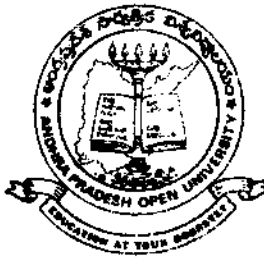


ZOOLOGY

CYTOLOGY, GENETICS, EVOLUTION,
ZOOGEOGRAPHY

BLOCKS 1 – 4

| | |
|-----------|--------------|
| BLOCK I | CYTOLOGY |
| BLOCK II | GENETICS |
| BLOCK III | EVOLUTION |
| BLOCK IV | ZOOGEOGRAPHY |



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PREFACE

This book deals with the topics in Cytology, Genetics, Evolution, Zoogeography, Ecology and Animal Physiology included in the syllabus for the third year of the Zoology course offered by the Andhra Pradesh Open University. These topics generally cover the "Core" area of the subject to be studied in the third year of the three year degree course in Science (B.Sc.). The syllabus for the sake of convenience is divided into several Blocks each of which comprise a number of units. Each Block generally covers a specific area of the subject. The units are prepared by specialists in accordance with the format so designed as to enable the student to read and understand them without much difficulty. Each unit brings with a statement of its objectives followed by synopsis and has at its end assignments intended to test the students comprehension of its subject matter. Technical terms with which the student may not generally be familiar are given at the end of each unit under the head "Glossary".

The course material of this paper is divided into Six Blocks. The Blocks are in turn divided into thirty six units. Block-I deals with the important topics in Cytology. The topics in Genetics are included under Block-II.

Important topics like human syndromes, inborn errors of metabolism and operon concept are also included under this Block.

Block - III deals with the general topics on evolution like theories, evidences, synthetic theory etc. Unit - 19, evolution of man and horse is given. Principles of Zoogeography is, given in Block-IV.

Block - V deals with Ecology. Besides general chapters, important topics like pollution and wild life conservation are included under Ecology.

The last Block is devoted for the topics on Animal Physiology. Special topics like Nutrition, Neurotransmitters, Biological rhythms and Immunological responses are given under the Seventh Block.

The University hopes that this material will help the students to get acquainted with the topics on Cytology, Genetics, Evolution, Zoogeography, Ecology and Animal Physiology.

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BLOCK - I
CYTOLOGY

BRAOU

Unit - 1 HISTORICAL ACCOUNT OF CYTOLOGY; METHODS OF STUDY

Contents

- 1.1 Objectives
- 1.2 Introduction
- 1.3 History of cytology or cell biology
- 1.4 Methods of cytological study
- 1.5 Ultrastructure of cell
- 1.6 Summary
- 1.7 Check Your Progress - Model Answers
- 1.8 Model Examination Questions.

1.1 OBJECTIVES

This unit gives an account of the origin of the concept of cell biology or cytology. By the end of this unit you will be able to describe:

- the methods of study in cell biology and
- the ultrastructure of a generalized animal cell.

1.2 INTRODUCTION

Cytology is a branch of biology which deals with the study of the cell (cyto = cell, logos = discourse). Now-a-days this branch of study is called 'cell biology'. Cytology deals with the structure of various components of the cell and their physiology.

The term 'cell' was coined by **Robert Hooke** (1665) to explain the texture of cork as found with the magnifying lenses. These observations were repeated by **Grew** and **Malpighi** on different plants. Later, **Leeuwenhoek** (1674) discovered free cells of **Hooke** and **Grew**. **Leeuwenhoek** made some observations on the structures within the cells like the nucleus in some erythrocytes. For the next 100 years and more, no new information was added to the field of cytology.

1.3 HISTORY OF CYTOLOGY OR CELL BIOLOGY

At the beginning of the nineteenth century several investigations were carried out on cell structure and function. Of them, the more important works were those of the German botanist **Schleiden** (1838) and the German Zoologist **Schwann** (1839). These works laid the foundation for the cell theory and its further growth and development. The cell theory was applied to various fields of biology by researchers like **Virchow** and **Kolliker**.

Other investigators like **Brown** (1831), **Dujardin**, **Schultze**, **Purkinje** and **von Mohl** made investigations on several angles of cell structure.

The cell theory, as proposed by **Schleiden** and **Schwann**, is summarized below:

1. Plants and animals are constructed entirely of cells, or substances produced by cells.

2. All cells arise from pre-existing cells. This view later confirmed by Virchow (1858). He expressed it in the form of the famous aphorism *Omnis cellula a cellula* ("Cells always arise from cells").
3. Cells have their own life.
4. The life span of a cell is subject to the lifespan of the organism as a whole.

As a result of the formulation of the cell theory, the cell is made up of a mass of protoplasm surrounded by a cell membrane and containing a nucleus.

After the establishment of cell theory, the knowledge in cytology made speedy progress.

The interesting changes shown by cells during cell division were investigated by numerous investigators. Flemming and Strassburger discovered the phenomena of amitosis (direct cell division). Indirect division was called Karyokinesis by Schleicher (1878) and the term mitosis was coined by Flemming (1880).

Waldeyer (1890) described the nuclear filaments or chromosomes. Equal division of the chromosomes between the nuclei (daughter cells) was found to be the fundamental event in mitosis.

Fertilization of the egg by the sperm and fusion of the two pronuclei were discovered by Hertwig (1875). In the cytoplasm the aster was described by von Beneden and Boveri, mitochondria by Altmann and Benda, and the particular apparatus by Golgi.

In 1892, O. Hertwig published his monograph *Die Zella und das gewebe* in which he summarized the cytological insights obtained upto his times. He thus created the discipline of cytology as a branch of biology.

The advances in cytology achieved in the present century (i.e., twentieth century) resulted from 2 causes:

1. Increased resolving power of instrumental techniques obtained by electron microscope and X-ray diffraction techniques.
2. Convergence of other fields of biology like genetics, physiology and biochemistry towards cytology.

Clarification of genetic phenomena through subcellular events, during mitosis and meiosis established close link between cytology and genetics and a separate field of enquiry named cytogenetics resulted from this linkage. Interpretation of sub-cellular phenomena through physiology paved the way for the formation of a special branch of biology named molecular physiology and biochemistry.

The recent advances made in the study of genetic raw material. DNA (Watson and Crick, 1953) and action material. RNA have resulted in the formation of the very young branch of biology, molecular genetics.

1.4 METHODS OF CYTOLOGICAL STUDY

Anatomy is an important branch of biology. It involves dissection of an organism, separation of the part and their study. Cytology also involves observation of a cell under a microscope to 'resolve' the structure and study them. Thus this is also an anatomic approach. While for the large organisms the anatomic study is "microscopic" anatomy, for the cell, the study may be considered to "microscopic anatomy".

Thus in the field of cytology, the physical principles of resolution and magnification are important. They are the principles on which the microscopes operate and microscopy thus

becomes an important instrumental technique in cytology.

By the application of basic principles of optics of lenses microscopes of varying magnification indices were made and these instruments helped in a finer resolution of the structure of the cell called the ultrastructure.

In the electron microscope instead of light a beam of electrons is used in the resolution of components of the cells. This instrument has revolutionized cytological enquiry and has paved the way for the study of molecular level of construction of cell constituents or organelles. This has helped in visualization of else correlation between form and function at the finest level of resolution and the fundamental, molecular level of organization.

Microscopic study involves preparation of material in form suitable for microscopic examination. This preparation comes under the routine laboratory field of 'micrology'.

Micrology includes preparation of material (animal tissue) according to established procedures for 'microtomy', preparation of ultra-thin-sections of material, fixation of sections and staining of sections. Using different stains the different structures located in a tissue and in the components of the tissue (cell) can be visualized and even photographed. The staining techniques are called histo-chemical staining techniques. The technique of photography using microscope is called microphotography and electron micrography depending on the magnifying 'instrument' used.

The large sized 'macroscopic' organisms can be measured in terms of meters and other 'macroscopic' units. These units of measurements cannot be applied to the cells and cell components at the microscopic level. Thus for these submicroscopic structures, different units of measurement (micromensuration, if one may call it) were evolved.

One such micromensuration 'longimetric' unit is 'micron' or micrometer. It is represented as μm . A μm is one millionth part of a meter or one thousand part of a millimeter. The other units of measurement used for microscopic situations are given in Table-1.

Table - 1
Units of Micromensuration (Microscopic Measurement)

| Name of the Units | Symbol | Expression in terms of meter (m) | |
|-------------------|--------|----------------------------------|--------------------|
| | | Fractional | Exponential |
| Millimeter | mm | 1/1000m | 10^{-3}m |
| Micrometer | m | 1/1,000,000 m | 10^{-6}m |
| Nanometer | nm | 1/1,000,000,000 | 10^{-9}m |
| Picometer | pm | 1/1,000,000,000,000 | 10^{-12}m |
| Angstrom Unit | A' | 10^{-8}m | 10^{-8}m |

Various organelles show sizes in the range of micrometers. The smaller constituents of the organelles can be measured in the range of nanometers

1.5 ULTRASTRUCTURE OF THE CELL

The cell under light microscope shows the structure as given in figure 1.1.A.

The electron microscopic picture of the structure of the cell shows the plasma membrane of the outer limiting membrane. This membrane shows several infoldings which are continuous with the 'membrane system' located in the cell interior. The membrane-system of the cell, interior is, therefore, though to have arisen from the plasma membrane itself through extensive 'invaginations' or infoldings.

The plasma membrane shows several tubes or out pocketings outfoldings or 'evaginations'. These form the organelles like cilia and flagella and structures like microvilli. The plasma membrane is also involved in the formation of pinosomes. The membrane is further involved in the formation of intercellular bridges like desmosomes.

The membrane systems of the cell interior is located in the endoplasm. Here, this appears as a network like system of canaliculi and tubules. This is named endoplasmic reticulum. In the endoplasm there are other structures which are considered to have been derived from the membrane system.

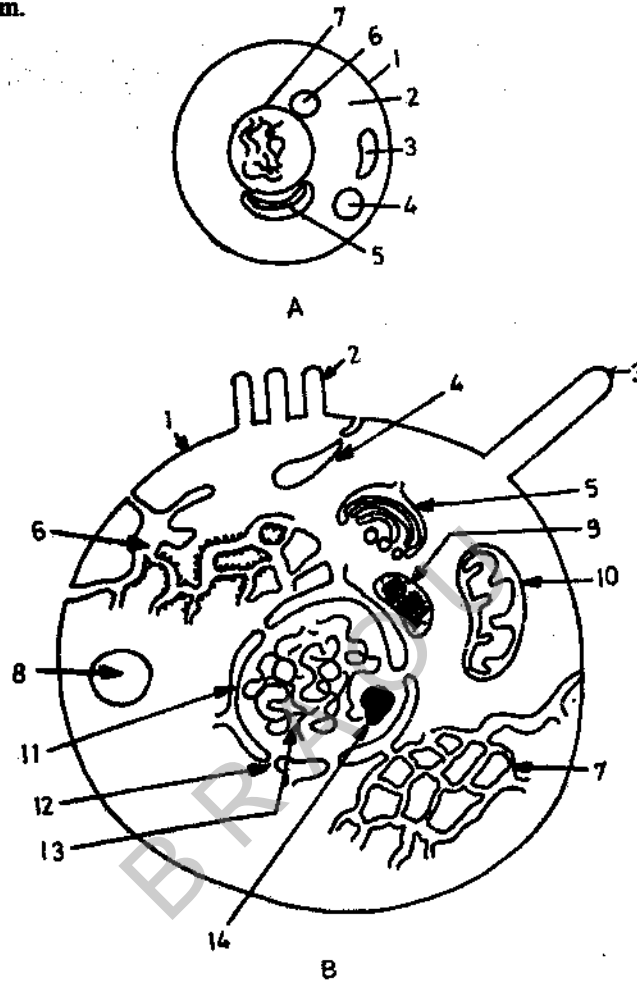


Fig. 1.1. Ultrastructure of the animal cell. A. Diagrammatic light microscopic view of the animal cell. 1. Plasma membrane 2. Cytoplasm 3. Mitochondrion 4. Vacuole 5. Golgi complex 6. Central body 7. Nucleus B. Electron microscopic view of the cell 1. Plasma membrane 2. Microvilli 3. Cilium or flagellum 4. Pinosome 5. Golgi complex 6. Granular endoplasmic reticulum (ER) 7. Agranular ER 8. Vacuole 9. Centriole 10. Mitochondrion 11. Nuclear membrane or karyolemma 12. Nuclear pore 13. Chromatin reticulum 14. Nucleolus.

Mitochondria are rod like or filamentous structures. Golgi complex is made of vesicles and membranous structures.

The centrosomes appear as structures with typical microfibrillar plan of construction. Lysosome and plastids of typical structure also are located in the cytoplasm. In addition typical membrane wrapped spaces are also located in the cytoplasm. These are the vacuoles.

The endoplasmic reticulum shows two regions one region where granular structures called ribosomes are studded on it. This is the granular or rough endoplasmic reticulum. The second region is devoid of the granules; this is the agranular or smooth endoplasmic reticulum.

The cytoplasm in its centre shows a spherical structure named the nucleus. This is composed of an outer double-membrane envelope, the nuclear membrane or karyolemma. The karyolemma

shows minute pores of special organisation, the nuclear pores. The interior of karyolemma is provided with a fluid, the nuclear sap. In the sap. In the resting nucleus, a network of fibrils can be seen the chromatin reticulum. During cell division or mitosis, these fibrils are condensed to form structures with typical and varying shapes, the chromosomes. Besides the chromatin reticulum or chromonemata the nucleus shows a structure named nucleolus.

The structures found in and on the cells are involved in the discharge of one duty or other connected with the biology of the cell (just as organs are involved in the discharge of functions in an 'organism' made of many cells). Thus these structures are called cell organs or organelles. These are dealt with in detail in succeeding units.

Check Your Progress

1. Microscopic study involves preparation of material in form suitable for microscopic examination. This preparation comes under the field of _____.
2. History of cytology begins with the term 'cell' coined by _____.

1.6 SUMMARY

1. Cytology is study of the cell.
2. History of cytology begins with the term 'cell' coined by Robert Hooke (1665).
3. Leeuwenhock's (1674) discovery of cells is the second step in the historical development of cytology.
4. The cell theory proposed by the German scientists Schleiden and Schwann is followed by rapid advances in cytological studies.
5. Hertwig (1892) establishes the discipline of cytology as a branch of biology.
6. In the twentieth century cytology makes many more advances due to more efficient instrumentation and convergence of genetics physiology and biochemistry on cytology.
7. The establishment of structure of DNA (Watson and Crick) (1953), leads to the emergence of molecular genetics as the youngest frontier science of biology.
8. For cytological study the techniques used involve several kinds of microscopy, microphotography and micrology.
9. The ultramicroscopic structures and phenomena are measured in appropriate units.
10. The cell shows several structures under the microscope. These have definite functions. Hence, they are termed cell organs or organelles.

1.7 CHECK YOUR PROGRESS – MODEL ANSWERS.

1. Micrology
2. Robert Hooke (1665).

1.8 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines:

1. Give a brief account of history of development of cytology.
2. Give an account of the electron microscope structure of the cell.

Unit – 2 STRUCTURE AND FUNCTIONS OF CELL ORGANELLES: PLASMA MEMBRANE; ENDOPLASMIC RETICULUM(ER); GOLGI COMPLEX

Contents

- 2.1 Objectives
- 2.2 Introduction
- 2.3 Plasma Membrane
 - 2.3.1 Chemical composition of plasma membrane
 - 2.3.2 Structure of plasma membrane
 - 2.3.3 Functions of plasma membrane
- 2.4 Endoplasmic Reticulum
 - 2.4.1 Finer structure
 - 2.4.2 Functions of Endoplasmic Reticulum
- 2.5 Golgi complex
 - 2.5.1 Chemical composition
 - 2.5.2 Functions of Golgi complex
- 2.6 Summary
- 2.7 Check Your Progress – Model Answers
- 2.8 Model Examination Questions

2.1 OBJECTIVES

This unit deals with some of the organelles found in the living cells viz., plasma membrane, endoplasmic reticulum and Golgi complex. By the end of this unit you will be able to describe the:

- structure of the organelles
- chemical composition and functions of these organelles.

2.2 INTRODUCTION

In the preceding unit we have learnt the ultrastructure of the animal cell. In this unit the functions of the various structures found in the animal cell will be given in some detail.

The multicellular animal is made of many cells which are organised as tissues, organs and organ systems. For all these structures, the cell forms the building block or brick. The cell is considered to be the structural and functional unit of construction of a multicellular animal.

As mentioned above, the animal is made of organs each discharging a particular duty or function. In the cell also different parts or structures do different duties. These structures are therefore to be named cell organs or 'organelles'. Thus, in this lesson the form and functions of different 'organelles' will be studied.

2.3 PLASMA MEMBRANE

Location

The cell is covered by a thin surface membrane named **plasma membrane**. This membrane controls the movements of ions and molecules into and out of the cell. This property is called **permeability**. Through this property the plasma membrane helps in the maintenance of the chemical composition of the cell interior or milieu interior as different from the chemical composition of the exterior or milieu exterior.

In different types of cells, the plasma membrane is enveloped by thicker protective layers. These layers called **extraneous coats** or **cell walls** are different from plasma membrane and have no role in permeability. These coats are named **glycocalyx**.

Plasma membrane had been isolated from several types of cells like liver cell, striated muscle, *Amoeba proteus* using different techniques. Haemolysis of erythrocytes has been found to be an easy method of preparation of plasma membrane

2.3.1 Chemical composition of the Plasma Membrane

The plasma membrane shows two major components in its chemical composition: protein and lipids. In addition to these components a small quantity (1 to 5%) of oligosaccharides also is present in the plasma membrane. In different types of cells, the lipid: protein ratio varies in nerve cells, the lipid is the larger component and in other cells, the protein forms the larger component (Table 2.1).

Table 2 : The relative composition of lipids and proteins in some plasma membrane preparations

| Source | Protein | Lipid |
|----------------------|---------|-------|
| Human Nerve : Myelin | 20 | 79 |
| Rat Skeletal Muscle | 65 | 35 |
| Human Erythrocyte | 60 | 40 |
| Rat Liver | 60 | 40 |

Source : 'Cell Biology' : De Robertis et al., 1975

The major fractions of the lipid of plasma membrane are phospholipids, cholesterol and galactolipids. The protein part of plasma membrane is made of different proteins. The protein molecules serve mechanical functions and act as enzymes, antigens and receptor molecules. The different kinds of proteins give to the plasma membrane the various properties like selective permeability, active transport, receptor function etc.

2.3.2 Structure of Plasma Membrane

In earlier studies, the structure of plasma membrane was interpreted on indirect information based on observations with permeability to various substances. Danielli (1934) stated that the plasma membrane contains a lipid bilayer with protein adhering to both outer and inner aqueous interfaces.

The later studies with electron microscope have confirmed the postulation of Danielli, in addition to throwing light on structural differentiation of plasma membrane in different types of cells.

Presently the plasma membrane of cells is named as 'trilayered' unit membrane. This unit membrane structure is found in other organelles inside the cell.

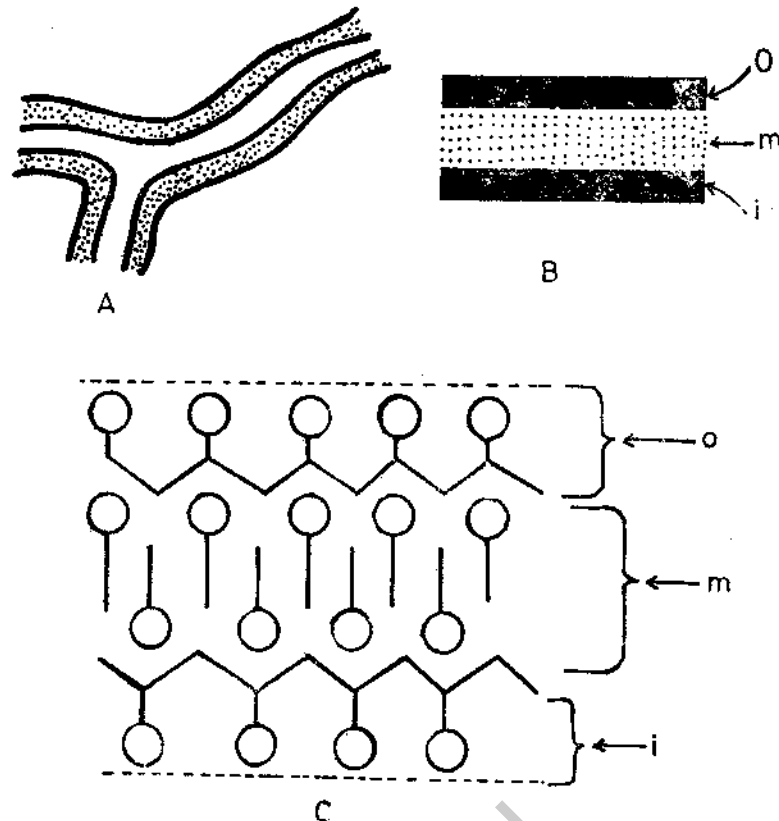


Fig 2.1 Unit membrane structure of plasma membrane A. The plasma membranes showing layered nature. B. Magnified view of the membrane showing outer (o) and inner (i) layers and middle (m) layer. C. Diagrammatic representation of outer (o) and inner (i) protein layers and middle (m) lipid bilayer.

The present day cell physiologists, however, are not satisfied with the oversimplified 'unit membrane concept' involving rather rigid organisation of molecular complex of the plasma membrane. They have put forward a model named 'liquid or fluid mosaic' model of the membrane structure. In this model, the biological membrane is considered to be a 'quasi-fluid' structure.

2.3.3 Functions of Plasma Membrane

Permeability : As mentioned above, the major function of plasma membrane is 'permeability' and this property is responsible for the maintenance of **compositional integrity of cytoplasm**. The property of permeability involves two major processes: active and passive transports.

In addition to this general function the plasma membrane also performs special functions in certain cells.

Specializations

- a) **Microvilli :** The mucosal cells of intestine show structures known as 'microvilli'. They appear under the light microscope as a **straited border**. These cytoplasmic processes increase greatly the effective surface of absorption (Fig. 2.2)
- b) **Intercellular junctions :** The plasma membrane forms intercellular junctions: tight junctions, intermediary junctions, desmosomes and gap junctions. These junctions forms the basis for intercellular organisation and tissue formation.
- c) **Formation of cilia and flagella :** The plasma membrane is involved in the formation of cilia and flagella which serve important functions in unicellular and multicellular organisms.

- d) **Formation of pseudopodia** : In some protozoans, the thin and highly flexible and distensible plasma membrane participates in the formation of pseudopodia and thus subserves the function of locomotion and food-capture.
- e) **Pinocytosis**: In microscopic organisms like amoeba the process of pinocytosis is concerned in transport of macromolecules like proteins into the cell interior. Plasmalemmal invaginations along with the surface adhered materials from channels which later are pinched off into the cytoplasm in the form of minute globules called pinosomes.
- f) **Myelination**: In mammalian nervous systems the neuronal axis is surrounded by a lipoprotein membrane called myelin sheath. This is a specialized plasma membrane. Here myelination leads to a faster conduction of electrical impulses along the neuron.

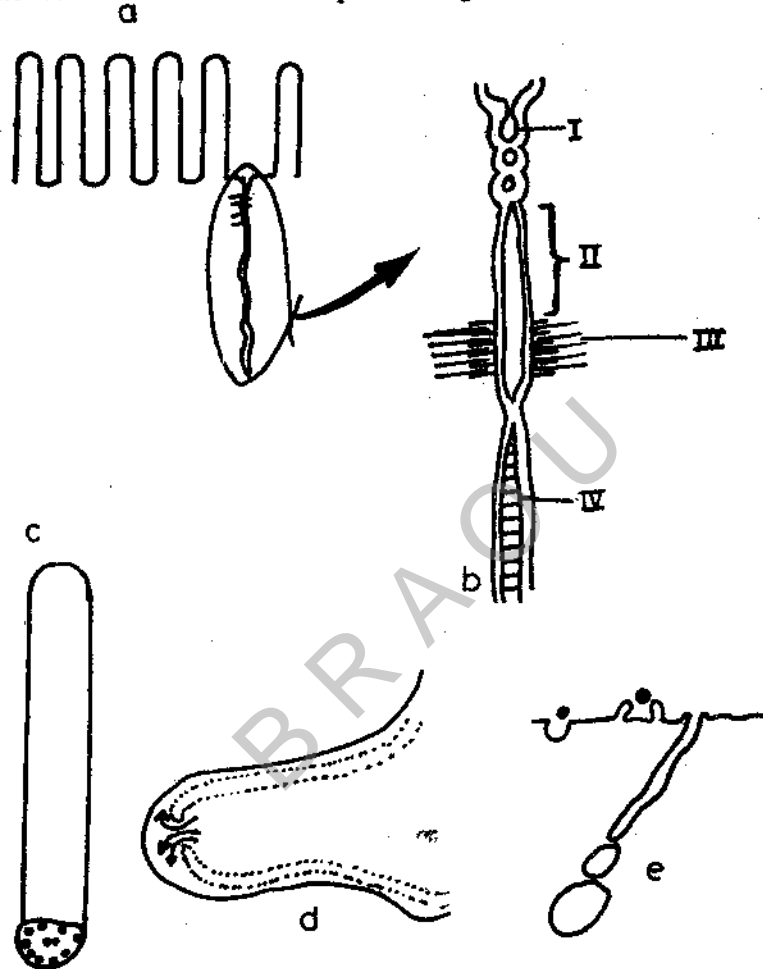


Fig 2.2 Specialization of plasma membrane a. Microvilli b. Intercellular junctions. I. Tight Junction II. Intermediary Junction III. Desmosome IV. Gap Junction c. Cilium d. Pseudopodium e. Pinocytosis.

- g) **Glycocalyx** : This is not a specialization of plasma membrane but the outer coat on plasmalemma. This serves several functions like molecular recognition and tissue organisation antigenicity and immune reaction and control of ultrafiltration.

2.4 ENDOPLASMIC RETICULUM

Location

Under light microscope, the reticular organisation of the endoplasm cannot be made out fully but under electron microscope, the reticular organisation of the endoplasm will be clear. This

complex has come to be known as endoplasmic reticulum (ER). ER is made of a membrane-system extending from the nucleus through the cytoplasm to the cell periphery showing tubular organisation at certain places and vacuolar or vesicular organisation at certain other locations. It has been named *ergastoplasm* (Greek: *ergazomai*, to elaborate and transform) by Garnier (1887) to indicate that this substance is concerned with biosynthesis.

2.4.1 Finer structure

The ER under very high magnification of thin-section preparations shows numerous microtubules which are in extensive inter-communication. In addition, the ER may show here and there vesicles and large flattened sacs named cisternae.

Several morphological features warrant the sub-division of the vacuolar system into the endoplasmic reticulum proper and the Golgi complex.

In the endoplasmic reticulum two regions may be recognized: Smooth or agranular ER and rough or granular ER. The rough ER shows on its membranes ribosomes arranged in a regular order so that the whole system appears rough. The smooth ER is devoid of the ribosomes (Fig. 2.3).

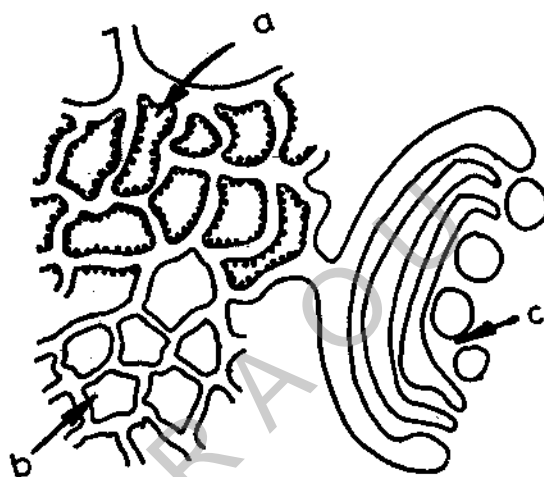


Fig. 2.3. Organization of endoplasmic reticulum (ER) a. Rough ER b. Smooth ER c. Specialized regions of smooth ER (Golgi complex).

Rough ER is well developed in cells engaged in active synthesis of protein. In glandular digestive enzyme producing cell, for example, the ER is highly developed.

The smooth ER is composed of a system of microtubules and is devoid of biosynthetic potentiality.

ER is absent in embryonic plant and animal cells. These cells, however, show the ribosomes dispersed in the cytoplasmic matrix.

The membranes of ER show the typical unit membrane structure.

In the tissue fractionation experiments we often obtain a fraction made 'microsomal' fraction. This is a 'preparation artifact' and represents parts of smooth and rough ER. This preparation has been found useful in experimental biological studies.

2.4.2 Functions of ER

As mentioned above the ribosomes located in the rough or granular ER carry out protein synthesis. The microtubular system of ER, gives mechanical support to the cytoplasmic matrix.

The ER-system also has ion transport capabilities by which certain electrical gradients are created. Such gradients are important in the functioning of certain cells like nerve cells. The ER-system has the 'canalicular transport system' in which cytoplasmic circulation and flow are facilitated. This property is useful for the export of RNA from the nucleus into the cytoplasm. The ER is also involved in detoxification of drugs and steroid hormones. In addition to protein synthesis mentioned above, lipoprotein and glycoprotein synthesis are also carried out by ER.

2.5 GOLGI COMPLEX

The specialized part of ER called Golgi complex was discovered by Golgi (1898) using 'silver staining' technique in his micrological work.

Structure

The Golgi complex is composed of membranes belonging to the vacuolar system of the cell. An important trait of the Golgi complex is the lack of ribosomes. Obviously, this organelle is incapable of protein synthesis. In cells with a polarized structure, the Golgi complex occupies a position between the nucleus and the pole of the cell, as a single large entity. In other types of cells including plant cells, there are 'multiple Golgi Complexes' showing no polarity. In liver cells, there may be as many as 50 Golgi complexes (Golgi apparatuses or dictyosomes as these were formerly called).

In the Golgi complex three membranous components can be recognized under electron microscope: (1) Flattened sacs or cisternae (2) clusters of vesicles or tubules of small (60 nm) diameter and (3) larger vacuoles filled with granular or amorphous material.

The Golgi cisternae are arranged in parallel, concentrically showing convex and concave faces. This cisternal system on the concave face often encloses a system of large vacuoles. On the convex face the system of small vesicles and tubules is located (Fig. 2.4).

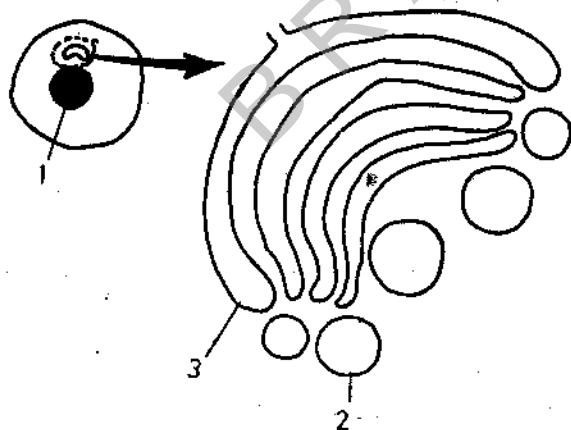


Fig. 2.4 Organisation of Golgi complex. 1. Zymogen granule 2. Golgi cisterna 3. Golgi vesicle

2.5.1 Chemical Composition

Gentle homogenization of the cells and differential gradient centrifugation have been used by cell physiologists for isolating Golgi complex. A chemical analysis of located Golgi complex shows that the complex is composed of 60% protein and 40% lipid. In addition to these predominant components, the Golgi complex shows very low levels of RNA, DNA and polysaccharides, glycolipids and phospholipids. The Golgi complex shows certain enzymes also. Thiamine pyrophosphatase, glycosyl transferases etc.,

2.5.3 Functions of Golgi Complex

- a) **Lipoprotein and lipid accumulation** : Evidence available so far suggests that the Golgi complex is involved in the accumulation of lipid and lipoprotein material. The complex does not play a role in the synthesis of these substances, which is done by the nearby endoplasmic reticulum.
- b) **Secretion** : In cells which are involved in active secretion of various substance of Golgi complex is much more elaborately developed. On this evidence one can imagine that this complex is closely involved in the cellular secretory mechanisms.
- c) **Lysosome formation** : In the organisation of lysosomes the complex is involved.
- d) **Glycoprotein storage** : The synthesis of glycoproteins is carried out by the endoplasmic reticulum. Accumulation and storage of this material are carried out by Golgi complex.

A liver cell elaborated two types of glycoproteins. One type is released to the exterior and the second is secreted onto the plasma membrane to form the cell coat or glycocalyx.

Check Your Progress

1. Danielli stated the plasma membrane contains a bilayer _____ with _____ adhering to both outer and inner aqueous interfaces.
2. Protein synthesis takes place above the _____ located in the rough or granular endoplasmic reticulum.

2.6 SUMMARY

1. The plasma membrane surrounds the cell. It is in turn surrounded by the cell coats or 'glycocalyx'.
2. This membrane shows unit membrane structure: outer and inner protein layers sandwiching middle lipid bilayer.
3. The membrane is made of lipoprotein complex, which may have rigid molecular arrangement or may form a 'fluid mosaic'.
4. The membrane controls permeability and absorption (microvilli). The intercellular functions of plasma membrane play a role in tissue formation.
5. The plasma membrane is involved in the formation of cilia flagella and pseudopodia.
6. The membrane plays a role in pinocytosis and phagocytosis.
7. The membrane is involved in myelination of nerve cells.
8. The endoplasmic reticulum (ER) is present as the microtubular reticulum in the endoplasmic region of cytoplasm. It is made of smooth (agranular) and rough (granular) region.
9. The ER membrane show unit membrane plan of structure.
10. The ER is the site of protein synthesis, microtubular transport and the sources for the organisation of other cytoplasmic organelles
11. The Golgi complex is made of cisternal and vacuolar structure and is concerned with cell secretions.

2.7 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Lipid, protein
2. Ribosomes.

2.8 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines :

1. Describe the structure of plasma membrane.
2. Give an account of the functions of plasma membrane.
3. Give an account of the structure and functions of endoplasmic reticulum.
4. Give an account of the structure and functions of Golgi complex.

BRAOU

Unit – 3 **STRUCTURE AND FUNCTIONS OF CELL ORGANELLES : MITOCHONDRIA, LYSOSOMES, CENTRIOLES, RIBOSOMES AND NUCLEUS**

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- 3.1 Objectives
- 3.2 Mitochondria
 - 3.2.1 Mitochondrial morphology
 - 3.2.2 Functions of mitochondria
- 3.3 Lysosomes
 - 3.3.1 Functions of Lysosomes
- 3.4 Centrioles
 - 3.4.1 Structure
 - 3.4.2 Origin of centriole
 - 3.4.3 Functions of mitotic spindle
- 3.5 Ribosome
- 3.6 Nucleus
- 3.7 Summary
- 3.8 Check your progress - Answers

3.1 OBJECTIVES

This unit deals with mitochondria, Lysosomes, Centrioles, ribosomes and nucleus. By the end of this unit you will be able to explain :

- structure and location,
- chemical composition and functions of above organelles.

3.2 MITOCHONDRIA

The mitochondria (sing: mitochondrion: Gr., mito = thread, chondrion = granule) are granular or filamentous cytoplasmic organelles popularly known as 'power house' or 'power plants' of the cell.

The mitochondria were first described by Altmann (1894) as 'bioplasts; and were renamed as mitochondria by Benda (1897). Altmann predicted the relation between mitochondrion and cellular oxidations.

3.2.1 Mitochondrial Morphology

The mitochondria can be visualized under dark field illumination and phase contrast, in suitable histological preparations.

The mitochondria show rapid changes in their appearance (shape and size) under different chemical, osmotic and mechanochemical conditions.

The mitochondria are generally filamentous or granular in appearance. Vesicular, club shaped and tennis racket-like appearance are also some times presented by mitochondria.

Distribution

In a majority of cases, the mitochondria are uniformly distributed throughout the cytoplasm. In certain special cases, the mitochondria appear around the nucleus or in the peripheral cytoplasm. During mitosis, they are located near the spindle (mitotic) and are distributed between daughter cells, almost equally. In some cells, the structures move freely in the cytoplasm, supplying energy where needed. In some others, the mitochondria are more or less permanently stationed in one particular part of the cell.

Orientation

In long cylindrical cells, the mitochondria show basi-special orientation. In other cells, the structures are radially arranged.

Number

The mitochondria are located in all aerially respiring organisms. In bacteria, they are absent. The number of these organelles varies between different cells. In the same cell the mitochondria cluster themselves in large numbers at places where there is high cellular activity: at synapses of nerve cells; in the actively beating sperm-tails; just under the striated border (microvilli) of the intestinal mucosal cells etc.

Structure

The ultrastructure of the mitochondrion can be observed using the high resolution electron microscope.

The mitochondrion is in the form of a bag whose wall is made of two lipo-protein membranes which are similar to plasma membrane and the membrane system of endoplasmic reticulum. Thus the mitochondrion shows two compartments, the outer compartment between the outer and inner membranes and the inner compartment inside the inner membrane. The inner compartment contains the mitochondrial matrix. (Fig. 3.1).

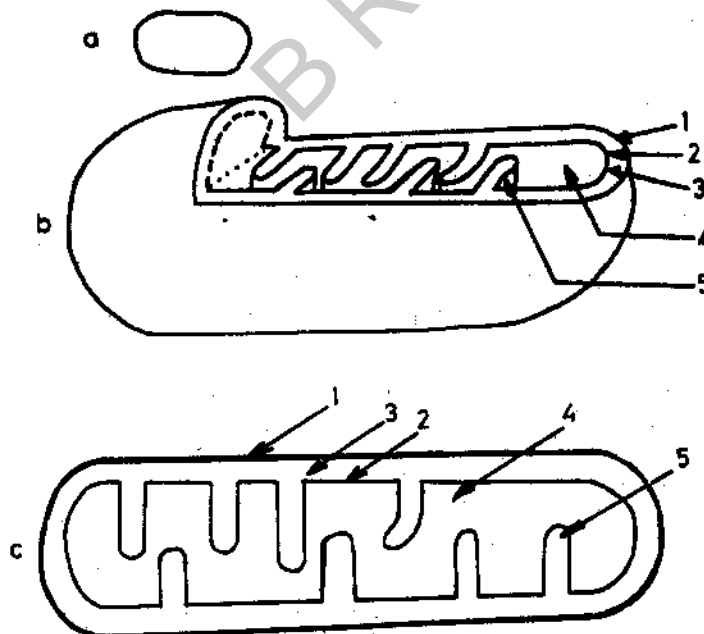


Fig. 3.1. Mitochondrial structure a. Entire b. Three-dimensional sectional view c. Longitudinal sectional view 1. Outer membrane 2. Inner membrane 3. Outer compartment 4. Inner compartment 5. Crista

The outer membrane is smooth and elastic. The elastic property provides for the swelling and shrinking of the mitochondrion. The inner membrane is thrown into folds named **crests mitochondriae** or **mitochondrial crests**.

The mitochondrial matrix is generally homogenous but in some cases contains filamentous or granular material. The granular materials are considered to be the sites of binding of divalent cations like Ca^{2+} and Mg^{2+} . The matrix in addition, contains soluble proteins and smaller molecules.

The mitochondrial crests projecting into the matrix form incomplete septa; so, the matrix is continuous.

The mitochondrial membranes show typical unit membrane plan of construction i.e., being made of two layers of high electron opacity (density) and a middle 'sandwiched' layer of lower electron capacity.

Special techniques of treatment of the mitochondria and electron microscopy have shown the remarkable molecular organisation of the mitochondrial crests (Fig. 3.2).

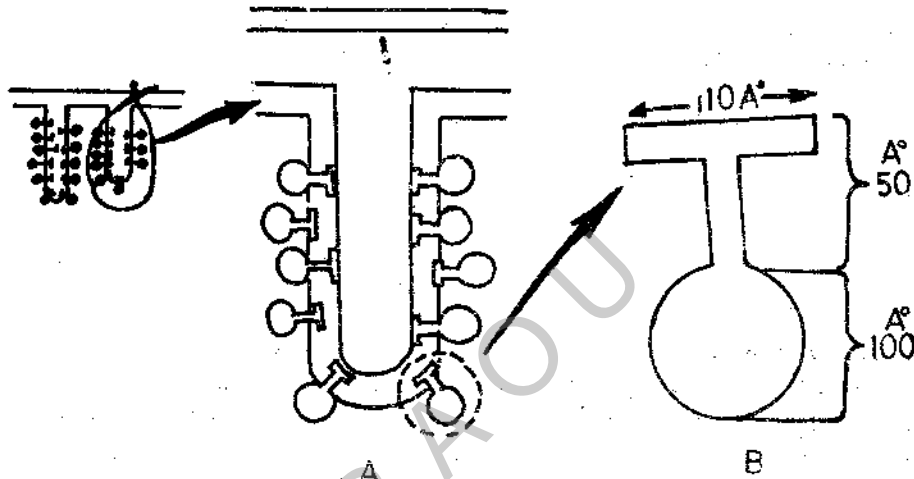


Fig. 3.2 Organisation of Crista A. Crista showing F₁ particles (F₁P) B. Magnified view of F₁P.

The crest membrane shows 'elementary' or 'F₁ particles' arranged at regular intervals in the membrane. These particles represent special ATPase involved in coupling oxidation and phosphorylation. Besides, the inner surface of the membrane (the surface facing the matrix) shows certain particles which show regular spatial arrangement. These 'assembly-lines' are the cytochrome batteries.

The outer membrane does not contain the F₁ particles but two important enzyme systems viz., NADH-cytochrome-c-reductase system (made of a flavoprotein and cytochrome b₅ and monoamine oxidases).

The outer chamber contains two enzymes concerned with nucleic acid metabolism.

The matrix contains enzymes of the Krebs' cycle concerned with aerobic degradation of metabolites.

3.2.2 Functions of mitochondria

1. **Aerobic degradation of cellular metabolites:** The matrix enzymes named Krebs cycle enzymes are concerned with the degradation of metabolites under conditions of oxygen availability. The glycolytic phase of carbohydrates for example, takes place in the cytoplasm. The terminal metabolite of glycolysis viz., pyruvate permeates through mitochondrial

membranes and reaches the inner compartment where it enters the Kerb's cycle. In this cycle pyruvate undergoes a series of decarboxylations and dehydrogenations. The dehydrogenations represent the oxidation of pyruvate.

2. **Electron transport** : Through dehydrogenations, pairs of hydrogen atoms are removed from the substrate and they are taken by flavoproteins. A pair of electrons from these hydrogen atoms is transferred to the cytochrome battery and along this battery the electrons travel causing a sequence of reversible reduction-oxidations. This is named as 'electron transport'; Four complexes are known to be connected with the operation of the process of electron transport: Complex I, II, III and IV (Fig. 3.3).

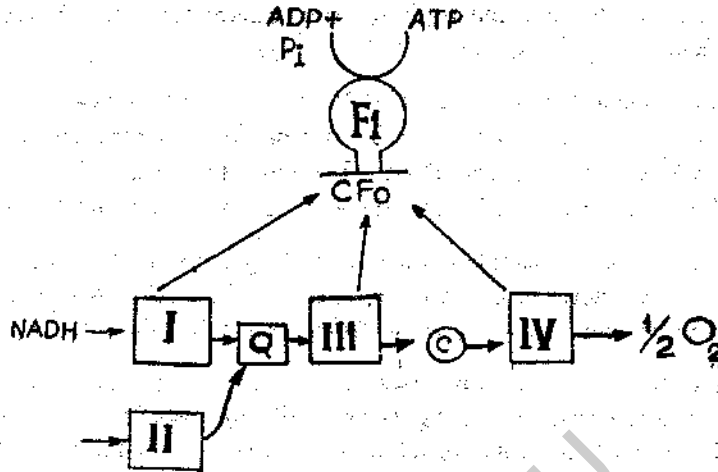


Fig. 3.3. Electron transferring complexes I, II, III and IV and ATP ase complex (F₁) present in the mitochondrial crest.

- 3) **Oxidative Phosphorylation** : As the pairs of electrons travel along the cytochrome battery, energy is released in quanta. This energy is incorporated into the high energy bonds and ATP molecules are synthesised. Thus the release of energy on oxidation and its incorporation into chemical bonds in phosphorylation (of ADP with P_i to form ATP) are coupled in a very efficient manner and the cellular energy currency-the ATP molecules-is synthesised. This is named oxidative phosphorylation or coupling of oxidation with phosphorylation. In this process, the F₁ particles play the key role but certain 'coupling factors' are located in the mitochondria which connect or 'couple' oxidation with phosphorylation.

When the coupling factors are absent or are neutralised, the process of oxidation will be 'uncoupled' from phosphorylation and the energy released during oxidation and electron transport will be 'wasted' as heat energy.

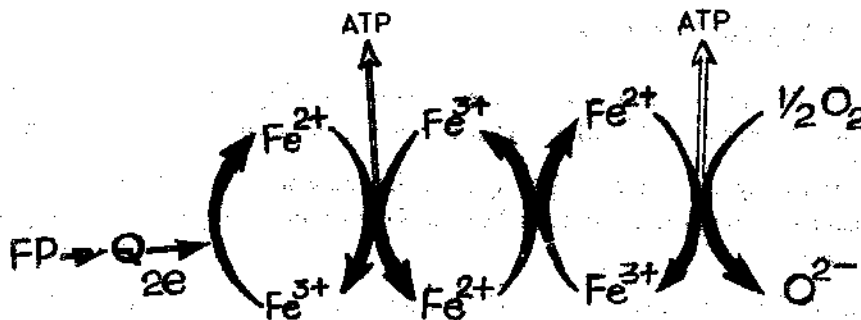


Fig. 3.4 Oxidative phosphorylation. The iron (Fe) prosthetic groups of the cytochromes b, c and a get reversibly reduced and oxidised as the electron-pair passes along the cytochrome battery. The energy released during oxidation of cytochromes is incorporated into high energy bond of ATP Molecule.

Since the synthesis of ATP, the cellular energy currency, takes place in a big way in the mitochondrion, it is called the 'power house' or 'power plant' of the cell.

- 4) **Control of energy requiring processes:** The mitochondrion, because of its capacity to synthesis ATP molecules participates in energy dependent processes like lipid and protein synthesis. In several locations where energy is immediately necessary in good quantities, these organelles show an orderly aggregation. In the synapses of neurons in the presynaptic nerve endings, the mitochondria are located in large numbers. Here they energise the processes of synaptic transmission. In the muscle cell, the mitochondria aggregate at the places where the energy requiring contractile mechanism is located. The mitochondria are located in good numbers in cell, at places where active transport of materials is going on : e.g. the striated border of mucosal cells of intestine. Similarly in secretory cells also, the mitochondrial aggregation can be observed.

Is mitochondrion a semiautonomous organelle? Recent researches indicate that the mitochondrion has a considerable degree of autonomy in its organisation and function. Mitochondria contain DNA which is different from nuclear DNA. Therefore, these organelles possess selfduplicating system. In addition, these organelles contain a special mitochondrial RNA.

There are two hypotheses in circulation about the biogenesis of mitochondria. One hypothesis states that new mitochondria originate by division of old mitochondria. The second hypothesis states that the mitochondria arise *de novo* from simpler building blocks.

The mitochondrion shows several resemblances to the prokaryotes like bacteria. The mitochondrion is considered by cytologists and cell biologists to be in symbiotic association with higher cells in which anaerobic metabolism is carried out by the host cell and the 'aerobic metabolism' is continued by the 'guests' or the 'symbiotic' viz. mitochondrion.

3.3 LYSOSOMES

Lysosomes are particles resembling mitochondrion but without the cristae. They are characterised by the presence of enzymes called hydrolases. As the name itself implies (Gr. Lysis = dissolution or breakdown; soma = body), the lysosomes are involved in 'intracellular digestion' of materials.

Size and Shape

Shape : Lysosomes were first isolated and characterised by DeDuve. The particles measure between 0.2 to 0.8 μm . They appear as spherical or cylindrical particles in cytoplasm. The particles are fairly stable in the living cell, and the contents of the particles, enclosed in a relatively 'tough' membrane are not in touch with the materials of the cytoplasm.

3.3.1 Functions of lysosomes

Phagocytosis: The lysosomes carry out the function of phagocytosis and in this connection present some structural modifications. This is referred to as polymorphism of the lysosomes.

1. The primary lysosome is a small body containing only one enzyme type. The enzymes of the primary lysosome are elaborated in the endoplasmic reticulum and transferred in the following sequence:

Endoplasmic reticulum ——— Golgi complex ——— Lysosomes

2. The secondary phagosome (heterophagosome or digestive vacuole) is formed after phagocytosis. The phagocytised material is surrounded by primary lysosomes to form the secondary phagosome.

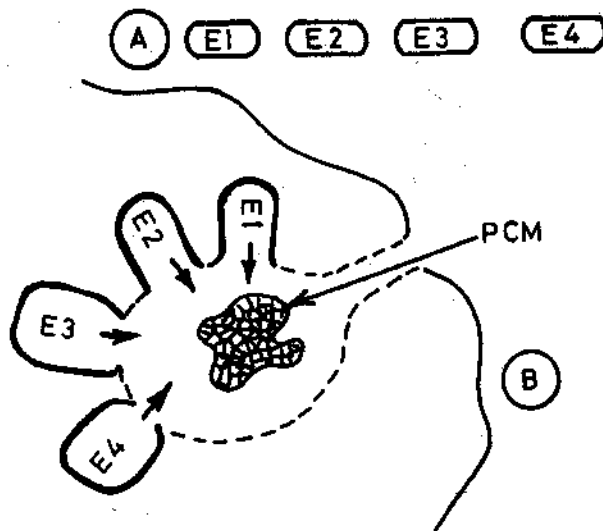


Fig 3.5. Process of phagocytosis, A. Primary lysosome containing one type of enzyme: E1 E2 E3 E4
B. Secondary phagosome phagocytised material (PCM) surrounded by several primary lysosomes.

3. The residual bodies result from incomplete digestion of the material in the lysosome or phagosome. Amoeba eliminates such residual bodies by defaecation.
4. The autophagic vacuole (cytolysosome or autophagosome) is a special body enclosing part of the cell itself for digestion.

Phagocytosis mentioned above is one form of endocytosis. Similarly, pinocytosis is also a form of endocytosis. The process of endocytosis is useful in nutriment supply in some cases and destruction of harmful foreign bodies in other cases.

Cell autophagy or autolysis : Lysosomes are useful in digesting and destroying parts of the cell or the whole cell. This is termed autolysis or cell autophagy. In the metamorphosis of amphibians, many cells are destroyed after which remodeling of tissues takes place. Such cell destruction is achieved through autolysis.

3.4 CENTRIOLES

Centrioles are particulate-filamentous organelles located near the nucleus and which participate in the formation of mitotic spindle during cell division. Some centrioles are concerned with the organisation of cilia and flagella. In these situations, these are named kinetosomes.

3.4.1 Structure

Under light microscope, the interphase cell show centrioles as small particles in the central body, near nucleus. The centrioles are surrounded by a substance the centrosphere. During mitosis, the centrosphere disappears and the centrioles released move towards two 'poles' to organise the 'mitotic figure' or spindle figure'. In this stage, centrioles are star-like and are named **asters**.

The centriole is a cylindrical structure measuring $0.2 \mu\text{m} \times 0.5 \mu\text{m}$. The cylinder is open at both ends.

The centriole has an outer envelope, the centriolar membrane. In the matrix of the centrioles nine groups of tubules are located in the periphery. Each group is made of 3 tubules. In the presence of the peripheral filaments the centriole resembles the cilium. But in the cilium, each tubule-group is made of 2 tubules. Additionally, the cilium shows axial filaments which are absent in the centriole.

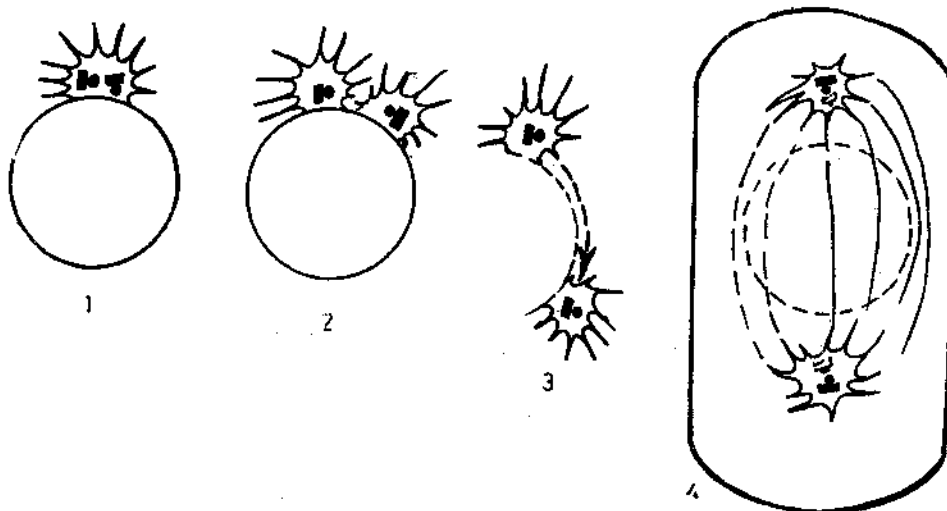


Fig. 3.6. 'Aster' formation 1. Common aster 2. Separation of two asters 3. Travel (semicircular) of one of the asters 4. Spindle figure formation.

3.4.2 Origin of Centriole

Like mitochondrion, the centrioles are considered to be semiautonomous organelles. 'Daughter' centrioles originate by the division of the old centrioles. The centrioles contain special type of DNA and RNA. These support the concept of semiautonomous status of centrioles.

The centriole of mitotic figure gives rise to the daughter centriole in the form of an annular pro-centriole. This structure later lengthens to result in the fully grown daughter centriole.

3.4.3 Formation of Mitotic Spindle

The centrioles undergo replication in the interphase. At the beginning of prophase, the two pairs of centrioles remain inside an 'aster' a structure with short radiating microtubules, resembling a star. One set of centrioles with one 'half' of the aster remains in position. The second set of centrioles with the other half of the aster moves away taking a semicircular path and ultimately the two set of centrioles come to be located in the antipodal positions, along with the asters, which, by this time, are fully formed. Between the two asters, a special microtubular system comes to be formed, which resembles a spindle. This provides the machinery for the chromosomal movement into two poles in an organised way (Fig.3.6).

Mitosis in which asters take part in spindle figure formation, is called astral or amphiastral mitosis. This is found generally in animal cells. In plant cells, the centrioles and asters are absent and thus in these cells 'anastral mitosis' occurs.

3.5 RIBOSOME

The ribosome is a particulate organelle of the cytoplasm. It is located in the rough or granular endoplasmic reticulum and participates in protein synthesis under direction from the nucleus.

Types

The ribosomes are usually located on the membrane system of endoplasmic reticulum. Such particles are named bound ribosomes. Others are free in the cytoplasmic matrix and are named free ribosomes. Often, the ribosomes occur in closely located functionally related clusters named polyribosomes or polysomes. The relative proportion of free and bound

ribosomes is different in different types of cells. In cells involved in active secretion like exocrine cells of pancreas or plasma cell (which secrete immunoglobulin) the membrane-bound ribosomes are predominant in their numbers. In a rapidly growing embryonic cell, the free ribosomes are greater in number than the bound ribosomes.

Shape

The ribosome is approximately spheroid in shape with 23 nm diameter. It is composed of 2 sub-units: larger and the smaller sub-units. The two sub-units show cohesion under low concentrations of Mg^{2+} (0.001M). If the concentration of Mg^{2+} is increased excessively (to 0.01M), two ribosomes combine to form a dimer.

In the organisation of polyribosome messenger RNA (mRNA) coming from nucleus participates.

Chemical composition

Ribosomes are composed primarily of ribonucleic acid (RNA). The particles get their name from this typical composition. The RNA of ribosome is called ribosomal RNA (rRNA). In addition to rRNA are in equal proportions. The ribosomes are strongly negatively charged and bind with cations and basic dyes.

Biogenesis of ribosomes

The process of origination of ribosomes is different between prokaryotic and eukaryotic cells. In the bacterial cells (prokaryotes) the ribosome is generated under the direction of a single 'operon'. But in the eukaryotes, the ribosome-genesis is a much more complicated process.

The nucleolus is known to be responsible for the synthesis of rRNA which in turn participates in the organisation of ribosome.

Functions of ribosome

The ribosome plays a key role in protein synthesis is a complicated process and is carried out in the cytoplasm. In this process rRNA of ribosomes, messenger RNA (mRNA) coming from nucleus and soluble transfer RNA (tRNA) of cytoplasm participate. Protein synthesis is the biochemical basis for life, since the protein forms the major constituent of living substance.

3.6 NUCLEUS

Nucleus is a spherical structure containing chromatin material which is charged with the function of controlling the cellular metabolism.

Structure

The nuclear shape, size and number per cell vary in different types of animal cells. But a typical eukaryotic cell is found to contain a single nucleus.

Under light microscope, in the nucleus, an outer envelope is easily recognisable, the nuclear membrane or karyolemma. This envelope contains a fluid named karyoplasm or nucleoplasm. In this material, one can note the presence of a meshwork of material, named chromatin material or chromatin reticulum. Besides this meshwork, one or two larger spherical bodies also are present in the karyoplasm, named nucleoli (sing:nucleolus). μ

Under electron microscope, the nuclear membrane shows double membrane construction. The membranes of the nuclear envelope are constructed on the unit membrane plan. The nuclear membrane shows several pores, the nuclear pores. These pores allow nucleo- cytoplasmic

interactions. At the pore, the outer and inner membranes are continuous into one another. The nuclear pores are well organized, with octagonal outlines, surrounded by special structural arrangements called 'pore complexes' which form 'annuli' around the nuclear pores. The space enclosed between the two membranes of the nuclear envelope is called perinuclear space. The chromatin reticulum is condensed from chromosomes during mitosis. In the interphase deoxyribonucleic acid (DNA) which goes into the construction of chromatin reticulum directs the various cellular activities. During cell division the chromatin material is doubled and divided equally between 'daughter nuclei'.

Origin

Nucleus originates from endoplasmic reticulum. Evidence for this origin is available during mitosis. At the telophase of mitosis, cisternae formed from endoplasmic reticulum surround the chromosomes which reach the poles. From this 'cisternal system' the nuclear envelope is organised.

Function of Nucleus

Nucleus controls synthesis of proteins and various other substances. The organelle is often referred to as the metabolic controller of the cell. During mitosis, the chromatin material after condensation into chromosomes (with duplication of chromatin material) is divided equally between two 'daughter cells'. This forms the physical basis of heredity and continuation of race. On other words, DNA, which is the basis for heredity and which goes into the composition of chromosomes, is equally divided between the daughter nuclei, for ensuring continuation of race.

Check your Progress

1 Match the following

- | | | |
|-----------------|-----|----------------------------|
| 1. Mitochondria | () | a. "an astral mitosis" |
| 2. Lysosomes | () | b. Protein Synthesis |
| 3. Centriole | () | c. Semiautonomus organelle |
| 4. Ribosome | () | d. autophagic vacuole |

3.7 SUMMARY

1. The mitochondria, the 'power plants' of the cell, are double-membraned structures of variable size and shape.
2. The membranes are of unit membrane construction.
3. The outer membrane is smooth and the inner membrane is thrown into folds named mitochondrial cristae.
4. The crests, the outer membrane and the 'compartments' contain several enzymes concerned with 'aerobic' degradation of metabolites.
5. The mitochondria group together in intracellular locations involved in high metabolic activity.
6. The lysosome in a mitochondrion-like particle without inner membrane or cristae (crests).
7. It contains hydrolases and is important in phagocytosis and autophagy or autolysis.
8. The centrioles are organelles with cilium-like ultrastructure.

