobulin** which is rich in iodine (65 % iodine). From this colloid, the hormones of the thyroid, **thyroxine** and **tri-iodothyronine**, have been isolated. These hormones regulate the body metabolism, development and growth of the organism, excitability of the nervous system, etc.

Hypothyroidism

Deficiency of the thyroid hormones occurring during infancy produces a condition known as **cretinism**. This is characterized by diminished meta-

bolism, retarded growth (dwarfism), deformity in various parts of the body, extremely low mentality and arrested sexual development.

Hypoactivity of the gland in adults results in a condition called **myxoedema** (mucus swelling), which is characterized by the deposition of mucous tissues under the skin, decreased metabolic rate, sleepiness and lack of spirit although the general intelligence is retained, increased body fat and hypercholesterolemia, greater susceptibility to cold, and disturbances in the sexual functions (cessation of menstruation in females).

Deficiency of iodine in the diet may lead to reduced production of the hormone and enlargement of the thyroid gland tissue, a disease known as simple or **endemic goitre**.

Hyperthyroidism

Excessive production of the thyroid hormones causes the disease known as **exophthalmic goitre** which is characterized by enlargement of the thyroid gland, bulging of the eye-balls (exophthalmos), increased metabolism, general muscular weakness and rapid fatigue, increased production of heat, nervous excitability, dissipation of fat stores, etc.

Effect of thyroxine on animals

When thyroxine is administered to lizards and birds, it causes premature moulting. In tadpoles, thyroxine accelerates the metamorphosis before attaining their full size, while the thyroidectomized tadpoles do not metamorphose to frogs.

PARATHYROID GLANDS

In mammals, the parathyroid glands are 4 small oval bodies lying adjacent to the posterior edge of the thyroid glands. In man, they are sometimes embedded in the thyroid tissue.

Histologically, the parathyroids are formed of cuboidal epithelial cells arranged in closely packed masses, separated by irregular bands of connective

tissue richly supplied with blood vessels. Two types of cells are identified :
 (a) **Chief cells** : these are small with large nuclei and pale non-granular cytoplasm. They are considered to be the active secretory cells which produce the hormone **parathormone**, (b) **Oxophil cells** : these are large cells containing eosinophil granules and are of unknown function.

Parathyroid hormones influence the increase of calcium level in the plasma, mobilize calcium from bones and increase the excretion of urinary phosphates.

Hypoparathyroidism

Parathormone deficiency is characterized by a drop in the calcium content of blood (**hypocalcemia**) and a rise in the blood phosphorus. The drop in calcium causes increased irritability in the peripheral motor fibres giving rise to tremors followed by tetanic spasms or muscle contractions (tetany). Death may result from spasms of the muscles of the respiratory system.

Hyperparathyroidism

This condition is due to malignant tumours in one or more of the glands. It is accompanied by an increase in the calcium content of the blood plasma together with a decrease in the inorganic phosphorus, while these 2 substances are excreted in large amounts in the urine. This is followed by diseases in the skeletal system due to withdrawal of calcium from the bones which may become deformed and caved, a condition known as **osteitis fibrosa**.

PANCREAS

The mammalian pancreas consists mostly of an exocrine portion, which secretes the digestive pancreatic juice, and an endocrine portion which secretes certain hormones. The endocrine portion is formed of groups or clusters of cells found between the enzyme-secreting acini, and are called **islets of Langerhans**. The islets of Langerhans contain three types of cells : alpha, beta, and gamma-cells.

Alpha-cells constitute about 25 % of the islets, they are large cells with

granular cytoplasm and are supposed to secrete the hormone **glucagon**.

Beta-cells are the most numerous (about 75 %) and occupy mainly the periphery of the islets. They are smaller than the others and contain acidophilic granules and are supposed to secrete the hormone **insulin**.

Gamma-cells are non-granular. They are of unknown function.

Insulin

This is a polypeptide consisting of 2 chains of amino acids, linked together by disulphide bridges. The insulin molecule does not contain zinc, but when it combines with zinc its effect becomes intensified.

Insulin influences carbohydrate metabolism by facilitating the transport of glucose and related monosaccharides in muscles and adipose connective tissues, but not in the liver tissues. It also facilitates the transport of amino acids, potassium ions, nucleotides and phosphates.

Hypofunction of the pancreatic islets, resulting in a decreased secretion of insulin, causes the disease known as **diabetes mellitus**. In this disease, the tissues cannot assimilate glucose normally and the liver fails to store glycogen. As result, the blood glucose increases (hyperglycaemia) above the normal level which is 80-120 mg. % . When the blood glucose increases than the renal threshold (180 mg %), glucose appears in the urine (glycosuria). Insulin deficiency also affects oxidation of fats. In severe cases, fats are only oxidised to intermediate substances known as ketone bodies (acetone, acetic acid and β - hydroxybutyric acid). Some of the proteins are also transformed into intermediate acid products. These products of incomplete fat and protein metabolism are harmful and may poison the individual causing cardiac weakness and loss of consciousness, a condition known as **diabetic coma**.

Some conditions, characterized by increased insulin secretion, (as occurring in tumours of the pancreas) are accompanied by a decrease in blood sugar (hypoglycaemia), which may show dangerous symptoms such as convulsions, drop in temperature and loss of consciousness, a condition known as **hypoglycaemic shock**.

Glucagon

This hormone is secreted by the alpha-cells of the islets of Langerhans. It is a polypeptide of relatively low molecular weight. Its effect is antagonistic to that of insulin. Glucagon promotes the intracellular conversion of inactive phosphorylase enzyme to an active form. This enzyme is concerned with the breakdown of glycogen into glucose, thus bringing about a sharp increase in the blood sugar level. It stimulates gluconeogenesis and potassium release from the liver. Also, it increases the rates of breakdown of lipids to fatty acids and glycerol in the adipose tissues and the liver.

ADRENAL (SUPRARENAL) GLANDS

These are two small bodies found near the kidneys in mammals and on the ventral side of the kidney in toads. Each gland is composed of 2 parts, the cortex and medulla, which are histologically and physiologically two different endocrine glands.

A. Adrenal cortex

This consists of 3 zones, an external **glomerular zone** (zona glomerulosa), a middle **fascicular zone** (zona fasciculata), and an internal **reticular zone** (zona reticularis). More than 40 corticosteroid compounds have been derived from the adrenal cortex, but only few are physiologically active. The cortical hormones may be classified into three groups :

1 — **Mineralocorticoids** : e.g. aldosterone and deoxycorticosterone. These are secreted by the glomerular zone and regulate metabolism of mineral salts, and distribution of water in the tissues.

2 — **Glucocorticoids** : e.g. cortisone. These hormones are secreted by the fascicular zone and influence the metabolism of carbohydrates, proteins and fats.

3 — **Sex hormones** : e.g. androgens and oestrogens. These hormones are secreted by the reticular zone. In old age, the internal secretions of the

sex glands (gonads) cease and the adrenal cortex becomes the only source of sex hormones. These hormones primarily affect the secondary sex characteristics.

Hypoactivity of adrenal cortex

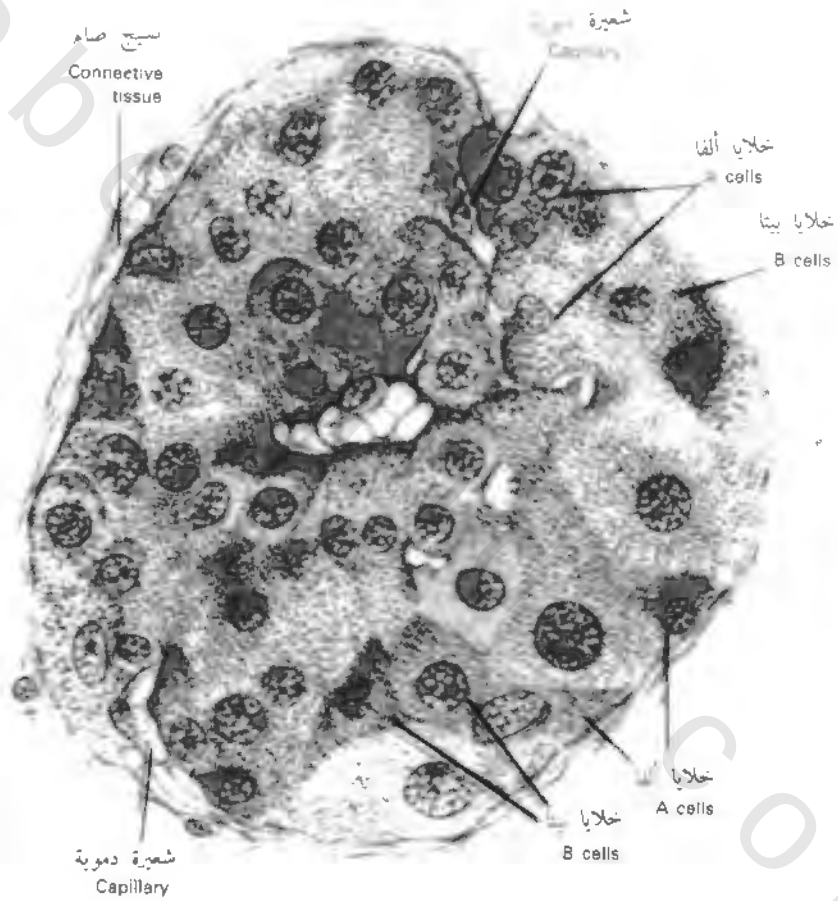
Adrenocortical insufficiency results in **Addison's disease**. This disease is characterized by disturbance in metabolism, loss of weight, loss of appetite, drop in blood pressure, decrease in blood glucose, acidosis of the blood, and a darkening of the skin due to deposition of melanin in the basal layers of the epidermis. The removal or destruction of the adrenal cortex is fatal within few days.