9. The centrioles form asters which are involved in the formation of spindle figure during mitosis of animal cell.
10. The ribosomes are spherical organelles located in cytoplasmic matrix in free state or bound to the rough endoplasmic reticulum.
11. The ribosomes are composed of ribosomal RNA (rRNA) synthesized in nucleolus.
12. The ribosomes are involved in protein synthesis.
13. The nucleus is located in the centre of endoplasm.
14. The nucleus is involved in nucleocytoplasmic interactions leading to protein synthesis.

3.8 CHECK YOUR PROGRESS - MODEL ANSWERS

- I 1. c 2. d 3. a 4. b

3.9 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines:

1. Give an account of the structure of mitochondrion.
2. Give the functions of mitochondrion.
3. Describe the structure and functions of centriole.
4. Describe the structure and functions of ribosome.

II. Answer the following in about 10 lines;

1. Oxidative phosphorylation
2. Structure of nucleus
3. Mitochondrion as a semi-autonomous organelle

Unit - 4 CHROMOSOMES

Contents

- 4.1 Objectives
- 4.2 Introduction
- 4.3 Chromosomal Morphology
- 4.4 Special Types of Chromosomes
 - 4.4.1 Polytene chromosomes
 - 4.4.2 Lampbrush chromosomes
- 4.5 Summary
- 4.6 Check Your Progress - Model Answers
- 4.7 Model Examination Questions

4.1 OBJECTIVES

This unit deals with the structural variation shown by chromosomes. By the end of this unit you will be able to :

- describe the ultra structure of chromosomes revealing the disposition of chromonemata.
- define special types of chromosomes viz., Polytene chromosomes and lampbrush chromosomes.
- explain the functions of chromosomes.

4.2 INTRODUCTION

Chromosomes (chroma = colour; soma = body) are bodies that appear during cell division. These are the carriers of hereditary messages and also controllers of general metabolism of the cell. The name 'chromosome' was coined by Waldeyer (1888).

4.3 CHROMOSOMAL MORPHOLOGY

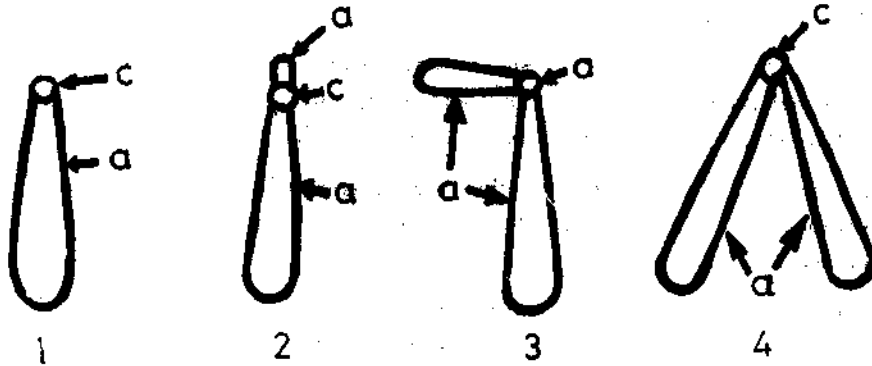
During mitosis, the chromatin reticulum located in the nucleus is organised into compact structures with a definite plan of construction. These are the chromosomes.

- a) **Appearance of chromosome** : The chromosome shows a typical constriction or a narrow zone somewhere along its length called centromere and this is the point at which the chromosomes is attached to the proteinaceous fiber of the spindle figure during mitosis. Depending on the location of the centromere one can recognize the following chromosome types:

1. Acrocentric
2. Telocentric
3. Submetacentric
- and 4. Metacentric

In the **acrocentric** chromosome, the centromere is located at one tip of the chromosome. In the **telocentric** chromosome, the centromere is located just behind the tip. In the **submetacentric** chromosome, the centromere is located towards the middle of the chromosome. This shows two 'arms' of unequal size and therefore appears 'L' shaped. In the **metacentric** chromosome, the centromere is located exactly in the middle so that it shows two arms of equal length. The structure thus resembles the letter 'V' (Fig. 4.1)

- b) **Size** : The diameter of the chromosome ranges between 0.2 to 30μ and the length range is from 0.5 to 30μ .
- c) **Number** : The number of chromosomes in the nucleus is typically constant for a given species. The chromosomal set in a somatic cell of an organism is known as 'Karyotype' and typically, this is composed of 2 sets of chromosomes. This is known as diploid condition. The set of chromosomes that appears in the gametes represents the haploid condition. Two such sets enter the zygote each coming from one parent. This haploid set of chromosomes found in the gamete is named 'genome'.



4.1 Chromosome types 1. Acrocentric 2. Telocentric 3. Submetacentric 4. Metacentric c. Centromere
a. arm

In man the genome is made of 23 (22+1) chromosomes. In *Drosophila* the genome is composed of 4 chromosomes. In the roundworm, *Ascaris magalocephala* the genome is made of just 1 chromosome.

- d) **Autosomes and sex chromosomes** : In the vertebrate karyotype, the chromosomes can be divided into 2 classes, the autosomes and sex chromosomes. The autosomes are the somatic chromosomes and the sex chromosomes are concerned with the expression of sexuality. In man and *Drosophila* the male organism shows the chromosomes X and Y as sex chromosomes. The females of human and *Drosophila* populations show two X chromosomes as the sex chromosomes.

Thus the Karyotype of an organism like man or *Drosophila* may be expressed as follows:

Karyotype $2n = 2A + \text{Sex Chromosomes}$

Karyotype in males is : $2A + XY$

Karyotype in females is : $2A + XX$

During gametogenesis, the X and Y chromosomes of the male pass into separate gametes and 2 types of gametes are formed : One is with the genome: $1A + X$ and the second has the genome : $1A + Y$. Thus the male in man and *Drosophila* is the heterogametic sex. The female organisms give rise to gametes which are of the same plan of chromosome composition: $1A + X$. Thus the females of these organisms constitute the homogametic sex.

In the interphase cell of female organism, only one X chromosome is active. The second X chromosome is converted into discreet structures called Barr bodies.

Structure of chromosome

As noted above, the detailed structure of the chromosome can be made out only in cell division.

The chromosome shows pellicle as the limiting membrane. Inside this a matrix is located. Both pellicle and the amorphous matrix are made of non-genetic material.

The chromatin material is embedded in the matrix in the form of 2 coiled threads. These are the 'chromatids'.

Somewhere along the length of the chromosome a constriction is located. This is named **primary constriction** or **centromere**. In addition to this constriction, the chromosome shows some more constrictions, which are **secondary constrictions**. Certain of the secondary constrictions are concerned with the formation of nucleolus and the therefore called **nucleolus organising regions**

Some of the chromosomes show at the ends of the arms rounded or cylindrical bodies, called **satellites** or **satellite bodies**.

The ends of chromosome usually show some special properties and polarity. The ends are thus called **telomers**. When a chromosome is fractured places do not fuse at the telomere. Thus the telomere gives an individuality to a given chromosome (Fig. 4.2)

The centromere is usually single in the case of many chromosomes. These are **monocentric chromosomes**. In others, there are more than one centromeres. These are **polycentric chromosomes**.

Idiogram is the diagrammatic representation of the morphological features of all the chromosomes forming the genome or karyotype of an organism.

Ultrastructure of Chromosome

Under electron microscope, the fine structure of the chromosome will be visible. The fine coiling of chromonemata in the matrix will be clear. A closer examination of the chromonema shows its coiled-coil type of construction.

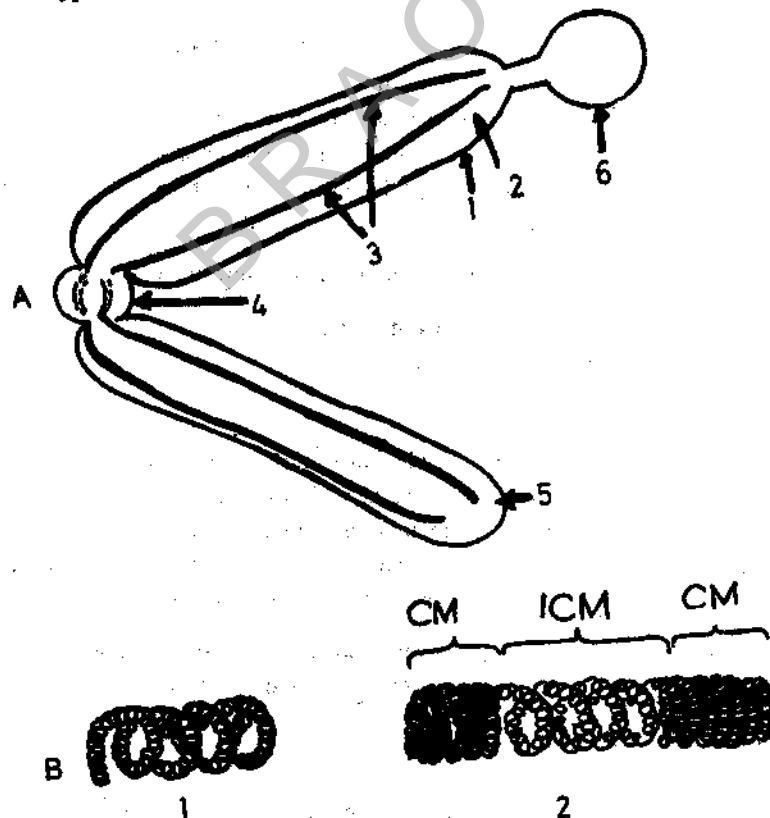


Fig 4.2 A. Structure of Chromosome 1. Pellicle 2. Matrix 3. Chromatids 4. Centromere 5. Telomere 6. Satellite body. B. Coiling of chromonemata 1. Coiled-coil type of organisation 2. Differences in compactness of coiling results in the appearance of chromomeres (CM) and interchromomeres (ICM).

Typically, the chromosome shows 2 chromonemata in each of its two chromatids. These threads show two types of coiling in relation to one another: plectonemic coiling in which the two threads are intertwined closely; and paranemic coiling in which intertwining of fibers is absent.

Chromomeres : The chromonemata of a chromosome shows small bodies at definite points along their length. These are called chromomeres. The intervals between the successive chromomeres are named interchromomeres. About the nature of chromomeres there are different views: of these views *White's (1936)* view is more acceptable. According to White, the chromomeres and interchromomeres are parts of the same continuous chain.

Histochemistry

Histochemically, the Chromonemata are composed of two types of chromatin material: euchromatin and heterochromatin. The chromatin material is typically stained by Feulgen nuclear stain for DNA. Euchromatin shows lighter staining with Feulgen stain whereas heterochromatin shows darker or denser staining. Heterochromatin is found near the centromere and the telomere. This differential staining of the two chromatin materials is 'heteropyknosis'.

Chemical composition : Present studies on the chemical composition of chromosomes suggest the chromosome to be mainly composed of DNA (deoxyribonucleic acid) In association with this certain acid proteins are also present. The two types of macromolecules together form nucleoproteins. These compounded macromolecules give stability to the chromosomal structure. Histone is one protein usually found in association with DNA to form nucleohistones.

The DNA macromolecule is composed to sugarphosphate (deoxyribose, phosphate) and base pairs (made of purine and pyrimidine structures). Adenine and guanine are the purines and cytosine and thymine are the pyrimidines that go into the composition of DNA.

Functions of Chromosome

The nucleus controls the metabolism of the cell and participates in heredity only through the mediation of the chromosomes.

The regions of euchromatin of chromosomes are locales of genetic activity and they control several functions or syntheses. Heterochromatin is genetically inert to a great extent. However, it is now known to contain certain 'polygenes' like ribosomal DNA, transfer DNA and 5S DNA. Heterochromatin is probably important in replication and transcription of DNA.

4.4 SPECIAL TYPES OF CHROMOSOMES

In some organisms, some cells under certain conditions show special types of chromosomes which are characterised by their large size or gigantism. These 'giant' chromosomes lead to proportionate increases of the sizes of the nucleus and the cytoplasm.

The special types of chromosomes include the polytene chromosomes, located in the dipteran larvae, especially in the salivary glands; and the lampbrush chromosomes found in the oocytes of some vertebrates and invertebrates.

4.4.1 Polytene Chromosomes

In the fruitfly *Drosophila melanogaster*, large sized chromosomes are found in the salivary glands of the larva. The volume of this 'giant' chromosomes is more than thousand times the volume of the normal chromosome.

The total length of the 'giant' set of chromosomes in a karyotype is 2000 μm whereas the length for the 'normal' chromosomes is found to be only 7.5 μm .

The giant chromosome shows 'dark' and 'light' bands (when stained with Feulgen nuclear stain) which show remarkable agreement and regularity when two homologous chromosomes are compared (Fig.4.3). Thus these chromosomes can be put to use for interpretation of abstract genetic maps prepared by earlier geneticists and cytogeneticists.

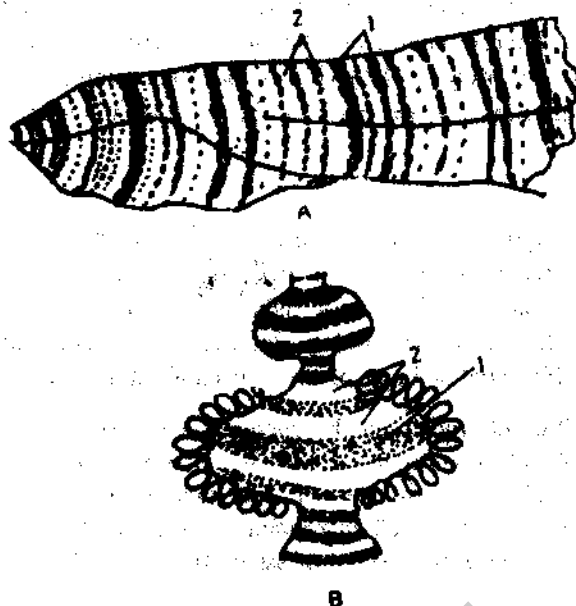


Fig. 4.3 A. Polyteap chromosome from the salivary gland of the fruitfly, *Drosophila melanogaster*. B. Puffs shown by polytene chromosomes. 1. Bands 2. Inter-bands.

The polytene chromosomes are known to be made of as many as 1000 chromonemata the term 'polytene' signifies 'bundling' up of many chromonemata.

The polytene chromosomes are supposed to have arisen by reduplication (10 times) of the chromonemata, in a process known as endomitosis. In this process, the chromonemata show reduplication, but remain together without separation. The question of the transport of chromonemata to poles also is not there in endomitosis. Repeated reduplications thus lead to the formation of polytene chromosome.

Bulbs, Puffs and Balbiani Rings : The larval stages of several insects show the giant chromosomes. During different stages of development of the larva on some chromosomes certain bands show bulbs or puffs. In certain cases more massive enlargements in the form of rings also appear. The ring like enlargements are the Balbiani rings. The appearance of such structure suggests that in these bands good level of genetic activity takes place in certain stages of larval development. In these regions, a sequence of uncoiling of chromosome bands, synthesis of RNA and synthesis of protein can be noted. Thus these structures indicated the method of working of chromosome in the control of physiology and metabolism of the organism.

4.4.2 Lampbrush Chromosomes

In the oocytes of some sharks, amphibians, reptiles and birds chromosomes resembling 'lampbrush' are found. These lampbrush chromosomes are of gigantic size and can be seen with the naked eye in the late diplonema stage of oocyte maturation.

In this chromosome, there is an axis made of 4 chromatids. These structures at repetitive intervals form 'loops' of large dimensions. The loops are not present in the region of the centromere. In the loop region, the axis is made of DNA and around this axis a 'matrix' is located. This gives 'hazy' appearance to the loop. The loops located all along the length of the chromosome give it the lamp brush-like appearance (Fig 4.4)

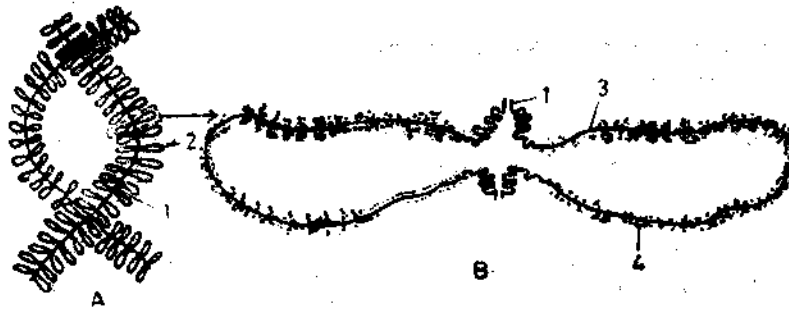


Fig. 4.4 Lampbrush chromosome 1. Chromosome axis 2. Loop 3. Chromosomal fibres (DNA)
4. Matrix (RNA and proteins).

In the lateral loops of the chromosomes, ribonucleoprotein fibrils are located in a vertical plane along the DNA axis.

Synthesis of RNA seems to take place at the thin end of the loop. The loop itself is supposed to be in a state of continuous movement. The loop spins out at the thin end and 'recoils' at the thick end. Along this loop, protein synthesis goes on continuously. When the synthetic activity is over, the RNA is given out by the loop which ultimately collapses.

Check Your Progress

1. Define the following
 - a. chromosomes
 - b. metacentric
2. Lampbrush chromosomes found in the _____ of some vertebrates and invertebrates.

4.5 SUMMARY

1. The chromatin reticulum or chromonemata of interphase get condensed and organised to form chromosomes, the vehicles of heredity.
2. The chromosome typically shows a centromere and arms. Depending on the location of the centromere along the length of the chromosome, different types of chromosomes can be recognised:
 - 1) Acrocentric 2) Telocentric 3) Submetacentric 4) Metacentric
3. The size and number of chromosomes are variable.
4. The number of chromosomes in the vegetative cell of an organism is the 'Karyotype' and half of this number, found in the gamete is the 'genome'.
5. In the Karyotype is composed of a set of autosomes and a set of sex chromosomes.
6. The chromosome shows pellicle, centromere, matrix and chromonemata in ultrastructure. It also shows satellite bodies and telomeres.
7. The chromonema is of a coiled coil type of construction.
8. Histochemically, the chromosome is made of 2 types of chromatin: euchromatin and heterochromatin. These two chromatins show differential staining with Feulgen's nuclear stain. This is 'heteropyknosis'.

9. The chromonemata are typically composed of deoxyribonucleic acid (DNA) and nucleoprotein.
10. The chromosome is the vehicle of heredity. It controls various synthetic and other metabolic functions during interphase.
11. Special types of chromosomes of gigantic dimensions are noted in organisms like *Drosophila* (polytene chromosomes in the salivary gland cells) and in the oocytes of fishes (lampbrush chromosomes).

4.6 CHECK YOUR PROGRESS – MODEL ANSWERS

1.
 - a. The chromonemata of a chromosome shows small bodies at definite points along their length. These are called chromomeres
 - b. In the metacentric chromosome, the centromere is located exactly in the middle so that its shows two arms of equal length.
2. Oocytes.

4.7 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines each:

1. Describe the structure of a typical chromosome with a note on its chemical composition.
2. Give an account of 2 types of giant chromosomes studied by you.

II. Answer the following in about 10 lines each:

1. Chromatin
2. Light microscopic appearance of chromosome
3. Types of chromosome based on centromere location

Unit – 5 CELL DIVISION

Contents

- 5.1 Objectives
- 5.2 Introduction
- 5.3 Amitosis
- 5.4 Mitosis and cell cycle
 - 5.4.1 Prophase
 - 5.4.2 Prometaphase
 - 5.4.3 Metaphase
 - 5.4.4 Anaphase
 - 5.4.5 Telophase
 - 5.4.6 Significance of mitosis
- 5.5 Meiosis
 - 5.5.1 Significance of meiosis
- 5.6 Comparison Between Mitosis and Meiosis
- 5.7 Summary
- 5.8 Check Your Progress – Model Answers
- 5.9 Model Examination Questions

5.1 OBJECTIVES

In this unit we deal with the various types of all divisions and their mechanism registered among multicellular organisms. By the end of this unit you will be able to

- discuss the concept of growth and development of an organism with reference to the multiplication and enlargement of its cells.

5.2 INTRODUCTION

The division and replication of cells are the basis for both sexual and asexual reproduction in most organisms. Even such primitive cell types as bacteria exhibit cell division; although the details of the process are not always recognised. With the exception of such cells, the mechanism of cell replication are similar or identical in plants and animals. The organisms grow and repair themselves through the medium of cell division. According to the cell theory put forward by Schleiden and Schwann (1840) and confirmed by Virchow (1855) new cells originate from the division of pre-existing cells i.e., *Omnis Cellular Cellula*.

Why cell division occurs in an organism? cell division is necessarily the avoidance of ageing. Usually the cell replication results in the differentiation and specialization. This in turn causes adaptability and also a better prospect for survival. Finally cell division is essentially for the perpetuation of the species.

Three kinds of cell division have been distinguished in animals:

1. Direct cell division or amitosis,
2. Indirect cell division or mitosis,
3. Reduction division or meiosis.

5.3 AMITOSIS

It is rare and of little importance and occurs in asexual reproduction of some unicellular organisms like bacteria and protozoans. In amitotic cell division the splitting of nucleus is followed by cytoplasmic constriction.

During amitosis the nucleus elongates first and assumes dumb-bell shaped appearance. The constriction deepens further and ultimately divides the nucleus into two bits. The division of the nucleus is followed by the constriction of cytoplasm which divides the cell into two equal or approximately similar halves. Thus simply without the occurrence of any nuclear changes two daughter cells are formed.

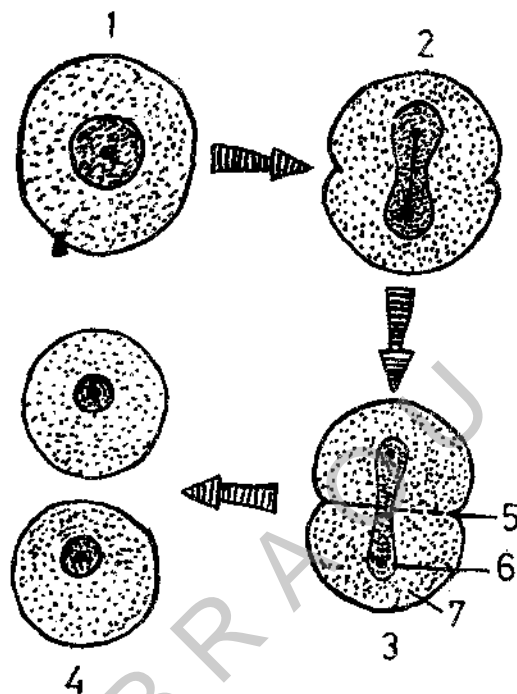


Fig. 5.1 Diagrammatic representation of amitosis. 1. Animal cell for division 2. Cell with constriction and dumbbell nucleus 3. Division of nucleus and cytoplasm 4. Daughter cells 5. Cytokinesis 6. Nucleus 7. Cytoplasm.

5.4 MITOSIS AND CELL CYCLE

The multiplication of a somatic cell into two daughter cells of equal size and containing the same number of chromosomes as the parent cell is called mitosis or somatic division. The term 'mitosis' was proposed by W. Flemming derived from Greek word for thread (mitos) which refers to thread like appearance of chromosomes early in mitosis.

The basic outline of mitosis remains the same in all living organisms. It includes four Phases namely G₁ Phase, S Phase G₂ Phase and M Phase (mitotic) which occur successively constituting the cell-cycle. The G₁, S and G₂ phases are collectively called the interphase. A typical cell-cycle including interphase lasts from 20 to 24 hrs, and an individual cell passes through following two main phases:

- A. Interphase
- B. Mitotic phase

A. Interphase

The stage between the two mitotic divisions is called interphase (L., inter = between, Gr., phasis = appearance). During interphase nucleus and cytoplasm remain metabolically active and thus increasing the volume of nuclear and cytoplasmic substances. The interphase is the longest phase of the mitotic cycle (about 2 days) including following three sub phases.

1. G₁ phase
2. S Phase
3. G₂ phase

G₁ Phase : It includes the synthesis and organization of the substrate and enzymes necessary for DNA synthesis. Therefore, G₁ phase is indicated by active transcription of rRNA, mRNA and synthesis of variety of proteins (Fig. 5.2)

S Phase : It includes replication and duplication of chromosomal DNA molecules and total DNA content doubles.

G₂ phase : It is the period following S and preceding mitosis (M), is often characterized by an increased nuclear volume. More significantly, G₂ is the time during which certain metabolic and organisational events occur as a prerequisite to mitosis. Thus during interphase the following events occur:

1. Doubling of chromosomal constituents takes place.
2. Chromosomes exhibit a minimum degree of condensation and hence they appear as long and less coiled chromatin fibres, commonly termed as relic coils.
3. Due to enhanced synthesis of ribosomal RNA (rRNA) and proteins, the nucleus as well as nucleolus are comparatively large in size.
4. The DNA amount becomes doubled.
5. A daughter centriole is originated near the original centriole leading to the initiation of mitotic phase.

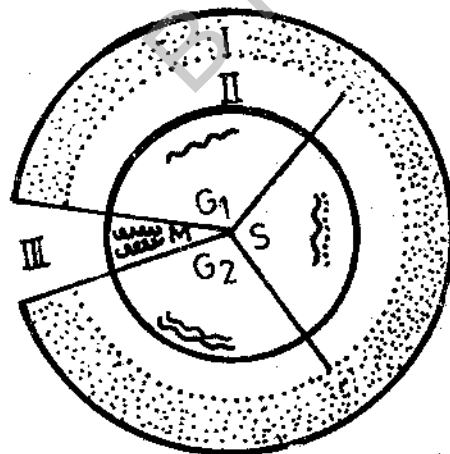


Fig. 5.2 The cell cycle of events in a mitotic cell G₁Pre-DNA synthetic phase; G₂ Post DNA synthetic phase M. Mitotic phase. S. Synthesis of DNA. 1) Protein and RNA synthesis 2) DNA synthesis. 3) Chromosome movements.

B. Mitotic phase

No single event seems to be responsible for the initiation of mitosis. However, the recent cytogenetical studies have shown that the preparatory process must be under genetic control.

At the end of interphase a series of changes begins in the physical and chemical organisation of the chromosomes. The main mitotic cell division occurs during mitotic phase (M) which includes following phases:

5.4.1 Prophase

Prophase (Gr: Pro = before) is usually the longest mitotic stage lasting from one to several hours. During this phase following visible changes take place:

1. The cell becomes more spheroid and refractive.
2. The nuclear envelope starts to disintegrate.
3. Each chromosome splits longitudinally consisting of two identical chromatids connected by a centromere.
4. As the prophase progresses the chromatids become shortened and thickened.
5. Disappearance of nucleolus starts.
6. Coiling of two chromatids about each other is seen. Being twisted together they cannot be separated easily. This kind of arrangement is called **Plectonemic coiling** unlike that in meiosis in which chromatids can be separated forming **paranemic coiling** (Fig 5.3).
7. The two centrioles which were present above the nucleus move apart from each other and migrate towards the opposite pole of the cell. Thin fibres appear between them as spindle.
8. Radiating fibres called astral rays arise from each centriole to form an aster. The spindle fibres along with two asters constitute an **amphaster**.
9. Both the chromatids remain closely associated along their entire length and begin to collect inside the spindle fibres.
10. Besides the above physical changes there occur chemical changes as the RNA content of chromosomes become increased. Another change is the increase in their phospholipoid content.

5.4.2 Prometaphase

In prometaphase (Gr., pro=before, meta = after, phasi = appearance) following events occur :

1. The nuclear envelope completely disintegrates.
2. The nuclear membrane disappears totally.
3. A clear zone known as the equator appears in between the mid- line of spindle and the nucleus.
4. The chromosomes move towards the equator.

5.4.3 Metaphase

The metaphase (Gr., meta = after) follows the prometaphase, which lasts for a very short time from 6 to 13 minutes; and during this phase following changes occur in the cell:

1. Each chromosome reaches to the equator and all chromosomes arrange themselves radially at the periphery of the spindle.
2. A mitotic apparatus is formed as the chromosomes lie at the equator of spindle with their centromeres towards the equator and their arms extending freely in cytoplasm. The apparatus is organized into highly oriented fibres with inter molecular S-S links and Sulphur linkages binding the proteins together.

3. As a result of final shortening of chromosomes, the chromatids, become separated from each other lying side by side.
4. Finally the centromere of each chromosome and are known as the chromosomal fibres. Certain other fibres of the spindle occur between the chromosomes and are called as interchromosomal fibres.

5.4.4 Anaphase

In the anaphase (Gr., ana=up, phasis=appearance) which is the shortest of all the stages in the mitotic cycle following changes take place:

1. The chromatids of each chromosome are separated and form two sister chromosomes.

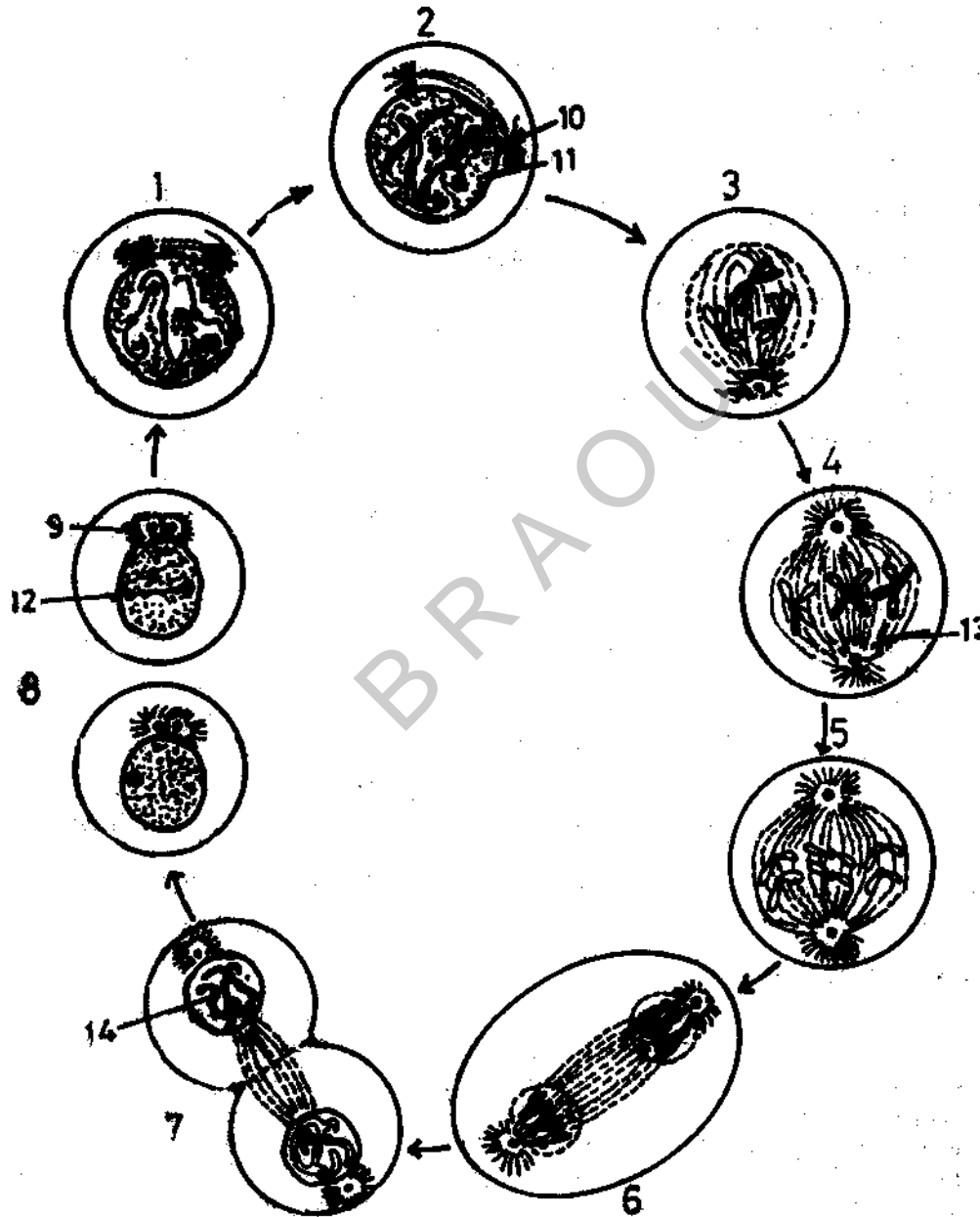


Fig 5.3 Stages in mitosis. 1. Early prophase 2. Mid prophase 3. Late prophase 4. Metaphase 5. Anaphase 6. Early telophase 7. Late telophase 8. Daughter cells 9. Centrioles 10. Astar 11. Nucleolus 12. Nucleolus 13. Spindle 14. Chromosomes.

2. The sister chromosomes become shorter and thicker and migrate towards the opposite poles of the cell.
3. The migration of sister chromosomes towards the opposite poles is achieved by the contraction of chromosomal fibres and stretching of interchromosomal fibres.

5.4.5 Telophase

The telophase (Gr., telo = end) is the final stage of mitosis and during this phase following events occur in the cell.

1. The chromosomes which reach at the opposite poles of the cell now begin to uncoil, elongate, and become thread-like.
2. The nucleolus reappears.
3. The new nuclear envelope around the chromosomes is formed from the endoplasmic reticulum.
4. The spindle fibres of the aster and mitotic spindle break down and absorbed in the cytoplasm.
5. The two nuclei thus formed due to karyokinesis at two poles develop other structures.
6. The karyokinesis is followed by cytokinesis. In this process the plasma membrane constricts in the middle forming a cleavage furrow which deepens further into the cytoplasm to form two daughter cells. Thus after the telophase which lasts from 30 minutes to 3 hours two daughter nuclei are formed through karyokinesis. It is followed by the division of cytoplasm called the cytokinesis resulting in the formation of two daughter cells which resemble each other and also the parent cell qualitatively and quantitatively.

5.4.6 Significance of Mitosis

1. The mitosis is meant for the growth and development of organs and organ systems of an organism.
2. Mitosis helps the cell in maintaining its size.
3. Through mitosis the chromosomal number can be maintained constant.
4. Through mitotic proliferation of cells, the old decaying and dead cells are replaced by the new ones.
5. In primitive organisms it helps in the multiplication of species through asexual reproduction.
6. The multiplication of sex cells from the gonads also takes place through mitosis.

5.5 MEIOSIS

The term 'meiosis' (Gr., meloun = to reduce) was coined by J. B. Farmer (1905). It occurs only in the gonads during the formation of sperms and ova. During gametogenesis the diploid number of chromosomes present in the germ cells is reduced to haploid number through meiosis or reduction division. In sexually reproducing plants, the zygote undergoes meiotic division resulting in the formation of haploid spores.

In the process of meiosis the chromosomes divide once and the nucleus and cytoplasm divide twice to form four haploid cells from a single diploid cell. The possibility for the initiation of meiosis is the relative amount of RNA and DNA. Meiosis occurs in two stages:

1. **Heterotypic division** : The first meiotic division is heterotypic in which diploid parent cell divides into two daughter cells having haploid (Monoploid) chromosome number.

2. **Homotypic division**: This is the second meiotic division and is mitotic in nature. The two haploid cells formed as a result of heterotypic division divide mitotically into two cells each. Thus from a single parent cell having $2x$ chromosomes (diploid) are produced four daughter cells having x number of chromosomes.

Both the meiotic division take place continuously and each includes the usual stages of the mitosis viz., prophase, metaphase, anaphase and telophase. The successive meiotic divisions can be represented as follows:

Meiosis

| I. Heterotypic division | II. Homotypic division |
|-------------------------|------------------------------|
| | a) Leptotene 1) Prophase II |
| | b) Zygotene 2) Metaphase II |
| i) Prophase I | c) Pachytene 3) Anaphase II |
| | d) Diplotene 4) Telophase II |
| | e) Diakinesis |
| ii) Metaphase I | |
| iii) Anaphase I | |
| iv) Telephase I | |

First Meiotic Heterotypic Division

The events that channel cells into meiosis occur during the premeiotic G_2 phase when the chromosomes are already replicated. The DNA synthesis is restricted to the S phase but compared with mitotic S in interphase, meiotic S is longer (Robertis, 1983). In the beginning of first meiotic division the nucleus swells up by absorbing water from the cytoplasm (hydration). After these events the cell enters into the first stage of first meiotic division, Prophase-I.

Prophase I

It is the longest stage of the meiotic division. During this stage the amount of DNA becomes double. It includes five substages:

- A. **Leptotene**: The leptotene stage is characterized by the following features:
1. The volume of nucleus begins to increase.
 2. Chromosomes become quite long and uncoiled with granular appearance due to beads of chromomeres.
 3. During late leptotene, chromosomes develop several small coils intervening major coils.
 4. The centriole, duplicates and each one migrates towards the opposite poles of the cell. On reaching the poles each centriole duplicates again and thus each pole has two centrioles.
- B. **Zygotene**: It is the most important stage of meiotic prophase with the following characters:
1. The most striking event of zygotene is the pairing or **synapsis** of homologous chromosomes (bivalent). Each chromosome divides into two chromatids, hence it consists of four chromatids and is referred to as **tetrad**.
 2. The pairing may begin at the ends of the chromosomes **proterminal** and progress towards the centromere or it may begin near the centromere (**procentric**) and progress towards the ends; or it may be random synapsis in a scattered pattern.

3. The chromosomes are oriented with their one end directed towards the same side of the nucleus forming bouquet and this particular stage of polarization of chromosomes is called bouquet stage.

4. After pairing coiling of chromosomes begins in paranemic coils.

5. Nucleolus increases in size and centrioles migrate to initiate the spindle formation.

C. **Pachytene** : It commences when the pairing of chromosomes is completed. It is one of the longer stages of prophase-I with the following features:

1. The chromosomes which are in synapsis now twist about one another as rational coils and each split up into two.

2. The chromosomes grow shorter and thicker and at this stage crossing over occurs. The chromatid which breaks at the point will unite with the chromatid of other chromosome. The breaks and exchanges of partners during crossing over produce a cross-shaped figure called chiasma.

D. **Diplotene** : 1. The Chiasmata are very easily discernible in this stage (Fig. 5.4).

2. Due to increased coiling the chromosomes become shorter and thicker with an apparent repulsion between homologous chromosomes.

3. As the chromosomes repel, terminalization of the chiasmata occurs causing the chromatids to separate.

E. **Diakinesis** : 1. During diakinesis the bivalents migrate to the periphery of the nucleus and are very short and thick called strepsineme.

2. The nucleolus begins to disappear.

3. Terminalization completed.

4. Disruption and disappearance of nuclear membrane and the appearance of spindle fibres indicate the last event of prophase-I

Metaphase - I

1. After the disruption of the nuclear envelope the chromosomes move to the equatorial region of the cell.

2. The orientation of chromosomes in meiotic metaphase-I is quite different from that in mitotic metaphase. i.e., Chromosomes lie near the equator with their centromere towards the poles and their arms towards the equator.

3. The centromere although remains functionally single, it is structurally double at the end of metaphase-I

4. Spindle fibres extended between the poles and are attached to the centromeres of the chromosomes.

Anaphase - I

1. The two chromosomes (bivalents) move to opposite poles of the cell during this stage.

2. The tetrads containing four chromatids become separated into dyads having two chromatids each.

3. The consequence of this stage of meiosis is a reduction of the chromosome by one half from the diploid to the haploid number.

Telophase - I

The events of telophase are practically the same in meiosis and mitosis.

1. The endoplasmic reticulum forms the nuclear envelope around the chromosomes.
2. Chromosomes become uncoiled.
3. The nucleolus reappears.
4. Cytokinesis is followed by Karyokinesis and two haploid daughter cells are formed.

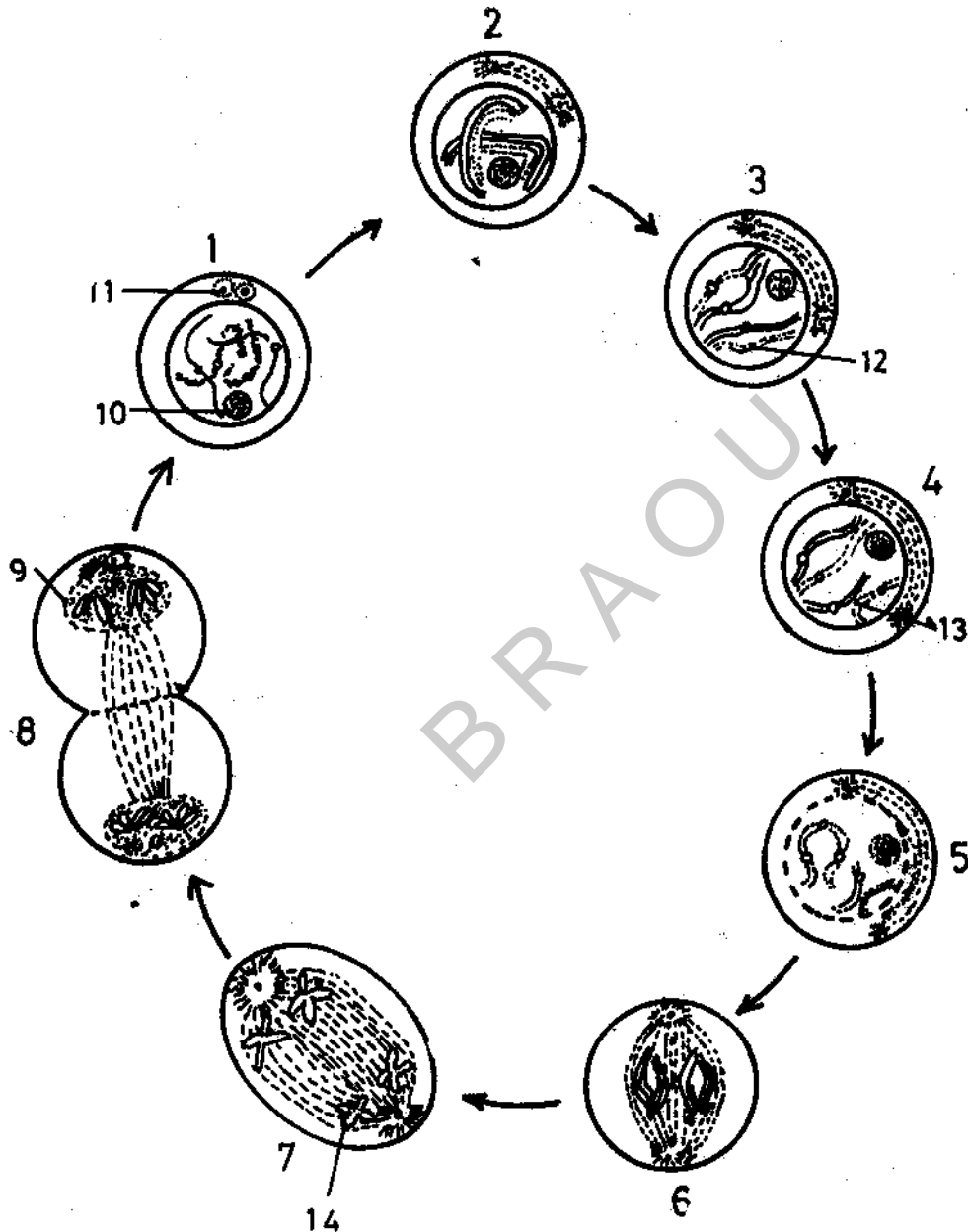


Fig 5.4 Stages in heterotypic division of Meiosis 1. Leptotene 2. Zygotene 3. Pachytene 4. Diplotene 5. Diakinesis 6. Metaphase-I 7. Anaphase-I 8. Telophase-I 9. Nuclear envelope 10. Nucleolus 11. Centriole 12. Centromere 13. Chiasmata 14. Chromatids.

Second Meiotic Homotypic Division

It is actually the mitotic division which divides each haploid meiotic cell into two cells. It includes the following stages:

Prophase-II

1. The arms of dyads remain separate with X-shaped figures of chromatids connected by centromere.
2. The nuclear envelope and nucleolus disappear.
3. Appearance of spindle fibres indicates the end of this stage.

Metaphase-II

1. Chromosomes get oriented on the equator of the spindle.

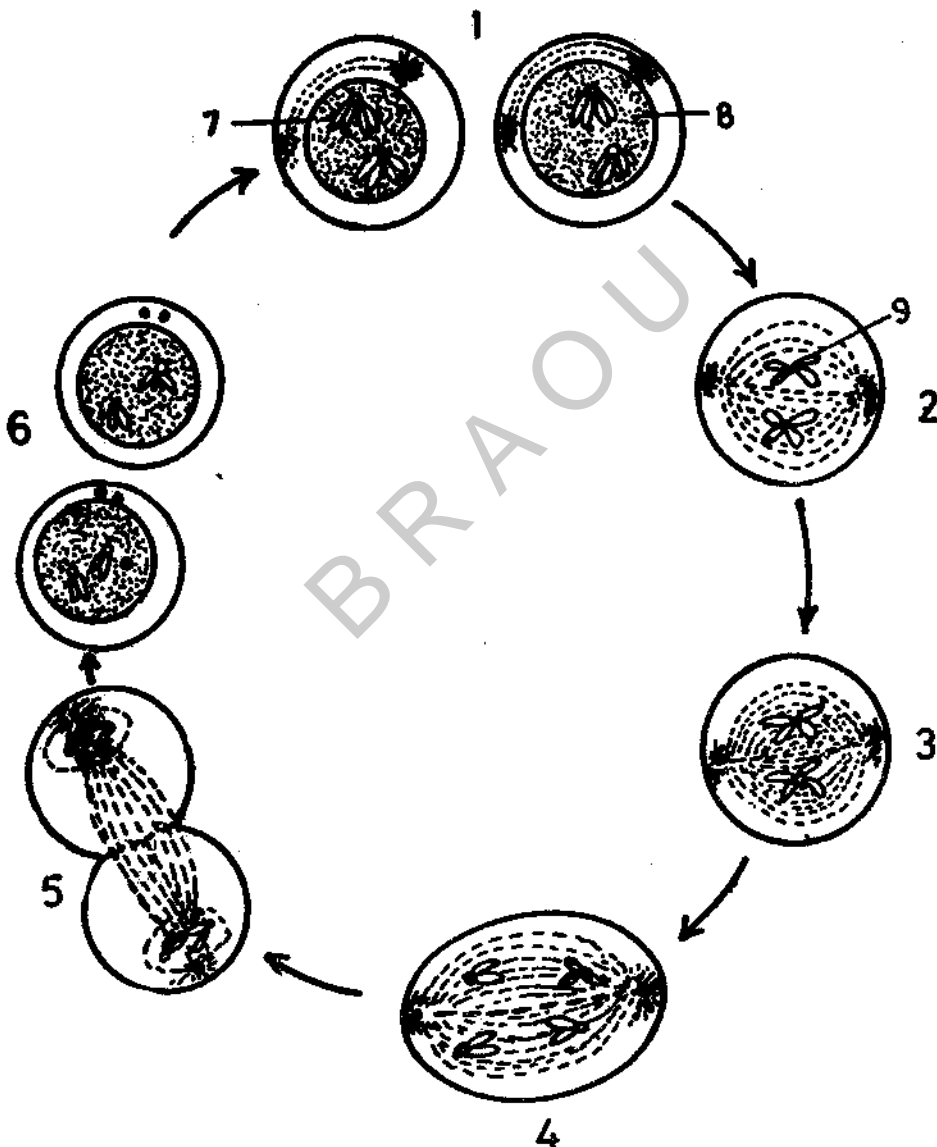


Fig. 5.5 Stages in homotypic division of meiosis 1. Daughter cells 2. Prophase-II 3. Metaphase-II 4. Anaphase-II 5. Late telophase with cytokinesis 6. Daughter cells 7. Nuclear envelope 8. Nucleus 9. Chromatids.

2. The centromere divides into two and each chromosome produces two daughter chromatids.
3. As soon as each centromere is functionally doubled the chromosomes begin moving to opposite poles.

Anaphase-II

Due to contraction of spindle fibres and stretching of interchromosomal fibres the daughter chromatids move to opposite poles.

Telophase-II

1. The polar groups of daughter chromosomes uncoil.
2. The nucleolus reappears, and a nuclear envelope forms around each group.
3. After karyokinesis each haploid meiotic cell undergoes cytokinesis to form four haploid cells.

The result of the two meiotic divisions is therefore a quartet of cells (4), each of which contains the haploid number of chromosomes. The first meiotic division is reductional with respect to the number of chromosomes and the second meiotic division equational.

5.5.1 Significance of Meiosis

1. It maintains a constant number of chromosomes in the organism.
2. Through meiotic cycle an orderly distribution of the genetic material occurs from generation to generation and permits great genetic diversity.
3. By crossing over, it helps for the exchange of the genes causing genetic variations among the species which in turn constitute the raw materials for evolution.

5.6 COMPARISON BETWEEN MITOSIS AND MEIOSIS

Comparison between Mitosis and Meiosis

| Mitosis | Meiosis |
|---|---|
| 1. Mitosis occurs in the somatic cells continuously | 1. Meiosis occurs in the germ cells during gametogenesis. |
| 2. Its duration comparatively of short duration. | 2. It is of longest duration. |
| 3. The whole process completes in one sequence. | 3. The whole process completes in two successive divisions. |
| Prophase | |
| 4. It is of short duration without any substage. | 4. Prophase is of longer duration with 5 successive substages viz., leptotene, zygotene, pachytene, diplotene and diakinesis. |
| 5. No pairing of synapsis occurs. | 5. Pairing or synapsis occurs between the homologous chromosomes. |
| 6. No crossing over and chiasma formation. | 6. Crossing over takes place with chiasma formation. |

Mitosis

7. Exchange of genetic material does not take place.

Metaphase

8. The chromatids occur in the form of dyads.
9. The centromeres of the Chromosome remain directed towards the equator and arms directed towards the poles.
10. Centromeres do not divide only partners of bivalents are set apart.

Anaphase

11. The chromosomes are having single chromatid.
12. The chromosomes are long and thin.

Telophase

13. Karyokinesis is followed by cytokinesis.
14. The chromosomal number in each daughter cell remains the same as the parent cell (diploid).
15. A diploid cell produces two daughter cells which are similar in quality.

Meiosis

7. Exchange of genetic material occurs between non-sister chromatids.

8. The chromatids occur as tetrads.

9. Arrangement is just reverse i.e., centromere lie towards poles and arms towards the equator of cell.

10. Centromeres divide in metaphase stage.

11. The chromosomes are having two chromatids and a single centromere.

12. They are short and thick.

13. Karyokinesis may or may not be followed by cytokinesis.

14. The chromosome number is reduced to half (haploid) in the daughter cells unlike the parental cell (diploid).

15. A diploid germinal cell produces four haploid daughter cells which are not similar.

Check your Progress

1. The stage between two mitotic divisions is called _____.
2. Interphase is the largest phase of mitotic cycle including following three sub-phases.
 - a. _____
 - b. _____
 - c. _____

5.7 SUMMARY

1. The development of multicellular organism from the unicellular zygote is achieved by the cell division and growth.
2. The asexual and sexual reproduction of the organisms also depend on the cell division.
3. The cell division is achieved by two integral activities such as Karyokinesis and Cytokinesis.
4. The asexual reproduction in unicellular organisms is by direct cell division called amitosis.
5. The multiplication of cell number during embryogenesis and further growth of an organism is facilitated by mitosis which occurs in the somatic cells.

6. The reduction division as seen in the gametogenesis during sexual reproduction is due to meiosis.

5.8 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Interphase
2.
 - a. G₁ Phase
 - b. S Phase
 - c. G₂ Phase

5.9 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines:

1. Describe the mitotic division in a typical cell. What is its significance
2. Describe the meiosis or reduction division with suitable sketches.
3. Mention the difference between mitosis and meiosis.

II. Answer the following in about 10 lines:

1. What is cell division ? Mention the changes which initiate the cell division.
2. Describe the process of amitosis.
3. Describe the characteristic events of zygotene and diplotene stages of meiotic division.
4. Mention the events that occur during Homotypic or second meiotic division of a cell.

Unit – 6 GAMETOGENESIS FERTILIZATION; PARTHENOGENESIS

Contents

- 6.1 Objectives
- 6.2 Gametogenesis
- 6.3 Spermatogenesis
- 6.4 Oogenesis
- 6.5 Fertilization
- 6.6 Parthenogenesis
- 6.7 Summary
- 6.8 Check Your Progress – Model Answers
- 6.9 Model Examination Questions
- 6.10 Glossary

6.1 OBJECTIVES

This unit deals with the process of gametes formation in sexually reproducing forms. By the end of this unit you will be able to:

- describe the mechanism of fertilization of female gametes, the ovum with the male gamete, the spermatozoa.
- elucidate the peculiar mode of sexual reproduction through parthenogenesis registered in different animal groups.

6.2 GAMETOGENESIS

The gametogenesis (Gr., gamos = marriage, genesis = origin) is the process by which gametes are produced in the gonads. The germinal cells form the gonads, the testes and ovaries in the sexually reproducing animals. The male gamete is known as spermatozoan or sperm and the process of production is called as the spermatogenesis. (Gr. sperma=seed). The female gamete is known as ovum or egg which is produced by the process of Oogenesis (Gr., oon=egg). Both the processes are complicated with successive mitotic and meiotic divisions.

6.3 SPERMATOGENESIS

It occurs in the male gonads or testes which contain several semi-niferous tubules. The germinal epithelium lining these tubules undergo spermatogenesis in two stages:

1. Formation of spermatids.
2. Spermiogenesis

Formation of Spermatids

The spermatids are produced from the diploid cells of male germinal cells of testes, called spermatogonia. Each spermatogonium is diploid with 2x number of chromosomes. The formation of spermatids takes place in three stages.

Multiplication phase : The primordial germ cells which contain chromatin-rich nuclei undergo repeated mitotic divisions to produce a large number of spermatogonia.

Growth phase : Each spermatogonium becomes enlarged in size by absorbing nutrients and accumulation chromatin material as well. Now each fully grown spermatogonial cell is known as **primary spermatocyte**. (Fig. 6.1)

Maturation phase : The primary spermatocytes undergo first meiotic or maturation (homotypic) division. The homologous chromosomal pairing (synopsis) and splitting take place resulting in the formation of tetrads. By chiasma formation crossing over occurs. Thus by first meiotic division two **secondary spermatocytes** are produced with haploid (x) number of chromosomes. Each secondary spermatocyte passes through the second meiotic or maturation (heterotypic) division and produces two **spermatids**. At the end of maturation phase each diploid spermatogonium produces four haploid spermatids which undergo metamorphosis into spermatozoa.

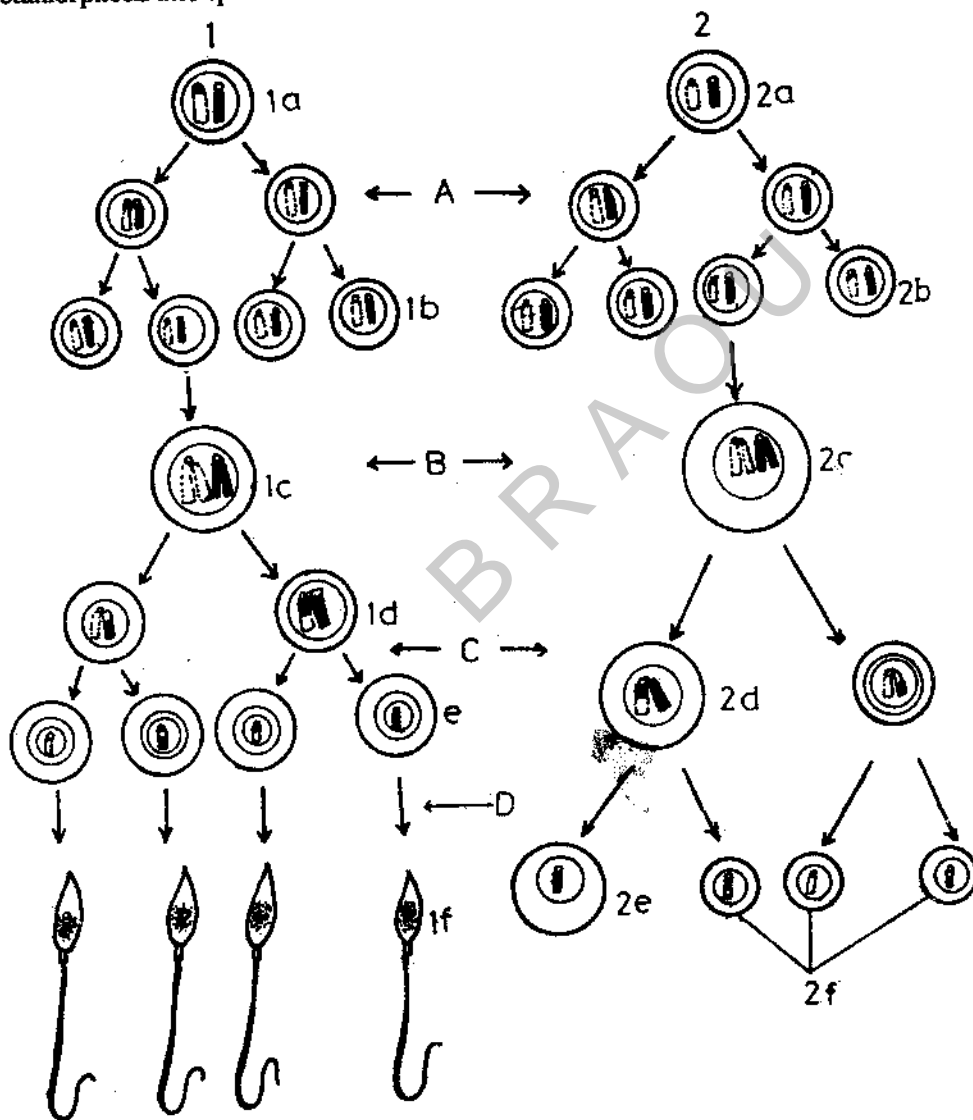


Fig 6.1. Spermatogenesis and Oogenesis. 1. Spermatogenesis 2. Oogenesis A. Multiplication phase B. Growth phase C. Maturation phase D. Spermiogenesis 1a. Primary germ cell 1b. Spermatogonium 1c. Primary spermatocyte 1d. Secondary spermatocyte 1e. Spermatids 1f. Sperms 2a. Primary germ cell 2b. Oogonium 2c. Primary Oocyte 2d. Secondary Oocyte 2e. Ootid 2f. Polar bodies.

Spermiogenesis

The metamorphosis of spermatids, which involves specific morphological and cytological changes is called spermiogenesis. The following changes occur during spermiogenesis:

1. Body of spermatids becomes elongated.
2. The cytoplasmic mass gets reduced.
3. Centriole divides into two. The distal centriole changes into basal body and gives rise to an axial filament of the sperm. The proximal centriole disappears later.
4. The nucleus shrinks and assumes different shapes in different animals, for example, in man and bull it becomes ovoid, in birds it is twisted.
5. The acrosome at the anterior side of sperm is formed by the Golgi complex.
6. Mitochondria which provide energy are more concentrated at the centriole region.
7. The axial filament develops an envelope, the axial sheath which together constitute the tail.

The mature motile sperm thus consists of a relatively large head composed of an elongated nucleus, covered proximally with a conical acrosome; a middle piece having two centrioles and a tail considerably longer composed of an axial filament with an axial sheath terminating in a naked end piece.

6.4 OOGENESIS

The process of Oogenesis occurs in the ovary of female animal. The germinal epithelium of the ovary known as primordial germinal cells undergo oogenesis in three successive stages as in spermatogenesis:

1. **Multiplication phase** : The primordial germinal cells divide repeatedly through mitotic divisions to form a large number of oogonia. Each oogonium has diploid number (2X) of chromosomes which pass through the next phase.
2. **Growth phase** : During this phase, the size of the oogonium increases enormously with the accumulation of fat and proteins in the form of yolk or deutoplasm. The yolk is usually concentrated towards lower portion of the egg forming the **vegetal pole**. The portion of the cytoplasm (Ooplasm) containing the egg pronucleus remains towards the upper side of the egg forming the **animal pole**. The full-grown oogonium with enormous yolk is now termed as **primary oocyte**.
3. **Maturation phase** : The primary oocyte undergoes first meiotic or maturation division. The homologous chromosomes exhibit pairing or synapsis, duplication (splitting), chiasma formation and crossing over. After karyokinesis the unequal cytokinesis occurs resulting in the formation of a large haploid **secondary oocyte** and a small polar body (Fig 6.1).

The secondary oocyte and first polar body pass through second maturation division of mitotic nature. As a result the secondary oocyte produces a larger mature ovum or egg and a small second polar body. The first polar body also divides to produce two more polar bodies. Thus, finally through the process of oogenesis a single nonmotile haploid ovum and three smaller haploid polar bodies are formed.

The egg thus produced becomes ready for fertilization having covered by the unit membrane. In addition to plasma membrane the eggs of most animals consists of primary, secondary and tertiary membranes. The cytoplasm of egg is called ooplasm in which the egg pronucleus is suspended. The nutritive yolk present in the ooplasm varies from species to species.

6.5 FERTILIZATION

The sexual union of male and female gametes is known as fertilization or syngamy. The term fertilization (L. fertilis = to bear) refers to the union of cytoplasm and pronuclei of ovum and sperm. In this process the haploid male gamete, sperm, which carries the paternal genetic information unites with the haploid female gamete, ovum, which carries genetic information of maternal side to form a diploid zygote.

Process of Fertilization

The mechanism of the fertilization includes two successive steps:

1. Activation of the egg.
2. The Amphimixis.

Activation of the Egg

The process of activation of egg takes place as follows:

- A. Movement of sperm towards the egg :** The sperms actively swim towards the egg at randomly and collide with the egg by chance. The chance of colliding of the sperms with the egg occurs due to large number of sperms and enormously large size of the ovum. It is found that the egg contains a chemical substance known as fertilization which dissolves the surrounding jelly water of the egg and makes the sperm entry easy.
- B. Activation of sperm :** The surface layer of sperm contains another substance known as antifertilizin. When the sperm with a specific antifertilizin comes in contact with the egg of its own species it gets activated. The acrosome elongates to form 1 to 75 μ long acrosomal filament and the sperm is said to be activated for ready penetration into the ovum. The acrosomal filament penetrates into egg jelly and vitelline membranes with the help of dissolving action of sperm lysins.
- C. Activation of egg and insemination :** As soon as the acrosomal filament touches the egg surface the ooplasm produces a cone-like process known as the fertilization cone (Fig 6.2). This fertilization cone engulfs the sperm. The penetration of sperm into the egg is described as the insemination. Immediately after the insemination a thin membrane known as the fertilization membrane is formed around the egg which prevents the entry of further sperms into the egg.

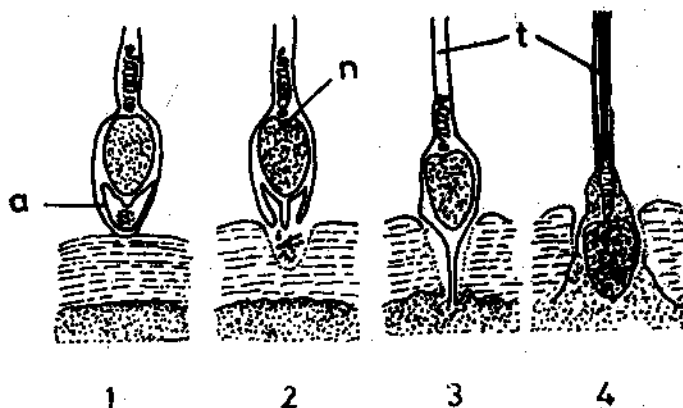


Fig 6.2. Process of fertilization. 1. Sperm coming in contact with egg envelope 2. Sperm penetration with the formation of acrosomal filament 3. Fusion of plasma membrane of egg and sperm 4. Fertilization cone formation a. Acrosome n. Nucleus t. Tail.

Amphimixis

It involves the fusion of two nuclei. During insemination the entire sperm may enter in the egg or the tail of the sperm remains outside the egg. The nucleus of the sperm is known as the male pronucleus which swells up by absorbing water from the surrounding ooplasm. The centriole of the sperm is surrounded by the centrosome and microtubules which form aster rays. The male pronucleus and the aster move towards the egg pronucleus (Fig 6.3).

As the two pronuclei come close to each other they fuse with each other with the disruption of their nuclear envelope. Then the nuclear contents of both the pronuclei are intermingled and this fused one is called zygote nucleus. The endoplasmic reticulum forms new common nuclear envelope around the diploid zygote nucleus. This kind of mixing of male and female pro-nuclear material is termed as amphimixis.

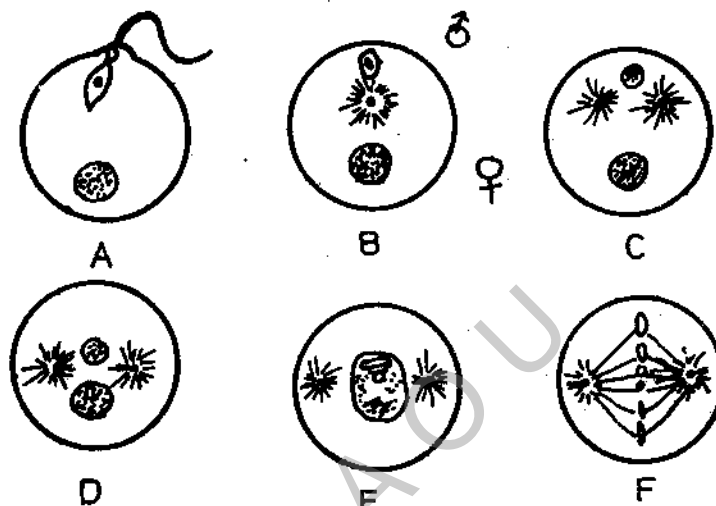


Fig. 6.3. Amphimixis in fertilization. A. Entry of sperm into the Ovum B. Ovum with male and female pronuclei and centriole C. Amphiaster formation D. Migration of male pronucleus towards female pronucleus E. Amphimixis or fusion of two nuclei F. Zygote, ready for cleavage.

Post-fertilization changes

After the fertilization the following changes take place in the zygote:

1. Polarity of the ovum is established after fertilization.

The side where the sperm penetrates into the egg is the future anterior and opposite and is the posterior side of the embryo.

2. The metabolic rate of the zygote increases enormously.
3. Oxygen consumption of the zygote increases rapidly.
4. The protein synthesis is started.
5. The zygote becomes ready for cleavage and embryogeny.

Kinds of Fertilization

1. **External fertilization** – If the fertilization occurs outside the body of organism as seen in some invertebrates, fishes and amphibians.

2. **Internal fertilization** – If the fertilization occurs inside the body of the organism as found in reptiles, birds and mammals.
3. **Monospermic fertilization** – When one sperm enters the egg and fertilizes, it is called monospermy. It is very common in most animals.
4. **Polyspermic fertilization** – When many sperms enter the egg, the fertilization is known as polyspermy found in molluscs, selachians, urodeles, reptiles and birds.
5. **Polyandry** – When two male pronuclei unite with a female pronucleus the phenomenon is called as polyandry e.g. rat and man.
6. **Polygamy** – When two egg nuclei unite with single male pronucleus, it is called as polygamy as seen in sea urchins, Polychaetes, nematodes and rotiferans.
7. **Gynogenesis** – When only sperm activates the egg but it never unites with the egg as found in planarians, nematodes and rotiferans.

Significance of Fertilization

1. The fertilization provides new genetic constitution to the zygote.
2. It activates the zygote for the cleavage and embryogenesis.
3. It enhances the rate of protein synthesis and metabolic activity of the zygote.
4. It ensures the usual diploidy of the organism by the fusion of haploid male and female pronuclei.
5. It helps in the transmission of paternal and maternal genetic information to the zygote.

6.6 PARTHENOGENESIS

The development of an egg into an embryo without fertilization is called **parthenotes**. The phenomenon of parthenogenesis occurs frequently in certain orders like Hymenoptera, Holoptera, Coleoptera, Crustaceans and Rotifers.

The parthenogenesis is of two types:

1. Natural parthenogenesis
2. Artificial parthenogenesis

Natural Parthenogenesis

In certain groups of animals the parthenogenesis occurs spontaneously, regularly, constantly, and naturally in their life cycles is described as **natural parthenogenesis**. Through this phenomenon some insects like bees, wasps and ants maintain their existence from generation to generation. It is of two types viz., complete and incomplete.

1. Complete Parthenogenesis

Certain insects and rotifers have no sexual phase or males. They depend exclusively on parthenogenesis for the continuity of race. This type is known as complete or obligatory parthenogenesis.

2. Incomplete Parthenogenesis

The life cycle of some insects includes sexual generation and parthenogenetic generation, both of which alternate to each other. In such cases the diploid eggs produce females and unfertilized eggs produce males. This type is known as **partial or cyclic parthenogenesis**.

The complete and incomplete type of natural parthenogenesis may be of two types:

- A) Haploid or Arrhenotokous parthenogenesis
- B) Diploid or Thelytokous parthenogenesis
- A) Arrhenotoky or Haploid Parthenogenesis

In some cases the haploid eggs are not fertilized by the sperma and develop into haploid male individuals. This phenomenon is called **arrhenotoky or haploid parthenogenesis**. It is seen in bees, wasps, ticks, mites and rotifers. Arrhenotoky is common in 'red spider' where male haploidy is common. Rotifers exhibit numerous variations in their life. In one of the rotiferan order Bdelloides males are unknown and thelytoky is the only method of multiplication.

B) Thelytoky or Diploid Parthenogenesis

In this type of parthenogenesis females are produced from unfertilized diploid eggs. On the basis of cytogenetic studies thelytoky is of two types-meiotic and ameiotic

I. Meiotic Thelytoky

In this, meiosis takes place in the egg and the chromosomal number is reduced. But this reduction is compensated by doubling of chromosome number (diploidy) at some stage of life cycle. This type is also called **automictic parthenogenesis** which occurs by two means:

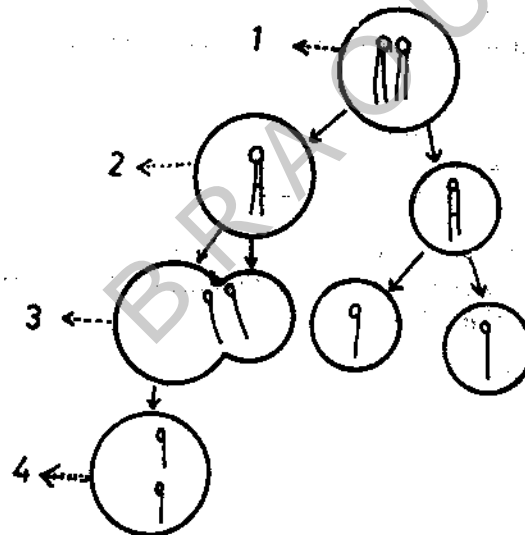


Fig. 6.4. Origin of Thelytoky by restitution. 1. Primary Oocyte 2. Secondary Oocyte with incomplete division 3. Restitution 4. Diploid Ovum.

- a) **By restitution** : Sometimes in primary oocyte the karyokinesis is not followed by the cytokinesis. The chromosomes first come together again in the middle of cell, as the first meiotic division is actually omitted. This counting together of chromosomes in diploid condition is called restitution (Fig. 6.4). Now with the second maturation division one diploid ootid and a diploid polar body are formed. It occurs in parthenogenetic Lepidoptera and Hymenoptera.
- b) **By auto fertilization**: It is the most wide spread type in which the egg fuses with polar body to form a diploid egg. This diploid egg develops into a new individual as seen in some lower crustaceans (Fig. 6.5).

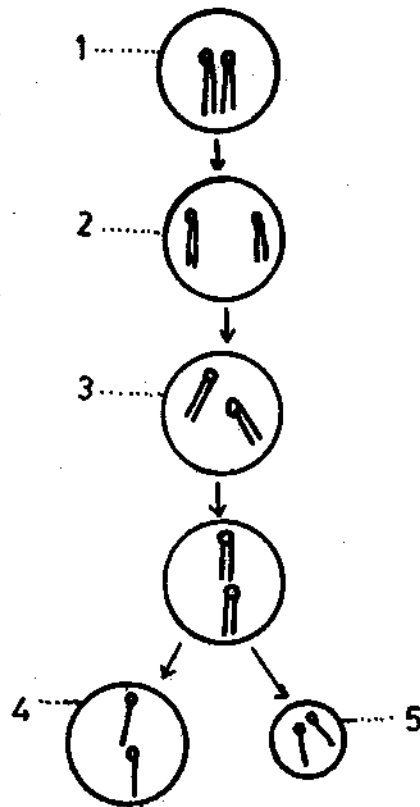


Fig 6.5. Origin of Thelytoky by auto fertilization. 1. Primary oocyte 2. Secondary oocyte 3. Second polar body fusing with ovum 4. Diploid ovum 5. Polar body.

ii) Amelotic thelytoky

In this type during oogenesis, first meiotic or reduction division does not occur but second meiotic division occurs as usual. Such eggs contain diploid number of chromosomes and develop into new individuals without fertilization. This is also called **apomictic parthenogenesis** and seen in isopods, Mollusca, Hymenoptera and Crustacea.

Artificial Parthenogenesis

In this process, the eggs are made to undergo parthenogenetic development by artificial means. It is a recently discovered process induced in a wide variety of animals by various workers in the eggs of most annelids, molluscs, echinoderms, amphibians, birds and even mammals. The artificial parthenogenesis may be experimentally induced by different physical and chemical means.

1. **Temperature** – The range of temperature may induce parthenogenesis in the eggs. For instance when the egg is transferred from 30°C to 10°C the parthenogenesis is induced.
2. **Electrical shocks** can cause parthenogenesis.
3. **Ultraviolet light** can induce parthenogenesis.
4. **Physical pricking** by the fine glass needles, the frog and sea urchin eggs may be stimulated to undergo development.
5. **Chemicals** like chloroform and weak solution of strychnine; chlorides of K^+ , Na^+ , Ca^{++} , and Mg^{++} ; weak acid such as butyric acid, lactic acid, and fatty acids; solvents like toluene, ether, benzene and acetone have been found to cause parthenogenesis in normal eggs of various animals.
6. **Sea water** – Loeb experimented extensively on the eggs of sea urchins and frog with hypotonic sea water and observed cleavage in them.

7. Even shaking, puncturing also induced artificial parthenogenesis. Only exceptionally do these artificially induced parthenotes reach the stage of metamorphosis or sexual maturity.

Significance of Parthenogenesis

1. Parthenogenesis is the most simple and stable process of reproduction.
2. It eliminates variations from the population.
3. It eliminates non-adaptive combination of genes and encourages the occurrence of advantageous mutant characters.
4. It acts as a device for rapid multiplication (aphids).
5. It serves as a means for the determination of sex in the honey bees, wasps etc.
6. The parthenogenesis also causes polyploidy in the organisms.
7. **Darlington (1978)** considers parthenogenesis as an escape from sterility, a sterility which might be due to incompatibility of gametes.

Check Your Progress

1. The metamorphosis of spermatids, which involves specific morphological and cytological changes is called _____.
2. The process of Oogenesis occurs in the _____ of female animal.
3. Define Parthenogenesis.

6.7 SUMMARY

1. The germinal cells produce the gametes by successive mitotic and meiotic divisions.
2. The gametes are of two types male spermatozoa and the female ovum.
3. The sperms are produced by spermatogenesis and the ova by oogenesis.
4. Fertilization involves the union of haploid male and female gametes to form diploid zygote.
5. The process of fertilization is very specific and includes two steps activation of gametes and amphimixis.
6. Parthenogenesis is of two types-natural and artificial. The mechanism and the significance of the said phenomena are discussed with examples.

6.8 CHECK YOUR PROGRESS – MODEL ANSWERS

1. Spermatogenesis
2. Ovary
3. The development of an egg into an embryo without fertilization is called parthenogenesis.

6.9 MODEL EXAMINATION QUESTIONS

- I. Answer the following in about 30 lines each :
 1. What is gametogenesis ? Describe the role of meiosis in the gametogenesis.
 2. Describe the spermatogenesis in animals and explain how it differs from oogenesis.
 3. What is fertilization ? Describe the mechanism and its significance.

II. Answer the following in about 10 lines each :

1. Describe different phases found in the process of oogenesis.
2. Mention different types of fertilization found in animals.
3. What is parthenogenesis? How is it artificially induced in various animals.
4. Describe arrhenotoky and thelytoky in animals with reference to parthenogenesis.
5. What are different kinds of eggs found in different animals with respect to yolk?

6.10 GLOSSARY

| | |
|------------------|---|
| Acrosome | A cap like structure at the tip of sperm responsible for easy penetration of the egg. |
| Active transport | The movement of materials across the membrane by means of a carrier, which perhaps an enzyme. |
| Amitosis | Direct nuclear division in which separation of daughter chromosomes never take place. |
| Anaphase | The third phase of mitosis and meiosis in which chromosomes move from equator towards its pole. |
| Animal pole | The upper pole of the egg which is opposable to vegetal pole. |
| Aster | The radiating structure of the centriole and astral rays in the early prophase of mitosis in the shape of a star. |
| Bivalent | The homologous chromosomes paired during meiosis. |
| Centromere | The point of spindle fibre attachment in the prophase of mitosis, also called as kinetochore. |
| Chiasma | Formed by two of the four chromatids of a bivalent breaking and crossing at the end of pachytene of meiosis. |
| Chromatid | A longitudinal half of the a chromosome formed during mitosis. |
| Chromation | Diffused chromosomal material in the nucleus. |
| Codon | Three bases which specify an amino-acid in protein synthesis. |
| Crossing over | An exchange of corresponding parts between two pairs of chromatids in pachytene stage. |
| Aster | Star shaped structure formed from centriole is involved in spindle figure formation during animal cell division. |
| ATP | Adenosine triphosphate molecule |
| Autosome | Component chromosome of genome or karyotype other than the sex chromosome. |
| Cell | The structural and functional unit of living organism. Is made of an envelope |
| Centriole | Filamentous organelle located near the nucleus. Is involved in the formation of spindle figure |

| | |
|----------------|--|
| Centromere | A special constriction (primary constriction) on the chromosome, useful for attachment to the spindle figure during animal cell division. |
| Chromatid | The thread-like constituent of chromosome. |
| Chromosome | The structure that is formed from chromatin reticulum of nucleus during cell division. Is the vehicle for the control of vital activity and heredity. |
| Complex, Golgi | The endoplasmic cisternal, microtubular, globular system concerned with secretion of lipoprotein and glycoprotein. |
| Crista | The intramitochondrial structural location present as infolding of inner mitochondria membrane. Contains FIP particles and other 'biochemical structures' concerned with aerobic metabolism. |
| Cytokinesis | The division of cytoplasm followed by Karyokinesis in cell division. |
| Diakinesis | The last stage in prophase of meiosis. |
| Diploid | Having double set of chromosomes. |
| Diplotene | A stage in the prophase of meiosis when bivalents split. |
| Dyad | One half of each tetrad |
| Gametogenesis | Series of changes by which gametes are formed. |
| Gene | A unit of hereditary factor in a chromosome. |
| Haploid | Having only a single set of chromosomes as in gametes. |
| Interphase | A preparatory state of cell before cell division. |
| Locus | Position of gene in the chromosome. |
| Meiosis | Process of reduction division of germ cells of chromosomes. |
| Operon | The functional unit of transcription. |
| Polar bodies | Very small non-functioning cells produced during oogenesis. |
| Polytene | Giant chromosomes in certain somatic cells of Diptera. |
| Pronuclei | The nucleus of sperm and egg which unite to form zygote. |
| Prophase | The first phase of cell division. |
| Protoplasm | Term used for the living substance. |
| Spindle fibre | Microtubules which run from centromeres to the poles of mitotic spindle. |
| Synapsis | Close association of homologous chromosomes in early meiosis. |
| Tetrad | A group of four chromatids in a pair of bivalents after synapsis. |
| Zygote | The cell formed by the union of male and female gametes |
| Cytology | Branch of biology dealing with the structures and functions of different organelles that go into the construction of the cell. The modern cell biology includes in its scope the classical cytology. |

| | |
|-----------------------------------|--|
| Electron Transport | Pairs of electrons transferred to cytochrome batteries (located on the cristae mitochondriae) pass along the battery from iron prosthetic groups of one cytochrome to those of the succeeding cytochrome et seq. This is electron transport. |
| Endocytosis | The process of intake of foreign material by the cell, for onward digestion and destruction includes pinocytosis and phagocytosis. |
| Ghost, RBC | A special preparation obtained by treatment of RBC (errthrocytes) with salt solution. The resultant erythrocyte ghosts (ECG) composed of plasma membranes are used in various studies on cell physiology. |
| Lysosome | Mitochondrion-like (but without double-membrane plan of structure) particles containing hydrolases. Useful for lysis of material occurring in phagocytosis and autolysis |
| Plasma Membrane | The outer envelop of animal. Cell, forming a 'learned' gate controlling entry and exit of materials from the cell. (Performs some other functions from the cell). Performs some other functions in certain cells and locations. |
| Unit Membrane | The plan of construction of Plasma membrane as a three-layered structure |
| Micron (or) micrometer | Unit of micromensuration. A millionth part of a meter ($10^{-6}m$) (meter = m). |
| Microscope | An optical physical instrument useful for magnification of images of minute organisms and preparations. Useful tool in cytology. |
| Microvilli | Located on the cells of intestinal mucosa/nephric lumen. These microscopic finger like outgrowths serve purposes like absorption and nephric function. |
| Mitochondrion | The 'power house' of the cell, made of double membrane. Is concerned with aerobic metabolism and generation of ATP, the cellular energy currency. |
| Nucleic acid (s) | The nucleic acids, Viz., deoxyribonucleic (DNA) and ribonucleic acid (RNA), are involved in the control of cellular metabolism. DNA is the major component of chromosomes and RNA, of the ribosomes. |
| Nucleus | The intra-cytoplasmic, porous, double-membrane structure controlling interphase metabolism and cyto-and karyokinesis metabolism. |
| Organelle | The functional component of the cell, charged with a specific function. |
| Oxydative Phosphorylation | The phosphorylation ADP with Pi to from ATP, which is coupled to the reversible reduction oxidation events taking place along the cytochrome battery during electron-transport. |
| Endoplasmic reticulum (ER) | The microtubular reticular system of endoplasm, made of rough (granular) and smooth (agranular) regions. |
| Ribosome | Particulate organelle location in rough ER. Contains RNA - controls protein synthesis under the direction of the nucleus. |

BRAOU

BLOCK – II
CLASSICAL GENETICS

BRAOOU

UNIT - 7 HISTORICAL ACCOUNT, IMPORTANCE OF GENETICS AND ITS APPLICATIONS

Contents

- 7.1 Objectives
- 7.2 Introduction
- 7.3 Importance of Genetics
- 7.4 Branches of Genetics
- 7.5 Application of Genetics
- 7.6 Genetic Engineering
 - 7.6.1 Artificial Synthesis of DNA
 - 7.6.2 Transduction in Genetic Engineering
 - 7.6.3 Genetic Engineering Studies on Gene Infection in Mammalian Cells.
- 7.7 Summary
- 7.8 Check Your Progress - Model Answers
- 7.9 Model Examination Questions

7.1 OBJECTIVES

This unit is about the historical background and development of genetics. By the end of this unit you will be in a position to explain

- the development of genetics
- importance of genetics and
- its application in various fields.

7.2 INTRODUCTION

Today, the science of Genetics is the most significant and youngest branch of modern biology in comparison to other biological sciences. It originated in 1900 with the discovery of scientific article originally published by William Bateson in 1906. It is derived from Greek language which means the "Science of coming into being".

It is an evident fact that offsprings always resemble their parents. Sexual reproduction is the fundamental basis among all organisms to transfer this biological information of perennial generation to the new organisms via egg and sperm. Thus, similar type of organism always produces the similar type. For example, human babies are always cast in human mold and resemble their parents or siblings; the puppies always resemble their parents and never cats or elephants. This inherent tendency of organisms to resemble their parents is known as "Heredity". Undoubtedly, the resemblances between parents and offsprings are close and never exactly alike. Thus, like begets like, but no two organisms of the same species are exactly alike. The offsprings of a particular parent thus differ from each other and from their parents in many respects. But the degree of difference is variable. Thus all the living organisms of a species have unique individuality. These characters or structural differences which provide individuality to a species, are known as variations.

The subject which deals with these phenomena of heredity and variation and the study of laws governing similarities and difference among related organisms largely in their evolutionary aspects is known as genetics. But a modern geneticist in addition to the heredity and variation includes in his scope, the study of all aspect of genes such as their origin, chemical nature, role in development and such other things related to germplasm which contain these genes. Thus, modern genetics may be defined as the science which contain these genes. Thus, modern genetics may be defined as the science which deals with the study of germplasm. The early philosophers, and workers had forwarded various speculations and theories to explain the phenomenon of inheritance but non could arrive with decisive results.

For the first time, Gregor Johann Mendel (1822-1884) was able to understand the exact mechanism of heredity. He laid the foundation stone to modern genetics in 1866. He was a strong believer of particulate hypothesis. He could understand the heredity problems more clearly than anyone in past, because his approach was simple, logical and scientific. By his experiments on pea plant he concluded that the inheritance is governed by certain factors, which occur in the cells of each parent. He thought that each parent has two such factors in their body cells while their sex cells (sperm or pollen and ovum or egg) have only one factor. Thus, his theory about the mechanism of inheritance is also referred to as the particulate inheritance or factor hypothesis. By performing certain hybridization experiments with pea plant, he formulated certain fundamental laws called laws of inheritance or heredity which formed a sound basis for further genetic research. In the present century, the science of genetics has advanced with tremendous speed due to valuable contributions of many hybridists., cytologists, geneticists, physiologists and biochemists. The research works of various post-mendelian workers have deep impact over the development of modern genetics. To name a few: Flemming (1882), investigated the process of mitosis. Oscar Hertwig (1857), discovered that fertilisation in both animals and plants consists of physical union of the two nuclei contributed by the male and female parents. W.Raux (1883), postulated that the chromosomes within the nucleus are the bearers of the heredity factors.

T. Boveri (1892), described synapsis and meiosis in *Ascaris*. Tschermak, de Vries, Correns (1900), rediscovered Mendel's work and recognised its importance. de Vries (1901), adopted the term "mutation" to describe sudden, spontaneous, drastic alteration in the hereditary material of '*Oenothera*' C.E. Meclung (1902), described the sex- chromosomes. W.S.Sutton (1902,) advanced the chromosome theory of heredity.

W.Bateson (1902-1909), introduced the terms genetics, allelomorphs, homozygote, heterozygote, F₁ F₂ and epistatic genes. W. Bateson and R.C.Punnet (1906) , reported the first case of linkage in sweet pea. W. Johannsen (1909), coined the words gene, genotype and phenotype T.H.Morgan (1910), discovered white eye and sex linkage in *Drosophila* studies and thus *Drosophila* genetics began. C.B.Bridges (1911-23), discovered different types of chromosomal abnormalities and aberrations. F. Herstein discovered that the A B O blood groups are determined by a series of allelic genes H.J. Mullar (1927), reported the artificial induction of mutations in animals by X rays. S. Stern (1931), gave cytological proof of crossing over in *Drosophila*. T.H. Morgan (1933), got a noble prize for his development of the theory of the gene. M.Schiesinger (1934), demonstrated that the bacteriophages are composed of DNA and protein.

G. W. Beadle and E.L.Tatum (1941), published their classical studies on the biochemical genetics of *Neurospora*. O. T. Avery, C. M. McLeod and M. McCarty described the pneumococcus transforming principle which suggested that it is DNA and not protein which is the heredity material. H. J. Muller got a nobel prize for his contribution in the radiation genetics. E. Chargaff (1952), demonstrated that in DNA the number of adenine and thymine bases are always equal and so are the number of guanine and cytosine bases. J. D. Watson

and F. H. C. Crick (1953). proposed a model for D N A comprising of two helically intertwined chains tied together by hydrogen bonds between the purines and pyrimidines. S. Ochoa and A. Kornberg (1959). received a nobel prize for their studies on the in vitro synthesis of nucleic acids. Crick and his colleagues (1961), showed that the genetic language is made up of three letter words. F. Jacob and J. Monod put forward the operon concept. Holley et al (1965), isolated and sequenced the transfer of R N A for the amino acid alanine. M. W. Nirenberg and H. G. Khorana (1968), worked out the complete genetic code and got noble prize for deciphering the genetic code. H.G.Khorana and K.L.Agarwal synthesised the gene in vitro which coded for alanine transfer R N A from yeast.

The further progress of the genetics was enhanced by various genetic engineers like Sures, Geoddel, Gray, Ullrich (1980), who discovered nucleotide sequence of human preproinsulin complementary D N A. Mercola, Stang, Browne and Cline (1981), inserted new gene of viral origin into bone marrow cells of mice. Clonal experiments were conducted with *Escherichia Coli* by Geoddel and others to produce biosynthetic insulin proteins.

7.3 IMPORTANCE OF GENETICS

The science of genetics proved worthy in removing the false concepts of man about inheritance, and has made a great impact on the cultural evolution of man. it forms the basis for production of better hybrid varieties of plants and animals which provide mankind its basic needs food, shelter and clothing. In the modern era genetics has revolutionised agriculture, horticulture, animal husbandry, dairy concerning sources and many other branches of science.

In the science of medicine, it has opened a new era because it helps in the understanding of various inherited diseases such as haemophilia, colour-blindness, some types of diabetes, anemia, alcaptonuria, etc.

Branches Of Genetics

The modern geneticists have divided the science of genetics into many branches. The following are some of the most important branches of genetics:

- 1) **Microbial genetics** : It deals with the genetics of micro- organisms.
- 2) **Myco genetics** : The genetics of fungi.
- 3) **Plant genetics** : The genetics of plants.
- 4) **Animal genetics** : The genetics of animals.
- 5) **Human genetics** : The genetics of man.
- 6) **Cytogenetics** : It deals with the cytological explanation of genetic principles.
- 7) **Molecular genetics** : It deals with genetical analysis in diagnosing various hereditary diseases in man and suggests the possible cures for them.
- 8) **Radiation genetics** : It deals with the genetical effects of radiation on the living organisms.
- 9) **Population genetics** : The genetics of the different populations of animal and plant species.
- 10) **Developmental genetics** : It applies genetical knowledge to the developmental biology.

Application Genetics

Eventhough Genetics is one of the youngest branches of biological science it has helped the man in the improvement of his agricultural, horticultural and dairy concern resources and to cope with his various kinds of hereditary diseases.

The following are some of the significant economic uses of genetical knowledge.

1. **Genetics and Agriculture:** By applying selective breeding methods, genetics has made valuable contributions in the improvement of food, ornamental and medicinally useful crops and domestic animals. The breeding of animals and plants for better hybrid is based purely on the knowledge of genetics. Increase in the yield of crops like corn and rice, improvement in the size and flavour, production of disease resistant plants, production of seedless varieties of fruits and increase in the production of milk from cattle, eggs from the chicken, meat from the swine are some of the most useful benefits to mankind furnished by genetics. Broadly speaking, the plant and animal production of today's India are the chief outcomes of application of genetics to agriculture and animal breeding.
2. **Genetics and Eugenics:** The suggestions for improving human genetic material have come under the name eugenics, a term proposed by Francis Galton. The eugenics may be considered as a serious attempt to diminish human suffering from a number of deleterious genes and improve the human gene pool. The development of all organisms including the human beings depends on both heredity and environmental factors. For better type of development, both good heredity and suitable environment are necessary. The need of eugenics is to increase the normal and gifted population, and to decrease the abnormal and deficient populations. The principle of eugenics can be applied by adopting two methods namely:
 1. Positive eugenics
 2. Negative eugenics

Positive eugenics is an approach towards the human betterment by conserving the desirable variety of germplasm. This can be attained mainly by encouraging marriage between fit individual, by avoiding germinal wastes and by enlarging human opportunity.

Negative eugenics is a negative aspect of improving mankind by restricting the transmission of poor germplasm. This restriction can be done by discouraging the marriages between undesirable persons, by isolating the defective persons, by controlling immigration of persons with undesirable germplasm.

The positive eugenics increases the frequency of beneficial traits, rather than merely decreasing the frequency of deleterious genes. It is somehow possible by selective breeding methods. Unfortunately, many characteristics such as high intelligence, aesthetic sensitivity, good physical health and longevity are not caused by single genes that are easily identified, but complexes of many genes acting together in appropriate environments. In such cases, the methods involve various complicated selection schemes, based on selection of families and testing progeny under controlled environmental conditions. The results of such experiments as discussed by Lerner and other, improved certain complex characters by some degree, but usually caused deterioration of others. The means of selection themselves assume paramount importance in man.

Muller and others, have proposed the utilisation of sperm banks containing the preserved frozen sperm of outstanding creative individuals. This method is called germinal choice or euteleogenesis. In this method, married women volunteers would choose to be artificially inseminated by males that were long dead but had highly desirable characteristics. Muller proposed to extend these donor fertilizations by educating couples to desire a genetically gifted children by this method. The other proposed eugenic methods involve direct manipulation of human DNA by "genetic engineering" which is discussed separately in brief in the coming pages.

3. **Genetics and Medical Science:** Genetics has great application in the medical field because, the genetical knowledge helps the doctors in quick and accurate diagnosis of heritable diseases

and simplifies the process of their treatment. Various human disease such as haemophilia, some types of diabetes, colour blindness, several types of haemophilia, some types of deafness and blindness, haemolytic icterus, anaemia, tuberculosis, heart diseases and many other psychological and pathological abnormalities have been found to have genetical basis.

4. **Genetics and Legality:** Genetics can help in solving various legal problems easily. Court cases of disputed parentage have been solved by the analysis of blood types or inherited characteristics. This provides a suitable solution to the legal problems of custody of children, divorce, support of illegitimate children, estate inheritance etc.

Genetic Engineering

It is one of the eugenically sound methods devised recently by human geneticists for the improvement of human race. Recent advances in molecular genetics have hoped that the geneticists would raise a new technology to correct and improve the genotype by acting directly at the DNA level. The methods of artificial synthesis of new genes and their subsequent incorporation into the genome of an organism or methods of correcting the defective genes of organism by molecular biological technique, is called genetic engineering. Genetic engineering usually implies that alien hereditary material is not merely acquired, but incorporated into the genetic material of the host. When the host is a bacterium, it normally means inserting an alien segment into the ring chromosome, after which this segment will reproduce itself and be capable of metabolic activity. The use of bacteria to incorporate bits of mammalian DNA is done in principle.

With the genetic engineering, we can create genes, beneficial mutations and various other processes that involve the creation of life itself. In this field some of the microgeneticists working on micro-organisms, have already achieved good results. Some of the important geneticists in this field are Kornberg (1961), Mullar and Beatty (1969), Shapiro, Mirrill, Gier (1971), Quasba and Aposhian (1971), Pal (1974), Bodman and CavokkuSfirsra (1976), Gray, Ullrich, Sures and Goeddel (1980), Mercola, Stang, Browne and Cline (1981), Goeddel and others (1981), who worked recently. Their work in this field can be studied under the following heads:

1. Artificial synthesis of DNA

Kornberg (1967) and his associated using a mixer of deoxyribonucleotides, enzymes, ions, synthesised new DNA molecules. These experiments were based on the double helix concept of gene. But the synthesised DNA was a bacteriophage DNA which was single stranded, which most of the DNA is double stranded as we know today. Later, double stranded DNA was synthesised by Har Gobind Khorana for yeast alanine transfer RNA. This great success of Khorana has paved the way for a better understanding of the complicated processes occurring within living organisms for the improvement of living organism through tailored genes and even the synthesis of living organisms by 2000 A.D. If it is possible to synthesis artificial DNA in a test tube then it may also be possible to create specific genes which may be then inserted into cells to cause transformations. In this manner, one can correct the mutation genes. For example, if the mutation for galactosemia disease can be indentified, then a normal gene which codes for the missing enzyme preventing it, could be synthesised and introduced into the individual's cells.

2. Transduction in Genetic Engineering

This phenomenon is found in micro-organisms. Transduction is a process by which virus carries genetic material from one cell to another, causing the second host cell to be changed after incorporating the genetic material into its own genome. With regard to transduction some

UNIT – 8 MENDEL'S LAWS OF INHERITANCE

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8.1 OBJECTIVES

This unit is to familiarize the students clearly with Mendel's laws of inheritance. By the end of this unit you will be able to:

- define Mendel's laws
- describe the exceptions of Mendel's laws.

8.2 INTRODUCTION

The foundation stone for modern genetics has been laid by Gregor Johann Mendel. He was the pioneer of classical genetics. To understand clearly the mechanism of heredity, Mendel conducted some historic experiments on *Pisum sativum* (garden pea plant) which made him the 'Father of Genetics'.

Johann Mendel was born in July 22, 1822 in Heinzendorf in Austrian Silesia. He graduated from the Gymnasium in 1840. In 1843, was admitted to the Augustinian monastery at Brunn in Moravia (a Czechoslovakian town), where he took a monastic title Gregor by which name he was thereafter known. During 1854-1868. Mendel taught physics and natural sciences in a higher secondary school of Brunn. Besides teaching he performed certain hybridization experiments on flowers, vegetables, fruit in the 'Annual Proceedings of the Natural History Society' of Brunn. But unfortunately his valuable piece of work remained unattended and unappreciated by the then scientists upto 1900. Probably, they were unable to understand his statistical approach. It was in the beginning of the 20th century, that, three botanists namely, Hugo devires of Holland (working on *Oenothera*), Kari Correns of Germany (working on Xenia, Maize and Peas). Eric Von Teschermak of Austria (working on various flowering plants), had drawn independently, the same conclusions like Mendel. In 1900 they rediscovered Mendel's papers already published at Brunn's library. They proclaimed its importance to the present modern world. In honour of Mendel they named it as, 'Mendel's Laws of Inheritance'.

6. The term genetic engineering means the methods of artificial synthesis of new genes and their subsequent incorporation into the genome of organism by molecular biological techniques.
7. Kornberg and his associates synthesised a single stranded bacteriophage DNA in vitro while Khorana synthesised double stranded DNA for yeast alanine transfer.
8. Mercola, Stabgm Browne and Cline inserted new gene of viral origin into bone marrow cells of mice (Science 208: 1033-5, 1981).
9. Sures, Goeddel, Gray, Ulrich discovered nucleotide sequence of human preproinsulin complementary DNA (Science 208:57-9, 1980).
10. Milstein did studies on monoclonal antibodies (Scientific American 1980, 56-65).
11. Goeddel and others conducted clonal experiments with *Eshcherichia coli* to produce biosynthetic human insulin proteins (Science 215:687-8,1982).

7.8 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Microbial genetics, Mycogenetics,
Plant genetic, Animal genetics,
Human genetics, Cytogenetics,
Molecular genetics, Population genetics,
And developmental genetics
2. Transduction is a process by which virus carries genetics material from one cell to another, causing the second host cell to be changed after in corporation the genetic material into its own genome

7.9 MODEL EXAMINATION QUESTIONS

- I. Answer the following in about 30 lines:
 1. Why is the study of genetics important for human society?
 2. Write an essay on genetic engineering?
- II. Answer the following in about 10 lines:
 1. Eugenics in genetics.
 2. Role of genetics in agriculture.
 3. Experiments on gene insertion into mammalian cells.

viruses are gene-specific. For example, some derivatives of lambda bacteriophages are known to transduce the lac operon in bacteria. Utilising this fact very recently J. Shapiro and his co-workers isolated some of the lac operon genes including promoter, operator and one of the structural genes namely, Beta galactosidase. It was for the first time, O. Miller and B. Beatty (1969) in *Triturus* had been isolated internationally and transferred from cell to cell. Thus, after isolation of genes using specialised viruses the normal genes can be introduced into the cells of mutant individuals.

3. Genetic Engineering Studies on Gene Insertion in Mammalian Cells

Various scientists have conducted experiments on the insertion of genes into mammalian cells using similar mechanism applied for bacteria. They used purified DNA as a vector for gene transfer and had a little success. In some experiments for example, a mutant line of mouse cells, incapable of synthesizing the enzyme thymidine kinase has been exposed to the herpes simplex virus. This virus contains a gene coding for this enzyme. The mouse cells treated in this way appear to have acquired the capacity to synthesize this enzyme. Later, Boadmer and Caali S.forza (1976), conducted similar experiments with the DNA on several cancer causing viruses such as polyoma virus (a mouse virus) and S V 40 (a monkey virus). The DNA of these viruses is capable of integrating into human chromosomes. Further, the genetic engineering studies of Sures, Goeddel, Gray, Ullrich (1980), in discovering nucleotide sequence of human preproinsulin complementary DNA, studies of Mercole, Stang, Browne and Cline (1981), on the insertion of new gene of viral origin into bone marrow cells of mice. Milstein studies on monodonal antibodies, experiments of Goeddel and others (1982), with *Eshcherichia coli* to produce biosynthetic human insulin proteins, formed a very good additive information in expanding the field of genetic engineering.

Check Your Progress

1. What are the branches of Genetics?
2. Transduction in genetic engineering

7.7 SUMMARY

1. The subject which deals with the phenomenon of heredity and variation and law governing similarities and difference among individuals by descent is known as genetics. Now a days the modern genetics may also be defined as the science which deals with the study of germplasm.
2. Mendel was the first investigator to lay foundation stone to modern genetics and to understand the exact mechanism of heredity. He forwarded factors hypothesis or particulate hypothesis. His factors are now known as genes. He is called "Father of Genetics".
3. During the present century much progress has been made in the field of genetics. Morgan, Bridges, Muller, Sturtevant, Sutton, Boveri, Beadle, Tatum, Watson, Ochoa, Nirenberg and Khorana are some of the several scientists inseparably associated with the progress of modern genetics.
4. Genetics formed the main basis for the production of better hybrid varieties of plants and animals, and helped in understanding various genetic diseases like Haemophilia, colourblindness, alkaptonuria etc.
5. Genetics is divided into various branches like plant genetics, animal genetics, human genetics etc., for the sake of convenience of study.

Mendel conducted his experiments with utmost care, knowing the failure of his predecessor hybridists. His approach was simple, logical, scientific, mathematical and analytical.

Mendel was very careful in the selection of his experimental material and method of study. Mendel's selection of material was not a mere chance affair. He selected *Pisum sativum* on account of following advantages:

1. This plant can be self pollinated;
2. There is constancy of characters in the pea plant;
3. The hybrids obtained by crosses between the pure strains are also fertile;
4. It is an annual plant with short life cycles so that one can study several generations within a short period.

Mendel selected seven contrasting characters of different traits in garden pea plant, which are tabulated as follows:

| Traits | Contrasting Characters |
|--------------------------|-------------------------|
| 1. Shape of the seed | Round or wrinkled |
| 2. Colour of the seed | Yellow or green |
| 3. Colour of seed coats | Grey or white |
| 4. Shape of the pod | Inflated or constricted |
| 5. The colour of the pod | Green or yellow |
| 6. Position of flowers | Axial or terminal |
| 7. Length of the stem | Tall or short |

To understand clearly the observation and results of Mendel, one should become familiar about a few genetical terms and symbols which are generally encountered in modern genetics. These have been coined by W. Bateson between 1902-1909, by W. Johannsen in 1909, and others. As the time when Mendel conducted his experiments, Cytology was in its very primitive stage, and the role played by the chromosomes during gametogenesis and fertilization was yet to be observed and interpreted. Even then, Mendel was very brilliant in revealing his explanation from his experiments. According to Mendel, the inheritance is governed by certain factors or elements which occur in the cells of each parent. He thought that each parent has two such factors for a trait while their sex cells (sperm or pollen and ovum or egg) has only one factor. The factors of Mendel are now known as genes, as coined by Johannsen (1909). Further, he predicated that each factor retained its individuality from generation to generation, and it was modified in the hybrid. These factors contributed by the parents united at random to produce the characters of a hybrid. Indirectly thus, he predicated the reduction division during gametogenesis and physical hereditary mechanism both of which were unknown to the then scientific world.

Allelomorphs or alleles : Two alternative forms of a gene, controlling the same characters and located at the same locus in the homologous chromosomes are known as allelomorphs or simply alleles.

Homozygous and heterozygous : An individual is known as homozygous or pure for a character when, both the genes controlling that character represent the same alternative of that character. These are identical alleles. An individual is known as heterozygous for a character when, both the genes controlling that character represent the two different alternatives of that character. These are dissimilar alleles. An individual is known as heterozygous for a character when, both the genes controlling that character represent the two different alternatives of that character. These are dissimilar genes and form alleles.

Dominant and Recessive: In a heterozygous individual only one gene of a pair is able to express its character while the other is not able to express its character. The gene which expresses is known as dominant gene, and that which is unable to express is known as, recessive.

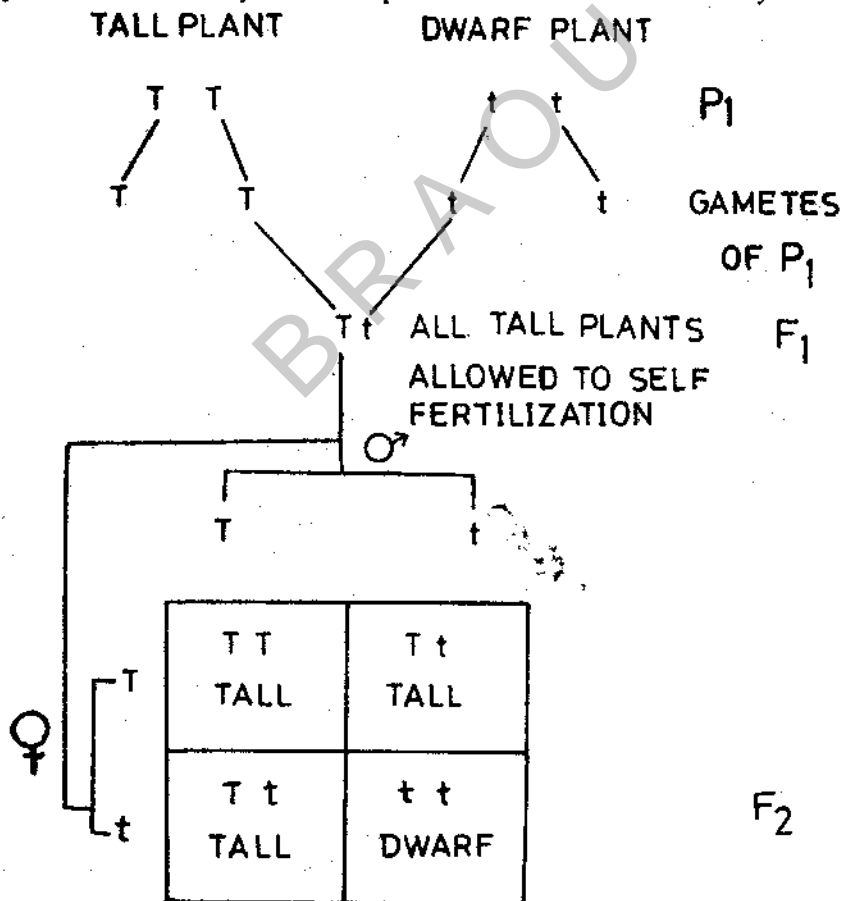
Genotype and Phenotype : Genotype refers to the entire assemblage of genes possessed by the individual. This includes both dominant and recessive genes. Phenotype refers to the aggregate of externally visible characters of an individuals.

8.3 MENDEL'S EXPERIMENTS

For his experiments, Mendel first selected homozygous plants. The plants involved in the crosses were called, parental plants and this generation is denoted by 'P'. The dominant character was represented by capital letters and recessive character by small letters. The generation of hybrids resulting from a cross between parents was called, the first filial generation and was denoted by F₁. The second generation of hybrids arising from the F₁. The second generation of hybrids arising from F₁ generation by self or cross fertilization was called, the second filial generation and was denoted by F₂. Likewise the subsequent generations were termed F₃, F₄ and so on.

8.3.1 Monohybrid Experiments

The crosses where parents differ in one trait or one pairs of alternative characters is known as monohybrid crosses and hybrids thus produced are known as monohybrids. Now, let us



MONOHYBRID RATIO = 3 TALL:1 DWARF

Fig. 8.1 Mendel's Monohybrid Cross between a Tall and a Dwarf Pea Plant

take the length of pea plant as a trait and study the monohybrid crosses conducted by Mendel. Length of the pea plant may be either tall or short. He crossed homozygous tall plant with homozygous short plant. He denoted the factor for tallness by 'T' and the factor for shortness by 't'. During fertilization in a cross between a tall and a short plant, the tall plant contributes gametes, each containing a single 'T' and the short plant contributes gametes, each containing a single 't'. After fertilization F₁ off springs will have both these factors T, and t. In appearance, these plants are tall because 'T' is dominant and 't' is recessive. Mendel spoke of the character which appeared in the F₁ generation as dominant and that which did not appear as recessive. Mendel allowed these hybrids to self-fertilisation (because same results could be reached by cross-fertilisation within the F₁ generation).

During self-fertilisation to give rise to the F₁ generation, F₁ plants having Tt produce gametes of two types in equal numbers, one type with 'T' and the other type with 't'. If the union of these F₁ gametes is at random he assumed, we will obtain tall and short plants on the ratio 3:1. This ratio is known as Monohybrid ratio. Mendel's monohybrid cross between a tall and a short plant can be represented in the figure as follows:

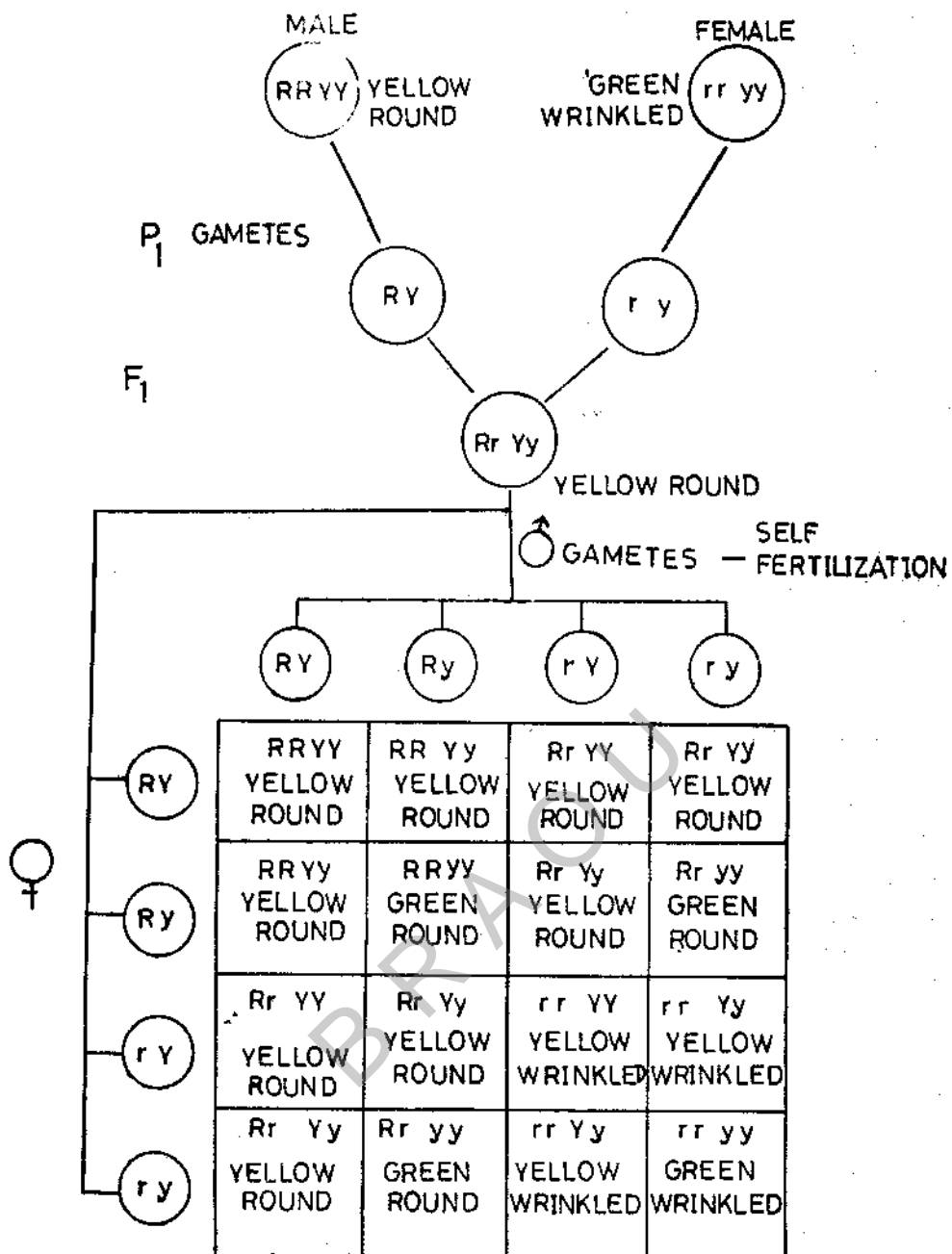
To determine the possible results of various crosses, for convenience of study, Chi-squares or checker boards are used. These are also known as punnet squares because these are introduced by R.C.Punnet (1906).

8.3.2 Dihybrid Experiments

The crosses where the parents differ in two traits or two pairs of alternative characters are known as, dihybrid crosses and the hybrids thus produced are known as dihybrids. In these experiments, Mendel selected two traits of pea plant. Now, for example, taking the shape of the seed and colour of the seed as two traits, let us study dihybrid crosses conducted by Mendel. the shape of the seed may be either round or wrinkled, the colour of the seed may be either yellow or green. The gene for roundness was denoted as 'R', for wrinkled as 'r', for yellow colour by 'Y' and green colour by 'y'. The round seed is dominant over wrinkled seed and the yellow colour is dominant over green. A plant with round yellow seeds was crossed with a plant with wrinkled seeds. All the F₁ plants showed round and yellow seeds. These were allowed to produce the F₂ generation plants with all the four possible varieties of seeds namely, 1) round-yellow, 2) round-green 3) wrinkled-yellow, 4) wrinkled- green of the 16 possible combinations, four varieties

| | |
|-----------------|----|
| Round yellow | 9 |
| Round green | 3 |
| Wrinkled yellow | 3 |
| Wrinkled green | 1 |
| | 16 |

This ratio 9:3:3:1 is called dihybrid ratio. In this dihybrid cross, all the four possible phenotypes appeared in the F₂ generation because the F₂ hybrid produces four types of gametes. Mandel's experiment on dihybrids has been summed up in the figure given below.



RATIO = YELLOW ROUND 9 : YELLOW WRINKLED 3 : GREEN ROUND 3 : GREEN WRINKLED 1
 ∴ 9 : 3 : 3 : 1

Fig. 8.2 Mendel's Dihybrid Cross in Pea Plant

8.4 MENDEL'S LAWS

On the basis of the result of his experiments, Mendel formulated the following three laws:

- 1) Law of dominance
- 2) Law of Segregation
- 3) Law of Independent Assortment

8.4.1 Law of Dominance

As we have already noticed, when Mendel made monohybrid crosses between tall and short plants, then tall plants appeared in the first filial generation (F_1). But when the F_1 progeny were allowed to be self-fertilized, both tall and short characters appeared in the F_2 generation. This shows that in F_1 hybrid, the character of tallness dominates or conceals the character of shortness and could not express itself in F_1 generation. Thus, the character which expresses itself in the F_1 generation is called by Mendel as dominant character while the character which remained unexpressed is called as recessive. Thus, the law of dominance states that "in a F_1 individual or hybrid or heterozygote one factor (gene) in a pair may mask or prevent the expression of the other". For instance, in Mendel monohybrid cross conducted between tall and short plants, heterozygous tall plant has one gene for tallness 'T' and one for dwarfness ('t'). The gene for tallness ('T') is dominant since the plant is tall while gene ('t') is recessive.

Towards the end of the 19th century, significant experiments were conducted by so many post-Mendelian workers. For example by Tschermak on peas, by Carreus on silk moths, by Davenport on poultry and by many other workers on a variety of animals. Their findings showed that the law of dominance had a wide application.

8.4.2 Law of Segregation

This law is most popularly known as 'Mendel's first principle' of heredity. It states that "the two factors or genes of each character segregate (separate) leaving one factor (gene) of a character in each gamete during gametes' formation: Mendel's monohybrid cross between a pure tall and a pure dwarf pea plant can be taken here in illustrating the principle of segregation. The pure tall plant having TT in its somatic cells produces all the gametes of 't' type. During cross-fertilization the 'T' type gametes of one sex fertilize 't' type gametes of other sex, and zygotes with 'Tt' genotype are produced. These heterozygous tall plants of the F_1 generation produce equal number of gametes of T and t type. Thus, alleles segregate during the gametes formation and the gametes produced are pure for tallness or dwarfness. the gamete is never a hybrid and hence, this law is also known as Law of purity of gametes'. Law of segregation holds good for, it is universal in applicability. An important implication of segregation is that alleles in a hybrid never mix. They pass on, unmodified into the gametes from generation to generation, without undergoing any sort of contamination in the hybrids.

8.4.3 Law of Independent Assortment

This law was an outcome of Mendel's dihybrid cross. It is also known as Mendel's second principle of heredity. Let us recall Mendel's Dihybrid cross conducted in plants between yellow round seed plant, green wrinkled seed plant. This law states that "the factors for different pairs of contrasting characters assort independent of one another during gamete formation". In the F_1 generation all the plants have yellow and round seeds. that is because the alternatives for both the characters under consideration are dominant. Then in the F_2 generation all the four possible types of seeds namely, yellow round, yellow wrinkled respectively appear in the ratio 9 : 3 : 3 : 1. From this ratio it is clear that yellow and green seeds (the two alternatives for the trait of seed colour) appear in the ratio of 12 : 4 = 3 : 1. Similarly the round and wrinkled (the two alternatives for the trait of seed shape) appear in the ratio of 12 : 4 = 3 : 1. Thus each of the two pairs of alternative characters namely yellow-green pair for colour of seeds and round-wrinkled pair for shape of seeds behave exactly as in a monohybrid cross. This means that during gamete formation the alleles for colour of seed do not interfere with alleles for shape of seed coat and the two pairs of alleles behave independent of each other. Though this law proved true in many cases, it failed to have universal in applicability. Cytological discoveries during the earlier part of this century revealed that those alleles part

of this century revealed that those alleles which are located in different homologous pairs of chromosomes assort independently during meiosis. Luckily the alleles considered by Mendel in *Pisum sativum* are present in seven different homologous pairs of chromosomes. Thus the F₁ hybrid for yellow and round seeds is capable of producing four types of gametes namely YR, Yr, yR, yr showing the independent assortment clearly.

If the alleles for different characters are present in homologous pair of chromosomes, they are governed by the phenomenon of linkage which you will study in the next unit. Thus in view of the latest cytological knowledge, the Law of Independent Assortment can be modified as follows. The alleles present on different homologous pairs of chromosomes will assort independently, whereas the alleles present on same homologous pair of chromosomes never assort but follow a phenomenon called linkage.