Hyperactivity of adrenal cortex

This condition is accompanied by changes in sexual development. In young children, premature puberty appears, e.g. a male child of 4 years old may show the sexual features of an adult. In young girls, the breast hypertrophies. In adult women, the voice deepens, menstruation ceases, the breasts atrophy and the hair may grow upon the face, chest and limbs.

B. Adrenal medulla

This is composed of closely packed groups of polyhedral granular cells. The medulla secretes a mixture of adrenaline (epinephrine) and noradrenaline. Adrenaline influences many functions, including intracellular metabolism. It promotes the breakdown of glycogen and reduces its reserves in the liver and muscles, with subsequent increase in the blood sugar level. In adipose tissues, it stimulates lipolysis releasing fatty acids and glycerol and thus increasing the rate of gluconeogenesis in the liver. It also intensifies and accelerates cardiac contractions and stimulates the constriction of arterioles, thus causing an increase in the arterial blood pressure. It must be noted, however, that noradrenaline is more effective in the stimulation of such changes. On the other hand, adrenaline inhibits the contractions of smooth muscles of the stomach, intestine branchioles and urinary bladder. Moreover, adrenaline postpones muscle fatigue, thus increasing the working capacity of the organism under certain conditions. It is therefore stated that adrenaline is released to prepare the animal to fight, flight and fright.



احدى جزر لانجرهانس في بنكرياس الإنسان

Islet of Pancreas in Man

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PITUITARY GLAND

This gland is considered the master gland of the endocrine system because it produces special hormones which affect the activities of other endocrine glands.

It is located in the cranial cavity below the brain. It originates partly from the brain and partly from the buccal epithelium in the roof of the buccal cavity. Thus the gland consists of two parts: the **adenohypophysis** formed of the anterior and intermediate lobes and the **neurohypophysis** formed of the posterior lobe together with the infundibular or neural stalk that attaches the gland to the floor of the brain at the hypothalamus.

Hormones of the adenohypophysis

1— Growth hormone: This hormone affects a number of metabolic processes including protein synthesis and control of growth. Deficiency of the hormone in early childhood causes **dwarfism**, a condition characterised by very slow growth, the genital organs remain infantile but the intelligence is not noticeably affected. Men suffering from deficiency of this hormone are impotent, i.e. they are unable to perform the sexual act; while women are sterile.

On the other hand, excessive production of the growth hormone in early childhood results in **gigantism**. But if this occurs in adults, the distal parts of the long bones (hands, feet, fingers and toes) and the bones of the face (cheek bones and the lower jaw) exhibit renewed growth, a condition called **acromegaly**.

2— Pituitary trophins: These are hormones secreted by the adenohypophysis that stimulate the activities of other endocrine glands. They include:

a— Thyrotrophin (Thyroid-Stimulating Hormone): This hormone stimulates the growth and activity of the thyroid gland. It initiates metamorphosis in tadpoles and other larvae.

b— Adrenocorticotrophin (ACTH): It controls the activity of the adrenal cortex and thus increases the synthesis of corticosteroids.

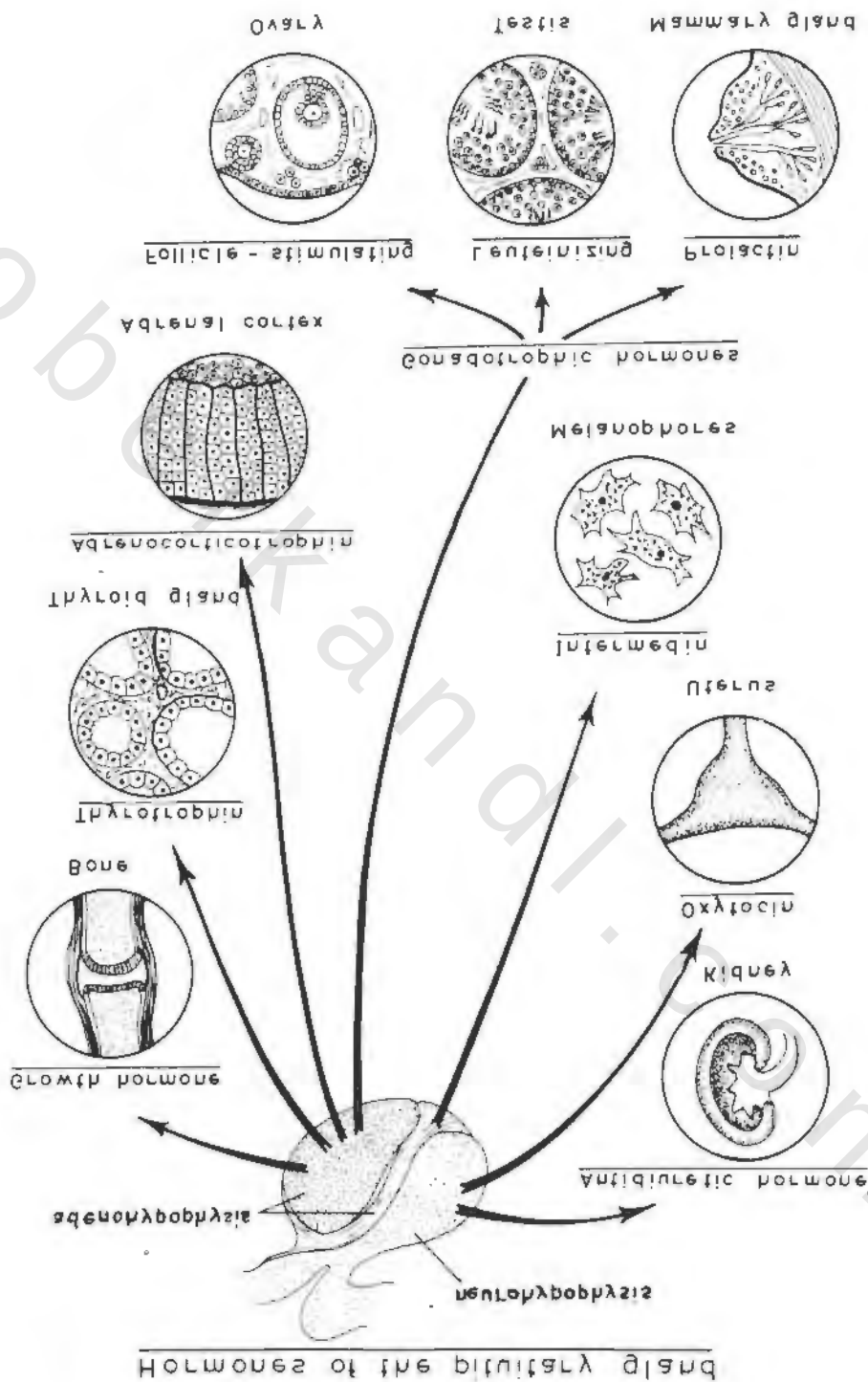
c— **Gonadotrophic hormones:** These include 2 hormones, the **follicle-stimulating hormone (F.S.H.)** and the **Luteinising hormone (L.H.)** which may be also called **Interstitial cell-stimulating hormone (I.C.S.H.)**. In the females, the F.S.H. promotes the development of follicles in the ovaries and their conversion into Graafian follicles, while in males it promotes the development of seminiferous tubules in the testes and accelerates spermatogenesis and the activities of the prostate gland. The luteinizing hormone (L.H.) stimulates the formation of the corpus luteum in the ovary, while the hormone in the male is responsible for the development and secretion of the interstitial gland cells of the testes. It is thus evident that gonadotrophic hormones are necessary for normal sexual development.

d— **Prolactin (Lactogenic hormone):** This hormone stimulates the secretion of milk in the mammary glands and the production of progesterone in the corpus luteum.

3— **Intermedin or Melanocyte-stimulating hormone (M.S.H.):** This hormone has a marked effect on the pigment cells in the skin of lower vertebrates by affecting the spreading and concentration of pigment granules in the chromatophores (See page 436). It is also believed that the hormone apparently increases the deposition of melanin by the melanocytes of the human skin.

Hormones of the neurohypophysis

Two hormones are secreted by the posterior lobe; the first is the **anti-diuretic hormone (ADH)** or **vasopressin**, which markedly decreases the volume of urine by enhancing reabsorption of water in the kidney tubules and increases blood pressure by inducing the contraction of the smooth muscles of the blood vessels. The second hormone is **oxytocin** which causes the contraction of the uterine muscles, particularly at the end of pregnancy, and its presence is indispensable for normal childbirth.



GONADS

In addition to producing gametes, gonads secrete hormones whose function is to develop the sexual organs and the secondary sex characters. Moreover, they participate in the regulation of metabolism. The male sex hormones are called androgens, whereas those of the female are called oestrogens.

Male sex hormones (androgens)

The interstitial cells of the testis (Leydig's cells) secrete 2 hormones, namely **testosterone** and **androsterone**. When these hormones are injected into castrated animals, they stimulate the growth of the prostate and the seminal vesicles, but they have no effect upon the seminiferous tubules. In man, these hormones are secreted continuously throughout the sexual life.

Female sex hormones (oestrogens)

The ovaries produce 3 hormones; oestradiol, progesterone and relaxin.

1 — **Oestradiol** : is normally secreted by the Graafian follicles, but during pregnancy by the placenta. It influences the sexual features, such as enlarging mammary glands, and regulating menstruation.

2 — **Progesterone** : is secreted by the corpus luteum. It influences the normal course of pregnancy, i.e. it controls the periodic changes in the mucous membrane of the uterus to be ready for the implantation of the fertilized egg. It also delays the maturation of Graafian follicles and is responsible for the changes occurring in the mammary glands during pregnancy. If the corpus luteum (which produces progesterone) is destroyed or removed, pregnancy will not take place.

3 — **Relaxin** : is also secreted by the corpus luteum. It causes relaxation of the pubic symphysis at the end of pregnancy to facilitate delivery of the young.