8.5 EXCEPTIONS TO MENDEL'S LAWS

The exceptions to Mendel's Laws mainly fall under two categories:

1. Exceptions to Mendel's Law of Dominance.
2. Exceptions to Mendel's Law of Independent Assortment

The exceptions to Mendel's Law of dominance constitutes a Phenomenon called incomplete dominance. The exception to Mendel's law of independent assortment constitutes a Phenomenon called linkage about to which you will study in a separate lesson. Now, let us study incomplete dominance in brief.

Incomplete Dominance

In case of Mendel's experiments the F₁ hybrids showed one of the parental characters clearly. But after Mendel, several cases have been recovered by various post Mendelian workers where the F₁ hybrid showed a blending of characters. That is, they showed intermediate characters between the two parents. So, this phenomenon is also known as intermediate inheritance or blended inheritance.

This phenomenon is because of the fact that neither a gene of the allelomorphic pair is dominant nor recessive and each express itself partially. Such genes are called intermediate genes. For this purpose, the experiments conducted on Andalusian fowl and 4 'O' clock plant can be taken as an example.

In Andalusian fowl, a cross between its pure black and white varieties result in blue hybrids. These blue hybrids on cross- fertilization within the F₁ generation yield offsprings in the ratio of 1 black, 2 Blue; 1 white instead of 3 : 1 ratio, as seen in the case of complete dominance observed by Mendel.

Mirabilis Jalapa (4 'O' clock plant), gives another excellent example of incomplete dominance. A cross between its two varieties, pure for red (RR), and white flowers (rr), result in pink flowers (Rr) in F₁ generation. These pink hybrids on self- fertilization produce red, pink and white offsprings in the ratio of 1 : 2 : 1 respectively. This 1 : 2 : 1 ratio of incomplete dominance in fact, is a modification of the 3 : 1 ratio seen in case of complete dominance. The heterozygous individuals show the dominant of complete dominance and intermediate character in case of incomplete dominance.

8.6 MULTIPLE ALLELES

So far it has been said that, a given phenotypic trait of an individual depends on a single pair of genes. these genes occupy a specific portion called the gene locus on a homologous

chromosome. Moreover, a particular gene for a character occurs in two alternative forms. Such different forms of the same gene for a character occurs in two alternative forms. Such different forms length of the same gene are referred to as alleles. For example, 'T' alleles for length of pea plant considered by Mendel where 'T' for tallness and 't' for dwarfness. Some genes, besides occurring in two alternative forms or alleles may occur in several alternative forms or alleles. Thus, when any of the three or more allelic forms of the gene occupy the same locus in a given pair alleles called multiple alleles. That is, all mutant forms (recessive gene) of a single normal type allele constitute a series of multiple alleles.

Characters of Multiple Alleles

The following are the important characteristics of multiple alleles :

1. The multiple alleles of a series always occupy the same locus in the chromosome.
2. No crossing over occurs within the alleles of a same multiple allelic series, because all multiple allelic series occupy same locus in chromosome.
3. The multiple alleles always influence the same characters.
4. The normal allele is always dominant. But the other mutant alleles in the series may show dominance or intermediate effect.
5. When a cross is involved between two mutant multiple alleles the phenotype is mutant and not the normal type.

Symbolism for Multiple Alleles

A capital letter is commonly used to designate the alleles which is dominant to all other alleles in the series. The corresponding small letter designates the allele which is recessive to all others in the series. Other alleles which are intermediate in their degree of dominance between these two extremes are usually assigned the small letter with some suitable super script.

Examples for Multiple Allelism

The best examples are the coat colour of rabbit and blood groups in man.

- a. **Coat Colour in Rabbits :** The coat colour in rabbit exists in four colours namely (1) Agouti (2) Chinchilla (3) Himalayan and (4) Albino.
 1. **Agouti :** It is the normal coat colour which is also known as full colour in which individuals have banded hairs. The portion nearest the skin being succeeded by a yellow band and finally a black tip. Because it is a dominant character it is represented by capital letter 'C'.
 2. **Chinchilla :** The coat in this case lacks yellow pigment and due to optical effect of black and grey hairs, it appears as silvery grey. The gene for chinchilla is represented as C^{ch} .
 3. **Himalayan :** In this type the coat colour is white except for black extremities like nose ears, feet and tail. The eyes are pigmented. The gene is represented by c^h .
 4. **Albino :** In this type the coat colour completely lacks pigment including eyes. The gene is represented by c.

When crosses are made between individual with different coat colours. It is revealed that the agouti (C) is dominant, to all others and albino (c) is recessive to all others. Likewise, c^h found dominant to allele c but recessive to C and c^{ch} . Further the allele for Chinchilla c^{ch} is found recessive to allele 'C' but dominant to C^h and c. The dominance hierarchy for the coat colour of rabbit may be thus represented as follows :

$$C > C^{ch} > c^h > c$$

The possible phenotypes and genotypes for multiple alleles for coat colour in rabbit are given below:

| Phenotypes | Genotypes |
|-------------------------|--|
| 1. Full colour (Agouti) | CC, Cc ^{ch} , Cc ^h , Cc |
| 2. Chinchilla | c ^{ch} , c ^{ch} , c ^{ch} , cc ^{ch} |
| 3. Himalayan | c ^h , c ^h , cc ^h |
| 4. Albino | cc |

b. A B O Blood Groups in Man

The A B O blood group system of man also provides an excellent example of multiple allelism.

Mr. Karl Landsterner (1900) discovered the blood groups in human beings. He grouped blood under four categories on the basis of the type of proteinous substance known as antigen found on the surface of the red blood corpuscles. Antigens are of two types namely, 'A' type and 'B' type. If A type antigen is present, the blood group is termed 'A', if B type antigen is present the blood group is termed 'B'. If both the antigens are present, the blood is called AB. If neither antigens is present the blood group is termed 'O'.

The inheritance of these groups is controlled by a set of three multiple alleles. After the name of the discoverer Landsterner these alleles for blood groups are named as I^A, I^B and I^O. The allele I^B contains B antigen. The alleles I^A and I^B are completely dominant to I^O which contains no antigen. The dominance heirarchy for human blood group is represented as follows:

$$(I^A = I^B) > I^O$$

The possible genotypes for four phenotype of blood groups are given below:

| Genotypes | Phenotypes |
|---|------------|
| I ^A I ^A , I ^A I ^O | A |
| I ^B I ^B , I ^B I ^O | B |
| I ^A I ^B | AB |
| I ^O I ^O | O |

Check Your Progress

Define the following:

1. First filial generation
2. Back cross
3. Alleles

8.7 SUMMARY

1. Gregor Johann Mendel conducted his historical experiments on "*Pisum sativum*" (pea plant), to understand clearly the mechanism of inheritance which made him the "Father of Genetics".
2. Mendel selected seven traits for his hybridization experiments from garden pea plant. He considered two alternative characters in each trait of which one showed dominant character

and other was recessive. The character which appeared in F_1 generation was called by Mendel as dominant, and the one which disappeared was called, recessive.

3. In his monohybrid experiments, he crossed two plants differing in only one trait and obtained monohybrid ratio.
4. In his dihybrid experiments Mendel crossed two plants differing in two traits or two pairs of alternative characters and obtained dihybrid ratio (9 : 3 : 3 : 1).
5. Basing on the experiments conducted, Mendel explained the phenomenon of dominance and derived his first and second principles. The first principle is known as the 'Law of Segregation' and the second principle is known as the 'Law of Independent Assortment'.
6. The Law of Segregation is universally accepted and it forms the bulk of Mendel's lavish discovery.
7. Afterwards post-Mendelian workers showed exceptions to Mendel's Law of Dominance and Law of Independent Assortment. The exceptions to the former, is known as incomplete dominance and the exception to the latter, is known as linkage.
8. The characters considered by Mendel were controlled by only two alternative factors or genes. Post-Mendelian workers showed that the genes besides occurring in two alternative forms or alleles occurred in several alternative forms or alleles which constituted multiple alleles. Examples : Coat colour of Rabbit, A,B,O,AB blood groups of man.

8.8 CHECK YOUR PROGRESS - MODEL ANSWERS

1. **First filial generation :** The generation of hybrids resulting from a cross between parents are called the first filial generation and denoted by F_1 .
2. **Back cross :** A cross of F_1 individual with either of the two parents is known as "back cross".
3. **Alleles :** Alleles, the abbreviated form of the term "allelomorphs" indicates alternative forms of the same gene.

8.9 MODEL EXAMINATION QUESTIONS

I. Answer the following in 30 lines

1. Give an account of 'Mendel's Laws of Heredity' and explain them with suitable experiments.
2. Write an essay on exceptions to Mendel's Laws ?
3. What is meant by incomplete dominance? Explain it with suitable examples.
4. What are multiple alleles? Explain them with one example you have studied.

II. Answer the following in 10 lines

1. Define and explain Mendel's Law of Segregation ?
2. Why did Mendel use pea as the experimental material in his hybridization experiments.
3. Give a brief like sketch of Mendel and state why his name is so significant for geneticists.

UNIT – 9 LINKAGE AND CROSSING OVER

Contents

- 9.1 Objectives
- 9.2 Linkage
 - 9.2.1 Linkage groups
 - 9.2.2 Types of Linkage
 - 9.2.3 Theories of Linkage
 - 9.2.4 Significance of Linkage
- 9.3 Crossing over
 - 9.3.1 Types of crossing over
 - 9.3.2 Significance of crossing over
- 9.4 Summary
- 9.5 Check Your Progress - Model Answers
- 9.6 Model Examination Questions.

9.1 OBJECTIVES

This unit is about the phenomenae of “Linkage” and “crossing over” and to show its importance among organisms. By the end of this unit you will be able to:

- explain various experiments conducted to confirm these phenomenae.
- describe different types and various theories that had been formulated.

9.2 LINKAGE

It is an exception to Mendel's Law of Independent Assortment. The alleles for the seven pairs of characters studied by Mendel in *Pisum sativum* are present in seven different homologous pairs of chromosomes as it was later on shown cytologically. Thus, Mendel was lucky enough in formulating his Law of Independent Assortment. But later on post-Mendelian workers discovered that the genes present on the same chromosome do not undergo random assortment but are inherited together. This type of co-existence of two or more genes in the same chromosome is known as **linkage**. The linkage can also be defined as the tendency of genes to remain together during the process of inheritance. This phenomena of linkage was discovered by **T. H. Morgan** in 1911, who won Nobel Prize in Medicine in 1933.

Experiments with Sweet Pea plant

The first exception to Mendel's Law of Independent Assortment was reported in 1906 by **W. Bateson** and **R. C. Punnet**. They worked on sweet pea *Lathyrus odoratus*. In this plant, they crossed a variety pure for blue flower colour and long pollen grains (BBLL) with one pure for red flower colour and round pollen grains (bbll).

The blue flower colour is dominant (B) over red (b) and long pollen grains (L) is dominant over round (l). As it is a dihybrid cross on the basis of Law of Independent Assortment, it was expected to produce 4 gametes. By test cross it was expected to produce 4 phenotypes in F₂ generation namely Blue long, Blue round, Red long, Red round in the ratio of 1:1 1:1 respectively.

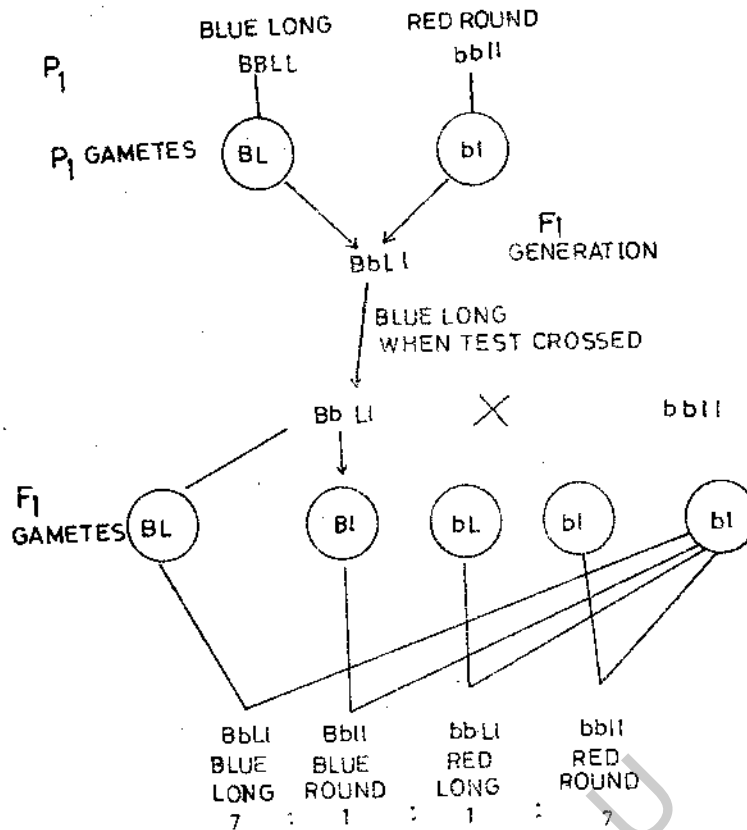


Fig. 9.1. Crosses made in between Blue long and Red round characters in sweet pea by Bateson and Punnett.

But it did not actually happen in this cross. Quite unexpected results were obtained. The four phenotypes namely Blue-long, Blue-red, Red-long, red-round were actually produced in the ratio of 7:1:1:7. This case clearly indicated that there was tendency in the dominant alleles and recessive alleles to remain together. The two original parental phenotypes namely, blue long and red round were dominating the ratio seven times than the two new combinations namely, blue round and red long. With this experiment, Bateson and Punnett concluded that alleles which come from the same parent tend to enter the same gametes which they called 'coupling and while those coming from different parents tend to enter different gametes which they called repulsion. The theory thus formulated by them is known as coupling and repulsion theory. Bateson and Punnett could not explain the reasons for coupling and repulsion and it was, Morgan who while performing experiments with *Drosophila* in 1910 conclude that coupling and repulsion are two aspects of a single phenomena which he called linkage. Actually, this phenomenon of linkage was predicted clearly by Sutton (1903) of Columbia University. But unfortunately, he could not prove this prediction experimentally.

Experiments with *Drosophila*

T. H. Morgan conducted experiments with *Drosophila* crossing grey body and long winged variety with the one having black body and vestigial wings. All the F₁ individuals had grey body and long wings because the gene for these two characters are dominant over their alleles. A test cross between a F₁ male and the double recessive parental female resulted in an F₂ generation in which, individuals with grey body and long wings and black body and vestigial wings were 50% each. That is equal to 1:1 respectively. Thus, we find that the grey body is inherited together with long wings and black body is inherited with vestigial wings. All these details are clearly shown in the figure.

As it is a complete linkage there was no possibility for non-parental characters and the test-cross ratio of Mendel's dihybridization 1 : 1 : 1 : 1 is changed to 1 : 1

9.2.1 Linkage Group

The genes which are present on the same chromosome linked with one other constitute a linkage group. Thus, the linkage groups in an animal or plant is equal to the number of pairs of chromosomes present in its cells. This idea was proved by experiments on *Drosophila melanogaster* by T. H. Morgan and his associates. Thus, for example, the 4 pairs of chromosomes of *Drosophila melanogaster* corresponds to 4 linkage groups, 7 chromosome pairs of *pisum sativum* corresponds to 7 linkage groups. 10 chromosome pairs of maize correspond to 10 linkage groups and so on.

9.2.2 Types of Linkage

There are two types of linkages namely, complete linkage and incomplete linkage.

Complete Linkage

It is a phenomena where the parental combinations of characters appear together for two or more generations in a continuous and regular manner. This happens when a chromosome does not undergo any breakage by accident or during gametogenesis. Eg: All the genes of male *Drosophila* remain completely linked.

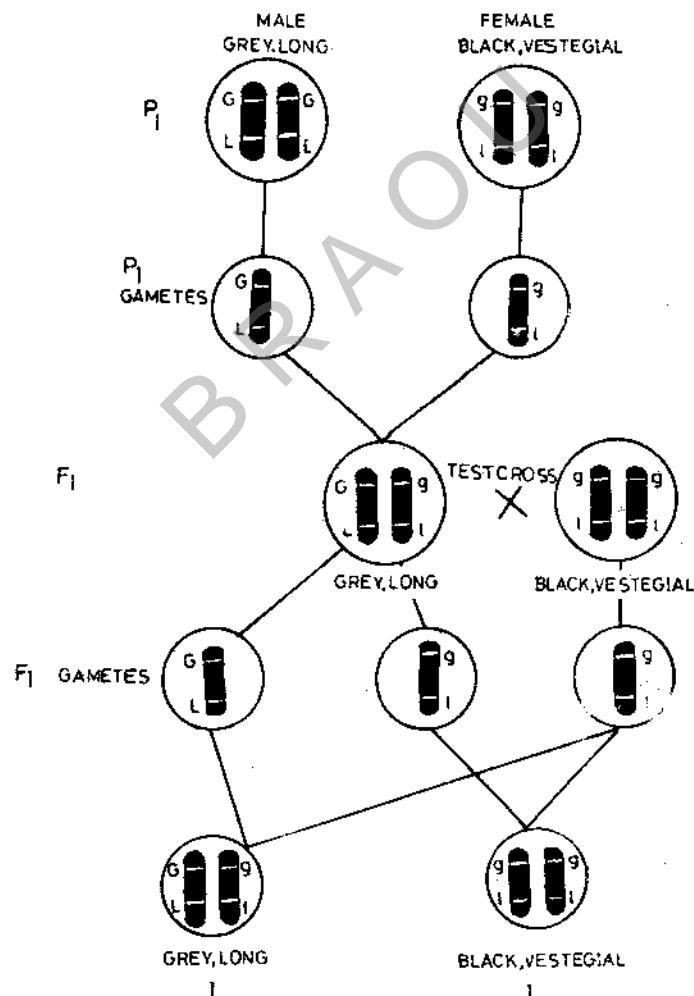


Fig. 9.2 Cross showing complete linkage in *Drosophila* in between grey long and Black vestigial characters.

Incomplete Linkage

The linked genes which are widely located in chromosomes and have chances of separation by crossing over, are called incompletely linked genes and the phenomenon of their inheritance is known as incomplete linkage.

Eg: It has been observed in pea tomato female *Drosophila*, mice, man, poultry, etc.

9.2.3 Theories of Linkage

Two theories were put forward to explain the phenomenon of linkage:

(1) Differential Multiplication Theory of Linkage

This theory was given by Bateson in 1930. According to this theory after the segregation of characters during gametes formation, the set of gametes having parental combinations multiplies more rapidly than the set having nonparental combinations. As a result of this, greater number of gametes, and thus the offsprings with parental combinations will be formed. This theory completely lacks the cytological basis and has been severely condemned. As per the present knowledge of gametogenesis after segregation only a single division occurs before the gametes are found.

(2) Chromosome Theory of Linkage

Morgan along with Castle, formulated the chromosome theory. According to this, the genes which show the phenomenon of linkage are situated in the same chromosomes and these linked genes usually remain bounded by the chromosomal material, so that, they cannot be separated during the process of inheritance. The extent of genes is correlated with the distance between the genes in the chromosomes-closer the genes, stronger the linkage and vice versa. The genes are arranged in a linear fashion in the chromosomes. This theory finds full support from cytologists and is universally accepted.

9.2.4 Significance of Linkage

The phenomenon of linkage has greater significance for living organisms for it reduces the possibility of variability in gametes unless crossing over occurs.

9.3 CROSSING OVER

In the preceding part, we have studied complete and incomplete linkage. The complete linkage is of rare occurrence. During meiosis breakage of chromosomes occurs accompanied by interchange of corresponding parts between chromatids of homologous chromosomes. Morgan termed this phenomenon as crossing over. This phenomenon can be defined as a process that produces new combinations (re-combinations) of genes by interchanging of corresponding segments between non-sister chromatids of homologous chromosomes.

Example of Crossing Over

We have already seen that a test-cross between the male F_1 hybrid having grey body and long wings and a double recessive *Drosophila* having black body and vestigial wings resulted in the appearance in equal numbers of original parental combinations in the F_2 generation. That is grey long 1, black vestigial 1.

For the same characters if the sex is reversed in cross i.e. if a female hybrid (GgLi) is backcrossed with double recessive male (ggll) the results obtained in the F_2 generation are different. Two new combinations namely grey-body vestigial wings (Ggll) and black body long wings

(*ggLl*) are seen in the F_2 generation because the F_1 female produces four types of gametes. Out of these, two types are normal non-crossovers (*GL* and *gl*) which are 83% and the other two types (*GL* and *gL*) which include the remaining 17% are produced as a result of crossing-over.

Stage of Occurrence and Mechanism

During the zygotene stage of the first prophase of meiosis homologous chromosomes pair up. This is called the two strand stage (diad). During pachytene stage each chromosome becomes twisted into two chromatids. This is known as the four-strand stage (tetrad). It is at this stage crossing over takes place. The same was proved by David Stadler in *Neurospora crassa* ascospores by Lindsay Olive in *Sardaria* ascospores by beautiful photographs.

The chromatids of four strand stage (tetrad) get spirally twined forming one or more points of contact. These points of contact are known as chiasmata. Only two chromatids participate in the formation of chiasma. Each of the two chromatids forming a chiasma belongs to a different member of the homologous pair of chromosomes. During the diplotene stage the chromatids at chiasmata may break and then rejoin in such a manner that homologous parts are interchanged between them. As a result, new chromatids acquire a changed genetic constitution. The process of chiasmata formation was clearly observed by Janssens (1909). But what actually initiates breakage and re-union of chromatids is not yet known.

9.3.1 Types of Crossing Over

Depending upon the number of chiasmata formed, crossing over may be of 3 types:

1. **Single crossing over:** In this type only one chiasma is formed resulting in the formation of single cross-over gametes. This occurs most frequently.
2. **Double crossing-over:** In this type two chiasmata are formed. Both the chiasmata may be between the same chromatids. Thus, double cross over gametes are produced in this type. This occurs less frequently.
3. **Multiple cross over:** In this type more than two chiasmata are formed. Basing on the number of chiasmata formed it is called triple (three chiasmata) quadruple (4 chiasmata) so on. It occurs very rarely.

Cytological Evidence of Crossing Over

Stern's experiment:

The first cytological experimental evidence to establish the occurrence of crossing over beyond doubt, was given by Curt Stern in 1931.

For his experiment Stern obtained a mutant strain of *Drosophila* which was one mutant dominant gene Bar (*B*) for narrow eyes, and one mutant recessive gene carnation (*c*) for light red eyes on its 'X' chromosome. The wild type female *Drosophila* has one recessive gene for round eyes (*b*) and one dominant gene (*C*) for red eyes on each of its rod shaped 'X' chromosomes. By crossing these two strains Stern obtained a dihybrid having *c* and *B* genes on one 'X' chromosome and normal genes (*C, b*) on other 'X' chromosome. Then he made both of the *C* chromosomes of this heterozygote female aberrant by treating such flies with X-rays. The X chromosome having genes *c* and *B* was broken into two segments, one fragment having both the genes considered by Stern in his experiment and other X chromosome having a fragment of the Y chromosome attached to it and contained normal alleles (*C, b*). Thus, this female was ideal for studying crossing over because it has a pair of 'X' chromosomes with cytologically detectable structural differences. Such a female was crossed with a normal male having X chromosome with *C* and *b* alleles. Four classes of eggs of which two types of eggs with

crossovers and two types of eggs with non-cossovers were produced which by fertilization produced four kinds of females as shown in the figure.

Thus flies with crossover was indicted phenotypically showed microscopic evidence of exchanges between homologous chromosomes. The physical or cytological basis of crossing over was thus established by Stern. The same was proved by Creighton and Mc clintock also by their experiments conducted on maize.

Frequency and the Factors Affecting the Frequency

The frequency with which crossing over occurs between two genes is known as, frequency of crossing over. It is expressed in terms of percentage of crossing over. Generally, the percentage of crossing over is directly proportional to the distance between two genes which has been confirmed cytologically. If the distance is high the percentage is more and vice versa. Thus, the percentage of crossing over between two genes indicates the distance between the two genes. This fact is of great significance because it helps in constructing chromosomal maps of animals and plants. In honour of Morgan the unit of crossing over is known as Morgan (the distance between two genes).

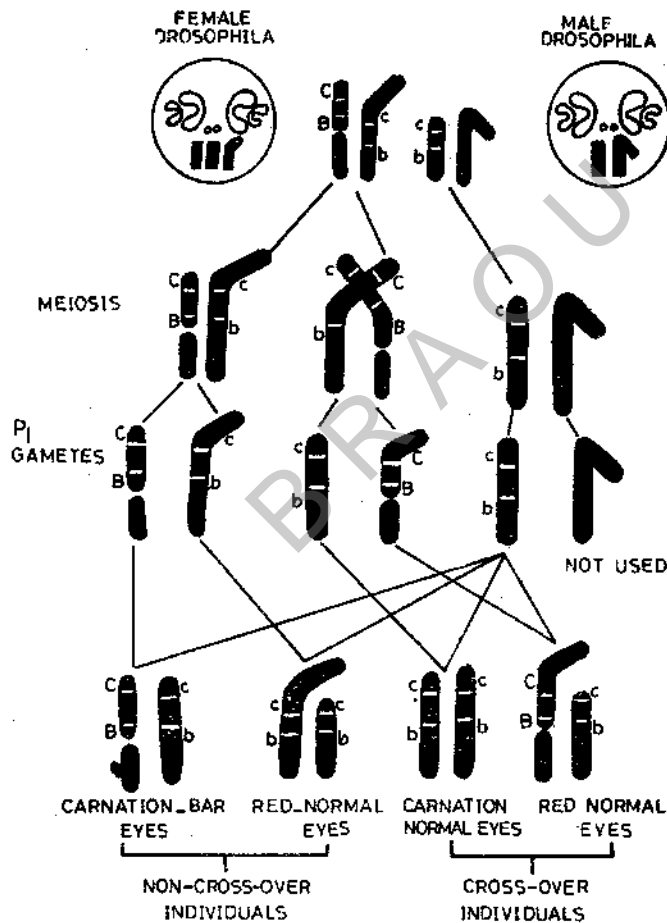


Fig. 9.3 Stern's cytological demonstration of Crossing over.

There are various factors controlling the frequency of crossing over. Plough showed that the high and low temperatures increase the frequency of crossing over. Muller demonstrated that the X-rays increase the frequency. Hanson showed that the irradiations by radium increase frequency. Gene mutations are known to decrease the frequency. The chiasma

formation at one point discourages the chiasma formation in vicinity. This phenomenon is called **Interference** which also decreases the frequency. The inversions of chromosomes are also known to suppress crossing over. In general, the factors which affect crossing over affect linkage inversely.

9.3.2 Significance of Crossing Over

The crossing over has great significance in genetics. It gives us a direct evidence that chromosomes are arranged in a linear fashion on chromosomes. The crossing over helps in constructing chromosome maps which are very useful in the study of genetics to establish linkage groups among various organisms. This phenomenon is also more useful to organisms because, it causes new combinations of genes which results in variations of offsprings. The variations in turn, are very essential for the evolution of new species.

Check Your Progress:

1. The tendency of genes to remain together during the process of inheritance is known as _____.
2. What is the main significance of "Crossing over".

9.4 SUMMARY

1. The tendency of genes to remain together during the process of inheritance is known as Linkage and this forms an exception to Mendel's Law of Independent Assortment.
2. Experiments conducted on *Lathyrus odoratus* by W.Bateson and R.C.Punnet and on *Drosophila melanogaster* C.B.Bridges and T.H.Morgan formed main basis to prove the phenomenon of linkage.
3. Linkage exists in either of the phases namely coupling or repulsion. The alleles which come from the same parent tend to enter the same gametes while those coming from different parents tend to enter different gametes. The former is known as coupling and the latter is known as repulsion.
4. It was proved by Morgan by experiments that the linkage groups in an animal is equal to the number of pairs of chromosomes present in its cells because the genes present on the same chromosome constitute a linkage group.
5. The linkage is said to be complete if the alleles present on the same chromosome continue for more generations without any break or exchange of chromosomal segments. The linkage is called incomplete if the chromosomes undergo breakage interfering with the linkage of the genes. This constitutes another phenomenon called crossing over.
6. The chromosomal theory of linkage proposed by Morgan finds full support by various cytologists according to which the genes are found in a linear fashion on chromosomes. The more the distance between the genes, the stronger the linkage and vice versa.
7. Crossing over can be defined as a process that produces new combinations of genes by interchanging of corresponding segments between non-sister chromatids of homologous chromosomes.
8. The experiments of David Sadle in *Neurospora crassa* proved that the crossing over takes place during four-strand stage (tetrad) of meiosis (pachytene) stage.
9. During crossing over, the chromosomes at the point of contact (chiasma) break, and the broken segments later rejoin in such a manner that the chromosomal parts are interchanged.

10. Various theories like Serebrousky's contact first theory, Muler's breakage first theory, Darlington's stain theory were put forwarded to explain the cause of crossing over. But the exact casue is still unknown.
11. Dependently on the number of chiasmata the crossing over may be single, double or multiple.
12. Curt Stern's experiments conducted on Drosophila eye colour and eye-shape formed full cytological evidence for the occurance of crossing over.
13. The variousfactors like temperature, X-rays etc., affect the the ercentage of crossing over. The percentage of crossing over means the frequency with which crossing over occurs between two genes. This is useful in constructing chromosome maps.
14. Linkage decreases the chances of variations among organisms which is the most significant for, it causes evolution among organisms.

9.5 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Linkage
2. The main significance of crossing over is it causes new combinations of genes which results in variations of offsprings. The variations in turn are essential for the evolution of new species.

9.6 MODEL EXAMINATION QUESTIONS

I. Answer the following in 30 lines each:

1. Define linkage. Illustrate the phenomenon with a suitable example.
2. What are linkage groups? Discuss the important theories of linkage.
3. Discuss the Mendel's law of Independent Assortment in the light of linkage.
4. Explain crossing over with suitable example. What are its different kinds?
5. Give an account of cytological evidence for crossing over and discuss its significance.

II Answer the following in 10 lines each:

1. Mechanism of crossing over.
2. Factors effecting the frequency of crossing over.

UNIT – 10 SEX-DETERMINATION

Contents

- 10.1 Objectives
- 10.2 Introduction
- 10.3 Chromosomal Mechanisms of Sex Determination
 - 10.3.1 Theory of Heterogametes
 - 10.3.2 Genetic Balance Theory of Bridges
 - 10.3.3 Sex Determination in Gypsy Moth
 - 10.3.4 Role of Parthenogenesis-Male Haploidy and Haplodiploidy Mechanism
- 10.4 Hormonally controlled Sex Determining Mechanism
- 10.5 Role of Environment in the Sex Determining Mechanism
- 10.6 Gynandromorphism
- 10.7 Summary
- 10.8 Check Your Progress-Model Answers
- 10.9 Model Examination Questions

10.1 OBJECTIVES

This unit is about the mechanism of sex-determination among different types of organisms. After completing this unit you will be in a position to:

- explain that, each type of organisms has different mechanism of sex-determination.
- justify the impact of hormones and environment etc., on determining the sex.

10.2 INTRODUCTION

The problem of predicting the sex of the unborn child has been the idle curiosity of the parent as much as the enigma for the biologist, in spite of the rapid advances in genetics. Before studying the various views and mechanisms involved regarding sex-determination let us first know about the importance of sex. In biological terminology sex is a comparison of the characteristics among the organisms in which sperm producing organisms differ from ova producing organisms. It also refers to the aggregate of the qualities of an individual which are recognised as maleness and femaleness. The sexually reproducing organisms are classified into two types namely, 1) Hermaphrodite organisms, 2) Unisexual organisms. In hermaphroditism the same individual produces both eggs as well as sperms. In these organisms the genetic features of the gametes only determine the sex and the morphological variations among individuals should not be taken into consideration. But in unisexual animals the sexuality relates to the aggregate of genetic, somatic (morphological), physiological and psychological contrasts between males and females. Reproduction is the primary biological function of sex. Reproduction without sex is known as asexual reproduction which is seen in several lower plants and animals. But the main difference between the asexual and sexual reproduction is that in the sexual reproduction there is a 'genetic mingling of nuclear material from two different cells' which are lacking in asexual reproduction. As a result of this, the primary function and the secondary function namely, genetic variety within the species is provided to ensure evolutionary success. Without sexual reproduction it is not possible. Thus sex has such a great importance.

Modern geneticists have studied many different mechanisms of determination of sex in the organisms. Now, let us study some of the important and common mechanisms of sex-determination among various animals.

10.3 CHROMOSOMAL MECHANISMS OF SEX DETERMINATION

H.Honking (1891), working on the bug *Phyrrhocoris* described the role of chromosomes during gametogenesis and discovered the 'X' chromosomes in sex-determination was clarified later by Wilson and Stevens (1905). Because of their importance these were called sex chromosomes and all others were called autosomes by Wilson and Stevens.

Futher researches in *Drosophila melanogaster* by Bridges and in Gypsomoth by R.B.Gold Schmidt revealed that chromosomes are responsible for sex determination. All these discoveries led to the formulation of the modern concept of chromosomal mechanisms of sex determination.

By further investigation it was revealed that the X chromosomes show a wide range of variations in different animals and each variation is associated with a characteristic mechanism of sex-determinatin. We can study the various chromosomal mechanisms under the following heads:

10.3.1 Theory of Heterogametes

According to this theory one of the sexes produces two types of gametes (Heterogametes). Each type of gamete on fertilization determines a different sex. This may be again divided into 4 types.

A. XO male - XX female type: In certain insects of Hemiptera and Orthoptera the females have two XX chromosomes (hence referred as XX), and hence called homogametic and the males have only one 'X' chromosome (hence referred as XO) and hence, called heterogametic. The male produced 2 types of sperms half with X chromosome and half without 'X' chromosome. The sex of the offspring depends upon the sperm that fertilizes the egg. (both the eggs carry 'X' chromosomes) Fertilization of a sperm with 'X' chromosome results in a female and a sperm without X chromosome results in male. It is clearly shown in the figure 10.1.

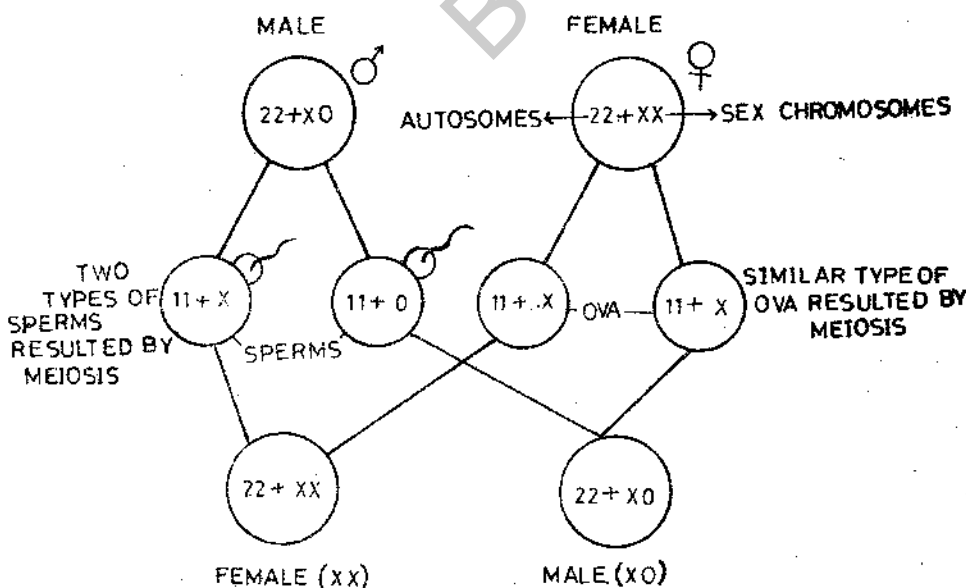


Fig 10.1. XO Male-XX Female type of sex-determination is Pyrrhocoris.

B. XO - XX type : In this case the male has two XX, while the female has only one 'X' chromosome and the female produces two types of ova, one with 'X' chromosome and the other without 'X' chromosome. Fertilization by the first type (with 'X'), results in males, while that of the second type (without 'X'), results in female. It is the rarest type seen in some members of Lepidoptera

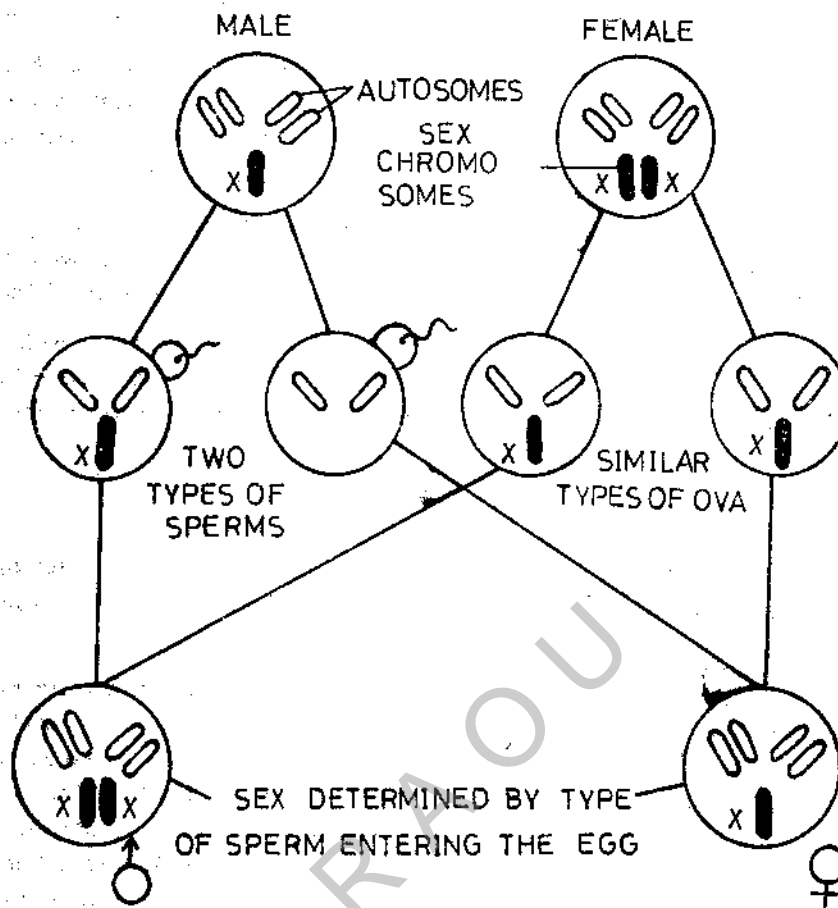


Fig. 10.2. XO Male-XX Female type of sex-determination.

C. XY-XX type : In man and in some insects like *Drosophila*, the female possesses two homomorphic X chromosomes in their body cells and produces similar types of ova. The male possesses heteromorphic sex chromosomes producing two types of sperms, half with X chromosomes (gynosperm) and half with Y chromosome (Androsperm). Fertilization by a gynosperm produces a female and fertilization by androsperm produces male, as shown in the figure 10.3.

D. ZW - ZZ type: This system is found in certain insects, fishes, reptiles and domestic chicken. In this type the male possesses single 'Z' chromosome in its body cells (hence referred to as ZW) and it is heterogametic producing two kinds of sperms half with 'Z' and half with 'W' chromosome. The female possesses two 'Z' chromosomes. The female being homogametic (ZZ), produces two types of sperms, each with a single 'Z' chromosome. The sex of the organism depends on the kind of egg as shown in the figure 10.4.

This is also known as XY Female-XX Male type: In order to avoid confusion with those where male is XY, and female XX the X and Y are designated as Z and W respectively.

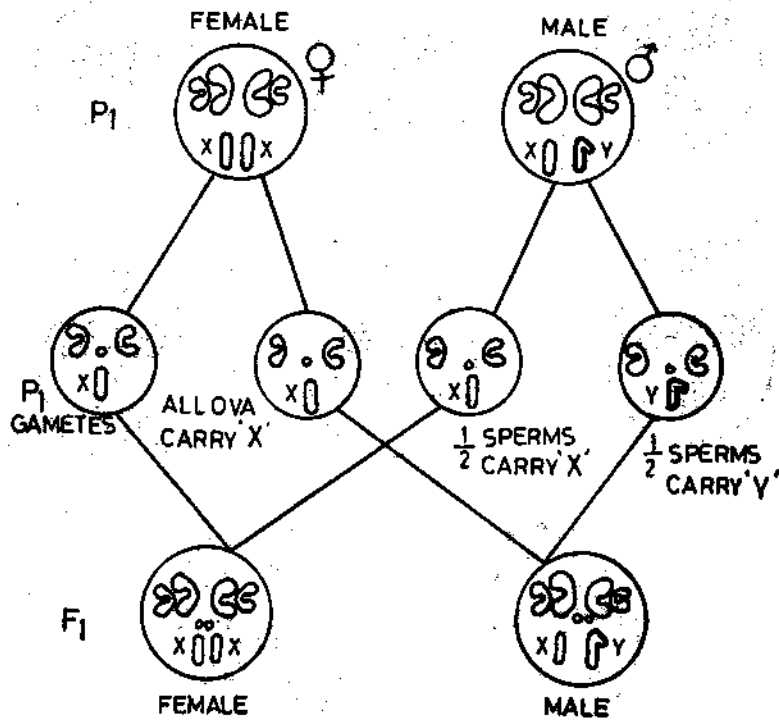


Fig. 10.3. XX Female type of sex-determination in *Drosophila*.

10.3.2 Genetic Balance Theory of Bridges

This type of sex determination was discovered by C.B. Bridges in 1925. He obtained an unexpected triploid female (with XXX chromosomes) *Drosophila* and crossed it with a normal

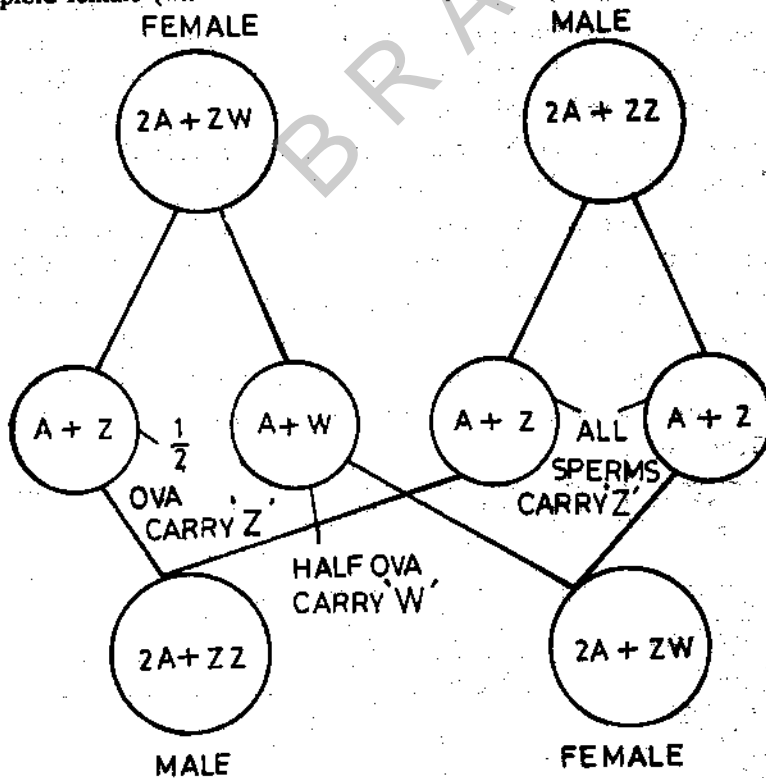


Fig. 10.4. ZW Female-ZZ Male type of sex-determination.

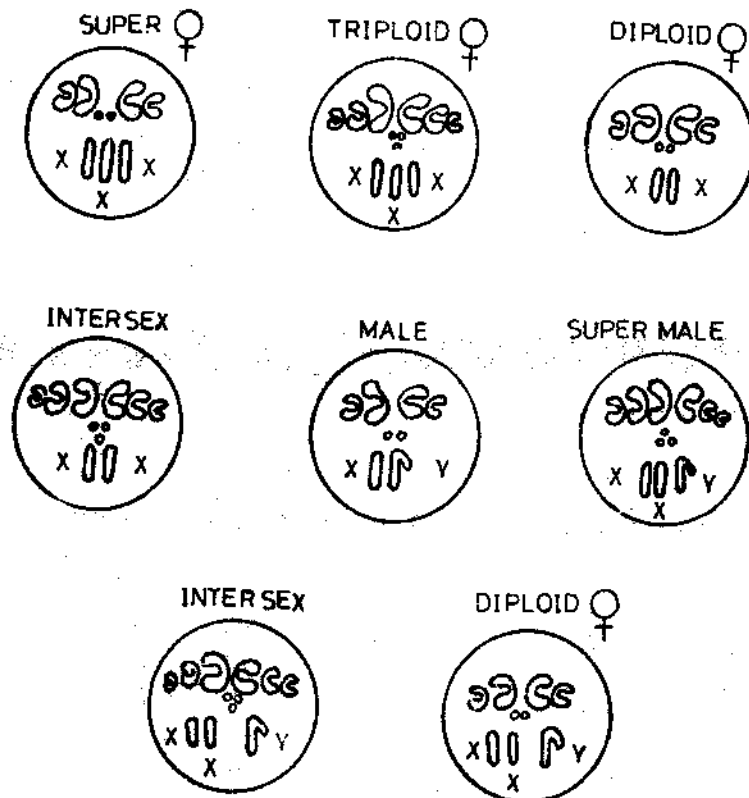


Fig. 10.5 Various organisms obtained by Bridges showing different chromosomal configurations.

diploid male. An interesting group of five types of offspring was obtained. They are: 1) Super females 2) Females 3) Intersexes 4) Males and 5) Supermales. In each organism, the chromosomal configuration was different as shown in the figure 10.5.

The appearance of intersexes and supersexes made Bridges to understand that 'Y' chromosome does not play any role in sex determination because, it contains a genetically inert material namely, the heterochromatin with few genes. This is also revealed from XO type of males of *Drosophila* where they behaved exactly the XY type of male. According to him, the genes for female characters are present on 'X' chromosomes and for male characters on autosomes, that means, all individual cell. Thus, in each sex, the potentiality for other sex is present. Then it is the interaction between these two sets of genes that determine the sex of individual. That is the ratio of the number of X chromosomes and the number of haploid sets of autosomes determines the Sex. Thus it is the quantitative balance between X chromosomes and autosomes Haploid set means one chromosome from each of the homologous pairs of chromosomes. Thus, a diploid organism contains 2, triploid 3 haploid sets of autosomes and so on. The various types of sexes, and their chromosomal configurations obtained by Bridges are tabulated (Table 10.1).

| S.No. | Sex | Number of 'X' Chromosomes | Number of Haploid (A) Sets of Autosomes |
|-------|-----------------|---------------------------|---|
| 1. | Super Female | XXX=3 | 2 |
| 2. | Triploid Female | XXX=3 | 3 |
| 3. | Diploid Female | XX OR XXY=2 | 2 |
| 4. | Intersex | XX OR XXY=2 | 3 |
| 5. | Male | XY=1 | 2 |
| 6. | Super Male | XY=1 | 3 |

If the sex determining ratio (X/A) value is 1, the sex will be female. In males, the value of the sex determining ratio is 0.5. If the ratio is between 0.5 and 1, the result is intersexes. The intersexes show intermediate characters between males and females and are sterile. Supersexes show minor differences from the normal females and males and the case may be, and they are also sterile. Thus according to Bridges, it is the quantitative balance between the chromosomes (X and autosomes) and hence the genes contained in them that determines the sex in *Drosophila*. Hence, this is known as chromosome balance theory or genic balance theory.

10.3.3 Sex Determination in Gypsy Moth

R.B. Goldschmidt while working on Gypsymoth, *Lymantria dispar* described the role of chromosomes in sex determination. In this insect, there are several well recognised geographical races. There is a well marked sexual dimorphism within a geographical race. The sex chromosome constitution for this insect is XX for normal diploid females. If the mating occurs among the individuals of the same geographic region it results in normal sexed males and females, as it has been observed. If the mating occurs between the individuals of different geographical regions, it results in diploid intersexes, for example a cross between strains of Europe and Japan or between Northern and Southern Japan. But these intersexes are fertile. These experiments made Goldschmidt to conclude that the sex determining factors for male are carried in 'X' chromosome and for female in cytoplasm. According to him, these factors are of different strength in individuals of different geographic localities. For example the factors are weak in European strains and strong in Japanese strains. Now, the sex can be determined by the interaction between these factors. For example if a European female (with weak factors) is crossed with Japanese male (strong); the offspring which are males are normal, while those which should normally be females become intersexes. If the cross is reversed the results are vice versa. These results are tabulated in the table-10.2.

| S.No. | Crosses | Offspring obtained | |
|-------|-----------------|--------------------|---------------------|
| | | Males | Females |
| 1. | European Female | Normal | Intersex Japan Male |
| 2. | European Male | Intersex | Normal Japan Female |

If the crosses occur between the strongest and the weakest factors, the sex reversal occurs. That is XX for females and XY males.

To explain the diploid intersexuality in insects, Goldschmidt put forward a hypothesis called **turning point hypothesis**. According to this, the individuals develop as males or females till a particular stage, called turning point after which, development proceeds in the direction of opposite sexuality.

10.3.4 Role of Parthenogenesis-Male Haplodidy and Haplodiploidy Mechanism.

The male haploidy or haplodiploidy or arrhenotokous parthenogenesis is common in hymenopterous insects namely, wasps, ants, bees etc. In these insects, the haploid eggs if fertilized, develop into females and if, not fertilized develop into fertile males parthenogenetically. In this experiments, it has been found that the quantity and the quality of food available to the diploid larva determines where the female will become a sterile worker or a fertile queen. Thus, the parthenogenesis also plays an important role in the determination of sex.

Role of Metabolism in Sex Determining Mechanism

According to some workers, metabolism to some extent plays a role in the determination of sex. A.F. Shull and Whitney have shown that by increasing metabolic rate in rotifers the

occurrence of male individuals increases than females. In the same way Riddle found that in pigeons and doves the increased rate of metabolism developed the male potency, while the decreased rate of metabolism caused female potency.

Sex Determination in Man

In man, like *Drosophila* XX-XY Type of sex-determination occurs. But here the Y chromosome contains potent male-determining genes which can completely overcome the feminizing action of the rest of the genotype. The evidence that Y chromosome is a determiner of fertility and sex of male individual came from following sources :

- 1) **Human syndromes (abnormal sexes):** For example, Turner's syndromes with XO are sterile female individuals with abnormalities like short stature congenital malformation, pronounced webbing of the neck, colour blindness etc. In the same way in Klinefelter's syndrome the persons with XX are males despite the presence of two X chromosomes display hermaphroditism having both ovarian and testicular tissues in their genitalia. In man the 'X' chromosome.
- 2) **Barr bodies:** first discovered by M.L. Barr (1949) in the nerve cells of female cat and named after him. It was absent in the male. It is a deeply stained chromatin body (i.e. a chromocentre), found in females, also known as sex chromatin. Later, such a body has been observed in most of the body cells of man's skin cells, oral epithelial cells, blood cells etc. Human females have Barr body in the nuclei of their body cells in higher proportion than males, and hence called as sex chromatin positive and the human males are called sex chromatin negative. In the neutrophil leucocyte of female Barr body appears as a small rod called the drum stick.

10.4 HORMONALLY CONTROLLED SEX DETERMINING MECHANISM

In higher animals it has been observed that sexual differentiation is controlled by hormones.

Examples

1. **Hermaphroditism:** A classical example of hormonal control of sex-determination in cattle was described by F.R. Little (1917). In cattle twins occur frequently. If the twins are of the same sex, zygotically of different sex, that is, if one is male and the other is female, then the development of female is not normal. It is because the male gonads differentiate precociously before the female gonads have differentiated. The male sex hormone of male gonads through common blood vessel reach the other embryo which has so far been developing as a female. Now, the development of female comes under the influence of the male sex hormones and it is shifted towards maleness. As a result, sterile intersex with external genitalia of female and internal sterile gonads of males formed such an organism is called freemartin.
2. **Sex-Reversal in *Xenopus* Larvae:** It is studied by Chang and Witschi. If the genetically male tadpoles of *Xenopus* animal are reared in aquarium water containing estrogenic hormones (female sex hormone), they develop into ovary bearing females. But the females retain their original male chromosome complement namely, XX chromosomal constitution.

10.5 ROLE OF ENVIRONMENT IN THE SEX DETERMINING MECHANISM

In some lower organisms, the environment determines the phenotype of the individual. This mechanism has been reported in a variety of organisms. Let us study its role in two organisms namely, *Bonellia* and *Crepidula*.

1. **Sex in Bonellia:** The mode of sex determination in *Bonellia viridis* was described by F. Baltzer (1935). It is a marine echiuroid worm. In this organism, there is a well defined sexual dimorphism. The males are rudimentary and microscopic (like protozoan) and lie in the uterus of female. The female is half an inch long and well developed organism. The larva which develop from the eggs are sexually undifferentiated.

Those larvae which settle on the proboscis of an adult female develop into male while those larvae which settle on some other substratum away from female develops as females. Further, if the incompletely developed male is detached from the proboscis of female, it becomes an intersex. Thus, it is the environment where the larvae develop which determines the sex. It is probably because a hormone like secretion from the female which encourages the development of larvae towards maleness.

2. **Sex in Crepidula:** It was demonstrated by Coe (1943). It also forms another good example. The young larvae of *Crepidula* (a snail) which are sexually undifferentiated, if reared in isolation from females they develop into females. But if allowed in close contact with females they develop as males. This is also because of some hormone-like secretion of the adult female.

10.6 GYNANDROMORPHISM

It is a phenomenon where an organism shows phenotypically male and female parts, (Gr. Gyno=Female ; Andro=Male ; Morphe=form). The gynandromorphs breed rarely. These are described in *Drosophila* and silk moth by T.H. Morgan, C.B. Bridges and R.B. Goldschmidt. Depending on the relative position of the two phenotypes the gynandromorphs are divided into 3 types:

a. Bilateral Gynandromorphs

These are discovered by Morgan and Bridges. In these gynandromorphs the male characters are on one lateral side of the body and female characters on the other side e.g. silkworm larvae, *Drosophila*.

b. Antero-Posterior Gynandromorphs

In this type the male characters are on anterior side, the female characters are on posterior side and vice versa, e.g. *Lucanus cervus*.

c. Sex Piebalds

In this type the individual is mainly either a male or a female with patches of tissue of the other sex scattered on it. e.g. *Drosophila*.

Origin Of Gynandromorphs

Various views have been put forward to explain the causes of gynandromorphism of which the following are the two important views:

1) Non-distinction of 'X' chromosomes

This was explained by T.H. Morgan and C.B. Bridges to explain the development of gynandromorphs in *Drosophila*. According to them, a *Drosophila* gynander begins development with two X chromosomes. But during the cleavage of the fertilized egg, one X chromosome is lost by some of the cells during anaphase of first mitosis due to nondisjunction. Thus, those cells containing a single X develop male character, while those containing XX develop female part of the body which results in bilateral gynander.

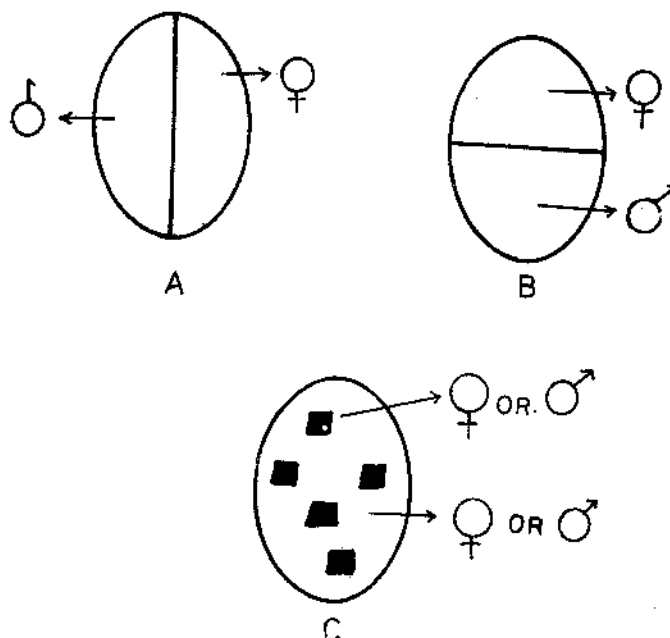


Fig. 10.6 Various types of gynandromorphs. A. Larval gynander. B. Antero-Posterior C. Sex-piebald.

2) Retention of polar nucleus in the egg

It was explained by Goldschmidt and Katsuki in silkworm gynanders. In silkworm, males are XX and females XY. During gametogenesis, normally, the X and Y separate one passing into the egg and the other into the polar body. But sometimes the polar body having one 'X' chromosome does not leave the egg and retain in the ooplasm along with egg nucleus. The egg becomes binucleate and has one nucleus with 'X' chromosome and other nucleus with 'Y' chromosome. Such an egg, if fertilised by two sperms, each fertilizing one egg nucleus results in the development of male and female parts of the body which result in antero-posterior gynandromorph.

Check Your Progress:

1. Super females have _____ X Chromosomes and _____ Sets of autosomes.
2. What is Gynandromorphism.

10.7 SUMMARY

1. In biological terminology sex is a comparison of the characteristics in which egg producing organism differs from sperm producing organism.
2. In hermaphrodites (containing male and female sex-organs in the same individual), the sex relates only to the genetic features of gametes, whereas in unisexual organisms it roles not only to genetic features but also to outer factors like morphological, physiological factors etc.
3. In the 19th century the role of chromosomes in the determination of sex was established by Stevens, Wilson Goldsmith, Bridges, Henkingh and others and the Chromosome. Theory of sex- determination was formulated.
4. The various chromosomal mechanisms fall under heterogametes. Parthenogenesis, genic balance theory etc.

5. In addition to the role of chromosomes other factors like hormones, environment, metabolism also played an important role in the determination of sex.
6. F.R.Lillie's experiments on cattle twins support fully the hormonal theory of sex-determination. Freemartins, the organisms in cattle with external genitalia of female but with internal male gonads are as a result of hormonal role in them.
7. In case of human beings X and Y chromosomes, occurrence of Barr bodies play a crucial role in sex-determination.
8. Abnormal sexes like gynandromorphs are also seen in certain organisms like *Drosophila* and silkworm. Gynandromorphism means the occurrence of phenotypically male and female parts in the same individual.

10.8 CHECK YOUR PROGRESS - MODEL ANSWERS

1. 3,2
2. Gynandromorphism is a phenomenon where an organism shows phenotypically male and female parts.

10.9 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines:

1. Describe with suitable examples the chromosomal mechanisms of sex-determination.
2. Describe the role of hormones in the determination of sex.
3. Describe the role of Parthenogenesis and environment in the determination of sex.

II. Answer the following in about 10 lines

1. Free martin
2. Gynandromorphs
3. Geneic balance theory of Bridges.
4. Sex-determination in gypsy moth.
5. Sex-determination in man.

UNIT-11 SEX LINKED INHERITANCE

Contents

- 11.1 Objectives
- 11.2 Introduction
- 11.3 Types of Sex-Linkage
 - 11.3.1 Heterogametic Male-Homogametic female type
 - 11.3.2 Heterogametic Female-Homogametic male type
- 11.4 Dominant Sex-Linked Genes
- 11.5 Sex Limited Genes
- 11.6 Sex Influenced Genes
- 11.7 Summary
- 11.8 Check Your Progress-Model Answers
- 11.9 Model Examination Questions

11.1 OBJECTIVES

This unit is about the various sex-linked traits found in different types of organisms. After going through this unit you will be in a position to describe:

- the different types of sex-linkages
- sex-linked traits in man and other organisms.