ROLE OF HORMONES IN REGULATION OF SEXUAL CYCLES

Introduction :

Sexual maturity (adolescence or puberty) is achieved in males and females when they reach a certain age (12–14 years). Then, the pituitary gland starts to secrete sex hormones which produce certain effects on the gonads (testes and ovaries) that complete their development and maturity. They start to produce, in turn, a number of secretions (hormones) which induce marked alterations in both males and females.

In males, the beard appears, hair grows in the pubic region, the voice becomes deep, muscles grow stronger and masculine and sperms undergo maturation.

In females, secondary sexual characteristics also appear such as growth of pubic hair, feminine musculature, high pitched voice, widening of the pelvis, growth of the breast, increase in size of uterus and vagina, besides the start of the **menstrual cycles**.

The menstrual cycle includes the occurrence of **menstruation** during which certain mucous materials which were lining the uterus are exuded outside the vagina accompanied by a relatively large amount of blood (50–60 cc.)

The menstrual cycle is known to take place regularly and lasts about 28 days, and it involves the development of an egg (ovum) ready for fertilization. Menstrual cycles continue in females until they stop at a certain age (45–50 years) which is known as the **menopause**. This means that eggs are no longer produced by females.

Hormonal influence during the menstrual cycle:

— At the beginning, the ovary does not contain any mature Graafian follicles, but possesses a considerable number of primary follicles.

— The start of the menstrual cycle is accompanied by the activity of the pituitary gland which secretes the **follicle stimulating hormone (F.S.H)** under the stimulating effect of the **hypothalamus** in the brain.

— The F.S.H. hormone promotes the development of one of the Graafian follicles which reaches maturity while the other follicles stop their development.

— The mature Graafian follicle starts to produce the female sex hormone **oestrogen** which acts to increase the thickness of the internal lining of the uterus (endometrium) and its blood supply.

— The Graafian follicle reaches its complete maturation 4–10 days after the end of the last menstruation, or 13–14, or 13–15 days starting from the onset of the previous menstruation.

— When the Graafian follicle is fully mature, the **luteinizing hormone** (L.H.), produced by the pituitary gland, acts to cause the liberation or extrusion of the egg (ovum) from the follicle. This process is known as **ovulation** and it takes place in the middle of the menstrual cycle, i.e. during 13–15 days from the start of the previous menstruation as mentioned before.

The L.H. hormone also acts to convert the remnants of the Graafian follicle (after the extrusion of the ovum) into a yellowish mass of cells called **corpus luteum** rich with blood vessels.

— The corpus luteum then secretes the second female sex hormone, namely **progesterone** which acts to prepare the uterus for receiving the foetus. The endometrium has been then much thickened under the effect of the female sex hormone oestrogen. Besides, the glands in the endometrium also become mature.

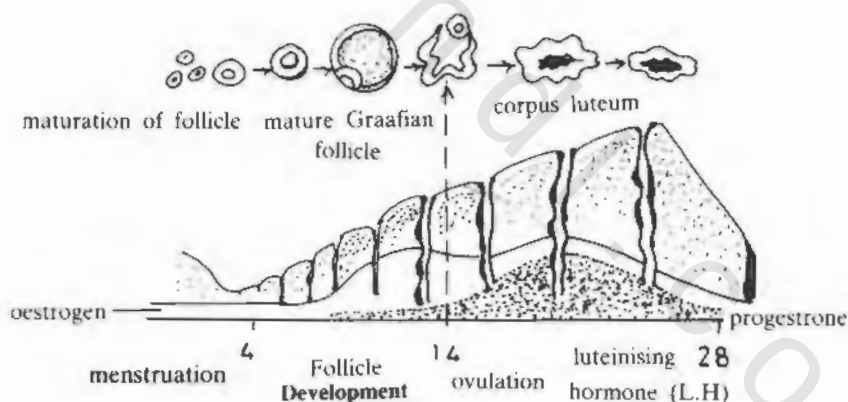
It is clear that the implantation of the fertilized egg in the endometrium does not take place without all these changes taking place under the effect of progesterone. That is why this hormone is called **pregnancy (conception) hormone**. It also acts to maintain the internal lining (endometrium) of the uterus. Besides, progesterone acts to stop the production of F.S.H. from the pituitary gland, and thus there will be no maturation of Graafian follicles in the ovary and there will be no menstruation.

Therefore, progesterone, together with a small amount of oestrogen enter in the formation of **birth control pills** which are taken daily and act to stop

the production of F.S.H. and L.H. and no maturation of Graafian follicles or ovulation.

— **If no fertilization takes place**, the corpus luteum undergoes degeneration and autolysis due to the lack of L.H. since its presence is essential for the maintenance of the corpus luteum and its functional activity (including the production of progesterone). This means the stoppage of progesterone secretion which is essential for the maintenance of the endometrium. Consequently, the endometrium is sloughed (detached) off together with bloody mucous secretions; a phenomenon which is known as menstruation, and hence a new menstrual cycle starts.

— Thus, it is evident that ovulation takes place in human females in the midst of the menstrual cycle nearly and copulation is not essential for ovulation to take place. This is opposite to the case of other animals like rabbits in which copulation must occur so as ovulation happens after $10\frac{1}{2}$ hours exactly.



Safe period (rythm method of birth control):

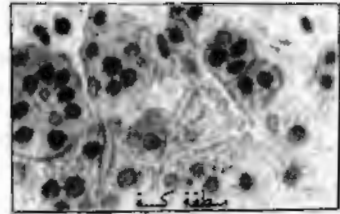
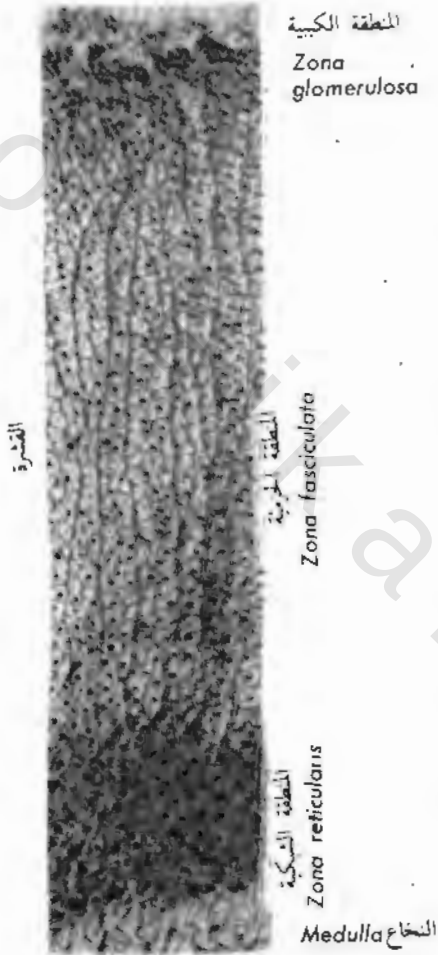
This means the period during which copulation can take place without the occurrence of pregnancy. It is known that egg fertilization only takes place during a limited period in the menstrual cycle, otherwise copulation happens without pregnancy. It is also known that the egg (ovum) starts to

degenerate 12–24 hours following its extrusion from the ovary (ovulation) and becomes useless for fertilization afterwards. Also fertilization does not take place except in the presence of sperms ready for fertilization in the upper third of the oviduct during this period. These sperms remain useful for fertilization for about 48 hours following their entrance into the vagina. This means that pregnancy can take place during 3 days along the menstrual cycle; i.e. during the 13th–15th day from the beginning of the menstruation period, and this is actually the period of ovulation.

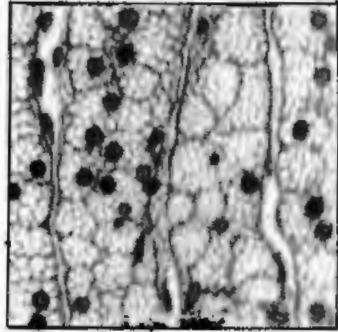
Detection of pregnancy:

When pregnancy takes place, the corpus luteum remains intact and continues to produce hormone progesterone to maintain and keep the pregnancy. In this case, part of the placenta secretes a **gonadotrophin** similar to the luteinizing hormone (L.H.) which is found in abundance in the urine of pregnant females and is taken as an indication of the occurrence of pregnancy.

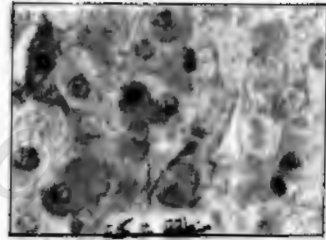
In such cases, a certain amount of this urine is injected into an experimental animal like frogs or rabbits. The hormone found in it causes ovulation in the female 24 hours following urine injection, or extrusion of sperms 6–8 hours after this urine injection in the males.



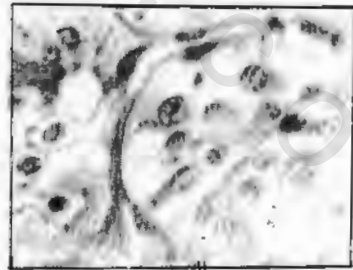
Z. glomerulosa



Z. fasciculata



Z. reticularis



Medulla

قطاعات من غدة الكظر في الإنسان
Sections of The Adrenal Gland

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PINEAL BODY

This gland is a rounded body situated at the end of the pineal stalk arising on the roof of the diencephalon. It secretes a hormone called **melatonin** which is so called because it affects the melanophores, causing paleness of the skin. This hormone probably also delays sexual maturation in animals, reduces the size of the ovaries, and inhibits the oestrous cycle in adult females. The removal of the gland results in the enlargement of the gonads, adrenals and the pituitary glands.

HORMONES OF THE MUCOUS MEMBRANES OF THE ALIMENTARY CANAL

The mucous membrane of the alimentary canal contains digestive glands which secrete the digestive juices. In addition, the mucous membrane secretes certain hormones of which are :

1 — **Gastrin** : stimulates gastric glands of the stomach to secrete the gastric juice.