11.2 INTRODUCTION

There are two types of sex chromosomes. They are 'X' and 'Y'. These chromosomes in addition to the genes responsible for sex-determination, bears many genes for such characters which have no relation with the sex. But, being on the same chromosome these are linked to the sex-determining genes and hence to the sex of the organism. On the genetical grounds both X and Y chromosomes have many differences. Some portion of both types of chromosomes has identical genes. So it is called homologous region. Remaining regions of X and Y chromosomes have differential regions. The crossing-over always remains restricted to the homologous regions of X and Y chromosomes. So the genes which are present in homologous regions of X and Y chromosome do not always inherit along with other genes of their respective chromosome because crossing over separates them from others. Such genes are called partially or incompletely sex-linked. The genes present in the non-homologous regions of 'X' and 'Y' chromosomes always inherit together according to the inheritance of their respective chromosomes. Because these genes never undergo crossing over. Such genes are called completely sex-linked genes. The completely sex-linked genes are of two types.

1. Holandric genes

Those genes which are confined to differential region of 'Y' chromosome are called holandric or Y linked genes. The inheritance of such genes is known as Y-linked inheritance or holandric inheritance. These genes are inherited along with Y chromosome and phenotypically expressed only in male sex.

2. Sex-linked genes

The genes which are only present in the differential region of 'X' chromosome are called sex-linked or linked genes. These genes have no corresponding allele on Y chromosome. The inheritance of such genes is known as X-linked inheritance or sex-linked inheritance.

The genes occur in homologous of X and Y chromosomes are called XY-linked genes and their inheritance known as XY-linked inheritance. They inherit like the autosomal genes as seen in Mendelian inheritance. Now, let us study the inheritance of X-linked genes.

11.3 TYPES OF SEX-LINKAGE

Basing on the mode of sex-determination, the sex-linkage is of two types:

- 1) Heterogametic Male-Homogametic Female type
- 2) Heterogametic Female-Homogametic Male type

11.3.1 Heterogametic Male-Homogametic Female type

This type is seen in animals like *Drosophila* and man etc. In which males are either XY or XO and females are XX. This is also known as *Drosophila* type of sex-linkage. The male is heterogametic producing two types of sperms, X type and Y type (or, O). The females are homogametic producing two similar types of ova, each carrying X. Now, let us study the inheritance of this linkage in *Drosophila* and man taking atleast one example in each.

A) Sex-linked Inheritance in *Drosophila*

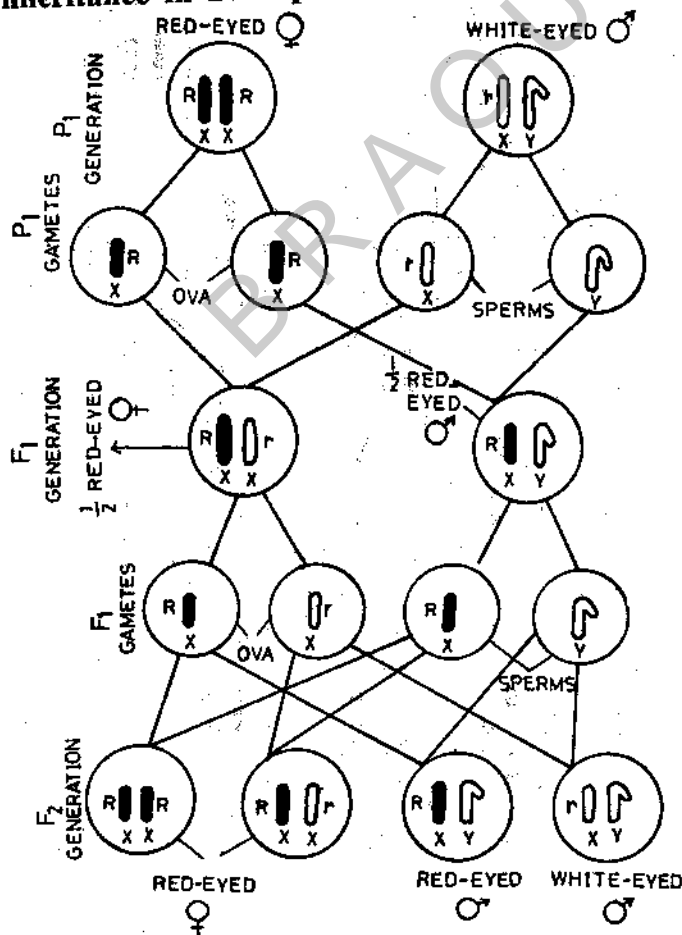


Fig. 11.1 Sex-linked inheritance in *Drosophila* Eye-colour (Red-eyed female with white-eyed male).

This was discovered by T.H.Morgan in 1910 in *Drosophila*. The wild type (dominant) *Drosophila* has red eyes. The mutant (recessive) has white eyes. The single pair of alleles controlling these characters are present on the X chromosome, and the Y chromosome does not contain any gene for this character. As shown in the figure, the white eyed male was mated with a homozygous red eyed female. Let the gene for red eye be 'R' and for white eye be 'r'. All the F₁ individuals were red eyed. The females were heterozygous (Rr), while the males were homozygous with a single allele (R) for the trait. These F₁ individuals when inbred (self-bred), produced the males and females F₂ generation as follows.

| | |
|----------------------------|-----|
| Males: Red eyed (R) | 50% |
| White eyed: (r) | 50% |
| Females : | |
| Homozygous red eyed-(RR) | 50% |
| Heterozygous red eyed-(Rr) | 50% |

It is very clear from the cross that the male transmits its X chromosome to the daughters only, while the female transmits its chromosome to both sons and daughters. The recessive sex-linked trait of male thus, passes on to 50% of his grandsons through his daughter and never to his grand daughters through his sons. The sex-linked trait in this case being recessive(r), is not expressed in the heterozygous condition in the grand daughters. This type of inheritance of the recessive sex-linked character from F₁ male to F₂ male through F₁ female is known as criss-cross pattern of inheritance. It is also termed digenic linkage.

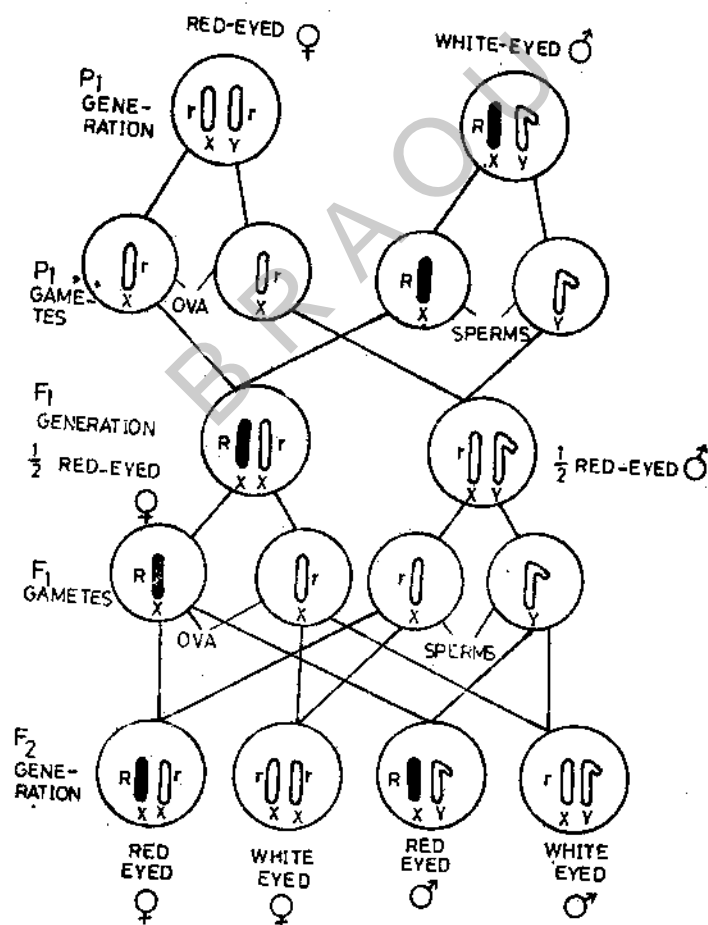


Fig. 11.2 Sex-linked inheritance *Drosophila* eye-colour (White-eyed female with red-eyed Male)

When a homozygous white eyed female (rr) is mated with a red-eyed male (R) in the F_1 generation, only the females are red eyed (Rr) while the males are white (r) eyed, on mating F_1 Males and females the F_2 generation produced the following types:

| | | | |
|----------|---------------------|---|-----|
| Male: | Red eyed (R) | = | 50% |
| | White eyed (r) | = | 50% |
| Females: | Red eyed (Rr) | = | 50% |
| | (heterozygous) | | |
| | White eyed (rr) | = | 50% |
| | homozygous) | | |

In addition to the expected progeny as derived above, Bridges also obtained some white eyed females and red-eyed males in F_1 generation. That was probably because of non-disjunction of the two X chromosomes of P_1 female.

B) Sex-linked Inheritance in Man

Colour-blindness and Haemophilia are important examples of this type of inheritance. Let us study the inheritance of colour blindness in man, in detail.

Colour blindness

This genetic disease refers to the inability of patient to distinguish between red and green colours. The single pair of controlling this character are present in the X chromosomes. The Y chromosome does not contain any gene for this character. The retina of man's eyes contain certain sensitive cells which are necessary for the distinction of red and green colour. The gene controlling this defect is recessive to the one controlling normal vision which is dominant. The heterozygous female apparently looks normal but actually carries a gene for the defect which can transmit it to her offsprings. Such a female is known as carrier.

The inheritance of this genetic disease can be studied in the following types of marriage:

1. Normal female-colour blind Male
 2. Colour blind female-Normal Male
 3. Carrier female-Colour blind male
 4. Carrier female-Normal male.
- 1) Marriage between normal female and colour blind male: As a result of this marriage the normal visioned male and female individuals will be produced.
 - 2) Marriage between colour blind female and normal male: This results in the production of colour blind sons and normal visioned carrier daughters.
 - 3) Marriage between colour blind male and carrier female: This results in the production of colour blind daughter colourblind sons, normal sons or normal visioned carrier daughters.

From the above crosses we can derive the following facts:

- 1) Colour blindness is more common in males than in females. This is because one gene in males and two genes in females are necessary to produce this defect.
- 2) All the females are carriers. Males are never carriers.
- 3) Women with normal colour vision but who had colour-blind fathers produce normal and colourblind sons in approximately the same ratio.
- 4) Colour blind Women always have colourblind fathers and always produce colourblind sons.
- 5) Colour blind Women produce colour-blind daughters only when their husbands are also colour blind.

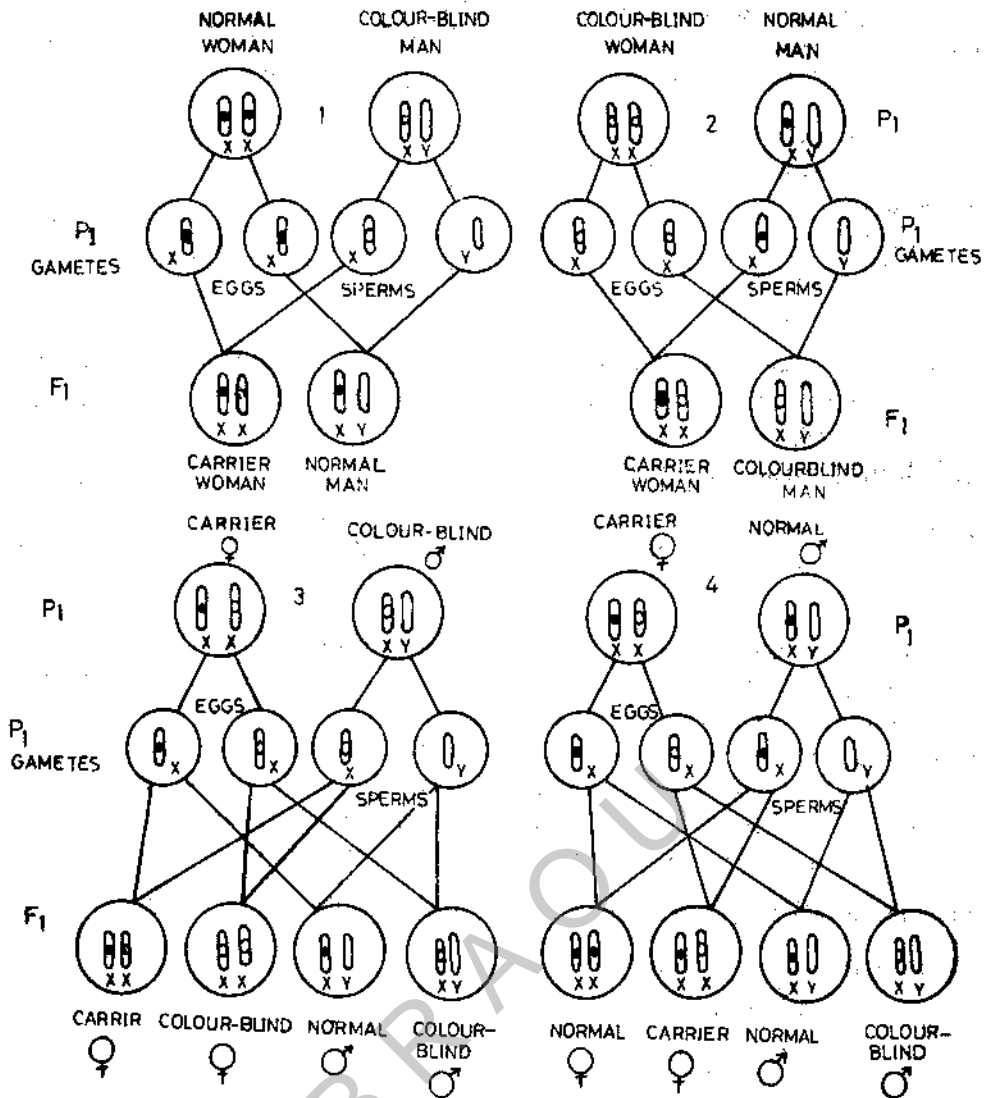


Fig. 11.3 Crosses showing colourblind sex-linked inheritance in man.

- 6) When both the husband and wife are colour-blind all the children carry the defect.

Haemophilia is also another genetic disease found in man. These patients lack a clotting factor in blood, as a result a small injury to the body will lead to continuous bleeding which could be fatal. Hence it is also known as **bleeder's disease**. This defect is also inherited in the same pattern as colour-blindness.

11.3.2 Heterogametic female-Homogametic male type

In this type of sex-linkage, the female is ZW or ZO and produces two types of eggs namely, 'Z' type and 'W' type (O), and hence the female is heterogametic. The male being homogametic (ZZ), produces similar type of sperms each carrying 'Z'. This type of linkage is just the reciprocal of the first type. This is seen in case of butterflies, moths and chicken. The inheritance of coloured (black and red) feathers in plymouth rock chicken can be taken as a good example for this type of inheritance.

In plymouth rock chicken the gene for barred feathers is dominant and the gene for black or red unbarred feathers is recessive. Both these genes are 'Z' linked. 'W' chromosomes carry no genes for this character. Let the gene for barred be 'B' and the non-barred be 'b'. When

the barred male with the genes BB is crossed with unbarred female containing single recessive gene 'b' in its 'Z' chromosome produce only barred males and unbarred females in F₁. When inbred these F₁ individuals produce the following offsprings in F₂ (Fig.11.4).

| | | | |
|-----------|--------------------------|---|-----|
| Males : | Homozygous-barred (bb) | = | 55% |
| | Heterozygous barred (Bb) | = | 50% |
| Females : | Barred (B) | = | 50% |
| | Non-barred (b) | = | 50% |

Here the male transmits its 'X' or 'Z' chromosomes to both sons and daughters while the female transmit her 'X' or 'Z' chromosome only to her sons. It is just the reverse of the cross seen in *Drosophila*. This is termed as diandric sex-linkage.

In a reciprocal cross when the barred hens and non-barred cocks are crossed, the F₁ will have half-barred males and non-barred females. These when inbred produce half-barred males and females and half non-barred males and females in F₂ generation.

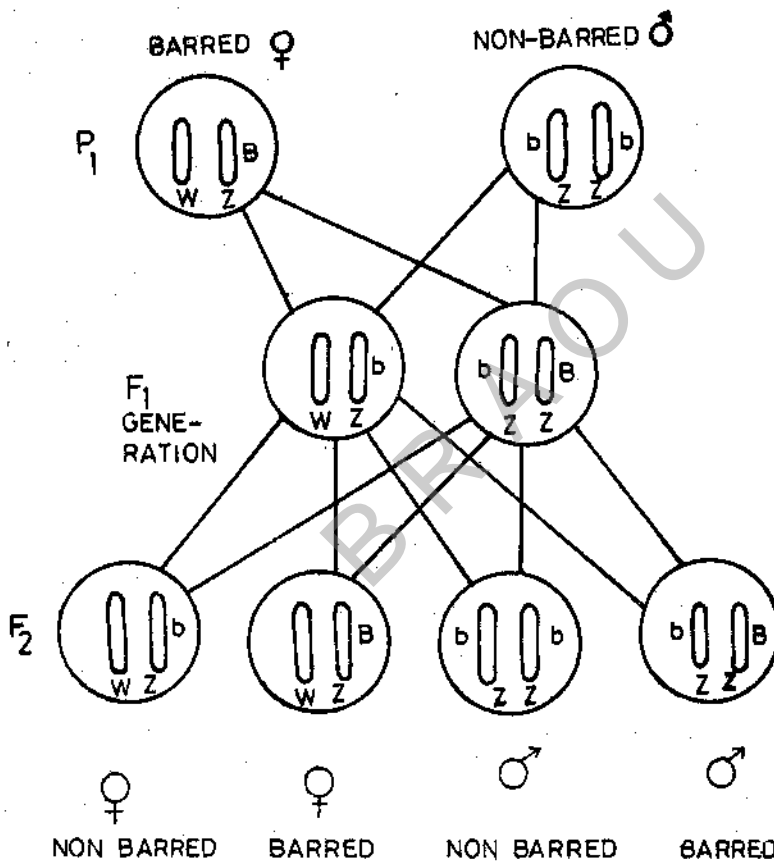


Fig.11.4. Sex-linked inheritance in Poultry (plumage pattern)

11.4. DOMINANT SEX-LINKED GENES

The sex-linked genes for white eye colour in *Drosophila* and colour blindness in man described earlier, are recessive characters. Being recessive, they expressed more frequently in male than in female. Some dominant genes are also noticed in man, for eg. genes for defective tooth enamel. This gene being dominant expresses itself even in heterozygous condition. Naturally

women have twice as many chances a men of receiving this gene. That is, the women posses this defect almost twice as frequently as men. In case of recessive genes, men possess the defect almost twice as frequently as women.

11.5. SEX-LIMITED GENES

The type of autosomal genes which can express in one sex and cannot express in other sex because of differences in the internal hormonal environment or because of anatomical dissimilarities are called, sex-limited genes.

The best example for sex-limited genes is plumage pattern or feathering in domestic fowl of Leghorn breed. Males have long, pointed, curved, fringed feathers on tail and neck, but feathers of female are shorter, rounded, straighter and without fringe. Thus, males are cock-feathered and females are hen feathered. By crosses it has been shown that hen-feathering result from a single gene 'H' and cock feathering from it allele 'h'. The expression of gene 'H' and 'h' depends upon the sex-hormones. The 'H' gene produces hen feathering in the presence of either sex hormone (male or female sex hormones), and cock feathering in the absence of any hormone. The 'h' gene produces cock feathering if female hormone is absent and hen feathering if female hormone is present. The various gene types for these phenotypes are tabulated below:

| Genotypes | Phenotypes | |
|-----------|-----------------|----------------|
| | Males | Females |
| HH | Hen feathering | Hen feathering |
| Hh | Hen feathering | Hen feathering |
| hh | Cock feathering | Hen feathering |

11.6. SEX-INFLUENCED GENES

The type of autosomal or sex-linked genes, whose phenotypic expression will be either as a dominant if the individual is male, or as a recessive if the individual is female, are known as sex-influenced genes. The best example is inheritance of bladness in man.

In man, in some families baldness is found to be inherited. In such inherited baldness, the hairs of a young man in his twenties or early thirties slowly become thin on the crown of the head leaving finally a fringe of hairs low on the peripheral part of the head. Such baldness is known a pattern baldness. The gene 'S' for baldness is found to be dominant in males and recessive in females. In heterozygous condition it expresses itself only in the presence of male androgenic hormone (in male sex). The inheritance of gene 'B' for baldness and 'b' for non-baldness in man and women are tabulated below:

| Genotypes | Phenotypes | |
|-----------|------------|----------|
| | Man | Woman |
| BB | Bald | Bald |
| Bb | Bald | Non-bald |
| bb | Non-bald | Non-bald |

Check Your Progress:

1. The genes which are confined to differential region of "Y" chromosome are called _____ or Y linked genes. These genes are inherited along with Y chromosome and phenotypically expressed only in _____ sex.
2. Give two important examples for sex linked inheritance.
3. The patients of _____ lack a clotting factor in blood, as a result a small injury to the body will lead to continuous bleeding which could be fatal.

11.7. SUMMARY

1. The inheritance of genes on differential portion of sex or 'X' chromosomes is known as sex-linked inheritance.
2. Depending on the mode of sex-determination the linkage is divided into two types namely (a) Heterozygous Male type and Homozygous Female type and (b) Heterozygous female type and Homozygous Male type.
3. Inheritance of eye colour in *Drosophila* and inheritance of colour-blindness of Haemophilia in man are taken as best examples for the first type of linkage.
4. Colour-blindness is a genetic disease in which a patient fails to distinguish between red and green colours. Haemophilia patients lack a factor essential for clotting of blood as a result of which a small injury causes a continuous bleeding of blood leading to the fatality of man.
5. In heterozygous male and homozygous female type of linkage males are never carriers. All the females are carriers. A carrier is one which carries recessive genes in the heterozygous condition but unable to express the character.
6. Plumage pattern in poultry is taken as an example for heterozygous Female and homozygous Male type of sex-linkage.
7. Sex-limited genes are those genes which can express in one sex and can not express in other sex because of the difference in the internal hormonal environment or because of anatomical dissimilarities.

Eg: Inheritance of feathering in Leghorn fowl.

8. Sex-influenced genes are those genes whose phenotypic expression will be either as a dominant if the individual is male or as a recessive if the individual is female.

Eg: Inheritance of pattern baldness in man.

11.8 CHECK YOUR PROGRESS : MODEL ANSWERS

1. Holandric, male
2. Haemophilia, colour blindness
3. Haemophilia

11.9 MODERN EXAMINATION QUESTIONS

I. Answer the following in about 30 lines:

1. What is a recessive sex-linked trait Explain it clearly taking an example you have studied.
2. What is sex-linked inheritance? Describe the digenic and diandric types of sex-linkages.

II. Answer the following in about 10 lines.

1. Dominant sex-linked genes.
2. Y-linked genes
3. Sex-limited and sex-influenced genes
4. Colour-blindness
5. Haemophilia

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UNIT-12 CHROMOSOMAL ABERRATIONS

GENE MUTATIONS

Contents

- 12.1 Objectives
- 12.2 Introduction
- 12.3 Classification of Mutations
 - 12.3.1 Chromosomal Aberrations
 - 12.3.2 Variations in Chromosome Number
 - 12.3.3 Variations in number and arrangement of genes within a Chromosome
- 12.4 Significance of Chromosomal Aberrations
- 12.5 Gene Mutations
 - 12.5.1 Nature of Gene mutations
 - 12.5.2 Significance of Gene Mutations
 - 12.5.3 Induced Mutations
- 12.6 Summary
- 12.7 Check Your Progress - Model Answers
- 12.8 Model Examination Questions

12.1 OBJECTIVES

This unit gives an account of certain structural variations in the chromosomes which produce phenotypic changes in an organism. By the end of this unit you will be able to:

- describe the structural variations in the chromosomes which will lead to phenotypic changes in the organisms.
- discuss about the sudden changes in the individual genes.
- explain about the artificially induced mutations and mutagenic agents.

12.2 INTRODUCTION

In a species variations may be caused by changes in the environment, by alterations in the heredity constitution or more commonly by a combination of both. If a variation appears only when the environment is changed and disappears when it is restored, it is not heritable. These are phenotypic variations known as modifications. If, however, changes occur which are independent of environment and heritable, they produce permanent changes in the genome of an individual. Hugo DeVries was the first hybridist who used the term 'mutation' to describe the heritable phenotypic changes of the evening primrose, *Oenothera lamarckiana*. The first scientific study of mutation was started in 1910 when Morgan started his work on fruitfly, *Drosophila melanogaster* and reported white eyed males among the red eyed male individuals. Later on, several cases of mutations have been reported in a variety of microorganisms, plants and animals, i.e., rodents, fowls and man. etc.

12.3 CLASSIFICATION OF MUTATIONS

Mutations arise spontaneously or they can also be induced with different mutagenic agents. The rate of spontaneous mutations is very low. The mutations are of two types:

1. Chromosomal mutations or chromosomal aberrations.
2. Gene mutation or point mutations.

12.3.1 Chromosomal aberrations

Chromosomes are the structures with definite organisation carrying genes in a definite linear order. Generally the chromosomes remain unchanged but under certain natural or artificial adverse circumstance certain structural changes may occur in the chromosomes. This results in change in the position of gene or loss of some genes. These structural alterations affect the phenotype of an individual in different degrees, and collectively, are called **chromosomal mutations**. The study of chromosome morphology has elaborated our information about certain forms of chromosomal aberrations like translocations. The various types of chromosomal aberrations can be broadly grouped under two categories:

1. Variations in chromosome number.
2. Variations in the arrangement of genes or the total number of genes within a chromosome.

12.3.2 Variations in Chromosome Number

Variation in the normal diploid ($2X$) chromosomal number is termed as **ploidy**. Ploidy is of three types, viz. **haploidy**, **polyploidy** and **heteroploidy**.

1. Haploidy

When the total number of chromosomes in an organism is represented by one number from each homologous pair of the normal diploid ($2X$) species, the condition is known as **haploid** or **monoploid** (X). For example, the corn plant has 20 pairs of chromosomes but haploids with only 20 chromosomes frequently appear. Haploidy is rare among animals. Among bees and wasps males are haploid, while females are diploid. The haploids are smaller than the normal diploids.

2. Polyploidy

When the chromosomes number exceeds the diploid number ($2X$) and is a multiple of haploid number (X), the condition is termed as **polyploidy**. For example, triploidy ($3X$), tetraploidy ($4X$), pentaploidy ($5X$), hexaploidy ($6X$), octoploidy ($8X$) etc. Several cultivated varieties of plants such as pears, blue berries, black berries, cherries, cranberries, wheat, grapes, apples etc., are polyploids. Polyploidy in animals is very rare. However, triploid *Drosophila* and rabbits, have been produced by treating eggs with chemicals just before fertilization.

An instance of polyploidy in man is also on record. A highly abnormal boy was found to have 69 chromosomes instead of the normal diploid number (46). This was obviously a case of **triploidy**. His chromosome complement was XXY. He was a male with abnormal cerebral development and syndactyly (fused digits) of hands and feet. The individual survived only foetal life and died at birth.

3. Heteroploidy

It involves changes in the chromosome number of a single haploid set of chromosomes. Such changes are brought about by the phenomenon of **non-disjunction** discovered by **Bridges** in *Drosophila*. Non-disjunction is the failure of two homologous chromosomes to segregate during cell division. Whenever this occurs in somatic cells, two types of daughter cells are produced, one type with $2X + 1$ chromosomes and the daughter cells are produced, one type with $2X - 1$ chromosomes. Non-disjunction during gametogenesis results in the formation of two types of gametes one type with $X+1$ and the other type with $X-1$ chromosomes.

Non-disjunction of sex chromosomes may give rise to the XXY sex chromosome complement in man. Such individuals are called **Klinefelter's syndromes**.

Such a syndrome is outwardly man, but sterile due to underdeveloped testes, and shows tendency towards female breast. The $2X+1$ condition is also known to result in XXX female. Such female have underdeveloped reproductive organs and secondary sexual characters but may be fertile.

12.3.3 Variations in number and arrangement of genes within a Chromosome

When aberrations remain confined to a single chromosome of a homologous pair with variations in number of genes and their arrangement within a chromosome, they are described as intrachromosomal aberrations. They are produced by the following methods:

1. Deletion
2. Duplication.
3. Inversion.
4. Translocation

1. Deletions or Deficiency

Refers to the missing of a chromosomal segment bearing one or more gene loci. Deletion is thus mutation effecting the phenotypic changes pertaining to the missing gene or genes. A deletion may be terminal or intercalary depending upon its occurrence at the tips or between the two ends of the chromosome (Fig 12.1). During pairing a bulging out as an unpaired loop, by the portion of the normal chromosome homologous to the deficient segment takes place. Such loops are called **deficiency loops** and observable during meiotic prophase.

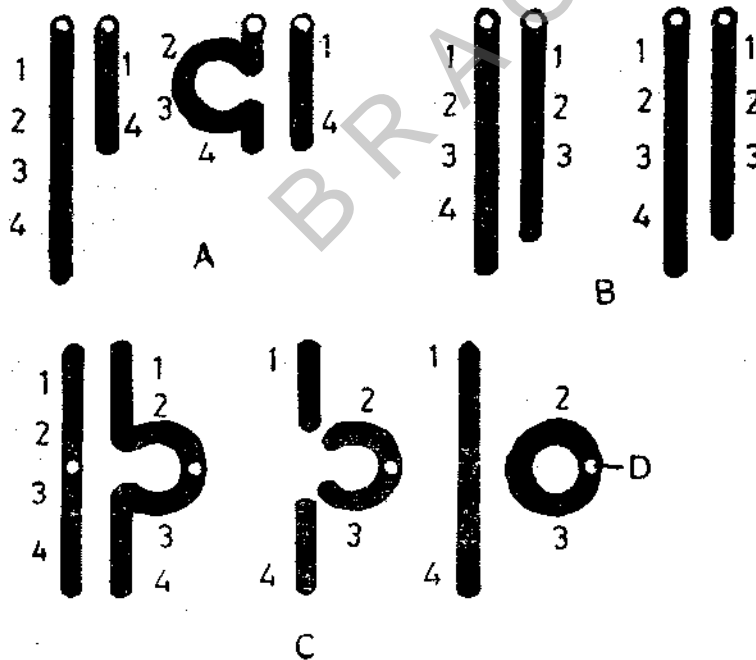


Fig. 12.1 Diagram showing different types of deletions. A. Interstitial deletion B. Terminal deletion. C. Formation of an acentric rod and deletion ring D. Centromere.

To account for the "notched" condition of wing margin in some fruitflies, **Bridges and Mohr (1945)** suggested a loss or deletion of small segment in the X-Chromosome. It has been shown that homozygous deletions are lethal. Deletions can be induced by ultraviolet and X-Rays.

2. Duplication

The doubling or addition of a chromosomal segment is called duplication. This extra-chromosomal segment may be a free fragment with a centromere or a chromosomal segment of the normal complement forms a loop to maximize the juxtaposition of homologous regions. In contrast to the deficiency loop, the duplication loop is formed by the duplicated segment. Pairing and crossing over in inverted and displaced duplications leads to different chromosomal aberrations such as reciprocal translocations, inversions, rings, acentric and dicentric chromatids.

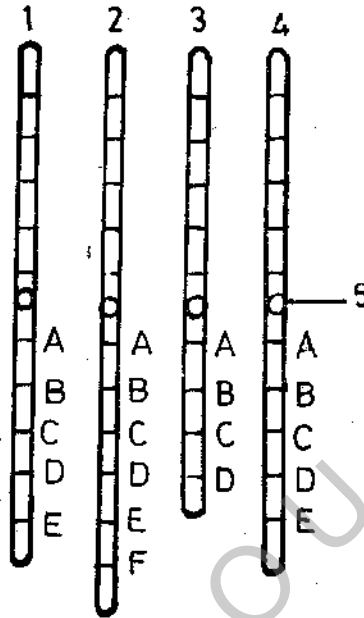


Fig. 12.2: Diagram showing duplication and deletion 1. Normal chromosome with genes 2. chromosome with duplication 3. Chromosome with deletion 4. chromosome with addition 5. Centromere

This Phenomenon of duplication was discovered by **Morgan and Sturtevant** in 1923. The best example of duplication is Bar eyed mutant in *Drosophila*. Duplications cause different abnormalities in the phenotype but their effects are less deleterious than those of deletions.

3. Inversions:

An inversion is an intrachromosomal aberration in which a segment is inverted 180 degrees. For example, if a chromosome has segments in the order of 1-2-3-4-5-6 and breaks occur in regions 2-3 and 5-6 and the broken piece 3-4-5 is reinserted in reverse order, then the inverted chromosome will have segments in order of 1-2-5-4-3-6 as shown in the figure 12.3. The inversions are of two types i) pericentric and ii) paracentric.

i) Pericentric inversions:

When the inverted segment of chromosome contains centromere, then such inversions are called pericentric inversions (Fig 12.3A). If crossing over occurs within the loop of a pericentric inversion, the resulted chromatids include half of the chromatids with duplications and deficiencies forming non-function. The other half of the chromatids form functional gametes.

ii) Paracentric inversions

When the inverted segment includes no centromeres and the centromere remains located outside the segment. (Fig. 12.3.B) then such type of inversion is called paracentric inversion. Crossing

over within the inverted segment of a paracentric inversion produces an acentric and dicentric chromosome. The acentric chromosome, as it lacks the centromere, fails to move to either poles, and so is not included in the meiotic products. The dicentric chromosomes contain two centromeres and form a bridge from one pole to another during the first meiotic anaphase. When anaphase chromosomes separate towards poles, this bridge breaks resulting in the fragment with duplications or deficiencies.

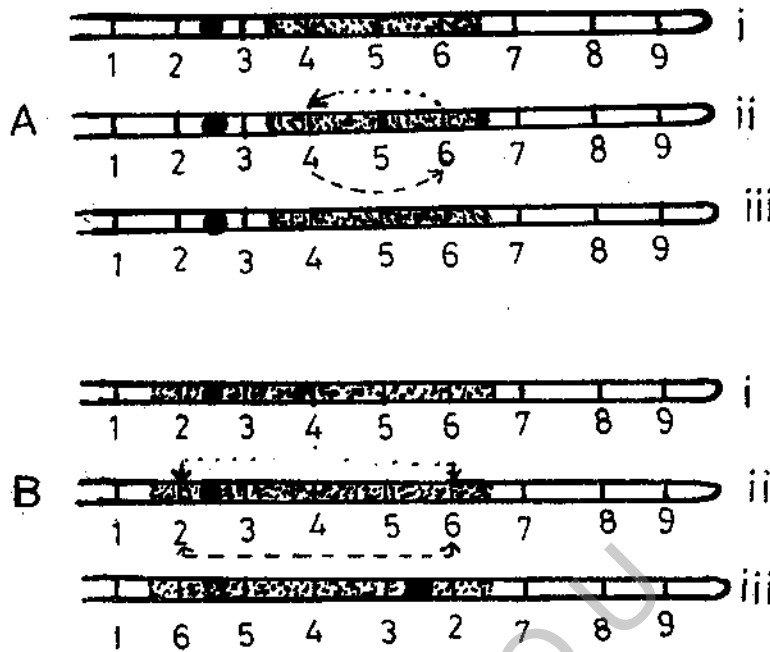


Fig. 12.3 Diagrammatic representation of types of inversions. A. Paracentric B. Pericentric i) Before inversion. ii) Breakage and inversion iii) After inversion.

4. Translocation

Translocation also referred to as reciprocal translocation, is an interchange of segments between non-homologous chromosomes. It is thus different from crossing-over, which involves an interchange between homologous chromosomes. The reciprocal translocation may be of the following types:

- i) **Homozygotic translocation:** In homozygotic translocation normal meiosis occurs and cannot be detected cytologically. Genetically they are marked by altered linkage group by the fact

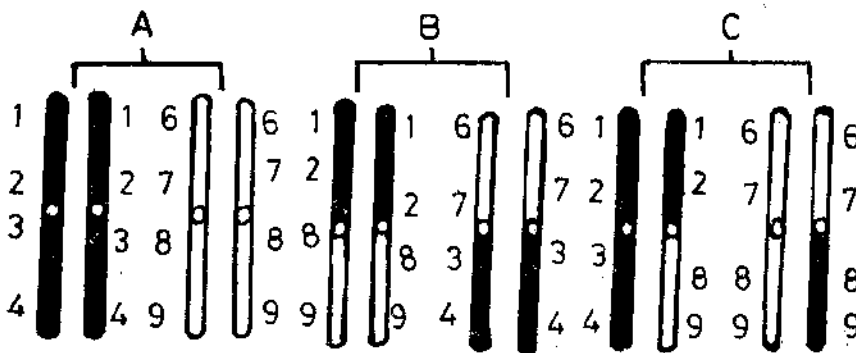


Fig. 12.4 Translocations A. Homologous chromosomal pairs B. Homozygotic translocation C. Heterozygotic translocation.

that a gene with new neighbours may produce a somewhat different effect in its new location (position effect)

- ii) **Heterozygotic translocation:** In this type a considerable degree of meiotic irregularity occurs. During meiosis, an individual which is heterozygous for a reciprocal translocation must form a cross shaped configuration in order to affect pairing of homologous segments.

Translocations were first discovered by **Bridges** in 1923. They have been thoroughly studied in the evening primrose and maize. Through radiations it is possible to induce translocations in maize.

12.4 SIGNIFICANCE OF CHROMOSOMAL ABERRATIONS

1. Haploidy, polyploidy and heteroploidy produce several phenotypic changes in the organisms.
2. Deletions alter phenotypic traits pertaining to the missing gene loci. Homozygous deletions are lethal.
3. Duplications cause various phenotypic abnormalities like barred eyes in *Drosophila*.
4. Inversions and translocations only bring about chromosomal rearrangements and they do not produce significant visible effects.
5. The phenotypic changes produced due to spontaneous or induced chromosomal mutations may result in the formation of new varieties of a species or new species itself.

12.5 GENE MUTATIONS

Disorders during the replication of genes lead to gene mutations. These mutations are also called **point mutations**. The earliest record of point mutations dates back to 1971 when **Sewal Wright** noticed a lamb with exceptionally short legs in his flock of sheep. Visualising the economic importance of this short-legged sheep, he produced a flock, each having short legs, by employing artificial breeding techniques. The short legged sheep were known as **Ancon Breed**. Later on, the trait of short legs was found to result from a recessive mutation.

When heritable alterations occur in a very small segment of DNA molecule, then this type of mutations are described as point mutations. The point mutations may occur due to following types of nucleotide changes in the DNA.

I. Deletion

The point mutation which is caused due to loss or deletion of some portion in a triplet codon of a cistron or gene is called deletion. This kind of mutations have been frequently reported in some bacteriophages.

2. Insertions

These are gene mutations where one or more additional nucleotide bases are inserted into the DNA molecule. The insertion mutations can be artificially induced by certain mutagens. Both deletion and insertion alter the code words and cause radical changes in the rest of the message. This can result in the production of an inactive protein and can lead to the death of the cell.

3. Substitution

A point mutation in which a nucleotide of a triplet is replaced by another nucleotide is called substitution mutation. It affects only a particular triplet codon. Such an altered triplet codon may designate a different amino acid and results in the production of a protein with a single

amino acid substitution. This kind of substitution mutations are of great genetic significance as they alter the phenotype of an organism. The substitutions are of two types:

- i) **Transitions** : When a purine (e.g. adenine) base of a triplet codon is replaced by another purine base (e.g. guanine) or a pyrimidine (e.g. cytosine) is substituted by another pyrimidine base (e.g. thymine) then such a kind of substitution is called transition.
- ii) **Transversions** : When replacement of a purine with a pyrimidine or vice versa takes place, then this type of substitution mutation is called transversion. It is extremely difficult to recognize transversions genetically. However, they can be recognised only by analysis of amino acid substitutions in proteins.

12.5.1 Nature of Gene Mutations

Though most genes are highly stable, genes mutate in all genetically examined organisms, from virus to man, but different rates depending on their relative chemical stability. Some genes mutate once in a few thousand cell divisions while others once in millions of cell divisions. Some genes are known to increase the mutation rate of other genes. Some genes in certain bacteria are known to increase the mutation frequency of other genes in the organism. Such genes are called mutator genes. A particular gene at different times, may mutate at different rates, depending upon the tissues and the stage of development of the organism.

A mutant gene may continue mutating in different directions causing diverse effects. The direction of mutation is, however, preferential i.e., it occurs more frequently in some directions than in others. A gene mutating in different directions forms multiple alleles which may effect different characters or the same character in different degrees.

A mutant gene may even mutate back to its normal original form. This is known as reverse mutation. The occurrence of back mutation indicates that mutation involves only a chemical change in a gene and not a loss of a gene.

12.5.2 Significance of Gene Mutations

1. The gene mutation is usually negligible or has no visual effects.
2. Some mutations like insertions and deletions however, produce major effects, which are generally harmful, and occasionally lethal, causing death of the organism.
3. In homozygous condition lethal genes have deleterious effects on the organism and cause death.
4. In heterozygous condition they are mostly recessive and hence remain unexpressed.
5. The vast majority of gene mutations are deleterious to the organism and are kept at low frequency in the population by natural selection.

12.5.3 Induced Mutations

Factors which induce mutations artificially are called mutation agents or mutagens. The following are the most well known mutagens in order of significance.

I. High Energy Radiation

Most of the natural mutations are caused by cosmic rays from outer space and radiations from radioactive elements. Mutations can be induced in organisms by exposing them to ionizing radiations like X-rays, gamma rays, ultraviolet light and beta particles. Such mutations are known as induced mutations. Now a days useful mutations are being induced and perpetuated in plants and animals.

H. J. Muller was the first to demonstrate that radiations cause mutations. For this he won the 1946 Nobel Prize for medicine and physiology.

Nuclear bomb explosions result in the disposal of radioactive vapours through the atmosphere which effect the life-processes. The effects of radiation are cumulative over long periods of time. For example 0.1R per day for 10 years is enough to increase the mutation rate to about 150 percent of the spontaneous level.

As the radiation dose increases the number of breaks increases and "aberrant" fusions become more and more likely. In man double or multiple chromosomal breaks are induced by acute exposures (eg. heavy medical irradiations, nuclear accidents in nuclear warfare), whereas single breaks are produced at low doses. Chromosomal aberrations have been observed in blood cultures of humans who have had radiation treatments or injections of radioactive substances. The genetic effect of radiation has been studied in space flights also. Atomic bombing of Hiroshima and Nagasaki (Japan) during II world war, has produced several mutations among the Japanese people. Such induced mutations will only amplify the human agony. A new branch, Radiogenetics has developed recently to deal with radiation effects on heredity as we are in the threatened nuclear age at present.

2. Chemical mutagens

Robson and Auerbach (1947) pioneered investigations on the mutagenic effects of some chemicals. Important mutagenic chemicals are mustard gas, nitrogen mustards, sulphur mustards, phenol, ethyl urethane, formaldehyde, nitrous acid, peroxide, permanganate, caffeine, benzopyrine etc. Certain chemical mutagens affect DNA directly and DNA replication will become defective. Certain chemical compounds called base analogues like amino purine, 5-bromouracil etc. Which closely resemble DNA bases are incorporated by DNA in the place of normal DNA bases which interfere with the integrity of DNA and its replication.

3. Temperature

It has been proved that temperature increase can enhance the rate mutation. Muller and Attenberg observed that *Drosophila* raised at 29° C underwent mutational changes 3.2 times more than those raised at 16° C. High temperatures are known to increase mutations in man and other animals also.

Thus by induction of mutations quantitatively and qualitatively improved plant and animal progeny can be produced. An awareness can be created better amongst people about induced genetic disorders due to nuclear wars and other mutagenic agents.

Check Your progress:

1. Define the following terms
 1. Haploidy
 2. Deletion
 3. Translocation

12.7 SUMMARY

1. Mutations are sudden changes in genotype involving qualitative or quantitative alterations in the genetic material itself.
2. There are two kinds of mutations - chromosomal and gene mutations.

3. Chromosomal mutations or aberrations may result in alterations in the amount or position of genetic material.
4. Gene or point mutations, result in permanent heritable changes within a gene.
5. The frequency of occurrence of these mutations in man and other organisms and their mechanism is elucidated.
6. The induced mutations through ionizing radiations, chemicals and temperature and significance of mutations are also discussed.

12.8 CHECK YOUR PROGRESS - MODEL ANSWERS.

Haploid : when the total number of chromosomes in an organism is represented by one number from each homologous pair of the normal diploid ($2x$) species, the condition is known as Haploid

Deletion: Deletion refers to the missing of a chromosomal segment bearing one or more gene loci.

Translocation: Translocation is an interchange of segments between non-homologous chromosomes.

12.8 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines :

1. What are mutation? Give an account of gene mutations.
2. Explain different types of structural changes that cause chromosomal aberrations, mention their significance.
3. What is meant by induced mutation? Explain different mutagens and their effect.

II. Answer the following in about 10 lines:

1. What is polyploidy? How does it help in mutation?
2. How does mutation help in species formation?
3. Distinguish between deletion and duplication with reference to chromosomal mutation.
4. Why are chromosomal aberrations are considered to have less significance than gene mutations?
5. What is the difference between pericentric and paracentric inversions.

UNIT- 13 CHEMICAL BASIS OF HEREDITY - NUCLEIC ACIDS

Contents

- 13.1 Objectives
- 13.2 Introduction
- 13.3 Chemical Structure of DNA
- 13.4 Replication of DNA
- 13.5 RNA
 - 13.5.1 Structure of RNA
 - 13.5.2 Types of RNA
- 13.6 Genetic Code
- 13.7 Protein Synthesis
- 13.8 Summary
- 13.9 Check Your Progress - Model Answers
- 13.10 Model Examination Questions

13.1 OBJECTIVES

This unit deals with the chemical basis of heredity in terms of DNA and the sequence of four bases of DNA as a genetic code and role of messenger RNA. By the end of this unit you will be able to:

- describe Watson and Crick's model of DNA, and its replication;
- structure and different types of RNA
- Mechanism of protein synthesis.

13.2 INTRODUCTION

Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), the principal genetic materials of living organisms, are chemically called nucleic acids. These are large molecules containing carbon, oxygen, hydrogen, nitrogen and phosphorus. The nucleic acids were first isolated by **Miescher** in 1868 from the nuclei of pus cells and gained their name from the fact that they were acidic and were identified in nuclei.

13.3 CHEMICAL STRUCTURE OF DNA

Deoxyribonucleic Acid (DNA)

Cytochemical studies on micro-organisms have established beyond doubt that DNA is the **primary genetic material** responsible for heredity. DNA occurs universally in all animal and plant cells with the exception of a few viruses in which RNA is known to be the genetic material. Almost the entire DNA complement of a cell lies in its nucleus forming a major component of the chromosomes.

DNA as a Genetic material

Total DNA content is the same in all the diploid (2X) cells of organisms of the same species which functions as the primary genetic material. Mitosis facilitates an equal distribution of DNA to daughter cells. The haploid gametes (X) contain half the amount of DNA and in polyploid cells it increases proportionately. DNA is capable of self-replication with utmost accuracy which is essential from generation to generation. It is also capable of controlling and regulating protein synthesis essential for the expression of traits.

Structure of DNA

DNA molecule is the largest of known natural polymers. It has a molecular weight upto 2×10^9 per molecule.

The molecular structure of DNA has two aspects:

1. Its chemical subunits.
2. The way in which these chemical subunits are arranged to form a long chain molecule.

The second aspect is very important as the accepted DNA model should be such that it explains biochemically the various activities of a gene, i.e., the capacity for replication, the capacity to store vast hereditary information in coded form. It should also be metabolically stable.

I. Chemical sub-units

Chemical analysis has shown that DNA is composed of three types of chemical substances:

- a. **Nitrogen bases:** These are of four types, viz., adenine, guanine, cytosine and thymine. Adenine and guanine are the **purine bases**. While cytosine and thymine are the **pyrimidine bases**. The purines have a double ring of carbon (C) and nitrogen (N) atoms. The pyrimidines have a single ring of four C and two N atoms, and thus smaller molecules than the purines (Fig. 13.2).
- b. **Deoxyribose:** It is a pentose of 5-carbon sugar.
- c. **Phosphoric acids:** It occurs as a phosphate group in combination with deoxyribose sugar.

2. Nucleotides

The three types of chemical substances are joined together into a larger sub-unit called **nucleotides**. Each nucleotide is made up of a phosphate group joined to a **nucleoside**. A nucleoside is made up of a deoxyribose sugar and any one of bases. Further, since the bases are of four types, four types of nucleotides are formed.

3. Polynucleotides strand

Several nucleotides are joined end to end to form a long polynucleotide strand. The strand has a chain of alternately attached sugar (s) and phosphate (p) molecules, with a base (B) attached to each sugar molecule. The order of the four types of nucleotides is not regular and varies from one section of the DNA molecule to the other. The number of nucleotides incorporated in a single DNA molecule is also variable. The number is usually large upto 2,00,000 or even more in some cases.

Due to the presence of nucleotides as long polynucleotide strands DNA appears as a long and thread-like molecule. Recently electron micrographs of DNA molecule have also confirmed its thread-like molecule. Recently electron micrographs of DNA molecule have also confirmed its thread-like appearance.

X-Ray Crystallographic evidence for DNA

The first person to give any thought to the three dimensional structure of DNA was **Astbury** (1940) who carried out X-Ray crystallographic studies on DNA molecule. Later **Wilkins** and **Franklin** obtained a superior X-Ray diffraction photograph of DNA with the following observations:

1. DNA from different species give identical X-Ray patterns.
2. DNA molecules are long and thin with a length greater than 30,000 and 20\AA thickness.
3. DNA has a repeating structure for every 34\AA .

Watson and Crick's model of DNA

In 1953, **J.D.Watson** and **F.H.Crick** proposed a model of the structure of DNA molecule based on the X-Ray diffraction data of **Wilkins** and **Franklin** which has since been confirmed by several workers. They have constructed a **double helix model** for the molecular structure of DNA molecule based on the following facts:

1. Electron micrographs show that a DNA molecule is about 20\AA wide. Since a single polynucleotide strand is only about 10\AA wide, it follows that DNA is made up of two polynucleotide strands lying side by side in chemical union.

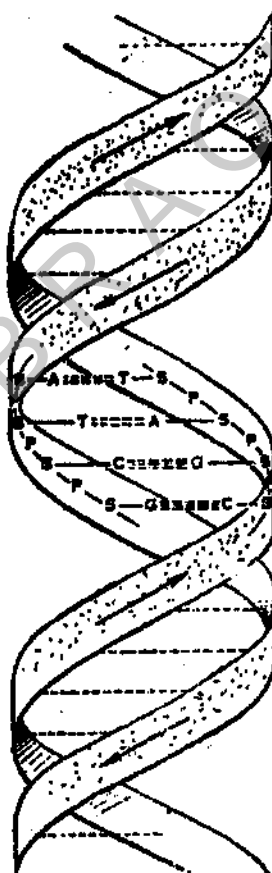


Fig. 13.1 Watson-Crick model of DNA. S. Pentose sugar. P. Phosphate group. A. Adenine G Guanine. T. Thymine. C. Cytosine.

2. A clue to the orientation of the two strands is provided by two facts. i) The nitrogenous bases are capable of forming a weak hydrogen bond with one another and ii) nitrogenous bases are hydrophobic i.e., they are repelled by water, while sugar and phosphate are hydrophilic i.e., readily form bonds with water molecules.
3. These clues indicate that the two polynucleotide strands are so oriented that they impart a ladder-like appearance. The sugar-phosphate chains form the frame lying outside of the ladder, while the bases of the two strands, united by hydrogen bonds, form the rings (steps) of the ladder. This plan may be broadly depicted as follows:

To be more precise, adenine (A) always pairs with thymine (T) and there are two hydrogen bonds between them ($A=T$), and guanine (G) always pairs with cytosine (C) and there are three hydrogen bonds between them ($G=C$). The evidence for this pattern of pairing comes from Chargaff's rules.

These are :

1. In a cell the amount of adenine is equal to the amount of thymine and that of guanine is equal to cytosine.
2. A DNA molecule contains equal amounts of purines and pyrimidines i.e., $A+G=T+C$.
3. The relative percentage of these bases in some organisms and the ratio $A+T/G+C$ differ from cells of one species to another species.

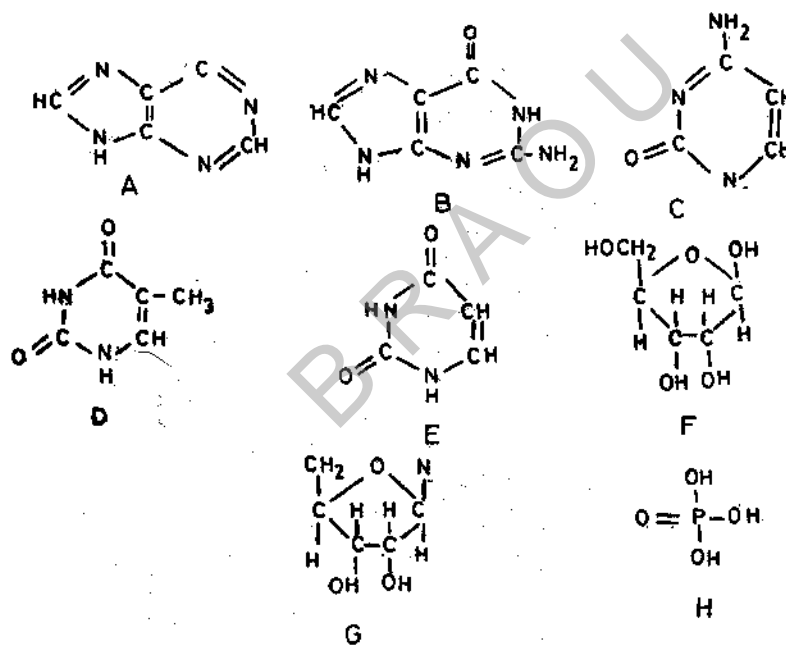


Fig. 13.2. Formulae of nitrogen bases, ribose, deoxyribose and phosphoric acid. A. Adenine. B. Guanine. C. Cytosine. D. Thymine. E. Uracil. F. Ribose sugar. G. Deoxyribose. H. Phosphoric acid.

13.4 REPLICATION OF DNA

Replication or duplication of the genetic material (DNA) is an essential feature of cell division. Doubling of DNA takes place during interphase i.e., S-period (synthetic phase) of the cell-cycle (Goodenough and Levene, 1979). The double helix model of DNA molecule of Watson and Crick beautifully embodied a built-in template system for self-replication. Thus, each

chain of the double helix can serve as **template** for the synthesis of the other. The constituents of DNA viz, phosphates, sugar molecules and bases are synthesized within the nucleus. These substances pair up to form the nucleotides ready to be incorporated into new DNA molecules during replication.

Watson and Crick (1953) proposed a mechanism of replication on the basis of their model which involves the disruption of hydrogen bonds followed by a rotation and separation of the two polynucleotide strands. The separation occurs in a manner resembling the unzipping of zip. The hydrogen bonds that held together the bases of the opposite strands being weak, easily permit the separation.

Each strand as it separates **attracts** a **complementary** or daughter strand. Thus unzipping of the parent strands from one end to the other is almost simultaneously by their replication or duplication. The pairing of the bases being specific ($A=T, G=C$), the sequence of base on the complementary strand can be predetermined by the sequence of base on the parent strand. Thus, each base of the parent strand attracts its complementary i.e., adenine attracts thymine, cytosine attracts Guanine and vice versa Fig. (13.3.)

Each daughter molecule conserves one polynucleotide strand from the parent molecule and one newly assembled strand. This method of DNA replication is often described as semi-conservative. **Watson and Crick** model of DNA replication later on verified by several workers like **Messelson and Stahl (1962)**, **Taylor (1964)**, **Hubreman (1976)** and it was found to be correct.

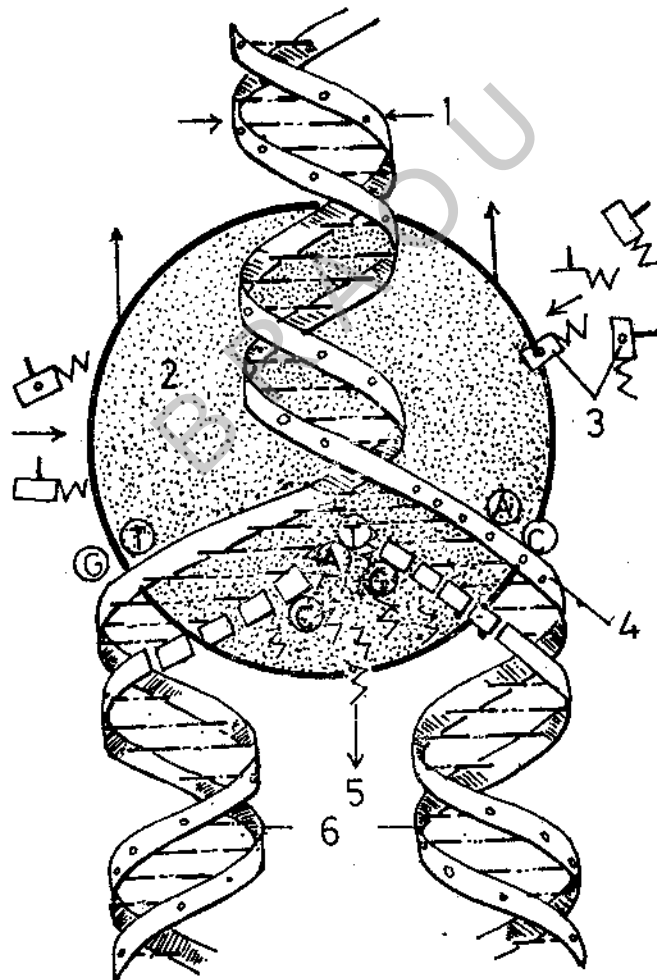


Fig. 13.3. Diagrammatic representation of replication of DNA 1. DNA molecule 2. DNA polymerase 3. Building units of nucleoside triphosphate 4. Template (old strand) 5. Phosphate 6. New DNA strand. A. Adenine G. Guanine T. Thymine C. Cytosine

What causes the parent strands to unzip is not yet clearly known. However, it is known that the amount of energy needed to break down hydrogen bonds is equal to the amount of energy needed for the separation of the polynucleotide strands of the DNA molecule.

In 1956 Arthur Kornberg successfully achieved the actual synthesis of a perfect copy of bacteriophage DNA polymerase. In May, 1970, Har Govind Khorana reported the artificial synthesis of gene (double stranded DNA).

13.5 RIBONUCLEIC ACID (RNA)

RNA plays an active role in cell metabolism and protein synthesis. It acts as an intermediary in the expression gene. Some plant viruses (eg. TMV, Turnip yellow mosaic viruses, wound turnover viruses etc.), animal viruses like influenza virus, foot and mouth virus, was, sarcoma virus, poliomyelites virus etc., and bacteriophages like MS₂ as their genetic material.