2 — **Secretin** : secreted by the mucous membrane of the duodenum and stimulates the secretion of pancreatic juices.

3 — **Cholecystokinin** : secreted also by the mucous membrane and induces the gall bladder to pour its bile.

CHAPTER VII

EMBRYOLOGY

EMBRYOLOGY

INTRODUCTION

Embryology is the study of the early development of living organisms. All animals and plants have the ability to reproduce new individuals to ensure the survival of their kind.

Reproduction takes place in different ways in the various kinds of animals. Generally, two main types of reproduction are recognized : asexual and sexual. In asexual reproduction, a single organism splits, buds or fragments to give rise to two or more individuals. This type of reproduction takes place without the intervention of sexual cells or gametes. On the other hand, sexual reproduction involves the fusion of two gametes; a male gamete or sperm, with a female gamete or egg to form the zygote or fertilized egg. Fusion of the male and female gametes would appear at the first sight to result in the doubling of the number of chromosomes, but this process, is prevented naturally by a reduction of the number of chromosomes during the process of gamete formation in the parents. Consequently, gametes will possess half (haploid) the number of chromosomes characteristic of the normal body or somatic cells. Thus, if the usual number of chromosomes characteristic of the normal body or somatic cells for a species is $2n$, this will be reduced to n in the male or female gametes. Fusion of the sperm with n chromosomes with an egg also having n chromosomes will restore the normal (diploid) number of chromosomes $2n$ in the somatic cells of the resulting offspring.

GAMETOGENESIS

The first step in the development of the young is the production of gametes by the parents, a process known as **gametogenesis**, which also involves the reduction of the chromosomes into haploid sets in the resulting gametes. Gametogenesis includes the formation of male germ cells, namely **spermatogenesis**, and that of the female germ cells, or **oogenesis**.

SPERMATOGENESIS

The formation of the male gametes or sperms takes place in the testes. Histologically, the testis is formed of a large number of **seminiferous tubules** in which countless numbers of sperms are produced. The walls of the seminiferous tubules are lined with the germinal epithelium formed of cuboidal **primordial germ cells** from which sperms are ultimately produced.

Spermatogenesis includes three successive phases : multiplication, growth and maturation phases.

a) Multiplication phase : The primordial germ cells undergo repeated mitotic divisions to produce a large number of **spermatogonia**, each containing the diploid number of chromosomes $2n$.

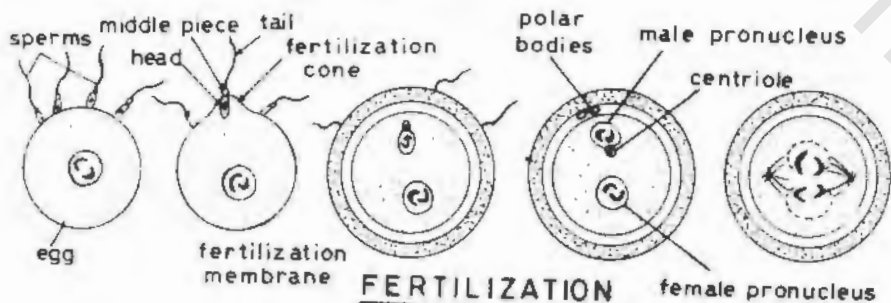
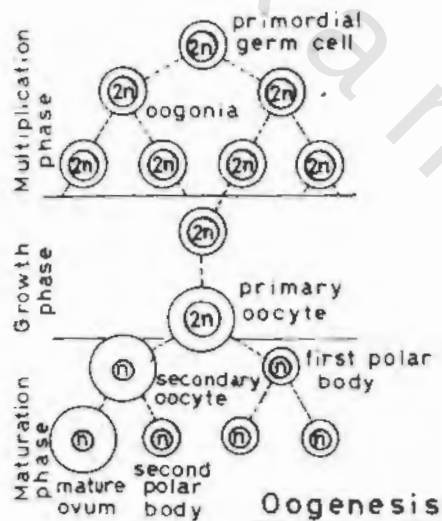
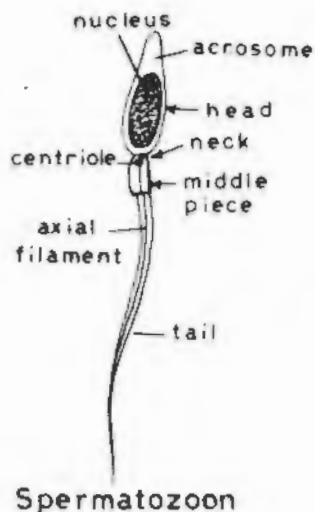
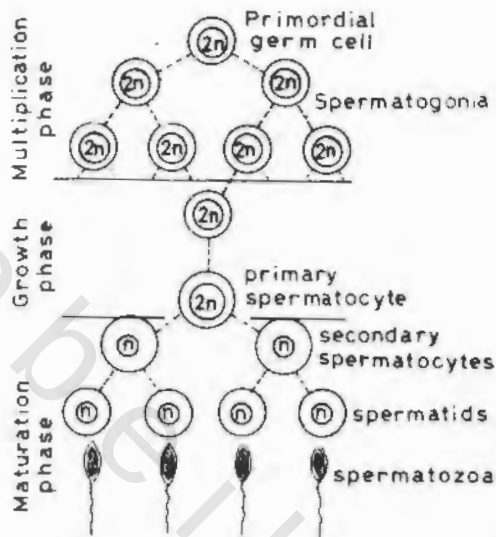
b) Growth-phase : Spermatogonia grow in size to form larger cells known as **primary spermatocytes**, which still contain the diploid number of chromosomes $2n$.

c) Maturation phase : Each spermatocyte undergoes meiosis which consists of two successive nuclear divisions known as the first and second meiotic divisions. The first division results in the formation of two cells of equal size, the **secondary spermatocytes**, the nuclei of which contain the haploid number of chromosomes n . The second division immediately follows and each secondary spermatocyte is divided into two **spermatids**, each having n chromosomes. Thus four spermatids are produced from each primary spermatocyte.

The spermatids then undergo certain changes, known collectively as **metamorphosis**, to form **spermatozoa**. During these changes, the nucleus shrinks, becomes more dense and forms the head of the spermatozoon. Most of the cytoplasm is shed, but the Golgi bodies aggregate at the anterior end of the spermatozoon to produce a pointed structure known as the acrosome. Behind the head, there is a mid-piece containing centrioles, and the posterior end of the cell acquires the form of a slender cytoplasmic tail.

Structure of the Sperm

Sperms are motile and able to swim in the seminal fluid. They vary



markedly in shape in different animals, being thread-like, elongated, oval or amoeboid. They also vary in size; in human beings they are 50-60 μ long, whereas they measure about 2,000 μ in some frog species.

Typically, the sperm consists of a head, a neck, a middle piece and a tail. The **head** contains a conspicuous **nucleus** enveloped by a scanty amount of cytoplasm. The head has an anterior pointed structure, the **acrosome**, produced by the Golgi bodies of the spermatid. The acrosome helps in the penetration of the sperms through the surface of the egg at the time of fertilization and thus the sperm gains entrance into the egg.

The **neck** is a short region attaching the head to the middle piece. It contains one or two **centrioles** which play a principal role in the fusion of the sperm nucleus with the egg nucleus during fertilization. A long thin filament, the **axial filament** starts from the neck and runs along the middle piece and the tail. In the middle piece, the axial filament is surrounded by a **mitochondrial sheath** formed by the mitochondria of the spermatid. The middle piece is known to supply the energy for the movement of the tail. The **tail** consists of two main parts: a **main piece** and an **end piece**. The former consists of the axial filament surrounded by a protoplasmic sheath, while the latter consists of the unsheathed terminal part of the axial filament only. It is worth mentioning that the tail of the sperm has the same structure as the flagellum or cilium of a protozoan, i.e. it consists of the usual pair of axial filaments surrounded by nine peripheral pairs of fibrils.

When fully mature, the spermatozoa leave the testis and wriggle in the seminal fluid secreted by certain reproductive glands, namely the seminal vesicles, prostate glands and Cowper's glands. This fluid contains glucose and fructose for nourishing the sperms, and inorganic salts which act as buffers to protect the sperms from the acids normally present in the reproductive tract. It also contains mucous materials which serve to lubricate the passages through which the sperms pass.

OÖGENESIS

Oögenesis, or development of the ova, takes place in the ovary. This process is more or less similar to that of spermatogenesis and consists of the usual three successive phases.

a) Multiplication phase : The **primordial germ cells** of the germinal epithelium surrounding the ovary multiply by repeated mitotic divisions giving rise to a large number of small cells, the **oogonia**; each contains the diploid number of chromosomes $2n$. Oogonia are usually accumulated in dense aggregates or **nests** of oogonia lying in the peripheral region of the ovary.

b) Growth phase : The oogonia undergo a considerable increase in size, as they store nutritive materials, and form the **primary oocytes**, each still containing the diploid number of chromosomes $2n$.

c) Maturation phase : In the vertebrates, this phase generally takes place after the primary oocytes have been released from the ovary, and its completion is frequently stimulated by the entry of spermatozoa during fertilization. In this phase, the primary oocyte divides by meiosis; which includes first and second meiotic divisions. In the first meiotic division, the primary oocyte divides into two unequal cells; a large cell known as the **secondary oocyte** and a smaller one known as the **first polar body** or **polocyte**. The secondary oocyte contains the haploid number of chromosomes n . The first polocyte contains n chromosomes enclosed in a small nucleus surrounded by a very thin layer of cytoplasm. The second meiotic division splits the secondary oocyte unequally into a large **ootid** and much smaller **second polocyte**, while the first polocyte divides into two small second polocytes; each of the ootids and second polocytes contains n chromosomes. The second polocytes then disintegrate while the ootid undergoes differentiation to form the **mature ovum** or **egg**. Thus, unlike the primary spermatocytes, each primary oocyte gives finally one mature ovum.