13.5.1 Structure of RNA

RNA molecule has the same structural plan as DNA. RNA is polymeric nucleic acid of four monomeric ribonucleotides. Each ribonucleotide contains three types of chemical substances viz, i) a pentose sugar (D-ribose) ii) a phosphate group and ii) four types of nitrogen bases. The nitrogen bases of RNA are two purines, **adenine** and **guanine** and two pyrimidines **cytosine** and **uracil**. These nucleotides are inter linked to form a polynucleotide strand. The four ribonucleotides also occur freely in nucleoplasm in the form of triphosphates of ribonucleosides such as adenosine triphosphate (ATP), guanosine triphosphate (GTP), cytidine triphosphate (CTP), and uridine triphosphate (UTP).

Molecular structure of RNA through X-RAY diffraction studies showed that it is a single or double stranded entity but not helical like DNA molecule. Single stranded RNA occurs as genetic material in plant viruses (TMV, TYM) animal viruses (influenza viruses, Poliomyelitis viruses, foot and mouth viruses) and bacteriophages (MS₂). The double stranded but not helical RNA occurs as the genetic material in some plant viruses (reoviruses).

13.5.2 Types of RNA:

1. Genetic RNA

In most plant viruses and many bacteriophages DNA does not occur. In them RNA performs the genetic functions of DNA. This type of RNA known as Genetic RNA or Viral RNA is single stranded as in TMV (Tobacco mosaic virus).

2. Non-Genetic RNA:

RNA is non-genetic and concerned mainly with protein synthesis. It is the case in most organisms where DNA acts as a genetic material. The non-genetic RNA is of three types:

- i) **Messenger RNA (m-RNA):** It constitutes only 5% of the total RNA content of a cell. It is synthesized in the nucleus along one strand of DNA. The synthesis (transcription) is aided by an enzyme called RNA polymerase. In the presence of this enzyme a portion of DNA double helix opens up and attracts a complementary strand with a predetermined base-sequence as in replication. However this strand possesses uracil instead of thymine (Fig. 13.4). As RNA polymerase moves along the DNA molecule, the complementary strand grows and eventually separates as m-RNA. The m-RNA molecules then leave the nucleus through the nuclear pores and reach the cytoplasm, where they get associated with ribosomes. The sequence of bases on m-RNA is determined by the DNA molecule on which it is synthesized, the latter is therefore referred to as a **template**.

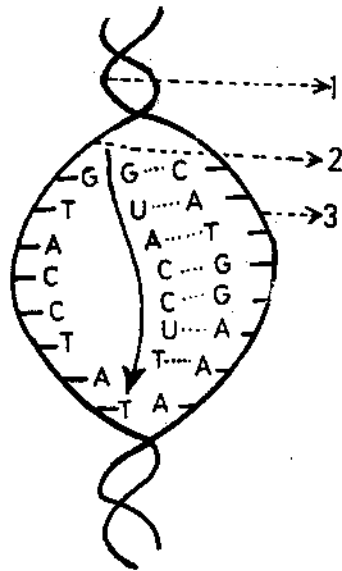


Fig. 13.4. Diagrammatic representation of formation of messenger RNA along one strand of parent DNA. 1. Inactive DNA strand 2. RNA. 3. Active DNA strand.

- ii) **Ribosomal RNA (r-RNA)** constitutes about 80% of the total RNA content of a cell. It is the most stable type of RNA. It occurs as a component of ribosomes forming nearly half their volume, the other half being protein. The r-RNA serves to join the ribosomes with m-RNA. It does not play direct role in protein synthesis. Like the m-RNA:1 it is also synthesized on the DNA as template.
- iii) **Transfer RNA (t-RNA):** It constitutes 10-15% of the total RNA content of a cell. It is a smaller molecule of about 80 ribonucleotides and folded back upon itself to form a double helix. The t-RNA molecules serve to select and transport the amino acids from the various parts of the cytoplasm to the ribosomes. There are specific t-RNA molecules for specific amino acids. Like m-RNA it is also synthesized by DNA.

13.6 GENETIC CODE

We know that DNA is the primary genetic material which carries information from generation to generation. If so, in what manner does the genetic information exist in the DNA molecule? Is it in the language of codes what is the nature of the genetic code? The basic problem of such a genetic code is to indicate how information in a four letter language (4 bases of DNA) can be translated into twenty two letter language (amino acids of proteins). The group of nucleotides that specifies one amino acid is a code word or code. The simplest possible code is a single code in which the nucleotide codes for one amino acid. A doublet code is also inadequate as it could specify, only sixteen (4×4) amino acids, whereas triplet code could specify sixty four amino acids. Therefore, it is likely that there may be 64 triplet codes for 22 amino acids.

The sequence in which the four bases of DNA and therefore of mRNA are arranged determine the type of protein to be synthesized. Thus, the sequence of the bases function like a genetic code, carrying genetic information which determines the specific traits. In recent years, several attacks were made on genetic code with a view to decipher it, i.e., to find out which sequence of bases synthesizes which protein. By 1961, Crick and others had discovered that the code for one amino acid. According to this triplet system, the four bases can (mathematically coded) have 64 codes (Table 13.1).

Table 13.1 Possible singlet, doublet and triplet codes of mRNA

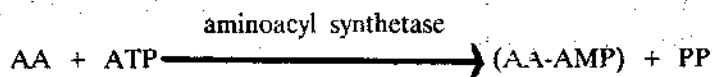
| Single code (4 words) | Doublet code (16 words) | Triplet Code (64 words) | |
|--------------------------|----------------------------|----------------------------|--------------------|
| A | AA, AG, AC, AU | 1. | AAA, AAG, AAC, AAU |
| G | GA, GG, GC, GU | 2. | AGA, AGG, AGC, AGU |
| C | CA, CG, CC, CU | 3. | ACA, ACG, ACC, ACU |
| U | UA, UG, UC, UU | 4. | AUA, AUG, AUC, GAU |
| | | 5. | GAA, GAG, GAC, GAU |
| | | 6. | GGA, GGG, GGC, GGU |
| | | 7. | GCA, GCG, GCC, GCU |
| | | 8. | GUA, HUG, GUC, GUU |
| | | 9. | GAA, CAG, CAC, CAU |
| | | 10. | CGA, CGG, CGG, CGU |
| | | 11. | CCA, CCG, CCC, CCU |
| | | 12. | CUA, CUG, CUG, CUU |
| | | 13. | UAA, UAG, UAC, UAU |
| | | 14. | UGA, UGG, UGC, UGU |
| | | 15. | UCA, UCG, UCC, UCU |
| | | 16. | UUA, UUG, UUC, UUU |

Nirenberg, and Ochoa made valuable contributions to decipher the genetic code for a specific amino acid. But it was Har Gobind Khorana who finally accomplished this feat. Khorana manufactured short DNA molecules having a known sequence of bases. These DNA molecules then synthesized m-RNA which then directed protein synthesis. From the sequence of proteins the codes were directly established. This is a milestone in the history of genetics. From the complete codon dictionary as established by Khorana, specific amino acid codes by a specific base sequence can be directly determined. Nirenberg, Ochoa and Khorana using different methods were ultimately able to assign codons for all the amino acids. The work of Khorana was very significant, and all the three got Nobel prizes for their work.

The work of Khorana and others has established the following important facts about the genetic code:

1. The code is degenerate i.e., more than one codon may code for a particular amino acid. Either the first two or the last two bases of all the codons coding for the same amino acid are usually the same.
1. Sometimes amino acids that are structurally and metabolically similar have similar codons.
3. **Nonsense codons:** Some codons such as UAA, UAG, UGA do not code for any amino acid. Such 'nonsense codons' fall at the end of a gene coding for a protein. They play a role in terminating a genetic message and are called terminator codons.
4. **Starting codons:** In bacteria the first codon in all cistrons is AUG. Such a codon is called a starting codon.
5. **Commaless:** The genetic code has been found to be universal because codon is reserved for punctuations.

- a) **Activation of amino acid** Each of 20-22 amino acids occur in the cytoplasm in active state. Each amino acid before its attachment with its specific tRNA is activated by a specific enzyme known as aminoacyl synthetase and ATP. This results in the formation of amino acid adenylic acid compound (AA-AMP) and release to pyrophosphate (PP) as shown below:



- b) **Attachment of activated amino acid to tRNA:** the AA-AMP compound react with tRNA to pass on the amino acid to the letter as shown below:



The tRNA then transports the amino acid to a ribosome. It is important to note that a specific amino acid is activated by a specific activating enzyme and can be transported by a specific type of tRNA.

4. Formation of Polypeptide

As the tRNA molecule carrying a specific amino acid approach a ribosome, the mRNA molecule arranges them in a specific sequence. This sequence is determined by the code on the mRNA. This code is of triplet nature and each triplet codon on mRNA attracts its complementary triplet code (or anticodon) on tRNA. For example the codon UUC will attract anticodon AAG, the codon GGU will attract anti codon CCA, and so on. This results in the arrangement of different tRNA, and hence amino acids in a specific sequence, the amino acids then link up by peptide bonds to form a polypeptide.

5. Elongation of Polypeptide

The elongation process of polypeptide involves the synthesis of a peptide bond by a reaction of an enzyme peptidyl transferase between the free amino group of the incoming amino acid and carboxyl group of first amino acid, which is esterified by tRNA.

Linkage between the codon and anticodon is a temporary nature. After tRNA has added its amino acid to the growing polypeptide chain, this linking is lost and the tRNA molecule leaves the ribosomes. It gets recharged with a new amino acid molecule for further reaction.

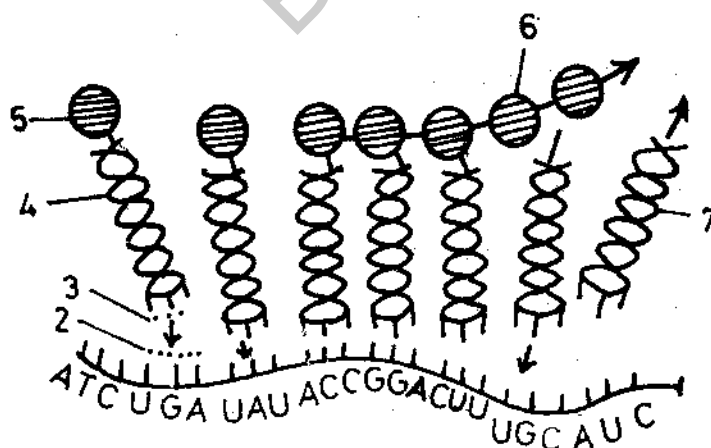


Fig 13.5 Diagrammatic representation of different stages in protein synthesis. 1.mRNA 2. Codon 3. anticodon 4. tRNA approaching mRNA 5. amino acid 6. Polypeptide chain under construction 7. tRNA leaving mRNA.

6. Release of Polypeptide chain

The terminator codons present in the mRNA interact with one of two specific protein factors called releasing factors, which effectively block further chain elongation. As the linkage is broken by hydrolysis the tRNA is left free, and thus releasing polypeptides from the ribosomes. The released polypeptides transform into specific proteins.

Thus the type of polypeptide chain (and hence protein), formed is determined by the number, type and sequence of amino acids incorporated into it, which in turn are determined by the DNA molecule.

Check Your Progress

1. The nitrogen base Thymine of DNA is replaced by _____ in RNA
2. The first and second steps of Central dogma as follows. _____ Duplication of DNA
_____ RNA _____ Proteins

13.8 SUMMARY

1. Chromosomes are composed of two types of nucleic acids-DNA and RNA.
2. DNA is the hereditary material exercising the main genetic control.
3. RNA plays a complementary role in this process leading to protein synthesis.
4. The genetic information flows from nucleic acids to proteins through genetic code which determines the kind of protein synthesized.

13.9 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Uracil
2. Transcription Translation

13.10 MODEL EXAMINATION QUESTIONS

- I. Answer the following in about 30 lines:
 1. Give a detailed account of the structure of DNA.
 2. Distinguish between aDNA and RNA.
 3. Explain the mechanism of protein synthesis.
- II. Answer the following in about 10 lines:
 1. "DNA is the active genetic material responsible for heredity". Discuss.
 2. Give an account of different types of RNA in a cell.
 3. Explain Watson and Crick model of DNA.
 4. Describe the mechanism of DNA replication and mention its significance.
 5. What is genetic Code? Mention the work of Har Gobind Khorana on genetic code.

UNIT - 14 FINE STRUCTURE OF GENE; GENE ACTION AND OPERON CONCEPT

Contents

- 14.1 Objectives
- 14.2 Introduction
- 14.3 Nature of Genes
- 14.4 Classical Concept of Gene
- 14.5 Classical definition of Gene
- 14.6 Modern definition of Gene
- 14.7 Fine Structure of the Gene
- 14.8 Gene Action
- 14.9 Operon Hypothesis
- 14.10 Summary
- 14.11 Check Your Progress - Model Answers
- 14.12 Model Examination Questions

14.1 OBJECTIVES

In this unit, we deal with the fine structure of Gene, classical and modern definition of gene. By the end of this unit you will be able to:

- define Cistron, Muton and Recon.
- describe one gene one enzyme, one gene one polypeptide-chain, one gene one trait hypotheses
- Explain the concept of Operon Hypothesis

14.2 INTRODUCTION

During the second decade of the present century, many fundamental concepts of genetics were established by Morgan and his students, especially **Structurevant. Bridges and Muller**. Their finding agreed with the gene hypothesis of Sutton stating that chromosomes are composed of unit of genes which are carriers of hereditary characters. The term gene was coined by **W.Johannesen** in 1909 to replace Mendel's factor or determiner.

A gene is the fundamental biological unit of inheritance. the hereditary units which are transmitted from one generation to the next generation are called genes.

A gene is the fundamental biological unit of inheritance. the hereditary units which are transmitted from one generation to the next generation are called genes.

14.3 NATURE OF GENES

Earlier cyto-geneticists proposed various hypothesis to explain the nature of genes. For instance **Hugo De Vries** postulated "One gene-one character: hypotehsis, according to which particular trait of an individuals is controlled by a specific gene. **Bateson and Punnet** advocate presence or absence theory. According to them, in a cross the character which dominates the other has a determiner while the recessive character has no such determiner. Morgan later proposed

the particulate theory, according to which genes were corpuscles arranged in a linear fashion in the chromosome. Each gene was considered to be different from all others.

At present this theory is widely accepted and supported by cytological observations.

14.4 CLASSICAL CONCEPT OF GENE

A lot of information about the nature of gene was established during 1930s and a classic concept was developed which can be summed up as follows: Inheritance involves the transmission of genes from parents to offspring. There are about 40,000 genes in a human cell which contains 23 pairs of chromosomes. A single gene may occur in several different forms dominant and recessive. Some genes have more than two alleles known as multiple alleles. Frequently a gene may show sudden change from one form to another through mutations. Therefore before, defining a gene, it is better to consider both the classical and modern definitions of a gene.

14.5 CLASSICAL DEFINITION OF GENE

Based on classic concept, the definition of gene as an operational one has different view points.

- (i) A gene is a unit of physiological function that occupies a definite locus in the chromosome and is responsible for a specific phenotypic character. Eg., Vestigial or long wings, white or yellow eyes in *Drosophila* etc.
- (ii) A gene is a unit of transmission or segregation because it can be segregated and exchanged during meiosis, through crossing-over.
- (iii) A gene is a unit of mutation because by spontaneous or induced changes it can give rise to a different phenotypic expression.

Due to recent discoveries in the field of molecular genetics these classical definitions of genes have been revised thoroughly.

14.6 MODERN DEFINITION OF GENE

After the discovery of DNA as a major component of a gene, and proper understanding of most of the molecular phenomena in the expression of a phenotypic trait, the gene has been defined as follows:

1. Cistron

The portion of DNA specifying a single polypeptide chain is termed a Cistron which is a synonym for the term, the gene of physiological function. The term cistron has been coined by Seymour Benzer, Haemoglobin for example, would require two cistrons for its globin protein fraction; one each for the alpha and beta chains. A cistron for alpha-chain has atleast $141 \times 3 = 423$ nucleotides and the cistron for the beta chain $146 \times 3 = 438$ nucleotides.

2. Muton

There are many sites within a cistron where mutations can occur due to several factors. Therefore, the gene as a unit of mutation is smaller i.e., it consists of fewer nucleotides than a cistron. Benzer coined the term muton to that smallest length of DNA capable of mutational

change. Thus, a muton can be defined as the smallest unit of genetic material which when charged or mutated produces a phenotypic effect". A muton may thus be delimited to a single nucleotide or some part of a nucleotide. Different forms of a mutationally defined gene are called homoalleles. For example, in bacteria muton may be a nucleotide pair and in cistron for haemoglobin, the muton may be a single nucleotide.

3. Recon

Crossing over or recombination occurs in a cistron frequently, which provides still other subdivisional concept of the cistron, known as recon. A recon therefore is the smallest unit of DNA capable of recombination. The separable forms of a cistron through recombination are called hetero alleles.

Some geneticists are not in agreement with these definitions of gene; and hence the following definition of gene may serve our purpose in general.

"The gene of function is that sequence of nucleotides with numerous sites for mutation and recombination which specifies the amino acid sequence of a specific polypeptide chain."

Fine structure of the Gene

Fennlgen, Oswald, Hershey and others have established beyond doubt that DNA is the Primary genetic material responsible for heredity. This fact is further confirmed by the structure of DNA which is in tune with the genes that are arranged in a linear fashion in a chromosome. DNA is capable of self-duplication with utmost accuracy, and regulates protein synthesis essential for expression of traits; preservation and transmission of genetic information from generation to generation. Therefore, the molecular structure of a gene is studied in terms of DNA.

The DNA (gene) has purine bases, the adenine and guanine and the pyrimidine bases, the cytosine and thymine joined end to end to form a long polynucleotide strand. The strand has a chain of alternately attached sugar (S) and phosphate (P) molecules.

In 1953, Watson and Crick proposed a model of the structure of DNA molecule in the form of a double helix resembling a spiral staircase. Very recently the double helical structure of DNA molecule has also been confirmed by actual X-Ray diffraction photographs with the help of electron microscope. The duplication or replication of the genetic material (DNA) is an essential feature of cell division. During replication each DNA molecule gives rise to two DNA molecules identical to each other as well as to the parent molecule.

Gene in terms of DNA

At this stage it is desirable to interpret the gene in terms of DNA structure. Broadly 'a gene' is that portion of a DNA molecule that produces a trait. It is thus a functional unit of DNA.

Gene Action

The understanding of co-relationship between genes and phenotype of an organism requires considerable information gained on normal gene action. Several hypotheses were advocated to explain the gene action.

1. One gene one enzyme hypothesis

Beadle, Tatum and other geneticists had got modern understanding of gene action by performing experiments on *Neurospora* and *Drosophila*. They found that mutational changes of genes can be related to loss of specific enzymes. This concept was widely known as "one gene one enzyme hypothesis".

A biosynthetic pathway often requires more than two enzymes and each enzyme is specified by a single gene. If there occurs any mutation in any gene, then either the production of normal enzyme will cease or a defective enzyme will be produced. This results in 'metabolic block'.

2. One gene-one polypeptide-Chain hypothesis

The hypothesis of one gene-one enzyme relationship has not been found correct by later findings of physiological genetics. There are various evidences in man and other organisms that the synthesis and structure of a single protein molecule can be controlled by two or more genes. Recent works have confirmed that a single gene controls the production of a single polypeptide chain of protein molecules. Therefore, the concept of one gene- one enzyme, now is termed as the concept of **one gene-one polypeptide** and it is proved by the following example:

The respiratory pigment, haemoglobin (Hb) of human red blood cells is conjugated protein containing four separate polypeptide chains viz., Alpha, Beta, Gamma and Tehta and four iron containing haem groups. In 1949, **Pauling** reported the formation of abnormal haemoglobin (Hb 'S') which differed from normal haemoglobin (Hb'A') by causing hereditary disease called the **Sickel-cell anaemia** in man. The RBC of such individuals undergo a reversible alteration in shape when oxygen tension of the plasma falls slightly and they assume elongate filamentous and sickle-like forms. The Hb'S' traits later on found to be controlled by two alleles of a single gene. Therefore, it indicates that in the case of haemoglobin atleast two genes are concerned with the formation of single protein.

3. One gene-one trait hypothesis

Hugo De Vries was of the opinion that a single gene is responsible for the expression of a single trait. This he stated as **one gene-one trait hypothesis** which however does not explain all kinds of inheritance. **Beteson** later stated that a single gene may influence the expression of more than one visible trait. On the other hand, more than one gene, multiple genes, may interact to influence the expression of a single visible trait.

Regulation of Gene Activity

The studies in molecular genetics indicate that not all genes act by determining the structure of a given enzyme or protein or polypeptide chain. Some are able to 'regulate' the action of other genes and these are called **regulatory genes**. The concept of gene regulation has come from the studies on **lac-operon** of *E. Coli* by **Jacob and Monod** (1961).

Operon Hypothesis

To explain the regulating mechanism of action of regulated genes at transcription level, **Jacob and Monod**, the Noble prize winners of 1965, forwarded a hypothesis called **operon hypothesis**. According to a recent version of operon hypothesis the genetic regulation in bacteriophages is performed by the following five key elements:

1. Operon 2. Promoter gene 3. Operator gene 4. Regulator gene and 5. Effector or Inducer gene.

1. Operon

In bacteria and bacteriophages different genes concerned with the same trait are often found clustered together in a group known as an **operon**. For example, the genes in a bacterial operon determine structure of those enzymatic proteins which control sequential metabolic steps of a biochemical reaction. A bacterial operon always consists of two or more distinct

genes. The bacterial operons possess the following genetic features:

1. The operon genes are unlike ordinary genes. They are all transcribed into a single mRNA molecule, often called polycistronic messenger starting from a single promoter site.
2. The component of genes of an operon are clustered in the genetic map and specify different proteins concerned with the same trait.
3. The genes of an operon are independent of complementation tests but are transcribed into a single mRNA.

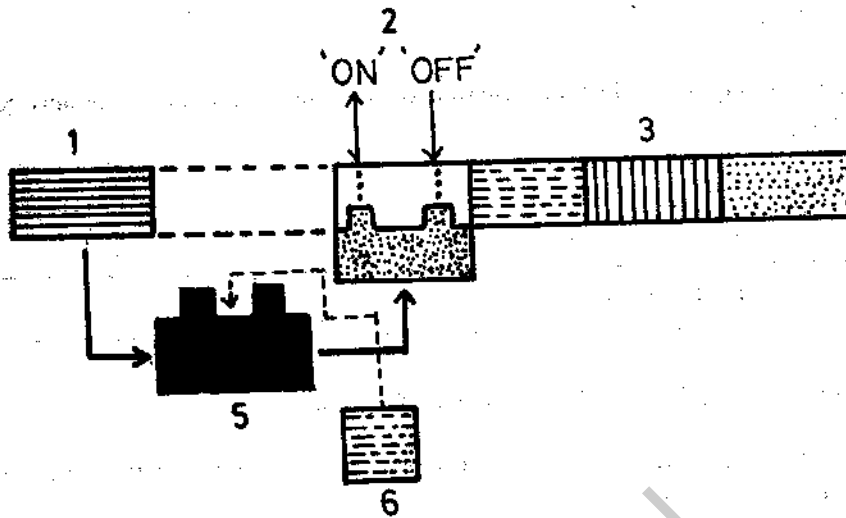


Fig. 14.1: Operon model showing regulation of gene action. 1. Regulator gene 2. Operator gene 3. Structural genes 4. Promoter 5. Repressor gene 6. Inducer (effector) gene.

4. The phenotypic expressions of component genes of an operon is regulated by promoter, operator and regulator genes.

2. Promoter-genes

The promoter gene represents a sequence of bases that are recognised by a DNA-dependent RNA polymerase enzyme. Promoter- polymerasae binding initiates transcription of neighbouring structural genes of an operon. Specifically certain promoters are regulated by certain specific proteins known as regulator proteins or repressors; which are specified by genes called regulator genes.

3. Operator gene

An operator gene also represents a sequence of bases that interacts with a protein. The protein is also called a regulator molecule, and operator-regulator interaction will either prevent or promote transcription of the regulated gene. It turns the structural genes "on" or "off". This type of regulator gene is called Operator gene. The major distinction between an operator and a promoter is that the operator is not normally the site of attachment of RNA polymerase.

4. Regulatory gene

The operator and promoter of an operon are under the control of yet another segment of DNA called a regulatory gene. It is situated apart from the perator, promoter and structural genes of an operon. The regulatory gene specifies a protein called a regulator protein which has the potential to bind specifically to an operator or a promoter region. This kind of binding is effected by an additional factor called effector gene.

5. Effector molecule

An inducer or effector molecule is a small molecule, a sugar, an amino acid or a nucleotide that can bind to a regulator protein, and thereby change its ability to interact with an operator or promoter. Jacob and Monod have suggested that regulator protein will bind to an operator and inhibit operon expression as long as the effector is not present. Thus, operon concept explains how genes influence the cytoplasm and cytoplasm exerts a feed back influence on genes for switching them "on" and "off".

Check Your Progress

1. The hereditary units which are transmitted from one generation to the next generation are called _____.
2. Define Cistron.

14.10 SUMMARY

1. A gene is the fundamental biological unit of heredity.
2. Classically, a gene was assumed to be a genetic unit of physiological function, segregation and mutation.
3. Based on the fine structure of a gene it has been defined as cistron, muton and recon.
4. One gene one enzyme and one gene-one polypeptide hypotheses are verified in terms of gene action.
5. In operon hypothesis the regulation of gene action is elucidated.

14.11 CHECK YOUR PROGRESS - MODEL ANSWERS.

1. Genes
2. The portion of DNA specifying a single polypeptide chain is termed as cistron.

14.12 MODEL EXAMINATION QUESTIONS

- i. Answer the following in about 30 lines:
 1. Discuss the classical concept of gene and give the classical definition of gene.
 2. Discuss the current concept of gene based on the modern definition of gene.
 3. Distinguish between Muton and Recon.

UNIT - 15 HUMAN GENETICS

Contents

- 15.1 Objectives
- 15.2 Introduction
- 15.3 Some Genetic Traits and their Inheritance
- 15.4 Some of the Common Human Syndromes
- 15.5 Inborn Errors of Metabolism
- 15.6 Summary
- 15.7 Check Your Progress – Model Answers
- 15.8 Model Examination Questions
- 15.9 Glossary

15.1 OBJECTIVES

This unit is to catalogue some of the interesting genetic traits of man and their mode of inheritance. By the end of this unit you will be able to

- describe sex chromosome abnormalities in human syndromes,
- common in born errors of metabolism

15.2 INTRODUCTION

Man is naturally more interested in his own inheritance than in that of *Drosophila*, *Neurospora* and other animals and plants. Genetic information about man, in earlier days, was obtained from the study of pedigree histories. The study of a particular character in family members given a clue to the nature of the inheritance of that gene responsible for the character. On thorough survey of human population, about 200 hereditary traits have been reported in man.

Different kinds of genetic traits in man are given below:

I. Physical Traits

1. Skin

- Piebald kin : Skin with white spots.
- Epidermolysis : Blistered skin.
- Albinism : Skin, hair and retina devoid of pigments.

2. Hair

- Colour of hair : Black, brown or red.
- Hypotrichosis : Hairlessness on the head and body.
- Hypertrichosis : Excessive growth of hair on the body.
- Baldness : Hairlessness on the head.
- Hair form : Straight or curly.

3. Eyes

| | | |
|---------------------|---|---|
| Eye colour | : | Black, brown or blue. |
| Hereditary cataract | : | Opacity of lens. |
| Glaucoma | : | Swelling of eye ball. |
| Night blindness | : | Inability to see in dim light. |
| Colour blindness | : | Inability to distinguish between red and green colours. |

4. Ears

| | | |
|----------|---|------------------------|
| Ear lobe | : | Free or attached. |
| Hearing | : | Normal or deaf mutism. |

5. Skeleton

| | | |
|---------------|---|------------------------------|
| Polydactyly | : | Extra digits. |
| Syndactyly | : | Fused digits. |
| Brachydactyly | : | Lack of one joint in digits. |

6. Muscles

| | | |
|-----------------|---|-------------------|
| Gower's disease | : | Muscular atrophy. |
|-----------------|---|-------------------|

7. Body stature

| | | |
|-----------|---|--------------------|
| Height | : | Tall or short. |
| Cretinism | : | Abnormal dwarfism. |

II. Physiological Traits

1. Blood

| | | |
|--------------|---|--------------------------|
| Blood groups | : | A, B, AB, O. |
| Rh factor | : | Rh positive or negative. |
| Haemophilia | : | Non-stop bleeding. |

2. Excretion

| | | |
|--------------------|---|-------------------------------------|
| Diabetes mellitus | : | Sugar in urine. |
| Diabetes insipidus | : | Excessive urination causing thirst. |

III. Mental Traits

| | | |
|----------------------|---|---------------------|
| Huntington corea | : | Mental retardation. |
| Friederick's disease | : | Mental instability. |
| Idiotism | : | With very low IQ |

15.3 SOME GENETIC TRAITS AND THEIR INHERITANCE

1. Hair colour and Texture

The great range of continuous variation in hair and arrangement of hair suggests, that this human character is influenced by multiple genes. Experiments indicate an overall dominance of the genes for dark hair over light hair. Red hair, however, often seems to result from a single pair of recessive genes. Albinos often have some colour in their hair as a result of other pigments. Negro albinos tend to have sandy red, hair and white persons often have golden yellow pigment, curly and kinky hair is dominant over straight hair.

2. Baldness

It is a characteristic genetic trait inherited as a result of sex-influenced gene which is dominant in man and recessive in women. The pattern of baldness which develops and the age at which it begins is also influenced by heredity. In some cases women also show baldness as a genetic trait.

3. Eye colour

Colour is imparted to the eyes as pigments on the iris. The human eye may be brown, black or blue. If this pigmentation is accompanied by pigmentation on the front side, the iris appears dark brown. The gene for brown eyes is dominant over its allele for blue eyes.

4. Night blindness

Another genetic trait which is very common, is the night blindness (Xerophthalmia). Persons with the congenital night blindness see very well in good light, but very poorly in dim light. Night blindness may also result from a deficiency of vitamin A in the diet, but feeding vitamin A in large amounts to a person who is congenitally night blind brings relief.

5. Colour blindness

Red-green colour blindness is inherited as a sex-linked recessive genetic trait. There appear to be three kinds of colour-sensitive cones which are sensitive to red, green and blue respectively. The most common type of colour blindness red-green blindness, causes confusion of these two colours. This colour blind test is very essential for the selection of drivers for motor vehicles, pilots and navigation, etc., where they have to discriminate between green and red colour light signals. The persons carrying one of the colour-blind genes at one of their two loci but a normal allele at the other locus, have poor colour aptitude. In 1911 Wilson assigned the specific gene for red-green colour blindness to the X-chromosome. This genetic trait is expressed in males 6% but in females it is only 0.5%. This is because males have only X-chromosome and therefore only one allele for this gene.

6. Polydactyly

Presence of extra fingers and toes called polydactyly was one of the first inherited trait to be traced in human pedigree. The extra digit may be appended to the little finger or toe or it may be attached to the thumb or the big toe. The condition is inherited as a dominant one with variable expressivity. Some persons have it in their hands, but not in their foot and vice versa.

7. Syndactyly

In some families there is a fusion of the skin, and sometimes of the bone also between some of the fingers or toes, usually the second and third. This condition is called as syndactyly. In some families this trait shows sex-linked inheritance.

8. Haemophilia

It is also known as **bleeder's disease**. The haemophilic patient lacks one of the ten known substances necessary for the clotting of blood. Thus bleeding once started does not stop and can cause the death of the person. Haemophilia is a sex linked recessive trait. The lines of ancestry (Pedigree) of several families are on record. The royal family of Europe is a well-known haemophilia family, where the disease has been traced out up to queen Victoria (Carrier) in whom it appeared as mutant.

Haemophilia is also inherited by an X-linked recessive gene. The disease is transmitted by females but is expressed in males. A few cases of haemophilia in females are due to homozygous condition. A haemophilic male, married to a normal female produces daughters who are apparently normal but are carriers of the recessive trait. These daughters transmit the disease to half of their sons, while their daughters are carriers.

9. Diabetes mellitus

It is one of the common diseases which result from an endocrine disturbance. Large numbers of pedigrees of families which show this disease have been collected and the influence of heredity upon it is not to be questioned. A predisposition to become diabetic seems to be inherited as a recessive, but the development of the disease may be avoided if the intake of carbohydrate foods is moderate.

10. Intelligence and Feeble-mindedness

The mental capacities of individuals like intelligence are now believed to be inheritable. The psychologists measure the mental capacity in terms of IQ. i.e., **Intelligence quotient** which can be calculated by a formula based on tests of memory, logic, recognition etc.,

$$I.Q. = \frac{\text{Mental age} \times 100}{\text{Chronological age}}$$

I.Q. of average persons is from 90 to 110. A person with I.Q. above 110 is **intelligent**, while one with I.Q. above 130 is a **genius**. Those with I.Q. below 90 are **dull or feeble minded**. He may be an idiot, an imbecile or a moron. An idiot has I.Q. below 20.

Studies on twins have revealed that intelligence and feeble mindedness are inheritable mental traits. Identical twins possess the same degree of intelligence or feeble mindedness, while fraternal twins differ considerably. **Harrison Hund (1968)** said that five pairs of genes determined intelligence.

15.4 SOME OF THE COMMON HUMAN SYNDROMES

There are some of the most common abnormalities found in sex chromosomes together with the clinical syndromes based on the sex chromatin. The most important aberrations of this type are noted below :

I Klinefelter's syndrome (xxy)

Since 1942, geneticists and physicians had been familiar with human abnormality of sex known as Klinefelter's syndrome. About one male child out of every 5000 who are born expresses the symptoms characterizing this syndrome. Such children are practically normal except for minor anomalies. They have proportionately small testes, frequent gynecomastia (enlarged breast), tendency to tallness, obesity, and under development of secondary sexual characteristics. Growth of face and hair are some what of feminine nature. Spermatogenesis does not occur, there by resulting in complete sterility. About 25% of them have some degree of mental retardation.

These individuals have a positive sex chromatin and 47 chromosomes (44 autosomes + xxy). Males with 48 chromosomes (44 autosomes + xxxy) and two Barr corpuscles have also been described. These individuals have features of klinefelter's syndrome and are mentally retarded. Persons with 49 chromosome (44 autosomes + xxxxy) have also been reported. They display extensive skeletal abnormalities, extreme hypogonadism and severe mental deficiency.

2. Turner's syndrome (xo)

Patients with Turner's syndrome usually have a female appearance with short stature, webbed neck (folds of skin extending from the mastoid to the shoulders) and generally infantile internal organs. The ovary does not develop and shows complete absence of germ cells. As a result of this ovarian dysgenesis, menstruation does not occur and secondary sexual characteristics do not develop. Persons afflicted with Turners syndrome are also dwarfed physically averaging only about 4 feet, 10 inches in stature. They often show mental retardation. About one out of every 3,000 female births results in a child with this abnormality.

The karyotype shows 45 chromosomes (44 autosomes + x) and there is no sex chromatin in persons with Turner's syndrome. There is only one x-chromosome and no y-chromosome. It is probable that the lack of one x-chromosome determines the progressive ovarian atresia by failure of primordial follicles. Females with triple x-constitution with 47 chromosomes (44 autosomes + xxx) was detected in phenotypically near normal females. A number of these females are mentally subnormal or psychotic and some of them menstruate. A few severely retarded patients with 48 chromosomes (44 autosomes + xxxx) have been found. These persons are called metafemales.

3. xyy syndrome.

Males having two y-chromosomes have been identified in the past in maximum security institutions. It was proposed that such individuals had a strong tendency towards anti-social behaviour and aggression. More recently, xyy individuals have been found in the normal population in a proportion of 1 to 650 male infants suggesting that the correlation with violence may not be as strong as was previously thought.

4. Down's syndrome (Mongolism)

It is the most important of autosomal aberrations characterized by multiple malformations. Persons affected with this syndrome have mental retardation and markedly defective development of the central nervous system. It was discovered that mongoloid has extra chromosome. Pair 21 is trisomic instead of normal. This aberration probably originates from nondisjunction of pair 21 during meiosis.

The phenotype of mongoloid is recognizable at birth. The face of such patient is round, with increased separation between the eyes, and a skin fold at the inner part of the eyes. The nose is flattened, the mouth is constantly open and the tongue protrudes. Mongolism is the most common congenital disorder present in more than 0.1% of births.

15.5 INBORN ERRORS OF METABOLISM

A fundamental step forward in our understanding of molecular genetics was the one gene-one enzyme hypothesis put forward by Beadle and Tatum in 1948. They studied metabolic pathways in *Neurospora* and found that any step of a metabolic chain could be blocked by mutation in a specific enzyme. We now know that one enzyme may be formed by several different polypeptides, so the modern version of Beadle and Tatum's hypothesis is one gene-one polypeptide chain.

In man the relationship between genes and specific proteins is clearly shown by the hereditary diseases known as inborn errors of metabolism. In 1939 an English physician A.E. Garrod published a book called 'Inborn errors of Metabolism'. In this he described various physiological abnormalities of man that appeared to be inherited. He proposed the hypothesis that some of these abnormalities developed because of the absence of specific enzymes which were present in normal persons. The following are some of the specific inborn errors of man reported so far:

1. Phenylketonuria

By 1930, it was discovered that certain patients who had a severe mental disorder, excreted an abnormal compound the phenylpyruvic acid in the urine. The disease was called phenylketonuria and was found to be associated with a recessive gene. In fact the disease manifests itself only in homozygous individuals, the probability of this condition appearing is increased by consanguineous unions Eg. cousin-cousin or uncle-niece.

In this disease phenylalanine a normal amino acid of the diet cannot be oxidised to tyrosine and is transformed into phenylpyruvic acid. The primary action of the mutation has been to produce an absence of the enzyme for normal metabolism.

Once it is in the cell, the phenylalanine may follow any of three paths, it may be:

1. Incorporated into cellular proteins
2. Converted to phenylpyruvic acid
3. Converted to tyrosine.

The conversion of phenylalanine into tyrosine takes place in the presence of phenylalanine hydroxylase enzyme, in the liver cells. Tyrosin is converted in turn to 3,4-dihydroxy phenylalanine (DOPA) by another enzyme. DOPA serves as a precursor for the hormones adrenaline and noradrenaline and for the black pigment melanin. Tyrosine itself serves as a precursor of the hormones thyroxine and triiodothyronine.

Persons with genotype 'pp' fail to produce enzyme phenylalanine hydroxylase with the result that phenylalanine fails to convert into tyrosine. This result in the accumulation of phenylalanine in the blood plasma, cerebrospinal fluid and urine. The urine of phenylketonuric (PKU) patient contains elevated amounts of phenylpyruvic acid, phenyl acetic acid and other derivatives of phenylalanine. PKU patients have light pigmentation and are physically and mentally retarded. The feeble-mindedness in PKU patients is thought to be due to an impairment of the brain by the concentrated phenylpyruvic acid in the cerebrospinal fluid. If the disorder is discovered early enough, the mental disorder can be prevented by a special diet that is low in phenylalanine.

2. Alkaptonuria

The persons with genotype 'hh' fail to produce the enzyme homogenetic acid oxidase which catalyses the oxidation of homogenetic acid. Therefore in those patients, normal oxidation

of homogentisic acid into water and carbon dioxide does not occur. This results in the accumulation of large amounts of homogentisic acid in the blood which is excreted in the urine, which turns black upon exposure to air. Persons with such phenotypic abnormalities are said to have alkaptonuria.

3. Tyrosinosis

The recessive gene 'tt' in its homozygous condition, blocks the conversion of p-hydroxy phenylpyruvate into 2, 5 - dihydroxy phenylpyruvate. This leads to the accumulation of tyrosine, excess of which is excreted. This condition is called tyrosinosis. It is reported in only few individuals and causes no harmful effect.

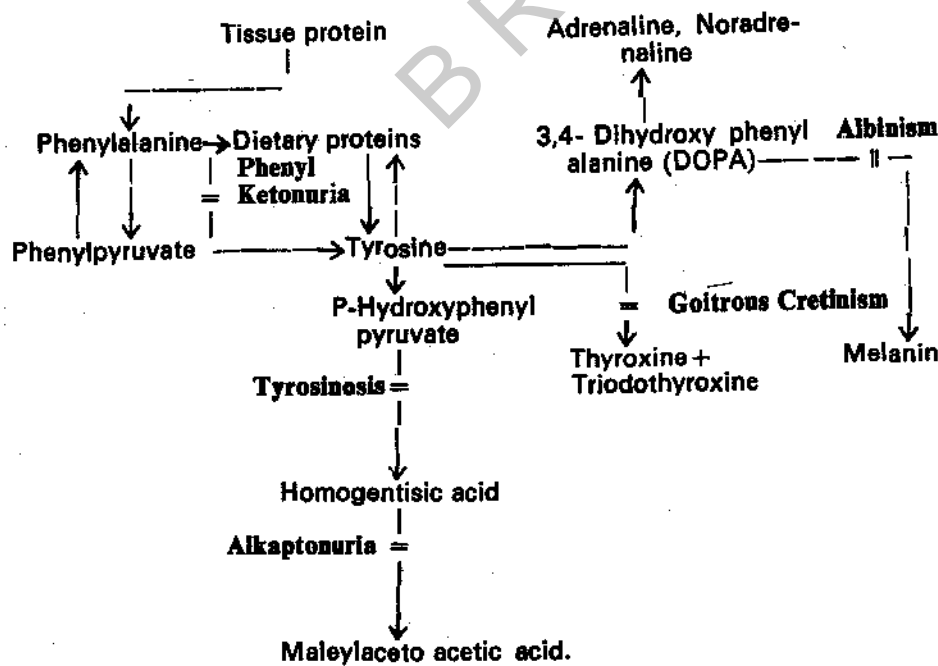
4. Goitrous cretinism

The person with 'cc' genotype fail to produce the enzyme which is required for the conversion of tyrosine into thyroxine and triiodothyronine hormones in their thyroid glands. This condition is called goitrous cretinism which is accompanied by a considerable degree of physical and mental retardation and hypertrophy of thyroid gland.

5. Albinism

The persons with recessive 'aa' genotype lack tyrosinase enzyme system which is required for the conversion of DOPA into melanin pigment inside the melanocytes. In an albino patient melanocytes are present in normal number but they lack melanin pigment. For this reason, the skin, hair and the whole body appear colourless. A person with this defect is referred to as albino. In albinos iris is devoid of pigment and hence appears pinkish. They can not stand bright light and usually resort to the use of sun- glasses.

To sum up the possible genetic blocks in the metabolism of phenylalanine and tyrosine in humans leading to the production of above mentioned genetic syndromes are represented as follows:



Check Your Progress

1. Patients having severe mental disorder, excreting an abnormal compound, the phenylpyric acids in the urine. The disease is called _____
2. In albino patient melanocytes are present in normal _____ but they lack _____
3. What is "Goitrous Cretinism"?

15.6 SUMMARY

1. There are various hereditary traits which are broadly categorised into three types: physical, physiological and mental traits.
2. The physical traits like skin colour, nature of hair, eye colour, night blindness, colour blindness, blood groups and physiological traits such as Haemophilia, Diabetes mellites etc., are inherited.
3. Abnormalities in the sex chromosomes may result in certain inheritable human disease syndrome like Mongolism, Klinefelter's and Turner's syndromes.
4. Genetic disorders in protein or enzyme synthesis may lead to inborn errors of metabolism like Alkaptonuria, Klinefelter's and Tyrosinosis.

15.7 CHECK YOUR PROGRESS- MODEL ANSWERS.

1. Phenylketonuria
2. Melanin Pigment
3. The person with 'cc' genotype fail to produce the enzyme which is required for the conversion of tyrosine into thyroxine and triiodothyronine hormones in their thyroid glands. This condition is called "Goitrous Cretinism".

15.8 MODEL EXAMINATION QUESTIONS.

- I. Answer the following in about 30 lines:
 1. Give an account of different genetic traits found in man.
 2. Describe the common human syndromes with reference to sex chromosomal aberrations.
 3. What are the inborn errors of metabolism? Explain with suitable examples.
- II. Answer the following in about 10 lines:
 1. Explain any two physiological inheritable traits of man
 2. Mention the karyotype and symptoms of klinefelter's syndrome.
 3. Explain how the metabolic block of phenylalanine results in several inborn errors.

15.9 GLOSSARY

| | |
|-------------------------|---|
| Acrocentric | A Chromosome with centromere at one end. |
| Adenine | A purine present in RNA and DNA which pairs normally with thymine. |
| Albino | An individual characterised by the absence of pigment. |
| Allele | One pair out of a pair of alternative genes situated at the same locus in homologous chromosomes. |
| Anticodon | A triplet of nucleotides specific to each t-RNA corresponding to the triplet codon of m-RNA. |
| Autosome | Any chromosome other than a sex chromosome. |
| Back cross | Any cross between a hybrid and a parent type. |
| Barr body | A mass of chromatin in the nucleus of resting cells resulting from inactivation of an X-chromosome. |
| Carrier | An individual carrying a recessive gene that is unexpressed due to heterozygous condition. |
| Chiasma | The cross over between two chromatids seen during prophase-1 of meiosis. |
| Chromatid | One of the two identical, longitudinal halves of a chromosome. |
| Chromatin | The readily stainable nuclear material composing the chromosome. |
| Chromosomal aberrations | Karyotypic alterations involving whole chromosome or portions of them. |
| Cistron | The genetic unit of biochemical functions. |
| Congenital defect | A defect present at birth. |
| Cytosine | A pyrimidine base present in DNA, pairs with guanine. |
| Dihybrid | An individual heterozygous for two pairs of alleles. |
| Diploid | An organism with two sets of chromosomes and hence two genomes. |
| Dominant | Ability of a gene to express itself in homozygous as well as heterozygous conditions. |
| Eugenics | Branch of genetics dealing with improvement of heredity traits of future generations of the human race. |
| Gene Pool | A total of all genes in a population. |
| Genetic code | The code which translates information from DNA in protein synthesis. |

| | |
|------------------------------------|---|
| Guanine | A purine base present in RNA and DNA pairs normally with cytosine. |
| Gynandromorph | A sex mosaic, an individual with one half of the body male and the other half female. |
| Haploid | A cell with only one complete set of chromosomes. |
| Hemizygous | A condition in which only one gene out of a pair of alleles is present. |
| Heterogametic | An individual of a sex producing unlike gametes. |
| Heterozygous | A condition in which only one gene out of a pair of alleles is present. |
| Homogametic | An individual of a sex producing like gametes. |
| Homozygous | A condition in which both the genes present for a trait represent the same alternative of the trait. |
| Hybrid | Heterozygous individual of homozygous parent. |
| Haemophilia | A sex-linked disorder characterised by free bleeding from even slight wounds. |
| Inborn errors of metabolism | Inherited diseases that can be explained as genetic blocks in specified metabolic pathways. |
| Inter sex | An individual showing secondary sexual characters intermediate between those shown by the two sexes. |
| Linkage | Tendency of genes to be inherited together |
| Locus | A fixed position of a gene in a chromosome. |
| Messenger RNA | A particular kind of RNA which provides a template for protein synthesis. |
| Mongolism | A old term used for Down's syndrome. |
| Monohybrid | An individual homozygous for one pair of alleles. |
| Monohybrid cross | A cross between two parents that differ in only one heritable character. |
| Multiple alleles | Three or more alternative conditions of a single gene producing different phenotypes. |
| Mutation | A sudden, stable, inheritable change in a gene having no relation to the individual's ancestry. |
| Muton | The smallest segment of DNA, sub-unit of cistron which brings about mutation. |
| Nucleotide | Portion of a DNA or RNA molecule composed of one deoxyribose phosphate unit (in DNA) or one ribose phosphate unit (in RNA) plus purine or a pyrimidine. |
| Operon | A system of cistrons, operator and promoter sites. |

| | |
|-----------------|--|
| Pedigree | The ancestral history of an individual. |
| Peptide bond | A chemical bond linking amino acid residues together in a protein. |
| Phenotype | Externally visible traits. |
| Purine | Nitrogenous base occurring in DNA and RNA-adenine and guanine. |
| Replication | To form replicates for the synthesis of new DNA from pre-existing DNA. |
| Recessive genes | The genes that are expressed only when homozygous. |
| Recon | A unit of DNA capable of recombination. |
| Segregation | Separation of parental and maternal chromosomes and hence, alleles during meiosis. |
| Sex-Chromosomes | Chromosomes (X,Y) concerned with the determination of sex. |
| Test cross | Back cross to a recessive parent. |
| Thymine | A pyrimidine base present in DNA, pairs with adenine. |
| Transcription | Formation of m-RNA strand complementary to one strand of DNA. |
| Transduction | The transfer of genetic information (DNA) from one bacterial strand to another, mediated by a phage. That kills the DNA donor and carries some of its DNA to a recipient cell, which is not killed by the phage. |
| Translation | The formation of polypeptide chain based on the information present in RNA. |
| Translocation | The shift of a portion of a chromosome to another part of the same chromosome or the different one. |
| Uracil | A pyrimidine base present in RNA. |

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BRAOU

BLOCK – III
EVOLUTION

BRAOU

UNIT - 16 ORIGIN OF LIFE " ORGANIC EVOLUTION" THEORIES AND EVIDENCES

Contents:

- 16.1 Objectives
- 16.2 Introduction
- 16.3 Organic Evolution
- 16.4 Theories of Evolution
 - 16.4.1. Lamarkism
 - 16.4.2. Darwinism
 - 16.4.3. Mutation Theory
- 16.5 Evidences of Evolution
 - 16.5.1. Embryological
 - 16.5.2. Palaeontological
 - 16.5.3. Physiological & Biochemical
- 16.6 Summary
- 16.7 Check your Progress – Model Answers
- 16.8 Model Examination Questions

16.1 OBJECTIVES

This unit deals with the beginning of life on earth. By the end of this unit you will be able to:

- Explain how variety of animals on the surface of earth show differences in form and structure through all have a common ancestry.
- describe how different groups of animals evolved from other groups of animals.

16.2 INTRODUCTION

We do not know exactly how the life began on the earth. Though life originated more than three billion years ago it did not leave a clear indication of the way of events in any fossil record. The best that the scientific world can do is to point out what might have happened, ever since the beginning of record history man has speculated on the origin of life. In ancient times, it was generally believed that animals were generated spontaneously from nonliving matter. Thus the ancient Indians believed that frogs came from the rocks or rain water, the ancient Egyptians believed that snakes arose from mud and the ancient Greeks believed that rats came from garbage. In 17th & 18th centuries it was widely Louis Pasteur disproved, once for all this theory. The main attraction of Pasteur's experiment on boiled nutrient broth in goose-neck flasks never yielded microorganisms. They were seen very quickly developed when the same were kept exposed. Pasteur reasoned that microorganisms had extended the flask from the atmosphere but they became trapped on the wall of curved tube and so failed to reach the broth. This has established the fact of biogenesis that living things come only

from other living things. From this grew the idea that all life comes from pre-existing life. But the question comes where did all life come from pre-existing life. But the question comes where did all the parents of animals and plants originally arise by spontaneous generation, though the process appears not to be repeated today. Even if it occur and today as Darwin pointed out multitudes of existing organisms would destroy the new protoplasm. 3 Million years ago there was not even a bacterium to harm the newly arising life substances and hence has had a chance of survival.

It is thought today that life began through a progressive series of synthesis of simple inorganic molecules that raised the organic elements to successively higher levels. The primitive life occurred about 3×10^9 years ago. The earth probably began about 5 billion years ago. The earth's atmosphere consisted of four simple gases: methane (CH_4), ammonia (NH_3) hydrogen (H_2) and water vapour. Oxygen gas could not have existed freely since the earth's atmosphere was too hot hence it would have combined with other materials like silicon, iron etc., as oxides of these are found in the crust of earth. The source for water vapour is believed to have been formed mainly from volcanic activity since erupted material contains 10% of water.

The stage was then set for synthetic reactions to give rise to organic molecules (the amino acids). Many suggestions have been put forward to explain how this might have happened. The most generally accepted theory is that the molecules were formed by ultraviolet or gamma radiation by Sun' by lightning or electrical discharges. Evidences for this is that scientists in 1950s have been able to perform such amino acid synthesis in laboratory successfully. These do show the way that such events could have taken place. Mixtures containing water, methane and ammonia were put into a flask and electricity was discharged through these for several days to simulate the lightning discharges of the early earth. When the contents of flask were examined many amino acids, fatty acids, sugars and other simple organic compounds were found to be present. Thus there is a reason to believe that out of these, more complex organic materials could be synthesised later. Thus all chemical reactions resulted in giving rise to a variety of organic compounds that accumulated in ancient seas.

16.3 ORGANIC EVOLUTION

The next crucial step is the development of cells, the first actual living units. The plausible assumption is that somehow or other, certain of the organic compounds came together to form the first living organisms. They must have combine in a manner that the chemical system thus formed is stable and is capable to release energy and replicate itself. Dismissing various unanswerable questions involved in this, we can safely assume that this system must have developed along the shores in microscopic sand pockets. It was possible to develop a surface film resembling the cell membrane. Since there was no oxygen gas, the respiration of this simple first organism must have been anaerobic to obtain energy on the available organic matters in water by some simple mechanism of diffusion. At this early stage of evolution reproduction must have been a simple asexual process involving the replication of proteins (macromolecules). Thus once when a system can reproduce itself from the raw materials of the environment, we can say that the first living organism originated on the earth. From such reproducing organisms rapid evolution would be expected to have produced more complex and better adapted forms. It is reasonable to suppose that natural selection (See Darwinism) began to operate. The systems that were best organised and most stable in primitive organisms according to Darwin, would show transmissible variations. In other words replication of its macromolecules would show deviation. This must have lead to the formation of various microorganisms. All though the evidence for this is still inconclusive, it suggests

that more than a billion years the dominance and perhaps the only forms of life on earth were microscopic organisms such as algae, bacteria and moulds. Our knowledge of gene mutations helps us to understand how present variations may have come. It is believed that sexual reproduction which arise at a very early stage would result in further possible variation as observed in bacteria.

16.4 THEORIES OF EVOLUTION

16.4.1. Lamarckism:

Jean Baptiste Lamarck (1744 - 1829), a French biologist formulated a theory of evolution for the first time known as Lamarckism which he explained in his publication, the "Philosophie Zoologique". Lamarck's theory as told by him briefly, is as follows: "The environment affects the shape and organisation of animals; frequent continuous use develops and enlarges any organ. While by permanent disuse it weakens until it finally disappears; all acquisitions and losses brought through influence of environment and hence through use and disuse are preserved by reproduction. Thus Lamarck's theory is based on four parts: (1) The environment influences an organism whereby an organ or structure involved is either developed to eminence if put to use or gradually degenerated if not used. (2) Better developed organs and degenerated organs are preserved in a generation. (3) Such preserved characters, otherwise known as **acquired characters**, are transmitted to the offspring. An existing individual is the sum total of characters, are transmitted to the offspring. An existing individual is the sum total of characters acquired by its forefathers in the preceding many generations, therefore, the present generation looks strikingly different from its ancestors. And so this generation has become a new species.

Lamarck supported his views by citing the following examples:

- (1) The shortnecked ancestors of modern giraffe came to live in dry African deserts where there was little vegetation available on ground (environment). The animal therefore, made continuous effort to browse on the leaves stretching up its neck and forelimbs (use of organs due to environmental effect). Consequently this led to slight elongation of neck and forelimbs (acquired characters). This increase in length was passed on to its offspring which became naturally better suited (transmission). This better character was further advanced through many generations for over a very long period until the present form was achieved. Thus the modern giraffe forms a new species when compared with its very old ancestors having a short neck and forelegs.
- (2) The lizard-like ancestors of modern snakes were with well developed paired limbs. To protect themselves from the attack of mammals they started crawling through narrow crevices in the thick jungle environment, stretching their bodies all along. In this process the body was elongated but the disuse of limbs in crawling movements caused their gradual degeneration and ultimately the legs were lost. Thus the present snakes without limbs have become new species.

As for the first part of the lamarckian theory concerning to the effect of environment on the animal and use and disuse of organs, there is no dispute but his conclusion that the acquired characters were heritable was challenged by a German biologist, **Augustein Weismann**. He practically demonstrated that cutting off the tails of newly born rats for over 80 generations did not lead to any degeneration of tails in succeeding offsprings. He quoted the observed facts that powerful muscles developed by blacksmith or a well built body of wrestler are not transmissible to the offspring.

16.4.2 Darwinism

Charles Darwin, (1809-1882), a British biologist propounded the theory of Natural Selection for the organic evolution. He published his work in an epoch making book entitled "The origin of species by Natural Selection". In 1859, Darwin's theory can be very briefly summarised as following:

First in every living species there are many differences among the individuals. Breeding experiments show that these individual differences are inherited. Second, it is evident that each generation produces larger number of individuals than the one before. One *Amoeba* asexually divides to produce two and these two divide, the next generation being four. Then there will be 8, 16, 32 and so on. Sexually reproducing organisms can multiply even more per generation. A doubling per generation is known as geometric progression. Third, if this increase were to go unchecked the number of individuals of any species would soon be greater than the available food and space on the earth, Fourth it is clear in nature that this increase is checked. The sizes of most populations seem to remain nearly the same. In other words many other members do die young. For this reason Darwin thought that there must be struggle for survival, a competition among members of a species for food and space. In this competition individuals with certain valuable characteristics more often survive than those which do not have these. Hence in each generation we should expect a slight increase in the number of individuals that do possess valuable characteristics and decrease in those which do not possess such qualities. The whole process involving all the four factors started above between "winners" and "losers" of the struggle, Darwin called Natural selection. By natural selection the species of organism becomes fully adjusted (adapted) to its natural environment. It acquires through the process of natural selection characteristics that improve its chance of survival and reproduction.

16.4.3 Mutation theory

Hugo de Vries (1848-1935), a Dutch Botanist, performed experiments on the evening primrose (*Oenothera lamarckiana*), observed that a few individuals in a species differed markedly from others in several characters and that they bred true. On the basis of these and other experiments he formulated his mutation theory. According to this theory new species arise not by small variations but by sudden changes called mutations. These changes may affect a number of characters which are inherited. Thus a new species may arise in a single generation not gradually as a result of selection operating for a long period.

16.5 EVIDENCES OF EVOLUTION

Embryological

The main evidence in support of the doctrine of organic evolution is embryological. The similarity in the early development of animals is so close that it would be logical to conclude that various animals are related to one another. It is remarkable to note that all metazoa start life from a single cell which undergoes development and passes through blastula, gastrula (diploblastic), and triploblastic stages. In many, formation of coelom and derivatives of germinal layers are similar. Due to common chordate ancestry divergent forms like fish, salamander, Lizard, chick, rabbit and man so closely resemble one another in their early embryonic stages that it is difficult to distinguish between them.

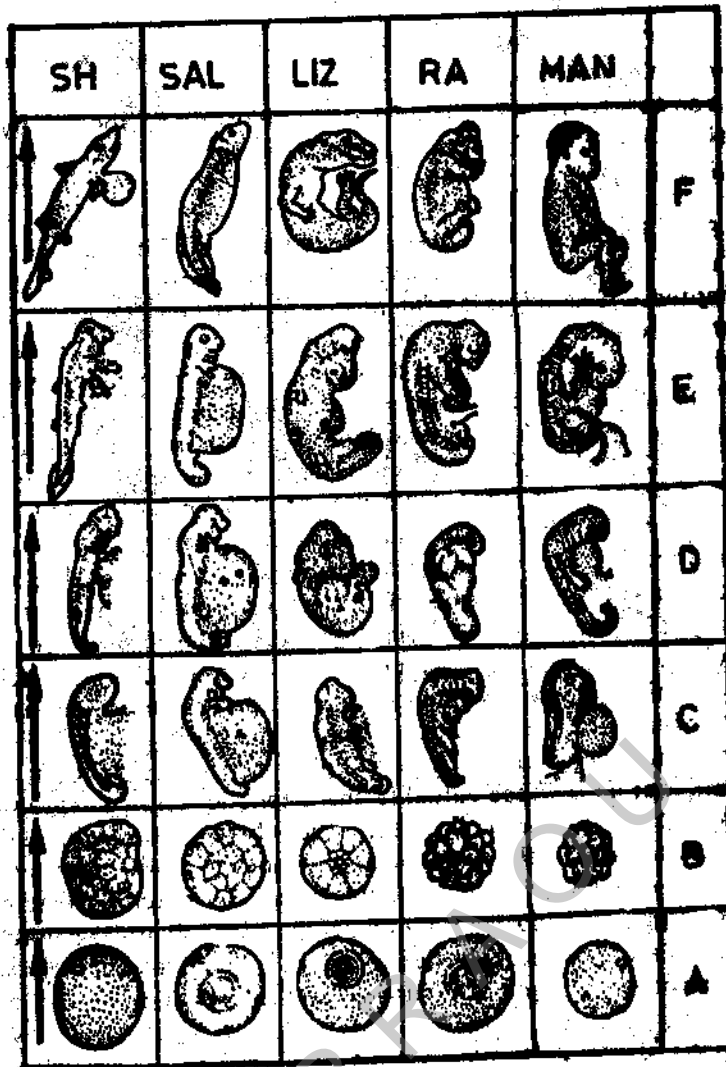


Fig 16.1 Comparative embryology from fish to man. SH : Shark; SAL: Salamander; LIZ : lizard; RA : Rabbit; A. Fertilized eggs B. Late cleavages C. Beginning of somites (body segments) D. Gills/lits and fore limbs formed E. Embryo with fore and hind limbs F. Late foetal newly hatched or New born.

Palaeontological

Fossils, the preserved remains of the past animals, dramatically give palaeontological evidence that life has been gradually changing over millions of years from one form to another. As this is a direct evidence hence is more reliable. A few complete series of fossils like horse and elephant representing their ancestry have been unearthed at various places of world. The study of these fossils furnishes a convincing evidence of evolution. These series of fossils not only speak of evolutionary history of horse and elephant, but also lead us to conclude that the present forms of animals are descended from preexisting other forms.

Physiological & Biochemical

The physiology and biochemistry have also contributed to support the idea of evolution. Different serological enzymatic and hormonal tests have shown that there are certain basic similarities in physiological and chemical properties that establish a physiological relationship among different groups of animals. Serological tests, otherwise known as precipitin tests on

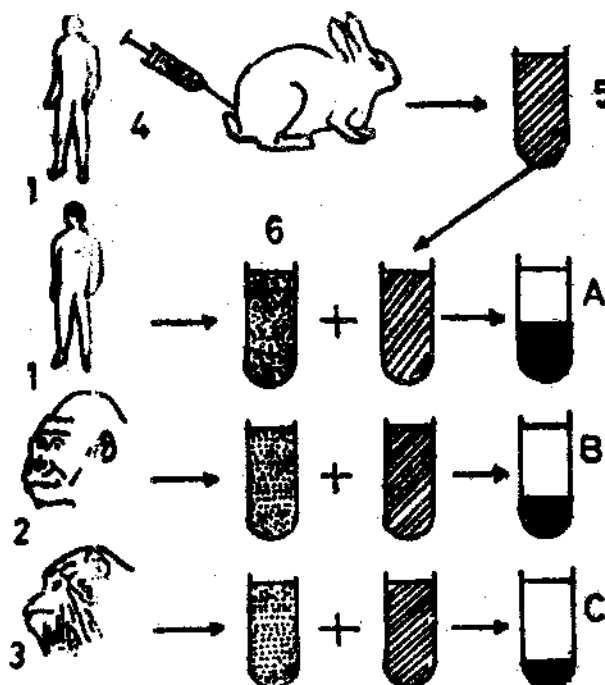


Fig 16.2. Immunology method of establishing evolutionary relationships. A blood-protein from a human is injected into a rabbit. This rabbit's serum mixed with more human blood-protein produces a precipitate, (A) Serum from the same rabbit mixed with blood protein from an ape produces more precipitate, (B) than when mixed with monkey blood protein. (C) This demonstrates a closer relationship between men and apes than between men and monkeys. 1 Man 2. Ape 3. Monkey 4. Blood protein 5. Rabbit serum 6. Blood protein A. Large precipitate B. Intermediate precipitate C. Small precipitate.

mammals like rabbit, chimpanzee, baboon, monkey, dog, pig and man indicate a much greater kinship between the blood proteins of man and chimpanzee than between man and monkey. Hormone reactions also reveal the relationship of diverse vertebrate members, as belonging to a common fraternity. The action of thyroid gland secretions is similar in all groups of vertebrates. The thyroxine deficiency in man can be compensated by the thyroid extract of cattle. The digestive enzymes also are similar in all animals. Proteolytic enzyme, like trypsin, is found from protozoa to Mammalia. These similarities can be explained on the basis that all animals have been gradually evolved from similar substances.

Check your Progress

- _____ theory states that, the environment influences an organism whereby an organ or structure involved is either developed to eminence if put to use or gradually degenerate if not used.
- Charles Darwin a British Biologist, propounded the theory of _____ for the organic evolution.

16.6 SUMMARY

- It is very difficult and impossible to understand how living substance has come into existence first. Therefore our knowledge is based mostly on indirect assumptions.
- According to the rate of cooling of earth several elements, gases, minerals etc., have evolved as inorganic molecules.

3. These molecules gradually synthesised into simple organic molecules leading into more complex amino acids which must have produced organic macromolecules. They form the basis of the life.
4. After the life took some form it gradually evolved from a simple form into existing complex forms which is described as evolution.
5. Many scientists attempted to explain how organisms evolved in their own way.
6. Lamarck's theory of evolution is based on the inheritance of the characters acquired by an animal during its life time under the influence of environment.
7. Darwin's theory explains that natural selection processes the animals and selects suitable species which is capable to survive and reproduce withstanding all competitive factors.
8. Contrary to Darwin, de Vries mutation theory propounds that changes in characters of a species are brought about all of a sudden. Therefore new forms arise by mutation.
9. The scientific evidences in support of evolution are seen in comparative embryology, palaeontology, physiology and biochemistry.

16.7 CHECK YOUR PROGRESS - MODEL ANSWERS.

1. Lamark's
2. Natural Selection

16.8 MODEL EXAMINATION QUESTIONS

I. Answers the following in about 30 lines each:

1. Describe the origin of life.
2. Discuss how chemical evolution has lead to biological evolution.
3. What experiments have lead to conclude that life has originated out of inorganic elements?
4. Discuss the merits and demerits of Lamarck's theory.
5. Describe in detail Natural Selection.
6. In what respects Darwinism and Lamarckism agree or differ?

II. Answer the following in about 10 lines each:

1. Biogenesis
2. Louis Pasteur's experiment
3. Inheritance of Acquired characters
4. Survival of the fittest
5. Describe in detail Natural Selection
6. Palaeontological evidences:

UNIT - 17 SYNTHETIC THEORY OF EVOLUTION

- MUTATIONS, GENETIC DRIFT, NATURAL SELECTION AND ISOLATION

Contents

- 17.1 Objectives
- 17.2 Introduction
- 17.3 Mutations
- 17.4 Genetic Recombinations
- 17.5 Genetic Drift
- 17.6 Natural Selection
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- 17.8 Summary
- 17.9 Check Your Progress - Model Answers
- 17.10 Model Examination Questions

17.1 OBJECTIVES

Evolution is the gradual change of organisms through time. Various existing organisms are derived from those that had lived in the past. By the end of this unit you will be able to explain:

- the diversity of animal world by combining various evolutionary processes, moulded into synthetic theory.

17.2 INTRODUCTION

The way in which evolution takes place, the factors which are involved to determine the rate of evolution and how these factors direct the evolution are the complex multifaced problems. To these evolutionary biologists of recent times have taken into account all relevant factors concerning to Palaeontology, Biochemistry, Genetics, Ecology and systematics. They have picked up all correlative facts from almost every sector of biology. Since the present evolutionary theory represents a sector of biology. Since the present evolutionary theory represents a synthesis of basic facts and ideas from above said many different fields of science, it is referred to as the Synthetic Theory of Evolution. Particular credit goes to eminent scientists who developed this theory namely J.B.S. Haldane, Stebbins, Wright and Mayr.

17.3 MUTATIONS

A change in the gene which is heritable is called a mutation and the possessing animal as mutant. It is observed in nature that mutations are rare and their expression in successive generations is random. At best only minor deviations are caused by them from a normal state.

But they definitely supply raw materials for evolutionary change. They cannot be accounted themselves singly for evolutionary trends in sexually reproducing organisms.

17.4 GENETIC RECOMBINATIONS

According to Mendel's second law, the Law of Independent Assortment, the alleles of different genes are assorted independently of each other during gamete formation. Gametes are haploid. During their formation chromosomal crossing over takes place. Consequently the genes independently assort, reshuffle and form many varieties of series. Thus none of the millions of spermatozoa that diploid males produces are likely to be genetically identical. The same is true of the ova produced by diploid females. From this it is clear that the offspring of a given pair of animals will be genetically different. Diploidy and sexual reproduction thus allow an animal population to possess enormous stock of genetic variation. This variation provides raw materials for potential genetic adaptations.

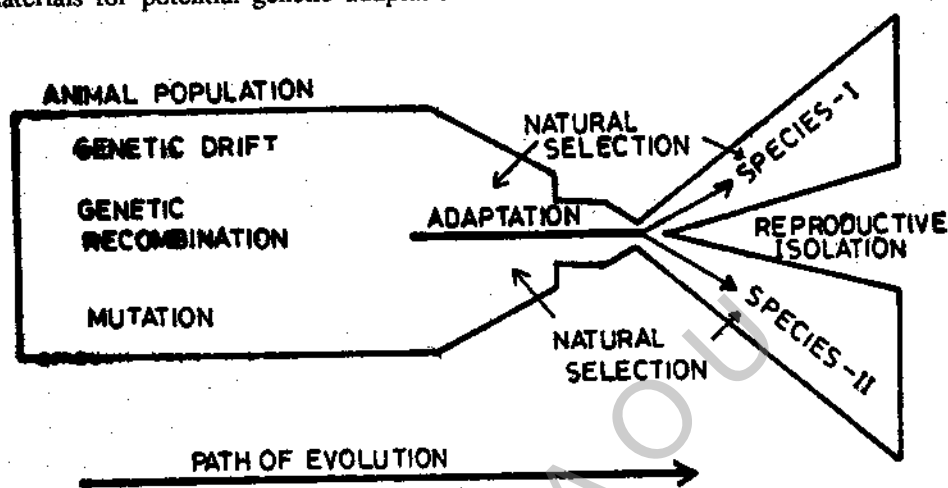


Fig.17.1 Diagrammatic representation of modern concept of evolutionary changes in organisms.

17.5 GENETIC DRIFT

Frequent appearance of any given gene when compared to the appearance of all its other contrasting genes (alleles) is known as the gene frequency. In a small population, by chance, none of the individuals reproduce a particular gene. The result will be that a gene may be lost altogether from a population as a result of pure chance. Thus in a small population due to this loss it is quite likely that a significant drop is brought about in the gene frequency. Such variations in gene frequency are known as genetic drift. But the chances of this happening become lesser in larger populations. Thus genetic drift can only be expected to produce significant changes in small populations.

17.6 NATURAL SELECTION

The idea of natural selection was first clearly understood by Charles Darwin. Though he had no knowledge of modern Genetics, he perceived that Natural selection depended on heritability. An effective fusion of Mendelian Genetics and Darwinian Natural selection was started fifty years back and continues today.

The present interpretation of natural selection is more concerned with the perpetuation or elimination of the genes carried by individuals. Any process that encourages the transmission of favourable genes and blocks the transmission of unfavourable genes can be said to contribute towards evolutionary progress. An animal with unfavourable genes is prevented to breed by nature. It is as well the genes are prevented to pass on to the next generation. It does not mean that bad genes are weeded out of population by natural selection.

There is always an interaction between expressive characters of an individual and the environment. All of ecology and other aspects of biology are involved in this. Genes possess the ability to increase or control the effectiveness due to which an animal adjusts itself to its biological environment. This capacity will be under the influence of natural selection to such an extent that it will be contributed to the next generation. This capacity is said to be adaptation. In other words adaptive characters enable an organism to survive adverse conditions of environment and enhance its capacities to obtain food, avoid predators and obtain a mate to produce more offsprings. All characters are favoured by selection. Any capacity that enhances adaptation will in a long run be favoured by selection and capacity that decreases the adaptation will not be selected. We have many evidences of such natural selection in action. Biochemical resistance to DDT in flies and mosquitoes, to Penicillin in bacteria and to the toxin warfarin in rats is observed to spread rapidly through their respective populations by natural selection. Recent investigations indicate that certain grasses subjected to industrial outflows have developed tolerance to heavy materials like copper, zinc and lead.

17.7 REPRODUCTIVE ISOLATION

Prevention of interbreeding between individual animals is called as the reproductive isolation. An animal population splits up into two or more separate groups with their own genetic makeup. These groups must be isolated from one another because if interbreeding between them is allowed, they will have as one population. If they are completely isolated mutation and selection can take place independently in those split up populations and each can develop into a distinct species.

Mutation, recombination, Genetic drift and Natural Selection as described above are the chief processes which account for diversity of animals. If all these processes are combined with reproductive isolation, then these populations qualify as separate series since there is no effective gene exchange between them.

Check your progress:

Define the following:

1. Genetic Drift
2. Mutations

17.8 SUMMARY

1. Sudden change in a gene of an animal known as genetic mutation supplies raw materials to some extent for evolution since it is heritable.
2. Mendel discussed in his laws of heredity that genes, during the process of gamete formation, independently separate and combine to give rise to a new serial order of genes. During gametic fusion only a few genes unite therefore express variations in the offspring.

3. In smaller population sometimes by chance some genes are lost due to which that particular character is permanently lost. Thus genetic drift occurs.
4. Natural selection works on the capacity of the genes which favour organisms to meet adverse environmental conditions adequately.
5. When animal populations split and migrate they become isolated. Then evolutionary processes act independently in them leading to distinct species which become incapable to interbreed.

17.9 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Genetic Drift: A gene may be lost altogether from a population as a result of pure chance. Thus in a small population due to this loss it is quite likely that a significant drop is brought about in the gene frequency. Such variations in gene frequency are known as genetic drift.
2. Mutations: A change in the gene which is heritable is called a mutation.

17.10 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines each:

1. Explain chief processes involved in Synthetic theory.
2. What do you mean by synthetic theory?
3. Briefly explain the role of Natural Selection according to Synthetic theory of Evolution
4. What is Mendel's contribution to the variation.

II. Answer the following in about 10 lines each:

1. Reproductive Isolation
2. Natural Selection
3. Genetic Recombination.

UNIT 18 ADAPTATIONS

Contents

- 18.1 Objectives
- 18.2 Introduction
- 18.3 Aquatic Adaptations
- 18.4 Desert Adaptations
- 18.5 Volant Adaptations
- 18.6 Animal Association
 - 18.6.1 Commensalism
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 - 18.6.3 Parasitism
- 18.7 Colouration and Mimicry
- 18.8 Summary
- 18.9 Check Your Progress – Model Answers
- 18.10 Model Examination Questions

18.1 OBJECTIVES

Various structural modifications in animals to adjust with their natural environment (air, water and desert) have been discussed in this unit. These modifications are known as adaptations. After completing this unit

- You will be able to show how various kinds of animals come in close contact for their survival.

18.2 INTRODUCTION

Every organism shows certain structural and functional characteristics which fit them successfully in their particular environment. Such features are called as adaptations. An animal must be adapted in such a way that it can reproduce its kind, defend itself from the attack of its enemies. It must compete successfully for food and other necessities. It must also respond efficiently and quickly to environment changes so as to maintain all those fundamental processes of life which have been stated above.

On the basis of habits and habitats most important adaptation seen in animals of diverse environments are aquatic, desert and volant or aerial adaptations.

18.3 AQUATIC ADAPTATIONS

In animals which live in water medium permanently like fishes or partially like reptiles or mammals modify their structures so as to fit them to aquatic life.

In these animals, the shape of the body is streamlined without any elevations over the body so that they move swiftly through waters. Locomotory organs like fins (fishes), or paddles (whales, turks) develop to the end.

Fishes are true aquatic animals bestowed with gill and air bladder for respiration and hydrostatic function respectively. Some air breathing terrestrial animals under adverse circumstances,

animals which have adapted aquatic life such as turtles, crocodiles (Reptiles), whales, dolphins, seals (Mammals) exhibit many peculiar structural and functional modifications as follows:

- a) since much of the energy is conserved, their size enlarges when compared to their relatives on land. The size of sulphur bottom whale is very larger than elephants.
- b) Neck is shortened and cervical vertebrae are fused as in whales and sea lizards.
- c) Tail region which helps in swimming in most aquatic forms becomes laterally compressed, limbs change into rudder-like paddles which help in propulsion. Digits are webbed and eyes are with nictitating membranes.
- d) Most marine animals have body fluids isotonic with sea water to prevent osmotic exchanges.
- e) Loss of hair, cutaneous glands (sweat and oil glands) and reduction of teeth are usual. Loss of hair in whales is compensated with a fatty layer (blubber) under the skin (Fig. 18.1).

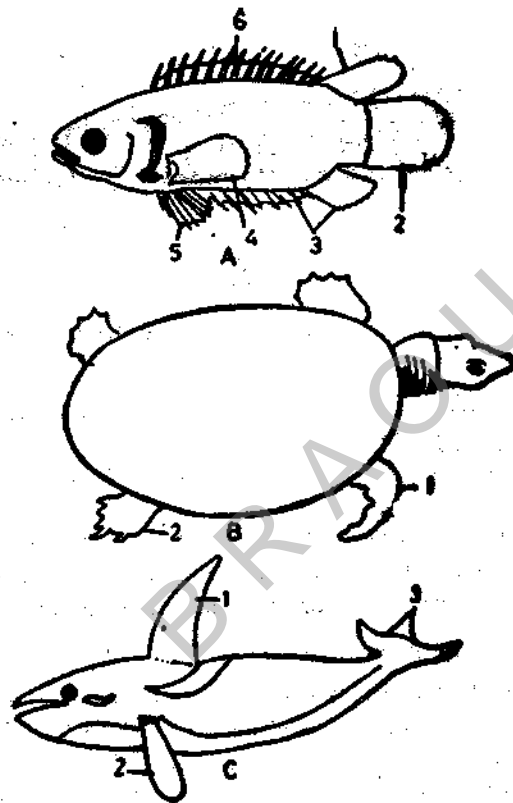


Fig. 18.1 Animals showing aquatic adaptations. A. Fish 1. Dorsal fin 2. Caudal fin 3. Anal fin 4. Pectoral fin 5. Pelvic fin 6. Spinous dorsal fin. B. Trionyx (Turtle). 1. Paddle 2. Webbed hind limb C. Whale 1. Dorsal fin 2. Flipper 3. Caudal fin

18.4 DESERT ADAPTATIONS

Due to scarcity of almost all vital necessities of life in deserts, like water, extreme conditions of temperature and unprotected life, the following adaptations are observed:

- a) Colouration of skin, usually matching to their environment and a thick spiny covering is present. Gila monster, a poisonous lizard with yellow black stipes and other with grey and brown colours. These are protective devices.
- b) Motoch, the desert lizard has a porous and spiny skin which absorbs water.

- c) Water conservation is made by filling water cells in the rumen of stomach (Camels).
- d) Protection from the drifting sand is done by scales hanging over the eyes (burrowing snakes) or by long eye lashes (Camels).
- e) Poison fangs present in many snakes (Rattle snake) and lizards (Gila monster).

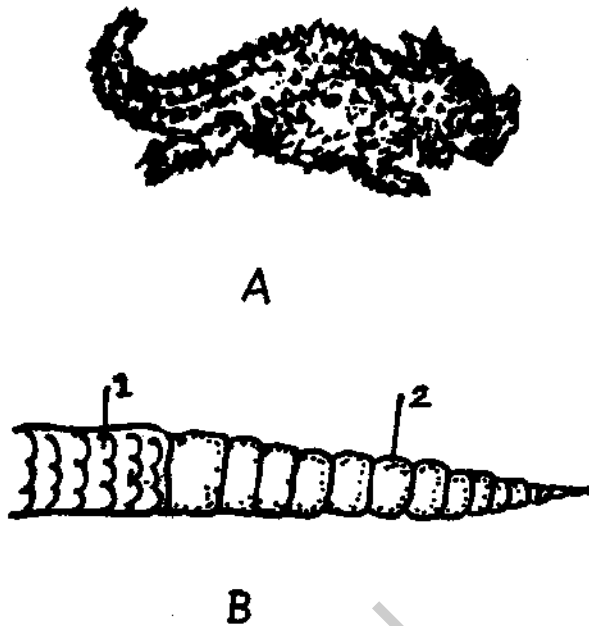


Fig. 18.2 Animals showing desert adaptations. A. Molach B. Rattle snake-posterior end. 1. caudal end 2. Rattle

18.5 VOLANT ADAPTATIONS

In order to escape themselves quickly from enemies and to travel speedily to distant places in search of food and abode, many animals have adapted to aerial life. They may simply glide or leap from a higher to a lower point or they may fly in the air. They express the following important traits:

The gliders develop folds of skin, the patagia (patagium singular) as in flying lizard, the *Draco* which develop laterally and are supported by ribs. In a fish the *Exocoetus*, pectoral fins enlarge like wings. The flying frog, *Rhacophorus*, lives on trees possesses webbed digits in fore and hind limbs, each digit ends in an adhesive pad which help in clinging fast to branches when it glides.

In flying animals the following structural modifications are very characteristic :

1. In birds fore-limbs modified into wings. They are covered by feathers, expanded network of epidermal parts. In bats (Mammals) skin stretches between the forelimbs, more so forms inter digital membrane. Wings are the powerful organs of flight. Insects also developed wings by expanding the chitinous body wall.
2. Most of the bones are hollow and contain air filling cavities as seen in pneumatic bones of birds.
3. Strong pectoral muscles and air sacs around the viscera increase propulsion in air and reduce weight respectively in the birds that fly. (Fig.3)

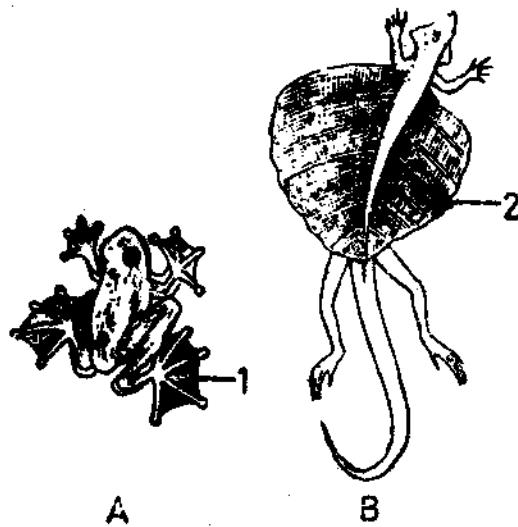


Fig. 18.3 Animals showing Volant adaptations. A. Rhacophorus B. Draco 1. Web 2. Patagium.

18.6 ANIMAL ASSOCIATION

Usually animals form groups or come in close association with one another. These associations become specialised in that the relationship between them is generally closer and more permanent than in ordinary situations. Three types of such associations are recognised :

18.6.1 Commensalism

As it literally means associated animals eat at the same table. Two animals one of which is a commensal gains while the other one the host neither gains nor loses. The sucker fish, fixes itself to a passing shark by its modified dorsalfin which acts like a sucker. Now and then it detaches and feeds and again rides the shark. No benefit is gained to the host, shark (Fig. 18.5)



Fig 18.4. Wings of bird (A) and bat (B).

18.6.2 Symbiosis and Mutualism

As this association is mutually beneficial and keeps the participants the symbiont and host 'living together'. A common example is the sea anemone fixed on the molluscan shell occupied by a crustacean hermit crab. As a symbiont sea anemone derives benefit by receiving free transportation. In turn the crab is prevented from being eaten by predaceous fishes due to the presence of stinging cells in sea anemone. There is no sharp dividing line between symbiosis and mutualism (Fig. 18.6).

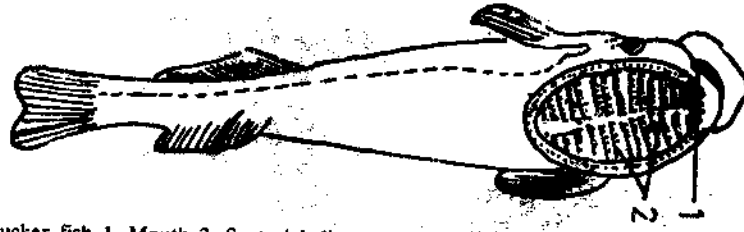


Fig 18.5 Sucker fish 1. Mouth 2. Suetorial disc.

18.6.3 Parasitism

The association between two animals in which one of the parasite lives in or on the host and derives benefits. Thus parasitism is a one way traffic. Some live on the other animal as ectoparasites (Head louse), whereas endoparasites live in the body (*Ascaris*, *Plasmodium*). Parasites may be temporary (mosquito, leech) or permanent (*Taenia*). They get shelter and food from the host but the host suffers.

18.7 COLOURATION AND MIMICRY

By adapting the colour of their or other more protective beings, animals escape their enemies. This surroundings adptation is called as colouration. In some situations an animal deceives by adapting or copying certain characters of another animal to avoid predators. The former is known as colouration and the latter is termed Mimicry. These two adaptations may be present either singly or combinedly.

There are cryptic colours which conceal the animal from the enemy to such an extent that the outline of the body is not distinguishable from its background. eg. grasshopper in green grass, tiger with its stripes in a groove of tall grass.

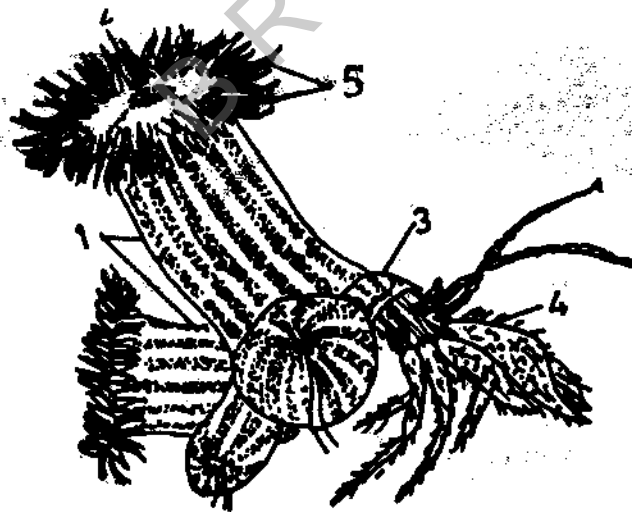
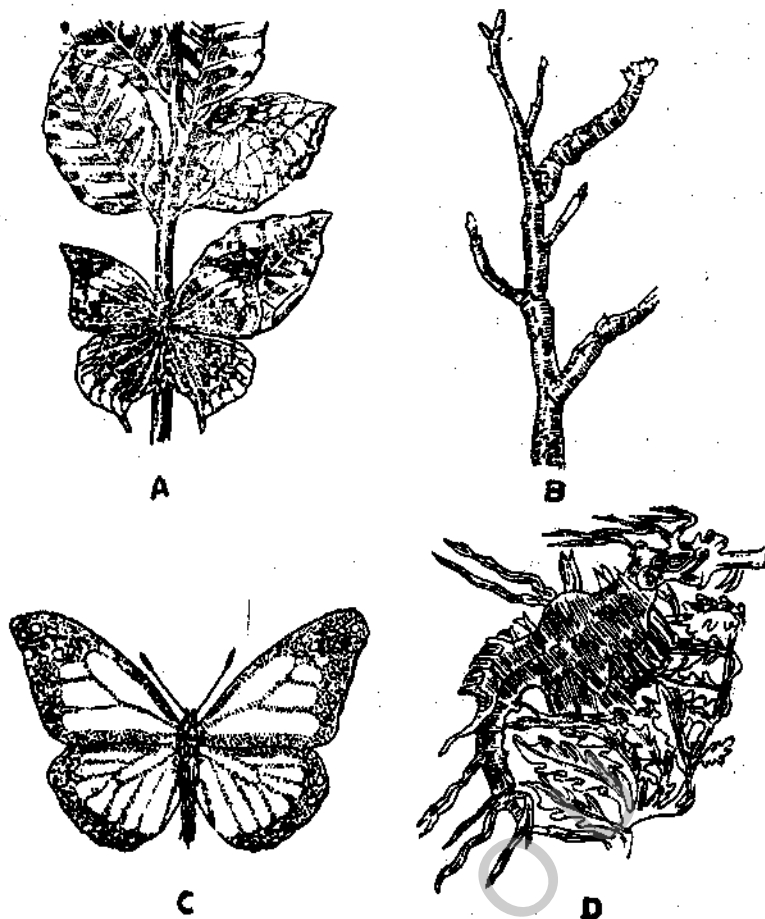


Fig. (18.6) Sea anemones attached to the gastropod shell occupied by a Hermit crab showing symbiosis. 1. Sea anemones 2. Mouth 3. Gastropod shell 4. Hermit crab. 5. Tentaes.

Structural modifications (mimicry) along with colouration are found in Australian sea horse, *Phyllopteryx* (Fig. 18.7). Due to numerous outgrowths on the body it resembles in colour and shape with the sea weed. Thus it becomes inconspicuous. Similar is the case with Indian leaf rutterfly, *Kallima* which copies a deadleaf in colour and shape.



18.7 Mimicry and colouration. A. Kallima, the Indian leaf butterfly, which, when its wings are folded, remarkably resemble a leaf. B. Larva of geometrid moth is coloured green and resemble a thin stem C. Viceroy butterfly D. Australian sea horses.

Mimicry is described as **Batesian** and **Mullerian**. Mimic is the animal which imitates the model, another animal. Two Brazilian butterflies (Monarch, Viceroy) fly together to avoid insatiable birds. The viceroy butterflies are eaten by the birds, contrary Monarch butterflies are unpleasant. Thus the Viceroy butterflies by mimicking the warning colouration of their model, Monarch butterflies, are saved from predation.

When two or more inedible or unpleasant species resemble each other both the mimic and the model appear to be protected. This mimicry is of advantages to both species as observed in a moth which mimics a wasp. Both are inedible.

Check Your Progress

1. The association between two animals in which one of the parasites lives in or on the host and derives benefits is known as _____.
2. Define commensalism

18.8 SUMMARY

1. Animals show certain modifications in their general plan of body which enable them to live fully adjusted within their natural environment. Such modifications are called as adaptations.

2. Animals which live in water have the advantage of the water pressure to support their body hence we find morphological adaptations in their size, shape, limbs and physiological changes in respiratory and energy conservation mechanisms.
3. Due to lack of water, extreme climatic conditions, non-availability of food, lack of protection etc., bestow the organism with desert adaptations.
4. Gliding and flying adaptations are characteristic of animals adapted to aerial life. Patagia, wings, strong pectoral muscles and all those adaptations which make such animals lighter, swifter and more energetic are included.
5. Animals of some species or different species live together in various manners. These may be more or less intimate. According to the degree of relationship, these of the associations are said to be commensalism, symbiosis, mutualism and parasitism.
6. Colouration and mimicry are nature's gifts for the animals since these protect, escape, and prevent the attack of their predators.

18.9 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Parasitism
2. Two animals one of which is a commensal gains while the other one neither gains nor loses.

18.10 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines :

1. Describe aquatic Adaptations in animals.
2. Write a short essay on Volant Adaptation.
3. What are the conditions in a desert. How these conditions are met by the desert animals?
4. Distinguish desert and aquatic adaptations.
5. What are the adaptive differences you come across between a bird and reptile?
6. How animals are related to form associations
7. Distinguish clearly between Commensalism, Symbiosis and Parasitism.
8. What are the advantages of Colouration and Mimicry to animals? Explain with suitable examples.

II. Answer the following in about 10 lines each:

1. Enumerate most important aquatic adaptations.
2. Meaning of adaptation with examples.
3. Any three desert adaptations.
4. Explain differences between wing and patagium.
5. A note on commensalism and Symbiosis.
6. Advantages of colouration in animals.

UNIT-19 EVOLUTION OF MAN AND HORSE

Contents

- 19.1 Objectives.
- 19.2 Evolution of man
 - 19.2.1 Introduction
 - 19.2.2 Changes undergone during evolution from apes to Humans.
 - 19.2.3 In what way did man lose and gain during his evolution?
 - 19.2.4 Evolutionary stages of Human being
- 19.3 Evolution of Horse
 - 19.3.1 The Evolutionary Stages
- 19.4 Summary
- 19.5 Check Your Progress - Model Answers
- 19.6 Model Examination Questions

19.1 OBJECTIVES

This unit is about the evolution of Man and Horse. At the end of this unit you will be able to explain.

- the various aspects of human evolution
- the history of horse and its various evolutionary stages.

19.2 EVOLUTION OF MAN

19.2.1 Introduction

Man is undoubtedly a product of mammalian evolution. He is one of the many lines of evolution that characterised the cenozoic age. As the evolution of horse, elephant, camel and so many other different lines are progressing, the evolution of man is also proceeding through various initial stages of primate evolution, the culmination of which is the appearance of modern man.

The evolutionary thinking certainly implied that man has no special status as far as his biological evolution is concerned and that he has evolved from prehuman, ape like primate ancestors over millions of years.

Man and Apes

There are several anatomical and physiological similarities between man and apes. They are as follows:

1. Though their brains are smaller (Gorilla 500 cc, Chimpanzee 400 cc, Man 1500 cc), the brains of apes are quite well developed. They have same patterns of convolutions as in the human brain, though in a simplified form. In details also the similarities are surprisingly precise.
2. These anatomical resemblances in the brain are correlated with physiological similarities.

3. Many features of the skull and other parts of the skeleton of the large apes and man (both extinct and living species) are very approximate. This is in part related to the erect posture which is being established in the Gorilla and Chimpanzee.
4. In their dentition also the apes show similarities to human pattern.
5. The arrangement of muscles in apes and man have similar disposition .
6. The various abdominal organs are situated in a common pattern in apes and man. Even the microscopic details are quite similar in structure.
7. The physiological aspects that may be stressed to show the phylogenetic relationship are blood groups, parasitic infestation susceptibility to certain diseases, immunological responses and so on.
8. The just born child of human possesses a sort of thick set hair reminiscent of the ancestral arrangement. This hair however drops mostly later.
9. The legs and hands of a young baby rise above, rather than stretch lengthwise along the trunk as in an adult. This is because the muscles and bones are set in a quadrupedal fashion.
10. The young humans have to learn to walk on two legs about the age of an year or so. Earlier the baby walks on all fours like a quadruped. The legs would not have acquired the stature required for bipedal progression by that age.
11. The behaviour of fingers and toes is noteworthy. The young baby clutches with its fingers any object that comes handy. This is reminiscent of the young of monkeys and apes. They hold tightly to the bodies of their mothers which move on all fours on trees jumping or otherwise. The toes, especially the big toe-move constantly in the baby. This indicates the free movement of the toes in the ancestors for holding objects, which facility is lost in the course of human evolution due to bipedal motion.

19.2.2 Changes undergone during evolution from apes to humans

The evolution of man from the earlier prehuman forms took place rather in a hurried way, as these things are understood on a geological scale. In other words that could have taken several millions of years was achieved in a few lakhs of years. Man rather hurried himself in the course of this evolution. Consequently there are several advantages as well as disadvantages in this process. Let us observe some of these aspects:

1. The hind limbs now carry the entire weight and hence they became stronger. In apes both are more or less similar.
2. The foot has an arch like curve at the bottom. This is convenient for running and walking but the toes have become shorter and quite similar in length. This is inconvenient for grasping. Apes have power to grasp with their feet also-in fact more with them.
3. The human hand has the best evolved utility structure in spite of its basic primitiveness. The fingers move delicately and independently. Without moving the upper arms, the lower arm can be twisted by 180° . The hand played a vital role in the evolution of man acting in unison with the specialisation of brain.
4. The face has become very nice to look at. The sight is now directed straight forwards. The projecting snout of the previous forms receded leaving only the prominent nose and a chin. The edges of the ears are rimmed. The delicate mucous membrane of the lips rolls out forming the attractive lips.
5. The hair is reduced vastly both in area as well as in thickness.

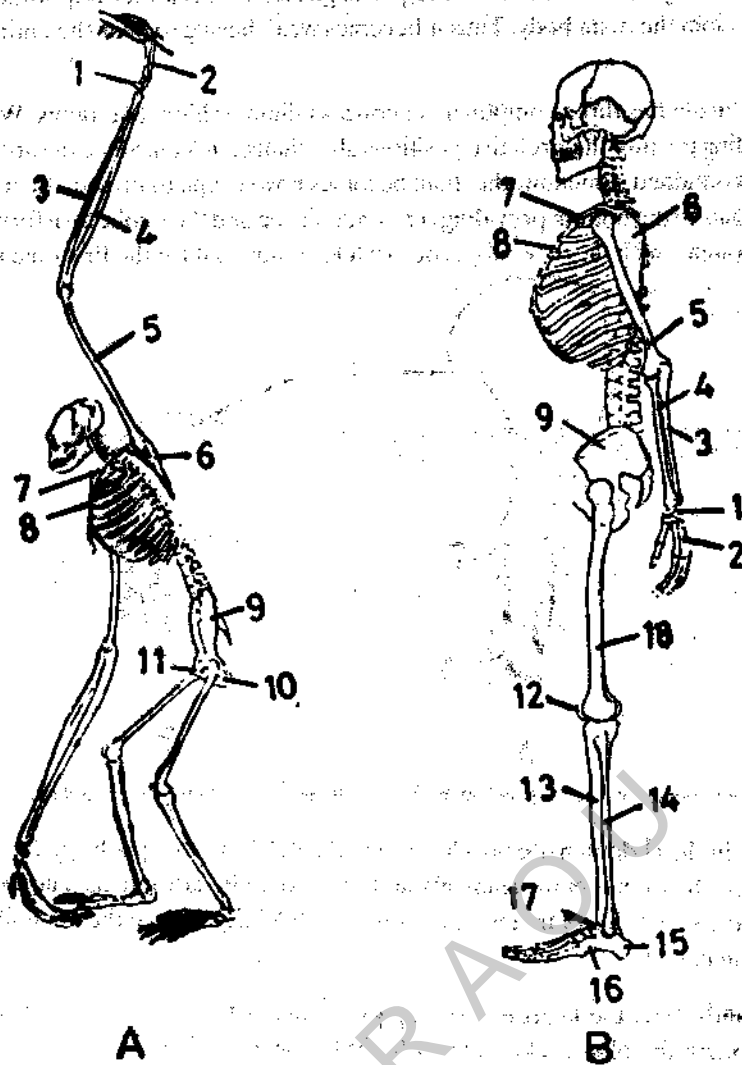


Fig. 19.1 Skeleton of Gibbon and Man. 1. Carpus 2. Metacarpal 3. Ulna 4. Radius 5. Humerus 6. Scapula 7. Clavicle 8. Sternum 9. Ilium 10. Ischium 11. Pubis 12. Patella 13. Tibia 14. Fibia 15. Calcaneum 16. Cuboid 17. Astralagus 18. Femur

19.2.3 In What Way did man loose and gain during his evolution?

As already remarked man's evolution, took place rather in a hurry. In normal course of evolution, given the adverse conditions through which his evolution proceeded man would have become extinct, being unable to cope up with the environment both the climatic as well as the biological.

It is the brain which saved man from this situation, by directing his destiny with its unfolding intelligence, Yet he has lost anatomically and physically on various counts. Some of them are as follows;

1. A quadruped has definite advantages of stability, on both counts, the vertebral column acting as a cantilever bridge. Heavier organs of the abdomen are located in the middle. The vertebral column is bow shaped. Man has to stand on his two legs now and thus lost this advantage. The vertical column becomes vertical and bends forward at two points from its original bow like shaped. This is because it has to bear the weight vertically. All in all, the vertebral column has lost much of its original advantage.

2. The responsibility now increases for the pelvic girdle. This is a very important region where the two legs join the main body. Thus it becomes weak having to bear the entire weight on its own.
3. The pelvic girdle has three components known as ilium, ischium and pubis. With the change in the standing posture their relative positions also change in man. Since the abdominal organs have to be contained somehow, the ilium becomes bowl shape to provide them a shelter. The ischium comes to the bottom providing seat while sitting and the public turn forward and forms an arch through which the new baby is born while coming out for the first time into this world.

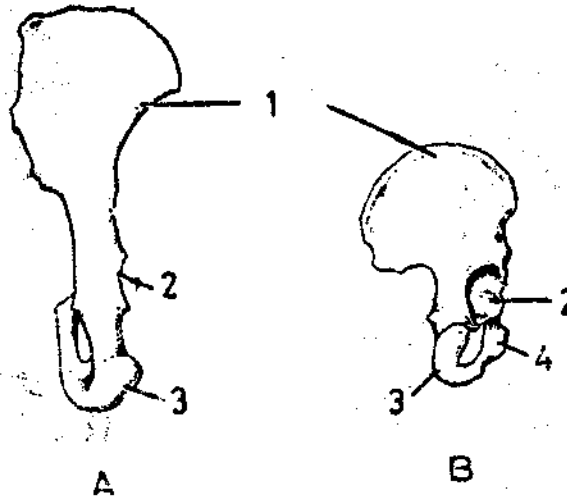


Fig. 19.2 Pelvic bones of ape (A) and man (B). 1. Ilium 2. Acetabulum 3. Ischium 4. Pubis

4. The organs in the abdomen are now located in the pelvis. In the quadrupedal form they hang from the vertebral column by ligaments and had a definite advantage. The weight runs now parallel to the vertebral column instead of perpendicularly. Hence the possibility of hernia is there in human beings
5. As man stands erect the heart is taken upward along with the chest. The heart has to work harder to pump the blood. The veins of limbs become swollen causing varicose veins. Piles also are caused by this.
6. While the enlargement of the brain has its definite advantages, it has some disadvantages also. The head becomes heavier and larger and the original neck muscles are unable to support the head in the child. Moreover the delivery itself become a problem as the head is larger. Frequent surgical assistance is necessary for a comparatively easier delivery.
7. The original number of teeth in mammals is 66. Out of which the grinding teeth number 44. The total number is reduced to almost half and we have now 32 teeth. The loss has effected mostly the molars and premolars. This is because of the more delicate and cooked food on which man started depending upon. The snout has lost existence and with it the number and size of the teeth also. There is a crowding of teeth and hence overlapping occasionally occurs. The last molar known as wisdom tooth sometimes fails to break.
8. The canine teeth are powerful and long in the apes and hence there is only a possibility of an up and down movement of jaws. With the reduction of prominence of canines the power of tearing the flesh is lost. But the advantage gained is the literal grinding by rotating by rotating the jaws in almost a circular fashion.
9. The jaws of ape are almost rectangular while in man they are a perfect parabola or horse-shoe shaped. In apes, the lower canine fits into a gap in the upper jaw between incisors and canines. This gap is known as simian gap. This is missing in human jaws.

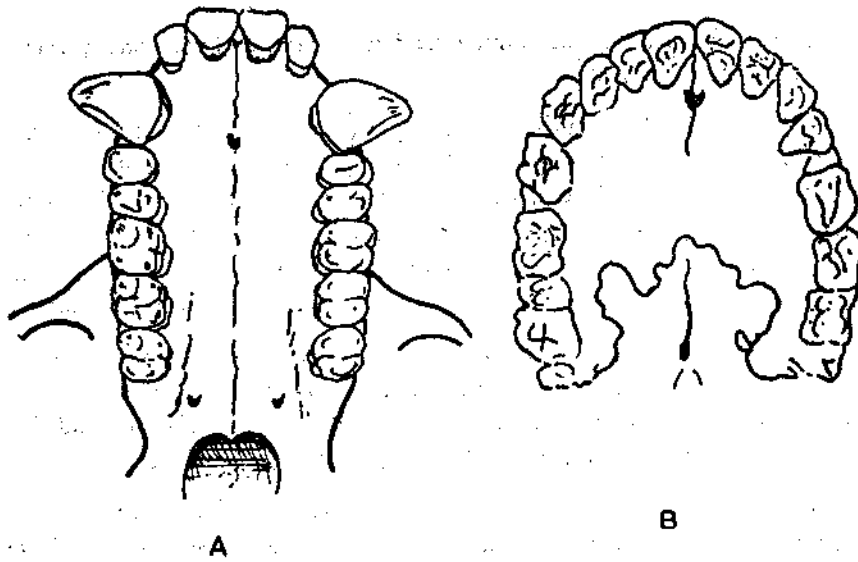


Fig. 19.3 Comparison of the upper jaw of ape (A) and man (B).

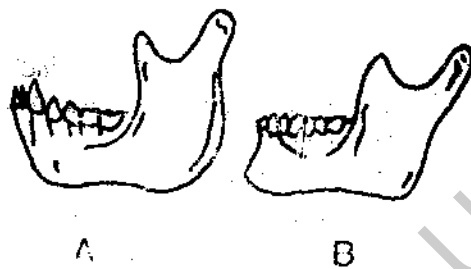


Fig. 19.4 Comparison of the Jaws (mandible) of ape (A) and man (B)

10. In apes again to support the powerful canines and molars there is a simian shelf in the lower jaw. With the loss of importance of these teeth in man, the simian shelf is also lost. This enabled the tongue to move freely making possible development of speech.
11. The apes have powerful nuchal crests and supraorbital ridges. The various muscles of jaws are attached there. Man no longer needs these powerful muscles as the food became delicate and easily manageable. Hence both the nuchal crests and supraorbital ridges are reduced.
12. There is some significance in the retention of nose and chin while the snout is reduced. Originally both of them are part of the snout. But with reduction of snout the nose also should have lost its height. This did not happen because the air that enters into the lungs during respiration needs removal of dust and preheating which is achieved by the enormous mucous membrane within the nasal cavities. The chin offers support to teeth. Hence the erect nose along with the chin below are left behind.

Man is a social being. All his achievements right from the beginning of his evolution upto date are achieved by unity. The child depends upon the society for considerably longer period and attachment to society is as much pronounced as his contribution for the advancement of the society later.

19.2.4 EVOLUTIONARY STAGES OF HUMAN BEING

Ramapithecus

It is certain that none of the present apes or monkeys are the direct ancestors of Human beings. At some stage in the main line of evolution ape-cum-man like beings split into two

lines one leading to modern apes and another leading to Human line. Exactly when or where it took place is not clearly indicated.

About 50 years ago, fossils of a significant anthropoid were discovered by G.E. Lewis in the siwalik hills of India. The specimen provided significant evidence that it is on the line of evolution of man and has left the line of ape characters behind. This is called as Ramapithecus but is represented only by fragments of the jaws and teeth are small and the canine tooth is reduced. This shows that forelimbs are used for food gathering and these characters seem to show a link between the primate and the later Australopithecus which walked upright.

The age of this form is estimated as 70 lakhs years. Later, other fossils are discovered and are referred to as Brahmipithecus. During the same period there lived similar forms in East Africa, the fossils of which were discovered by L.S.B. Leaky. This hominid is called as Kenyapithecus vickeri which is referred to about one crore years of age.

In neither of these specimens the limb bones are found. Yet the scientists are convinced about their upright nature and nearness to australopithecine forms (see below). Ramapithecus was about the size of Gibbon, but smaller than Australopithecus which was about 1 metre.

Australopithecus

In 1924 in Taung South Africa, the fossil of an adolescent individual is found by Raymond Dart. This was named originally as *Australopithecus africanus*. After this Dr. Broom discovered other fossils named as *Plesianthropus africanus* and later another called as *Paranthropus robustus*. Several other fossils were found in Swartkans, South Africa.

The australopithecine skull has the following features:

- (1) Small cranial capacity.
- (2) Large sagittal crest.
- (3) Massive projecting jaws.
- (4) Large molar and premolar teeth but small incisors and canines.
- (5) Pelvis and limb bones constructed on hominid plan but significantly different pattern.

Despite three or four prominent ape like characters, the nature of the pelvis and limbs make these forms more hominid. The reasons for this line of thinking is cranial height, the low position of occipital condyles, the back ward bulge of the head, and the shape of the mandible. It is certain that these forms walked erect like Homo, the limb bones and pelvis being specifically constructed for an upward erect posture.

In 1959, for the first time a hominid fossil was found in the African continent outside south Africa. L.S.B. Leaky found the cranium and upper jaw of a hominid in Olduvai Gorge (Kenya).

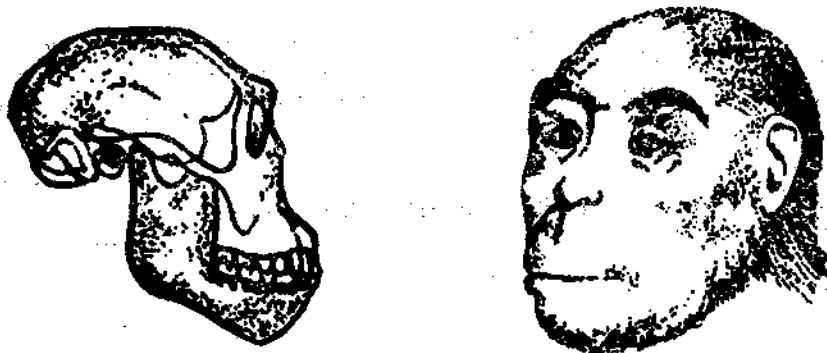


Fig. 19.5 Restoration of head and skull of Australopithecus

It was called then as *Zinanthropus*, but later found to be not quite distinct from the other African human fossils which were also named by different genetic names. At best, all of them are to be regarded as one genus *Australopithecus*.

In 1960, another discovery was made—below the layers of *Zinanthropus*. The sides of the skull, clavicle, hand bones and the bones of foot are found besides several stone tools. This discovery was assigned to not only a new species but a new genus as well, called as *Homo habilis*. But this claim of separate nature is seriously disputed though this material is gracile when compared to the other human fossils which are very robust.

In fact there is some confusion regarding the taxonomical status of various human fossils found in African continent during the past sixty years, since the original discovery of **Taung's child**: Whether there are two species *A. africanus* and *A. robustus*, whether they belong to only one species, the difference being of sexual nature, or whether the robust material is to be assigned to a genus *Paranthropus* and the gracile material to the genus *A. Homo* (*Homo africanus*). It is not clear yet. A fourth view would regard the existence of two genera. *Australopithecus* and *Homo*. According to this view *Australopithecus* has no direct ancestry to the modern human species and it diverged quite early. It regards both species coexisting for a quite a long period.

Homo erectus

In the year 1891, a skull cap and a femur bone were discovered in Trinil Java by Dutch Scientist **Eugene Dubois**. In 1907 at Mauer, Germany a massive chin less lower jaw was unearthed. In 1927 a molar tooth and in 1929 a cranium were found in chow kou tien near Pecking. These were called *pithecanthropus erectus*, *Homo heidelbergensis*, *sinanthropus pekinensis*. This is not the end of the story. *Telanthropus* in S.Africa, *Atlantropus* in Algeria, *Australopithecus* (as noted) and several other genera and species were discovered and named.

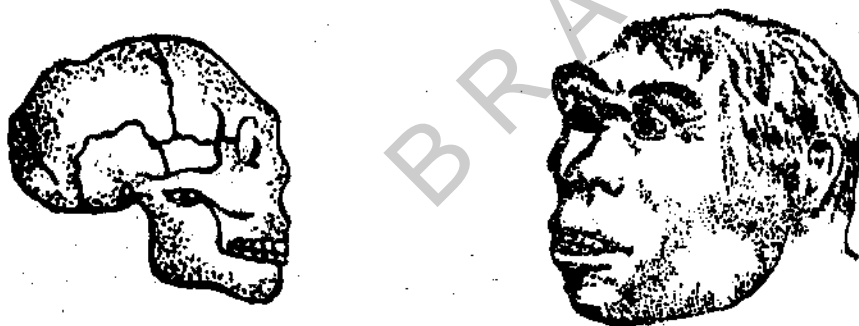


Fig 19.6 Restoration of head and skull of *Homo erectus*.

Now it is universally agreed that all of them belong to a single species *Homo erectus* and at best they may be assigned the status of variety. *Homo sapiens* is perhaps one to three lakhs year old. *H. erectus* lived between 25 lakhs year to 10,000 years ago.

H. erectus is well placed to have been the direct ancestor of *H. sapiens*. He is modern man's immediate predecessor. But where and how the transition took place is doubtful.

For nearly 100 years, fossils have been coming to light and every one of them was regarded as quite distinct from the others. The minor differences are given undue importance. Yet one school of opinion regards *Australopithecus* or *Paranthropus* an earlier genus, having given rise to *H. erectus* which in turn gave rise to the modern man.

The skulls of *H. erectus* show a series of distinctive features;

1. The brain case is low with sides that taper upwards.
2. The bones of the cranium are thick.
3. There are heavy massive supraorbital ridges.
4. A thick shelf of bone is present on the hind end of skull.
5. There is a receding forehead.
6. The front part of the cranium immediately behind the supraorbital ridge is constricted from side to side.
7. The nose is wide.
8. The jaws and palate are broad, some what prominent.
9. The teeth on the whole are larger than those of *H.sapience* (but smaller than *Australopithecus*).
10. Through some primitive features are found in the dentition, it is one the whole more hominid than pongid (ape like).

Behaviour of *H. erectus*

H. erectus lived in caves Though in Olduvai Gorge and Trinil, the bones are found in the open. At Chou kou tin the fossils are found in caves along with charred animal bones indicating the achievement of mastery of fire. With this, he was able to keep himself warm and thus moved into cold parts of the world. With the cooking of food and thereby reducing the work on the part of teeth-less cutting and tearing. The teeth got reduced in size and prominence.

Chopping tools were made from split pebbles. Stone flakes and bone artifacts are found. These are called at Chou kou tien as 'Chopper chopping-tools'. At Ternifine a totally different kind of stone implements are found. They are known as bifaced hand axes and scrapers (Acheulean). *H. erectus* thus associated with chopper chopping tool tradition in some parts and at other parts Acheulean bifaced hand axes industry. This indicates that there is no connection between the anatomy of a human species and the cultural manifestation of tool industry. *H. erectus* had considerable versatility.

There is no indication that *H. erectus* believed in super natural things. No burials were found as such and there was no indication of rituals. But one indication was there that he was a cannibal. All the fossils were only of Heads-about 40 of them are discovered. But other animal bones are discovered. Further the base of the cranium has been missing consistently in all of them around the region of foremen magnum seems to be a deliberate act probably to scoop out the contents within.

L.S.B. Leaky (1903-1972) regarded *H. erectus* too specialised to be the ancestor of modern man. He regarded *H. habilis* of Olduvai Gorge as to be in the direct line of modern man's ancestry *H. erectus* did not contribute to the evolution of modern man and become extinct.

But the modern view is quite contrary. *H. erectus* is a polytypic species having a number of variants both in time and space. Several authors even deny the separate status for Australopithecines as indicated below. *H. habilis* of Leaky was only a variant of *H. erectus* according to the modern view.

Neanderthal Man

Darwin proposed his Evolution theory in 1859. Earlier in 1848 in Gibraltar. in 1856 in Neander valley certain human skulls were discovered which missed the recognition of Scientific world. Darwin was remarking still that human fossils would be found in due course. In 1886 two

similar skulls were found with implements of chipped stone and animal bones. These animals (with whose bones also the implements were made) are extinct now. Starting from this landmark in 100 years (to be exact) several more human fossils were found, to piece together evolutionary history of modern man on a sound basis.

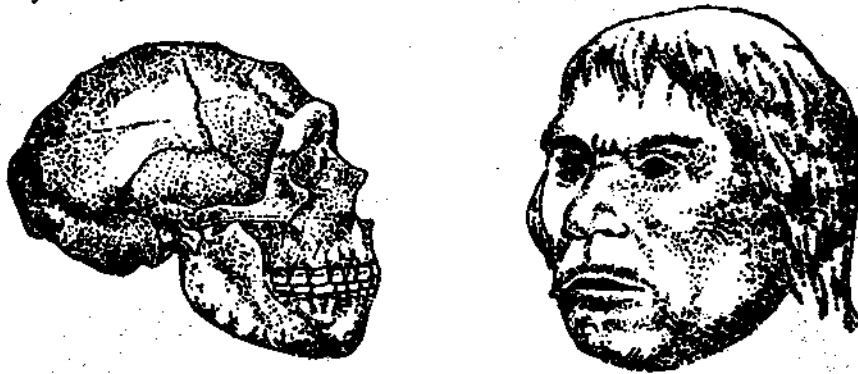


Fig. 19.7 Restoration of head and skull of Neanderthal man.

The Neanderthal man lived in much of Europe and near east during the upper Pleistocene. The place and the time of Neanderthal origins are still unknown. Who the predecessors were for the Neanderthals is not known. They lived since 100,000 may be 150,000 years. They differ in dental and skull morphology form *H. erectus*. They are regarded as early representative of *Homo sapiens*.

The name *H. sapiens neanderthalensis* was given in 1864 and now it is regarded as a subspecies of modern man *H. sapiens neanderthalensis*.

Why Neanderthal man suddenly disappeared from the earth is quite a mystery. There is a clear gap in culture in several European settlements between 38,000 BC to 32,000 BC. They are superseded by a more advanced and cultured human known as Cromagnon man. Whether this man is responsible for their extinction or the lack of adaptation. The warmer climate in the inter glacial age, disease or any other cause is not certain. But it is generally agreed that atleast in part the Neanderthal man's genes intermingled with the genes of modern Cromagnon man.

Cro-Magnon Man

In 1868, in a rock shelter at Cromagnon, Dordogne in France, several prehistoric skeletons of modern type of man were discovered which were called as Cromagnon man since then. The age of these skeletons is fixed to be about 25,000 BC.

The following characters are distinguishable in these skeletons:

1. The skull is as long as seen from above with a pentagonal outline.
2. The parietal bones have an outward bulging.
3. The forehead is straight and vertical.
4. The brow ridges are only slightly projecting.
5. The cranium is flattened and is without nuchal ridges (sagittal crest).
6. The occipital bone projects backwards.
7. The cranial capacity is large being about 1600 CC.
8. The face is short and wide.

9. The eye sockets are, rather square.
10. The nasal aperture is narrow and projects prominently down wards.
11. The chin is very prominent.
12. The dentition is nearly, identical to that of modern man. However most of the teeth especially the last molar is larger than in the modern man.
13. The skeleton is robust. The fore arm and the thigh are relatively long.
14. The hand skeleton is large with short fingers.
15. The foot has a prominent heel.
16. Normal height is about 1.7 m.



Fig. 19.8 Restoration of head and skull of Cro-Magnon man.

Cromagnon man is considered to be ancient version of Homosapiens. The question of the relationships of Cromagnon man to the modern man is not quite settled. Even before the appearance of Cromagnon man, several instances of human populations with modern human traits were located in middle Pleistocene i.e., between 5 to 1 lakh years.

In 1933 at Steinheim in West Germany a human skull was found. The features of the skull are mixed. The frontal and facial portions seem to be rather Neanderthal, while the back portion is more modern. This is said to be about 2 1/2 lakh years old.

Similarly at Swanscomba, Kent, England another skull was discovered in 1935 and later. This is similar in age to Steinheim skull. the skull is generally accepted to be a representative of early *Homo sapiens* though there are Neanderthal features as well.