Structure of the egg

The egg or ovum is usually spherical in shape, consisting of a round **nucleus** surrounded by a cytoplasmic mass which contains a variable amount of **yolk**. The ovum is bounded by certain membranes of different kinds and origin. It is usually surrounded by a very delicate **vitelline membrane**, which is secreted by the ovum itself and is therefore generally known as the **primary egg membrane**. This membrane may be enveloped by a **secondary membrane** formed by the follicle cells which surround the egg in the ovary.

The amount of yolk and its distribution in the egg cytoplasm are very important in determining the course of embryonic development. In this

respect, the following types of eggs are recognized :

a) Isolecithal eggs : These are eggs containing a small amount of yolk scattered more or less uniformly throughout the cytoplasm. These eggs are common for lower chordates such as *Amphioxus*. In such cases, the embryo proceeds to an independent feeding existence at a very early stage. The fertilized ovum of *Amphioxus* develops rapidly and hatches very early into a free swimming larva. Isolecithal eggs are laid down in great numbers to compensate for the high losses expected to occur among the resulting helpless larvae.

In man and other mammals, ova are also isolecithal, but this type is regarded to be secondarily isolecithal and is presumably a modification of the heavily yolked eggs of reptiles. This change has occurred in correlation with the alteration in the mode of development. Instead of the egg being laid and having to rely on its own resources for nourishment, it is retained in the oviduct where it receives nutrients from the mother. An exceptional group of mammals, the Monotremes, differ from other mammals in the fact that they still retain the primitive reptilian habits.

b) Centrolecithal eggs : Eggs of this type are found in Arthropods. These are comparatively large in size and contain a considerable amount of yolk concentrated in the centre of the egg.

c) Telolecithal eggs : In this case, the yolk is mainly concentrated on one side of the ovum, away from the nucleus which lies in an area of more or less yolkless cytoplasm. This type is found in the toad, where the yolk lies at the lower or **vegetative (vegetal) pole**, while the nucleus is situated at the upper or **animal pole**. However, the toad's ova are known to be **moderately** telolecithal and do not contain enough yolk to feed the young throughout the whole of their development. Hence, the young hatch out as larvae (tadpoles) that feed by themselves.

In reptiles and birds, ova contain enormous quantities of yolk. Only a small part of the ovum at its upper part (animal pole) is left for the cytoplasm and nucleus. This part is known as the **germinal disc**. This type of ova are described as being **heavily telolecithal**. The yolk in these ova enables the young reptile or bird to develop to an advanced stage within the egg, and to emerge from the egg in a more or less complete form. In general, these heavy-yolked ova are produced in comparatively small numbers.

FERTILIZATION

Fertilization is the process in which two gametes or germ cells, an egg from the female and a sperm from the male, unite to form the zygote. Fertilization may be internal or external.

External fertilization is almost limited to aquatic animals. In this case, both kinds of gametes are shed into the surrounding medium, and the sperm cells swim or are carried with water currents to the egg cells. Nearly all aquatic invertebrates, most fishes (with the exception of sharks) and many amphibians perform external fertilization. Such animals are known to release vast numbers of eggs and sperms to account for the losses expected among these cells in water.

Internal fertilization occurs in most terrestrial animals including vertebrates and invertebrates. In this case, the egg cells remain within the genital system of the female until they are fertilized by the sperms introduced into the female by the male during copulation.

Following fertilization, the fertilized eggs of some animals (e.g. birds, most insects and many aquatic invertebrates) pass outside the body to complete their development. In this case, the females lay the eggs from which the young eventually hatch. Such animals are said to be **oviparous** (egg-laying).

In a second category of animals, e.g. mammals, which are described as **viviparous** animals, living young develop from the eggs retained within the mother's body, particularly in the uterus, and nourished by the blood stream until they reach a certain stage of development at which they are born.

A third group of animals, identified as the **ovo-viviparous** animals, produce eggs that are incubated and hatched within the mother's body. In this case, the developing young receives nourishment from the nutrient materials stored in the eggs, and there is no organic connection between the developing foetus and the mother. Examples of such animals are sharks and lizards.

The actual process of fertilization begins when the sperms come in the

vicinity of the eggs. It has been found that the eggs of some species secrete a substance, **fertilizin**, which is an important constituent of the jelly coat surrounding the egg. Fertilizin causes the sperm to stick to the surface of the egg. A large number of sperms are attached to the egg, but only one usually succeeds to penetrate into it; other sperms degenerate. At the point of contact of the sperm with the egg, the egg surface produces a conical projection, known as the **entrance cone**, which engulfs the sperm. After the entrance of the sperm, a thin membrane is thrown off and soon becomes considerably thickened forming the **fertilization membrane**, which is separated from the surface of the egg by a fluid-filled space, the **perivitelline space**. It serves to prevent the entrance of other sperms into the egg, so that only one sperm is allowed to pass inside the egg.

However, fertilization not only involves the penetration of the egg by the sperm, but also the activation of the egg to undergo cleavage and development. The egg may be at any stage of development from the primary oocyte to the mature ovum at the time of sperm penetration, but the fusion of the sperm and egg nuclei occurs only after the egg has matured.

During the process of fertilization, the head and the middle piece of the sperm pass into the cytoplasm of the egg, whereas the tail is cast off and remains outside. Soon, after the entry of the sperm into the egg, the egg nucleus begins to complete its maturation by moving towards the peripheral region of the egg where the first polar body is released, then the second maturation division takes place and the ovum with **female pronucleus** is produced.

Inside the egg, the sperm rotates in such a way that the middle piece lies between the sperm head and the female pronucleus. The cell centre or centrosome in the neck of the sperm acquires astral rays and divides into two centrioles which move away from each other but remain connected by the spindle fibres (mitotic spindle). The sperm nucleus increases gradually in size and becomes spherical in shape, being known at this stage as the **male pronucleus**. Then the male and female pronuclei move towards the central region of the egg and each pronucleus comes to lie on one side of the spindle. Chromosomes become distinct in these nuclei, the nuclear membranes of both pronuclei disappear and their chromosomes attach to the spindle fibres. This stage represents the prophase stage of mitosis. Consequently, a zygote or fertilized egg is produced having the diploid number of chromosomes.

Parthenogenesis

In some animals, eggs can be stimulated to develop without fertilization by the process known as parthenogenesis (virgin birth). Some species of arthropods have been found which apparently consist solely of females that reproduce parthenogenically. In other species, parthenogenesis occurs for several generations, then some males are produced which develop and mate with the females. The queen honeybee is fertilized by a male just once during her lifetime, in her "nuptial life". The sperms are stored in a pouch within the genital tract. If sperms are released from the pouch as she lays eggs, fertilization occurs and the eggs develop into females including queens and workers. If the eggs are not fertilized, they develop into males or drones.

EMBRYONIC DEVELOPMENT

The embryonic development of any animal starts from the fertilized egg or zygote and it usually passes through three main stages: Cleavage, Gastrulation and Organ formation (Organogeny).

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Cleavage includes the repeated mitotic divisions of the original zygotic cell, resulting in the formation of a large number of small cells known as **blastomeres**. As cleavage proceeds, the blastomeres become arranged in the form of a hollow ball, the **blastula**, which includes a central cavity, the **blastocoel**. Cleavage may be holoblastic or meroblastic. In the **holoblastic cleavage**, the entire zygotic cell divides, while in the **meroblastic** type, only a part of the protoplasm of the cell divides.

Gastrulation includes the subsequent stages in which the blastomeres are arranged to form the ectoderm and endoderm.

Organogeny consists of the differentiation of various tissues and organs from the original germ layers.

EMBRYONIC DEVELOPMENT OF AMPHIOXUS

The development of *Amphioxus* represents the simplest type of chordate development. Spermatozoa and ova are released in water and thus fertilization is external.

Cleavage

The zygote divides into two equal blastomeres by a furrow which extends in a meridional plane from the animal to the vegetal poles. This cleavage is of the holoblastic type.

The second cleavage takes place by a furrow extending in a meridional plane which runs at right angles to the first division, thus four equal blastomeres are produced.

The third cleavage takes place by a horizontal furrow, slightly above the equator, that divides the four blastomeres into eight blastomeres, four small upper **micromeres** and four larger lower **macromeres**.

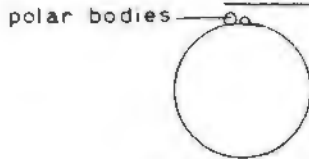
The fourth and fifth cleavage take place by a double meridional and a double horizontal furrows respectively, to form eventually a 32-blastomeres stage which may be referred to as the **morula stage**.

Further divisions, then take place, but macromeres are known to divide at slower rate than the micromeres. A hollow sphere of cells, the **blastula**, is then formed. It consists of a single layer of cells enclosing a cavity, the **blastocoel**.

Gastrulation

It begins by flattening and invagination of the macromeres at the vegetal pole of the blastula. Invagination continues until the layer of macromeres comes to lie against the micromeres, thus obliterating the blastocoel. As a result, a two-layered, cup-shaped larva, the **gastrula** is produced. The outer layer of the gastrula (formed from the micromeres) is known as the **ectoderm**, while the **endoderm** forms the inner layer (formed from the macro-

DEVELOPMENT OF AMPHIOXUS



Fertilized egg



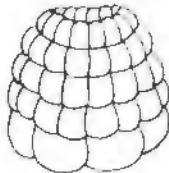
2 blastomeres



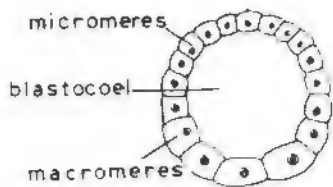
4 blastomeres



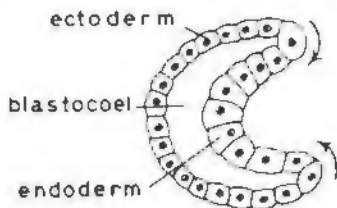
8 blastomeres



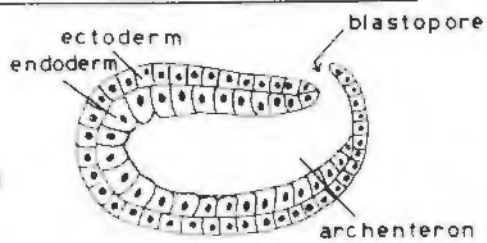
Blastula



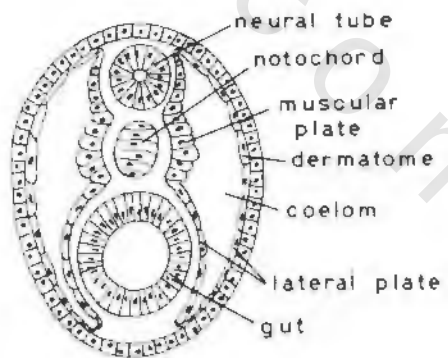
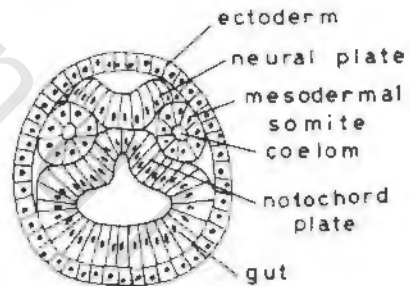
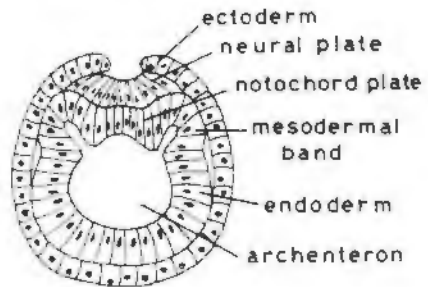
V.S. of blastula



Early gastrula



Late gastrula



Organogony

meres). A new cavity known as the **archenteron** which opens to the exterior by the **blastopore**, appears in a sectioned gastrula.

Organogeny

A strip of ectodermal cells extending along the dorsal surface of gastrula is differentiated into a distinct flattened structure, the **neural plate** which sinks gradually below the ectoderm. Both ends of the neural plate grow dorsally and medially until they meet each other, thus the neural tube is formed. This tube develops gradually into the central nervous system, whose anterior part becomes enlarged to form the brain while the remaining posterior part forms the tubular spinal cord. While these changes are taking place, the ectodermal cells on both sides of the neural plate grow dorsally and medially until they completely surround the developing larva. During later development, this remaining part of the ectoderm become differentiated to form the epidermis of the skin as well as other epidermal structures.

Similar changes take place at the same time in the endoderm. A dorsal band of the endoderm cells lying below the neural plate becomes clearly distinguished from the rest of the endoderm and forms the **notochord plate**. Cells of this plate develop eventually into a solid mass forming the **notochord**. The rest of the endoderm becomes differentiated into two lateral bands, the mesodermal bands, and a ventral gut plate.

The **mesodermal bands** grow as two **mesodermal pouches** evaginating from the endoderm, one on either side. These pouches enclose a cavity which is in connection with the archenteron. Each of these mesodermal pouches is at first continuous throughout the whole length of the developing embryo, but later it becomes divided by transverse septa into a linear series of mesodermal somites. The cavity of each somite remains for some time connected with the archenteron, but gradually this connection becomes obliterated and closed sacs known as the **mesodermal somites** are formed. Each somite encloses a cavity that represents the future **coelom**.

Every two opposite somites grow ventrally until they meet each other in the mid-ventral line and their cavities become continuous with each other. Thus, a **mesodermal plate** is produced, being formed of two layers of cells enclosing an internal cavity. This plate becomes divided into two parts by a transverse partition, an upper part, the **epimere**, and a

lower one, the **hypomere**. The inner part of the epimere is known as the **muscle plate** and the outer part as the **dermatome**. The lower part of the former plate gives rise to a small rudiment known as the **sclerotome**, and the remaining part becomes known as the **myotome**.

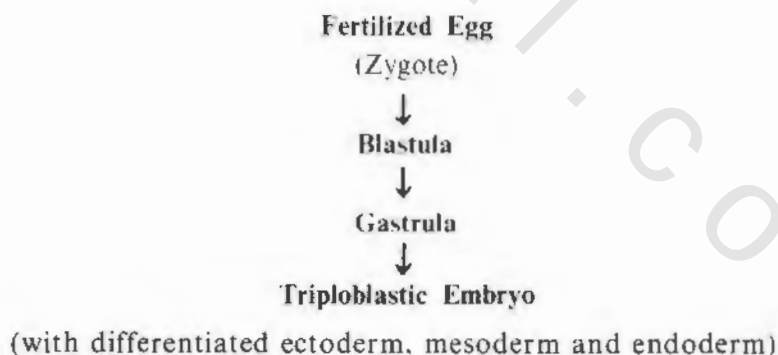
The **hypomere** is now formed of an outer layer of cells, the **somatic mesoderm** (somatopleure), and an inner layer, the **splanchnic mesoderm** (splanchnopleure). The two layers enclose the coelomic cavity or coelom.

The **myotomes** give origin to the body musculature, and the **sclerotome** are responsible for the formation of all other structures which are known to be of mesodermal origin such as the different skeletal structures of the body.

The **coelom** becomes bounded externally by the **parietal mesoderm** (somatopleure) lining the body muscles, and limited internally by the **visceral mesoderm** (splanchnopleure) which spreads on the outer surface of the alimentary canal and which is commonly known as the serous coat or **serosa**.

In the mean time the lateral sides of the **gut plate** grow dorsally and medially to form a closed tube, the **gut**. Its internal cavity is the **enteron**.

ORGAN DIFFERENTIATION IN VERTEBRATE EMBRYOS



1. Ectoderm forms :

Neural plate Nervous system.

Sense receptors.

Epidermis and epidermal derivatives :

Hair,

Sweat glands,
Mammary glands,
Linings of buccal cavity, nose and cloaca,
Enamel of teeth.

2. **Mesoderm** forms :

Notochord Vertebral column.
Mesodermal somites, which form :
 Skeleton,
 Connective tissues,
 Heart, blood and blood vessels.
 Dermis,
 Muscles,
 Excretory system,
 Reproductive system,
 Peritoneum,
 and mesenteries.

3. **Endoderm** forms :

Lining epithelium of alimentary canal.
Liver,
Pancreas.
Thymus gland.
Thyroid gland.
Parathyroid gland,
Germ cells.

EMBRYONIC DEVELOPMENT OF THE TOAD

The eggs of the common Egyptian toad are laid in water in a long spawn formed of two layers of jelly. The sperms are then shed by the male over the eggs in water; thus fertilization is external. One sperm penetrates each egg and the zygote is thus produced.

Cleavage

Shortly after fertilization, cleavage starts. The first cleavage furrow makes its appearance as a meridional groove extending from the animal to the vegetal poles and thus two equal blastomeres are produced.

The second cleavage is affected by a meridional furrow which appears at right angle to the first, thus four equal-sized blastomeres are produced.

In the third cleavage, a horizontal furrow appears, which lies at 30° above the equator, and divides the four blastomeres into eight blastomeres: four small micromeres and four larger macromeres at the animal and the vegetal poles respectively. At the end of the third cleavage, a distinct cavity, the **blastocoel**, starts to appear between the inner walls of the eight blastomeres.

The fourth cleavage furrow is meridional and double while that of the fifth cleavage is horizontal and double. At the end of the fifth cleavage a 32-blastomeres stage is produced.

Cleavage then continues by the repeated divisions of the blastomeres but the rate of the division of blastomeres at the animal pole is higher than that at the vegetal pole. A hollow sphere of cells, the **blastula**, is produced. The blastula is a cellular sphere, with the blastocoel eccentrically located nearer to the animal pole. The roof of the blastocoel is formed of 3-4 layers of small blastomeres, while the floor consists of a number of larger blastomeres.

Gastrulation

The process of gastrulation in the toad is not as simple as that described above in *Amphioxus*. In the toad, the process involves three main activities :

a) The small cells found near the animal pole divide more rapidly than the larger cells at the vegetal pole. These small cells or micromeres grow downwards to cover eventually the larger cells by a process known as *epiboly* or overgrowth.

b) While epiboly is proceeding, the larger cells or macromeres undergo a process of invagination.

c) Epiboly and invagination continue until all the macromeres become covered by the micromeres except at a certain region on the vegetal pole known as the **yolk plug**. At this region the downward moving micromeres start to turn into the developing embryo and this process is known as **involution**. The slit formed at the point where the micromeres involute is called the **blastopore**. As involution continues, the **archenteron** is formed; it grows rapidly as the blastocoel becomes smaller.

At the end of these activities, the **gastrula** is formed with the outer two layers formed of micromeres constituting the **ectoderm**, while the inner layer formed of several macromeres in thickness represents the **endoderm**.

Organogeny

The dorsal part of the ectoderm becomes differentiated into a neural plate whose lateral edges grow upwards and inwards until they meet together to form the **neural tube**. The anterior part of this tube becomes enlarged to form the brain, while the rest of the neural tube gives rise to the spinal cord. The remaining part of the ectoderm contributes to the formation of the epidermis of the skin as well as other epidermal structures.