In 1965, Vertesszollos, Hungary, skulls resembling modern man were discovered. Their age is estimated to be about 3 lakh years. This man is supposed to be at the root of the modern man evolution. There are several modern human features along with some Neanderthal features. The skull capacity is about 1400 CC almost of modern human proportion.

The criteria for a modern man as distinct from *Homo erectus* man are as follows:

| | | | |
|----|--|----|---|
| 1. | A mean cranial capacity of both 1350 CC with a high maximum breadth. Thin cranium (5mm). | 1. | Smaller cranial capacity being about 1000 CC. Cranial wall thick (10 mm) and maximum skull breadth. |
| 2. | An approximately vertical fore head. | 2. | Flat receding forehead. |

| | | | |
|----|--|----|--|
| 3. | A founded occipital part of the skull with a smaller area behind for the attachment of neck muscles. | 3. | Occipital part projects behind with larger area for the attachment of muscles. |
| 4. | Jaw and teeth are reduced in size and the facial region. | 4. | The facial region is larger. Jaw and teeth larger. |
| 5. | Small canine teeth of spatulate form. | 5. | Larger canines. |
| 6. | The presence of pointed projecting chin and prominent nose. | 6. | No chin and no prominent nose |

The Cromagnon man is later genetically absorbed slowly into the later European population. There are still some populations, who are said to be basically of Cromagnon type in Canary islands.

Culturally Cromagnon man is quite advanced. There are different types of stone and bone implements, blades, scrapers, chisels, spear heads etc. The culture is referred to as *Aurignacian culture* which succeeded the *Mousterian culture* of Neanderthal man. He lived a fairly settled type of life. They were successful hunters having subjugated bison, horse, rein-deer and even mammoth. They were individual and collective hunters, though their hunting methods are not known. But however they must be quite effective.

They buried their dead with elaborate rituals. Many were artists and sculptors. Some of their paintings reserve to be kept in the present day art museums.

The chart below gives an idea of modern thinking in the taxonomy of man:

| Single | Europe | N. Africa Algeria | Kenya E. Africa | S. Africa | E. Asia (China) | S. E. Asia (Java) |
|--------|--|----------------------------|--------------------------------|--------------------------------------|-----------------------------------|---|
| 5. | Homo sapiens Vertesszollo Hungary | | | | | |
| 4. | | | | | | H. erectus solensis |
| 3 | H. erectus heidelbergensis Germany | H. erectus mauritanicus | H. erectus boisei Leaky | | H. erectus pekinensis Black | H. erectus |
| 2 | | | | | | H. erectus erectus Dubois |
| 1 | | | H. erectus habilis Leaky | H. erectus capensis Dark Brown | H. erectus lantianensis | H. erectus madjocartensis Koenigs- world |

19.3 EVOLUTION OF HORSE

Horse has been one of man's best friends from prehistoric times. The evolution of this mammal has been largely traced by collection of fossils by Prof. Marsh, and later by H.F.Osborn. The

evolution of horse has been mainly directed towards mechanism of food gathering and attaining greater and greater speed. The evolution and specialisation is such that scientists consider that the entire body mechanism is highly specialised lacking in basic primitive features. The modern horse is called *Equus caballus*. The evolutionary tendencies of horse during course of about 6 to 7 crores of years can be summarised as follows:

- 1) Increase in size and height.
- 2) Lengthening of limbs.
- 3) Reduction in ulna and fibula, thereby limiting the range of movement.
- 4) Perfection of unguligrade from the original Plantigrade posture.
- 5) Loss of digits to the middle toe.
- 6) Increase in the height of teeth along with complexity in pattern.
- 7) Premolars assuming *molariform* characters.

Horse is one of the best living machines that attained a great sustained speed. This is achieved by among other things by the perfection of body contour by removing all angular projection reducing the air resistance. While running, the body as a whole, including head, neck assumes a perfectly symmetrical form almost like a bird or fish. The muscles of the limb are concentrated at the shoulder and thigh, only the slender tendons passing downwards.

The horse walks or runs on the tip of the middle digit. The primitive plantigrade gait where all the digits with metatarsals and metacarpals touch the ground, has been gradually shifted to unguligrade type of gait there by increasing the height of limbs. Besides, the various bones of the limbs also lengthened more giving progressively greater height during the course of evolution.

Corresponding to this the ulna and fibula bones reduced. This limits the freedom of rotatory movement but at the same time in that limited range greatly increases the freedom of movement. All the limb joints are of tongue and groove variety.

While the height is increased by the lengthening of limbs, there is an absolute need for similar lengthening of neck and head in order to reach the ground.

In general there is what is known as "speed index" in all the running forms. This is indicated by the ratio of length to the diameter of the limb bones. This is also coupled with the skull, vertebrae, ribs and so on. What is more important here is the fact that the horse has attained the maximum possible perfection for speed. The hoof is a marvel of adaptation. This is equivalent to our middle digit in either limb. If we realise that while galloping, the horse touches ground only with these front hoofs and thus withstands such a shock only through these two fingers, we can appreciate the perfection it achieved and reached.

The skull is very elongated with a long face. The eyes in effect are above the ground to increase the range of vision. The orbits are completely surrounded by bone. There is lot of room, provided in the jaws for the perfection of deep crowned grinding teeth. Because of this elongation the other teeth the canines and incisors are separated from the grinding teeth by a gap called diastema. Though this is not the intention of the nature, this gap is used by man to subjugate the horse by placing the "bit".

In the dentition, the first premolar is reduced and is known as "wolf tooth" and is often shed. The canines are mostly absent in female but present in a simplified form in males. The incisors are long crowned and possess a pit like depression which later becomes worn way. This gives an indication to the age of the horse.

There are three premolars and behind them 3 molars in each half of each jaw. They are deep crowned and called as hypsodont type of teeth. They are supported by three buttresses on the outer surface. Out of the three materials are elaborately inter woven and produce a complex pattern. While the rest two (dentine and cement) wear away comparatively quickly, the enamel forms on the surface this pattern which provides an effective grinding surface.

With regard to other characters, the brain is large in size with rich convolutions. The horse is quite intelligent, more intelligent than cattle but less than the elephant. With great smartness the horse tries to escape from adverse conditions which may prove harmful it learns from experience and is willing to get trained by the master. But the greatest weakness of the horse is to run away from any possible or imaginary danger. This sometimes leads the rider also the trouble or even death. But we must remember that in a wild state this is an important means of defence for the horse. It has keen senses of hearing sight as well as smell.

19.3.1 The Evolutionary Stages

The evolution of horses at any rate commenced in a contiguous Holarctic region though the main evolutionary stages are surprisingly well preserved in the North American continent.

There are ten important stages recorded from Eocene, Oligocene, Miocene, Pliocene, Pleistocene to recent. The ten stages starting from Eocene are as follows:

- | | | |
|-----|-------------|-----------|
| 1) | Eohippus | |
| 2) | Orohippus | Eocene |
| 3) | Epihippus | |
| 4) | Mesohippus | |
| 5) | Miohippus | Oligocene |
| 6) | Parahippus | |
| 7) | Merychippus | Miocene |
| 8) | Pliohippus | |
| 9) | Plesippus | Pliocene |
| 10) | Equus | |

Eohippus evolved from some five fold ancestors. Condylarths are generally regarded as the possible ancestors of this primitive horse. It is significant that similar forms known as Hyracotherium are found in European continent of the same age but that was the end of its line, they having become extinct.

The following are the basic characters of the ten evolutionary stages of horse :

Eohippus

This is four toed horse, about 30 cm in height something like a big cat or a small dog. The head and neck are short. Limbs are of moderate length. The feet are digitigrade. The hand has four complete digits with hoof like nails. There is no trace of the first digit. The foot had only three digits. The vestiges of the other two are seen. Ulna and fibula are slender, separate and complete. Molars are showing their future complication. The fourth premolars are tending to become molariform.

Orohippus

The foot has lost completely the splint of the fifth digit. The outer finger of the hand has shortened. The middle finger has slightly increased. The third and fourth premolars have become almost molariform. The height increased by 4 more cm (about 34-35 cm).

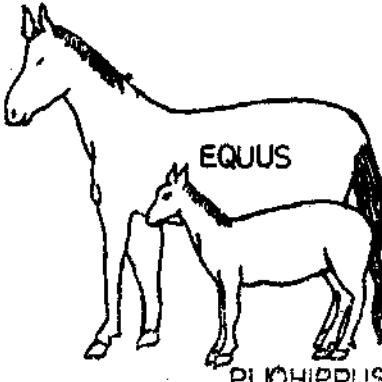
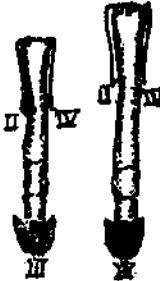


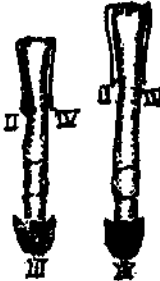

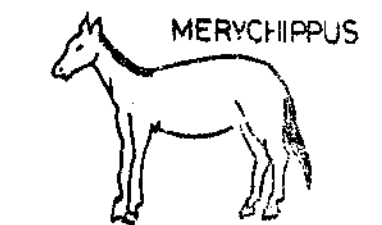
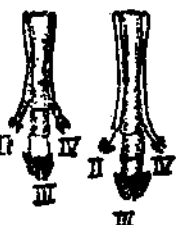


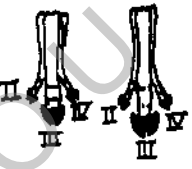




| | | | |
|-------------|---|--|---|
| PLEISTOCENE |  |  |  |
| PLIOCENE |  |  |  |
| MIOCENE |  |  |  |
| OLIGOCENE |  |  |  |
| EOCENE |  |  |  |
| | SIZE | FORE LIMB HIND LIMB | MOLAR TEETH |

Fig. 19.9 Diagrammatic representation of the ancestry of horse.

Epihippus (Upper Eocene)

The third and fourth premolars are now completely molariform. The digits of the hand are still four the outer most still functional, though reduced further.

The foot has three digits with the middle digit attaining functional superiority. Only fragmentary fossils of the horse are available. No estimates of the height are possible. Moreover this might not have led directly to the Oligocene horses to be described presently.

Mesohippus

This is of the size of a large wolf or an Alsatian Dog (about 45 cm to 60 cm). Both hand and foot have three functional digits. the fifth one may be still present in the hand as a small splint. The middle digit has attained greater responsibility in bearing the weight of the animal relieving the lateral digits much of this burden. Ulna and fibula are still present but much slender. It is evident that the horse has already attained considerable speed. The premolar teeth are fully molariform with the exception of small simple first premolar.

Miohippus (Upper Oligocene)

This is almost similar to the earlier form *Mesohippus* except that there is an increase in height in *Miohippus*.

Parahippus (Lower Miocene)

This is a classical example of step by step evolution. The earlier form of this species are almost similar to the previous Oligocene horse *Miohippus*. While the later form are indistinguishable from the future horse species the *Merychippus*. For the first time the gaps between the crowns of teeth become filled up with cement. The amount increases gradually with the progress of the species. The lateral toes vary greatly. In some they are as well developed as in *Miohippus* where as in others they are much reduced.

Merychippus (Middle Miocene)

This is the transitional form between the earlier forms with short crowned and fully, cemented. This type of change in teeth is required to adapt to harsh vegetation of the plains. The young of these forms have short crowns without cement while the adult teeth are heavily cemented and intermediate in height prophetic of the future.

Incidentally this is one of the most remarkable instances of ontogenetic evidence of evolution among horses.

Pliohippus (pliocene)

This is the first one toed horse. In some forms the lateral toes may still be present. This is about 100 cm in height. One peculiar character of this genus is the presence of pit in front of the orbit which might have lodged a scent gland.

Plesippus (pliocene)

This is quite large, attaining the size of a modern horse. The teeth are of greater height, an advance over those of *Pliohippus*. There is no trace of the lateral toes. Skull is *Equus* like. The facial pits are absent.

Equus

This is the culmination of horse evolution and is the final or the 10th stage. The feet are one toed. Well developed splints of 2nd and 4th digits are still remaining, either free or fused to the cannon bone. The teeth are long and columnar with a very intricate enamel pattern. Maximum height is reached in some breeds (180 cm). They attained region. North and South America. They were taken to the American continent again by man during historic times.

Check Your Progress

1. Answer the following:
 1. Steinheim skull
 2. Wolf tooth
 3. Zinganthropus
 4. Speed index

19.4 SUMMARY

1. Man is the modern product resulted by the primate evolution among the mammals.

2. With reference to this evolution, fossils are being obtained as evidence from the earth's crust.
3. Apart from them, even within the anatomical aspects also these evidences are available.
4. In a similar way with regard to the evolution of horse during the past 6,7 crores of years, it's fossil history is treasured nicely within the earth's layers.

19.5 CHECK YOUR PROGRESS - MODEL ANSWERS

1. In 1933 at stoinheim in west Germany a human skull was found. The features of the skull are mixed. the frontal and facial portions seem to be rather meanderthal, while the back portion is more modern. This is said to be about 2 1/2 lakh years old.
2. In evolution of Horse, in the dentition, the first promotar is reduced and is known as "Wolf tooth".
3. In 1959, for the first time a homonid fossil was found in the African continent outside South Africa. L.S.B. Leaky found the cranium and upper jaw of homonid in olduwai Gorge (Kenya). It was called then as Zinganthropus.
4. The "Speed index" is indicated by the ratio of length to the diameter of the limb bones.

19.6 MODEL EXAMINATION QUESTIONS

- I. Answer the following in about 30 lines:
 1. Describe the various features that show links between apes and men.
 2. Write an essay on Homo erectus.
 3. Describe the various features of Cro-Magnon man.
 4. What are the 10 stages in the evolution of modern horse? Briefly describe each in about 3 lines.
 5. What are the various evolutionary changes brought about during the evolution of man?
- II. Answer the following in about 10 lines:
 1. Ice age.
 2. Ramapithecus
 3. Modern views of man's ancestry
 4. Primate characteristics.

BLOCK – VI
PHYSIOLOGY

BRHOU

BRAOU

Unit-20 ZOOGEOGRAPHICAL REALMS WITH SPECIAL REFERENCE TO ORIENTAL FAUNA

Contents

- 20.1 Objectives
- 20.2 Introduction
- 20.3 Palaearctic Region
- 20.4 Ethiopian Region
- 20.5 Nearctic Region
- 20.6 Neotropical Region
- 20.7 Australian Region
- 20.8 Oriental Region
- 20.9 Antarctic Region
- 20.10 Island Fauna
- 20.11 Discontinuous Distribution
- 20.12 Summary
- 20.13 Check Your Progress – Model Answers
- 20.14 Model Examination Questions
- 20.15 Glossary (Evolution of Zoogeography)

20.1 OBJECTIVES

To know the peculiarities of distribution of various animals in different parts of the world.
At the end of this unit you will

- understand the reasons behind such a peculiar distribution of animals.

20.2 INTRODUCTION

The earth is populated by a variety of living beings. Concentrating our attention on the vertebrates especially mammals and birds (and even reptiles amphibians), we find there is a glaring disparity in the distribution of the above forms in various parts of world. The reason for this is not far to seek, if we take into consideration the primary factors of evolution like origin, dispersal, barriers and isolation. Briefly these four factors may be explained as below.

Every animal population or species takes its origin in relatively small area some where in the world. It succeeds depends upon various aspects like its reproductive capacity and adaptability to new conditions in the widest sense. When it becomes successful and increases in numbers it spreads to wider areas (due to population pressure) and gets dispersed. But this dispersal is not universal because any animal has limited capacity to migrate given its power of locomotion. It gets obstructed by some sort of boundry known as barrier. For example land animals can not cross wide areas of water like sea. Forest dwelling forms can not cross deserts and so on. Thus the animals ultimately get confined to within certain boundaries and cannot spread through out the world. This is isolation.

This distribution of the animals is partly influenced by the occasional changes (in fact change which continue to take place though quite imperceptibly) that take place on the physical face of the earth. The land areas become isolated by development of water passages, or water recedes and land bridges are established. In recent and historic times, man has also contributed largely in this dispersal carrying horses, rabbits, mongoose and so on.

Various naturalists become interested in the study of the distribution of these animals and attempted to divide the world into various regions based on other distribution. Apart from individual objectives considerations, attention given to particular animal groups also gives rise to certain discrepancies. But by and large there is a broad agreement in this regard and the following scheme is universally accepted for Text book purposes:

1. Palearctic region: (Region is also called as realm)

Subregion: i) Europe ii) Mediterranean iii)Siberia iv) Manchuria.

2. Ethiopian region:

Subregion: i)East Africa ii) West Africa iii)South Africa iv)Malagasy (Madagascar).

3. Oriental region:

Subregion: i)Indian subcontinent ii) Sri Lanka iii) Indo-China region iv) Indo-Malay.

4. Australian region:

Subregion: i) Austro-Malayan island ii) Australia iii) Polynesia iv) Newzealand.

5. Neotropical region:

Subregion: i) Chile ii) Brazil iii) Mexico iv) Antilles

6. Nearctic region:

Subregion: i) California ii) Rocky Mountain iii) Alleghany iv) Canada.

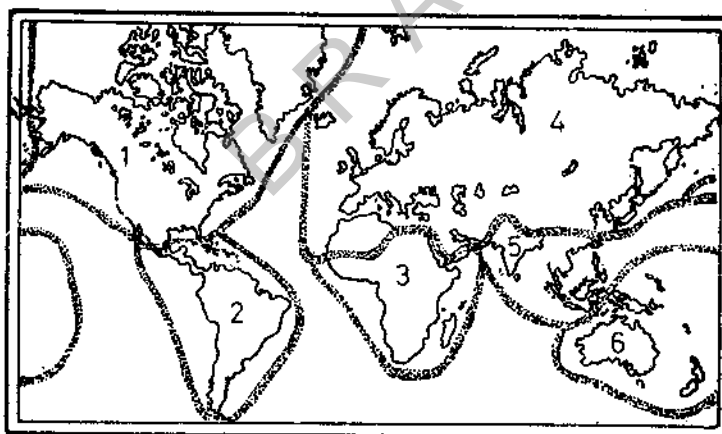


Fig. 1. Zoogeographical regions of the world. 1. Nearctic 2. Neotropical 3. Ethiopian 4. Palearctic 5. Oriental 6. Australian

20.3 PALAEARCTIC REGION

This is the largest of the six regions. It embraces the whole of Eurasian continent excluding Indian subcontinent below Himalayas, but including Parsia (Iran), Afghanistan, Africa north of Sahara, Great Britain and Japan. It also includes various continental islands.

Regarding the physical features, there is a wide range of temperature, greater fluctuation in the amount of rainfall and diversity of physical features.

There are certain similarities found between the Palaearctic and Nearctic regions which prompted the clubbing them together into huge Holarctic region.

The Palaearctic region possesses 135 families of terrestrial vertebrates. Among them are Birds (68), Mammals (33), Reptiles (24), Amphibians (10). Two families of Rodentia are quite peculiar, to this region. The following are characteristic to the region:

Mammals: 1) Talpidae (Moles) 2) Castoridae (Beavers)

Birds: 1) Regulidae (Goldcrests) 2) Colymbidae (Divers) 3) Tetraonidae (Grouse)

Amphibians: 1) Proteidae (*proteus*) 2) Salamandridae (Salamanders) 3) Amphiumidae (fish like salamander), *Alytes*, *Bufo*, *Racophorus*, *Hyla*, *Rana*.

Some of the important forms of the region are as follows:

Reptiles : *Testudo*, *Trionyx*, *Aligator*, *Geckos*, *Chameleons*, *Varanus*, *Typhlops*, sand boas and so on.

Birds : Grebes, Loons, Hawks, Herons, Storks, *Cygnus ciconia ardea*, Ducks, Cuckoos, Kingfishers, Swifts, wood peckers, swallows etc.,

Mammals : *Erinaceus* (Hedgehog), *Talpa europea* (Mole), Shrew (Sorex), Pandas, Horses, Pigs, Cattle, Squirrels, Moles. Rats, *Macaca*, *Equus caballus*, *Bos*, *Canis*.



Fig. 20.1 Giant Panda

It is to be noted that Palaearctic reptiles are related to African and Oriental forms. Palaearctic birds and mammals are related to the Nearctic forms.

Generally speaking the Palaearctic region is less rich than Ethiopian and Oriental regions with regard to the vertebrae fauna. however in the warmer areas of the zone there is considerable richness in fauna.

20.4 ETHIOPIAN REGION

Africa south of Sahara but including much of the desert, Madagascar, Southern Arabia.

Sahara forms the greatest barrier being the largest in the world. The Ethiopian region is provided with luxuriant vegetation especially in the eastern, western regions and almost uniform condition prevail in the region. In general it is a warm region.

Most of the animals living in the region appear to be peculiar to this region. However similarities exist with the fauna belonging to Palaearctic and Oriental regions. It is an indication that at one time these regions were united together.

The fauna of this region is one of the most varied and of rich type. There are 161 terrestrial vertebrate families and a good number of them are not found outside this region.



Fig. 20.3 A. Zebra B. Giraffe

Mammals: Chairomyidae (Aye Aye), Chrysochloridae (Golden moles), *Anomaluridae* (Flying squirrels), Giraffidae (Giraffe) Hippopotamidae (Hippopotamus), Orycteropidae (Aard wark).

A list of the important amphibious mammals are as follows:

Felis leo, *Felis concolor*, *Felis pardus*, *Acinonyx jubatus*, *Hyaena hyaena*, *Gorilla gorilla*, Baboon, Chimpanzee, Mandrill, *Macaca sylvana* (Monkey), *Cercopithecus* (Monkey), *Diceros bicornis* (Rhinoceros), *Equus burchelli* (Zebra), *Camelus dromedarius* (Camels), Ibox, several kinds of Antelopes, *Loxodonta africana* (Elephant), *Hystrix cristata* (porcupine), *Manis* (Scaly anteater), *Rhinolophus* (Bats) and several types of Cats, Squirrels, Rats, Foxes, Elephants, Shrews.

Birds: Serpentaridae (Secretary birds), Numididae (Guinea Fowls), Musophagidae (Plantain eaters), *Aerocharidae* (Helmet birds) are peculiar to this region. There are 67 families of birds. 17 of them peculiar to this area. The main birds of this region are *Struthio camelo* (Ostrich), *Sarcogyps* (Vulture), *Bubo* (Owl), *Eudynamis* (Koel), *Orioles*, *Psittacula* (parrots), *Crocopus* (pigeons), *Ciconia* (Stork), Herons, *Halcyon* (King fisher), Larks, Swallows, Horn Bills, Bec eaters, Weaver Birds.

Reptiles: *Chelonia*, *Amyda triumgus* (marine turtle), *Testudo pardalis*, *Testudo oculifera* (Fresh water), *Crocodylus cataphractus*, *Crocodylus niloticus* in Congo and Nile rivers, *Python sebse*, *Python reglus*, *Stenodactylus petrel* (Flying Geckos), *Varanus*, *Microsaura pumila* (Chaemeleon), *Lacerta lepida*, *Angama stellio*, *Cordylus cordylus* (Lizards), *Naja, naja* (Cobra), *Bitis arietans*, *Ceraster* (Elapids) are present. *Typhlops*, Sand Boa are non poisonous snakes.

Amphibians: Caecilians, *Salamandra salamandra* and frogs of genera *Rana*, *Bufo*, *Rhacophorous*, *Trichobatrachus* are found here, which are also in general found outside this region. Clawed toad (*Dactylethridae*) is peculiar to this region.

Fishes: Ganoid fish, *Polypterus*, Protopterus (Lung fish) are peculiar to this region.

The fresh water fishes, birds and mammals show strong similarities to the oriental region. *Amphibians* and reptiles are also less distinctive. The two regions share many families of

vertebrates. However there are certain fishes, mammals which are endemic to Africa and not found outside. The fauna is very diversified in the tropical regions.

20.5 NEARCTIC REGION

North America Greenland, New Foundland are included in this region. The region presents a great variety. Greenland being Arctic with thick ice, grass lands in the middle region Northern region (Tundra) being coniferous and eastern part being deciduous in the nature of their forests. Western region has mountains.

Fauna: The Nearctic fauna shows similarities to Palaearctic region. Heilprin thus included both of them in the Holarctic region.

Amphibians: Salamanders, Pelobatids, Toads, *Bufo*, *Hyla*, *Rana* are the amphibians here. Among salamanders *Amblystoma*, *Cryptobranchus*, *Necturus*, *Siren*, *Axolotl* are the common forms. They are mostly similar to the common forms. They are mostly similar to the Palaearctic region.

Reptiles: The reptiles here are similar to those found in Neotropical as well as Palaearctic region. Alligator (crocodiles) *Amyda*, *Trionyx*, *chelydra*, *Pseudemos*, *Terrapins* (Chelonians), *Heloderma* (Poisonous lizard), Pit vipers, Rattle snakes (*Crotalus*), *Bothrops*, *Ancistrodon vipera*, are the vipers found here. *Lachesis mutus* is the biggest viper in the world found here. *Typhlops* is also found here. Coral snakes *Elaps* is also represented. Among lizards skink, *Amphisbaenids*, *Anguids* are distributed. Several are similar to Palaearctic region.

Birds: Hawks, Vultures, Sirokes, Herons, Flamingos, Cranes, Sandpipers, Kingfishers, Storks, Pelicans, Woodpeckers, Swifts, Swallows are found. There are 49 species of birds among which some come only during summer, Grebes, Turkeys, *Pelecanus*, *Cuculus*, *Milvus migrans*, *Eudynamus* (Cuckoo).

Mammals: *Rangifer*, *Blastoceros* (Deer) *Ursus horribilis*, *Ursus americanus* (Bears), *Bos bison* (American bison), *Canis lupus*, (coyote), *Felis concolor*, (puma), *Felis onca*. *Lopus arcticus*,

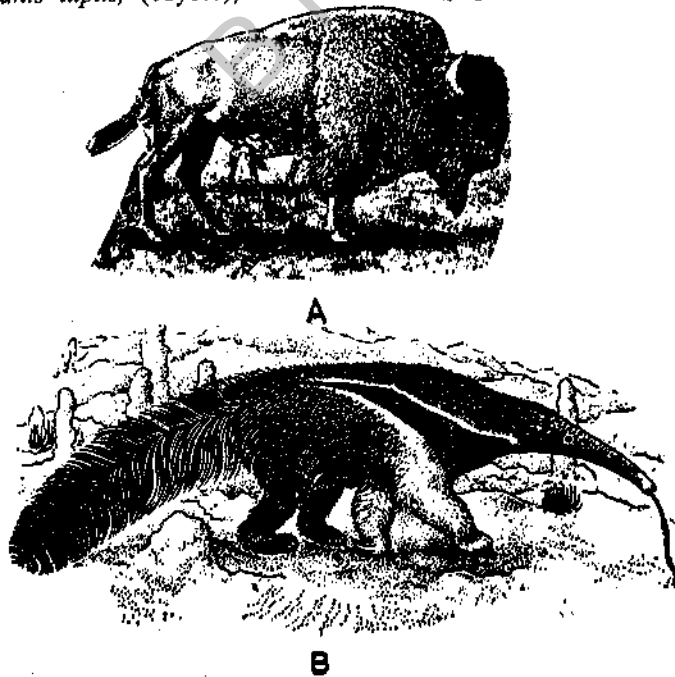


Fig. 20.4 A. American Bison B. Great ant eater

Glaucomys. Flying squirrels, *Oreamnos*, (Goat), *Hapcceros* (mountain goat), *Ovis ammon* (Sheep), *Desmodus* (Vampire bats), *Didelphys chironectes* (Opossums), Armadillo, Porcupine, *Cavia poacellus* (guinea pigs), Moles, *Scalops* (Jumping mice), *Badger* (*Taxidea*). The badger, bison, mountain goat, webfooted mole (*scalops*) are peculiar to this region as also grouse and turkies.

Though there are similarities in several of the above general between Nearctic and *Palaearctic*, there are several exclusive forms. All in all, the fauna present here is not rich.

20.6 NEOTROPICAL REGION

This region is composed of south and central America, besides southern Mexico and the adjoining West Indian islands. This is one of the three main regions and is called as Neogaea.

This is a tropical region but as one progresses south ward the temperature gets reduced. Amazon region has thick forests. Savannahs grass lands, and deserts in the western region are present. The Neotropical and Nearctic regions are separated for long periods giving opportunity for independent evolutionary centers. Andes is the important mountain range in the region.

Fauna: There is a great wealth of peculiar fauna as well as large number of special types. Apes are absent and monkeys are very peculiar, known as New world monkey or platyrrhini. The bats are very peculiar. Insectivores are not represented well. There are species of carnivores which are very peculiar. Ungulates are quite remarkable. They are represented by peculiar types of *deers*, *pigs*, *camels*, *antelopes*, *sheeps*, *goats*, *cattle*.

Amphibians: *Dendrobates* (poisonous frog), *Pipa pipa*, *Bufo*, *Leptodactylus*, *Pseudis paradoxa* are some of the frogs. Besides *Sipponops annulatus* (Caecilian), *Cryptobranchus* (Salamander) are found here.

Reptiles: Turtles are represented by *Testudo*, *crocodiles* (*Crocodylus acutus*), *caimans*, *lizards* represented by *igvana Ignana*, *Heloderma suspectum*, *Phymosoma suspectum* (Horned toad). *Amphisbaena* (legless lizard) *Bipes canaliculatus* (also a leg-less lizard), flying geckos are available. Among snakes, *Typhlops*, Coral snakes (*Elaps corallinus*), Pit vipers, *Boa*, *Constrictor constrictor* are found here.

Birds: *Rhea americana*, *Tinamous*, are peculiar. Besides the other birds present are *Corvus*, *Towcan*. *Acridotherus* (Mynah), *Arhotomus* (Tailor bird), *Plosius* (Weaver Bird), *Brachypterus* (wood packer), *Psittacula krameri* (parrot), *Cucuius* (Koel), *Columbus* (Loon) are distributed here. There are no cranes and ducks. The region is famous for birds having about 67 families of birds.

Mammals: These include *Caenolestes* (Opossums) and bee eaters, two characteristic Simian families, Llamas Pigs, Sloths, Armadillos, Deer, Rabbits, Caels, Tapir, Pocket gophers, Pocket mice, porcupines, *Ateles* (Spider monkey). The monkeys represent a parallel case of evolution. Edentates are no less spectacular than the Australian marsupials. *Wolves*, *foxes*, *jaguar*, *puma*, *bears* among carnivores.

Out of a total of 155 families of terrestrial vertebrates 39 are confined to this region. Cebidae, Callitrichidae are the two families of monkeys. The other families of mammals are Chinchillidae (*Chinchilla*), Dasyproctidae (*Agouti*), Bradypodidae (*Sloths*), Myrmecophagidae (Anteaters) Cavidae (Cavies), *Dendrobates* (Solid chested tree frogs) are peculiar. Mud terrapin among reptiles are also peculiar.

Neotropical birds are quite extensive and many of them belong to families exclusive to South American continent. The vertebrate fauna is regarded as remnants of the older Tertiary fauna.

20.7 AUSTRALIAN REGION

This is one of the main regions called as Notogae. This includes Australia, New Guinea, Moluccas, New Caledonia, Tasmania, Newzeland and Polynesian and Melanesians and other adjoining islands. Polynesian islands are made up of Volcanic islands and atolls. Part of the area is tropical like New Guinea and of the region is colder as Tasmania and NewZealand. There are also rain forests Gand grass lands. The region is separated from the main regions of the world since a long time resulting in peculiar Fauna being evolved.

Fauna: Higher mammals are unrepresented.

Fishes: *Neoceratodus* is the peculiar being fish of the region is Queensland area. *Osteoglossid* fishes are also peculiar to this region.

Amphibians: Hylids and Ranids are represented by a few forms like *Rana tigrina*, *Rhacophorus reinwardii*, *Ichthyophis glutinosus*, *Liopelma* is a primitive frog.

Reptiles: *Hatteria* (sphenodon or Tuatara), *Caretto cheledidae* (Turtles) *Pygopodiae* (Scale footed Lizards), are the representatives. *Egernia cunninghami* are the lizards. Elapid snakes are represented. Pythons are in North Eastern region.

Birds: Birds of paradise are vary characteristic *Emus*, *Mallee fowl*, frog moths, lyre birds, bower birds and Australian Magpies. A total of 58 families of birds are living in this region. Cassowary, Emu, *Apteryx* are peculiar here. Moas have become extinct only a few centuries back. Honey eaters, parrots, pigeon are also found. The absence of more advanced placental mammals have allowed the birds in New Guinea into a bizarre bird fauna.

Mammals: The entire group of monotremes and almost the entire group of Marsupials are found here. Of placental mammals only bats, water rats, and dingo (domestic dog) have penetrated the Australian region.

A highly differentiated adaptive expansion of marsupial mammals has provided a remarkably balanced fauna to compensate for the absence of placentals.

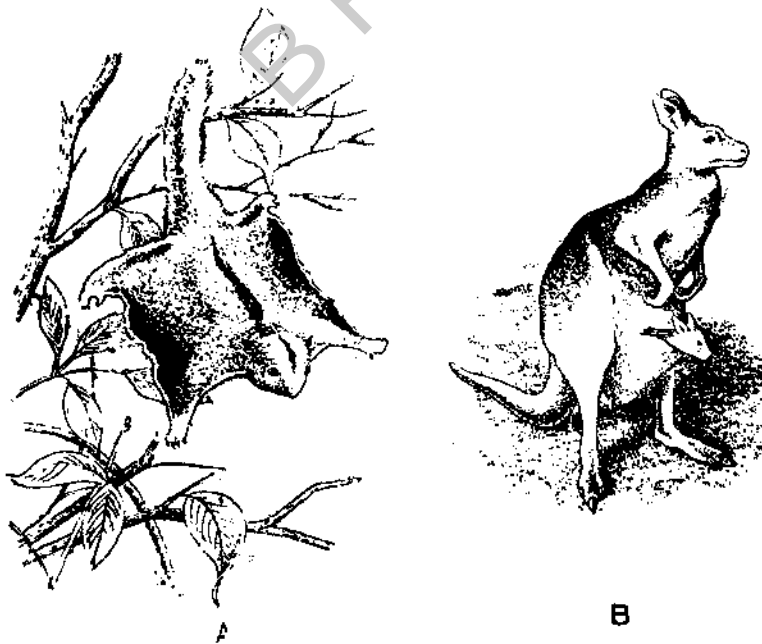


Fig 20.5 A. Flying opossum B. Kangaroo.

The mammals thus include *Omythorhynchus*, *Echidnas* which are the egg laying mammals, duck-billed platypus and spiny ant eater. The Marsupials are pouched mice, dasyures. *Thylacine* (*Thylacinus*), pouched moles (*Notoryctes*). Bandicoots (*Perameles*), Phalangers (flying opossum) koala (pouched bear), Wombats and Wallabies, Kangaroos (*Macropus*) and rat kangaroos.

There are 134 families of terrestrial vertebrates out of which 30 are quite peculiar (8 mammals, 17 birds, 3 reptiles, 2 amphibian families).

20.8 ORIENTAL REGION

Included in this region are Indian Subcontinent including India, and other countries, Southern China, Srilanka, Borneo, Sumatra, Java, Bali Formosa, Philippines and other islands. The eastern parts are considerably wet while the western regions are dry. On the Northern limits are the climate is conducive and forests, grass lands abound. The features vary considerably. Rich fauna is found in the forest areas.

The Southern Indian continent is provided with Eastern and Western Ghats with accompanying thick forests and varied forms of Vertebrates. Sri Lanka, Indo-China, Borneo, Malaya etc., also have similar forest regions.

Fauna: The oriental fauna shows considerable similarities to the Ethiopian, rather than the Palaearctic region. That at one time early, the Indian and African subcontinents were together united (Gondwana Land) and Indian and Asian continents were separate. The present arrangement is only due to the continental drift.

Fishes:- *Scoliodon*, *Pristis*, *Rhinobatis*, *Mylobatis*, *Sphyma*, *Zygaena* are the cartilagenous fishes in the Indian Ocean. Among the bony fishes in the Indian Ocean are *Echeneis* (Sucker fish), *Mastacembolus armatus* (Eel), *Chelmon* and *Chaetodon* (Butterfly fishes), *Aeoliscus* (Razor fish), *Hippocampus* (Sea horse), *Exocoetus* (Flying fish), *Barbus*, *Mystus*, *Ompok* (Catfishes), *Ipnotis* (Lantern fish), *Anabas*, *Periophthalmus*, *Ophiocephalus*, *Heteropneustes* are the fresh water fishes. Most of the fresh water fishes in Indian Subcontinent are also found in Sri Lanka, Sumatra and Borneo. But Celebes, a nearby island to Borneo, does not contain them and hence this is regarded as belonging to Australian region. Bali has in addition *Puntius* and *Rosbora cyprinid* fishes. There are no primitive fresh water fishes in oriental region.

Amphibia: These include caecilians, a few salamanders, Rhacophorids, *Rana*, *Hyla*, and Brevicipitids. *Ichthyophis*, *Geganophis*, *Barkudia insularis* (Visakhapatnam) among the snake like Caecilians, *Salamandra* in Indo-china, *Rana*, *Hyla*, *Bufo*, *Rhacophorous* throughout the region. *Megaphrys* (Pelobatid) is present in the eastern islands of the region. Java, Borneo have no Caecilians.

Reptiles: Marine Turtles include *dermochelys*, *Caretta caretta*, *Chelone mydas*. Among the fresh water Tortoises are *Geomyda trijuga*, *Kachuga*, *Trionyx*, *Testudo clegans* and so on. Among the Lizards are *Hemidactylus*, wall lizard, pink tailed lizard, *Mabuya*, *Chamaeleon* (*Chamaeleon*), *Calotes*, Garden lizard, Flying lizard, *Draco*. *Varanus*, *Uromastix* and so on. Among the Crocodile *Gavialis gangeticus* in Ganga, Brahmaputra, Godavari, *Crocodylus porosus*, *Crocodylus palustris* are found in the subcontinent. They are of great wild life importance. Among the snakes the most important are *Naja naja* (Cobra), *Ophiophagus* (king cobra), *Vipera russelli*, *Echis carinatus* (Vipers), *Trinuresureus* (pit viper), *Dryophis*, *Bungarus fasciatus*, *Bungarus coeruleus* (Kraits) and several non-poisonous snakes like *Lycodon*, *Typhlops*, *Python*, *Eryx johni* and several others. *Enhydrina*, *Hydrophis* are the marina poisonous snakes.

Birds: Several birds belonging to other regions are found in this region also. There are about 66 families of birds. Three of them are found in Africa also and five are found in Australia also.

The following are the birds:

Corvus (crow), *Passer domesticus* (Sparrow), *Acridotheres* (Mynah), *Dicrurus macrocercus* (King crows), *Saxicoloides* (Robins), *Oriolus oriolus*, *Orthotomus*, *Dryobates* (Wood pecker), *Columba livia*, *Crycopus* (Pigeons), *Psittacula eupatria* (Parrots), *Pavo cristatus* (Peacock), *Cuculus*, *Eudynamis*, (Koels), *Anas*, *Anser*, *Cygnus* (Ducks, geese), *Myiurus migrans* (kites), *Pseudogyps* (Vulture), *Ketupa* (Owls), and great Indian bustard. There are no flightless birds. Darters, Pelicans, *Hoopes* (*Uppa epops*) are some of the birds found in Australian regions also.

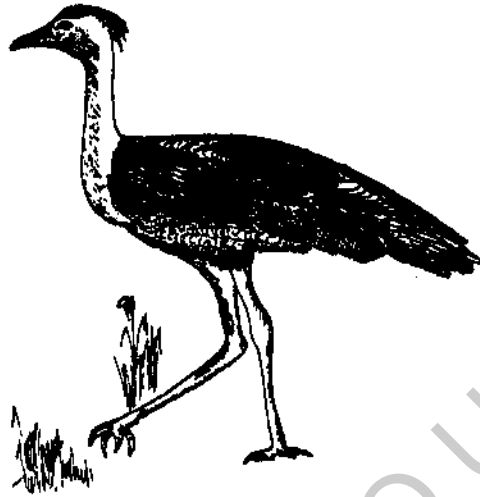


Fig. 20.6 Great Indian bustard

Siberian crane (*Grus leucogeranus*) is a migratory bird on the verge of extinction. Black necked crane *Grus nigricollis* and another Great Indian Bustard (*Choriotis nigricans*) is a bird of great wild life importance on verge of extinction present in Andhra Pradesh, Rajasthan etc., Grey Pelicans, *Peleconces phillipensis*.

Mammals: Mainly Hedgehogs, Shrews Flying Lemur, Catarrhini (Monkeys), Tarsiers, Cats, Bears, Elephant, Tapir, Rhinoceros, Rabbits, Giddons, Orangutan, Varied typed of bats are found in this region.

In its totality the region is note worthy for the mammals. *Elephas maximus* (Elephant), *Felis leo* (Lion), *Felis uncia* (Leopard) in the Himalayana region known as snow leopard which is

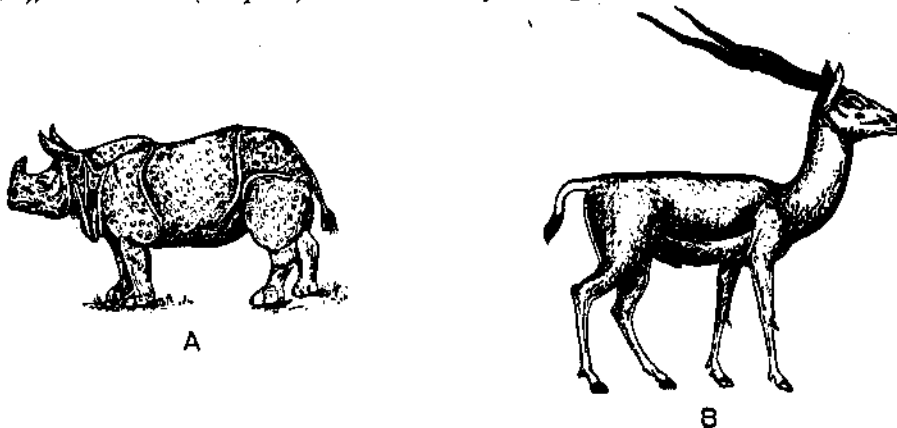


Fig. 20.7 A. Rhinoceros B. Black buck

almost extinct). *Felis poardus* (Leopard), *Panthera tigris* (Tiger), *Acinonyx jubata* (Cheetah that became extinct recently in India). Other forms are *Hyalobates* (Gibbon), *Macaca mulatta* and *M. silenus* (Lion tailed monkey), *Presbit priamsus*, *Hannuman monkey*, *Ratula indica* (Squirrel), *Manis* (Scaly ant eater), *Pteropus giganticus*. *Magadermalyra* (Bats) *Equus asinus* (Ass), *Axis axis* (Deer) besides several deer like forms are brow antlered deer (Thamin). Kashmir stag (Hangal), *Swamp deer* (Barasinga). Musk deer *Moschus*, wild Buffalo (*Bubalus bubalis*). *Indian bison* (*Bos geurus*). Four horned antelope (*Tetraceros quadricornis*), *Indian Gazelle*, *Chinkara*, *Gazella dorcas bennetti*, *Black buck* (Antelope cervicapra) (our state animal) etc., and *Herpestes* (Mongoose). *Cuon alpinus dukhunensis* is a wild dog, *Nycticebus*, *Loris* are the lemuroids.

Rhinoceros unicornis is in the Indian continent. Other species have become recently extinct.

Wallace Line:

In 1860 Wallace reported that the western and eastern islands of Malay Archipelago had fauna more distinct than any other two regions in the world. "South America and Africa separated by Atlantic do not differ so widely as Asia and Australia". He had only limited knowledge at that time. He considered that straits of Lombok between Bali and Lombok as the dividing line between Oriental and Australian regions. T. H. Huxley called this as wallace's line. It runs between Bali-Lombok, up through Makassar straits between Celebes (Sulawesi now) and Borneo (Kalimantan now).

Later doubts arose regarding the validity of this line. Wallace line is no longer accepted as the boundary between the two regions now. Bali and Lombok are separated by only 32 km wide strait. Yet there is vast difference between their fauna or between Borneo's rich fauna and Celebes poor fauna. The differences are mainly regarded as due to the western islands being continental islands and the eastern ones mostly oceanic islands and having insular fauna (See below). Attempts are made to draw another line or even a broad belt. But difficulties arise as to what group of animals are to be considered.

Discussion on oriental region

The presence of Horn Bills (Bucerotidae), Honeyguides, weaver birds seem to favour the recognition of a single palaeotropical zoogeographical region which includes oriental and ethiopian regions. Similarly leopard occurs without variation from China to South Africa.

But the tiger is mainly oriental not being present in the Ethioplan, but extending into Palaearctic region in the form of siberian tiger and others. The fauna of peninsular Indian and Srilanka is generally poor. This may be due to extinctions caused by Tertiary volcanic activity and pleistocene aridity. But Burma, Indo-china regions are among the richest areas in the world and the natural wealth of Malaya, Borneo, Sumatra, Java are well known. The central India has dry savannahs, in south west are tropical mountain forests and at the foot hills of Himalaya are luxuriant wood lands.

The mountain of Kashmir from a junction where Palaearctic and Indian Fauna (kashmir stag.) mix Palaearctic fauna penetrate into oriental. Examples: Great tit to Borneo, Java, the jay to Himalayas, Burma, Thailand and Indo-china, Gray headed wood pecker to the Malayan mountains and Northern Sumatra.

The oriental has the following large mammals. Elephant from Sri Lanka to Sumatra, Borneo. Malayan Tapir in Malaya, Sumatra and Borneo. Three species of Rhinoceros, Indian, Javan and Sumatran (two later are extinct or almost extinct. through the former has escaped this fate), several species of buffalo like Gaur of India, Couprey and Banteng, several species of Langur, Monkeys, Macaques, several gibbons, Orangutan (now present only in small areas of

Sumatra and Borneo), Blue Buck, Nilgai and the Black Buck in India. There are three species of Pangolin related to Ethiopian region lorises, 20 species of tree shrews mainly from Malaysia and Philippines.

The oriental region is famous for various kinds of Wood peckers, Babblers and pheasants and also for a small number of parrots when compared to Notogae and Neogae where they are in large numbers.

It is recognised that Sumatra, Borneo and Java are continental Islands and hence had several opportunities to unite or separate during pleistocene. They are separated now and then via a continental sheet, known as Sunda Shelf. Hence, there were repeated opportunities for isolation alternating with union. This gave rise to ample opportunities for speciation and forming ample faunal richness.

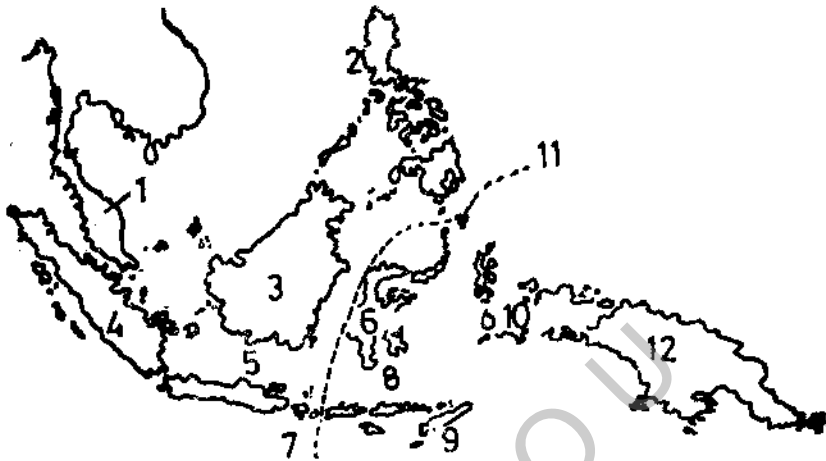


Fig.20.8. Representation of course of Wallace line 1. Malaya 2. Philippines 3. Borneo 4. Sumatra 5. Java 6. Celebes 7. Bali 8. Lombok 9. Timor 10. Moluccas 11. Wallace line 12. New Guinea.

The border of Sunda shelf was considered by Wallace as forming the border of oriental region. The line running between Bali and Lombok, northward between Borneo and Celebes and South of Philippines beside Mindanao island is known as Wallace line (see discussion above). The islands east of this line lack Minnows, Wild cats, Dogs, and Deer. There is however an admixture of Australian fauna here, like Bandicoots, Phalanger, Cuckatoos and Birds of paradise increasing as one proceeds eastwards.

The border of Australia's continental shelf (Sahul Shelf) runs west of New Guinea and the papuan Islands of Waigeo and others. This is known as Lydekker's line. The islands between the Wallace line and Lydekker's line like Celebes, Moluccas form a famous Zoogeographical transitional area. There is also what is known as Weber's line running West of Moluccas and the kei islands. This denotes the places where there is 50-50 distribution of Australian and Oriental fauna. Celebes has dwarf Buffalo, Babirusa, two species of monkeys, Tarsier, Squirrels, Civet. It even had an elephant during the pleistocene age. Thus it was on the most changing areas of the World.

20.9 ANTARCTICA REGION

At present this is thickly covered with ice sheets. During earlier geological ages rich animal life was present. Permian showed fossil insects. Triassic showed a Labyrinthodonty Jurassic showed a beetle. At present the fauna is such it warrants the creation of a separate region.

Mites, ticks, springtails of which 90% are confined to this region. Penguins, Albatrosses, petrels and Seals are the main animal groups. Skua is both like a Vulture and Falcon. The Leopard seal is active both on land and sea and depends upon penguins.

20.10. ISLAND FAUNA (Insular fauna)

Throughout the world distributed in the oceans and seas, there are a number of islands both large and small, isolated or in groups nearer to the main lands or farther away from large continents.

There are mainly two types of islands. The continental and oceanic islands. The fauna of either of them offers a fascinating chapter in the study of Zoogeography.

Continental islands are those which have been connected to the main land nearby during sometime in the geologic past. On several occasions the sea level falls by several kilometers by raising of the continents. Hence land bridges will be established via the continental shelves buried in the sea. Thus sufficient similarity exists between the fauna of these islands and nearby main lands. The difference that exists is directly proportional to the time gap that elapsed since their separation. For example Great Britain is a young continental island and Formosa, Sri Lanka are older continental islands. However regarding Madagascar the separation is very old and it is not certain whether it is connected at any time to the main land Africa. If the time gap is long say several crores of years, there is a two way opportunity for the discrepancy. Though at the time of separation both have similar fauna, later the new species that arise do not have the opportunities to enter the island. So also the limited environment in the island that gives rise to new forms cannot enter main land and the evolution proceeds fairly on two different lines.

Oceanic islands are those that never had an opportunity of physical contact with many of the main land masses and so also to the free access of the Biological migration. They may have a volcanic origin or by building of coral reefs and occasionally by a combination of both. They are far removed from the main land. The fauna here will be very poor, if at all present. The large land animals invariably will be absent. By the wind or sea currents bringing drifted bodies, the islands will be populated. In other words the animals will be of chance, assemblage of heterogenous nature. Amphibians being fresh water will be always absent. So also fresh water fishes. Since there will be no severe competition, absence of predators,



Fig 20.9 Diagram representing oceanic sub-continental islands. 1. Oceanic islands 2. Continental islands 3. 1000 Fathom line

flightless birds like do on Maritius tend to evolve. When the group of islands themselves vary a local adaptive radiation is possible. Further since competition is scarce, the same species or genus tends to evolve into different types of forms adapted for different types of diet as in Drepanid Birds of Hawai or Finches of Galapagos islands.

It may also be mentioned here that the characters of islands are not always easy to distinguish because of overlapping of the above characters. For example Galapagos islands are regarded as oceanic islands by Charles Darwin who made an extensive study and survey of them. But recent studies show that they are continental islands some of the more important continental islands are Britain, Borneo, Java, Sumatra, Philippines, Formosa, Japan, Sri Lanka, New Guinea, Trinidad, New Foundland, Green land, Tasmania, Falkland islands, West Indies, Celebes, Madagascar, Newzealand and so on.

The oceanic islands are Hawai, Galapagos, Bermuda, Azores, Andaman, Nicobar, Laksha Dweep, Maldives and so on.

Newzealand, Madagascar are regarded in general as ancient islands, which seem to have separated from the mainland quite early in the geologic history.

20.11 DISCONTINUOUS DISTRIBUTION

From the above account one might have noted a peculiarity in the nature of distribution of certain animals. The lung fishes are present in Australia (Neoceratodus), Africa (Protopterus) and South America (Lepidosiren). Similarly Tapir is present in Malaya as well as in the far off region in South America. The case of camels also can be cited, they being present in Arabia and Central Asia and South America (In the form of Llama and Alpaca).

All these cases of distribution are referred to as discontinuous distribution. The peculiarity here is they are not found in continuous regions but only in regions which have one connection to each other and are separated by wide areas of land and sea.

It is explained that at one time the animals belonging to this group are distributed widely but later on during the geologic past, the populations became extinct due to local adverse conditions in the intervening regions leaving them in pockets in widely separated areas.

Check your progress:

1. The animals ultimately get confined to within certain boundaries and cannot spread throughout the world. This is _____.
2. _____ runs between Bali-Lombok, up through Makassar straits between Celebes (Sulamesi now) and Beeneo(Kalimantan now).

20.12 SUMMARY

1. All the animals are not found in all parts of the world though the physical and climatic conditions may be the same in any two given parts of continents.
2. The geographical nature of the earth's land masses is not always the same and is subject to constant drift, however imperceptible and slow the change may be.
3. This continental drift may create land bridges where they were not existing or cut of two land masses which were originally connected.

4. Thus, the origin, increase in populations, migration, barriers for migration, isolation are some of the important factors which explain the present state of affairs i.e., the reasons for the presence or absence of any particular species or group of animals on any land mass.
5. These various factors are also contributory causes for the acceleration or otherwise of the course of organic evolution.

20.13 CHECK YOUR PROGRESS-MODEL ANSWERS

1. Isolation
2. Wallace Line

20.14 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines each:

1. Give an account of the history and factors leading to the division of earth into various zoogeographical regions. Briefly mention the various regions and their subdivisions.
2. Give an account of the Ethiopian region.
3. Give an account Neotropical region.
4. Briefly describe the relationship between Oriental and Australian regions.
5. Describe the various features of the island fauna.

II. Answer the following in about 10 lines each:

1. Madagascar.
2. Mammals in Australian region.
3. Discontinuous distribution.
4. Wallace line.
5. Continental and Oceanic islands.

ANDHRA PRADESH OPEN UNIVERSITY
SYLLABUS - PAPER - III
GENERAL ZOOLOGY
(CYTOLOGY, GENETICS, EVOLUTION,
ZOOGEOGRAPHY, ECOLOGY & ANIMAL PHYSIOLOGY)
THEORY

CYTOLOGY

- Historical account of Cytology : Methods of study : Ultra structure of the cell.
- Structure and function of cell organelles : Plasma membrane : Endoplasmic reticulum : Golgi Complex.
- Structure and function of cell organelles; Mitochondria; Lysosomes; Centrioles; Ribosomes; Nucleus.
- Chromosomes; Morphology, Ultra structure, Molecular compounds and Special types of chromosomes.
- Cell division : Amitosis, Mitosis, Meiosis, Cell cycle
- Fertilization; Gametogenesis; Parthenogenesis

CLASSICAL GENETICS

- Historical account; Importance of Genetics and its application.
- Mendel's laws of inheritance.
- Linkage and Crossing over
- Sex determination
- Sex linked inheritance.
- Chromosomal aberrations, Gene mutations : Spontaneous and induced.
- DNA, Replication of DNA, RNA; Genetic Code, Elementary knowledge about Protein synthesis
- Fine structure of gene; Classical definition, Modern definition; Cistron, Muton and Recon and Operon Concept.
- Human genetics : Genetic traits in man, Human syndromes, Inborn errors of metabolism

EVOLUTION

- Origin of Life (brief account); Organic evolution : Theories (Darwinism, Lamarckism, Mutation theory) : Evidences (Embryologica, Palaeontologica, Physiological and biochemical).
- Synthetic theory of Evolution - Mutations, Genetic recombinations, Genetic drift, Natural selection and Isolation.
- Adaptations : Aquatic, Desert, Volant adaptations; Commensalism; Mutualism : Symbiosis, Parasitism; Colouration and Mimicry
- Evolution of Man (briefly) and horse.

ZOOGEOGRAPHY

- Zoogeographical realms with special reference to Oriental fauna

ECOLOGY

- Introduction of Ecology; Various branches and its relation to other sciences, Fundamental concepts of Ecosystem taking terrestrial, Pond and Estuarine as examples, Food chains, Energy flow, Trophic levels.
- Ecological factors; physical factors - temperature, light, Water; their effects on organisms; Adaptations of organisms; Adaptations of organisms to these factors.

- **Community Structure and Ecological succession**
- **Population Ecology; Population characteristics and factors determining population growth**
- **Environmental Pollution (major concepts); Radiation hazards**
- **Wild Life Conservation**

ANIMAL PHYSIOLOGY

- **Elementary Knowledge on chemistry and metabolism of carbohydrates, proteins and fats; Geological oxidation.**
- **Nutrition requirements; Balanced diet; Vitamins; Enzymes (a brief account); A brief account on gastrointestinal hormones.**
- **Osmoregulation : Principles of osmotic and ionic regulation; water balance in aquatic and terrestrial animals.**
- **Respiration : Blood pigments; Transport of O₂ and CO₂. Oxygen dissociation curve, Bohr effect, Chloride shift.**
- **Circulatory system; Blood groups; Blood coagulation; Origin, conduction and regulation of heart; cardiac cycle.**
- **Nervous system; Synaptic transmission : Neurotransmitters**
- **Muscle contraction : Ultra structure of skeletal muscle; Physiology of contraction.**
- **Physiology of reproduction in mammals; Endocrinological control of testicular and ovarian functions; Female reproductive cycle; Elementary idea of implementation, gestation and birth**
- **Biological Rhythms**
- **Immunological Responses**

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ANDHRA PRADESH OPEN UNIVERSITY

Faculty of Science

ZOOLOGY

COURSE - III

(Cytology, Genetics, Evolution, Zoogeography,
Ecology and Animal Physiology)

ASSIGNMENT - 1

N.B.

1. Do not copy the answer directly from any of the books.
 2. As far as possible try to answer the questions independently in your own words.
 3. If it is necessary to quote from any source give the correct reference.
 4. Use your own foolscape pages for writing the assignments.
 5. Leave sufficient margins for the comments of the evaluator.
 6. Completion of this assignment should not take more than two hours time.
-

I. Answer the following questions in about 30 lines.

1. Give an account of the structure of mitochondrion and mention its important functions.
2. Briefly describe the relationship between Oriental and Australian regions.
3. What is Osmosis? Explain various mechanisms of Osmoregulation in hypotonic medium with examples?

II. Answer the following questions in about 10 lines.

1. Components of Golgi Complex.
2. Role of genetics in agriculture.
3. Mention the importance of iodine in the metabolism.

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ASSIGNMENT - 2

N.B.

1. Do not copy the answer directly from any of the books.
 2. As far as possible try to answer the questions independently in your own words.
 3. If it is necessary to quote from any source give the correct reference.
 4. Use your own foolscap pages for writing the assignments.
 5. Leave sufficient margins for the comments of the evaluator.
 6. Completion of this assignment should not take more than two hours time.
-

I. Answer the following questions in about 30 lines:

1. Define linkage. Illustrate the phenomenon with a suitable example?
2. Write an essay on the environmental pollution and its control methods.
3. Describe the structure of neuromuscular junction? Add a note on neurotransmitters.

II. Answer the following questions in about 10 lines:

1. Describe Myofibril.
2. Define and explain Mendel's Law of Segregation?
3. Describe the significance of ionic regulation in animals.

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