A band of endodermal cells extending along the roof the archenteron becomes differentiated to form the **notochord**. In the meantime, the mesoderm arises as two sheets of cells which split from the endoderm on either side of the notochord. After the separation of the notochord and the mesoderm, the rest of the endoderm forms the gut in a way similar to that described above in *Amphioxus*. As development proceeds, both the meso-

DEVELOPMENT OF THE TOAD

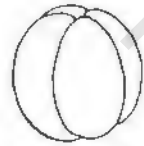
polar bodies



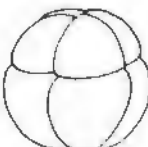
Fertilized egg



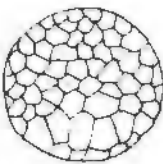
2 blastomeres



4 blastomeres



8 blastomeres



Blastula

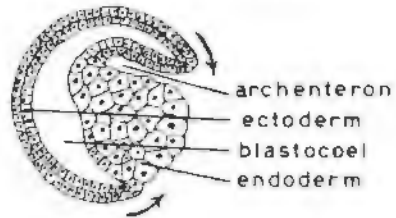
micromeres



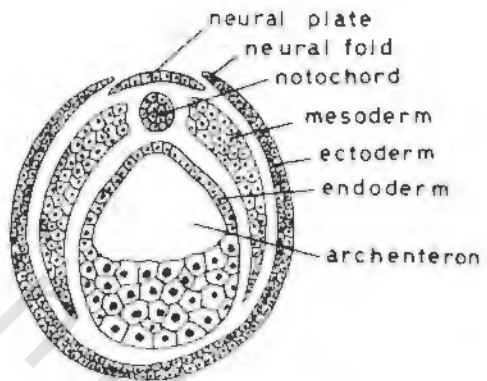
macromeres

blastocoel

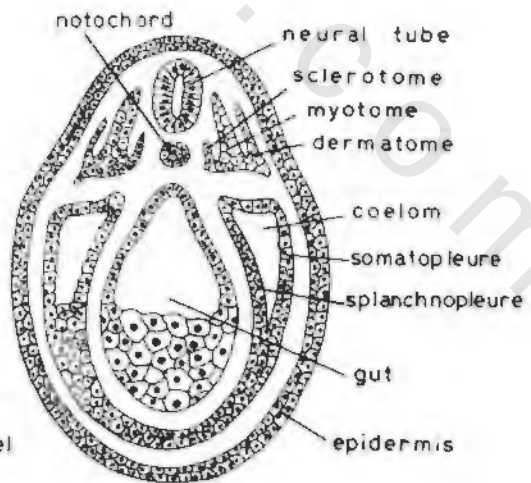
V.S of blastula



Gastrula



T.S.



derm and gut become differentiated into the usual structures (p. 606). Thus, connective tissues, muscles, dermis, etc develop from the mesoderm and the midgut develops from the endoderm.

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DEVELOPMENT OF THE CHICK

The ovum of the chick, as other eggs of birds, is of the heavily telolecithal type. It consists of a central mass of yolk containing a large quantity of nutrients in the form of fats and proteins. On the top of the yolk mass there lies a clear portion of protoplasm, the **germinal disc**, in which the nucleus is found. The yolk and the germinal disc are enclosed by a thin, transparent **vitelline membrane**.

The ovum is fertilized in the upper part of the oviduct (internal fertilization) and during its passage downward to the exterior, it is covered by a series of additional structures secreted by the epithelial cells lining the walls of the oviduct. The ovum becomes surrounded by the white or **albumen**, composed of a clear transparent protein. Outside the egg albumen, two membranes are deposited. The inner membrane is tough, somewhat leathery and is called the **shell membrane**. This membrane consists actually of two layers lying very close to each other, but at the rounded end of the egg the two layers are separated to enclose a small **air cavity** containing air, that serves for breathing of the young chick before hatching. Surrounding the shell membrane is the **calcareous shell**, which is hard, porous, though very brittle.

At either end of the yolk there appears a twisted structure, the **chalaza**, which stretches across the albumen from the shell membrane to the ovum and helps in keeping the ovum in its position. The chalaza results from the twisting caused in the albumen as the ovum rotates in its descent down the oviduct.

Cleavage

Cleavage begins immediately after fertilization. Thus, the earliest stages of development take place within the oviduct, and even before the albumen, shell membranes and shell have been secreted. Segmentation can proceed for about eighteen hours before the egg is laid down.

The presence of a large amount of yolk in the egg has a great effect on cleavage, which becomes confined to the small yolk-free germinal disc from the beginning. Thus, the cleavage planes do not pass down the yolk, and accordingly cleavage is of the meroblastic type.

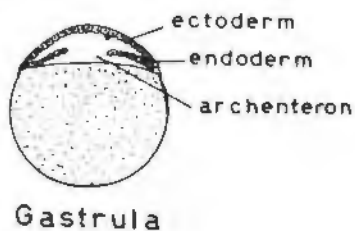
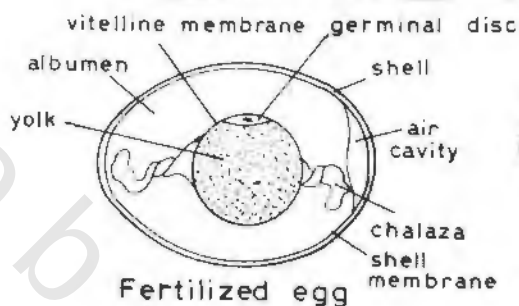
The first cleavage furrow appears as a meridional groove in the germinal disc resulting in the formation of two blastomeres. This cleavage is soon succeeded by a second one which is produced by another furrow which lies at right angles to the first one, thus four blastomeres are produced.

In the third cleavage two furrows, which lie on each side and parallel to the first cleavage furrow appear simultaneously, and eight blastomeres are produced. Cleavage then becomes irregular until a mosaic of cells that form the **blastoderm** is produced. The so-called cells of the blastoderm, are not in fact true cells separated by parallel complete divisions of the cytoplasm. Actually, the furrows which appear during repeated divisions do not pass across the whole depth of the germinal disc, but leave an undivided mass of cytoplasm on the lower side, adjacent to the yolk. A fluid is accumulated below the central cells of the blastoderm which become detached from the underlying yolk to form the **blastocoel**, and the embryo is now in the **blastula** stage. The central part of the blastoderm, whose cells form the roof the blastocoel, appears more transparent and is called the **area pellucida**, while the marginal parts of the blastoderm form the **area opaca**.

Gastrulation

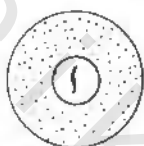
Three theories are put forth to explain the way (or ways) by which the ectoderm and endoderm develop in the blastoderm. The first theory suggests that delamination occurs in the thick blastoderm which therefore splits into an upper **ectoderm** and a lower **endoderm**. The second one postulates that the cells found at the posterior part of the blastoderm free themselves from the underlying yolk, and involute inwards while continuing to grow to form the endoderm below the superficial layer of cells now known as the ectoderm. The third theory indicates that the endoderm is simply formed from some cells which fall down below the original cells of the blastoderm, which persist as the ectoderm.

DEVELOPMENT OF THE CHICK

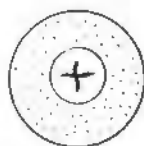


Fertilized egg

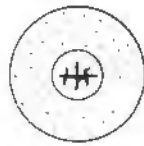
Gastrula



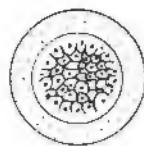
2 blastomeres



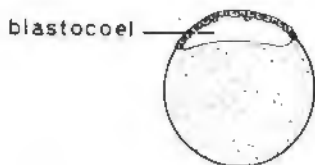
4 blastomeres



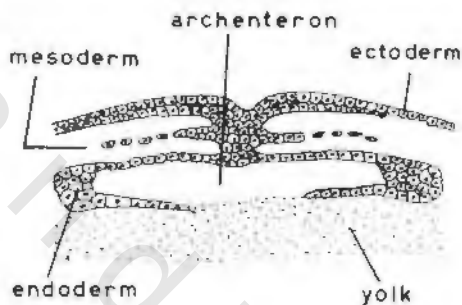
8 blastomeres



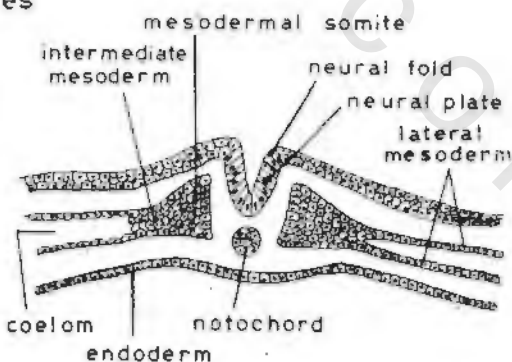
Blastula



V.S. of blastula



Formation of mesoderm



T.S. of 24-hour embryo

Following the formation of the two-layered blastoderm, the cells at the edges multiply progressively so that the area of the blastoderm is markedly increased and eventually forms a large cap lying on top of the underlying yolk. The cavity included between the endoderm and the yolk is now called the **archenteron**.

Later, a short line known as the **primitive streak**, appears in the area pellucida. This line appears in section to be formed as an inward growth of ectodermal cells, traversed along its length by a groove, the **primitive groove**. The primitive streak is actually the region of highest activity in the developing embryo.

The cells of the upper layer in the region of the primitive streak move inwards and downwards, then spread out laterally and anteriorly between the ectoderm and endoderm. These cells represent the developing **mesoderm**.

Organogeny

The mesodermal cells which pass anteriorly, in the mid-line below the ectoderm, develop into a long strip of cells that form the **notochord**.

The ectodermal cells immediately above the notochord become flattened to form the **neural plate** which sinks down later to give rise to the neural groove. The two edges of the neural plate become elevated to form the neural folds which grow dorsally then medially until they meet in the mid-dorsal line to form the **neural tube**.

The mesoderm becomes differentiated into **axial**, **intermediate** and **lateral** portions. The axial portion of the mesoderm lying on both sides of the notochord develops into the **mesodermal somites**. The thin intermediate portion of the mesoderm develops later to form certain excretory structures. The lateral mesoderm develops into two layers, an outer **somatic mesoderm** and an inner **splanchnic mesoderm**, with the **coelomic cavity** appearing in-between. The somatic mesoderm passes below the ectoderm and both form together the **somatopleure**. The splanchnic mesoderm passes above the endoderm and both layers form the **splanchnopleure**. As development proceeds, many organs arise simultaneously and appear in successive stages of chick formation.

Embryonic membranes

During later developmental stages of the embryo, a number of embryonic membranes which lie outside the embryo are produced. These are : the amnion, chorion, allantois and yolk sac. They are sometimes referred to as the extra-embryonic structures since they do not form parts of the embryo proper. These membranes perform a number of functions during the development of the embryo, then they are thrown at the time of hatching.

Amnion and Chorion : The formation of amnion and chorion starts in the front region of the head of the embryo. In this region there arises a fold of the blastoderm, known as the **head amnion fold**. This fold originally consists of the ectoderm, then the mesoderm develops in this region. The fold becomes directed backwards over the head. Its sides become elongated backwards giving rise to 2 **lateral amnion folds**. Lastly, a **tail amnion fold** is produced in the posterior region of the embryo. These folds become elevated upwards over the embryo. They eventually meet in the mid-line and fuse together; thus forming two double-walled membranes which cover the embryo completely. The inner membrane is known as the **amnion** and the outer one as the **chorion**. The amnion encloses a space, the **amniotic cavity** which surrounds the embryo. It contains a fluid known as the **amniotic fluid** which serves to protect the embryo. The amnion consists of an inner layer of ectoderm and an outer layer of mesoderm. On the other hand, the chorion has an outer layer of ectoderm and an inner layer of mesoderm. The development of the amnion and chorion is completed by the end of the third day of incubation.

Allantois : This arises as an outgrowth from the ventral wall of the hind-gut. This outgrowth becomes directed backwards and gradually increases in size pushing its way between the amnion and chorion. The allantois becomes highly vascular and acts as a respiratory organ for the young chick during its development inside the egg.

Yolk sac : This is developed from the extra-embryonal splanchnopleure. The blastoderm increases progressively until it spreads over the whole yolk. In this way, the edges approach one another and consequently the yolk becomes almost surrounded by two membranes; the outer is the chorion, while

the inner is the yolk sac formed of two layers; an outer mesodermal layer and an inner endodermal one.

During development and until hatching (which usually takes place about the nineteenth or twentieth day), the yolk sac becomes absorbed, while the allantois is still functional. As the lungs complete their development, the allantois begins to dry up and eventually becomes separated from the point of attachment on the ventral wall of the umbilicus.

EMBRYONIC MEMBRANES AND PLACENTA IN MAMMALS

The early stages of embryonic development of mammals retain most of the characteristic features found in reptiles and birds, though their ova contain a small amount of yolk. Hence, a blastoderm similar to that of the chick is produced. This is followed by the development of embryonic membranes.

As in birds, a head amnion fold and a tail amnion fold are produced. When the **amnion** is completed, the embryo lies free in the cavity formed within the **chorion**. It is soon attached by the **allantois**. This membrane develops early; it arises from the hind gut and passes out into the outer lateral cavity known as the **extraembryonal coelom**. It passes around the dorsal side of the embryo and comes to lie in close opposition to the chorion. At the same time, the **yolk sac** has become vascular and acts for a short time as an organ for the transportation of nourishment and oxygen from the mother. In this way, a temporary structure, the **yolk-sac placenta** is produced. This is later replaced by another structure, the **allantoic placenta**. This structure is supplied by the mother from the uterine tissues. From the closely opposed allantois and chorion, a number of small outgrowths, the **chorionic villi** project towards the wall of the uterus, which in this region becomes thickened and vascular. These villi grow into crypts, or depressions by the disintegration of a certain region of the wall of the uterus. The villi become branched and consequently the tissues of the foetus and those of the mother become closely associated. Both parts of the placenta develop a rich supply of blood vessels, which divide up into very fine capillaries distributed in the villi and in the tissue surrounding the villi. However, the blood circulations of the foetus and mother do not fuse, but remain distinct in the placenta. Thus, the placenta is regarded as a vascular organ, where an interchange of materials can take place from the maternal to the fetal blood and vice versa. Nutrients and oxygen dissolved in the blood of the mother diffuse through the thin walls of the uterine capillaries into the foetal capillaries in the villi, whereas waste products, such as urea and carbon dioxide,

pass from the foetal to the mother's blood.

At birth, the amnion and chorion are ruptured to set free the foetus. The stalk of the allantois and that of the yolk sac constitute the **umbilical stalk** which is connected to the foetus during parturition. The place of attachment of the stalk remains as the **umbilicus** or navel.

Types of placentae

The shape of the placenta differs among various kinds of mammals. Hence, the following types are recognised :

1 — **Discoidal placenta** : In this type, the placenta is a single round, button-like disc on the dorsal side of the foetus and containing the villi. This type is found in the rabbit and in most of the rodents. The placenta of man is somewhat similar, but is situated on the ventral side and is considered of the **metadiscoidal type**.

2 — **Cotyledonary placenta** : This type is found in ruminants. In this case, the villi are found over the surface of the chorion in numerous small patches termed the **cotyledons**.

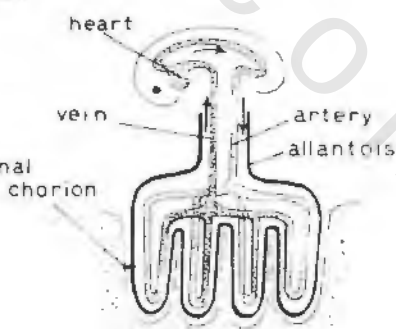
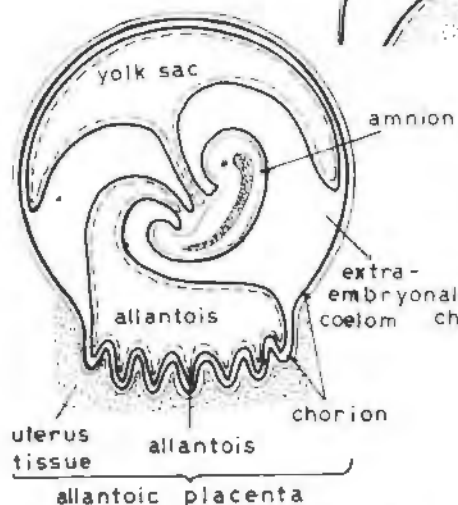
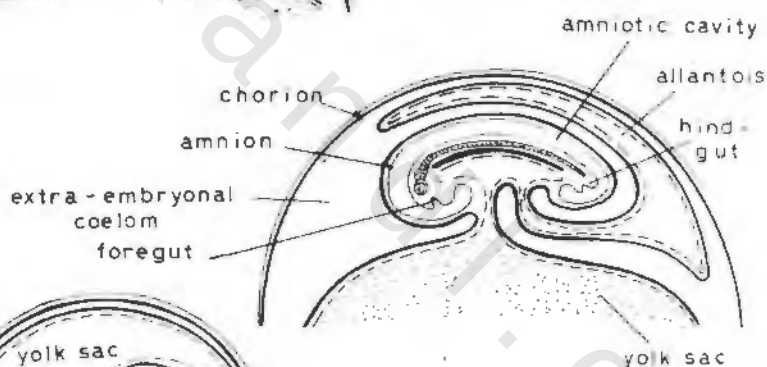
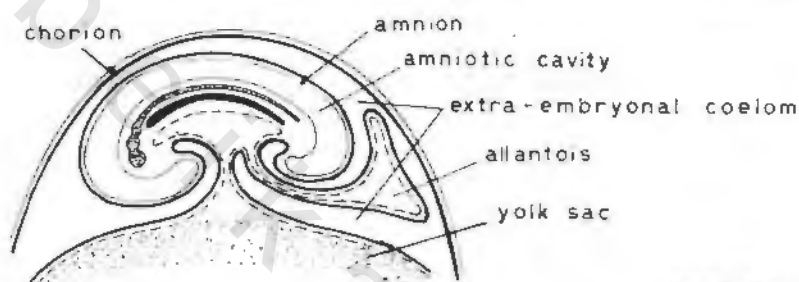
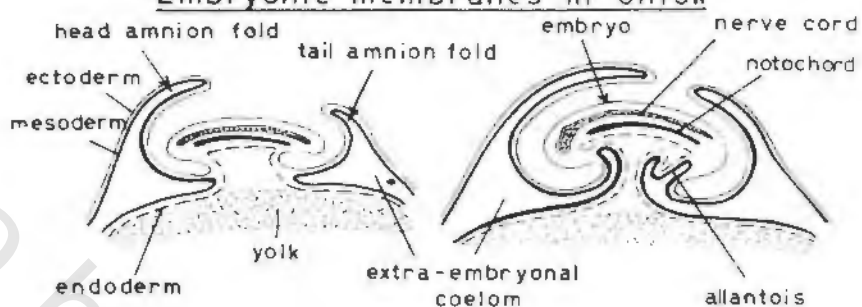
3 — **Zonary placenta**: In this case, the villi are found in a band or zone around the chorion, e.g. that of carnivorous mammals.

Non-deciduate and deciduate placentae

Placentae also differ in behaviour at birth in the various groups of animals. In the more primitive types, the foetal part of the placenta does not form an intimate connection with the uterus. Thus, this foetal portion comes away leaving the uterine portion in its place. This type is known as the **non-deciduate type**, e.g. placenta of the pig.

In the second type, known as the **deciduate type**, both maternal and foetal portions of the placenta are so closely associated and cannot be separated. Both are shed at birth forming a structure called the **decidua** or "after-birth". This type is found in higher mammals including man.

Embryonic membranes in chick



Faetal circulation in
placenta of rabbit

Embryonic membr. in rabbit

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